Contract for Work

concluded in accordance with Section 2586 et seq. of Act No. 89/2012 Coll., Civil Code, as amended (hereinafter the "**Contract**")

I. CONTRACTUAL PARTIES

1. Client:
   Ústav fyziky plazmatu AV ČR, v. v. i.
   With its seat at: Za Slovankou 1782/3, 182 00 Praha 8 – Libeň
   ID No.: 61389021
   VAT No.: CZ61389021
   represented by: doc. RNDr. Radomír Pánek, Ph.D., Director

   Banking details:
   Československá obchodní banka, a. s.
   Account No.: 101256398/0300
   (hereinafter the "**Client**")

   and

2. Contractor:
   ELEKTROTECHNIKA, a.s.
   With its seat at Kolbenova 936/5e, 190 00 Praha 9, Czech Republic
   ID No.: 25727206
   VAT No.: CZ25727206
   Registered with Municipality "Městský soud v Praze", section B, file 5743
   Represented by [redacted]

   Banking details:
   Raiffeisenbank a.s., Hvězdova 1716/2a (City Tower), 140 78 Praha 4
   Account No: 503 001 9151/5500
   (hereinafter the "**Contractor**")

   (the Client and the Contractor may be referred to jointly as the "**Parties**" or with respect to each individually as the "**Party**").

II. FUNDAMENTAL PROVISIONS

1. The Client is the recipient of funding provided by the Ministry of Education, Youth and Sports of the Czech Republic for the Project "COMPASS-U: Tokamak for cutting-edge fusion research", Reg. No. CZ.02.1.01/0.0/0.0/16_019/0000768, granted within the framework of the Operational Programme Research, Development and Education (hereinafter "**OP RDE**" and the "**Project**").

2. The objective of the Project is to design and build a high magnetic field tokamak under the name of COMPASS-U, including all operational and support systems, including a complete Power Supply system for the tokamak, which is the subject matter of this Contract.

3. In order to successfully implement the Project, it will be necessary to execute certain work according to this Contract.

4. The Contractor won the public procurement procedure announced by the Client pursuant to Act No. 134/2016 Coll., on Public Procurement, as amended (hereinafter the "**Public Procurement Act**" or "**PPA**"), for tender entitled "**Power Supply System for COMPASS-U Tokamak - Round 2**" (hereinafter the "**Tender**").

5. Documentation for the execution of work includes:
   a) technical specifications relating to the performance to be provided which forms an integral part hereof as Annex 1 (hereinafter the "**Technical Specification**"). This Technical Specification also formed a part of the tender documentation in the Tender as its Annex No. 1;
   b) part of the Contractor's bid as submitted in the Tender which describes the work in technical detail (hereinafter the "**Bid**"); the Bid is attached as Annex 2 to this Contract and forms an integral part hereof.
   c) the tender documentation used in the Tender.

6. The Contractor declares that while fulfilling this Contract he shall be capable, within the meaning of Section 5 (1) of Act No. 89/2012 Coll., Civil Code, as amended (hereinafter the "**CC**"), to act with knowledge and care which is required of his profession or professional status, and that he shall be fully liable for any actions lacking this required professional care. The Contractor shall not misuse his professional qualities or his economic position to create or exploit dependence of a weaker party hereto or to achieve an obvious and unjustified imbalance in the mutual rights and duties. The Contractor further declares that there are no obstacles on his part that would prevent him from executing the work contracted hereunder.

7. The Contractor declares that he possesses all professional qualifications required to execute the work hereunder, including sufficient knowledge of guidelines relating to subsidy grants, and that he is fully authorized to provide the performance required hereunder.

8. The Contractor is aware that the Client does not act as an entrepreneur in relation to the subject-matter of this Contract.

9. The Contractor declares that he assumes the risk of change in circumstances within the meaning of Section 1765 (2) CC.

10. The Contractor acknowledges that the deadlines for execution of the work or its parts as defined herein in Article VI. are vital for the Client with regard to the Project tie-in activities and the date by which this Project has to be implemented, and that in the event of a failure to meet these deadlines, damage may arise to the Client. The Client has notified the Contractor what are the tie-in deadlines specified hereunder in connection with the Project deadlines.

III. SUBJECT AND EXTENT OF WORK

1. The subject-matter of the Contract is providing of a technological system called the Power Supply System for the COMPASS-U tokamak (hereinafter referred to as the "**System**"), which includes the following:

a) design, development and production of the System;

b) preliminary testing of the System at the Contractor's premises or at the premises of subcontractor in possible cooperation with the Client;

c) handover of the System;

d) procurement of the System;

e) assembly and commissioning of the System at the Client's premises;

f) testing of the System after its assembly at the Client's premises;

g) regular maintenance and service of the System, as specified in paragraphs 5 and 6 of Article IV hereof, after its assembly at the Client's premises and during the warranty period for the Basic Configuration as well as for individual Extended Options;

h) training of the Client's employees to operate the System properly and provision of consultations related to the function and operation of the System;

definition of the subject-matter of the Contract is provided in detail within the Annexes to this Contract, particularly Technical Specification and the Bid and in Article IV. herein (all supplies, work and services pursuant to this Contract and its Annexes shall be referred to as the "**Work**").

2. Should it be necessary, in order to meet the Client's requirements as specified in the Contract and/or to duly complete the Work hereunder, to provide additional supplies or perform other work which had not been expressly defined in this Contract, the Contractor shall be obliged to provide such supplies or work and include such in his performance at his own cost with no impact to the price agreed herein.

3. The Contractor undertakes, at his own cost and risk, to duly complete the Work specified in the Technical Specification and to hand it over to the Client in timely manner in full compliance with the terms and conditions defined herein. The Work shall be executed in the extent, manner and quality as defined herein and any accompanying documentation, including any amendments hereto and supplementing documentations that may be agreed between the Parties or arising from decisions issued by competent authorities.

4. The Client undertakes to take delivery of the timely and duly completed Work. The Client shall be obliged to pay the price for the Work to the Contractor in line with terms and conditions and manner agreed herein. The Client undertakes to provide to the Contractor necessary cooperation in creation of the technical design of the System.

5. Unless agreed otherwise herein, the Contractor shall not be authorized nor obliged to execute any changes to the Work without prior written agreement with the Client that shall be executed in the form of a written Amendment hereto. Handover of the Work or its part and its acceptance by the Client, shall not be understood to represent a written agreement on changes according to the first sentence of this paragraph.

6. The Contractor shall secure such equipment as may be required to execute the Work defined hereunder, unless the Contract stipulates otherwise. The Client shall provide to the Contractor free of charge selected parts of the Client's current power supply system to be incorporated into the System, the specification of such parts being specified in the Technical Specification. The Contractor shall be obliged to examine the parts of the Client's current power supply system and properly test

them by performing appropriate tests in order to clarify suitability of these parts for re-use. All parts of the Client's current power supply system selected for incorporation into the System shall be disassembled (if necessary), incorporated, controlled, connected and secured by the Contractor at his own cost with no impact to the price agreed herein. Should the Client provide to the Contractor any equipment that may be required to execute the Work, such equipment shall remain in the Client's ownership throughout.

7. The Contractor shall be obliged to provide all services related to the execution of the Work (including among others activities of project leader, chief designers and other technicians as well as technical testing services etc.) by persons whose qualification has been proven to the Client. A list of these persons forms an integral part hereof as Annex 3 (hereinafter the "**List of qualified persons**"). If there is a need to change any qualified person included on the List of qualified persons, the Contractor shall not be authorized to replace any such qualified person without a prior written consent of the Client. The Client may refuse to accept person proposed by the Contractor and in such a case the Contractor shall be obliged to propose another qualified person.

IV. SPECIFICATION OF THE WORK AND WORK RESULTS

1. The outcome of the Work shall not be deemed to have been completed in compliance herewith or properly executed with respect to any of its parts, if it fails to meet the requirements defined below and if any defects thereof will not have been remedied on the basis of the Client's notification (respectively on the basis of a notification issued by person authorized to perform control / inspections according to this Contract).

2. As part of the execution of the Work under this Contract, the Contractor shall be obliged to properly design, prepare and deliver Contractor's Implementing Documentation, As-built Documentation, Accompanying Documentation and other additional documentation in accordance with documentation which forms an integral part hereof as Annex 4 (hereinafter the "**Documentation**").

3. The outcome of the procurement of the System shall be the delivery of the System or its part to the Client in accordance with Article VI. hereof. The outcome of the assembly and commissioning of the System at the Client's premises shall be provided in accordance with Technical Specification.

4. The testing of the System after its assembly at the Client's premises shall be understood as period of time when the System will not be in ordinary operation, its function will be optimized in order to achieve full capacity of the System's ordinary operation according to the requirements of the Client, which means complete Work or its part and without evident and/or latent defects.

REGULAR MAINTENANCE AND SERVICE OF THE SYSTEM

5. Regular maintenance of the System shall be carried out at least twice per calendar year by way of a preventive inspection of the System under the following conditions:
   - 5.1. the period of time between two inspections shall not exceed 7 months;
   - 5.2. during regular preventive inspection of the System, the Contractor shall perform testing of the System in cooperation with the Client;
   - 5.3. after preventive inspection, the Contractor shall prepare a written protocol and hand over this protocol to the Client;

5.4. the Contractor undertakes to inform the Client of his intention to carry out this inspection at least one month prior the planned day of the regular preventive inspection; the Contractor acknowledges that the Client is entitled to appoint another suitable date for carrying out this inspection if the proposed term by the Contractor is not convenient for a serious reason.

6. Service of the System shall be provided by the Contractor in case of malfunction of the System under the following conditions:

6.1. the Contractor is obliged to provide service of the System no later than by noon of the first business day following the date of System malfunction notification as made by the Client on business days from 8:00 to 18:00 [Client's local time];

6.2. the Contractor is obliged to provide service of the System no later than by 18:00 on the day following the date of System malfunction notification as made by the Client on business days from 18:00 to 24:00 or no later than by 18:00 on the day of System malfunction notification as made by the Client on business days from 0:00 to 8:00 [Client's local time];

6.3. if the Clients notifies a System malfunction on non-working days, the Contractor is obliged to provide service of the System no later than by 18:00 on the first business day following the date of System malfunction notification as made by the Client [Client's local time].

The Client shall notify a malfunction of the System to the Contractor in accordance with Article XXI paragraph 4 of this Contract using contact details provided in Article XXI paragraph 1 of this Contract. If no contact person is appointed by the Contractor, the Client shall be entitled to notify a malfunction of the System to any person which is in employment relationship or other similar relationship with the Contractor and to any e-mail address of the Contractor that is available to the Client.

7. The regular maintenance and service of the System specified in paragraphs 5 and 6 of this Article shall be provided during the warranty period for the Basic Configuration as well as for individual Extended Options under Article IX hereof. The Contractor shall be entitled to provide regular maintenance and service of the System specified in paragraphs 5 and 6 of this Article through his subcontractor within the deadlines specified herein and under the terms and conditions as specified in Article XVI hereof.

TRAINING AND CONSULTATIONS

8. The Contractor shall be obliged to train five of the Client's employees as may be appointed by the Client no later than by the date of the Final Acceptance of the Work defined in Article XV hereof under the following conditions:

8.1. the extent of the training shall be at the minimum 24 hours (i.e. 3 working days);

8.2. the training shall take place according to the following rules:
- 2 working days of the training shall take place at the premises of the Contractor,
- 1 working day of the training shall take place at the premises of the Client;

8.3. the Contractor shall bear all costs related to the training;

8.4. upon completion of the training, the Client's employees shall be able to individually operate the Work in its entirety and individually perform its management and maintenance;

8.5. upon completion of the training, the Contractor shall issue to the trained employees a written certificate that he/she had successfully completed the training and that he/she is fully competent to operate, maintain and control the System.

9. In addition to the paragraph directly above, the Contractor shall be further obliged to train a maximum of three of the Client's employees for each year of the effectiveness of this Contract under the following conditions:

    9.1. the Client shall be entitled to appoint three employees at his own discretion and the Contractor shall be obliged to provide training for those employees in order that they obtain all necessary competences to operate, maintain and control the System;

    9.2. the extent of the training shall be at the minimum 24 hours (i.e. 3 working days);

    9.3. the training shall take place at the place designated by the Contractor and the Contractor shall bear all costs related to the training;

    9.4. upon completion of the training, the Client's employees shall be able to individually operate the Work in its entirety and individually perform its management and maintenance;

    9.5. upon completion of the training, the Contractor shall issue to the trained employees a written certificate that he/she had successfully completed the training and that he/she is fully competent to operate, maintain and control the System.

10. Consultations relating to the function and operation of the System shall be provided upon request of the Client under the following conditions:

    10.1. the Client is entitled to request a consultation related to the function and operation of the System at any time during the working hours of the Contractor but at least from 9:00 to 14:00 [Client's local time];

    10.2. the request for consultation may be submitted by the Client to the Contractor using means and contact details provided in Article XXI hereof.

    10.3. the Contractor shall be obliged to provide consultations to the Client using a qualified professional appointed by him without undue delay, but no later than by the next business day after submitting a request;

    10.4. the scope of such consultations (including time spent on preparing the answers) shall not exceed 15 hours per month during the warranty period for the Basic Configuration and thereupon 7 hours per month during the warranty period for the Extended Option.

V. <u>FULFILMENT OF COVENANTS AND TRANSFER OF OWNERSHIP RIGHTS</u>

1. The Work shall be executed by delivery/provision of the partial performance of the Work, which shall be divided as follows:

    a) Contractor's Implementing Documentation
    b) First new flywheel generator
    c) High voltage switchgear
    d) Low voltage switchgear
    e) Transformers for TF coils
    f) Transformers for PF coils
    g) Prototype of Power supplies for PF coils (IGBT transistor based)

h) PF coils capacitor bank

i) Power Supplies for PF coils (IGBT transistor based)

j) Power Supplies for TF coils (Thyristor based)

k) Auxiliary systems (cables, chokes, protections, filters, lubrication unit, etc.)

l) Control system, SW

m) Final assembly

n) Commissioning and acceptance tests

(hereinafter each the "**Partial Performance**" and all together the “**Basic Configuration**”)

and the following partial performance constituting the Extended Options:

1) Second new flywheel generator and its auxiliary systems,

2) Increase of the capacitor bank(s) energy by +0.5 MJ and

3) Short circuit test at full nominal pulsed voltage of a selected transformer.

(hereinafter the "**Extended Options**"); the provisions hereof dealing with Partial Performance (e.g. Article VIII. and IX.) shall apply to the Extended Options similarly, unless inappropriate (e.g. not feasible). For the sake of clarity, the Parties acknowledge that the "Extended Options" include also their installation and full integration into the System including its control and protection system.

2. The Contractor undertakes to execute and hand over the Partial Performance, eventually its part, outside of the Client's premises under the terms and conditions specified herein. The Contractor shall be obliged to store manufactured, tested and handed over Partial Performance or its part at his own cost and responsibility till its final assembly according to the Article VI paragraph 4 hereof.

3. Completed evaluation and subsequent acceptance of the Work or its part does not release the Contractor from its liability for the correctness and completeness of the Work in part or as a whole.

4. The Client is entitled to refuse the handover of the Work if the Work is not compliant with the Contract and its Annexes.

5. The ownership rights to the Work, more precisely to Partial Performance or its part, shall pass to the Client upon its handover pursuant to terms defined hereof. The risk of damage shall pass to the Client at the same moment unless agreed otherwise herein. Nevertheless, the Contractor shall be liable for proper, careful and professional storage of the Partial Performance pursuant to paragraph 2 of this Article so that no damage is incurred to it till its final assembly according to the Article VI paragraph 4 hereof.

VI. <u>TERM – TIME SCHEDULING</u>

1. This Contract is concluded for a definite period until the full, proper and timely (within the given deadlines) completion of execution of the Work defined in Article III. hereof.

2. The Contractor undertakes to execute and hand over the Work consisting of the Partial Performances and Extended Options in line with the timeline defined in this Contract.

3. The Contractor undertakes to partially execute and hand over the Partial Performances according to the deadlines defined in the summarizing table including schedule and deliverables in detail which forms an integral part hereof as Annex 5 (hereinafter the "**Price Schedule and Deliverables**").

Simultaneously, the Contractor shall be obliged to deliver and handover a portion of the Partial Performances defined under Article V. paragraph 1 letters a) - k) hereof or parts thereof in the total value reaching at least CZK 90 million (excluding VAT) till 18 months after the Contract signature; the value includes all delivered and handed over parts of Partial Performances as specified and appraised in the Detailed Itemized Budget in the Contractor's Implementing Documentation within the meaning of Article V. paragraph 1 letter a) hereof. The preceding sentence deals with the "1st milestone" being the condition of some advance payments pursuant to *Annex 5 - Price Schedule and Deliverables*.

4. The Client shall notify the Contractor about the date on which the final assembly work, as specified under letter m) of Article V. paragraph 1 hereof, may be commenced at least 2 months in advance. The Contractor shall be obliged to complete and finally hand over the Work to the Client within 6 months after the date of assembly as notified by the Client pursuant to the previous sentence with observance of the deadline for the Partial Performances defined under Article V. paragraph 1 letters m) and n) hereof that shall be December 31, 2022.

5. The Contractor shall be obliged to train the Client's employees in accordance with Article IV. paragraph 8 hereof and to fulfil all the requirements designated by this Contract by December 31, 2022.

6. The Contractor undertakes to execute and hand over an Extended Option within the delivery period for the Extended Option as defined in *Annex No. 5 – Price Schedule and Deliverables* starting by the Client's call. Should not the Client call the Contractor for execution of an Extended Option within the deadline for such call defined in *Annex No. 5 – Price Schedule and Deliverables*, the Contractor's commitment to execute and hand over the Extended Option as well as the Client's commitment to take delivery and pay the price for the Extended Option shall expire. The Contractor is not entitled to claim on the Client any payment or compensation due to such expiry. Non-calling for an Extended Option does not affect other Extended Options nor other parts of the Work.

7. The Contractor undertakes to observe deadlines set forth for individual processes and solutions as provided in his Bid submitted in the Tender.

VII. PLACE OF DELIVERY

1. Unless agreed otherwise by the Parties or in this Contract, the place of execution and hand over of the Work shall be the premises of the Client at Prague (place of delivery: U Slovanky 1770/3, Praha 8).

2. The Contractor undertakes to deliver the Work pursuant to DDP INCOTERMS® 2010 in the meaning of Article V paragraph 2 hereof; in case of conflict, the provisions of this Contract shall take precedence over the DDP INCOTERMS® 2010.

3. The Contractor undertakes to execute the Work in the extent, manner and in the quality stated in his Bid. The Contractor shall specifically observe the fixed list of his subcontractors according to the affidavit submitted by him, including the specification of the Work to be executed by the individual subcontractors (hereinafter the "**Subcontractors' List**").

VIII. PRICE OF THE WORK; INVOICING; PAYMENT

1. The total (maximum) price of Work has been set forth on the basis of the Contractor's Bid in the amount not exceeding the maximum possible amount of **CZK 290.000.000,- excluding VAT** (in words: two hundred and ninety millions CZK, excluding VAT), i.e. **CZK 350.900.000,- including VAT** (in words: three hundred and fifty millions and nine hundred thousand CZK, incl. VAT), (hereinafter the "**Price**"). The Price consists of the total price for all Partial Performances and the total price for all Extended Options. The breakdown of the total price for all Partial Performances excl. VAT is provided in the Price Schedule and Deliverables (Annex 5) through the completion of its respective cell called the "Total Offered Price of The Basic Configuration excluding VAT".

2. The Contractor expressly declares that he has been fully briefed by the Client about the extent and nature of the Client's requirements with respect to the resulting Work and all supplies, services and work which form the subject-matter hereof, and that he has correctly specified, evaluated and priced the Work, including all supplies, services and work which may be necessary to meet the obligations assumed by the Contractor hereunder, and that he considered, in defining the Price, the following aspects:
   a) the facts mentioned in Article III paragraph 1 hereof;
   b) local conditions for executing and delivering the Work and performing the associated services and works,
   c) the Contractor correctly and fully reflected any and all technical and commercial conditions defined herein.

3. The Price shall cover any and all performance provided by the Contractor in order to fulfil all of the Client's requirements to properly execute and deliver the Work hereunder, and includes all costs that may be accrued by the Contractor during the execution of the Work and its delivery to the Client incl. all travel expenditure, fees, customs duties and insurance as well as all claims of the Contractor that may arise on the basis of intellectual property laws.

4. Considering the fact that the Price defined herein is final and cannot be exceeded, the Contractor shall have no right to any payment in excess of the Price, unless the change in the legal regulations affecting the VAT will be adopted or unless the Client and the Contractor duly agree on a change of the commitment hereunder within the meaning of PPA. Any such change shall be subject to concluding a written amendment hereto.

5. The Parties have agreed that upon Contractor's request, the Client shall provide advance payments for the financing of the Project. The maximum amounts and the terms of the advance payments are specified in the Price Schedule and Deliverables.

6. The Contractor shall be obliged to prepare a detailed breakdown of the Price in the form of detailed itemized budget for each category of Partial Performance based on his Bid, terms specified hereof and with observance with the breakdown of the Price stated in the Price Schedule and Deliverables (hereinafter the "**Detailed Itemized Budget**") and he shall submit this Detailed Itemized Budget to the Client as an integral part of the Contractor's Implementing Documentation defined in Article V paragraph 1 Letter a) hereof in the form of its annex.

7. The Contractor shall be authorized to invoice the price of the Partial Performance based on the Detailed Itemized Budget after handover of the Partial Performance completed in accordance with

letters a) – n) of Article V. Paragraph 1 hereof and confirmed by the relevant handover protocol. In case the Partial Performance is not executed as a whole, the Client shall be entitled to take delivery of and pay the invoiced price only for the actually handed over / delivered / completed individual items of the Partial Performance in accordance with the Detailed Itemized Budget. VAT shall be imposed on top of all payments made hereunder according to the valid legislation.

8. Upon completion of the Partial Performance, the Contractor shall be obliged to notify the Client about his right to handover the Partial Performance without undue delay in the written notification delivered to the Client's registered address. The notification shall include specification of the executed Partial Performance, including reports from the carried-out tests, the certificates of used materials, the products and procedures, if issued, and draft of handover protocol. If the Partial Performance is temporarily stored or executed outside of the Client's premises, the notification shall specify times when the Client or a person authorized by him may inspect the storage or execution of this Partial Performance. In case that a Partial Performance does not comply with the Contract the Client has the rights stipulated in Article XIII hereof (e.g. to refuse its acceptance). Provided that the Partial Performance to be handed over complies with the Contract, the Client shall accept its handover by the Contractor and the Parties shall confirm the handover by signing a handover protocol with respect to that Partial Performance. The tax documents – invoices for handed over Partial Performance shall be issued by the Contractor within five (5) business days from the Client's signature of the handover protocol regarding that Partial Performance and shall comply with all applicable legal regulations of the Czech Republic and include the following data:

   a) Commercial name and seat of the Client,
   b) Tax identification number of the Client,
   c) Commercial name and seat of the Contractor,
   d) Tax identification number of the Contractor,
   e) Number of the tax document – invoice,
   f) Quantity (extent) and nature of performance supplied or services rendered,
   g) The date of issue of the tax document – invoice,
   h) The day of the supply of performance, in so far as it differs from the issue date of the tax document – invoice,
   i) Due Date,
   j) Detailed description of the executed Partial Performance,
   k) The respective part of the Price (including a breakdown of the executed Partial Performance which shall be in accordance with Detailed Itemized Budget) and
   l) Statement that the performance is provided in connection with the Project "COMPASS-U: Tokamak for cutting-edge fusion research", Reg. No. CZ.02.1.01/0.0/0.0/16_019/0000768, pursuant to the respective order, or instruction in writing from the Client;

   and, furthermore, the tax documents – invoices shall also be in compliance with agreements on avoidance of double taxation, if applicable in particular cases. The Client is entitled to request itemization of the Price at his discretion. The Client is obliged to inform The Contractor about this request in advance.

9. Should a tax document – invoice not be issued in compliance with the payment terms defined herein or should it not meet the statutory requirements, or if a notification or handover protocol pursuant to the paragraph directly above should not be issued in compliance with the terms defined herein,

or should the executed Partial Performance not be executed properly (i.e. with defects or outside the extent, manner and the quality defined herein), the Client is entitled to return the tax document-invoice back to the Contractor within ten (10) business days from the date of its delivery to the Client. In such a case, the Client shall not be in default with the remittance of the Price or any portion thereof. Upon proper correction of the tax document-invoice or notification or upon proper completion of the Partial Performance, the Contractor shall issue a corrected invoice with a new but identical maturity period which shall commence to run on the day of delivery of the corrected or re-issued tax document-invoice to the Client.

10. The final invoice for the execution of the Basic Configuration shall be issued by the Contractor within fifteen (15) days from the signature of the Final Acceptance Protocol for the Basic Configuration defined in Article XV hereof by the Client. The final invoice shall include, in addition to the notification and data defined in paragraph 8 of this Article, the total cost of the Basic Configuration, the identification of all the previous invoices issued by the Contractor and the remaining amount of the Price to be paid for the execution of the Basic Configuration. The Client shall pay the final invoice only if the Contractor confirms in writing by his / her affidavit that no rights of third parties are attached to the Basic Configuration. The final invoice for the execution of the Extended Option No. 1, final invoice for the execution of the Extended Option No. 2 and final invoice for the execution of the Extended Option No. 3 shall be issued by the Contractor within fifteen (15) days from the signature of the Final Acceptance Protocol for the relevant Extended Option. The final invoice shall include, in addition to the notification and data defined in paragraph 8 of this Article, the total cost of the relevant Extended Option, the identification of all the previous invoices issued by the Contractor and the remaining amount of the Price to be paid for the execution of the relevant Extended Option. The Client shall pay the final invoice only if the Contractor confirms in writing by his / her affidavit that no rights of third parties are attached to the relevant Extended Option. Principles defined in paragraph 9 directly above shall also apply to the final invoices.

11. All invoices issued hereunder shall be payable 30 (thirty) days from the date of their delivery to the Client (hereinafter the "**Due Date**"). The Client shall not be in default with the remittance of the Price or any portion thereof till the Contractor provides the original of the guarantee according to Article X. Any payment of the amounts invoiced shall be understood to be effected on the day such are remitted to the bank account of the Contractor.

12. The last invoice of each calendar year must be delivered by the Contractor to the Client no later than on December 15 of that calendar year.

13. The Client’s invoicing details are given in Article I hereof.

14. No payment on invoice issued by the Contractor shall constitute acceptance of the Work or its part or a statement on flawlessness of invoiced performance or conclusive acceptance of flawlessness of the Work or its part.

15. The Contractor shall not be authorized to perform unilateral set offs of its receivables against the Client.

IX. WARRANTY, WARRANTY AND POST-WARRANTY SERVICE

1. The Contractor guarantees that any Work handed over is without any defects and will have the

properties set forth in this Contract, and in the generally applicable legal regulation and/or the Czech Technical Standards, as well as the properties of the top quality of the execution and will be executed in accordance with the verified technical practice. The Contractor shall be liable to deliver fully functional and usable Work or any part thereof.

2. The Work shall be deemed to be defective if its implementation or its parts fail to meet the qualitative conditions, extent, properties and standards defined herein, and in generally applicable legal regulation and/or the Czech Technical Standards.

3. The Work shall be deemed to be defective if there are defects in the documentation related to the Work to be delivered by the Contractor to the Client hereunder together with the Work. If such provided documentation is defective, the Client shall be entitled to return the respective documentation to the Contractor at the Contractor's expense and/or to request provision of such documentation that is without defects. In such a case, the Contractor shall, without undue delay, but no later than within ten (10) days from the return of the defective documentation or from the delivery of the Client's request, deliver to the Client complete documentation free of any defects.

4. The Contractor shall be liable for any defects on the Work or any of its parts at the time of its handover and acceptance, during the period between its handover and starting day of the warranty period, as well as for any defects that may be discovered on the Work or its parts during the entire warranty period (quality guarantee). For the avoidance of any doubt, the Parties exclude application of Section 2112 and 2618 CC.

5. The Contractor shall provide quality guarantee for the Work for 24 months. The quality guarantee consists of up to four independent warranties, i.e. warranty for the Basic Configuration, warranty for the Extended Option No. 1, warranty for the Extended Option No. 2 and warranty for the Extended Option No. 3, with independent warranty periods. The warranty period for the Basic Configuration commences running from the date of signature of the Final Acceptance Protocol for the Basic Configuration as defined in Article XV hereof. The warranty period for an Extended Option commences running from the date of signature of the Final Acceptance Protocol for that Extended Option as also defined in Article XV hereof. Where warranty certificates of technology, equipment, materials or products determine different warranty periods, the longest period shall apply.

6. Any requests to remove defects on the Work or its part during the warranty period shall be exercised in writing by the Client against the Contractor without undue delay after such were discovered, no later than on the last day of the warranty period (hereinafter the "**Warranty Claim**"). Any Warranty Claim transmitted by the Client, even if made on the last day of the warranty period, shall be deemed to have been exercised in time. The Warranty Claim shall include an indication and brief description of the defect, the date of detection of the defect, the claim selected under paragraph 7 of this Article and alternatively the term for the removal of the defect which shall be adequate to the nature of the defect and with respect to the selected claim. For the avoidance of any doubt, the Parties agree that the choice of claim for liability for the defects of the Work lies exclusively within the Client's authority.

7. Regardless of the nature of the defect and the seriousness of the breach of the Contract due to a provision of defective Work, the Client shall be entitled to choose any of the following claims and/or their combination:
   A) have the defect removed by having a new Work/its part supplied that is without defect or a

missing part;

B) the removal of the defect by having the Work repaired;

C) a reasonable reduction of the Price;

D) withdrawal from the Contract;

E) to inspect the Work either by himself or through a third person, to have the relevant defect removed and/or to ensure the performance of the substitute Work/its part instead of the Contractor. In such a case, the Contractor shall be obliged to pay all costs related to the removal of defect to the Client without undue delay upon Client's request; the Client shall be entitled to seek damages in addition to the costs paid in such instance.

8. The Contractor undertakes to review all submitted Warranty Claims, notify the Client whether he recognizes the claim, and inform the Client in writing of the deadline for the removal of the defect within one (1) week of the date on which the claim was delivered to him by the Client.

9. The Contractor undertakes to remedy any claimed defects on the Work or its parts free of charge and without undue delay. The maximum period for removal of a defect is specified in the Technical Specification depending on the category of defects, and all deadlines commence to run on the date when the Warranty Claim was notified to the Contractor, unless the Client and the Contractor agree otherwise and the nature of the defect makes any such alternative deadline feasible.

10. If the Contractor does not remove the defect under paragraph 7 A) or/and B) of this Article within the specified deadline or if prior to the expiration of the stated deadline the Contractor notifies the Client that he is not willing to remove the defects, the Client shall be entitled to withdraw from this Contract, or to exercise his other rights under paragraph 7 of this Article, and to impose contractual penalties pursuant to Article XVII paragraph 1.5 and 1.6 hereof.

11. The Contractor shall be obliged to remove defects on the Work or its parts according to the Client's choice also in instances when the Contractor is of the opinion that he is not liable for such defects or that the term for the removal of a defect is not feasible. Cost accrued in connection with the removal of defects in these disputable cases shall be borne by the Contractor until such dispute is resolved.

12. Removal / remedy of claimed defects shall be subject to a protocol in which the Parties confirm the defect’s removal. The warranty period shall be extended by any period that passed between the Warranty Claim notification and actual removal of the defect taking into account each commenced calendar day. In the event of the removal of the defect of the Work or its part pursuant to paragraph 7 A) of this Article, the Parties agree that a new warranty period commences running from the date of takeover of the new Work/its part by the Client.

13. The rights and obligations of the Parties arising from the Contractor's warranty survive withdrawal of any of the Parties from this Contract.

14. After the end of the warranty period the Contractor shall be obliged to enter with the Client into a service contract stipulating the Contractor’s obligation to provide service support for the installed Work and its necessary maintenance as well as to provide, at the Client’s request, post-warranty service on the Work outside the existing warranty. Post-warranty service shall be principally understood as upgrades, removal / remedy of defects after the warranty period, repairs and replacements of defective parts and provision of spare parts due to wear. The price and conditions

for services outside the existing warranty shall be defined by agreement between the Parties in a specific service contract(s) and the price itself should be in line with the usual market prices for similar services.

15. Acts of the Parties shall constitute claims pursuant to this Article if made by the means and representatives of the Parties using contact details specified in Article XXI hereof.

16. Unless agreed otherwise by the Parties or in this Contract and exempt for the re-used parts under paragraph 17 of this Article, those of the re-used parts of the Client's current power supply system defined in Article III. paragraph 6 herein that are marked in the Technical Specification as "**Category A (Prescribed re-use)**" (e.g. existing flywheel generators, HV switchgear, etc.) are excluded from the warranty but the warranty includes all newly installed parts, integration, control and protection. This provision must be interpreted in a way that a fault caused by malfunction of the re-used part is not included in the warranty, while the fault or non-functionality caused by integration, control, connection, faulty protection or wrong use in the System is included in the warranty.

17. The warranty pursuant to paragraphs 1 through 15 of this Article includes also those of the re-used parts of the Client's current power supply system, within the meaning of Article III. paragraph 6 hereof, that are marked in the Technical Specification as "**Category B (Free re-use)**".

X. BANK GUARANTEES

1. Execution bank guarantee for Basic Configuration and Extended Option No. 1:

The Contractor shall provide to the Client, by the date of signature hereof, the original of the guarantee (bank guarantee) or the original written agreement with an attorney-at-law or a notary as regards the opening of the special secured custody account (hereinafter the "**custody**") securing proper execution of the Basic Configuration as well as Extended Option No. 1 and passage of the ownership title to the Basic Configuration as well as Extended Option No. 1 to the Client in the total amount of CZK fifteen (15) million. The Contractor shall be entitled to choose either bank guarantee or the attorney's or notarial custody at his own discretion. The guarantee or the custody shall remain valid and effective for the entire period of the Basic Configuration as well as Extended Option No. 1 being executed until either the ownership title to the Basic Configuration as well as Extended Option No. 1 passes to the Client or the ownership title to the Basic Configuration passes to the Client and Contractor's commitment to execute and hand over the Extended Option No. 1 expires pursuant to Article VI. paragraph 6 hereof. The Contractor undertakes to keep the guarantee or the custody valid and effective for that period even if extended under this Contract. The Contractor declares that the bank guarantee is irrevocable, unconditional and payable on demand, i.e. the bank guarantee permits unconditional draw down, without the bank having recourse to objections within the meaning of Section 2035 CC, without the need for the Client to notify the Contractor to observe his obligations, in all cases where the Contractor may default on any of his obligations defined herein. Requirements stipulated in previous sentence for bank guarantee shall apply mutatis mutandis (similarly) to the custody, in particular an attorney-at-law or a notary shall be obliged to pay to the Client financial claims demanded by the Client unconditionally. The bank guarantee or the custody securing the proper execution of the Basic Configuration as well as Extended Option No. 1 shall cover financial claims of the Client against the Contractor (statutory or contractual sanctions including contractual penalties, damages including reimbursement for damage to the System or Client's property caused by the Contractor and/or its subcontractor(s), costs related to the transfer of ownership rights, sanctions resulting from delays with even a single Partial Performance etc.), which may arise due to the breach of the Contractor's obligations in relation to the proper execution of the Basic Configuration or Extended Option No. 1 in agreed quality and timeframe, which the Contractor failed to observe even after a prior notification by the Client. The bank guarantee or the custody shall also cover the above obligation of the Contractor to keep the bank guarantee or the custody valid and effective for the entire above period until the ownership title to the Basic Configuration passes to the Client, ownership title to the Extended Option No. 1 passes to the Client or Contractor's commitment to execute and hand over the Extended Option No. 1 expires pursuant to Article VI. paragraph 6 hereof, whichever comes later.

2. **Warranty bank guarantee for Basic Configuration and Extended Option No. 1:**

   The Contractor shall provide to the Client, before the signature of the Final Acceptance Protocol with respect to the Basic Configuration defined in Article XV hereof, the original of the guarantee (bank guarantee) securing claims of the Client arising out of the Contractor's warranty pertaining to the Basic Configuration as well as Extended Option No. 1 in the total amount of CZK ten (10) million; the guarantee shall remain valid and effective for the entire warranty period pertaining to the Basic Configuration or Extended Option No. 1 (whichever lasts longer) and the Contractor undertakes to keep the guarantee valid and effective for that period even if extended under this Contract. The Contractor declares that the bank guarantee is irrevocable, unconditional and payable on demand, i.e. the bank guarantee permits unconditional draw down, without the bank having recourse to objections within the meaning of Section 2035 CC, without the need for the Client to notify the Contractor to observe his obligations, in all cases where the Contractor may default on his obligation to remove defects on the Basic Configuration or Extended Option No. 1 or other obligation defined in Article IX hereof. The bank guarantee securing claims arising out of the Contractor's warranty shall cover financial claims of the Client against the Contractor relating to warranty defined herein (including reimbursement of costs and damages related to the removal of defects by the Client or third party instead of the Contractor), which may arise due to the breach of the Contractor's obligations, which the Contractor failed to observe even after a prior notification by the Client. The bank guarantee shall also cover the above obligation of the Contractor to keep the bank guarantee valid and effective for the entire warranty period pertaining to the Basic Configuration or Extended Option No. 1 (whichever lasts longer).

3. The bank guarantees shall be issued by a bank authorized by the Czech National Bank to act as a bank in the Czech Republic under the respective laws. The attorney's custody agreement shall be concluded with an attorney-at-law registered in the list of attorney-at-law maintained by the Czech Bar Association under the respective laws. The notarial custody agreement shall be concluded with a notary who is a member of the Notarial Chamber of the Czech Republic under the respective laws.

4. The Contractor shall be obliged, within 14 (fourteen) calendar days after each draw down against any of the bank guarantee or the custody by the Client (creditor), to deliver to the Client a new bank guarantee (i.e. the instrument) or a new custody in the amount equal to the original bank guarantee or the original custody prior to the draw down, or to top up the guarantee or the custody, from which the draw down was made, to the originally agreed amount.

5. Failure to observe the obligation stipulated in this Article by the Contractor shall be deemed to have constituted a material breach hereof.

XI. INTELLECTUAL PROPERTY RIGHTS

1. In the event that in connection with the execution of this Contract the Work as a whole or any part thereof shall constitute a copyrighted work within the meaning of the Act No. 121/2000 Coll., on Copyrights, Rights Related to Copyright and on amendment of certain other Acts, as amended (hereinafter referred to as the "**Copyright Act**"), such will be considered as the Work under commission as defined in Section 61 of the Copyright Act. In these cases the Contractor shall grant to the Client a non-exclusive royalty-free licence to use the copyrighted work in its original, processed or other modified form of the copyrighted work, as a whole or any of its parts, individually, in a set, or in connection with any other work or elements or included in collection for the purposes of this Project and/or for the purposes defined herein and/or for the purposes of research and education or publication activities, for the entire period of validity of copyright to each copyrighted work, on the worldwide territory.

2. Within the licence provided in paragraph 1 of this Article, the Contractor shall, with a consent and authorisation of authors of the Work, give his consent also to release, modification, elaboration, and translation of the copyrighted work, as well as to change of its name or to connect this copyrighted work with another work or to include this copyrighted work in collection. If it is necessary for the full use of the licence in its above-mentioned scope, the Client is also entitled to any other activities which may encroach upon the personal rights of authors of the copyrighted work. The Client is entitled to exercise its rights under this paragraph itself or by a third person.

3. Copyrighted work (Article XI. paragraph 1) and industrial rights (Article XI. paragraph 3), as well as other intangible goods (Article XI. paragraph 4) are jointly referred to, for the purposes hereof, as **intellectual property rights**. In the event that the execution of this Contract and/or the Project will result into Work or any part thereof, which the Contractor is entitled to register through any form of industrial rights (i.e. trademark, patent or invention, utility or industrial design etc.) protected according to the valid legal regulation in the Czech Republic or in another country, or international or supra-national body, the Contractor undertakes to (i) grant the Client a non-exclusive royalty-free licence to use the Work for the purposes of the Project and/or this Contract and/or for the purposes of research and education activities, as well as for any unlimited other way of use on the worldwide territory; and (ii) keep and maintain valid and in effect all necessary registrations and protection of industrial rights under this Contract on its own costs in the extent necessary for operation of the Work by the Client for the time period required by the purposes of the Project and/or this Contract. The terms and conditions defined in this paragraph shall apply also in the event that the execution of this Contract will result into Work or any part thereof, which has already been registered through any form of industrial rights.

4. In the event that in connection with the execution of this Contract the Work or any of its parts shall constitute a subject of intellectual property, which could not be considered as a copyrighted work and/or a subject of industrial property rights, but is able to be expressed in an objectively perceptible form and is important for execution of this Contract, in particular the know-how, confidential information, improvement proposals and other ("intangible goods"), the Contractor shall grant to the Client a non-exclusive royalty-free licence to use the Work for the purposes of the Project and/or this Contract and/or for the purposes of research and education activities, as well as for any unlimited other way of use on the worldwide territory.

5. The Contractor shall assign/submit to the Client valid licences to use the software, which is subject

to the license terms, bought by the Contractor, at the latest upon signing the Final Acceptance Protocol defined in Article XV hereof. The assignment of the licences shall be in accordance with the licensing policy of the software vendors.

6. The Client shall be entitled to transfer the exploitation rights of any subject of intellectual property acquired in accordance with Article XI. of this Contract in whole or in part to a third person, or to sub-licence the above-mentioned rights. The Client shall be entitled to disclose the results of the Work to any third party without Contractor's previous consent.

7. The Contractor undertakes to transfer the complete documentation created during the execution of the Work or its part in connection with the execution of this Contract, which is relating to the subjects of intellectual property under this Article. For the avoidance of any doubt, the Parties have agreed that all software created in connection with the execution of this Contract as the copyrighted work (meaning software on PCs, FPGA, microcontrollers, microprocessors and other programmable devices) shall be received by the Client under the following conditions:

   - **Type of SW compilation procedure and back-up solution**

     If possible, the System software will be compiled on virtual machines backed-up by the Contractor in order to maintain the possibility of compilation of the software throughout the expected longevity of the Work.

     Alternatively, the bit copies of real computers with the installed software along with a detailed PC description will be backed up.

   - **Access to the source code of the SW specifically developed for the realization of the System delivery**

     If the software is developed by the Contractor or third parties specifically for the System, the Client will obtain the source codes (source code in language used by programmer to write the code), binary files and compilation instructions (including the programs used for the compilation, list of dependencies and deployment manual).

   - **Access to the source code of the SW developed by the Contractor independently to the System delivery**

     If the software belongs to the Contractor, was developed independently on the System delivery and the Contractor is not willing to provide the source codes to the Client, then the Client requires to obtain binary files at delivery of the System and the source codes after 10 years from the delivery at latest.

   - **Access to the source code of the SW developed by the third parties independently to the System delivery**

     If the software belongs to a third party and it was developed independently on the System delivery, the Contractor is required to make demonstrable effort to obtain the source codes for the Client. If it is not possible, the Client requires at least backed-up binary files and software documentation.

8. The Contractor declares that he is not aware of any rights of third persons relating to any subject of intellectual property within the meaning of this Contract. The Contractor undertakes, that the rights provided to the Client, are not and will not be in any way territorially or temporally limited, in particular not in its content or quantity. In case that the Contractor breaches the obligations under this paragraph, the Client is entitled to claim the damages arising from this breach.

9. The intellectual property rights according to Article XI. shall pass to the legal successor of the Client or to the future operator of the Work provided for the Project, for the duration of the protection period granted to that particular intellectual property right and/or period of existence of ownership rights to copyrighted work or without any restriction to other intangible goods within the meaning of this Contract.

10. The Parties declare that they have agreed that the Contractor's remuneration for the provision of any licence pursuant to this Article XI. hereof has already been included in the Price for the Work.

11. In the event of a violation of the rights pertaining to the intellectual property created under this Contract, their owner / proprietor shall be entitled to enforce these rights before the competent authorities. The bearer of the license shall be obliged to inform the owner / owners of intellectual property rights without delay in any case when he learns of a breach in accordance with the previous sentence. In the event that a third party claims against the Client any rights relating to the intellectual property rights defined hereof, the Contractor undertakes to hold negotiations, alternatively civil litigation or other dispute with such third party at his own expense in order to protect the rights and legitimate interests of the Client. If a third party is successful in negotiations, civil litigation or other dispute, the Contractor undertakes to compensate all Client's costs incurred in this connection (i.e. any demonstrably incurred expenses, any contractual fines or other penalties, damages, or any other financial or non-pecuniary damage caused to the Client).

12. In the event that the Work or its part has been produced as a result of joint effort of the Contractor and the Client, the Parties undertake to submit a joint application for any industrial rights as co-applicants. All natural persons participating on the creation of Work or its part shall be co-authors.

13. All licences and other entitlements under this Article of the Contract shall be provided as irrevocable. Termination of the Contract has no influence on granting of licences.

14. Any further data, information and outputs of testing stages executed in framework or in connection with this Contract and/or with the project ("testing data") will immediately belong to the Client. The Contractor shall without any delays hand over the testing data to the Client. The Contractor is entitled to use the testing data only in connection and for the purposes of this Contract. The Contractor shall not provide or disclose the testing data to any third person without a previous consent of the Client.

15. In the event that the Contractor fails to meet his obligation under this Contract and/or does not execute the Work in accordance with this Contract and/or generally applicable legal regulation and/or Czech Technical Standards, the Client shall be entitled to ensure the execution of the Work itself or through a third party. For this purpose, the Contractor shall provide at the Client's request, within 10 (ten) days from the date of receipt of this notice, all technical and other documentation, source codes and other necessary information concerning technical and other solutions and procedures for the execution of the Work. The Client shall be entitled to use and/or to permit the use and handling by third parties of the provided documentation, source codes and other necessary information.

XII. RIGHTS AND OBLIGATIONS OF THE PARTIES

1. The Contractor undertakes to fulfil all of its commitments entered into hereunder with professional

care, at its own cost and risk, and to observe the deadlines stipulated in the Technical Specification, for the Price set forth in Article VIII. hereof.

2. The Parties are entitled to provide each other with the list of responsible persons (including their contact information) according to Article XXI paragraph 5 hereof.

3. The Contractor undertakes to observe all publicity rules that may be required to observe under the OP RDE binding documentation.

4. The Client undertakes to deliver to the Contractor any and all source documents, materials or other information that are necessary for the execution of the Work and which the Contractor can reasonably request from the Client under the condition that the Contractor raised any such requirement with sufficient advance ensuring fulfilment of the deadlines for the execution of the Work.

5. The Contractor shall be required, in executing the Work hereunder, to constantly and with due professional care examine the suitability of the Technical Specification for the Work and other documentation that defines the subject-matter and the scope of Work, according to which he is obliged to execute the Work.

6. The Contractor is obliged to verify whether these documents are in accordance with applicable laws, rules, regulations, technical standards and norms of the Czech Republic and other countries, and shall be required to follow them before commencing work, performance or service on the Work. The Contractor shall be also obliged to immediately notify the Client in writing about any potential unsuitability of documentation. The Contractor shall comply, in executing the Work, with all standards and requirements of any collective agreements, related laws and regulations, protection orders, insurance and assistance. The above applies to legislation, standards and technical regulations which may not be explicitly mentioned herein or in Annexes hereto.

7. The Contractor shall comply with technical standards relating to the drafting the project, delivery of materials, provision of services and application of procedures and methods applicable in the country of his seat. In the event that such standards in the country of the Contractor’s seat do not exist, the Parties may agree on use of another set of relevant standards.

8. In the event that at the time of delivery of the Work or any part thereof hereunder the laws or technical standards of the European Union or the Czech Republic, or technical conditions governing goods and its operation in force shall be different from legal or technical standards in effect at the time of conclusion of this Contract, the Contractor shall take into account the content of such standards or legislation.

9. If the Contractor fails to meet obligations stipulated in paragraph 6 above, he shall be liable for defects thus caused to the Work and shall be obliged to bring the Work in compliance with applicable laws, rules, regulations and standards at his own expense; the Contractor shall also be fully responsible for other consequences that may be associated with this particular breach, including damages that may arise to the Client due to such omission on the part of the Contractor. The Contractor shall be obliged to contractually oblige any third parties (its subcontractors) which he may use, in accordance herewith, in executing the Work.

10. The Contractor shall be obliged to take into account, in the execution of the Work hereunder, all

requirements of the Client that are aimed at achieving the highest quality of the objectives hereof, unless such are contrary to the law.

11. The Contractor undertakes, under the terms and conditions hereof, in accordance with instructions issued by the Client and using all due professional care, to:

    i. duly archive all written material prepared in connection with the execution of the Work hereunder and to provide access to the Client to these archived documents until the end of 2033. The Client shall be entitled to take possession of these documents after 10 (ten) years from completion of the Work hereunder from the Contractor free of charge; the Contractor shall contractually bind its potential subcontractors to adhere to the same rules.

    ii. cooperate during financial inspections carried out in accordance with Act No. 320/2001 Coll., on Financial Inspections, as amended, i.e. to allow the managing authority of the OP RDE to access also those portions of the tender (bid) submitted within the Tender, the Contract, Orders, partial contracts for work and related documents which may be protected by special legal regulation, given that all requirements set forth by legal regulation with respect to the manner of executing such inspections will have been observed; the Contractor shall bind any of its sub-contractors to comply with this obligation accordingly.

XIII. <u>QUALITY OF THE WORK, CONTROL BY THE CLIENT</u>

1. The quality of the Contractor's performance shall comply with all requirements defined in technical standards relating to the performance provided under this Contract, specifically with the Czech Technical Standards.

2. All equipment and products supplied by the Contractor shall be chosen for the defined purpose and function, shall be operationally certified, safe, constructed and executed in accordance with the relevant Czech Technical Standards and/or internationally recognized standards ensuring their equal or higher quality and safety. The Contractor shall supply equipment and products only from reputable manufacturers possessing recognized references. The Contractor shall provide or cause to be provided, for all equipment and products to be integrated within the Work and subject to provisions of Section 13 Act No. 22/1997 Coll., on Technical Requirements for Products, as amended, valid Certificate(s) of Conformity, whether to the Client or a person authorized by the Client, or directly to the relevant authority, as applicable. All work and supplies will be executed and delivered in accordance with the Czech sanitary, fire & safety regulations as well as any other related and applicable regulation.

3. The Contractor shall use for the Work only materials, equipment and products of a corresponding quality and properties ensuring that throughout the Work's anticipated life-span, assuming ordinary maintenance, its operating life will be fully guaranteed, as well as the required mechanical strength and stability, fire safety properties, sanitary requirements, health and environmental protection standards, safety of use and protection against noise.

4. The Contractor confirms that he has implemented, documented and verified system of quality management in line with ISO 9001 requirements and undertakes to maintain such quality management until the Work will have been finally executed. All activities of the Contractor and its subcontractors during execution of the Work shall comply with the quality plan specified below.

5. The Contractor shall be obliged to execute the Work in accordance with the quality plan approved

by the Client (hereinafter the "**Quality Plan**"); the Contractor shall submit the proposed Quality Plan to the Client together with the Contractor's Implementing Documentation specified in the Documentation. The Client shall be obliged to approve the submitted proposed Quality Plan in accordance with deadlines, terms and conditions specified in the Documentation for Section "Contractor's Implementing Documentation". Decision not to approve the Quality Plan shall not establish a reason for extension of the delivery dates for the Work or its part(s). In case the proposed Quality Plan is not approved, the Contractor shall be obliged to submit a new Quality Plan, addressing all comments submitted by the Client, within ten (10) days from receiving the comment from the Client. The Quality Plan shall include an inspection and test plan (hereinafter the "**ITP**").

6. Once the Client approved the Quality Plan, including the ITP, it shall form a part of the documentation for the execution of the Work hereunder and shall be binding for the Contractor.

7. All inspections, trials and tests carried out in relation to the execution of the Work by the Contractor and subcontractors shall be performed in accordance with ITP and related documentation and the Contract in general. Successful performance of any test, trial or inspection of the Work or its part, or delivery of any certificate, confirmation or approval of the Client at any time during the execution of the Work does not prejudice the Contractor's obligation to execute the Work and all its parts in proper and timely manner in accordance with this Contract, nor the Contractor's liability for any breaches hereof.

8. The Quality Plan shall be modified by the Contractor in the form of duly recorded revisions / versions / annexes of the Quality Plan, duly approved by the Client. The cost of revising the Quality Plan are included in the Price for the Work. The Contractor shall be obliged to submit the proposed revisions of the Quality Plan including ITP to the Client in sufficient advance depending on the planned execution of the Work so that the Contractor is able to execute the Work in accordance with the Client-approved Quality Plan revision under the terms hereof. Should the Client discover that the Quality Plan does not comply with the Contract, the Contractor shall be obliged to prepare and submit to the Client, within deadline defined by the Client, a revision of the Quality Plan, which will be compliant with the Contract. Any revision of the Quality Plan shall become effective only when and if approved by the Client in accordance with the Documentation, Section "Contractor's Implementing Documentation", and upon such approval, the revised Quality Plan becomes binding for the Contractor.

9. The Contractor shall modify the Quality Plan within ten (10) business days (i) after corresponding request from the Client triggered by change in the Client's internal regulations, (ii) after effective date of corresponding change in the generally applicable regulation of the Czech Republic or of the Czech Technical Standards or requirements of the public supervisory authority or (iii) after discovery of the need to implement rectifications or preventive measures arising from an inspection or (iv) after the request to that effect is made by the Client in case of change in other requirements by the Client in accordance with this Contract.

10. The Contractor shall be obliged to allow the Client or its representative, at any time prior to completing the Work, to inspect without delay the progress in execution of the Work and any of its part, including all things, work, services, rights of use, plans and drawings, documentation and information, so that the Client may satisfy himself that they are in accordance with the Contract.

11. All inspections, trials and tests shall be carried out at the Contractor's place of business, or at the subcontractor's place of business, in manufacturer's plants, during transport or at the site. The right of the Client to carry out an inspection, trial or test shall not be prejudiced by the fact that the Work

or any of its part had already been inspected, made subject to a trial or tested, should such process be executed without the Client in attendance or should such inspection, trial or test be unsuccessful.

12. Whenever the Contractor is prepared to organize any inspection, trial or test as laid down in the ITP, the Contractor shall notify the Client with sufficient advance, no later than fourteen (14) days prior, by fax, e-mail or registered post about such inspection trial or test and the place and time where it should be carried out. The Contractor shall secure all required authorizations or consents from any relevant third party or manufacturer allowing the Client's representative to attend such inspection, trial or test. The Contractor shall confirm to the Client, by fax or e-mail, the date of inspection, trial or test no later than three (3) business days prior to commencing an inspection, trial or test.

13. All results, protocols and/or certificates confirming performed inspections, trials or tests shall be recorded in a document called "Inspection and Test Ledger" which shall be handed over to the Client as a part of the As-built Documentation specified in the Documentation no later than five (5) days before the anticipated final handover of the Work. The Contractor shall submit to the Client all protocols recording results of any and all inspections, trials or tests.

14. Should the Client's representative fail to participated in an inspection, trial or test, regardless of the fact that he/she had been properly and timely invited, then the Contractor may perform the inspection, trial or test without the Client in attendance, however the Contractor shall submit to the Client within three (3) days thereof the resulting protocol(s) recording its results for the Client's review.

15. The Client shall be entitled to participate in all inspections, trials and tests. The Client shall bear the cost and expenses arising to him in connection with such participation, such as travelling expenses, accommodation and board. In the event any inspection, trial or test is unsuccessful for reasons which can be attributed to the Contractor, the Contractor shall compensate all cost and expenses related to the Client's attendance of such unsuccessful inspection, trial or test to the Client. The Client shall be entitled to a compensation of costs and expenses related to his attendance in an unsuccessful inspection, trial or test.

16. For the purposes of any inspection, trial or test, the Contractor shall allow and facilitate to the Client or its representative(s) an access to such inspection, trial or test at any time and any place where the work is carried out, services provided, parts manufacture or usage rights provided under this Contract.

17. Should any of the inspected, trialled or tested part(s) of the Work, including any related work, services or things, fail to comply with the Contract, generally applicable legal regulation or the Czech Technical Standards, the Client may refuse to accept it and the Contractor shall either replace such refused part of the Work with new, flawless performance or, if agreed by the Client, carry out all modifications (changes) that are necessary to meet the specified requirements free of charge to the Client. Any repeated inspections, trials or tests of any newly delivered or rectified parts of the Work shall be carried at the sole cost of the Contractor. The Contractor shall bear in such cases also all cost and expenses accrued in this relation by the Client.

18. If the Contractor fails to make accessible or to execute any part of the Work in a manner allowing inspection, trial or test in accordance with the Contract, he shall, at his own cost, make it accessible in a manner allowing inspection, trial or test.

19. Any work or service to be carried or delivered by the Contractor, or any replacement or rectification

of any part of the Work, that may be triggered by repeated test or refusal by the Client to accept such part may not be understood as a modification of the Work and the Contractor shall not be entitled for this reasons to carry our any revisions to the Quality Plan, to modify the Price, deadlines for execution or delivery of the Work and/or the Price Schedule and Deliverables. Any costs of such services or work, things and rights of use shall be borne by the Contractor, including all cost of repeating the inspections, trials or tests and securing these activities.

20. Unless otherwise specified herein, all inspections, trials or tests and related activities shall be performed by the Contractor and all costs and expenses relating to these inspections, trials or tests, including costs relating to replacement of any parts that may be destroyed during such inspections, trials or tests shall be borne by the Contractor and considered to have been included in the Price for the Work.

21. Nothing in this Article shall in any way, manner or form prejudice the Contractor's obligations relating to the timely and proper execution and quality of the Work, or relating to maintaining guarantees or other undertakings assumed by the Contractor under this Contract.

XIV. EXECUTION OF THE WORK, COOPERATION BETWEEN THE PARTIES

1. While executing the Work the Contractor shall be obliged to follow the instructions of the Client specifying means and times of access to the site of the Client and use of particular premises at the Client's site. If such instructions are not handed over within a reasonable period of time to the Contractor by the Client upon Contractor's request, the Contractor shall not be responsible for delay with delivery of the part of the Work for which the instructions have not been handed over by the Client. The Client shall appoint a person or persons authorized to hand over the instructions to the Contractor. The instructions shall be communicated to the Contractor either in writing or orally by authorized person.

2. The Contractor undertakes to effectively cooperate with the Client in creation of instructions for the execution of the Work in order to execute the Work in cooperation with other persons carrying out the work for the Client at his site. Effective cooperation shall include informing the Client about the possibility to execute a particular part of the Work, about the time and space preferences necessary for execution of such part of the Work. If the Contractor refuses to inform the Client in the manner specified above, the potential extension of deadlines defined in Article VI hereof shall be considered to be caused by the Contractor.

3. The Parties undertake to make every effort to create the necessary conditions for the execution of Work under the conditions specified herein. This shall also apply in cases where it is not expressly provided in the provisions hereof.

4. If either Party learns about facts that may prevent or will prevent it from honouring its contractual obligations, this Party shall immediately notify the other Party in writing. The Parties further agree to immediately rectify all circumstances, within their means, that may hinder their own fulfilment of contractual obligations.

5. The Contractor undertakes, depending on the facts arising in the course of executing his obligations hereunder, to propose and implement any and all measures to comply with the conditions laid down hereby, to protect the Client against damage, loss and unnecessary expenditure and to provide the Client or the Client's representatives acting in technical matters and other persons participating in

the implementation of the Work, with all necessary documentation, consultations, help and other assistance.

XV. ASSEMBLY, TESTING AND FINAL ACCEPTANCE OF THE WORK

EXECUTION AND COMPLETION OF ASSEMBLY

1. The Contractor shall assemble the Work in line with this Contract, generally applicable legal regulation, the Czech Technical Standards and the Quality Plan. There will be up to four phases of assembly (i.e. one for the Basic Configuration and three for the Extended Options), including four Complex Tests in total as well as four protocols of each type required in this Article (i.e. the below APP, ACP, CTEP and Final Acceptance Protocol for the Basic Configuration; APP, ACP, CTEP and Final Acceptance Protocol for the Extended Option No. 1; APP, ACP, CTEP and Final Acceptance Protocol for the Extended Option No. 2 as well as APP, ACP, CTEP and Final Acceptance Protocol for the Extended Option No. 3).

2. Prior to commencing assembly of any of the relevant parts of the Work (i.e. Basic Configuration, Extended Option No. 1, Extended Option No. 2 or Extended Option No. 3), the Contractor shall submit to the Client an assembly preparedness protocol with respect to that part of Work for approval. The assembly preparedness protocol shall contain:

   a) confirmation that all relevant documentation required to commence assembly had been approved by the Client,

   b) confirmation that all things, equipment and their parts, which are being delivered for the assembly in line with the Quality Plan have passed the required inspections and tests,

   c) confirmation that all assembly equipment and their parts, which had been delivered to the assembly site had been duly inspected and tested in line with the Quality Plan,

   d) confirmation that the Client approved all revisions of the Quality Plan pertaining to the assembly,

   e) confirmation that all persons which will be involved in the execution of the Work have been instructed in the required extent with all regulations related to the performance of the Contract,

   (hereinafter the "**APP**").

   The Client shall not unreasonably deny approval to the APP and shall be issued as soon as possible after its delivery to the Client by the Contractor. In case the APP is not approved by the Client within ten (10) business days, or the Contractor is not informed of any reasons why it was not approved, the APP shall be considered to have been approved.

3. As soon as the Work, or any part of the Work is in the opinion of the Contractor considered assembled, the Contractor shall notify the Client in writing.

4. For the completion of the Basic Configuration, Extended Option No. 1, Extended Option No. 2 or Extended Option No. 3, the Contractor shall be obliged to prepare and submit to the Client for approval an assembly completion protocol, respectively all its parts, once all individual tests of the assembled equipment as prescribed by this Contract (specifically in the Technical Specification), and in the Quality Plan, including ITP, for individual equipment will have been completed, including all post-assembly cleaning operations (hereinafter the "**ACP**"). Assembly of the Basic Configuration, Extended Option No. 1, Extended Option No. 2 or Extended Option No. 3 shall be completed by the

Client's approval of the ACP for the relevant part of the Work. Assembly of the Work shall be completed by the Client's approval of the last ACP.

5. Successful completion of all individual tests shall be demonstrated by relevant attests and protocols on completion of tests, to be issued in line with the Quality Plan and signed by representatives of the Parties. Simultaneously, the Contractor shall hand over to the Client all relevant, yet undelivered parts of the Accompanying Documentation specified in the Documentation.

6. The Client shall be obliged, if he refuses to confirm the ACP, to notify to the Contractor in writing all potential defects or unfinished work within seven ten (10) business days from receiving the ACP draft. The Contractor shall be obliged to rectify these defects and finish any unfinished work and proceed as defined in this Article to seek the Client's final confirmation of the ACP.

7. Should the Client not confirm the ACP and not inform the Contractor of any defects or unfinished work within seven ten (10) business days from receiving the draft ACP, then it shall be understood that the Client had confirmed the draft ACP as of the date of its receipt by the Client.

8. The ACP may be confirmed only once the Client took receipt of approved Accompanying Documentation specified in the Documentation. The Client shall be obliged to approve the submitted drafts within thirty (30) days from their receipt or inform the Contractor of the reasons why they cannot be approved. Lack of approval shall not constitute a reason for extending the Work completion and delivery deadlines (or its parts). In the event that the draft Accompanying Documentation specified in the Documentation will not be approved by the Client, and no reasons for not approving the draft or comments are communicated to the Contractor, this Accompanying Documentation shall be considered to have been approved. In case the draft is not approved, the Contractor shall be obliged to submit, in accordance with comments communicated by the Client, a revised draft within ten (10) days from receipt of such comments by the Contractor. Subsequent process for approval of the draft / revised drafts shall follow the principles above until the Accompanying Documentation will have been finally approved, provided that the deadline for the Client to comment on any subsequent draft(s) shall be shortened to fourteen (14) days.

9. The Contractor shall be responsible for damage on the individual technological units and sub-systems of the Work incurred during their assembly and handover tests prior to the handover of the Work to the Client. The Contractor shall be further responsible for damage caused on buildings and facilities, which are not subject to assembly activities, but they were provably damaged by the Contractor's activities or his subcontractors or business partners.

COMPLEX TEST OF THE WORK

10. Complex test of the Work (hereinafter the "**Complex Test**") shall be carried out by the Contractor once approved by the Client in accordance with this Contract and requirements specified in the Technical Specification. There will be up to four Complex Test, one for the Basic Configuration and one for each of the Extended Options. Complex Test may be carried out only on the basis of the approved ACP.

11. Complex Test shall be carried out within the framework of a complex trial of the entire Basic Configuration as one functional whole or the Extended Option, respectively. By completing the Complex Test the Contractor demonstrates operability, failure-free operation, reliability, safety, problem-free inter-operability of all systems and technologies and quality of the Work, including fulfilment of all guaranteed parameters and limits as may be defined in the Technical Specification. The Complex Test shall beyond all doubt demonstrate that all required limits and parameters

specified in the Technical Specification have been duly and properly met, considering maximum possible simultaneity and critical parameters of all technologies and systems within the Work.

12. Complex Test shall be considered successful if all parameters and limits defined by requirement for the Complex Tests according to the Technical Specification will have been duly achieved. At Complex Test completion, the Contractor shall submit to the Client for approval the Complex Test execution protocol (hereinafter the "**CTEP**").

13. In the event that for any reasons that may be attributed to the Contractor the Complex Test does not result in achieving all requirements for the complex test, i.e. primarily the requirements relating to the operability, failure-free operation, reliability, safety, problem-free inter-operability of all systems and technologies and quality of the Work, the Contractor shall be obliged to carry out, at his own costs, any necessary modification and changes in order to meet these requirements. The Contractor shall notify the Client once these modifications and changes will have been completed, and shall be obliged, upon the Client's instruction, to repeat the Complex Test until all requirements for complex tests will have been met and achieved in accordance with Technical Specification. This repeated Complex Test shall be carried by the Contractor at his own cost, and the Contractor shall also compensate the Client for any demonstrated costs and expenses accrued by the Client in relation to this repeated Complex Test. Repeating the Complex Test shall not prejudice the Client's right to seek payment of contractual penalty or damages by the Contractor.

14. In the event that for any reasons that may be attributed to the Contractor the Complex Test does not result in achieving all requirements for the complex test, i.e. primarily the requirements relating to the operability, failure-free operation, reliability, safety, problem-free inter-operability of all systems and technologies and quality of the Work, even after all modifications and changes carried out by the Contractor in accordance with the paragraph directly above, and the Work continues to show only marginal deviations from requirements defined for the complex test above and/or requirements defined in the Contract, which do not have a material effect on the operability, failure-free operation, reliability, safety, problem-free inter-operability of all systems and technologies and quality of the Work, then the Client may elect to notify the Contractor in writing that he agrees with the signature of the CTEP provided that all such deviations shall be listed as defects or unfinished work and will be rectified or completed within the deadline defined therein by the Client.

FINAL ACCEPTANCE OF THE WORK

15. Final acceptance of the Basic Configuration shall take place upon completion of both the following conditions:

    a) all other provisions of the Contract with respect to the Basic Configuration will have been met (including provision of the original of the warranty bank guarantee pursuant to Article X. paragraph 2 hereof), and simultaneously

    b) the CTEP regarding the Basic Configuration will have been duly signed.

    (hereinafter the "**Final Acceptance of the Basic Configuration** ").

16. Once all conditions for the Final Acceptance of the Basic Configuration will have been met, the Contractor shall submit to the Client a draft final acceptance protocol (hereinafter the "**Final Acceptance Protocol for the Basic Configuration**") within seven (7) days of handing over all relevant documentation and fulfilling all other obligations under the Contract with respect to the Basic Configuration. The necessary prerequisite for its approval by the Client shall be fulfilment of all

obligations on the part of the Contractor under the Contract, primarily the proper completion of the Basic Configuration in line with the Contract, including training of the Client's personnel, handover of all documentation foreseen in the Contract and handover of the Basic Configuration without legal or factual defects to the Client.

17. Final acceptances of Extended Options shall take place for each Extended Option separately upon completion of both the following conditions regarding the Extended Option:

    c) all other provisions of the Contract with respect to the Extended Option will have been met and simultaneously

    d) the CTEP regarding the Extended Option will have been duly signed.

    (hereinafter the "**Final Acceptance of the Extended Option"**).

18. Once all conditions for the Final Acceptance of the relevant Extended Option will have been met, the Contractor shall submit to the Client a draft final acceptance protocol (hereinafter the "**Final Acceptance Protocol for the Extended Option**") within seven (7) days of handing over all relevant documentation and fulfilling all other obligations under the Contract with respect to the relevant Extended Option. The necessary prerequisite for its approval by the Client shall be fulfilment of all obligations on the part of the Contractor under the Contract, primarily the proper completion of the relevant Extended Option in line with the Contract, including handover of all documentation foreseen in the Contract and handover of the relevant Extended Option without legal or factual defects to the Client.

19. The Work shall be considered to have been duly executed and completed by the signature of the last Final Acceptance Protocol by both Parties.

FULL PERFORMANCE TESTS OF THE WORK

20. The Contractor shall be obliged to provide technical support (including staff on-site) for the System full performance tests, which will occur during the warranty period for the Basic Configuration or Extended Option No. 1 defined in Article IX. hereof (hereinafter the "**Full Performance Tests**"). The expected duration of the Full Performance Tests is 1-3 weeks (probably 2x1 week). The Full Performance Tests will repeat significant part of the Complex Test, but on the full performance parameters specified in the Technical Specification; provisions concerning the Complex Test stipulated herein shall apply accordingly on Full Performance Tests. The Full Performance Tests will be directed by the Client, while the Contractor will execute the Full Performance Tests on his costs and responsibility. The Contractor's liability for proper execution thereof is not excluded by the Client's assistance nor instructions even if they are inappropriate. If the Client's assistance or instructions are inappropriate the Contractor must warn the Client of their inappropriateness. The Contractor shall check proper functionality of the System, assure safety and protection of the System and its parts and operate, control as well as supervise the System during the Full Performance Tests. Failure to comply with the full performance parameters within the Full Performance Tests or another imperfection revealed in the System within the Full Performance Tests will be considered defect covered by the warranty under Article IX hereof.

XVI. SUBCONTRACTORS

1. The Contractor shall be obliged to ensure and finance all subcontracted work and bear full liability for such work in the full extent under this Contract. The Contractor shall be obliged to provide to the Client, upon a request in writing, at any time during the Work's execution, a full list of all its

subcontractors.

2. The Contractor assumes all liability for damage caused by any persons involved in executing the Work on the Work during the entire term of executing the Work, i.e. until the Final Acceptance Protocol is signed by the Client and the Work is executed without defects, as well as during the term of trial operation and warranty period, and for any damage as may be caused by the Contractor’s activities on the Client's or any third parties' property, i.e. in case of any invasion or damage to property, the Contractor shall be obliged, without unnecessary delay, to rectify such damage and if that proves impossible to provide corresponding financial compensation.

3. The Contractor shall not be authorized to replace subcontractors listed in the Contractor’s bid as submitted within the tendering process without a prior consent of the Client. The Client undertakes to inform the Contractor of its position with respect to such proposed replacement within ten (10) calendar days from the date of receipt of the Contractor’s request; the Contractor shall be obliged to specify in such replacement request also description of the proposed subcontractor’s performance and documents proving qualification of the proposed subcontractor corresponding to his proposed performance. The Client shall be entitled to withhold such consent in case where the proposed new subcontractor fails to meet the necessary qualifications to provide the performance proposed by the Contractor or in case such replacement subcontractor is subject to insolvency proceedings where a decision had been passed or the insolvency petition was rejected due to the fact that the value of assets is insufficient to cover the costs of insolvency proceedings, or where bankruptcy proceedings were cancelled for insufficient assets on the part of the subcontractor. The Client's consent does not need to be issued in the form of an amendment to this Contract; the consent shall be confirmed by the responsible person on the part of the Client. Each Party undertakes to submit a list of responsible persons after the Contract’s signature. Breach of any obligation defined in this provision shall be understood as a material breach of this Contract and shall entitle the Client to withdraw from the Contract.

4. Should a subcontractor fail to meet (or cease to meet) the basic and professional qualification requirements under the PPA or does not poses (or ceases to poses) the sufficient professional capacity to execute a defined part of the subject-matter of the Contract, the Client shall be entitled to require that the Contractor replace such subcontractor without delay, and the Contractor shall be obliged to accommodate such request within twenty (20) days from receipt of such request from the Client. In case the Contractor fails to terminate activities of such non-compliant subcontractor in executing the Work within twenty (20) days from receipt of such request from the Client and fails to submit and get approved an adequate replacement subcontractor within the same deadline, the Client shall be entitled to withdraw from the Contract due to material breach on the part of the Contractor. This provision shall be adequately applied to replacement of subcontractor under paragraph 3 above.

5. The Parties agreed that provisions of paragraphs 3 and 4 of this Article shall also apply to those subcontractors who will deliver, in executing the Work or its part, whether in providing work or supplies, a total value exceeding 5% of the Price. Such subcontractors shall be listed by the Contractor without delay on the Subcontractors' List and submitted to the Client.

6. The Contractor shall be obliged to provide to the Client a final list of all subcontractors who have participated, in any way or form, on the execution of the Work no later than within thirty (30) days from the signature of the Final Acceptance Protocol.

7. The Client shall be entitled to request, in justified cases, that the Contractor removes any subcontractor from executing the Work. The Contractor shall be obliged to comply with such

request without delay, within the meaning of this Article. Cost of terminating cooperation with such subcontractor in accordance with this Article shall be borne by the Contractor. Failure to fulfil this obligation shall be considered as a material breach of this Contract by the Contractor and the Client shall have the right to withdraw from this Contract.

8. Approval of the subcontractors' selection by the Client does not in any way prejudice the Contractor's undertakings, obligations and liability arising from this Contract, specifically liability for proper and timely execution of the Work.

9. The subcontractor shall be understood, for the purposes of this Contract, as any subject participating in the execution of the Work or any of its part under the direct or indirect instruction of the Contractor, or in direct or indirect relation to the Contractor.

XVII. <u>LIABILITY, SANCTIONS</u>

1. The Contractor shall be obliged to pay to the Client a contractual penalty in the following cases:

   1.1. if the Contractor fails to deliver/handover a portion of the Partial Performances defined under Article V. paragraph 1 letters a) - k) hereof or parts thereof at least in the total amount reaching CZK 90 million (excluding VAT) within 18 months after the Contract signature pursuant to Article VI. paragraph 3 second sentence hereof, the Contractor shall be obliged to pay to the Client a contractual penalty in the amount of 0,03 % from the amount equal to the difference between the value of the performance delivered within 18 months after the Contract signature and the amount of CZK 90 million, excluding VAT for each day of delay. The total sum of the contractual penalty resulting from this paragraph shall be capped at 10 % of the amount equal to the difference between the value of the performance delivered within 18 months after the Contract signature and the amount of CZK 90 million excluding VAT. The value of the delivered performance includes all delivered and handed over parts of Partial Performances as specified and appraised in the Detailed Itemized Budget in the Contractor's Implementing Documentation within the meaning of Article V. paragraph 1 letter a) hereof.

   1.2. if the Contractor fails to deliver/handover Partial Performance defined under Article V. paragraph 1 letters a) - k) hereof till December 31, 2021, the Contractor shall be obliged to pay to the Client a contractual penalty in the amount of 0,035 % from the total value of undelivered Partial Performance for each day of delay;

   1.3. if the Contractor fails to complete/handover the Basic Configuration to the Client within 6 months after the date designated by the Client for commencement of final assembly work in accordance with Article VI paragraph 4 hereof, the Contractor shall be obliged to pay to the Client a contractual penalty in the amount of 0,035 % of the Total Offered Price of The Basic Configuration excluding VAT for each day of the delay;

   1.4. the total sum of the penalties resulting from paragraphs 1.2. and 1.3. shall be capped at 10 % of the Total Offered Price of The Basic Configuration excluding VAT;

   1.5. the Contractor shall be obliged to pay to the Client a contractual penalty in the amount of CZK 10.000 for each commenced calendar week of the duration of the situation when either any part of the Basic Configuration or Extended Option does not meet the parameters requested by the Client or the Contractor is in delay with the removal of defects in the warranty period if these facts/defects do not cause the total non-functionality of the System (the state of non-functionality of the System and categorization of defects in the warranty period with corresponding deadline for the removal of the defect after which a contractual penalty shall apply is provided in detail within the Technical Specification);

1.6. the Contractor shall be obliged to pay to the Client a contractual penalty in the amount of CZK 30.000 for each commenced calendar week of the duration of the situation when either any part of the Basic Configuration or Extended Options does not meet the parameters requested by the Client or the Contractor is in delay with the removal of defects in the warranty period if these facts/defects cause the total non-functionality of the System (the state of non-functionality of the System and categorization of defects in the warranty period with corresponding deadline for the removal of the defect after which a contractual penalty shall apply is provided in detail within the Technical Specification);

1.7. the total sum of the penalties resulting from paragraphs 1.5. and 1.6. shall be capped at CZK 12 million;

1.8. the Contractor shall be obliged to pay to the Client a contractual penalty in the amount of CZK 5.000 for each commenced day of the delay with the provision of service pursuant to Article IV paragraph 6 hereof;

1.9. the Contractor shall be obliged to pay to the Client a contractual penalty in the amount of CZK 100.000 for each breach of his obligation to provide training pursuant to Article IV paragraphs 8 and 9 hereof;

1.10. the Contractor shall be obliged to pay to the Client a contractual penalty in the amount of CZK 100.000 for each breach of his obligation to follow Client's instruction pursuant to Article XIV paragraph 1 hereof;

1.11. the Contractor shall be obliged to pay to the Client a contractual penalty in the amount of CZK 100.000 for each breach of his obligation under Article VII paragraph 3 and/or under Article XVI hereof;

1.12. the Contractor shall be obliged to pay to the Client a contractual penalty in the amount of CZK 20.000 for each breach of his obligation defined within Documentation (including, but not limited to, meet the deadlines for issuance of documentation, meet the deadlines to incorporate the comments of the Client after his previous refusal of the draft documentation);

1.13. if the Contractor fails to deliver/handover any of the Extended Options defined under Article V. paragraph 1 No. 1) - 3) hereof within the deadlines stipulated in Article VI. hereof, the Contractor shall be obliged to pay to the Client a contractual penalty in the amount of 0,02 % from the price of the Extended Option for each day of delay. The penalty resulting from this paragraph shall be capped at 10 % of the price of the Extended Option to which the penalty pertains; this cap shall apply for each Extended Option separately.

The contractual penalties of the Contractor under this Article may be combined with each other, unless this is impracticable due to its nature.

2. For the sake of avoidance of any doubt, the Parties have agreed that the Contractor shall not be in default if the delay was caused exclusively by late payment of any part of the Price or late provision of technical data on the part of the Client.

3. In case of delay with the payment of the Price for the Work or any part thereof the Client undertakes to pay to the Contractor an interest at the statutory rate.

4. The due date of all contractual penalties stated hereunder shall be thirty (30) days from the date of delivery of complaining Party notification to the other Party. The notification under this paragraph

shall include a description and timing of an event that entitles one of the Parties to impose a contractual penalty on the other Party. In case of delay with the payment of the contractual penalty the breaching party undertakes to pay to the other party an interest in the amount of 0.1% of the outstanding contractual penalty for each day of delay.

5. The Client shall be entitled to set off any receivables he may have at any time on the basis of his right to claim contractual penalty hereunder, against any of the Contractor's receivables arising from his right to claim the Price for the Work or its part hereunder.

6. For the avoidance of any doubt, if there is a repeated breach of obligation, the Parties agree that the contractual penalties agreed hereunder for violation of individual obligations may be repeated. The Parties further declare that the amounts of the contractual penalties provided hereunder are reasonable.

7. The Parties exclude application of Section 2050 CC, i.e. the Client shall be entitled to seek damages in addition to any contractual penalty hereunder.

8. If either Party breaches its duty arising from this Contract or it should or could know about such a breach, it shall inform the other Party, which may incur damage, without undue delay and warn it of potential consequences; in such a case, the Party suffering damage has no right to be compensated for damage which it could avoid after being notified hereunder.

XVIII. INSURANCE

1. The Contractor declares that he has concluded an insurance policy covering liability for damage caused to third parties, particularly with regard to the specific scope of services / work provided hereunder, and that this policy equals at least the amount of CZK 200 million. The scope of the aforementioned insurance policy shall cover also liability for damage caused by the Contractor and/or its subcontractor(s) to the System or Client's property.

2. The Contractor further undertakes to properly and timely perform all obligations under the insurance policy and to maintain valid insurance cover according to the paragraph directly above for the entire duration of the execution of the Work (including all Partial Performances as well as Extended Options) until passing the Full Performance Tests but no earlier than upon Final Acceptance of the Work, its last Partial Performance or last Extended Option, whichever comes later. The Client shall be entitled to request submission of the copy of an insurance policy to verify the range of insurance coverage. The Contractor shall be required to meet such requirement within at latest 7 (seven) calendar days.

XIX. HEALTH AND SAFETY

1. During execution of the Work, the Contractor shall be obliged to ensure compliance with all safety, sanitary and environmental measures as well as measures relating to fire protection, in the extent and manner prescribed by relevant regulation and at the level of the standard "OHSAS 18001" and the safety guidelines of the Client. The Client undertakes to appoint a person or persons authorized to hand over the safety guidelines to the Contractor and the Contractor undertakes to appoint a person or persons authorized to take over the safety guidelines from the Client. The Client undertakes

to hand over his safety guidelines in a printed form by authorized persons.

2. The Contractor shall be fully responsible for the health and safety of all persons who are involved with his knowledge in execution of the Work.

3. The Contractor shall perform its own supervision and continuous control of work safety and fire protection regulation during execution of the Work.

4. Should there occur any injury during execution of the Work or during activities related to the execution of the Work, the Contractor shall ensure that any such accident is properly investigated and protocoled. If necessary, the Client shall be obliged to provide the Contractor with all necessary cooperation.

XX. TERMINATION, VIS MAJOR:

1. This Contract may be terminated by its fulfilment / completion, by agreement of the Parties or by withdrawal from the Contract for reasons specified in law or in this Contract.

2. The Client shall be entitled to withdraw from the Contract without sanction should any of the below specified events occur:
   a) any expenditure or any part thereof, which may arise on basis of this Contract, are declared by the financial support provider or other controlling body to be ineligible, or
   b) the Client’s financial support (aid) provided toward implementation of the Projects is not granted or is withdrawn;
   c) the Contractor loses the licence to execute activities, which constitute the subject-matter hereof; the Contractor shall be obliged to inform the Client without delay about the mere fact that he may be subject to proceedings leading to a potential withdrawal of his authorization to perform activities hereunder;
   d) the Contractor enters into liquidation;
   e) insolvency proceedings were commenced against the assets of the Contractor (or similar proceedings under the laws of another country), where a decision on bankruptcy was issued, or insolvency petition rejected because of insufficient assets to cover the costs of insolvency proceedings, or where bankruptcy was cancelled because property was completely insufficient or receivership was introduced by special legislation;
   f) any of the documents or reports submitted by the Contractor to the Client hereunder do not comply with the technical or other parameters foreseen by this Contract or Annexes even after the Client has twice notified the Contractor to fulfil these, respectively to observe / comply with these in additional time;
   g) it has become obvious, considering all pertinent facts and circumstances, that the Contractor’s activities do not lead to the fulfilment of a material part of objectives defined herein due to reasons on the part of the Contractor;
   h) if a contractual penalty potentially claimed against the Contractor will have reached its maximum limit according to Article XVII. hereof;
   i) it is revealed that the Contractor stated in the bid certain information or submitted documents which do not correspond to reality and which had or could have had impact on the results of the Tender that lead to the conclusion hereof [Section 223 paragraph 2 letter c) PPA];

j) in the event that the Contractor yields, transfers or assigns its rights and obligations hereunder to a third party without prior consent in writing from the Client;

k) the Contractor breaches this Contract in another material instance.

3. As a material breach caused by the Contractor shall be considered in particular, but not limited to, the following:

   a) breach of duties imposed by law or agreed by the Parties herein in relation to the processing of personal data, unless the subject data were disclosed by Contractor in good faith;

   b) the Contractor violates, during execution of the Work, continuously or repeatedly (continuous) laws, regulations, technical standards and norms of the Czech Republic or other countries, which he agreed to observe herein;

   c) the Contractor breaches this Contract in such a manner that the Client will not be able to meet his objectives for which he concluded this Contract, or if such conduct on the part of the Contractor causes considerable damage to the Client;

   d) the Contractor breaches his obligations associated with provision of the bank guarantee under Article X. hereof;

   e) the Contractor breaches his duty to arrange insurance policy under Article XVIII. hereof;

   f) the Contractor is in delay with execution of the Work and fails to reach any milestone as stipulated in the Article VI hereof or Annex No. 5 (*"Price Schedule and Deliverables"*) hereto for more than sixty (60) days;

   g) the Contractor is in delay with removal of a defect;

   h) the Contractor has been executing the Work unprofessionally or in contradiction to this Contract, Technical Specification, generally applicable legal regulation, the Czech Technical Standards, Contractor's documentation or any other documentation he is obliged to follow or the Contractor has been using defective or non-approved functional elements / components, products or technologies in order to execute the Work;

   i) the Contractor uses a subcontractor to execute the Work or its part without the prior consent of the Client within the meaning of Article XVI hereof;

   j) the Contractor has been breaching his obligation under this Contract repeatedly (i.e. at least twice) within three consecutive calendar months;

   k) the Contractor leaves the place of execution of the Work or otherwise expresses his intention not to continue to perform his obligations under the Contract.

4. In case of the Contract's termination due to reasons given in paragraph 2 of this Article, the Contractor shall be eligible for payment for the actually executed part of the Work for the Client, if such had been executed in accordance with the terms and conditions hereof.

5. In the event of termination of this Contract by the Client for other reasons than for the reasons of a breach of obligations on the part of the Contractor, the Contractor shall have the right to payment of costs which he accrued in connection with the fulfilment of his obligations hereunder prior to the Contract termination by the Client, which could demonstrably not be cancelled in time and if such costs accrued by the Contractor are not covered from other sources.

6. The act of withdrawal from the Contract shall become effective on the day of delivery of the notification in writing from one Party to the other with consequences of the Contract termination effective in the "*ex nunc*" regime.

7. Withdrawal from the Contract does not affect the right to be paid a contractual penalty or default interest if already due, the right to be compensated for damage resulting from a breach of a contractual obligation, or a stipulation which, given its nature, is to oblige the Parties even after the withdrawal, including, but not limited to, a stipulation on the resolution of disputes.

8. In the event of the termination of Contract, the Contractor shall in particular be obliged:
   a) to stop the execution of the Work, to follow the instructions of the Client, to take all necessary measures to prevent damage to the executed parts of the Work and to ensure the safety of property and health of the persons;
   b) to make a list of all executed work and deliverables to be supplied including price list in accordance with this Contract, that must be approved by the Client,
   c) to deliver the executed part of the Work to the Client within a period of time specified by the Client in accordance with the conditions defined herein (taking into account that only part of the Work is handed over), in particular to deliver the documents related to the part of the Work and original warranty letters;
   d) upon takeover of the completed part of the Work by the Client and upon the Client's approval of the price, to issue a tax document including price for the executed part of the Work;
   e) to assign the rights to the Client he acquired at the date of the termination of the Contract, including, but not limited to the rights under license agreements, patents, know-how, the rights under the subcontracting contracts at the Client's request; in addition, the Contractor shall be obliged to terminate other subcontracting contracts and settle all claims arising from these contracts.

9. The Contractor shall be entitled to withdraw from the Contract without sanction should any of the below specified events occur:
   a) the Client intentionally fails to act in accordance with this Contract which causes impossibility or complications beyond a reasonable limit to execute the Work or to continue in execution of the Work;
   b) the Client fails to pay a due payment under the issued invoice submitted by the Contractor in due time, not even in substitute term set by the Contractor;
   c) the Client becomes insolvent.

10. Circumstances precluding liability shall be deemed to have been constituted by such obstacle(s) which arose independently of the will of the obliged Party, and which prevent fulfilment of that Party’s obligation, provided that it could not be reasonably expected that the obliged Party could overcome or avert this obstacle or its consequences, and furthermore that such Party could foresee such obstacle when it entered into the respective covenants (hereinafter "**Vis major**"). Liability cannot be precluded by obstacles that arose only after the obliged Party was in default with fulfilment of its obligations, or which arose in connection with its economic situation. The effects precluding liability shall be limited to the period during which the obstacles causing these effects persist.

11. Should a situation occur, which the Party could reasonably consider to constitute Vis major, and which could affect fulfilment of its obligations hereunder, such Party shall immediately notify the other Party and shall attempt to continue in its performance hereunder in a reasonable degree. Simultaneously, such Party shall inform the other Party of any proposals, including alternative modes of performance; however, without consent of the other Party, it shall not proceed to effect

such alternative performance.

12. If a situation constituting Vis major occurs, the deadlines imposed hereunder shall be extended by the period of the duration of the said Vis major event.

XXI. REPRESENTATIVES, NOTICES

1. The Contractor has appointed the following representatives responsible for the management and execution of the Work hereunder and communication with the Client:

   In technical matters:

   [redacted]

   In contractual matters:

   [redacted]

2. The Client has appointed the following representatives responsible for communication with the Contractor for the purposes of realization of the Work:

   In technical matters:

   [redacted] (Director's Office, Secretary)

   [redacted]

   In contractual matters:

   [redacted]

3. Any and all notices transmitted between the Parties hereunder must be made in writing and delivered to the other Party by an authorized delivery service, delivered in person (with a written confirmation of receipt), by a registered letter sent by post or in the form of electronic communication as follows: The Contractor shall send his electronic communication to the Client's data mailbox **zipnqqk** or by e-mail carrying electronic signature sent to [redacted] Simultaneously, the copy of such communication shall be sent by the Contractor via e-mail to the Client's representatives for communication in technical and contractual matters under paragraph 2 of this Article. The Client shall send his electronic communication to the following Contractor's e-mail: [redacted] and [redacted] .

4. In expert or technical matters (matters related to preliminary assessment of the Work, Service, Maintenance, Warranty Claims etc.) written, fax or electronic communication will be acceptable between the appointed representatives for technical matters to contact details as provided in paragraphs 1 and 2 here above. In training and consultation matters written, fax or electronic communication will be acceptable between the appointed representatives for contractual matters to contact details as provided in paragraphs 1 and 2 here above. Telephone contacts shall serve only to support the topics that have been communicated by the above means.

5. The representatives of a Party responsible for communication according to paragraph 1 or 2, respectively, here above shall be entitled to appoint, revoke or replace the authorized and/or responsible persons, as may be required herein (e.g. Article XII paragraph 2, Article XIV paragraph 1, Article XVI paragraph 3 or Article XIX paragraph 1 hereof), and provide the list of such persons (including their contact information) and its updates to the other Party.

6. If personal data are processed during the execution hereof within the meaning of Regulation (EU) 2016/679 of the European Parliament and of the Council of April 27, 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation) and other related legal regulation of the Czech Republic, the Contractor shall comply with all obligations arising from this Regulation and if it is necessary to seek consent from data subjects to such data processing, the Contractor shall secure such consent so that it is possible to transmit any collected personal information to the Client. For the avoidance of doubt, any breach of legal obligations or agreement between the Parties hereto in relation to the processing of personal data on the part of the Contractor shall be considered to constitute a serious breach hereof.

XXII. GOVERNING LAW, INTERPRETATION RULES, DISPUTES

1. This Contract and any and all legal relations arising hereof shall be governed exclusively by the laws and regulations of the Czech Republic. To ensure legal certainty, the Parties exclude application of the United Nations Convention on Contracts for the International Sale of Goods (Vienna, 1980).

2. The Parties acknowledge and recognize that areas not explicitly regulated hereby shall be regulated by the respective provisions of CC (Act No. 89/2012 Coll., Civil Code).

3. This Contract shall be considered for the comprehensive unit and obligations and rights shall be always interpreted in accordance with these documents. The order of precedence between individual contractual documents shall be set as follows: Technical Specifications shall take precedence over the wording of this Contract and the Contract shall take precedence over the wording of the Documentation.

4. Any and all disputes arising in connection herewith, including any disputes relating to the validity hereof and consequences of any potential invalid provisions, shall be resolved by the Parties by negotiations. In cases where a dispute cannot be resolved amicably by negotiation within 60 (sixty) days, such a dispute shall be decided upon a motion of one of the Parties by a competent court in the Czech Republic. The jurisdiction of the Czech courts shall be exclusive.

XXIII. FINAL AND OTHER PROVISIONS

1. This Contract represents a complete agreement between the Client and the Contractor.

2. Should any of the provisions hereof appear or shall be determined invalid, ineffective, non-existent or unenforceable at a later date, then such invalidity, ineffectiveness, non-existence or unenforceability shall not cause the invalidity, ineffectiveness, non-existence or unenforceability hereof as a whole. In such a case, the Parties undertake, to clarify without undue delay any such defective provisions herein within the meaning of Section 553 (2) CC, or to replace it, by mutual agreement, by a new provision that most closely reflects the intentions of the Parties at the time of conclusion hereof, to an extent permitted by the laws and regulations of the Czech Republic.

3. The Parties agree on publishing of this Contract and related information according to Public Procurement Act and Act No. 340/2015 Coll., on Special Conditions for the Effectiveness of Certain Contracts, the Disclosure of These Contracts and the Register of Contracts (Act on the Register of Contracts), as amended.

4. This Contract becomes valid on the date of its signature by the authorized representatives of both Parties and effective on the date of its registration into the Register of Contracts.

5. This Contract may be amended or modified exclusively in the form of written and numbered amendments specifying the time thereof, and signed by the authorized representatives of the Parties. In accordance with Section 564 CC, the Parties explicitly exclude executing amendments hereto in any other manner or form.

6. This Contract was made out in four (4) counterparts, each having the force of original. Each Party shall obtain two (2) counterparts.

7. The Annexes listed below form an integral part of this Contract:
   Annex 1: Technical Specification
   Annex 2: The Contractor's Bid submitted within the Tender (technical part only)
   Annex 3: List of qualified persons
   Annex 4: Documentation
   Annex 5: Price Schedule and Deliverables

8. By attaching their signature hereto the Parties express their consent with the content hereof in its entirety.

In Prague on 19th February 2020

On behalf of: **Ústav fyziky plazmatu AV ČR, v. v. i.**

____

Name: doc. RNDr. Radomír Pánek, Ph.D.
Function: Director

In Prague on 19th February 2020

On behalf of: **ELEKTROTECHNIKA, a.s.**

____

Name: Ing. Michal Divín
Function: Chairman of the Board and General Manager

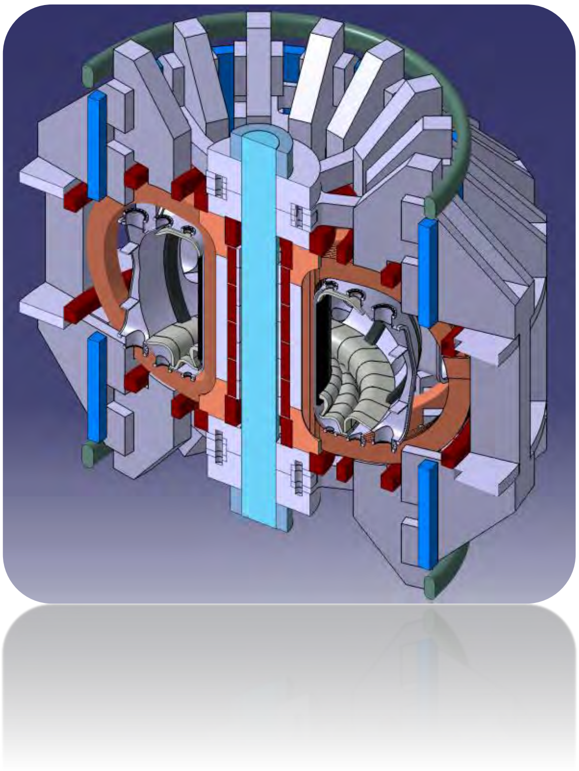
____

Name: Ing. Ivan Malý
Function: Deputy Chairman of the Board

Technical specification

for

Power Supply System for COMPASS-U Tokamak – Round 2



Institute of Plasma Physics of the Czech Academy of Sciences

1 Table of Content

2 Power Supply System for COMPASS-U: Extent of delivery

2.1 Extent of delivery

The "Power Supply System for COMPASS-U tokamak" includes the development, design, manufacturing, temporary storage, transportation to the site of installation, installation and commissioning of the entire Power Supply System for the magnetic coils and additional heating systems of the COMPASS-U tokamak. The extent of delivery for Power Supply System contain all parts necessary to accumulate energy from power distribution grid (power available from the grid is limited) and power the tokamak coils (Power Supply System endpoints - connectors for tokamak coils are in tokamak hall on the wall) and additional heating repeatedly, in controlled and safely manner according specification, including all design works, installation works, tests, commissioning, training of the Client's employees / staff and documentation.

For the purpose of the procurement procedure, the "Power Supply System for COMPASS-U tokamak" is divided into these parts:

1. Mandatory part:
    a. "Power Supply System for COMPASS-U tokamak - Basic Configuration", also referred as "Basic Configuration"
2. Extended Options:
    a. "Second new flywheel generator and its auxiliary systems"
    b. "Increase of the capacitor bank(s) energy by +0.5 MJ"
    c. "Short circuit test at full nominal pulsed voltage of a selected transformer"

Throughout this document (Technical specification for Power Supply System for COMPASS-U Tokamak – Round 2), the term "Power Supply System for COMPASS-U tokamak" refers to the entire system, including both Basic Configuration and Extended Options. If it is not specifically stated otherwise, all technical specifications and requirements are valid for both the Mandatory part – Basic Configuration and also for the entire "Power Supply System for COMPASS-U tokamak", which includes both the Basic Configuration and Extended Options.

The main parts of the Power Supply System for COMPASS-U tokamak are listed in the following list:

1. Two new flywheel generators according to the specifications given mainly in chapter 5.2, together with all their auxiliary devices (excitation, cooling, lubrication, braking system) and control. Motors for spinning-up generators with accessories and control. All mechanical and electrical connections. Delivery and installation of the flywheel generators on the Client's site, connection of the power output to the HV switchgear (including protection), development, design and installation of the generators control and protection system, commissioning of the generators, etc.
    a. One flywheel generator is part of the Basic Configuration, including its auxiliary systems (excitation – transformer and converter, cooling, lubrication, braking system, motor, motor accessories and control – including motor frequency converter, connections, etc.), delivery, installation and commissioning.
    b. The second flywheel generator is part of the Extended Options (Second new flywheel generator and its auxiliary systems), including its auxiliary systems (excitation – transformer and converter, cooling, lubrication, braking system, motor, motor accessories and control – including motor frequency converter, connections, etc.),

delivery, installation and commissioning.

c. The control system of the Power Supply System (described in the chapter 5.8) must be prepared for the control of both new generators already in the Basic Configuration.

2. Utilization of the presently existing flywheel generators (see description of the existing Power Supply System in chapters “6.2 - General description of the background of the intended Power Supply System use” and “6.5 - Existing Power Supply System”, see required utilization of the existing Power Supply System in the chapter “5.12 - Requirements for the utilization of the existing Power Supply System”). Control of the existing auxiliary systems (excitation, cooling, lubrication, braking system) and their incorporation into the control system of the Power Supply System shall form part of the delivery hereunder.

3. Delivery of all transformers described mainly in chapter 5.3, their installation in dedicated place in the Client’s tokamak building including the connections to power converters, cable trays, cable terminals, barriers against unauthorized entry, etc.

4. Re-use of the existing transformers as described in chapters 5.3 - Transformer requirements and 5.12 - Requirements for the utilization of the existing Power Supply System.

5. Low-voltage and high-voltage switchgear (as described in Chapter 5.4), which will utilize a large part of the existing Power Supply System (see chapter 5.12 - Requirements for the utilization of the existing Power Supply System). Connection of HV switchgear to transformers, cable trays, cable terminals, small construction activities (connection of the cable trays to the walls including drilling, connection of the cables to the walls or floors, fixing the fences to the floor, cutting the holes into the walls, sealing of cable ducts including certified fire-proof sealing, cleaning after the small construction activities …), etc.

6. Extension of the quantity and/or current rating of the existing thyristor converters to allow the supply of the current to the Toroidal Field coils according to chapter 5.5. Manufacture of their new control, protections (including crowbar protection with resistor, capable of dissipation of the excess energy that returns from the tokamak TF coil; protection against short-circuit on thyristor converter), cooling system and communication with superior control system. Installation and commissioning of the additional converters in dedicated place in the Client’s tokamak building.

7. Manufacture and test a prototype PF coils Power Supply unit (see requirements in Chapter 5.10 - Acceptance tests requirements).

8. Development, design, manufacturing, installation and commissioning of new transistor-based H-bridge converters for the Poloidal Field coils according to chapter 5.6, including mainly Capacitor bank(s) and Energy Dissipator (for dissipation of the excess energy that returns from the tokamak coils), but also control, protections, cooling system and communication with superior control system. The Capacitor bank(s) is (are) part of the Basic Configuration and besides that there is an Extended Option “Increase of the capacitor bank(s) energy by +0.5 MJ”.

9. Connection of the converters for the Poloidal Field and Toroidal Field coils to the tokamak inlet points in the Client’s tokamak hall area. The inlet points are required to be located on the north side of the first underground floor of the tokamak hall (one inlet point for the Toroidal Field Power Supplies and multiple inlet points for the Poloidal Field Power Supplies). The Contractor will provide connection of the respective Power Supplies through the walls of the tokamak hall, including extension of the connection 4 m into the tokamak hall area. The exact position of the inlet points will be specified by the Client during the realization of the Contract. The

necessary construction works to provide holes in the walls of the tokamak hall for the cabling will be done by the Client after specification agreed with the Contractor.

10. Delivery of the control system of the Power Supply System, diagnostic and monitoring system, described in Chapter 5.8. The control system of the existing Power Supply System will be completely replaced/removed as a part of the delivery hereunder. The control, diagnostic and monitoring system in the Basic Configuration must be capable of controlling the entire Power Supply System (including both Basic Configuration and Extended Options – second flywheel generator and increased capacitor bank/s energy).

11. Sufficiently dimensioned UPS (uninterruptible power supply) for all critical parts of the delivery where interruption of power supply could cause significant damage of Power Supply System or connected system or danger conditions for personnel (e.g. generator lubrication units, control systems, transistor drivers, etc.).

12. Installation of all parts of the Power Supply System at the Client's site (including assembly material and small construction activities related to the installation of electrical equipment) are parts of the delivery hereunder.

    a. The Client will provide the Contractor with access to switchboards with 3 x 400 VAC from the public electric grid; the power for the Power Supply System must be limited to less than 1 MW (the total available power at the Client's site, including the consumption of the administrative building, is 2 MW). The first switchboard will be available in the Low Voltage Switchgear area, the second one in the new building north of the current assembly hall (see tentative switchboards placement in Figure 6.6.2).

    b. The Client will provide the Contractor with access to the cooling station with water distribution mains (see the placement of the cooling station in Figure 6.6.1). The Client will provide continuous cooling power sufficient to remove the heat from the Power Supply System (up to 320 kW). Pulse generated heat will be removed in the time between the Power Supply System's pulses.

    c. The heat exchanger/s, secondary cooling loops (possibly including heat storage for pulse operation) and their control are part of the delivery hereunder.

    d. The connection of the Power Supply System to the respective primary cooling water loops/s and electric distribution mains is part of the delivery hereunder and, therefore, it is the responsibility of the Contractor.

    e. The Client will provide foundation/s for the flywheel generators. The Client will provide space in the building for the Power Supply System (see chapter 6.6 - Description of the available space in the buildings). The Client will provide environment temperature control in the building (with target temperature 22 °C) – the maximum temperature in building on the Client defined place will be lower than 35°C before start of the tokamak discharge, the minimum temperature and temperature distribution will not be guaranteed, even during Power Supply System operation. The Contractor is required to provide list of requirements on the building.

13. Performance of the revisions of the mounted re-used equipment and passing all equipment acceptance tests (as defined in Chapter 5.10), provision of the test protocols, certificates of product quality and completeness, declarations of conformity, etc. The Extended Option "Short circuit test at full nominal pulsed voltage of a selected transformer" is an optional part of the acceptance tests.

14. Provision of the project documentation of all levels, software licenses and intellectual property rights as defined in Chapter 5.11, provision of the training of the Client's employees / staff for operation and maintenance. Provision of training of the Client's employees / staff focused on use of software and firmware – programming, deploying, functionality, errors description and searching for causes.

15. The Site Acceptance Tests (see 5.10 - Acceptance tests requirements) are part of the delivery hereunder and will be performed by the Contractor under supervision of the Client, unless stated otherwise.

16. The warranty period for the Power Supply System is part of the delivery hereunder. The necessary requirement for the start of the warranty period is successful completion of the Site Acceptance Tests (the warranty commences running from the date of signature of the Final Acceptance Protocol).

17. The Contractor is obliged to provide technical support (including staff on-site) for Power Supply System Full Performance Tests (see 5.10 - Acceptance tests requirements), which will occur during the warranty period.

18. The delivery shall include spare parts (see 5.1 - General requirements).

3 Specifications for the Contractor's Bid and Warranty

The chapter "3 - Specifications for the Contractor's Bid and Warranty" contains (part of the) information, which are directly referred to from the Contract for Work and from the Tender Documentation. The further warranty related information is for example in the chapter 5.12 - Requirements for the utilization of the existing Power Supply System.

3.1 Table of minimal technical details to be included in the Contractor's Bid and recommended structure of the Contractor's Bid

This document (Technical Specification for Power Supply System for COMPASS-U Tokamak – Round 2) contains very detailed specifications and requirements, which must be followed and fulfilled by the Contractor during the realization phase of the tender – i.e. during the detailed design and subsequent construction of the Power Supply System. This chapter (chapter 3.1) contains: a) the minimal technical details, which must be included in the Contractor's Bid, b) recommended (but not mandatory) structure of the Contractor's Bid.

The technical part of the Contractor's Bid, which will be submitted within the public tender, **is required to provide:**

1. **A brief general overall description** of the offered Power Supply System (two standard pages as a minimal extent).
2. **The minimal technical details and parameters**, as required by the **Table 3.1.1: Table of minimal technical details to be included in the Contractor's Bid.**
3. **The specific statement that the Power Supply System detailed design** (which will be created by the Contractor during the realization phase) **will fulfil all of the requirements** contained **in this Technical Specification**, and specifically **in the chapter 5 of the Technical Specification (Technical requirements table)**. This specific statement is included in the Table 3.1.1: Table of minimal technical details to be included in the Contractor's Bid.
4. All **information, tables and figures required by the Annex No.5 - Evaluation matrix**. The "Table 3.1.1: Table of minimal technical details to be included in the Contractor's Bid" contains rows, which require the specific information or reference to the table / figure.

The **recommended structure (and extent) of the technical part of the Contractor's Bid is as follows**:

1. <u>Technical part of the Bid</u> [contains information required by the Client]:
   - I. General overall description of the Power Supply System [≥ 2 pages]
   - II. Technical details and parameters provided in the "Table 3.1.1: Table of minimal technical details to be included in the Contractor's Bid" [it is recommended to use the table as a template]
   - III. Specific statement that the detailed design will fulfil all of the requirements in the Technical Specification and in its chapter 5 - Technical requirements table [it is recommended to use "Table 3.1.1: Table of minimal technical details to be included in the Contractor's Bid" as a template]
   - IV. Information required by the Annex No.5 – Evaluation matrix [it is recommended to use "Table 3.1.1: Table of minimal technical details to be included in the Contractor's Bid" as a template + provide tables and figures required by the Annex No.5 – Evaluation matrix].

2. Annexes to the Technical part of the Bid [contain information which is recommended, i.e. not required mandatorily, by the Client; follows structure of the Technical Specification chapter 5 - Technical requirements table]:

    I. Annex 1 of the Technical part of the Bid: *Details for general overall description of the Power Supply System* [it is recommended to include general electrical schematics; recommended < 5 pages]

    II. Annex 2 of the Technical part of the Bid: *Details for flywheel generators* [recommended < 1 - 2 pages + drawings, if available]

    III. Annex 3 of the Technical part of the Bid: *Details for transformers* [recommended < 0.5 - 2 pages]

    IV. Annex 4 of the Technical part of the Bid: *Details for HV switchgear* [recommended < 0.5 - 1 page]

    V. Annex 5 of the Technical part of the Bid: *Details for converters for Toroidal Field coils* [recommended < 1 - 2 pages]

    VI. Annex 6 of the Technical part of the Bid: *Details for converters for Poloidal Field coils, capacitor bank and energy dissipator* [recommended < 1 - 2 pages]

    VII. Annex 7 of the Technical part of the Bid: *Details for additional heating systems and other loads* [recommended < 0.5 pages]

    VIII. Annex 8 of the Technical part of the Bid: *Details for control system* [recommended < 1 - 2 pages]

    IX. Annex 9 of the Technical part of the Bid: *Details for safety and protection systems* [recommended less than 1 page]

    X. Annex 10 of the Technical part of the Bid: *Details for acceptance tests* [recommended less than 1 page]

    XI. Annex 11 of the Technical part of the Bid: *Details for documentation and SW backup* [recommended less than 1 page]

    XII. Annex 12 of the Technical part of the Bid: *Details for utilization of the existing Power Supply System* [recommended less than 1 – 2 pages]

The recommended structure of the technical part of the Contractor’s Bid, as provided above, is not required mandatorily by the Client. This means that the Contractor can organize and structure the technical part of the Bid in a different way, as long as all required information is provided.

Table 3.1.1: Table of minimal technical details to be included in the Contractor's Bid

No.	Name / description of the requirement	Allowed value / description	Contractor's offered value / description
General requirements			
[The Contractor is advised to note that the majority of the inequality signs (< "greater than", < "less than") are strict inequalities. This means that the offered value is not supposed to be equal to the threshold value, e.g. when request is "> 290 a.u.", then the offered value should not be 290 a.u., but be greater, e.g. 290.1]			
1	The Power Supply System (excluding existing flywheel generators, their cables and lubrication unit; see details in Table 5.1.1: General requirements) must **fit into the allocated available installation space**.	Installation (floor) area for the Power Supply System is required to be from 800 m^2 to 1000 m^2.	[value in m^2]
2	Power Supply System must be **capable of simultaneously** (in one tokamak discharge) **delivering usable energy to its outputs** (see details in Table 5.1.1: General requirements).	TF coils output: > 290 MJ TF coils output in Basic Configuration (i.e. without 2nd new flywheel generator): > 145 MJ PF coils Power Supplies outputs: > 80 MJ additional heating or other loads outputs: >50 MJ	TF coils output: [value in MJ] TF coils output in Basic Configuration: [value in MJ] PF coils Power Supplies outputs: [value in MJ] additional heating or other loads outputs: [value in MJ] additional heating or other loads outputs in Basic Configuration: [value in MJ] Note that the row #7 of this table contains "Total mechanical energy stored in the two new flywheel generators" and that the total

No.	Name / description of the requirement	Allowed value / description	Contractor’s offered value / description
		additional heating or other loads outputs in Basic Configuration (without 2nd new flywheel generator): > 30 MJ	mechanical energy stored in the existing flywheel generators is 2x56.6 MJ. The values listed in this row (#2) should be consistent with these values, taking into account expected losses in the Power Supply System (cables, transformers, generator excitation …) – the sum of the appropriate values here should be lower than the sum of the mechanical energies of all of the flywheel generators.
3	The offered Power Supply System fulfills all requirements in the Technical Specification for Power Supply System for COMPASS-U Tokamak – Round 2.	Confirmation statement (for example “Yes”)	[Contractor’s confirmation statement]
4	The offered Power Supply System fulfills all requirements in the Technical Specification, chapter 5.1 - General requirements.	Confirmation statement (for example “Yes”)	[Contractor’s confirmation statement]
Requirements for flywheel generators			
5	**Power** available from the Power Supply System at the output (see details in 5.2 - Requirements for flywheel generators).	>80 MW for PF coils > 90 MW for TF coils (>45 MW in Basic Configuration, i.e. without 2nd new flywheel generator) > 25 MW for additional heating	Output for PF coils: [value in MW] Output for TF coils: [value in MW] Output for TF coils, in Basic Configuration: [value in MW] Output for additional heating or other loads: [value in MW] Output for additional heating or other loads, in Basic Configuration:

No.	Name / description of the requirement	Allowed value / description	Contractor’s offered value / description
		and other loads (>15 MW in Basic Configuration, i.e. without 2nd new flywheel generator) The Power Supply System must be capable of delivering these values simultaneously.	[value in MW]
6	**Output voltage** and **number of phases** of the new flywheel generator / generators.	The values are not prescribed (preferred 6 kV and 3-phase for compatibility with existing flywheel generators).	New flywheel generators output voltage: [value in Volts, line-to-line RMS voltage, no load] New flywheel generators number of phases: [value]
7	**Total mechanical energy** stored in the two new flywheel generators for rotation speed decrease from maximal operational to minimal operational rotation speed while providing energy to the tokamak.	>360 MJ	Mechanical energy stored in the first flywheel generator (Basic Configuration) = [value in MJ] Mechanical energy stored in the second flywheel generator (Extended Option) = [value in MJ] Total mechanical energy stored in the two new flywheel generators = [value in MJ]
8	**Moment of inertia** of the new flywheel generators. Note that the value should include all rotating parts storing the energy –	Any value is allowed.	Moment of inertia of the first flywheel generator (Basic Configuration) = [value in $kg.m^2$] Moment of inertia of the second flywheel generator (Extended Option) = [value in $kg.m^2$]

No.	Name / description of the requirement	Allowed value / description	Contractor's offered value / description
	motor, flywheel (if applicable) and generator.		
9	**Operational rotation speed** of the two new flywheel generators usable when providing energy to the tokamak.	Any value is allowed.	Maximal operational rotation speed = [value in rpm, revolutions per minute] Minimal operational rotation speed = [value in rpm, revolutions per minute]
10	**The stability of the output voltage** of the two new flywheel generators during the pulse when generator provides nominal pulsed energy. Pulse in this context: rotation speed decrease from maximal operational to minimal operational rotation speed with nominal pulsed power load (TF current and additional heating and other loads). For the purpose of the evaluation of the public tender (in this criterion!), the load cycle definition is: a) TF coils with self-inductance 9.5 mH and resistance 1.05 mOhm b) no losses on cables, choke coils, transformer or TF Power Supply c) TF Power supply provides for the TF coil <= 750 VDC and <90	< 34%	New flywheel generators output voltage change: [value in %]

No.	Name / description of the requirement	Allowed value / description	Contractor's offered value / description
	MW (this determines the current ramp-up duration) d) for the duration of the TF current flat-top, the auxiliary heating system drains from the two new flywheel generators 25 MW (with cos phi = 0.9) e) the duration of the TF current flat-top is selected in such a way that the flywheel generator/s reach minimal operational rotation speed at the end of the current flat-top		
11	Reference to the **section of the document and to the figures** describing the **model of the behavior of the two new flywheel generators** during the defined load cycle (above in the "The stability of the output voltage" requirement).	Reference to the document / section of the document and figures location (e.g. name of the figure and name of the document section).	Reference to the document or section of the document describing the model: [reference, e.g. name] Reference to the figures with: 1. TF current: [reference, e.g. name, section] 2. TF voltage: [reference, e.g. name, section] 3. TF Power Supply cos phi: [reference, e.g. name, section] 4. auxiliary heating power: [reference, e.g. name, section]
12	Reference to the required **readable tables describing the behavior of the two new flywheel generators** during the defined load cycle (above in the "The stability of the output voltage"	Reference to the document or the file in the human readable format - ASCII / text (e.g. name of the table and name of the	Reference to the tables containing the time evolution of the flywheel generators: 1. Output voltage, line-to-line, (actual instantaneous value with ~ms resolution): [reference, e.g. name, file]

No.	Name / description of the requirement	Allowed value / description	Contractor's offered value / description
	requirement).	document, or name of the file).	2. Output voltage, line-to-line, effective (RMS): [reference, e.g. name, file] 3. Output current, line-to-line, (actual instantaneous value with ~ms resolution): [reference, e.g. name, file] 4. Output current, line-to-line, effective (RMS): [reference, e.g. name, file]
13	Reference to the required **figures describing the behavior of the two new flywheel generators** during the defined load cycle (above in the "The stability of the output voltage" requirement).	Reference to the figures location (e.g. name of the figure and name of the document section, or name of the file).	Reference to the figures containing the time evolution of the flywheel generators: 5. Output voltage, line-to-line, (actual instantaneous value with ~ms resolution): [reference, e.g. name, section] 6. Output voltage, line-to-line, effective (RMS): [reference, e.g. name, section] 7. Output current, line-to-line, (actual instantaneous value with ~ms resolution): [reference, e.g. name, section] 8. Output current, line-to-line, effective (RMS): [reference, e.g. name, section]
14	The offered Power Supply System fulfills all requirements in the Technical Specification, chapter 5.2 - Requirements for flywheel generators.	Confirmation statement (for example "Yes")	[Contractor's confirmation statement]
Transformer requirements			
15	The offered Power Supply System fulfills all requirements in the Technical	Confirmation statement (for	[Contractor's confirmation statement]

No.	Name / description of the requirement	Allowed value / description	Contractor's offered value / description
	Specification, chapter 5.3 - Transformer requirements.	example "Yes")	
HV switchgear			
16	The offered Power Supply System fulfills all requirements in the Technical Specification, chapter 5.4 - HV switchgear.	Confirmation statement (for example "Yes")	[Contractor's confirmation statement]
Converters for Toroidal Field coil			
17	Type of the converter	Either 12-pulse thyristor converter or 24 pulse thyristor converter.	Type of the converter: [12 or 24 pulse]
18	Toroidal Field Power Supply (TFPS) **nominal pulsed output current** (see details in 5.5 - Converters for Toroidal Field coils)	>199.5 kA DC in flat-top	TFPS nominal pulsed output current: [value in kA DC]
19	**Energy deliverable to the TF coils by the TFPS.** This is a requirement for the capability of the toroidal Field Power Supply, transformers and connection (cables) between these parts (see	> 290 MJ	Energy deliverable to the TF coils by the TFPS: [value in MJ]

No.	Name / description of the requirement	Allowed value / description	Contractor's offered value / description
	details in 5.5 - Converters for Toroidal Field coils).		
20	The offered Power Supply System fulfills all requirements in the Technical Specification, chapter 5.5 - Converters for Toroidal Field coils.	Confirmation statement (for example "Yes")	[Contractor's confirmation statement]
Converters for Poloidal Field coils, capacitor bank and energy dissipator			
21	The Contractor is required to choose whether to use two output voltage levels for the PF coils Power Supplies or whether to use only one voltage level. See details in 5.6 - Converters for Poloidal Field coils, capacitor bank and energy dissipator.	1 voltage level (1 kV DC with specified allowed range 920 – 1020 VDC, no load) or 2 voltage levels (1 kV DC and 660 V DC, specified allowed ranges 920 – 1020 VDC, 660 VDC +/- 5%, no load)	Number of voltage levels: [1 or 2]
22	Power Supplies **nominal pulsed output current rating range** at nominal switching frequency 1 kHz, PWM switching. See details in 5.6 - Converters for Poloidal Field coils, capacitor bank and energy dissipator.	CS PS1, CS PS2, CS PS3, CS PS4: more or equal than +/-50 kA PF1U PS, PF1L PS, PF2U PS, PF2L PS, PF3U PS, PF3L PS: more or equal than +/-25 kA PF4U PS, PF4L PS: more or equal	CS PS1, CS PS2, CS PS3, CS PS4 (4 converters): [value in kA] PF1U PS, PF1L PS, PF2U PS, PF2L PS, PF3U PS, PF3L PS (6 converters): [value in kA] PF4U PS, PF4L PS (2 converters): [value in kA]

No.	Name / description of the requirement	Allowed value / description	Contractor's offered value / description
		than +/-30 kA	
23	Type of the PF coils Power Supplies (all of them).	H-bridge with IGBT transistors (i.e. four-quadrant converter)	Type of the PF coils Power Supplies: [type]
24	The offered Power Supply System fulfills all requirements in the Technical Specification, chapter 5.6 - Converters for Poloidal Field coils, capacitor bank and energy dissipator.	Confirmation statement (for example "Yes")	[Contractor's confirmation statement]
Additional heating systems and other loads			
25	The offered Power Supply System fulfills all requirements in the Technical Specification, chapter 5.7 - Additional heating systems and other loads.	Confirmation statement (for example "Yes")	[Contractor's confirmation statement]
Control system requirements			
26	The offered Power Supply System includes control system, which fulfills all requirements in the Technical Specification, chapter 5.8 - Control system requirements.	Confirmation statement (for example "Yes")	[Contractor's confirmation statement]

No.	Name / description of the requirement	Allowed value / description	Contractor’s offered value / description
Safety and Protection requirements			
27	The offered Power Supply System fulfills all requirements in the Technical Specification, chapter 5.9 - Safety and Protection requirements.	Confirmation statement (for example “Yes”)	[Contractor’s confirmation statement]
Acceptance tests requirements			
28	The Contractor declares that the requirements in the Technical Specification in the chapter “5.10 - Acceptance tests requirements” will be followed.	Confirmation statement (for example “Yes”)	[Contractor’s confirmation statement]
Documentation and SW backup requirements			
29	The Contractor declares that the requirements in the Technical Specification in the chapter “5.11 - Documentation and SW backup requirements” will be followed.	Confirmation statement (for example “Yes”)	[Contractor’s confirmation statement]
Requirements for the utilization of the existing Power Supply System			

No.	Name / description of the requirement	Allowed value / description	Contractor's offered value / description
30	The Contractor declares that the requirements in the Technical Specification in the chapter "5.12 - Requirements for the utilization of the existing Power Supply System" will be followed.	Confirmation statement (for example "Yes")	[Contractor's confirmation statement]

3.2 Categorization of the defects for the purpose of the warranty

The defect is any obstacle causing that the Power Supply System (PSS) does not meet all requirements or the Power Supply System is not capable or allowed (e.g. due to the safety concerns) to operate at required parameters. The categorization is in the following “Table 3.2.1: Categorization of the defects for the purpose of the warranty”.

If the defect can be classified in more than one category, then it is classified in the category with the lower number (shorter deadline).

Each defect will be classified separately when both of these two conditions are fulfilled:

1) the state of non-functionality is caused by more than one component / part or it affects more parts
2) at least partial functionality of the PSS (=the remaining defects do not cause the total non-functionality of the System) can be achieved by repairing part / parts with the lower defect category

The defect is considered as resolved when the PSS meet the related requirements, related part of the PSS is capable and allowed to safely operate at required parameters and the PSS is compliant with the design and documentation.

Table 3.2.1: Categorization of the defects for the purpose of the warranty

Defect category	Definition/description of the defect	Deadline
1	***Defects related to:*** • SW/HW PSS control system • Components and parts of high or low voltage switchgear, commonly available at the market, with the standard delivery time for the replacement part or repair realization time for the defective part that does not exceed 1 week. • Components and parts of converters, commonly available at the market, with the standard delivery time for the replacement part or repair realization time for the defective part that does not exceed 1 week. • Components and parts of generators and related technological units, with the standard delivery time for the replacement part or repair realization time for the defective part that does not exceed 1 week. • Other defects, unclassified above in this category, with the standard delivery time for the replacement part or repair realization time for the defective part that does not exceed 1 week.	***2 weeks***
2	***Defects related to:*** • Components and parts of high or low voltage switchgear, available at the market, with the standard delivery time for the replacement part or repair realization time for the defective part that does not exceed 7 weeks.	***2 months***

	• Components and parts of converters, available at the market, with the standard delivery time for the replacement part or repair realization time for the defective part that does not exceed 7 weeks. • Components and parts of generators and related technological units, with the standard delivery time for the replacement part or repair realization time for the defective part that does not exceed 7 weeks. • Other defects, unclassified above in this category, with the standard delivery time for the replacement part or repair realization time for the defective part that does not exceed 7 weeks.	
3	***Defects related to:*** • Components and parts of generators and related technological units, with the standard delivery time for the replacement part or repair realization time for the defective part that exceeds 7 weeks. • Components and parts of transformers, with the standard delivery time for the replacement part or repair realization time for the defective part that exceeds 7 weeks. • Other defects, unclassified above in this category, with the standard delivery time for the replacement part or repair realization time for the defective part that exceeds 7 weeks.	***4 months***

3.2.1 The state of non-functionality of the System

The **Contract for Work differentiates two types of the non-functionality**. The Technical Specification (this document) provides the definition for these two types of the non-functionality:

a) The type, which do not cause the total non-functionality of the Power Supply System. Both of these conditions must be fulfilled:

  - It is possible to operate the functional part of the Power Supply System in a way, which allows operation and scientific exploitation of the tokamak COMPASS-U with plasma at lower plasma parameters.
  - The Power Supply System operation is not in a conflict with laws, rules, legally binding standards or rules for Power Supply System safe operation including rules protecting personnel health and safety.

b) The type, which causes the total non-functionality of the Power Supply System. Either of these conditions is fulfilled:

  - It is not possible to operate the Power Supply System in a way, which allows operation and scientific exploitation of the tokamak COMPASS-U with plasma at lower plasma parameters.
  - The Power Supply System operation is in a conflict with laws, rules, legally binding standards or rules for Power Supply System safe operation including rules protecting personnel health and safety.

The **minimal requirements for the tokamak operation at lower plasma parameters** are:

a) functionality of the control and protection system of the Power Supply System,

b) capability of the Power Supply System to achieve toroidal magnetic field at least 2 T (79.8 kA in TF coils) for at least 1 second,

c) all 12 PF coils must be protected by the Power Supply System against plasma disruption,

d) all 12 PF coils Power Supplies must be capable of providing at least 60% of their current rating and at least 80% of their voltage rating,

e) the PSS must be capable of providing at least 40 MJ for the PF coils during the duration of the plasma pulse,

f) TFPS and PFPS protections (crowbars, energy dissipator, capacitor banks ...) must be functional.

4 General schematics of the Power Supply System for COMPASS-U

4.1 General Schematics

This chapter contains General schematics of the Power Supply System for COMPASS-U.

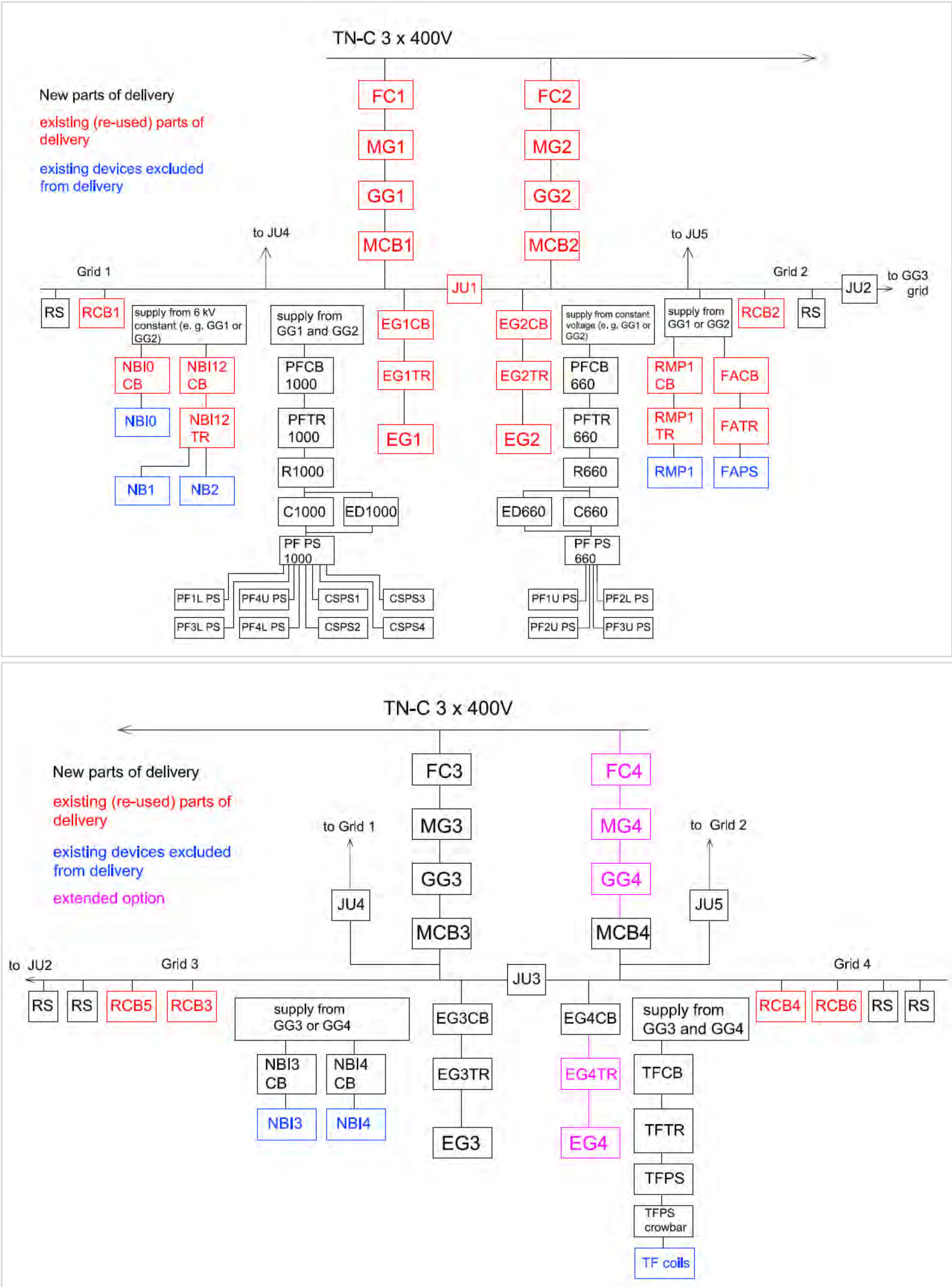


Figure 4.1.1: General schematics of the Power Supply System for COMPASS-U. See chapter "4.2 - Terminology, names and dictionary" for explanation of the shortcuts.

4.2 Terminology, names and dictionary

Names and shortcuts of the Power Supply System components, used in the general schematics in the previous section 4.1, are described in the table below.

Table 4.2.1 Description of used acronyms

Acronym	Brief description	
TN-C	Electrical grid with common neutral and protective earth/ground wire	
JU	Junction between HV grids	
GG	Flywheel generator	
	GG #1,2	Existing flywheel generators
	GG #3,4	New (additional) flywheel generators
MG	Motor of flywheel generator	
FC	Frequency converter of the motor of flywheel generator	
MCB	Main circuit breaker for flywheel generator (or pyrobreaker)	
EG	Converter for excitation of flywheel generator	
	EGTR	Transformer
	EGCB	Circuit breaker / contactor
TF	Toroidal field coils	
PF	Poloidal field coils (PF1U, PF1L, PF2U, PF2L, PF3U, PF3L, PF4U, PF4L)	
CS	Central solenoid coils (CS1U, CS1L, CS2U, CS2L, CS3U, CS3L, CS4U, CS4L)	
TFPS	Toroidal field power supply	
TFTR	Transformer for toroidal field power supply	
TFCB	Circuit breaker for toroidal field power supply	
PFPS	Poloidal field power supply	
	PFPS1000	Power supply for poloidal field coils PF1L, PF3L, PF4U, PF4L, and central solenoid coils CS1U,CS1L, CS2U,CS2L, CS3U,CS3L, CS4U, CS4L
	PFPS660	Power supply for poloidal field coils PF1U, PF2U, PF2L, PF3U
PFTR	Transformer/s for poloidal field power supply	
	PFTR1000	Transformer/s for PF coils converters with 1 kV no load voltage
	PFTR660	Transformer/s for PF coils converters with 660 V no load voltage
PFCB	Circuit breakers for poloidal field power supply	
	PFCB1000	Circuit breakers for PFPS1000 circuit
	PFCB660	Circuit breakers for PFPS660 circuit

<table>
<tr><td rowspan="3">R</td><td colspan="3">Rectifier for the capacitor bank</td></tr>
<tr><td>R1000</td><td colspan="2">Rectifier for the PFPS1000 circuit</td></tr>
<tr><td>R660</td><td colspan="2">Rectifier for the PFPS660 circuit</td></tr>
<tr><td rowspan="3">C</td><td colspan="3">Capacitor bank for PF coils converters</td></tr>
<tr><td>C1000</td><td colspan="2">Capacitor bank for PF coils converters with 1 kV no load voltage</td></tr>
<tr><td>C660</td><td colspan="2">Capacitor bank for PF coils converters with 660 V no load voltage</td></tr>
<tr><td rowspan="3">RMP</td><td colspan="3">Resonant magnetic perturbations power supply (existing)</td></tr>
<tr><td>RMPTR</td><td colspan="2">Transformer 1,5 MVA for RMP circuit</td></tr>
<tr><td>RMPCB</td><td colspan="2">Circuit breaker for RMP circuit</td></tr>
<tr><td rowspan="9">NBI</td><td colspan="3">Neutral beam injection system</td></tr>
<tr><td>NBI12</td><td colspan="2">Existing 400 kW NBI systems</td></tr>
<tr><td>NBI0</td><td colspan="2">Procured 1 MW NBI system</td></tr>
<tr><td>NBI3</td><td colspan="2">Planned new NBI systems</td></tr>
<tr><td>NBI4</td><td colspan="2">Planned new NBI systems</td></tr>
<tr><td rowspan="2">NBITR</td><td colspan="2">Transformer for NBI circuit</td></tr>
<tr><td>NBI12TR</td><td>Existing 1,5 MVA transformer for both NBI12 systems</td></tr>
<tr><td rowspan="2">NBICB</td><td colspan="2">Circuit breaker for NBI circuit</td></tr>
<tr><td>NBI12CB</td><td>existing common circuit breaker for both NBI12 systems</td></tr>
<tr><td rowspan="3">FAPS</td><td colspan="3">Fast amplifier power supply (existing)</td></tr>
<tr><td>FATR</td><td colspan="2">Existing 750 kVA transformer for FA</td></tr>
<tr><td>FACB</td><td colspan="2">Circuit breaker for FAPS</td></tr>
<tr><td>RCB</td><td colspan="3">Reserve circuit breaker</td></tr>
<tr><td>RS</td><td colspan="3">Reserved space for circuit breaker</td></tr>
</table>

Table 4.2.2 List of Abbreviations

ABD	As-built Documentation (final documentation of real manufactured equipment)
AD	Accompanying Documentation (operational and maintenance documentation)
Basic Configuration	The procurement of the “Power Supply System for COMPASS-U tokamak” consists of the mandatory part: “Power Supply System for COMPASS-U tokamak - Basic Configuration” and Extended Options: a) “Second new flywheel generator and its auxiliary systems”, b) “Increase of the capacitor bank(s) energy by +0.5 MJ” and c) “Short circuit test at full nominal pulsed voltage of a selected transformer”.
CID	Contractor’s Implementing Documentation (project design documentation)
CODAC	Control, Data Acquisition and Communication system. Main control system of the tokamak.
COMPASS-U	COMPASS-U: Tokamak for cutting-edge fusion research
CS	Central Solenoid
ECRH	Electron Cyclotron Resonance Heating
EFPS	Equilibrium Field Power Supply
Extended Options	The procurement of the “Power Supply System for COMPASS-U tokamak” consists of the mandatory part: “Power Supply System for COMPASS-U tokamak - Basic Configuration” and Extended Options: a) “Second new flywheel generator and its auxiliary systems”, b) “Increase of the capacitor bank(s) energy by +0.5 MJ” and c) “Short circuit test at full nominal pulsed voltage of a selected transformer”.
FA	Fast Amplifiers
FF	Fast Feedback
G1, G2	Flywheel Generator 1,2
HVS	High-Voltage Switchgear (note that the term “high voltage” is used for 1000V to 50 kV according Czech standards, the international standards call this range “medium voltage”)
IPP	Institute of Plasma Physics (of the Czech Academy of Sciences)
LVS	Low-Voltage Switchgear
Machine Protection	The system used to protect the tokamak against damage (e.g. the Machine Protection system can request to stop the currents supplied by the Power Supply System). The system is not part of the delivery, it belongs and it is operated by the Client.
MFPS	Magnetizing Field Power Supply
MFPS/OH	Magnetizing Field Power Supply / Ohmic Heating
NBI	Neutral Beam Injection
OP RDE	Operational Programme Research, Development and Education
Personnel Interlock	The system used to protect people entering the experimental area (e.g. tokamak hall). The system is not part of the delivery, it belongs and it is operated by the Client.
PF	Poloidal Field

PSS	Power Supply System
PWM	Pulse Width Modulation
RMP	Resonant Magnetic Perturbations
SFPS	Shaping Field Power Supply
TF	Toroidal Field
TFPS	Toroidal Field Power Supply
VKPS	Vertical Kicks Power Supply
VMF	Virtual Magnetizing Field
VS	Vertical Stability

5 Technical requirements table

The requirements in the tables in the entire section "5 - Technical requirements table" are divided to sections for clarity only. Therefore, if requirements has impact outside of the section scope then it must be fulfilled regardless of the section scope.

5.1 General requirements

Table 5.1.1: General requirements

No.	Name and description of the requirement	Value / description
1	The Power Supply System must **fit into the allocated available installation space**. The description of the spatial constraints is available in the section 6.6 - Description of the available space in the buildings. The offered installation (floor) area in this requirement does not include: 1. the floor area of the separated building used for the housing of the existing flywheel generators GG1 and GG2 (64 m^2), 2. the floor area for their cables leading to the assembly hall (2 m^2) 3. the floor area housing the lubrication unit for the existing generators (12 m^2; underground floor, west of the Location 4, see section 6.6 - Description of the available space in the buildings) The reason for exclusion of this floor area (64 + 2 + 12 m^2) is that the existing generators and lubrication unit are not supposed to undergo any movement during the Power Supply System installation.	Installation (floor) area for the Power Supply System is required to be from 800 m^2 to 1000 m^2. The Contractor will specify the exact upper limit for the public tender. The Contractor will have to adhere to this specified upper limit. This criterion is valid for the entire Power Supply System for COMPASS-U tokamak, i.e. Basic Configuration together with the Extended Options.
2	The **Power Supply System must be capable of providing power and energy for the COMPASS-U tokamak during the tokamak experiment**. The text description of the intended use is in the sections **6.2 - General description of the background of the intended Power Supply** System use and **6.3 - Description of the Poloidal Field coils** behaviour.	Yes
3	Power Supply System must be **capable of simultaneously** (in one tokamak discharge) **delivering usable energy to its outputs**	TF coils output**: > 290 MJ** TF coils output in Basic Configuration (i.e. without 2nd new flywheel generator):

	Definition: TF coils output = output of the TFPS converter in the experimental area (choke coils and output filters are part of the TFPS converter) PF coils Power Supplies outputs = output of the converters of Poloidal Field coils in the experimental area (choke coils and output filters are part of the PFPS converters) additional heating or other loads outputs = output of the circuit breakers (other outputs are e.g. RMP PS, FAPS ..., which are not PF or TF converters or excitation for generators)	> 145 MJ PF coils Power Supplies outputs**: > 80 MJ** additional heating or other loads outputs: **>50 MJ** additional heating or other loads outputs in Basic Configuration (i.e. without 2nd new flywheel generator): > 30 MJ
4	The Contractor will provide a **model of the Power Supply System in the software Matlab Simulink or in other compatible software**. The model will have the following features: 1) the model must be compatible with Matlab Simulink version newer than from the year 2015 (e.g. Simulink 8.5 or newer) 2) the model will be capable of determining the energy losses in the Power Supply System (including energy losses for excitation of the flywheel generators) with precision < 15 % 3) the model will be capable of determining the inductive voltage drop in the Power Supply System with precision < 15 % 4) the model will include changing frequency of the flywheel generators and it will predict their energy drain with accuracy < 5% 5) the model will be capable of simulating different failure modes in the Power Supply System, e.g. capability to determine the short-circuit currents in case of simulated failure of control system to control individual power elements 6) the model will be capable of determining the transient events in the Power Supply System: voltage transients, voltage oscillations, frequency of oscillations …	Yes
5	The **stray magnetic field** of the Power Supply System **must be minimized** by utilizing these features: 1) Cables: Use four-wire cable harnesses to connect the	Yes

	various parts of the Power Supply Systems. In each of the cables, the current must be drawn away from the source by one pair of diagonally located conductors and back by the other pair. This reduces the magnetic field generated in the surrounding area. 2) Busbars: If used, the + and – lines must be located as close to each other as possible to minimize stray magnetic field. 3) Air choke coils: locate the coils as far from the tokamak as possible. Spatially distribute the choke coils in a way that their magnetic fields generated near the tokamak vessel counter each other	
6	**The delivery** of the Power Supply System **will include spare parts**, which will become property of the Client. The spare parts for the following classes of components is required: 1. Fuses used in the HV switchgear, in the TFPS protection: **for each used type more than 3 % from the installed number** in the entire PSS 2. Drivers (for thyristors and transistor modules): for each used type **more than 3 %** from the installed number in the entire PSS 3. Thyristor modules used in the Power Supplies (both PFPS and TFPS), including crowbar/s, protections and energy dissipator/s: for each used type **more than 3 %** from the installed number in the entire PSS 4. Transistor modules used in the Power Supplies (both PFPS and TFPS), including crowbar/s, protections and energy dissipator/s: for each used type **more than 3 %** from the installed number in the entire PSS 5. Diode modules: for each used type **more than 3 %** from the installed number in the entire PSS 6. Capacitors used in the capacitor bank/s and in the snubbers of the Power Supplies: for each used type **more than 3 %** from the installed number in the entire PSS 7. Control system parts: low level controllers, sensors, system monitoring parts, data acquisition boards, communication units; for each used type **more than 10 %** (but at least one piece) from the installed number in the entire PSS	Yes
7	**Training of the Client employees** / staff for operation, maintenance and control of the Power Supply System (see “Contract for Work” for time extent and organization) must have **content divided into these**	Yes

	topical areas: 1) Power Supply System in its entirety 2) Flywheel generators 3) Transformers, switchgear and auxiliary systems 4) Transistor based Power Supplies 5) Thyristor based Power Supply 6) Control system **For each of the topical areas, the training must include** these sections: 1) Introduction: description of the function, parameters and interactions with other parts of the PSS 2) Operation: daily start, stop, operation; solution of the commonly occurring errors and faults; location of further information about faults 3) Maintenance: maintenance procedures, including periodic checks and list of long term maintenance requirements (for example 1x per 10 year X-ray check of transformers) 4) "Safety and Health Protection During Work" training: according Czech law requirements (BOZP – Bezpečnost a ochrana zdraví při práci) 5) Training of emergency situations handling: including training in reactions to serious faults 6) Overview of assembly and disassembly instructions and procedures The Contractor must provide for each of the topical areas (in electronic form and in the printed hardcopy): 1) Outline 2) Synopsis 3) Materials used during the training The training can be performed as oral lecture with Power Supply System technical documentation as basis. Provide training focused on software and firmware – use, programming, deploying, functionality, errors description and searching for causes.	
8	The **expected longevity of the Power Supply System**. This requirement does not specify warranty period, it specifies that the system and its parts must be designed for this longevity. This longevity is valid unless specified otherwise in the individual parts of the Power Supply System.	More than 30 000 tokamak pulses with full performance parameters or at least 15 years – whichever from these two conditions is satisfied first.

	Note: the expected number of tokamak pulses per year is 2000 – 2500 (not all of the pulses are performed at full performance parameters).	
9	The **cooling system/s** of the Power Supply System must be realized in a way that the Power Supply System parts are **protected against the condensation of the air humidity**. This requirement means that the cooling circuit for the transistor modules of the PF coils Power Supplies must not use temperature of the cooling medium lower than the room temperature.	Yes
10	The Power Supply System **must not return power back to the public electricity** (power) **grid**. For example, the braking of the flywheel generators must be realized in a way that the excess energy is dissipated in the resistors and it is not returned into the public grid.	Yes
11	The Power Supply System must be designed and constructed in a way that allows its routine operation in the **building**, which **does not have humidity control**.	Yes
12	The Power Supply System must be designed and constructed in a way that allows its routine operation under the conditions where the **tokamak stray magnetic field** is present (**< 10 mT** at the outer wall of the tokamak hall).	Yes
13	**The components** of the Power Supply System, which are not re-used from the existing Power Supply System, **must be newly manufactured**, i.e. not re-used or refurbished. This requirement is among others valid for the new flywheel generators, the circuit breakers, the transformers, the control system, the PF coils Power Supplies IGBT modules, and the drivers for the IGBT modules.	Yes

5.2 Requirements for flywheel generators

This section summarizes main requirements for the flywheel generators of the Power Supply System.

It should be noted that the (see general schematics, Figure 4.1.1):

a) **Basic Configuration includes**:
   a. flywheel generators – GG1, GG2 and GG3
   b. motors – MG1, MG2 and MG3
   c. frequency converters – FC1, FC2 and FC3
   d. excitation transformers – EG1TR, EG2TR and EG3TR
   e. excitation converters – EG1, EG2 and EG3

b) **Extended Option "Second new flywheel generator and its auxiliary systems" includes**:
   a. flywheel generator – GG4
   b. motor – MG4
   c. frequency converter – FC4
   d. excitation transformer – EG4TR
   e. excitation converter – EG4
   f. installation
   g. complete integration into the Power Supply System control system, complete integration into the protection system
   h. commissioning and testing

It should be stressed that **all main circuit breakers** (MCB1, MCB2, MCB3 and MCB4) and **all excitation circuit breakers/ contactors** (EG1CB, EG2CB, EG3CB and EG4CB) **are part of the Basic Configuration**.

Table 5.2.1: flywheel generators requirements

No.	Name and description of the requirement.	Value / description
	The term "flywheel generator" means a rotating device used for accumulation of energy, capable of delivering electrical power. This can be either motor-flywheel-generator or motor-generator, if moment of inertia of the generator is large enough to provide sufficient amount of energy.	
1	**Power** available from the Power Supply System at the output. Output: ▪ sum of output of converters for Poloidal Field coils, ▪ output of converters for Toroidal Field coils, ▪ output of circuit breakers for additional heating (or other loads) if the transformer is not part of the delivery OR output of the transformer for additional heating (or other loads) if the transformer is part of the delivery (see Figure	>80 MW for PF coils (same value in the Basic Configuration) > 90 MW for TF coils (>45 MW in Basic Configuration, i.e. without 2nd new flywheel generator)

	4.1.1 for explanation which transformers are part of the delivery)	> 25 MW for additional heating and other loads (>15 MW in Basic Configuration, i.e. without 2nd new flywheel generator) The Power Supply System must be capable of delivering these values simultaneously.
2	**Energy** delivered from the Power Supply System at the output Output: sum of output of converters for Poloidal Field coils, output of converters for Toroidal Field coils, and output of circuit breakers for additional heating if transformer is not part of the Power Supply System, output of transformer for additional heating if transformer is part of Power Supply System	>420 MJ (>255 MJ in Basic Configuration, i.e. without 2nd new flywheel generator) Both two new flywheel generators (resp. one new flywheel generator in Basic Configuration) and the two existing flywheel generators are included in this value. Required duration of flywheel generator excitation without ramp-up and ramp-down: 7 seconds
3	**Output voltage** and **number of phases** of the new flywheel generator / generators.	The values are not prescribed (preferred 6 kV and 3-phase for compatibility with existing flywheel generators).
4	The **stability of the output voltage** of the two **new flywheel generators** during the pulse when generator provides nominal pulsed energy. Pulse in this context: rotation speed decrease from maximal operational to minimal operational rotation speed with nominal pulsed power load (TF current and additional heating and other loads). For the purpose of the evaluation of the public tender (in this criterion!), the load cycle definition is:	< 34% E.g., the output voltage can change from 6 kV to 4 kV during the pulse, which is 33,3% change of output voltage.

	a) TF coils with self-inductance 9.5 mH and resistance 1.05 mOhm b) no losses on cables, choke coils, transformer or TF Power Supply c) TF Power supply provides for the TF coil <= 750 VDC and <90 MW (this determines the current ramp-up duration) d) for the duration of the TF current flat-top, the auxiliary heating system drains from the two new flywheel generators 25 MW (with cos phi = 0.9) e) the duration of the TF current flat-top is selected in such a way that the flywheel generator/s reach minimal operational rotation speed at the end of the current flat-top	
5	**Energy recuperation** requirements. Note: this is recuperation from the tokamak coils into the flywheel, not to the public electricity grid.	Existing flywheel generators: not required. New flywheel generators together: >60 MW, > 90 MJ from Toroidal Field coils, after flat-top phase (resp. > 30 MW, > 45 MJ in Basic Configuration, i.e. without 2nd new flywheel generator).
6	Assumed load of the existing flywheel generators are Power Supplies for PF coils, additional (auxiliary) heating power supplies and other loads. Assumed load of the new flywheel generator(s) are TF coils Power Supplies, additional (auxiliary) heating power supplies and other loads.	
7	**Time duration** between the order to start the flywheel generator/ generators to **reaching maximal operational rotation speed**	< 50 min
8	**Time duration** between the order to stop the flywheel generator/ generators rotating at maximal operational rotation speed to **reaching zero rotation speed** Note: the section “5.1 - General requirements” has a requirement that energy must not be returned to the public power grid. This necessitates usage of the braking resistors or similar method to dissipate the energy on-site.	< 50 min

9	The **new flywheel generators** must be **designed in a way, which allows future installation of an independent emergency braking system**, which should be capable of stopping the new flywheel generators in case of emergency situation (failure of the standard braking system, electric power loss, failure of the control system , fire …). The Contractor's Implementing Documentation (CID) must contain conceptual plan for this independent emergency braking system.	Yes
10	**Time duration** to increase flywheel generator(s) speed from **minimal** operational rotation speed **to maximal operational rotation speed**	< 25 min
11	**Possibility to set the power of the motors** of all flywheel generators for the **flywheel generator start-up** from the Graphical User Interface (GUI)	Yes
12	**Possibility to set time sequence of the flywheel generators start-up** from the GUI	Yes
13	**Starting motor**, which will be supplied from main grid 3 x 400 V, will be **controlled by frequency converter** The frequency converters FC1, FC2 and FC3 are part of the Basic configuration. Frequency converter FC4 is part of the Extended Option – Second new flywheel generator and its auxiliary systems.	Yes
14	Minimal **number of rotation speed sensors** installed for each new generator. Measuring of rotation speed of new flywheel generator (or generators) will be performed at two different places on the generator, with three speed sensors. At least one of these two different places must be on the flywheel or on the generator (i.e. must not be on the motor). At least two functional sensors will be required by control system to allow operation of the flywheel generator.	≥ 3
15	All **auxiliary devices and protective elements** necessary for safe operation of the generator included in the delivery (lubrication unit, motor, converter for the motor, control, UPS …).	Yes
16	The **connection line from the generator terminals to the main switch** must be made in such a way that there is **no**	Yes

	possibility for short circuit, which could destroy the generator, under expectable circumstances (standard operation, service and manipulation states, expectable failure situations).	
17	**Noise of the new flywheel generators when enclosed** in cover. Note: an additional bunker or separated building will be provided by the Client in order to further soundproof the flywheel generators.	<70 dB
18	**Operational controls**, including all accessories, are **remotely controllable** and monitor-able from tokamak control room and dedicated place in switchgear.	Yes
19	The **generator(s) output to the HV switchgear** is provided with a **main circuit breaker** (or pyrobreaker combined with circuit breaker/disconnector), dimensioned according to the short-circuit conditions at the generator outlet and the thermal load given by the pulse nominal pulsed current and the pulse length given by the accumulated energy. All four main circuit breakers are part of the Basic Configuration, including main circuit breaker MCB4 intended for the 2nd new flywheel generator (GG4).	Yes
20	The lubrication unit and circuit will be able to ensure that the **flywheel generator stops safely when power is lost** from the outside electrical grid without damage to the flywheel generator.	Yes
21	Delivered new **generator(s)** have to be **newly manufactured**, not re-used or refurbished.	Yes
22	Implementation of existing Power Supply System control functionality into the new Power Supply System control and GUI.	Yes
23	All flywheel generators (existing and new) must be equipped with **current measurement of all output phases**, with sampling rate > 1 kHz and recording in control system.	Yes
24	All flywheel generators (existing and new) must be equipped with **fast detection of dangerous overcurrent**,	Yes

	which will stop the drain in the case of overcurrent.	
25	The **control system must stop the pulse if it detects** (or predicts) **over-temperature** in the flywheel generators (existing and new). Example: the control system must stop the pulse if it calculates that the temperature of the generator rotor (field / primary / exciter) winding exceeds allowed value due to the unusually long excitation duration.	Yes
26	The new flywheel generators must be equipped with the **redundant sensors for determining the temperature** of the windings and bearings.	Yes
27	The **temperature sensors in the bearings** must be **replaceable** (i.e. removable and exchangeable) without replacing the entire bearings.	Yes
28	Generator and connecting lines to the HV switchgear will be protected as a whole by **differential protection** or other necessary protection.	Yes
29	The **generator's excitation windings will be powered from static converters**. For excitation of the generator and testing without load will be used first exciter powered by an external 400V / 50Hz. The second exciter will feed the excitation winding from the own generator´s grid via the transformer. The excitation converters EG1, EG2 and EG3 are part of the Basic configuration. Excitation converter EG4 is part of the Extended Option – Second new flywheel generator and its auxiliary systems.	Yes

5.3 Transformer requirements

The Power Supply System includes these transformers (see general schematics, Figure 4.1.1):

- New transformers, to be manufactured and installed within the contract:
  - Transformer EG3TR for excitation of the new generator GG3 (transformer is part of the Basic Configuration)
  - Transformer EG4TR for excitation of the new generator GG4 (both the transformer and cables to the appropriate circuit breaker EG4CB are part of the Extended Option "Second new flywheel generator and its auxiliary systems")
  - Transformer or transformers for supplying Toroidal Field Power Supply (TFTR1, TFTR2 …)
  - Transformer or transformers for supplying Poloidal Field coils Power Supplies. There are either two different voltage levels for the Power Supplies: 1 kV DC (no-load) and 660 V DC (no load), or the Contractor can choose to utilize only higher voltage level (1 kV, DC, no-load) for all PF coils Power Supplies. These two options have different requirements in the following table for the transformers PFTR1000 and PFTR660.
- Existing transformers to be installed within the Power Supply System:
  - Two transformers (EG1TR, EG2TR) for excitation of existing generators GG1 and GG2
  - Transformer for existing Neutral Beam Injectors 1 and 2 (NBI12TR), the NBI1 and NBI2 are not part of the Power Supply System
  - Transformer for existing converters RMP PSs (RMP1TR), the converters are not part of the Power Supply System
  - Transformer for existing converter Fast Amplifier Power supply FAPS (FATR), the converter is not part of the Power Supply System

The current requirements for the transformers required in this section (5.3 - Transformer requirements) are valid for the Basic Configuration, unless stated otherwise.

Table 5.3.1: Transformer requirements

No.	Name and description of the requirement	Value / description
1	**Type** of the transformers.	Dry transformer for indoor usage.
2	All **new transformers** must be designed to and **must withstand hard short circuit** at their output without damage until circuit breaker disconnects them in the case of fault situation.	Yes
3	Transformers will work with impulse load, thus high current shock. The **winding of transformer**, including inlets and outlets, **must withstand mechanical stress in case of fault and short circuit** until circuit breaker disconnects them.	Yes
4	Electrical connection of the **transformer inlets and outlets** (cables or busbars) **must withstand mechanical stress in case of fault and short circuit** until circuit	Yes

	breaker disconnects them.	
5	**Thermal protection for transformers windings**, connected to the HV switchgear control logic.	Yes
6	**Transformers** have to be able to **work with changing frequency** depending on generators output.	Yes
7	Transformer or group of **transformers (TFTR) for Toroidal Field Power Supply nominal pulsed current** (effective = RMS) on converter side. If there will be the option with more than one transformer, all transformers must have identical (design) power rating.	> 141 kA
8	Transformer or group of **transformers (TFTR) for Toroidal Field Power Supply line-to-line RMS (effective) voltage** on converter side under no-load condition (I = 0 A). Note: nominal (i.e. at nominal pulsed current) line-to-line RMS (effective) voltage on converter side will be therefore lower than this value.	< 780 V
9	Transformer or **transformers for Toroidal Field Power Supply relative short circuit test voltage** Uk (nominal pulsed current / short-circuit current). The value must be valid for the entire operational range of the frequencies of the transformer as determined by operational range of rotation speed of the flywheel generator.	< 20 %
10	Transformer or **transformers for Toroidal Field Power Supply real part of the relative short circuit test voltage** Ur (resistive losses, magnetization losses and eddy current losses). The value must be valid for the entire operational range of the frequencies of the transformer as determined by operational range of rotation speed of the flywheel generator.	< 4%
11	Transformer or **transformers for Toroidal Field Power Supply pulse load characteristics**.	> 7 seconds 100 % load, followed by 25 minutes no load (0 %).

12	Transformer or **transformers for Toroidal Field Power Supplies must be supplied from new generator** or generators (GG3, GG4).	Yes
13	Transformer or **transformers for Poloidal Field Power Supplies nominal pulsed current** (effective = RMS) on converter side. If there will be more than one transformer (for either PFTR1000 or PFTR660 option), all must have identical (design) power rating.	PFTR1000: > 80 kA PFTR660: > 14 kA (in case that four PF coils Power Supplies with required DC voltage 660 V no-load have independent transformer and capacitor bank) OR PFTR1000: > 90 kA PFTR660: does not exist (in case that all PF coils Power Supplies use DC voltage 1 kV no-load and have common capacitor bank)
14	Transformer or **transformers for Poloidal Field Power Supplies relative short circuit test voltage** Uk (nominal pulsed current / short-circuit current). The value must be valid for the entire operational range of the frequencies of the transformer as determined by operational range of rotation speed of the flywheel generator.	< 20%
15	Transformer or **transformers for Poloidal Field Power Supplies real part of the relative short circuit test voltage** Ur (resistive losses, magnetization losses and eddy current losses). The value must be valid for the entire operational range of the frequencies of the transformer as determined by operational range of rotation speed of the flywheel generator.	< 4%
16	Transformer or **transformers for Poloidal Field Power Supplies pulse load characteristics**.	> 1 seconds 100 % load, followed by 25 minutes no load (0 %).
17	Transformer or **transformers PFTR1000 for Poloidal Field Power Supplies must be supplied from both**	Yes

	existing generators (GG1 and GG2) Note: Energy requirement for PF coils is higher than energy provided by a single existing generator.	
18	If utilized, the transformer or **transformers PFTR660 for Poloidal Field Power Supplies must be supplied from generator or generators with output voltage not changing with generator rotation speed** (e.g. existing generators GG1 or GG2). Note: if PFTR660 is utilized and powered from existing flywheel generator/s, it may be necessary to connect transformer/s PFTR660 to both of these generators to balance the energy drain from the two generators.	Yes
19	**PFTR1000** and **PFTR660 type of transformer**. Explanation: 12-pulse rectifier for each transformer is required.	Three-winding
20	Transformer **EG1TR** for excitation of existing flywheel generator GG1: **re-use existing transformer 1TR2A** (see section 5.12 - Requirements for the utilization of the existing Power Supply System, description in section 6.5.4 - Transformers).	Yes
21	Transformer **EG1TR must be supplied from GG1**.	Yes
22	Transformer **EG2TR** for excitation of existing flywheel generator GG2: **re-use existing transformer 2TR2B** (see section 5.12 - Requirements for the utilization of the existing Power Supply System, description in section 6.5.4 - Transformers).	Yes
23	Transformer **EG2TR must be supplied from GG2**.	Yes
24	Transformers **EG3TR, EG4TR** for excitation of new flywheel generators GG3 and GG4: **one separated transformer for each new flywheel generator**, parameters of the transformer must allow generator to be operated according its required specification. Transformers **EG3TR, EG4TR must be supplied from the generators GG3, GG4** respectively. Note: this requirement is motivated by intention to have independent, electrically separated excitation for each	Yes

	transformer. The transformer EG3TR is part of Basic Configuration. The transformer EG4TR is part of the Extended Option “Second new flywheel generator and its auxiliary systems”.	
25	Transformer **NBI12TR** for supplying existing Neutral Beam Injectors 1 and 2 (the NBI1 and NBI2 are not part of the Power Supply System): **re-use existing transformer 9TR09** (see section 5.12 - Requirements for the utilization of the existing Power Supply System, description in section 6.5.4 - Transformers).	Yes
26	Transformer **NBI12TR must be supplied from generator or generators with output voltage not changing with generator rotation speed** and matching to transformer specification (e.g. existing generators GG1 or GG2).	Yes
27	Transformer **RMP1TR** for existing converters RMP PSs (the converters are not part of the Power Supply System): **re-use existing transformer 0TR10** (see section 5.12 - Requirements for the utilization of the existing Power Supply System, description in section 6.5.4 - Transformers).	Yes
28	Transformer **RMP1TR must be supplied from generator or generators with output voltage not changing with generator rotation speed** and matching to transformer specification (e.g. existing generators GG1 or GG2).	Yes
29	Transformer **FATR** for existing converter Fast Amplifier Power Supply FAPS (the converter is not part of the Power Supply System): **re-use existing transformer 8TR08** (see section 5.12 - Requirements for the utilization of the existing Power Supply System, description in section 6.5.4 - Transformers).	Yes
30	Transformer **FATR must be supplied from generator or generators with output voltage not changing with generator rotation speed** and matching to transformer specification (e.g. existing generators GG1 or GG2).	Yes

5.4 HV switchgear

Note that the term “high voltage” is used for 1000 V to 50 kV range, according to the Czech standards; the international standards use the term “medium voltage” for this voltage range.

HV Switchgear can be sorted to individual grids according of their supply generator: grid 1, grid 2, grid 3 and grid 4, see Figure 4.1.1. These grids can be connected by junctions JU1 - JU5 (if the grids are working on the same voltage level and with three phases each). Grid 1 and 2 are supplied from the existing generators and grid 3 and 4 are supplied from the new generators. Both grid 3 and grid 4 are part of the Basic Configuration.

The purpose of the junction JU1 (between grid 1 and 2) and JU3 (between grid 3 and 4) is to allow operation of the Power Supply System with limited performance in case of unavailability of one flywheel generator from the pairs GG1/GG2 and GG3/GG4.

The purpose of the junctions JU2, JU4 and JU5 is to allow higher degree of interoperability between individual grids and flywheel generators. The purpose of the JU2, JU4 and JU5 must be kept, but exact distribution is not strictly required if number of grids (4) is different from example schematics in the Figure 4.1.1 or if new additional generators do not allow under any circumstances connection to the grid 1 and 2.

The Client requires modular and unified HV switchgear with withdrawable circular breakers. Circuit breakers should be interchangeable if working power and voltage is in the range or it is possible to set value of the circuit breaker.

List of required fields and circuits breakers (or pyrobreakers) in the HV switchgear:

- MCB1, MCB2, MCB3, MCB4: one Main Circuit Breaker or pyrobreaker for each flywheel generator. All four Main Circuit Breakers are part of the Basic Configuration, i.e. the MCB4 is not part of the Extended Option “Second new flywheel generator and its auxiliary systems”.
- EG1CB, EG2CB, EG3CB, EG4CB: Circuit breakers / medium voltage vacuum contactors with fuses for converters providing excitation of the flywheel generators. All four circuit breakers for excitation transformers are part of the Basic Configuration, i.e. the EG4CB is not part of the Extended Option “Second new flywheel generator and its auxiliary systems” (while transformer EG4TR and exciter EG4 is part of the Extended Option).
- NBI0CB, NBI12CB, NBI3CB, NBI4CB: Circuit breakers for Neutral Beam Injectors 0, (1 and 2), 3, 4
- TFCB, PFCB1000, PFCB660: Circuit breakers for transformers for Toroidal Field coils Power Supply, Poloidal Field coils Power Supplies with voltage 660 V and 1 kV
  - the number of circuit breakers depends on the number of transformers (e.g. it is probable that TFTR will be composed from two or four transformers)
- RCB1, RCB2, RCB3, RCB4, RCB5, RCB6: Reserve circuit breakers – circuit breakers without assigned load, usable as replacement, these circuit breakers are part of the delivery of the Power Supply System
- JU1, JU2, JU3, JU4, JU5: Junctions between the grids
  - JU1 is already existing (re-used) part – isolating truck 12 kV, 50/60 Hz, 1250 A nominal current, short-time withstand current: 31.5 kA for 3 seconds. See section 5.12 - Requirements for the utilization of the existing Power Supply System.

- RS (6x): reserved space for switchgear rack cabinet (the rack cabinet is not part of the delivery)
- FACB: circuit breaker for FAPS - Fast amplifier power supply (existing)
- RMP1CB: circuit breaker for RMP circuit - Resonant magnetic perturbations power supply (existing)

Table 5.4.1: HV switchgear requirements

No.	Name and description of the requirement	Value / description
1	We require **re-use of existing HV switchgear and circuit breakers according chapter 5.12 - Requirements for the utilization of the existing Power Supply System**, e.g. for re-used transformers (8TR08, 0TR10, 9TR09, 1TR2A, 2TR2B) and for re-used generators (GG1 and GG2). Existing HV switchgear is Unigear ZS1, with VD4 / P 12.12.32 P150 ABB and with VD4 / P 12.06.32 P150 ABB circuit breakers and medium voltage vacuum contactors VSC7/P 80, see sections 6.5 - Existing Power Supply System, specifically 6.5.3 - High-voltage switchgear.	
2	**Type** of the used **circuit breakers**	Withdrawable type The MCB3 and MCB4 (main circuit breakers of the new generators GG3 and GG4) can be Fixed type if MCB3 and MCB4 are realized by pyrobreaker.
3	It must be **possible to manually disconnect any individual node of the Power Supply System** in such way that the control system cannot re-connect the node.	Yes
4	**Circuit breakers, disconnectors and contactors required longevity**. Note: this requirement does not assume that the circuit breaker/s turns off in all of the tokamak pulses. The requirement is not intended for the pyrobreakers.	More than 30 000 tokamak pulses with nominal pulsed current rating of the connected transformer/s.
5	**Main circuit breaker for GG1 and GG2** (existing generators): **re-use of MCB1 and MCB2** (type VD4 / P 12.12.32 P150 ABB, see 6.5.3 - High-voltage switchgear) from existing switchgear, incorporate into the Power Supply System control and protection system.	Yes
6	**New main circuit breakers MCB3**, **MCB4 for each new generator GG3 and GG4**: a) **use either circuit breaker or pyrobreaker** (Is-limiter) with disconnector/circuit-breaker b) must have **capability to protect flywheel generator/s**	Yes

	against short-circuit c) must have **capability to disconnect the flywheel generator from the HV grid** (e.g. grid3 and grid4) in no-load state	
7	**Junction JU1** – disconnector which can connect 6 kV grid from GG1 and GG2 (not standard operation, use as a back-up if one of generators do not work). Re-use the existing disconnector in ER614 (isolating truck 12 kV, 50/60 Hz, 1250 A nominal current, short-time withstand current: 31.5 kA for 3 seconds).	Yes
8	**Junction JU3** – disconnector between grid 3 and grid 4. Performance requirement: lifetime >30 000 pulses for normal current rating determined from the source (flywheel generator) or from the load (grid).	Yes
9	**Junctions JU2**, **JU4** and **JU5**. JU2 – disconnector between grid 2 and grid 3. JU4 – disconnector between grid 3 and grid 1. JU5 – disconnector between grid 4 and grid 2. If the new additional generators are using 6-phase output, the junctions still have to be included in the delivery. If new additional generators use different output voltage than the existing generators GG1 and GG2, the junctions must be equipped with SW and HW protection, which prevents application of dangerous overvoltage on any load on any grid. E.g. if new generators have higher output voltage than 6 kV, the excitation of new generators will not allow to excite them over 6 kV if any of the junctions JU2, JU4, JU5 are connected. Performance requirement: lifetime >30 000 pulses for normal current rating determined from the source (flywheel generator) or from the load (grid).	Yes
10	Main circuit breakers **MCB1, MCB2, MCB3, MCB4** and junctions **JU1 – JU5** must be **equipped with key interlocks** (safety mechanical interlock) which do not allow accidental connection of incompatible flywheel generators into one grid.	Yes

11	Contactors **EG1CB** and **EG2CB** and fuses for excitation of existing flywheel generators GG1 and GG2: **re-use of existing** (type VSC7/P, rated voltage 7.2 kV, normal current 400 A, see 6.5.3 - High-voltage switchgear) from existing switchgear, incorporate into the Power Supply System control and protection system.	Yes
12	Contactors **EG3CB, EG4CB** and fuses for excitation of new flywheel generators GG3, GG4. **Rated voltage and normal current** will be according to the demands of the generators excitation transformers EG3TR, EG4TR, incorporate into the Power Supply System control and protection system.	Yes
13	Circuit breaker **NBI0CB** for NBI0 – **re-use of existing circuit breaker** (rated voltage 12 kV and normal current 630 A, rated short-time withstand current Ik = 31.5 kA) from existing switchgear, incorporate into the Power Supply System control and protection system.	Yes
14	Circuit breaker **NBI12CB** for NBI12 – **re-use of existing circuit breaker** (rated voltage 12 kV and normal current 630 A, rated short-time withstand current Ik = 31.5 kA) from existing switchgear, incorporate into the Power Supply System control and protection system.	Yes
15	Circuit breaker **NBI3CB** for NBI3 – breaker rated voltage Ur depends on voltage of grid 3 or 4, normal rated current Ir to be selected accordingly to power input of NBI3, which is maximally 6 MVA. Incorporate into the Power Supply System control and protection system.	Yes
16	Circuit breaker **NBI4CB** for NBI4 – breaker rated voltage Ur depends on voltage of grid 3 or 4 , normal rated current to be selected accordingly to power input of NBI4, which is maximally 6 MVA. Incorporate into the Power Supply System control and protection system.	Yes
17	Circuit breaker(s) **PFCB660** for Poloidal Field coils Power Supply PF PS 660 (group of Power Supplies with voltage level 660 VDC). Use CB(s) suitable for existing HV switchgear: rated voltage higher than 6 kV and normal current Ir according to load, rated short-time withstand current higher than 29 kA, e.g. Ik = 31.5 kA. Incorporate into the Power	Yes

	Supply System control and protection system. The rated (nominal, normal) continuous current of the circuit breaker/s PFCB660 must be higher than at least 20 % of the nominal pulsed current of the connected transformer/s. If the PF PS 660 is not used in the Power Supply System (all PF coils Power supplies are powered from PF PS1000), the circuit breaker/s PFCB660 will not be part of the Power Supply System. The circuit breaker(s) PFCB660 must be included in the warranty of the Power Supply System provided by the Contractor. If a circuit breaker from the existing PSS is used, it must be refurbished, tested and included in the warranty. This requirement has the priority over the categorization in the 5.12 - Requirements for the utilization of the existing Power Supply System. Note: if PF PS 660 is utilized and powered from existing flywheel generator/s, it may be necessary to connect transformer/s PFTR to both of these generators to balance the energy drain from the two generators. Then two circuit breakers may be required.	
18	Circuit breaker(s) **PFCB1000** for Poloidal Field coils Power Supply PF PS 1000 (group of Power Supplies with voltage level 1000 VDC). Use CB(s) suitable for existing HV switchgear: rated voltage higher than 6 kV and normal current Ir according to load, rated short-time withstand current higher than 29 kA, e.g. Ik = 31.5 kA. Incorporate into the Power Supply System control and protection system. The rated (nominal, normal) continuous current of the circuit breaker/s PFCB1000 must be higher than at least 20 % of the nominal pulsed current of the connected transformer/s (e.g. if PFTR1000 is composed from two transformers, each with rating 6 kV / 5.4 kA, then the minimal allowed circuit breaker rated continuous current is ≥1080 A). The circuit breaker(s) PFCB1000 must be included in the warranty of the Power Supply System provided by the Contractor. Note: the PF PS 1000 must be supplied from both existing generators GG1 and GG2, see 5.3 - Transformer requirements. At least two circuit breakers may be required if GG1 and GG2 have two independent 6 KV grids and connection is realized on the converter side of	Yes

	the transformers.	
19	Circuit breaker(s) **TFCB** for Toroidal Field Power Supply TF PS. **Rated voltage Ur suitable for new generators** (GG3 and GG4). **Rated current Ir suitable for TFPS**. The rated (nominal, normal) continuous current of the circuit breakers TFCB must be higher than at least 25 % of the nominal pulsed current of the connected transformer/s. The circuit breaker(s) TFCB must be included in the warranty of the Power Supply System provided by the Contractor. Incorporate into the Power Supply System control and protection system.	Yes
20	Circuit breaker **RMP1CB** for RMP PS – **re-use of circuit breaker type VD4 / P** (rated voltage 12 kV and normal current 630 A) from existing HV switchgear, incorporate into the Power Supply System control and protection system.	Yes
21	Circuit breaker **FACB** for FAPS – **re-use of circuit breaker type VD4 / P** (rated voltage 12 kV and normal current 630 A) from existing HV switchgear, incorporate into the Power Supply System control and protection system.	Yes
22	**Reserved space RS in the existing, re-installed HV switchgear area** for additional switchgear field and circuit breaker, which can be incorporated to the Power Supply System in the future. There must be enough space for connection of the switchgear field to the rest of the HV switchgear. The Power Supply System control system must have reserves for the expandability of the switchgear.	1x RS in grid 1 1x RS in grid 2
23	**Reserved space RS in the new HV switchgear area** for additional switchgear field and circuit breaker, which can be incorporated to the Power Supply System in the future. There must be enough space for connection of the switchgear field to the rest of the HV switchgear. The Power Supply System control system must have reserves for the expandability of the switchgear.	2x RS in grid 3 2x RS in grid 4
24	Reserve circuit breakers **RCB1** and **RCB2**. There will be one reserve CB in the grid 1 and one reserve CB in the	1x CB in grid 1

	grid 2 without dedicated load. **Re-use of circuit breaker type VD4 / P** (rated voltage 12 kV and normal current 630 A) from existing HV switchgear, incorporate into the Power Supply System control and protection system.	1x CB in grid 2
25	Reserve circuit breakers **RCB3, RCB4, RCB5** and **RCB6**. There will be two reserve CB in the grid 3 and two reserve CB in the grid 4 without dedicated load. The Contractor will **either re-use of circuit breaker type VD4 / P** (rated voltage 12 kV and normal current 630 A) from existing HV switchgear (if voltage, number of phases and type of switchgear of the grid 3 allow it), **or the Contractor will provide new suitable circuit breaker of similar parameters** (e.g. pulsed power rating 6 MVA or more). Incorporate into the Power Supply System control and protection system.	2x CB in grid 3 2x CB in grid 4
26	The new high voltage switchgear must have ability to ground individual loads (same or similar grounding solution as have Unigear ZS1)	Yes

5.5 Converters for Toroidal Field coils

The requirements for the Converters for toroidal Field coils are valid for the "Power Supply System for COMPASS-U tokamak - Basic Configuration".

Table 5.5.1: Converters for Toroidal Field coils

No.	Name and description of the requirement	Value / description
1	TFPS: **type** of the **converter**	Either 12-pulse thyristor converter or 24 pulse thyristor converter, with real-time controllable current.
2	**TFPS** must be **capable of generating controlled current waveforms into the TF coils**; current waveforms and the TF coils are described in the sections: 6.2.3 - Energy Requirements for COMPASS-U, 6.2.6 - Power Supplies, 6.3.2 - Real life temporal evolution of currents on the COMPASS tokamak.	Yes
3	Toroidal Field Power Supply (TFPS) **nominal pulsed output current**	>199.5 kA DC in flat-top
4	TFPS **effective voltage on TF coil**	Minimal: >460 V DC (at nominal pulsed output current) Maximal: requirement is restricted by transformer/s in section 5.3 - Transformer requirements.
5	TFPS **pulse load characteristics**.	> 1 seconds 100 % flat-top current load + ramp-up and ramp-down, followed by 25 minutes no load (0 %). > 6 seconds 50% flat-top current load + ramp-up and ramp-down, followed by 25 minutes no load (0 %).
6	TFPS **must utilize** (and if necessary extend) **existing thyristor converter rack cabinets** (1RU01 TFPS - 8RU08 TFPS and ARU10, BRU11, CRU12, DRU13, ERU14, see section 6.5.5 - Converters and Accessories, see "Accompanying documentation.zip", specifically in "COMPASS_existing_Power_Supply_system_Technical_d	Yes

	ocumentation.zip"; see 5.12 - Requirements for the utilization of the existing Power Supply System). Note: It is recommended to extend the 13 existing rack cabinets by at least 3 more of the same type, or perform a reconstruction of the existing rack cabinets with exchange of thyristor type.	
7	**Energy deliverable to the TF coils by the TFPS.** This is a requirement for the capability of the toroidal Field Power Supply, transformers and connection (cables) between these parts. Note: This is energy in ohmic losses in the TF coils summed with the TF coils energy in magnetic field at the end of the most demanding TF current flat-top phase. Losses in the damping coils (chokes), Power Supply, transformers and flywheel generator/s are not part of this value.	> 290 MJ
8	**Capability** to **recuperate energy into the flywheel generator/s** (see recuperation requirement in the 5.2 - Requirements for flywheel generators)	Yes
9	**Energy recuperation** requirements	Same value as in the section 5.2 - Requirements for flywheel generators.
10	**Toroidal Field coil** circuit must be **equipped with crowbar with resistor**. The crowbar must be controllable by: i) overvoltage, ii) overcurrent, iii) optical signal from CODAC system (3x), iv) fault signal (optical) from the Power Supply System. The TFPS crowbar must provide redundant signalization both to the CODAC and to the Power Supply System when it is activated.	Yes
11	**Fuse between the TFPS and TFPS crowbar**. In case that there is short-circuit on a part of the TFPS, the fuse must disconnect the section. Note: One of the possible realizations for this requirement is to place fuse (or 2-3 fuses in parallel) at the output of each thyristor 6-pulse module.	Yes
12	**Protection against loss of voltage on transformer** or transformers for Toroidal Field Power Supply. The TF coil current must be redirected into the TFPS crowbar	Yes

	resistor – freewheeling through the TFPS is not allowed. Explanation: If flywheel generator/s are disconnected from the transformer/s TFTR, these transformers stop providing voltage for thyristor Power Supply TFPS. Then the TFPS will be left in status when it is connected in parallel with TFPS crowbar. The current would flow through the TFPS and not through the crowbar, which would thermally overload the TF coils (energy would be dissipated in the TF coils). This situation must be either prevented or protected against by stopping the flow of current in TFPS (= forcing the current into crowbar resistor). This can be achieved e.g. by utilizing disconnector or by discharging commutation capacitor into the TFPS.	
13	**Protection against short-circuit of thyristor/s in TFPS**. The TF coil current must be redirected into the TFPS crowbar resistor – freewheeling through TFPS is not allowed.	Yes
14	TFPS **crowbar power switch and control electronics redundancy**	At least 2x
15	TFPS **crowbar resistance**	2-6 mΩ
16	TF **crowbar resistor capacity** for **dissipated energy**	> 190 MJ
17	TF **crowbar resistor longevity**	> 2000 pulses at 100% current load
18	TF **crowbar reaction time** (from the fault signal to the activation of the switch)	< 5 ms
19	**Maximal allowed ohmic losses** between the TFTR and inlet of the TF coils. Explanation: Includes cables, choke coils (!), busbars. Does not include transformer/s, does not include thyristor losses.	< 10 MJ for 1 second flat-top current ≥199.5 kA, with ramp-up and ramp-down accounted.
20	**Output current measurement and control accuracy** of the Toroidal Field Power Supply (for measurement combined bandwidth ≥ 5 kHz; combined = bandwidth of the sensor combined with the filter of the data acquisition)	Better than 1 % from measured value + 500 A

Toroidal Field Power Supply control		
21	**TFPS output control**	current
22	**TFPS Reaction time** (from request to output reaction)	< 10 ms
23	**Number** of **TFPS firing angle discrete steps** (if not continuous)	>= 150
24	**TFPS control must be unified** for all parts including re-used parts	Yes
25	The **control unit of the TFPS** (including the control of the thyristor gates of the re-used existing thyristor converter rack cabinets 1RU01 TFPS - 8RU08 TFPS and ARU10, BRU11, CRU12, DRU13, ERU14) **must be replaced and a new one must be manufactured** as part of delivery of the Power Supply System.	Yes

5.6 Converters for Poloidal Field coils, capacitor bank and energy dissipator

There are either two different voltage levels for the Power Supplies: 1 kV DC (no-load) and 660 V DC (no load), or the Contractor can choose to utilize only higher voltage level (1 kV, DC, no-load) for all PF coils Power Supplies.

The **Power Supply System includes these components** for powering Poloidal field coils (see general schematics, Figure 4.1.1):

- Poloidal Field coils Power Supplies:

PF coils Power Supplies		
Power Supply name	Minimal nominal pulsed current range [kA]	Operational output voltage [V] (no load)
CS PS1	+/- 50 kA	1000 V (920 V – 1020 V is allowed range)
CS PS2	+/- 50 kA	1000 V (920 V – 1020 V is allowed range)
CS PS3	+/- 50 kA	1000 V (920 V – 1020 V is allowed range)
CS PS4	+/- 50 kA	1000 V (920 V – 1020 V is allowed range)
PF1U PS	+/- 25 kA	660 V +/- 5% or 1000 V (920 V – 1020 V is allowed range)
PF1L PS	+/- 25 kA	1000 V (920 V – 1020 V is allowed range)
PF2U PS	+/- 25 kA	660 V +/- 5% or 1000 V (920 V – 1020 V is allowed range)
PF2L PS	+/- 25 kA	660 V +/- 5% or 1000 V (920 V – 1020 V is allowed range)
PF3U PS	+/- 25 kA	660 V +/- 5% or 1000 V (920 V – 1020 V is allowed range)
PF3L PS	+/- 25 kA	1000 V (920 V – 1020 V is allowed range)
PF4U PS	+/- 30 kA	1000 V (920 V – 1020 V is allowed range)
PF4L PS	+/- 30 kA	1000 V (920 V – 1020 V is allowed range)

- Capacitor bank/banks:
  - Each group of Power Supplies has one common capacitor bank (C1000, C660) shared between the Power Supplies of the voltage group. If only one voltage level (1000 V DC, no load) is used for all PF coils Power Supplies, only one common shared capacitor bank is used (C1000).
  - The capacitor bank/s with full functionality and protections are part of the Basic Configuration. There is an Extended Option "Increase of the capacitor bank(s) energy by +0.5 MJ".
- Energy dissipator/s:
  - Capacitor bank or banks (C1000, C660) do not have capability to store energy returning from the tokamak coils during each tokamak discharge or during fault

condition. Therefore, capacitor bank or banks must be equipped with a device for controlled (and emergency) energy dissipation. This is a combination of the chopper and crowbar (with resistor). The name/names are ED1000 and ED660.

- Rectifier/rectifiers:
  - Capacitor bank or banks (C1000, C660) are supplied from transformer/transformers PFTR1000 and PFTR660 through the voltage rectifier/rectifiers R1000, R660.The rectifier/s are either diode or thyristor type.

The **Extended Option "Increase of the capacitor bank(s) energy by +0.5 MJ" includes**:

a. capacitors
b. protective resistors and their cooling solution
c. Housing (e.g. rack cabinets)
d. installation
e. complete integration into the Power Supply System control system, complete integration into the protection system, including measurement of the local over-voltage on the extended capacitor bank/s
f. commissioning and testing

Table 5.6.1: Converters for Poloidal Field coils

No.	Name and description of the requirement	Value / description
PF coils Power Supplies		
1	Power Supplies **nominal pulsed output current rating range** at nominal switching frequency 1 kHz, PWM switching	CS PS1, CS PS2, CS PS3, CS PS4: more or equal than +/-50 kA PF1U PS, PF1L PS, PF2U PS, PF2L PS, PF3U PS, PF3L PS: more or equal than +/-25 kA PF4U PS, PF4L PS: more or equal than +/-30 kA
2	Power Supplies **nominal output voltage range, no-load**	CS PS1, CS PS2, CS PS3, CS PS4, PF1L PS, PF3L PS, PF4U PS, PF4L PS: +/-1000 V, allowed range from 920V to 1020 V PF1U PS, PF2U PS, PF2L PS, PF3U PS: either +/- 660 V or +/-1000 V, allowed range +/- 5 % or from 920V to 1020 V Note: the Contractor can chose to supply all twelve Power supplies from same voltage level (one transformer/s PFTR1000, only one common capacitor bank C1000, only one

		energy dissipator ED1000)
3	Power Supplies **capability to supply PF coils** – i.e. high inductive, low resistance coils with strong mutual inductances. Self-inductances 2-10 mH, resistances 1.5 mΩ – 70 mΩ. Note: there is upper limit 7 mΩ when the coils are at cryogenic temperature; when the coils are operated at room temperature, the resistance can be up to 70 mΩ. See section “6.3.1.1 - Basic electrical parameters of the PF coils (resistance, self-inductance, turn count) and their assigned Power Supplies” for expected parameters at the cryogenic temperature.	Yes
4	PF coils Power supplies **pulse load characteristics**.	> 2 seconds flat-top 100 % nominal pulsed current load + ramp-up and ramp-down, each 700 ms, followed by 25 minutes no load (0 %). > 4 seconds flat-top 50% of nominal pulsed current load + ramp-up and ramp-down, followed by 25 minutes no load (0 %).
5	**Converters type**	H-bridge with IGBT transistors
6	PF coils Power Supplies must be **capable of generating controlled current waveforms into the PF coils**; current waveforms and the PF coils are described in the sections: 6.2.3 - Energy Requirements for COMPASS-U, 6.2.6 - Power Supplies, 6.3 - Description of the Poloidal Field coils behaviour.	Yes
7	**Maximal energy deliverable to the PF coils by all PF coils Power Supplies**. This is a requirement for the capability of the Power Supplies, capacitor bank/s, energy dissipator/s, transformers and connection (cables) between these parts. Note: This is energy in ohmic losses in PF coils summed with PF coils energy in magnetic field during the top performance tokamak discharge. Losses in the damping coils (chokes), Power Supplies, transformers and flywheel generator/s are not part of this value.	> 80 MJ

8	**Nominal pulsed output current** of the **power transistors** in the Power Supplies	Required to be less than 70 % of “continuous DC collector current” (nominal current) according the power transistor manufacturer datasheet Note: it is not “maximal peak current” or “Repetitive peak collector current”.
9	**Maximal allowed temperature of IGBT and diode junction**, as defined **from Absolute Maximum Ratings** (= Maximum Rated Values), for the purpose of limiting lowest allowed quantity of IGBTs and diodes used in the Power Supplies. This criterion means that the number of IGBTs and diodes connected in each Poloidal Field coil Power Supply will be selected in such a way that it satisfies this criterion. Definition: For the purpose of this criterion: • the junction temperature is calculated for steady state for switching losses 1 kHz (1000 turn on and 1000 turn off in 1 second at nominal pulsed output current and at nominal voltage) summed together with losses calculated for 100 % duty cycle (for both IGBT and diode separately) with nominal pulsed output current in the Power Supplies (e.g. +/- 50 kA for CS PS1); the used parameters must be at relevant temperature and voltage • the calculation uses up to date datasheet information for all parts creating a single IGBT, diode, or half bridge, or other cooling unit • The cooling medium has constant temperature 35°C in the calculation. • The thermal grease maximal allowed specific thermal conductivity is 3 W/(m*K) in calculation. The thermal grease used in construction must have similar or higher value. • For the purpose of this calculation, the derating (variation of distribution of current between individual IGBT or diode modules) 10 % will be assumed Calculation submission: The calculation must be submitted to the Client in symbolic form and with all values, sources of these	< 66 % of Absolute Maximum Rating temperature The value is valid for both transistor and diode! Example: 66% from Absolute Maximum Rating temperature 175 °C is 115.5 °C.

	values, calculation procedure and manufactures application notes or the other information sources relevant to this calculation at latest in the project design phase.	
10	**Maximal allowed temperature of IGBT and diode junction**, as defined **from Maximum temperature under switching conditions**, for the purpose of limiting lowest allowed quantity of IGBTs and diodes used in the Power Supplies. This criterion means that the number of IGBTs and diodes connected in each Poloidal Field coil Power Supply will be selected in such a way that it satisfies this criterion. Definition: For the purpose of this criterion: • the junction temperature is calculated for steady state for switching losses 1 kHz (1000 turn on and 1000 turn off in 1 second at nominal pulsed output current and at nominal voltage) summed together with losses calculated for 100 % duty cycle (for both IGBT and diode separately) with nominal pulsed output current in the Power Supplies (e.g. +/- 50 kA for CS PS1); the used parameters must be at relevant temperature and voltage • the calculation uses up to date datasheet information for all parts creating a single IGBT, diode, or half bridge, or other cooling unit • The cooling medium has constant temperature 35°C in the calculation. • The thermal grease maximal allowed specific thermal conductivity is 3 W/(m*K) in calculation. The thermal grease used in construction must have similar or higher value. • For the purpose of this calculation, the derating (variation of distribution of current between individual IGBT or diode modules) 10 % will be assumed Calculation submission: The calculation must be submitted to the Client in symbolic form and with all values, sources of these values, calculation procedure and manufactures application notes or the other information sources relevant to this calculation at latest in the project design phase.	< 77 % of Maximum temperature under switching conditions The value is valid for both transistor and diode! Example: 77% from Maximum temperature under switching conditions 150 °C is 115.5 °C.

11	**Disconnection** of one **PF coils Power Supply** from the **common capacitor bank** (C1000, C660) for the purpose of tests and maintenance.	Must be disconnectable within < 1 hour of work of one technician (e.g. use disconnector switch or easily accessible dismountable connection).
12	The PF coils Power Supplies must be **capable of working with slew rate of current at least 50 kA/ms**. Note: the worst routinely expected (with exception of failures like short-circuit on leads to PF coils) slew rate is lower than 8 kA/ms.	Yes
13	The PF coils Power Supplies must be equipped with **output filter** (e.g. LF filter or ferrite rings) with **time constant > 5 μs**.	Yes
14	The Poloidal Field coils Power Supplies **protection against plasma disruption induced over-current**. The plasma disruptions are described in the section 6.3.3 - Protection of the Power Supplies against plasma disruptions. The protection can be provided either by the Power Supply capability to withstand the over-current or by including crowbar with non-inductive resistor with triggering from the over-current. If the crowbar with resistor is used, the resistor must be selected in a way, which allows safe discharge of the current from the tokamak coil, ensuring that the coil is not damaged by either overvoltage, overheating or the plasma breakdown on the coil inlets.	Requirement: Protection against current induced from the plasma in 5 ms time, absolute values of possible induced currents are: CS PS1, CS PS2, CS PS3, CS PS4: 40 kA PF1U PS, PF1L PS: 11 kA PF2U PS, PF2L PS: 19 kA PF3U PS, PF3L PS: 15 kA PF4U PS, PF4L PS: 17 kA Protection against overvoltage if necessary.
15	The Poloidal Field coils Power Supplies **protection against plasma disruption induced overvoltage**.	Yes if necessary (i.e. if the Power Supplies have self-inductance large enough to require such protection)
16	The **protection against plasma disruptions must not allow disconnection of the coil from the Power Supply**. Explanation: the overvoltage on the coil would reach up to 30 kV on PF4U if the Power Supply were not	Yes

	connected. This would create an electric arc and would destroy the insulation.	
17	Poloidal Field coils Power Supplies **must be protected** (i.e. must survive without damage) **against:** 1. Overcurrent 2. Overvoltage 3. Overheating 4. **Short-circuit at their output** (e.g. short-circuit on the leads to the PF coils) 5. **Short-circuit failure of one of the transistors in the H-bridge** (in this case the remaining part of the PS must survive without damage, not the already damaged short-circuited transistor).	Yes
PF coils Power Supplies control		
18	**Converter modulation type**	Selectable before tokamak experiment (plasma pulse): 1) Unipolar PWM modulation 2) bipolar PWM modulation 3) bang-bang modulation with dead zone All three options must be available.
19	**Minimal number** of **discrete time steps** in **PWM modulation** in **one modulation period** This means that the minimal number of voltage levels (averaged during modulation period) settable by PWM is given by the requested value (if the PWM has discrete count of settable voltages).	>= 25
20	**Converter control** by	1) current request 2) Average voltage request, averaging time = selectable multiple of modulation period
21	Converter **controller request signal** (current / average voltage) **sampling period**	<= 0.25 ms

22	Converter **controller output signal sampling period**	<= 0.25 ms
23	**Maximal time duration** between **receiving request signal** from tokamak control system CODAC (current / average voltage) and **reaction of modulation state** of individual converter	<= 0.35 ms
24	**Modulation period** Note: nominal pulsed current of the Power supplies is valid for nominal switching frequency 1 kHz and PWM control	For PWM: 2 ms – 0.5 ms settable even during tokamak discharge For bang-bang modulation with dead zone: 1 ms – 0.25 ms
25	**Control cycle synchronization** on external time signal	Yes
26	**Adjustable** and **settable start time** of **control cycle** and **modulation period**	Yes
27	Converter **modulation parameter must be settable** (e.g. modulation index)	Yes
28	**Output current measurement and control accuracy** of the Power Supplies (for measurement combined bandwidth ≥ 5 kHz; combined = bandwidth of the sensor combined with the filter of the data acquisition)	Better than 1 % from a measured value + 100 A
Capacitor bank/s (C1000, C660)		
	The requirements on the Capacitor bank/s (C1000, C660) are valid for both the Basic configuration and Extended Option “Increase of the capacitor bank(s) energy by +0.5 MJ”, unless stated otherwise.	
29	Each group of Power Supplies must have **one common capacitor bank** (C1000, C660) **shared between the Power Supplies of the voltage group**. If only one voltage level (1000 V DC, no load) is used for all PF coils Power Supplies, only one common shared capacitor bank will be used (C1000).	Yes
30	The **capacitor bank** (C1000 or C660) must **allow energy transfer** between the individual PF coils Power Supplies	Yes

	(in one voltage level of Power Supplies).	
31	The **capacitor bank** (C1000 or C660) must have **sufficiently low self-inductance** in order to prevent overvoltage occurrence on the Power Supplies. The requirement includes the occurrence of the plasma disruption, which can induce up to 40 kA in 5 ms into the PF coils Power Supplies, see 6.3.3 - Protection of the Power Supplies against plasma disruptions	Yes
32	**Energy capacity** of the capacitor bank/s. Explanation: For the purpose of the determination of the energy capacity, both the snubber capacitors connected on the individual Power Supplies and the dedicated capacitors of the capacitor bank are calculated together. Snubber capacitors are connected without protective resistor and with very low inductance. Dedicated capacitors have protective resistor and are connected farther from the Power Supplies, inductance of the connection plays a role. Exact capacity of the capacitor bank/s is not provided, because the Power Supplies have allowed tolerance of no-load voltage (e.g. 660 V +/- 5%).	C1000: more than **0.8 MJ** (**> 0.4 MJ** in **Basic configuration**, add another **> 0.4 MJ** in **Extended Option** “Increase of the capacitor bank(s) energy by +0.5 MJ”), for voltage change -20 % from Power Supplies nominal output voltage C660: more than **0.2 MJ** (**> 0.1 MJ** in **Basic configuration**, add another **> 0.1 MJ** in **Extended Option** “Increase of the capacitor bank(s) energy by +0.5 MJ”), for voltage change -20 % from Power Supplies nominal output voltage (in case that four PF coils Power Supplies with required DC voltage 660 V no-load have independent capacitor bank) OR C1000: more than **1.0 MJ** (**> 0.5 MJ** in **Basic configuration**, add another **> 0.5 MJ** in **Extended Option** “Increase of the capacitor bank(s) energy by +0.5 MJ”), for voltage change -20 % from Power Supplies nominal output voltage C660: does not exist (in case that all PF coils Power

		Supplies use DC voltage 1 kV no-load and have common capacitor bank) Example: if Power Supplies connected to the C1000 have nominal output voltage 950 V, then -20% is -190 V and capacitor bank energy capacity is dE = 0.5*C*(950V^2-760V^2)
33	**Expandability** of the capacitor bank/s. The design of the Power Supply System will incorporate the plan for expanding the capacitor bank up to this value. Note: The capacitor bank/s energy capacity in Basic Configuration is minimal needed value. The Extended Option “Increase of the capacitor bank(s) energy by +0.5 MJ” is first expansion of the minimal needed value. Future expansions, which are not part of this public tender, are envisaged and enabled by this requirement.	C1000: expandable up to 2 MJ C660: expandable up to 0.4 MJ The energy capacity is measured for voltage change - 20 % from Power Supplies nominal output voltage (dE=0.5*C*U^2*(1^2-0.8^2))
34	Required **type of the capacitors** in the capacitor bank/s	Self-healing Halogen free Specifically intended for DC-interlink usage (e.g. Metalized polypropylene)
35	Required **rated / nominal DC voltage of the capacitors** in the capacitor bank/s Note: the capacitor banks will be operated with routine excursions above Power Supplies nominal output voltage, because the energy dissipator should activate above no-load nominal output voltage. For example, the C100 should routinely experience voltage excursions to 1200 V.	More than 110 % of Power Supplies nominal output voltage E.g. if the connected Power Supplies have nominal no-load voltage 950 VDC, the rated voltage of the capacitors must be higher than 1045 VDC.
36	Required **test / absolute maximum / peak DC voltage** of the **capacitors** in the capacitor bank/s	More than 140 % of Power Supplies nominal output voltage E.g. if the connected Power Supplies have nominal no-load voltage 950 VDC, the test voltage of the capacitors must

		be higher than 1330 VDC.
37	Required **Imax, periodic / peak / absolute maximum current** of the **capacitors** in the capacitor bank/s	C1000: > 3.0 MA (> 1.5 MA in Basic configuration and > 1.5 MA in Extended Option “Increase of the capacitor bank(s) energy by +0.5 MJ”) C660: > 1.0 MA (> 0.5 MA in Basic configuration and > 0.5 MA in Extended Option “Increase of the capacitor bank(s) energy by +0.5 MJ”) (in case that four PF coils Power Supplies with required DC voltage 660 V no-load have independent capacitor bank) OR C1000: > 4 MA (> 2 MA in Basic configuration and > 2 MA in Extended Option “Increase of the capacitor bank(s) energy by +0.5 MJ”) C660: does not exist (in case that all PF coils Power Supplies use DC voltage 1 kV no-load and have common capacitor bank) Note: the required values for the Basic Configuration are ~5x higher than the nominal pulsed current rating of the connected Power Supplies.
38	Capacitor bank/s must be equipped with **protective resistors or fuses** in series with capacitors (both in the Basic Configuration and in the Extended Option “Increase of the capacitor bank(s) energy by +0.5 MJ”). The purpose of the protection resistors or fuses is to prevent cascade failure caused by damaging current drain from the neighbouring capacitors in case that one capacitor suffers short-circuit failure. The protective resistors must have inductance low enough to allow operation of the capacitor bank in according requirements and expected conditions of the	Yes

	Power Supply System. The protective resistors can be realized as busbars or cables if technically feasible. The snubber capacitors in the individual Power Supplies are not required to be equipped with the protective resistors.	
39	The **maximal allowed ohmic losses in the protective resistors** or fuses for nominal pulsed current of all connected Power Supplies flowing through the protective resistors. Example: if all 12 Power Supplies are connected to the C1000, the combined nominal pulsed current is > 410 kA, then the maximal allowed resistance of all protective resistors in Basic Configuration only is 2MW/(410kA)^2 = 1.19×10^{-5} Ω; if 100 capacitors in parallel are used, one protective resistor must have resistance lower than 1.19 mΩ. If the Extended Option “Increase of the capacitor bank(s) energy by +0.5 MJ” is added, then the maximal allowed resistance of all protective resistors is 1MW/(410kA)^2 = 5.95×10^{-6} Ω; if 200 capacitors in parallel are used, one protective resistor must still have resistance lower than 1.19 mΩ.	**C1000**: less than **0.75 MW for the entire PSS** (Basic Configuration with Extended Option “Increase of the capacitor bank(s) energy by +0.5 MJ”), less than **1.5 MW in Basic Configuration only** (i.e. without Extended Option “Increase of the capacitor bank(s) energy by +0.5 MJ”) **C660**: less than **0.25 MW for the entire PSS** (Basic Configuration with Extended Option “Increase of the capacitor bank(s) energy by +0.5 MJ”), less than **0.5 MW in Basic Configuration only** (i.e. without Extended Option “Increase of the capacitor bank(s) energy by +0.5 MJ”) (in case that four PF coils Power Supplies with required DC voltage 660 V no-load have independent capacitor bank) OR **C1000**: less than **1 MW for the entire PSS** (Basic Configuration with Extended Option “Increase of the capacitor bank(s) energy by +0.5 MJ”), less than **2 MW in Basic Configuration only** (i.e. without Extended Option “Increase of the capacitor bank(s) energy by +0.5 MJ”) C660: does not exist (in case that all PF coils Power

		Supplies use DC voltage 1 kV no-load and have common capacitor bank)
40	The **minimal allowed resistance** of the **protective resistors** is determined in such a way that short-circuit current flowing through the protective resistor is limited on less than: • 20 % of the Imax, periodic / peak / absolute maximum current of the capacitor bank for the Basic Configuration only (i.e. without Extended Option “Increase of the capacitor bank(s) energy by +0.5 MJ”) • 10 % of the Imax, periodic / peak / absolute maximum current of the capacitor bank for the entire Power Supply System, i.e. Basic Configuration with Extended Option “Increase of the capacitor bank(s) energy by +0.5 MJ” included Example: If 100 capacitors, each with peak current 60 kA, are used for the Basic Configuration, then the peak current of the bank is 6 MA; 20 % from 6 MA is 1200 kA; for 950 VDC nominal output voltage, the resistance of one protective resistor must be higher than 950 V/1200 kA = 0.79 mΩ. If the Extended Option is added, then 10 % from 12 MA is still 1200 kA, therefore, the threshold resistance is same.	Yes
41	The **protective resistors repetition time** for full power tokamak pulse. Note: this criterion limits temperature rise of the protective resistors, together with their cooling.	less than 25 minutes
42	The capacitor bank/s must **not be disconnected** from the PF coils Power Supplies **during tokamak operation** (required for Power Supplies protection against disruptions).	Yes
43	The **energy dissipator/s** (or part of the energy dissipator) **will be activated** in order to discharge the capacitor bank/s in case that signal is sent to the Power Supply System from **Personnel Interlock** (unauthorized personnel in the experimental area)	Yes
44	The **energy dissipator/s will be activated** in order to discharge and protect the capacitor bank/s in case that	Yes

	overcurrent is detected in the capacitor bank/s (i.e. in case of short-circuit failure)	
Energy dissipator/s (ED1000, ED660)		
45	Each voltage group of Power Supplies must be **equipped with Energy Dissipator** (ED1000, ED660) - device capable of controlled and emergency dissipation of energy from capacitor bank during tokamak pulse. If only one voltage level (1000 V DC, no load) is used for all PF coils Power Supplies, only one energy dissipator will be used (ED1000).	Yes
46	Energy dissipator/s must **provide controlled and emergency overvoltage protection** for the capacitor bank and Power Supplies. The controlled protection must be provided by IGBT transistor chopper, emergency protection by thyristor switch.	Yes
47	Energy dissipator/s must be **capable of dissipating energy returning from the Poloidal Field coils** to the capacitor bank.	Yes
48	Energy dissipator/s **chopper switch** (controlled) **current rating**	**ED1000**: more than **80 kA** for long pulse (at least **1 second**) More than **200 kA** for short pulse (at least **40 ms long**) **ED660**: more than **20 kA** for long pulse (at least **1 second**) More than **50 kA** for short pulse (at least **40 ms long**) (in case that four PF coils Power Supplies with required DC voltage 660 V no-load have independent capacitor bank) OR **ED1000**: more than **100 kA** for long pulse (at least **1 second**) More than **250 kA** for short

		pulse (at least **40 ms long**) ED660: does not exist (in case that all PF coils Power Supplies use DC voltage 1 kV no-load and have common capacitor bank) This short pulse (> 40 ms) is repetitive – it is necessary for plasma breakdown in every tokamak pulse
49	Energy dissipator **thyristor switch** (emergency) **current rating**	ED1000: more than **310 kA** ED660: more than **100 kA** (in case that four PF coils Power Supplies with required DC voltage 660 V no-load have independent capacitor bank) OR ED1000: more than **410 kA** ED660: does not exist (in case that all PF coils Power Supplies use DC voltage 1 kV no-load and have common capacitor bank)
50	Energy dissipator/s **reaction time** on control signal	< 100 µs
51	Energy dissipator/s must **protect against local overvoltage** (transient overvoltage on part of the capacitor bank or on one Power supply). Explanation: This requirement means that there must be local overvoltage measurement on individual Power Supplies and parts of the capacitor bank/s. The local overvoltage measurement must be capable of directly turning the energy dissipator (or its part) on. This requirement also means that the energy dissipator/s must have low self-inductance and low inductance of connection to the individual Power Supplies – this anticipates that the energy dissipator is	Yes

	modular and it is distributed close to the Power Supplies.	
52	Energy dissipator/s must be **controllable in parts** (per partes). This means that it must be possible to switch on only part of the energy dissipator/s.	Yes
53	Energy dissipator **control logic** must attempt to **minimize the time when it dissipates energy useful for the PF coils** (e.g. if energy is flowing to the coils from flywheel generator, the energy dissipator should not be activated); and it must dissipate energy from coil that is impossible to be safely stored in the capacitor bank	Yes
54	Energy dissipator/s **operational voltage**	More than 120 % of Power Supplies nominal output voltage E.g. if the connected Power Supplies have nominal no-load voltage 950 VDC, the operational voltage of the energy dissipator must be higher than 1140 VDC.
55	Energy dissipator/s **absolute maximum voltage**	More than 140 % of Power Supplies nominal output voltage E.g. if the connected Power Supplies have nominal no-load voltage 950 VDC, the absolute maximum voltage of the energy dissipator must be higher than 1330 VDC.
56	Energy dissipator/s **capability to dissipate energy**. This requirement limits the minimal mass of the resistors used in the energy dissipator/s construction. Note: The PF coils can store up to 40 MJ of energy in magnetic field. Depending on the current waveforms, this energy will be dissipated in the energy dissipator/s during every tokamak pulse, followed by repeated rise of the current in the PF coils and another period of energy dissipation. Therefore, the energy dissipator must be capable of routine operation while dissipating the energy.	ED1000: more than 50 MJ ED660: more than 10 MJ (in case that four PF coils Power Supplies with required DC voltage 660 V no-load have independent capacitor bank) OR ED1000: more than 60 MJ ED660: does not exist

		(in case that all PF coils Power Supplies use DC voltage 1 kV no-load and have common capacitor bank)
57	The energy dissipator/s resistors **repetition time** when loaded with full energy dissipation capability. Note: this criterion limits temperature rise of the resistors, and creates requirement on their cooling.	Less than 25 minutes
58	**Maximal allowed temperature of chopper switch IGBT junction**, as defined from **Absolute Maximum Ratings** (= Maximum Rated Values), for the purpose of limiting lowest allowed quantity of IGBTs used in the chopper. This criterion means that the number of IGBTs connected in chopper switch will be selected in such a way that it satisfies this criterion. Definition: For the purpose of this criterion: • the junction temperature is calculated for steady state for switching losses 500 Hz (500 turn on and 500 turn off in 1 second at long pulse current in the chopper and at nominal voltage) summed together with losses calculated for 100 % duty cycle with long pulse current in the chopper (e.g. 100 kA if only ED1000 is used); the used parameters must be at relevant temperature and voltage • the calculation uses up to date datasheet information for all parts creating a single IGBT or half bridge, or other cooling unit • The cooling medium has constant temperature 35°C in the calculation. • The thermal grease maximal allowed specific thermal conductivity is 3 W/(m*K) in calculation. The thermal grease used in construction must have similar or higher value. • For the purpose of this calculation, the derating (variation of distribution of current between individual IGBT modules) 10 % will be assumed Calculation submission: The calculation must be submitted to the Client in symbolic form and with all values, sources of these values, calculation procedure and manufactures application notes or the other information sources	< 66 % of Absolute Maximum Rating temperature Example: 66% from Absolute Maximum Rating temperature 175 °C is 115.5 °C.

	relevant to this calculation at latest in the project design phase.	
59	**Maximal allowed temperature of chopper switch IGBT junction**, as defined from **Maximum temperature under switching conditions**, for the purpose of limiting lowest allowed quantity of IGBTs used in the chopper. This criterion means that the number of IGBTs connected in chopper switch will be selected in such a way that it satisfies this criterion. Definition: For the purpose of this criterion: • the junction temperature is calculated for steady state for switching losses 500 Hz (500 turn on and 500 turn off in 1 second at long pulse current in the chopper and at nominal voltage) summed together with losses calculated for 100 % duty cycle with long pulse current in the chopper (e.g. 100 kA if only ED1000 is used); the used parameters must be at relevant temperature and voltage • the calculation uses up to date datasheet information for all parts creating a single IGBT or half bridge, or other cooling unit • The cooling medium has constant temperature 35°C in the calculation. • The thermal grease maximal allowed specific thermal conductivity is 3 W/(m*K) in calculation. The thermal grease used in construction must have similar or higher value. • For the purpose of this calculation, the derating (variation of distribution of current between individual IGBT modules) 10 % will be assumed Calculation submission: The calculation must be submitted to the Client in symbolic form and with all values, sources of these values, calculation procedure and manufactures application notes or the other information sources relevant to this calculation at latest in the project design phase.	< 77 % of Maximum temperature under switching conditions Example: 77% from Maximum temperature under switching conditions 150 °C is 115.5 °C.
60	Short pulse energy dissipator/s **chopper switch current rating** (e.g. 250 kA if only ED1000 is used) must be lower than combined Continuous DC collector current (IC,nominal) of the used IGBT transistors	Yes

	Example: If short pulse (e.g. at least 40 ms) current rating is 250 kA, and the Continuous current rating of one transistor is 3600 A, then at least 70 (70x3.6 kA = 252 kA) transistor modules must be used.	
General requirements		
61	**Maximal allowed ohmic losses** of the parts between the transformer/s and the capacitor bank/s (cables, choke coils, busbars …). Maximal allowed ohmic losses are calculated for the PFTR transformer/s nominal pulsed current (effective = RMS) on converter side (as allowed in these technical requirements).	ED1000: < 1.5 MW ED660: < 0.5 MW (in case that four PF coils Power Supplies with required DC voltage 660 V no-load have independent capacitor bank) OR ED1000: < 2 MW ED660: does not exist (in case that all PF coils Power Supplies use DC voltage 1 kV no-load and have common capacitor bank)
62	**Maximal allowed resistance** between the Power Supplies and the PF coils (cables, choke coils, busbars)	CS PS1, CS PS2, CS PS3, CS PS4: less than 0.15 mΩ (each) PF1U PS, PF1L PS, PF2U PS, PF2L PS, PF3U PS, PF3L PS: less than 0.25 mΩ (each) PF4U PS, PF4L PS: less than 0.3 mΩ (each)
63	**Longevity** of Poloidal Field coils Power supplies, rectifier/s, capacitor bank/s, energy dissipator/s, including resistors and drivers	> 30 000 tokamak pulses at full load (1 kHz switching of the connected Power Supplies, > 2 seconds flat-top 100 % nominal pulsed current load + ramp-up and ramp-down, each 700 ms, followed by 25 minutes no load (0 %)).
64	**Rectifier/s type** (R1000, R660, see Figure 4.1.1) Explanation: all of the transformers used in the PFTR1000 or PFTR660 must be three-winding	12-pulse (or higher number of pulses) diode or thyristor rectifier

	transformer supplying 12-pulse rectifier	
65	**Expandability** of the number of converters for Poloidal Field coils. The design of the Power Supply System will incorporate the plan for expanding the number of converters for Poloidal Field coils by two Power Supplies with operational output voltage 1 kV and nominal pulsed current range +/- 50 kA. Note: The two additional converters are not part of the Power Supply System delivery (or this tender)	Yes

5.7 Additional heating systems and other loads

Table 5.7.1: Additional heating systems and other loads

No.	Name and description of the requirement	Value / description
1	**Minimal reserved input power** and **minimal reserved energy** of the Power Supply System for additional heating systems and other loads which are not PF or TF converters or excitation for generators	Power: more than 25 MW Power in Basic Configuration (i.e. without 2^{nd} new flywheel generator) : more than 15 MW Energy: see section 5.1 - General requirements
2	**Reserved input power** and **energy** for additional heating and other loads provided from the **existing flywheel generators** GG1 and GG2 (i.e. NBI0, NBI12, RMP1, FACB, RCB1, RCB2, RS …).	The maximal power drain of the devices is up to 10 MW, utilization 50 %, therefore, the reserved input power is 5 MW. The maximal energy drain from the devices is up to 10 MJ.
3	**Reserved input power** and **energy** for additional heating and other loads provided from the **new flywheel generators** GG3 and GG4 (i.e. NBI3, NBI4, RCB3, RCB4, RS …).	More than 20 MW is required (>10 MW in Basic Configuration) More than 40 MJ is required (>20 MJ in Basic Configuration) Note: for existing and future planned devices
4	Circuit breakers in HV switchgear for additional heating systems and other loads (e.g. RMP PS, FAPS …) are specified in chap. 5.4 - HV switchgear	
5	Additional heating systems are not part of the delivery of the Power Supply System. The transformers of the additional heating systems are not part of the delivery of the Power Supply System (see Figure 4.1.1).	
6	The **existing transformers** NBI12TTR, RMP1TR and FATR must be **installed** and their **protection included into the control system** of the Power Supply System (see Figure 4.1.1). This is part of the delivery of the Power Supply	Yes

	System.	

5.8 Control system requirements

The **control system of the Power Supplies System (PSS) is part of the delivery and performs these tasks and purposes**:

1) Control of the Power Supply System
2) Setting of the Power Supply System parameters
3) Monitoring of the Power Supply System
4) Storage of all measurements, operational states, errors - warning and faults logs, settings and access logs (for limited time)
5) Communication with external systems (systems that are not part of Power Supply System)
6) Communication with responsible personnel (graphical user interface, e-mail notice)
7) Personnel safety - dangerous conditions or situations caused by Power Supply System or Power Supply System operation or faults must be safely handled
8) Power Supply System safety – prevents damage or faults within Power Supply System

The **most important features of the PSS control system** are:

1) The control system must block commands and setting parameters, which compromise personnel safety, which can damage any part of the Power Supply System or which are out of the defined limits.
2) The PSS control system must ensure safe turn-off of the whole Power Supply System in the case of Power Supply System failures or power outage.
3) The PSS control system must allow for unambiguous identification of the fault causes in the case of Power Supply System failures.
4) The PSS control system must allow access to all stored information (settings, measurements, logs …) in standardized way (file format, program access …).
5) The graphical user interface must indicate state of Power Supply System, allow set parameters of Power Supply System, inform about warnings, errors and faults and allow access to all measurements.

The tokamak main control system (not part of the delivery, to be built and operated by the Client) is named CODAC – Control, Data Acquisition and Communication system. The CODAC communicates with individual subsystems of the tokamak, including PSS control system. The tokamak Machine Protection and Personnel Interlock systems are responsible for protection of the tokamak and personnel, respectively.

The communication between tokamak control systems (CODAC, Machine Protection, and Personnel Interlock) together denoted as TCS and PSS control system can be divided into **three different categories**.

The first category is **slow communication** used for transfer setting, state, pre-discharge and post-discharge check, all operational parameters and measurements, and all kind of faults and warnings.

The second category is **real time communication** used for real-time control of all Power Supplies connected to the tokamak. The TCS is periodically sending request (typically on required output current), calculated in the TCS feedback loop, to all Power Supplies that should be realized immediately. The TCS is simultaneously receiving information about basic Power Supplies status (power supply is OK or not, the request was transferred correctly or not, the request is valid or not, error and state code) and preferably measurement of the Power Supplies outputs (current, voltage). The latencies and time delays are important for the real-time communication, because these latencies are part of the control feedback loop of the tokamak COMPASS-U. Therefore, this communication must be low latency communication and the Power Supplies must have as short as possible response time on request (time from the moment when the request has been sent to the start of the Power Supply output reaction on request). The existing COMPASS tokamak uses control cycle 0.5 ms for “slow” Power Supplies control and 0.05 ms for “fast” Power Supplies control. The target control cycle periods for COMPASS-U are shorter. The communication protocol will be specified and agreed in cooperation with the Client.

The third category are **optical interlock signals** in both directions (from and to tokamak control systems) for personnel safety, machine safety and critical Power Supply System checks and faults based on the detailed design of the Power Supply System and risks analysis. This interlock must carry information that allow safe existence (operation, maintenance …) of the Power Supply System. The type of interlock, exact function and integration to TCS will be specified and agreed in cooperation with the Client.

The individual Power Supplies must have synchronisation to common clock and they must provide internal clock output and external clock input with indication of used clock. The internal control cycles of the Power Supplies must allow phasing with respect to common time and allow external measurement of the actual phase.

The communication interfaces, data formats, list of measured channels and signals, precision of measurements and sampling frequency, data storage requirements, safety management and exact behaviour of PSS control system depends on exact design of Power Supply System, therefore exact definition of these will be specified and agreed in cooperation with the Client.

The PSS control system is dividable to modules - functional unit (e.g. flywheel generators, capacitor bank, energy dissipator, switchgears, Power Supplies …). This division and some hierarchy of control is assumed in the following table of requirements. The PSS control system can have different structure, but with equivalent functionality.

The **PSS control system** in its entirety **is part of the Basic Configuration**, **including the capability to control and protect the Extended Options** “Second new flywheel generator and its auxiliary systems” and “Increase of the capacitor bank(s) energy by +0.5 MJ”. The control system of the existing Power Supply System will be completely replaced as a part of the delivery.

Table 5.8.1: Control system requirements

No.	Name and description of the requirement	Value / description
1	The PSS control system (incl. interface) actively **blocks commands, which are unsafe for the Power Supply System,** which can damage any part on Power Supply System, which set parameters dangerous for any part of the PSS, which are out of defined limit or which compromise personnel safety. The plasma breakdown (nearly all PF coils Power	Yes

	supplies activated at full power, exceeding long pulse capability of the energy dissipator) must be allowed	
2	New control system and interface have to **contain all parts of new and existing Power Supply System**. (Reference in the existing control interface of the tokamak COMPASS).	Yes
3	The **Power Supply System** must **cooperate** and be **connectable** to systems that **control safety (Machine Protection, Personnel Interlock), TCS and systems for cooling.**	Yes
4	**Software** of the control, diagnostic and monitoring system must be **modular and extendable**, it must be possible to add and update of additional functions according to requests for tokamak operation. Example: the architecture of the control system SW should for example allow adding another flywheel generator (in excess to the two new generators required in the PSS), transformers, circuit breakers in the switchgear and Power Supplies. The architecture must allow modular addition of SW protections.	Yes
5	The **errors or malfunctions** in one or several modules (here functional units) must **not affect functionality of the PSS control system, monitoring system and user interface** for the other modules. (e.g. if status of the TFPS is not accessible than the status of capacitor bank or generators… must be visible in the user interface, monitored and controlled)	Yes
6	**Modules of the control system** have to enable and ensure: a) the **safe operation and functioning of technological protections** and **interlocks**, including links between blocks, b) **control hierarchy**: local control of functional units, passing the proceedings to a higher level, c) **monitoring** of **control commands**. d) **transfer of control** to a superior level (central system)	Yes
7	The Contractor will provide **source codes** of actual used version of control and interface software with **list of**	Yes

	dependencies and **compilation manual** (if compiled language is used) and **deployment manual**, so that we will be able to maintain whole system by ourselves, at these time points: 1. When the Site Acceptance Tests are started. 2. Between the successful completion of all of the SATs and signing of the Final Acceptance Protocol. 3. When the warranty period ends. The source codes must be in the programming language in which the program was written by the programmer (not translated to).	
8	**Phasing** of P**ower Supplies control cycles** The internal control cycles of the individual Power Supplies must allow phasing with respect to PSS common time and allow external measurement of the actual phase. Note: the purpose of this requirement is that synchronous switching of the PFPS (IGBT transistor switches) would lead to un-optimized currents into the capacitor bank/s and un-optimized use of the energy dissipator/s.	Yes
9	**Synchronization** of the Power Supply System **control system date and time**.	Yes
10	The PSS control system must store all measurements, operational states, errors - warning and faults logs, settings and access logs, preferably in database. The stored information must contain timestamps. The information must be stored for the last 2000 pulses. Continuous data (have sense also in stand-by state, e.g. flywheel rotation speed) can be loosely compressed (e.g. decimated) after 10 days.	Yes
11	**Critical parameters** for safe operation are **monitored and stored**.	Yes
12	The PSS control system must monitor and allow access to statistical parameters of PSS usage (Power Supplies, generators, capacitor bank, energy dissipator, crowbars … **diagnostic, lifetime** and **performance statistic records**	Yes

	…). The PSS control system must contain maintenance plan with ranges (e.g. check cooling liquid each 9 – 12 months) The PSS control system warns in advance if maintenance is required (warning is based on maintenance criteria e.g. PSS usage statistic).	
13	All information and data (e.g. measurements, operational states, settings, logs …) stored by PSS control system must be accessible in standardized way (file format, data coding, names …) with program access. The access to data must not have influence on PSS operation. The access must be possible anytime. It must be possible to export data out of the system in standard data format.	Yes
14	Setting of all parameters and reference waveforms must be available as an output dataset so that they can be processed (stored) by the TCS. The output dataset format must be compatible with PSS control system (So the dataset can be used for PSS setting)	Yes
15	Setting of all parameters and reference waveforms for Power Supply System must be possible: a) from PSS control system graphical user interface b) by reading the setting used in the previous discharge – load from the database c) by setting from TCS d) by selecting from predefined set of setting	Yes
16	**Minimal list of used signals** C1. presence of input power grid/s, C2. state and power of backup devices (e.g. UPS), C3. all motors actual power consumption, C4. all motors rotation speed, C5. all flywheels rotation speed, C6. all flywheels lubrication state or flow, C7. all flywheels emergency braking status, C8. all flywheels braking power, C9. all flywheels vibration, C10. all flywheels torque, C11. all generators temperatures(e.g. windings, bearings, oil …) , C12. all generators cooling media temperature, C13. all generators excitation current,	Yes

	C14. all generators output voltages, C15. all generators outputs currents, C16. state of all switching elements (circuit breakers, junctions, ...), C17. TFPS input voltages, C18. TFPS modules output currents, C19. TFPS output current, C20. TFPS output voltage, C21. TFPS crowbar current, C22. TFPS crowbar voltage, C23. TFPS crowbar resistor temperature, C24. TFPS temperature (one sensor in each TFPS module), C25. temperature of TFPS cooling media (water or air …), C26. flow of TFPF cooling media, C27. PFPS input voltages, C28. rectifiers currents, C29. capacitor bank voltages (places will be determined during project phase), C30. capacitor bank(s) temperature on several critical places (to be determined during the realization), C31. energy dissipator(s) current (multiple places monitoring parallel currents in the energy dissipator), C32. energy dissipator(s) voltage (multiple critical places), C33. energy dissipator(s) control signal(s) (both from transistor and thyristor switches; purpose is to know behaviour of the dissipator during the tokamak pulse), C34. all PF power supplies input current, C35. all PF power supplies output current, C36. all PF power supplies output voltage, C37. all PF power supplies temperatures, C38. temperature of PF power supplies cooling media, C39. flow of PF power supplies cooling media, C40. indication of access to areas with restricted access, C41. indication of ongoing maintenance, C42. indication of ongoing tests (tests of power supply subsystems), C43. ready for tokamak pulse signal, C44. general enable signal, C45. general stop signal, C46. set PSS to safe state, C47. power supplies output (typically current) (real-	

	time) for all power supplies, C48. power supplies state (real-time) for all power supplies, C49. error signal (real-time) for all power supplies, C50. error signal (real-time) for whole Power Supply System, C51. flywheels spin-up signal (to spin up after tokamak pulse), C52. flywheels emergency break signal, C53. error signals for all subsystems, C54. alert signals in case of fire or another hazardous situation The main purpose for existence of the minimal list of the signals is to **ensure monitoring of PSS**, detection of nonstandard behaviour and **unambiguous identification of the fault causes** (the possibility of the post-mortem analysis of the data is required). Therefore, measurement is required for signals that can be measured by common measurement instruments (e.g. voltages …). The precision of measurements must be high enough to fulfill the main purpose. Signals that are produced by measurements are referred as measurements.	
17	**Logical optical interlock signals** in both directions (from and to Tokamak Control Systems) for personnel safety, machine safety and critical Power Supply System checks and faults. Examples of usage (to be specified during realization of the PSS delivery): Direction TCS – PSS control: 1. Intrusion to experimental area: unauthorized access of personnel into experimental area; stop currents and discharge capacitors connected with the experimental area. 2. Freewheel currents: set all PF coils Power Supplies output to freewheeling (zero voltage applied) 3. Terminate currents: set Power Supplies output to 0 amps	At least **six signals** from PSS control and at least **6 signals** to PSS control are required.

	4. Total stop: set Power Supplies output to 0 amps, turn off all circuit breakers, activate TF crowbar … 5. … Direction PSS control – TCS: 1. HV switchgear turned on (circuit breakers connected, flywheel generators spinning …) 2. Experimental area is in dangerous state (e.g. capacitor bank/s are charged) 3. Total stop activated 4. …	
Interface with Tokamak Control Systems (CODAC, Machine Protection, Personnel Interlock)		
18	Error propagation delays must be as short as necessary for protection of personnel safety and PSS with all connected systems. The reserves for delays in TCS must be included (TCS must have time for correct reaction on error). The errors that are not serious from safety point of view must be also propagated without unnecessary delays. Therefore, the TCS can arrange safe operation (not emergency turn-off) in case of limited functionality of PSS. (e.g.: If cooling circuit stops working and if the cooling system is still capable of cooling then it is not necessary to stop pulse by emergency stop. However, the error of cooling must be propagated without delays in order to properly react on error before the next pulse and prevent possibly serious situation.)	Yes
19	It will be possible **set the generators spin-up sequence in the user interface** between tokamak pulses and start this sequence by command from TCS Note: After the tokamak pulse, the generators have lower rotation speed. It is not necessary to spin-up them immediately after tokamak pulse. It is beneficial to spin-up them on command from TCS approx. 3 min before tokamak pulse. In addition, it is not necessary to spin-up generator to maximal rotation speed for each tokamak pulse.	Yes

20	**Synchronization** on **external clock**, external clock input, indication of external clock use Backup for the case of loss of the external clock: presence of the internal clock.	Yes
21	**Internal clock output**, which allows connection of the e.g. oscilloscope or data acquisition.	Yes
22	**Real-time communication link** dedicated for real-time Power Supplies control, capable to transfer a request to each Power Supply and response from each Power Supply every **0.25 ms** or faster.	Yes
23	The PSS control system must **allow testing of SW** and testing of **cooperation with the TCS system**, and **protections**. Example: Power Supplies must be capable to simulate correct function and simulate faults in order to test real-time communication with TCS without real tokamak pulse.	Yes
24	The Power Supply System must **allow tests of protections**, including HW at safe conditions (small voltages, small currents)	Yes
25	The PSS control system must be capable and allow to test each subsystem (functional unit of PSS), monitor and diagnose their operation	Yes
Safety and protection		
26	**Fault conditions** are **handled in safe way**, **logged** (with timestamps and all measurements and states shortly before and after the fault) and propagated (displayed) to proper place (and person).	Yes
27	In case of **fault** where several options of safe handling are possible, than the **selected variant must consider safety of connected devices** (e.g. tokamak) and **personnel** that can be present in accessible locations influenced by fault.	Yes

28	The control system must have **protections**, which in the case of errors of the Power Supply Systems **safely stop discharge (PSS operation)** and turn the Power Supply System to the safe regime.	Yes
29	**Detection** and **warning** about **isolating and grounding state.**	Yes
30	The Power Supply System must have **self-test procedure** that is **capable to diagnose faults** and **nonstandard behaviour** of the system and report them. Self-test must be run on every flywheel generator/s turn-on. It must be possible to run the self-test on command from the user interface.	Yes
31	PSS control system must ensure transition to safe state of subsystem in case of lost communication with the superior subsystem and appropriate state of all others linked subsystems.	Yes
User interface		
32	The monitoring and graphical user interface must **allow verification of the proper operation and setting** of the entire Power Supply System. In the case of system failures, it must allow for **unambiguous identification of the fault causes**.	Yes
33	The monitoring and graphical user interface must **indicate** clearly and evidently **state of the Power Supply System: both operational and safety state**.	Yes
34	There will be **two places** from where will be **possible to control** the Power Supply System. First is a **control room** of the tokamak COMPASS/COMPASS-U, second will be in suitable area in **switchgear room**. The remote access within the Client site must also be available. Possible solution: The PSS could be controlled from one (or more) server(s), with two remote access workstations placed in the control room and in the switchgear and remote access within the Client site. In this case, the two remote access workstations are part of the delivery.	Yes

35	Monitoring and user interface must provide **reading from all redundant sensors and must provide warning that they do not match each other.**	Yes
36	**Generators excitation** must be **monitored** and **reference waveform and parameters** for excitation controllers must be **editable from user interface**.	Yes
37	Handling of the **user rights**. Not everyone has access to every setting; changes in setting are logged.	Yes

5.9 Safety and Protection requirements

The requirements in the section 5.9 - Safety and Protection requirements are valid for both Basic configuration and for all (three) Extended Options, both separately and together (i.e. when forming the entire PSS).

Table 5.9.1: Safety and Protection requirements

No.	Name and description of the requirement	Value / description
1	The Power Supply System must **ensure safe operation regarding personnel safety**. It must minimize chance and handle dangerous situations and faults.	Yes
2	The **PSS must fully protect itself** and connected systems in case of faults. This includes protection against incorrect use or commands or settings. The Power Supply System must be **fully self-reliant** (i.e. not dependent on other systems) **for the purpose of the self-protection**.	Yes
3	The Power Supply System **control, monitoring system** and all other systems that are necessary for safe turn-off of Power Supply System (e.g. flywheel generators lubrication units, PFPS drivers, energy dissipator, crowbars) must be **protected against power outage**. The UPS must ensure continuous operation of protected system without reset or any others negative effect caused by power interruption till safe turn-off of Power Supply System without loss of control or monitoring. Example: UPS and backup connection to another grid is used together to provide this protection in the existing PSS.	Yes Minimal time for operation during power outage >=30 min
4	The **UPS** (uninterruptible power supply) **must be based on** the technology using a **chemical battery**. Neither diesel generator nor capacitor nor rotary UPS is allowed.	Yes
5	The devices will **comply with valid European standards** and **installation regulations**, including how to protect against dangerous touch voltage.	Yes
6	The **areas with restricted access** must be bordered by a **protection fence or** protected by **other protections** (e.g. cabinet rack with sensor for opening and automatic discharging). Both fence and other protections are part	Yes

	of the delivery of the Power Supply System. Access to the restricted areas must be controlled.	
7	All **energy accumulating devices** (capacitor bank/s, flywheel generators) must have **protection that ensure personnel safety** (e.g. restricted access, proper coverage, safe discharging …).	Yes
8	All **capacitor bank/s** must be equipped with **protective discharging** that dissipate energy in the case of maintenance or personnel access to restricted area. The capacitor bank/s must be discharged (and without possibility to accidentally charge) during the time in between the tokamak discharges when the experimental area and PSS area is accessible for personnel.	Yes
9	**PF capacitor bank/s** have to be equipped with **automatic grounding systems** for personnel safety. If HV switchgear is connected, capacitor bank is disconnected from ground.	Yes
10	The PF coils capacitor bank/s **capacitors** must have **explosive-resistant construction** and they must be properly shielded in the case of explosion.	Yes
11	The Power Supply System **must withstand short circuit** in each Power Supply, short circuit in transformer and short circuit in tokamak coils (including PF coils leads) – Power Supplies outputs.	Yes
12	The **cabling must withstand short circuit currents** (acting forces, thermal stress).	Yes
13	The Power Supply System incl. cabling **must be protected against leakage of coolant** or water leak from the other sources (i.e. systems located close to the PSS, which are not the PSS – e.g. additional heating cooling …).	Yes
14	Some specific required protections are mainly described in sections: ▪ 5.4 HV switchgear ▪ 5.5 Converters for Toroidal Field coils ▪ 5.6 Converters for Poloidal Field coils, capacitor	Yes

	bank and energy dissipator ▪ 5.8 Control system requirements	

5.10 Acceptance tests requirements

The three following categories of acceptance tests will be required (note that the categories may overlap):

1. All tests of the equipment required by the relevant Czech and European rules and regulations. Furthermore, all relevant tests of the equipment generally considered as a good practice in the field. This requirement specifically includes routine tests and type tests.

2. Tests proposed by the Contractor during the project design preparation, within the Quality Plan and its Annexes.

3. Key tests specifically required by the Client. The list and description of these key tests is provided in the Table 5.10.1: Acceptance tests requirements.

The proposal for the tests have to be approved by the Client (see "Contract for Work" for details) as a part of the Contractor's Implementing Documentation delivery, which includes the Quality Plan. The Contractor is obliged to create the Quality Plan (see section 5.11 - Documentation and SW backup requirements) which will contain list of FAT and SAT complete tests. The list of the tests will be elaborated (extended and specified) by the Contractor with the exact required test values and thresholds before the tests start. The specified tests will become Annex of the Quality Plan. The Quality Plan Annex must be approved by the Client before the individual acceptance test is started. The output (report) and the execution of the acceptance test also must be approved by the Client.

Factory Acceptance Tests

The required acceptance tests are divided into FAT (Factory Acceptance Test) and SAT (Site Acceptance Test). FAT of individual Power Supply System components will be performed at the site of the Contractor or at the site of the third party. After the FATs are successfully performed, the tested Power Supply System components are cleared to be accepted by the Client and they could become the property of the Client, if other requirements of the Contract for Work are fulfilled.

The FATs of the Power Supply System - Basic configuration and of the Extended Options (i. Second new flywheel generator and its auxiliary systems, ii. Increase of the capacitor bank(s) energy by +0.5 MJ and iii. Short circuit test at full nominal pulsed voltage of a selected transformer) are both described in the Table 5.10.1: Acceptance tests requirements.

As a part of all FATs, the Contractor will provide technical documentation (drawings, electrical schematics, datasheets, and test protocols of the components …) which proves that the tested part of the Power Supply System fulfils the required overall parameters. This technical documentation will become part of the As-built Documentation.

Successful execution of all FATs (either for Basic Configuration alone or for Extended Options) in the Table 5.10.1 is mandatory requirement and part of the "assembly preparedness protocol", which is defined in the article XV. in the Contract of Work.

Site Acceptance Tests

SATs of the installed part of the Power Supply System (either Basic Configuration alone or Basic Configuration with already realized Extended Options or individual Extended Options) will be performed after its installation at the Client site. After successfully passing all SATs and signing the Final Acceptance Protocol, the installed part of the system will be considered as delivered and accepted by the Client. SATs will cover tests and checks of the basic parameters of the Power Supply System including use of additional measurement systems installed by the Client. SATs will be performed at partial or full parameters of the Power Supply System.

If the individual Extended Options are installed / performed later than the realization of the SATs for the Basic Configuration, the individual SATs of the Basic Configuration will be repeated if:

a) The test is necessary to prove functionality of the newly installed device,

b) The test is necessary to prove functionality of the Power Supply System as whole with the newly installed device

c) The repeated SAT is specifically listed in the Table 5.10.1: Acceptance tests requirements.

The "Complex Test", which is mentioned in the article XV. in the Contract of Work, is defined by successful execution of all relevant SATs (either for Basic Configuration alone or for Basic Configuration with realized Extended Options or for individual Extended Options) in the Table 5.10.1. The Complex Test is mandatory requirement for the Final Acceptance of the Work.

In order to clarify, the above-mentioned procedure means that there are four Complex Tests and four Final Acceptance Protocols / Final Acceptances of the Work – one for the mandatory part "Power Supply System for COMPASS-U tokamak - Basic Configuration" and three for the Extended Options (i. Second new flywheel generator and its auxiliary systems, ii. Increase of the capacitor bank(s) energy by +0.5 MJ and iii. Short circuit test at full nominal pulsed voltage of a selected transformer).

The Client has a right to supervise and participate on both FATs and SATs, including use of additional measurement systems installed by the Client.

Full Performance Test

Power Supply System Full Performance Tests will be performed during the warranty period at the request of the Client, with the Contractor's technical support (including staff on-site). The tests will be performed by the Contractor under the direction of the Client. The Contractor will check proper functionality of the Power Supply System and assure its safety and protection. The tests will repeat significant part of the Complex Tests, but on the full performance parameters of the Power Supply System and with connected COMPASS-U tokamak coils as a load for the Power Supply System.

Information for the Table 5.10.1

The table contains list of the FATs and SATs for the:

1. "Power Supply System for COMPASS-U tokamak - Basic Configuration" – **BC** in the Table
2. Extended Option No. 1 (Second new flywheel generator and its auxiliary systems) – **EO1** in the Table
3. Extended Option No. 2 (Increase of the capacitor bank(s) energy by +0.5 MJ) – **EO2** in the Table
4. Extended Option No. 3 (Short circuit test at full nominal pulsed voltage of a selected transformer) – **EO3** in the Table
5. Full Performance Test – **FPT** in the Table

If the test is required for both the BC (Basic Configuration) and FPT (Full Performance Test), then it is assumed that the acceptance test for the Basic Configuration will be performed at partial performance parameters limited by the available dummy load. The full performance parameters, as defined by the relevant part of this Technical Specification document must, be demonstrated during the Full Performance Test.

Definition of successful (passed) test: The test is successful if the results of measurements with uncertainties of measurements are within the range defined in the design of Power Supply System for evaluated parameter that ensure correct function of Power Supply System according requirements defined in the section “5 - Technical requirements table” of this document. The evaluated parameters for the tests are listed in plans for the test (Quality Plan). The results of measurements and indication of compliance with criteria for passed test for each evaluated parameter are part of the testing protocol.

Definition of the “if possible” and “if necessary” in the column “Valid for” in the Table 5.10.1:

- “If possible”: if the test can be physically performed with the equipment available to the Client at the time of the testing. The equipment availability refers to the available dummy load / COMPASS-U tokamak coils, status of the procurement / installation of the Extended Options, etc.
- “If necessary”: It is not necessary to repeat the test if the test was already performed at full parameters and demonstrating full capabilities as a part of other previous test.

Table 5.10.1: Acceptance tests requirements

No.	Name and description of the requirement	Valid for	Value / descript.
PF coils - rectifiers			
1	**FAT:** Connect the rectifier to an input grid (transformer with effective (RMS) line-to-line voltage higher than 20 V) and a dummy load, **measure the parameters** (voltage and current distribution between parallel parts of the rectifier/s) **for current load higher than 1 kA**. Connect the rectifier/s to the input, which will energize the no-load output to DC voltage 140% of planned nominal voltage (e.g. test at ~1400 VDC for rectifier R1000). The main goals are to prove that rectifier complies with PSS design, and measure parameters for PSS model. The rectifiers prove capability to carry current without overheating parts i.e. current will be equally distributed over parallel connected parts and cooling will be balanced, too. The test has to prove that rectifiers can work at designed voltage and current for designed time. The parameters for PSS model will be measured e.g. power loses, voltage drop, differential resistance, reverse recovery time, leakage current.	BC	Pass the test
2	**SAT:** Rectifiers are **connected in the complete Power Supply System** installed at IPP site and the PF coils **converters** are **powered from the rectifier/s** during the PF coils Power Supplies acceptance tests. Contractor will measure voltage and current distribution on individual	BC, FPT	Pass the test Demonstrated by correctly providing power

	parallel parts of the rectifier/s. The test has to prove that rectifiers are reliable and compatible with the other parts of PSS also at full parameters.		and energy during the SAT tests of the PF coils Power Supplies
PF coils - capacitor bank/s			
3	**FAT**: **Charge, discharge to 140 % of nominal no-load voltage** of appropriate Power Supply (e.g. test at ~1400 V for C1000). Protection test (test of discharging – both passive and active). Measure resistance of the protective resistors and parameters for model total resistance, capacity. The test has to prove that capacitor bank sustain maximal voltage, the protection works, and no oscillation behaviour occur.	BC, EO2	Pass the test
4	**SAT**: Capacitor bank is **connected in the Power Supply System** installed at IPP and the PF coils **converters** are **powered from the capacitor bank/s** during the PF coils Power Supplies acceptance tests. Contractor will measure voltage and current distribution on individual parallel parts of the capacitor bank/s. The test has to prove that capacitor bank work and it is capable to handle discharging and charging currents (also during breakdown) safely, reliably and without overheating or capacitor degradation.	BC, EO2, FPT	Pass the test Demonstrated by correctly providing power and energy during the SAT tests of the PF coils Power Supplies
PF coils - Energy dissipator/s			
5	**FAT**: Measurement of **reaction time**, measurement of **other parameters (resistance, inductance)**; **Resistor** in the energy dissipator: connect to power source and demonstrate capability to dissipate appropriate amount of energy (see requirement on capability to dissipate energy in section 5.6) and capability to regenerate (= lower the temperature) before next tokamak pulse (see requirement on repetition rate in section 5.6) for representative part of the energy dissipator; **Switching element** in the energy dissipator: can be tested in several parts, demonstrate capacity to switch appropriate part of the PF coils current (at least part of the energy dissipator switching element must undergo	BC	Pass the test

	nominal current tests); the test is required for both controlled chopper switch and for thyristor switch **Controlled switching element** in the energy dissipator: measure the temperature between the heatsink and the switching module for representative part of the energy dissipator/s + compare it with modelled expectation for the given power load The aim of the test is to prove that energy dissipator protect capacitor bank, react quickly enough, and can carry high currents without overheating.		
6	**FAT**: **EMC immunity test** of the control electronics under switching conditions of the energy dissipator (or representative part of the energy dissipator). The EMC immunity must allow safe operation in an environment where all the other Power Supplies are running and creating noise and expected stray magnetic fields from tokamak and Power Supply System are present. The test has to prove that energy dissipator can reliable work in noisy environment (normal operation), and during faults of PSS parts i.e. noise level is above normal operation noise level.	BC	Pass the test
7	**SAT**: **Controlled switching dissipation** and **emergency dissipation** test from a fully charged capacitor bank C1000 (and C660, if used) with full nominal pulsed current rating and full nominal voltage of the Energy dissipator/s. The Contractor must demonstrate capability of the Energy dissipator to deal with the maximal possible power/current influx from the PF coils Power Supplies into the capacitor bank. The Contractor must demonstrate capability to dissipate appropriate amount of energy required from the dissipator (see section 5.6) and possibility to reach the required repetitive rate. Measure voltage drop on the path between the Power Supplies and energy dissipator resistor, this test can be performed only on one representative part of the system capacitor bank – Energy dissipator – Power Supply Temperature of representative resistors will be measured during the tests.	BC, EO2, FPT	Pass the test

	The tests can be performed by parts. The test has to prove that energy dissipator can carry full currents during normal operation (including plasma breakdown) and in emergency cases. The current rise in energy dissipator must be fast enough.		
PF coils - Power Supplies (prototype tests)			
8	**Manufacture** a **prototype PF Power Supply unit** (IGBT based), which will be used for the tests. The prototype will be a representative modular part of one of the PF coils Power Supplies, with a nominal pulsed current rating >= 5 kA and a 4-quadrant operation.	BC	yes
9	**FAT**: **EMC immunity** tests of the prototype unit under switching conditions. The EMC immunity must allow safe operation in an environment where all the other Power Supplies are running and creating noise and expected stray magnetic fields from tokamak and Power Supply System are present.	BC	Pass the test
10	**FAT**: Test the prototype unit to a **dummy load** at least on the **nominal pulsed parameters** (>=5 kA, 2 seconds current flat-top, 1 second ramp-up and ramp-down, for both current polarities). The dummy load will be inductive (the energy deposited to the magnetic field will be higher than the resistive losses during ramp-up from 0 A to the nominal pulsed current). The dummy load will be provided by Contractor.	BC	Pass the test
11	**FAT**: The prototype unit will demonstrate **protection against plasma disruption**; e.g. if a disruption current is expected to flow through the Power Supply to the capacitor bank, then the capability to withstand this current will be demonstrated.	BC	Pass the test
12	**FAT**: The **temperature of the IGBT and diode** will be evaluated during the prototype testing by measurement of the temperature on the case to heatsink transition or by measurement on the internal sensor of the module. The public tender requirement on the PF coils Power Supplies IGBT and diode junction will be compared with the indirectly measured value.	BC	Pass the test
PF coils - Power Supplies demonstration tests			

13	**FAT**: The **capability of the control system** of the PF Power Supplies to **change the current output** according to the requested current waveform will be demonstrated either on the prototype unit or on the final production PF coils Power Supply. The test has to prove that output current is controlled as required. Control latency statistics will be measured.	BC	Pass the test
14	**FAT**: At least one of the PF coils Power Supplies (e.g. PF3U PS, +/-25 kA) will be **tested as a whole on lower parameters** (voltage and current at least 20% of the nominal pulsed values, pulse duration more than 50 ms, both current polarities) in order to demonstrate the distribution of the current between the modules. The Power Supply can be powered from a capacitor bank for these tests. The test has to prove that current (and heat) is equally distributed between parallel parts.	BC	Pass the test
PF coils - Power Supplies			
15	**FAT**: All individual Power Supplies (or all their modules when testing by parts) will be **tested on lower parameters** (voltage and current at least 20% of the nominal pulsed values, pulse duration more than 50 ms, both current polarities). The Power Supplies can be powered from a capacitor bank for these tests. The test has to prove that all Power Supplies and all parts works, and complies with design parameters, the parameters of similar parts must have acceptable low tolerances.	BC	Pass the test
16	**FAT**: The **temperature of the IGBT and diode** will be evaluated for at least one Power Supply by measurement of the temperature on the case to heatsink transition or by measurement on the internal sensor of the module. The public tender requirement on the PF coils Power Supplies IGBT and diode junction will be compared with the indirectly measured value. The test has to prove that temperatures of IGBT and diodes (or other heated parts) is in specified range that allow operation at full parameters. Note: Exactly same test is required for the prototype unit. Here, the one final Power Supply is tested.	BC	Pass the test

17	**FAT**: **EMC immunity** tests of one of the PF coils Power Supplies (selected by the Client) unit under switching conditions. The EMC immunity must allow safe operation in an environment where all the other Power Supplies are running and creating noise and expected stray magnetic fields from tokamak and Power Supply System are present.	BC	Pass the test
18	**SAT**: The Client will provide a dummy load (either tokamak coils or a similar representative dummy load) capable of testing current higher than 20 kA for 2 seconds flat-top, 1 second ramp-up and 1 second ramp-down. The Contractor will provide cooperation to **connect the dummy load** to the parts of individual Power Supplies (both PFPS and TFPS!) of the Power Supply System for the purpose of the SAT. The Contractor's cooperation may include necessary work to compartmentalize the individual Power Supplies into the 20 kA parts, which can be tested by the dummy load to the nominal pulsed parameters.	BC, EO2	Yes
19	**SAT**: All of the **individual Power Supplies** (and, therefore, the rest of the Power Supply System) will be tested into the dummy load with a **current higher than 20 kA** for 2 seconds flat-top, 1 second ramp-up and 1 second ramp-down, **up to the nominal voltage, for both current polarities**. The individual Power Supplies will be tested separately (one after one). The current distribution on individual parallel parts of the Power Supplies will be measured. The test has to prove that all Power Supplies and all parts works, and complies with design parameters, the parameters of similar parts must have acceptable low tolerances.	BC, EO2	Pass the test
20	**SAT**: All of the **individual Power Supplies** (and, therefore, the rest of the Power Supply System) will be tested into the COMPASS-U tokamak coils with the **nominal pulsed current** for 2 seconds flat-top, 1 second ramp-up and 1 second ramp-down, **at the nominal voltage, for both current polarities**. The individual Power Supplies will be tested both separately (one after one) and simultaneously (more Power Supplies	FPT EO2, if possible	Pass the test

	together). The current distribution on individual parallel parts of the Power Supplies will be measured. The test has to prove that all Power Supplies and all parts works, and complies with design parameters, the parameters of similar parts must have acceptable low tolerances.		
21	**SAT**: All PF coils **Power Supplies** (and, therefore, the rest of the Power Supply System) will be simultaneously tested into the COMPASS-U tokamak coils with the **representative current waveforms appropriate for the full performance plasma discharge** (2 MA in plasma current, 5 T toroidal magnetic field, and additional heating systems active). The tests can be performed with or without presence of the plasma in the COMPASS-U tokamak – either representative waveforms will be used or active feedback from the plasma parameters will control the current waveforms. It is expected to perform the test repeatedly, **while triggering or simulating various failure modes of the Power Supply System** (e.g. protection against disruption, failure of the tokamak control system, loss of the communication, emergency termination of the discharge …). The current distribution on individual parallel parts of the Power Supplies will be measured; other parameters mentioned in the SATs of the individual systems of the Power Supply System (e.g. voltage on the capacitor banks, current distribution in the rectifier …) will be measured as well during the Full Performance Test. The test has to prove that all Power Supplies and all parts works, and complies with design parameters, the parameters of similar parts must have acceptable low tolerances.	FPT EO2, if necessary	Pass the test
22	**SAT**: The dummy load will be used to **test separate parts** of the individual Power Supplies **to 120 % of the nominal pulsed current** (2 seconds flat-top, 1 second ramp-up and 1 second ramp-down), up to the **nominal voltage**, for **both current polarities**. The Contractor will prepare the Power Supplies for this test (e.g. by disconnecting parts of the Power Supply). All of the parts of the Power Supplies will undergo this test. The test has to prove that Power Supplies are designed with sufficient margin. It is assumed that at least this margin is needed to allow required longevity of the	BC	Pass the test

	Power Supplies.		
23	**SAT**: The COMPASS-U coils will be used to **test the individual Power Supplies to 120 % of the nominal pulsed current** (2 seconds flat-top, 1 second ramp-up and 1 second ramp-down), at the **nominal voltage**, for **both current polarities**. All Power Supplies will undergo this test. The test has to prove that Power Supplies are designed with sufficient margin. It is assumed that at least this margin is needed to allow required longevity of the Power Supplies.	FPT	Pass the test
24	**SAT**: At least **three Power Supplies** (selected by the Client) will be tested with **short-circuit on the output** at **nominal voltage**. The test has to prove that Power Supplies survives short circuit without damage (shorted coil).	BC, EO2	Pass the test
25	**SAT**: At least **three Power Supplies** (selected by the Client) will be tested for **protection against a short-circuited power transistor** (either by rigging incorrect switch-on signal or by installing external short-circuit rig) under the nominal pulsed operation. The test has to prove that Power Supplies handles situation if case of transistor fail without damage on the other parts of PSS.	BC, EO2	Pass the test
26	**SAT**: The Contractor will demonstrate the **response** of the individual Power Supplies **to all relevant protection signals** (e.g. overcurrent, overvoltage, thermal, dI/dt …) The test has to prove functionality of required protections.	BC	Pass the test
27	**SAT**: At least **three Power Supplies** (selected by the Client) will demonstrate **protection against plasma disruption**; e.g. in case the disruption current is expected to flow through the Power supply to the capacitor bank, then the capability to withstand this current will be demonstrated. The test has to prove that Power Supplies survives disruption without damage.	BC, EO2, FPT	Pass the test
TF coils - crowbar			

28	**FAT**: Measurement of **crowbar reaction time**. Measurement of **other parameters (resistance, inductance)**. The test has to prove that crowbar react fast enough to overtake current and protect TF coil.	BC	Pass the test
29	**FAT**: Test of the **resistor** in the crowbar: connect to power source and demonstrate **capability to dissipate appropriate amount of energy** (see requirement on capability to dissipate energy in section 5.5 - Converters for Toroidal Field coils) for representative part of the TFPS crowbar. The test has to prove that resistor can dissipate required energy without damage and with required repetitive rate.	BC	Pass the test
30	**FAT**: Test of the **switching element** in the TFPS crowbar: Demonstrate the **capacity to switch the appropriate part of the TF coils current** (at least part of the full switching element must undergo live current tests). Can be tested in several parts. The test has to prove that TFPS crowbar can reliably work at full parameters, and current is equally distributed between parallel parts.	BC	Pass the test
31	**FAT**: **EMC immunity** test of the **TFPS crowbar** including its control electronics under switching conditions of the TFPS crowbar. The EMC immunity must allow safe operation in an environment where all the other Power Supplies are running and creating noise and expected stray magnetic fields from tokamak and Power Supply System are present. The test has to prove that TFPS crowbar can reliable work in noisy environment (normal operation), and during faults of PSS parts i.e. noise level is above normal operation noise level.	BC	Pass the test
32	**SAT**: **Dissipate energy** from a **charged capacitor bank**, measure the temperature of resistors. Perform **emergency dissipation** test. The test has to prove that resistors can repetitively dissipate energy without damage.	BC	Pass the test

33	**SAT**: **Dissipate energy** delivered either from the TF coils or from the available dummy load provided by the Client. The test **energy and current** will be **limited by the available dummy load**. The crowbar will be tested by parts (per partes) in order to simulate behaviour under nominal pulsed load. The test has to prove that resistors can repetitively dissipate energy from TF coil without damage and that the switching elements work reliably under the pulse characteristics.	BC EO1	Pass the test
34	**SAT**: **Dissipate energy** delivered from the TF coils loaded with **their nominal pulsed current**. The crowbar will be tested as whole, with separated measurements of the parts to prove acceptable spreading of the load in the parallel branches. The test has to prove that resistors can repetitively dissipate energy from TF coil without damage and that the switching elements work reliably under the pulse characteristics.	FPT EO1, if possible	Pass the test
35	**SAT:** Demonstrate the **capability** of the TFPS protection **to disconnect the Toroidal Field Power Supply** from the circuit “crowbar – load” in case that the TFPS crowbar is activated. The load will be either the dummy load or the TF coils of the tokamak. The test has to prove that activation of TFPS crowbar causes disconnection of TFPS.	BC	Pass the test
36	**SAT:** Demonstrate the **capability** of the TFPS protection **to disconnect the Toroidal Field Power Supply** from the circuit “crowbar – load” in case that the TFPS crowbar is activated in the situation when there is the nominal pulsed current in the TFPS. The load will be the TF coils of the tokamak. The test has to prove that activation of TFPS crowbar cause disconnection of TFPS.	FPT, EO1	Pass the test
37	**SAT:** Demonstrate the capability of the TFPS crowbar to **function correctly** (i.e. transfer current from the Power Supply to the TFPS crowbar) **in case of the loss of the Toroidal Field Power Supply input voltage** (e.g. activation of the circuit breaker on the TFTR transformers). The test has to prove that TFPS crowbar can protect	BC, EO1, FPT	Pass the test

	TFPS in case of TFPS input disconnection.		
38	**SAT:** Demonstrate the capability of the TFPS crowbar to **function correctly** (i.e. transfer current from the Power Supply to the TFPS crowbar) **in the case of short-circuit of thyristor/s in TFPS** (either by rigging incorrect switch-on signal or by installing external short-circuit rig) under the nominal pulsed operation. The test has to prove that TFPS crowbar can protect TFPS in case of thyristor/s damage.	BC	Pass the test
39	**SAT**: Demonstrate the capability of the **TFPS fuse to safely disconnect the short-circuited module of the TFPS** (i.e. module where two thyristors located above each other are short-circuited) under the conditions when the TFPS is loaded with the current and it powers the dummy load (test in Basic configuration) or the tokamak coil under the nominal pulsed operation (FPT). The short-circuit has to be created either by rigging incorrect switch-on signals or by installing external short-circuit rig. The test has to prove capability of the fuse to disconnect the affected short-circuited module and the capability of the rest of the TFPS protections to react adequately.	BC, if possible FPT, if necessary	
Toroidal Field Power Supply			
40	**FAT**: **EMC immunity** tests of the control electronics and Power Supply under switching conditions of the TFPS. The EMC immunity must allow safe operation in an environment where all the other Power Supplies are running and creating noise and expected stray magnetic fields from tokamak and Power Supply System are present. The test has to prove that TFPS can reliable work in noisy environment (normal operation), and during faults of PSS parts i.e. noise level is above normal operation noise level.	BC	Pass the test
41	**FAT**: Test the Toroidal Field Power Supply by parts to a dummy load at least on the **nominal pulsed parameters** (>6 kA, >1 seconds current flat-top, >1 second ramp-up and ramp-down). The dummy load must be inductive (the energy deposited to the magnetic field will be higher than the resistive losses during ramp-up from 0 A	BC	Pass the test

	to the nominal pulsed current). The test has to prove that all Power Supplies and all parts works, and complies with design parameters, the parameters of similar parts must have acceptable low tolerances.		
42	**FAT**: Demonstrate the **capability of the control system** of the TF Power Supply to **change the current output** according to the requested current waveform. The test of the control system can be performed on the part of the TFPS. The test has to prove that TFPS output current is controlled with required accuracy and with low latency.	BC	Pass the test
43	**SAT**: The Client will provide a dummy load (either tokamak coils or a similar representative dummy load) capable of testing current higher than 20 kA for 2 seconds flat-top, 1 second ramp-up and 1 second ramp-down. The Contractor will provide cooperation to **connect the dummy load** to the parts of individual Power Supplies (both PFPS and TFPS!) of the Power Supply System for the purpose of the SAT. The Contractor's cooperation may include necessary work to compartmentalize the individual Power Supplies into the 20 kA parts, which can be tested by the dummy load to the nominal pulsed parameters.	BC, EO1	Yes
44	**SAT**: The **Toroidal Field Power Supply** (and, therefore, the rest of the Power Supply System – transformers, flywheel generator/s) will be tested into the dummy load with a **current higher than 20 kA** for 2 seconds flat-top, 1 second ramp-up and 1 second ramp-down, on the **nominal voltage**. The test has to prove that TFPS and all parts works, and complies with design parameters and TFPS can power TF coil.	BC	Pass the test
45	**SAT**: The **Toroidal Field Power Supply** (and, therefore, the rest of the Power Supply System – transformers, flywheel generators) will be tested into the tokamak coils with **the nominal pulsed current** (or at least 80 % of the nominal pulsed power if the tokamak coils are not capable) for at least 1 second flat-top, on the **nominal voltage**. The various failure modes will be tested during the test (e.g. behaviour of the protection system if one	FPT EO1, if necessary	Pass the test

	of the flywheel generator circuit breakers activates, etc.). The test has to prove that TFPS and all parts works, and complies with design parameters and TFPS can power TF coil. The parallel operation of the two flywheel generators must be demonstrated. The safety of the Power supply system operating with two parallel flywheel generators must be demonstrated.		
46	**SAT**: The dummy load will be used to test **separate parts** of the Toroidal Field Power Supply to **120 % of the nominal pulsed current** (2 seconds flat-top, 1 second ramp-up and 1 second ramp-down), on the **nominal voltage**. The Contractor will prepare the TF Power Supply for this test (e.g. by disconnecting parts of the Power Supply). All of the parts of the TFPS will undergo this test. The test has to prove that all Power Supplies and all parts works, and complies with design parameters, the parameters of similar parts must have acceptable low tolerances.	BC	Pass the test
47	**SAT**: The Contractor will demonstrate the **response** of the TFPS **to all relevant protection signals** (e.g. overcurrent, overvoltage, thermal, dI/dt …) The test has to prove functionality of required protections.	BC	Pass the test
Flywheel Generator/s			
48	**FAT**: Spin up from 0 rpm to at least the **maximal operational rotation speed**. Slow down from the maximal operational speed to 0 rpm. Test **emergency slowdown** from the maximal operational speed to 0 rpm. Excite the generator to at least the **nominal voltage**. The test has to prove that flywheel generator can spin up and slow down, can brake in case of emergency, and generate nominal voltage. The functionality of flywheel generator/s with the support systems (lubrication, cooling, excitation …) has to be proved.	BC, EO1	Pass the test
49	**SAT**: Flywheel generator/s will **power the Power Supply System converters** during their SAT acceptance tests, testing them on **partial power**. If it is allowed by the	BC, EO1	Pass the test

	actual status of the tokamak (acting as a dummy load), the generator/s will power multiple grids at once in order to perform their full energy and/or power drain. The test has to prove that flywheel generator/s can power PSS.		
50	**SAT**: Perform a measurement showing that the existing flywheel generators **GG1 and GG2 have acceptable distribution of the power drain** when powering the Poloidal Field coils Power Supplies during the PFPS SAT. The test has to prove that GG1 and GG2 can reliable work to common load (PF coils).	FPT BC, if possible	Pass the test
51	**SAT**: Perform a measurement showing that the existing flywheel generators **GG1 and GG2 have acceptable distribution of the power drain** when powering the Toroidal Field Power Supply (when both are connected to the TFTR). The purpose of the measurement is to demonstrate the TFTR and TFPS are capable of acceptable distribution of the power drain from GG3 and GG4 (GG1 and GG2 are used as substitute). If possible (i.e. if Extended Option “Second new flywheel generator and its auxiliary systems” is installed), use GG3 and GG4 for this test.	BC, EO1, FPT	Pass the test
52	**SAT:** Measure the noise of the new flywheel generators when enclosed in cover. The measurement must be performed at several points along the contour defined by distance 1 m from the generator cover, 1.5 m from the ground. The purpose of the measurement is to demonstrate that the new flywheel generators satisfy the hygienic limits, when the flywheel generators are enclosed in their cover, when placed inside the bunker or separated building and, when accelerating to the full operational rotation speed and being nearby the full operational rotation speed. The test will be performed with two new generators running.	BC, EO1	
HV and LV switchgear, including junctions			
53	**FAT**: Provide **technical documentation** and **test protocols** issued by the manufacturer according to valid Czech and European rules and regulations. This is valid for the HV switchgear, junctions and LV switchgear.	BC	yes

54	**SAT**: Test of the **interlocks**. Test of **switching**. Set up a false trigger and perform interruption of current at significant part of the nominal pulsed parameters, as allowed by the available dummy load (e.g. for the purpose of the test, send a false signal to the control logic of circuit breakers, forcing to interrupt current under operation at significant part of its nominal pulsed current). The test has to prove that HV and LV switchgear works, and allow safe operation.	BC, EO1 FPT, if necessary	Pass the test
55	**SAT**: Demonstration of the **mechanical interlock of the junctions** (e.g. mechanical interlock does not allow their connection when main circuit breakers of the flywheel generators are connected). The test has to prove that it is not possible connect parts that must not be connected.	BC, EO1	Pass the test
Transformers			
56	**FAT**: Provide **technical documentation** and **test protocols** issued by the manufacturer according to valid Czech and European rules and regulations.	BC, EO1	yes
57	**SAT**: Transformers will **power the converters** of the Power Supply System during their SAT acceptance tests, testing them on partial power. The test has to prove that transformers complies PSS design.	BC	Pass the test
58	**FAT:** If the appropriate Extended Option is realized, **perform the test “Short circuit test at full nominal pulsed voltage of a selected transformer”**: 1) The Client can select any of the newly manufactured transformers for this test, including the largest one (which is one of the transformers in either TFTR or PFTR1000). 2) The selected transformer must go undergo the routine tests and type tests before the “Short circuit test at full nominal pulsed voltage of a selected transformer”. These tests must include insulation resistances measurement. The status of the selected transformer must be documented by the Contractor, including photographical evidence of the physical status of the transformer and exactly measured technical drawings as manufactured.	EO3	

	3) The Contractor is obliged to ensure transport of the selected transformer to and from the test site, where the short-circuit test is performed. This includes uninstallation and re-installation of the selected transformer from/to the Client's site, if the test is being performed after the transformer was installed at the Client's site. The de-installation, transport and re-installation are included in the cost of the Extended Option "Short circuit test at full nominal pulsed voltage of a selected transformer", i.e. the cost will be covered by the Contractor. 4) The selected transformer will be tested by the short circuit on the converter side of the winding with the nominal pulsed voltage applied on the generator side of the winding. The selected transformer has to achieve absolute value of the currents and duration of the currents, which is same or larger than the predicted values if such short circuit happens while transformer is installed in the Power Supply System. Specifically, the duration of the short circuit must be longer than breaking time of the appropriate circuit breaker. The voltage applied to the selected transformer during the test on the generator side must be kept same or higher than the voltage, which can be provided by the generator values if such short circuit happens while transformer is installed in the Power Supply System. 5) After the short circuit test is performed, the routine and type tests of the transformer must be repeated. These tests must include insulation resistances measurement. After the short circuit test is performed, the status of the selected transformer must be documented by the Contractor, including photographical evidence of the physical status of the transformer and exactly measured technical drawings after the test. Furthermore, the industrial radiography (or other non-destructive testing method) must be used to prove that the transformer was not damaged during the short-circuit test. 6) If the transformer is damaged during the short circuit test at full nominal pulsed voltage, the Contractor will repair or replace the transformer on its own expenses. The purpose of the test is to prove that the transformers used in the Power Supply System are designed to and are capable of withstanding the hard short circuit at their output without damage until circuit breaker disconnects them in the case of fault situation.		

Power Supply System Control system			
59	**SAT**: Test of **all safety functions**. The correct countermeasure must occur on **simulated** dangerous situation (including different simultaneous faults). The test has to prove that PSS Control System safely handle PSS in any state. In this row of this table, the term “Partial test” means to test the functions, which are either new or influenced by realization of the Extended Option.	BC Partial test for EO1, EO2	Pass the test
60	**SAT**: Test of Power Supply System **communication with CODAC** and the others systems The test has to prove that PSS is correctly integrated to all tokamak systems.	BC	Pass the test
61	**SAT**: Test of **real-time communication** The test has to prove that real-time control of PSS works.	BC	Pass the test
62	**SAT**: Test of logical optical **interlocks signals.** The test has to prove that interlock signals works and operation is safe.	BC, EO1, EO2	Pass the test
63	**SAT**: Test of Power Supply System **measurements** and **diagnostics**. The test has to prove that PSS sensors and diagnostics works. In this row of this table, the term “Partial test” means to test the functions, which are either new or influenced by realization of the Extended Option.	BC Partial test for EO1, EO2	Pass the test
64	**SAT**: Test of Power Supply System setting. **Capability to set parameters of used control** (parameters of modulation). Test of **monitoring** and **logging** system. The test has to prove that PSS control system works.	BC, EO1, EO2	Pass the test
65	**SAT:** Test of the UPS system. 1) Turn off input power and check if protected parts are working properly and measure UPS output power. If UPS has more phases, then check load on each phase and	BC, EO1	Pass the test

	power balancing. 2) Turn on input power and check, that protected parts are powered from main power source. 3) Turn off input power when all protected parts are in operational state (nominal flywheel rotation speed, control system running, power supplies provide measurable nonzero currents (few kA)) and check proper system reaction – safe turn-off of Power Supply System. The main power will be turned on after UPS will be fully discharged. The UPS output power (time evolution) will be measured. Time when UPS provide back-up power will be measured. Additionally, the logs and monitoring records will be used for checking correct Power Supply System functionality. The goal is to prove that UPS is able to reliable protect Power Supply system during power outage and have sufficient energy to power UPS protected parts till safe turn-off. The test has to prove that PSS control system works and react safely during power outage.		

5.11 Documentation and SW backup requirements

Documentation:

For all Power Supply System components, the Client requires the necessary documentation for its successful operation, maintenance and repairs even after a long period of operation. Specifically required is:

1. Contractor's Implementing Documentation: including the project design documentation.
2. As-built Documentation: final documentation of real manufactured equipment, including documentation of all performed acceptance tests, accompanying documentation arising from relevant technical and safety rules and regulations.
3. Accompanying Documentation: operational and maintenance documentation, list of parts, installation and commissioning instructions.
4. Quality Plan: quality assurance plan. The basic part includes list of FAT (Factory Acceptance Test) and SAT (Site Acceptance Test) complete tests. The list of the tests will be elaborated (extended and specified) by Contractor with the exact required test values and thresholds before the tests start, in the form of the Annex to the Quality Plan.

Further requirements (primarily legal and organizational) for the documentation are in the Annex 4 of Contract ("Annex 4: Documentation").

Further requirements on the documentation and backup of the SW are in the section 5.8 - Control system requirements.

The requirements listed in this chapter (5.11 - Documentation and SW backup requirements) must be fulfilled in a way that the documentation, source codes and backups provided for the Basic Configuration contain overall information for the entire Power Supply System (e.g. Contractor's Implementing Documentation provided for the Basic configuration must cover the entire PSS). Furthermore, the documentation, source codes and backups will be provided in sufficient detail for the realized Extended Options.

Table 5.11.1: Documentation, source code and intellectual property requirements

No.	Name and description of the requirement	Value / description
Documentation		
1	**Contractor's Implementing Documentation** ("CID")	Provides detailed design documentation and specification of the proposed technical solution of the designed equipment, including: ▪ technical drawings ▪ connection schemes and diagrams ▪ parameters and tolerances of the individual parts ▪ spatial distribution of the PSS and requirements on the building and other

		auxiliary systems (cooling, heating, air conditioning, fire prevention …) ▪ EMC concept, including grounding scheme of the entire Power Supply System and its requirements on the building, and cable shielding concept ▪ cooling scheme ▪ tolerance analysis of the critical system parts ▪ analysis of possible resonance behaviour of the critical parts of the system (e.g. parallel operation of the flywheel generators, capacitor bank, mechanical modal analysis of the new flywheel generators, including shaft-line torsional frequencies …) ▪ analysis of major failure modes ▪ conceptual plan for the independent emergency braking system for the new flywheel generators (the emergency braking system is not part of the delivery, only the conceptual plan is required; see 5.2 - Requirements for flywheel generators) ▪ safety requirements including control and regulation of the installed systems ▪ basic considerations (analysis) of the lifetime of the individual parts of the PSS, including analysis of the lifetime when used at partial power rating ▪ basic considerations of the operation (in between tokamak pulses, during PSS daily start and stop) and maintenance (e.g. service of cooling system, cleaning of the filters …) ▪ basic considerations regarding possibility to operate the PSS on partial parameters in case of failure of sub-system (e.g. one transistor in one Power Supply) The basic part of the Quality Plan (i.e. Quality Plan without Annexes) is included in the Contractor's Implementing Documentation and will be delivered together. The Detailed Itemized Budget is part of the contractor's Implementing Documentation and must be delivered together with it. The Detailed Itemized Budget is subject of the same approval rules from the Client as the rest of the CID.

		The Contractor's Implementing Documentation must provide level of details, which demonstrates that this Technical requirements table (see 5 - Technical requirements table) is satisfied.
2	**As-built Documentation** ("ABD")	Detailed description of the final, real status of the manufactured equipment at the moment of signature of all protocols of the Site Acceptance Tests of the Power Supply System. It includes technical drawings, connection schemes and diagrams, technical sheets of the used components, descriptions of technical realizations and parameters of individual parts, incoming and outgoing revision documentations of components, declaration of conformity, etc. It includes documentation of all performed acceptance tests according to section 5.10 - Acceptance tests requirements, as well as final attestations and certificates. It includes complete production documentation, including e.g. mechanical drawings, for the new flywheel generator and its auxiliary systems for the purpose of its service, maintenance and production of spare parts that may be necessary.
3	**Accompanying Documentation** ("AD")	Detailed description (manual) of the operation, handling and maintenance of the equipment and its accessories, including operation manuals, instructions and requirements for periodic checks and maintenance, maintenance plans of the individual parts of Power Supply System, documentation of basic system settings (SW and HW). Includes list of parts, recommended assortment and quantity of spare parts. Includes migration plan for the control system and special electronics (e.g. communication links, drivers of the transistors and thyristors …) – the plan how to replace the electronics / migrate to different electronics when its lifetime ends. Includes installation and commissioning

		instructions (SW and HW).
4	**Quality plan**	Quality assurance plan is a document defining which actions will be taken and which resources will be used to realize the project at the required quality. Quality assurance plan contains a plan and detailed description of all checks and tests necessary for the successful realization of the project – including FAT and SAT tests. The basic part of the Quality Plan contains complete list of the planned FAT and SAT tests. Detailed description of the FAT and SAT tests, including exact required values and thresholds to be achieved during the tests, will be contained in the Annexes to the Quality Plan and will be elaborated by the Contractor before the tests start. The Annexes will be created after the basic part of the Quality Plan is accepted by the Client. The Annexes will undergo separate acceptance procedure.
Software		
	These requirements cover software on PCs, FPGA, microcontrollers, microprocessors and other programmable devices.	
5	SW **long term support**	The development tools for the Power Supply System software must be backed-up by the Contractor in order to maintain the possibility of software and FPGA design upgrade 10 years after the delivery of the PSS.
6	Type of SW **compilation procedure** and **back-up solution for compilation devices** (e.g. PC)	If possible, the Power Supply System software will be **compiled on virtual machines** backed-up by the Contractor in order to maintain the possibility of compilation of the software many years after the delivery. Alternatively, the **bit copies of real computers** with the installed software along with a detailed PC description will be backed up.
7	**SW backup**	The Client will obtain the binary files, deployment manual and description of the HW

		for which the binary files are intended.
8	**Communication protocols** documentation and signal description	The Client will obtain description of all communication interfaces, used protocols and signals used for communication with and within the Power Supply System.
9	Access to the **source code** of the SW	Any source code provided to Client according to the rules specified in the Contract for Work will be provided in the electronic form. The source code will be provided in programming language used by programmer to write the code. The Contractor will also provide compilation instructions, programs used for the compilation, description of the version of the used compilation programs, list of dependencies and deployment manual. The equivalent information will be provided for FPGAs (design, synthesis and implementation process setting) and other programmable devices.
10	The Contractor **will provide complete source code and complete SW** of the Power Supply System in its entirety, with list of dependencies and compilation manual (if compiled language is used) and deployment manual**, at these three specified time points**: 1. When the Site Acceptance Tests are started. 2. Between the successful completion of all of the SATs and signing of the Final Acceptance Protocol. 3. When the warranty period ends.	Yes

5.12 Requirements for the utilization of the existing Power Supply System

This section provides:

1. the list of the individual components and parts of the existing Power Supply System,
2. their required function in the new Power Supply System (either explained in this section; or reference to the appropriate section),
3. their categorization with respect to the required type of the re-use.

The **categorization with respect to the required type of the re-use** divides the individual components and parts of the existing Power Supply System into these three Categories:

- **Category A (Prescribed re-use):** the component or part must be re-used, specific function in the new Power Supply System is prescribed by the Client. The warranty is governed by the paragraph 16 in the Article IX. in the Annex No. 2 - Binding draft of Contract for Work. The disassembly responsibility is governed by the paragraph 6 in the Article III. in the Annex No. 2 - Binding draft of Contract for Work.
- **Category B (Free re-use):** the component or part must be re-used, specific function is not prescribed by the Client. The warranty is governed by the paragraph 17 in the Article IX. in the Annex No. 2 - Binding draft of Contract for Work. The disassembly responsibility is governed by the paragraph 6 in the Article III. in the Annex No. 2 - Binding draft of Contract for Work.
- **Category C (Do not re-use):** the component or part must not be re-used. The Client will disassemble and remove these components or parts at his own cost.

The **primary purpose of this section** (5.12 - Requirements for the utilization of the existing Power Supply System) **is to provide the above-mentioned categorization**.

The description of the existing Power Supply System is primarily provided in the sections **6.2 - General description of the background of the intended Power Supply System use**, **6.5 - Existing Power Supply System** and in the in the compressed file “Accompanying documentation.zip”, specifically in:

”COMPASS_existing_Power_Supply_system_Technical_documentation.zip”.

Further details on the required / prescribed re-use (components and parts in the Category A) are in the other sections of the chapter **5 - Technical requirements table**.

The individual components and parts of the existing Power Supply System must be installed into the new Power Supply System as part of the Basic Configuration.

Table 5.12.1: Requirements for utilization of the existing Power Supply System

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category
General					
1	GG1	Existing flywheel generator	GG1 (see chapters 6.2, 6.5)	GG1 (see 2.1 - Extent of delivery and 4.1- General Schematics)	A (Prescribed re-use)
2	GG2	Existing flywheel generator	GG2 (see chapters 6.2, 6.5)	GG2 (see 2.1 - Extent of delivery and 4.1- General Schematics)	A (Prescribed re-use)
3	MG1	Motor of the flywheel generator	MG1 (see chapters 6.2, 6.5)	MG1 (see 2.1 - Extent of delivery and 4.1- General Schematics)	A (Prescribed re-use)
4	MG2	Motor of the flywheel generator	MG2 (see chapters 6.2, 6.5)	MG2 (see 2.1 - Extent of delivery and 4.1- General Schematics)	A (Prescribed re-use)
5	Lubrication unit	Lubrication unit and cooling unit	Unit provides lubrication, pressurization and cooling of the	Same function as in the existing PSS. The Contractor will control	A (Prescribed re-use)

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category
	0MM03		bearing oil of the existing generators GG1 and GG2	the lubrication unit and provide safe emergency stop of the generators (see 5.9 - Safety and Protection requirements).	
6	GG1 and GG2 air cooling system	The existing generators draw the air from outside of the assembly hall. This air is used for their cooling. The air cooling system decides whether the warm exhaust air is ejected outside of the assembly hall or inside of the assembly hall (in order to support its heating during the winter). The decision is provided by control of 2x2 shutters.	Air cooling of the GG1 and GG2.	Same function as in the existing PSS. Incorporate / interface the control of the generator's air cooling system into the control system of the new PSS.	A (Prescribed re-use)
7	GG1 and GG2 braking system	The braking of the generators from the operational rotation speed to the 0 rpm is provided by 3 means: 1) generator is exciting itself (speed > 700 rpm), 2) generator is excited from the electric grid (100-700 rpm), 3) active braking by the motor (0-100 rpm), with energy being dissipated in the resistors.	Braking of the generators GG1 and GG2	Braking of the generators GG1 and GG2	A (Prescribed re-use)

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category
8	Power cables	Power cables used in the existing Power Supply System	Connection between parts of the existing Power Supply System		Category B (Free re-use)
9	Cable trays	Cable trays used in the existing Power Supply System	Support for the cables connecting parts of the existing Power Supply System		Category B (Free re-use)
10	Server IOTOKCOM	Server (computer) with name IOTOKCOM, equipped with communication with PSS slow and fast control system.	Top level of the PSS control system, communication with Simatic PLCs, communication unit …	The Contractor will create completely new control system, see 2.1 - Extent of delivery, 5.8 - Control system requirements and 5.9 - Safety and Protection requirements	C (Do not re-use)
11	Terminals for IOTOKCOM	Client terminals (computers) for communication with the IOTOKCOM server	GUI (Graphical User Interface) for operating personnel	The Contractor will provide similar functionality, see 5.8 - Control system requirements	C (Do not re-use)
Transformers					
12	1TR2A	See section 6.5 - Existing Power Supply System, particularly 6.5.4 - Transformers	Excitation transformer for GG1	Excitation transformer EG1TR for GG1 (see 5.3 - Transformer requirements)	A (Prescribed re-use)
13	2TR2B	See section 6.5 - Existing Power	Excitation transformer for GG2	Excitation transformer EG2TR	A (Prescribed re-use)

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category
		Supply System, particularly 6.5.4 - Transformers		for GG2 (see 5.3 - Transformer requirements)	
14	0TR10	See section 6.5 - Existing Power Supply System, particularly 6.5.4 - Transformers	Transformer for the RMP Power Supplies	Transformer RMP1TR for the existing converters RMP PSs (the converters are not part of the Power Supply System), see 5.3 - Transformer requirements	A (Prescribed re-use)
15	3TR3A	See section 6.5 - Existing Power Supply System, particularly 6.5.4 - Transformers	Transformer for TF Power Supply		C (Do not re-use)
16	4TR3B	See section 6.5 - Existing Power Supply System, particularly 6.5.4 - Transformers	Transformer for TF Power Supply		C (Do not re-use)
17	9TR09	See section 6.5 - Existing Power Supply System, particularly 6.5.4 - Transformers	Transformer for existing Neutral Beam Injectors NBI1 and NBI2	Transformer NBI12TR for existing Neutral Beam Injectors 1 and 2 (the NBI1 and NBI2 are not part of the Power Supply System), see 5.3 - Transformer requirements	A (Prescribed re-use)
18	8TR08	See section 6.5 - Existing Power Supply System, particularly	Transformer for Fast Amplifier FAPS	Transformer FATR for existing converter Fast Amplifier Power Supply FAPS (the converter is	A (Prescribed re-use)

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category
		6.5.4 - Transformers		not part of the Power Supply System), see 5.3 - Transformer requirements	
19	5TR04	See section 6.5 - Existing Power Supply System, particularly 6.5.4 - Transformers	Transformer for EF Power Supply		C (Do not re-use)
20	6TR05	See section 6.5 - Existing Power Supply System, particularly 6.5.4 - Transformers	Transformer for SF Power Supply		C (Do not re-use)
21	7TR06	See section 6.5 - Existing Power Supply System, particularly 6.5.4 - Transformers	Transformer for MF Power Supply		C (Do not re-use)
LV switchgear (see general schematics “2018_Energetic_tokamak_en.pdf” in “Accompanying documentation.zip”, specifically in “COMPASS_existing_Power_Supply_system_Technical_documentation.zip”)					
22	1RM01	frequency converter for motor, see section 6.5.1 - Technological Part of Flywheel Generators	frequency converter for motor MG1	frequency converter FC1 for motor MG1; assumed to stay on the same place in the LV switchgear area	A (Prescribed re-use)
23	2RM02	frequency converter for motor, see section 6.5.1 - Technological	frequency converter for motor MG2	frequency converter FC2 for motor MG2; assumed to stay on	A (Prescribed re-use)

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category
		Part of Flywheel Generators		the same place in the LV switchgear area	
24	0RB01	Converter for excitation of flywheel generator GG1, see section 6.5.1 - Technological Part of Flywheel Generators	EG1	Converter EG1 for excitation of flywheel generator GG1; assumed to stay on the same place in the LV switchgear area	A (Prescribed re-use)
25	0RB02	Converter for excitation of flywheel generator GG2, see section 6.5.1 - Technological Part of Flywheel Generators	EG2	Converter EG2 for excitation of flywheel generator GG2; assumed to stay on the same place in the LV switchgear area	A (Prescribed re-use)
26	0RS00 rack field 1 and 2	electrical wiring for administration building		Not part of the Power Supply System; assumed to stay on the same place in the LV switchgear area	C (Do not re-use)
27	0RK00	Rack for reactive compensation	Reactive compensation of the PSS and other loads (administrative building, cooling, …) for compliance with the public grid regulation	Not part of the Power Supply System; assumed to either stay on the same place in the LV switchgear area or the be removed by the Client	C (Do not re-use)
28	0RH00 rack field 1	electrical inlet to the building	Provides electric inlet for the PSS	Not part of the Power Supply System; assumed to stay on the same place in the LV switchgear	C (Do not re-use)

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category
				area	
29	0RH00 rack field 2	Fuses for auxiliary devices	Provides electric inlet for the PSS	Not part of the Power Supply System; assumed to stay on the same place in the LV switchgear area	C (Do not re-use)
30	0RH00 rack field 3	circuit breakers and fuses	Provides electric inlet for the PSS	Not part of the Power Supply System; assumed to stay on the same place in the LV switchgear area	C (Do not re-use)
31	0RH00 rack field 4	Back-up electric line, fuses	Back-up electric line for the Power Supply System	Not part of the Power Supply System; assumed to stay on the same place in the LV switchgear area	C (Do not re-use)
32	UPS	Uninterruptible power supply	UPS for 9RR09, exciters, AR610, 0RG00	This particular unit must not be used in the new PSS; similar functionality is required from the UPS delivered by the Contractor, see sections 2.1 - Extent of delivery, 5.2 - Requirements for flywheel generators, 5.8 - Control system requirements , 5.9 - Safety and Protection requirements	C (Do not re-use)

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category
33	T19	Insulating transformer 400/400 V, 150 kVA	Insulating transformer used to power the tokamak hall with the tokamak (including power sockets)	Not part of the Power Supply System; assumed to stay on the same place in the LV switchgear area	C (Do not re-use)
34	0RG00	Rack cabinet with manual and automatic control of the generators GG1 and GG2 and their accessories	Part of the PSS control system	The rack must not be used in the new PSS; similar functionality is required from the PSS control system delivered by the Contractor, see sections 2.1 - Extent of delivery, 5.8 - Control system requirements , 5.9 - Safety and Protection requirements	C (Do not re-use)
35	1RT17	circuit breakers for tokamak hall		Not part of the Power Supply System; assumed to stay on the same place in the LV switchgear area	C (Do not re-use)
36	1RT18	circuit breakers for back-up supply systems	Part of the PSS safety and protection systems	This rack must not be used in the new PSS; similar functionality is required from the PSS delivered by the Contractor, see sections 2.1 - Extent of delivery, 5.9 - Safety and Protection requirements	C (Do not re-use)

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category
37	6RC01	Simatic panel and communication unit	Part of the PSS control system	The rack must not be used in the new PSS; similar functionality is required from the PSS control system delivered by the Contractor, see sections 2.1 - Extent of delivery, 5.8 - Control system requirements , 5.9 - Safety and Protection requirements	C (Do not re-use)
38	7RC02	Monitors of checking sensors and emergency stops, communication with regulators	Part of the PSS control system	The rack must not be used in the new PSS; similar functionality is required from the PSS control system delivered by the Contractor, see sections 2.1 - Extent of delivery, 5.8 - Control system requirements , 5.9 - Safety and Protection requirements	C (Do not re-use)
39	0RZ00	Uninterruptible power supply	UPS of generators’ lubrication station	This particular rack and UPS unit must not be used in the new PSS; similar functionality is required from the UPS delivered by the Contractor, see sections 2.1 - Extent of delivery, 5.2 - Requirements for flywheel generators, 5.9 - Safety and	C (Do not re-use)

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category
				Protection requirements	
HV switchgear (see general schematics “2018_Energetic_tokamak_en.pdf” in “Accompanying documentation.zip”, specifically in “COMPASS_existing_Power_Supply_system_Technical_documentation.zip”)					
40		The switchgear rack cabinets can be physically moved from their existing position in the HV switchgear area, if required by the layout of the new Power Supply System.			
41	1R601	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.12.32	Main circuit breaker for GG1, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	MCB1 or MCB2, see 5.4 - HV switchgear	A (Prescribed re-use)
42	2R602	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.06.32	Circuit breaker for EF Power Supply transformer, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	One of the circuit breakers described in the section 5.4 - HV switchgear, for example RCB1	A (Prescribed re-use)
43	3R603	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.06.32	Circuit breaker for SF Power Supply transformer, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage	One of the circuit breakers described in the section 5.4 - HV switchgear, for example RCB2	A (Prescribed re-use)

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category
			switchgear		
44	4R604	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.06.32	Circuit breaker for MF Power Supply transformer, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	One of the circuit breakers described in the section 5.4 - HV switchgear, for example RCB3	A (Prescribed re-use)
45	5R605	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.06.32	Circuit breaker for FA Power Supply transformer, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	One of the circuit breakers described in the section 5.4 - HV switchgear, for example NBI0CB	A (Prescribed re-use)
46	6R606	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.06.32	Circuit breakers for Neutral Beam Injectors 1 and 2 transformer, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	One of the circuit breakers described in the section 5.4 - HV switchgear, for example NBI12CB	A (Prescribed re-use)
47	7R607	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.06.32	Circuit breakers for RMP Power Supplies transformer, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	One of the circuit breakers described in the section 5.4 - HV switchgear, for example RMP1CB	A (Prescribed re-use)

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category
48	8R608	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.06.32	Reserve, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	One of the circuit breakers described in the section 5.4 - HV switchgear, for example FACB	A (Prescribed re-use)
49	9R609	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.06.32	Reserve, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	One of the circuit breakers described in the section 5.4 - HV switchgear, for example RCB4	A (Prescribed re-use)
50	AR610	Medium voltage switchgear UniGear ZS1 + internal electrical connection	Bridge 1, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear		Category B (Free re-use)
51	BR611	Medium voltage switchgear UniGear ZS1 + internal electrical connection	Junction 1, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear		Category B (Free re-use)
52	CR612	Medium voltage switchgear UniGear ZS1 + contactor VSC7/P SC0; 80A	Contactor for generator GG1 excitation transformer, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	EG1CB or EG2CB, see 5.4 - HV switchgear	A (Prescribed re-use)

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category
53	DR613	Medium voltage switchgear UniGear ZS1 + contactor VSC7/P SC0; 80A	Contactor for generator GG2 excitation transformer, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	EG1CB or EG2CB, see 5.4 - HV switchgear	A (Prescribed re-use)
54	ER614	Medium voltage switchgear UniGear ZS1 + Isolating truck TE 1212-34	Junction 2 (disconnectable), see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	Junction JU1 between the grids, see 5.4 - HV switchgear	A (Prescribed re-use)
55	FR615	Medium voltage switchgear UniGear ZS1 + internal electrical connection	Bridge 2, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear		Category B (Free re-use)
56	GR616	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.06.32	Circuit breaker for TF Power Supply transformer, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	One of the circuit breakers described in the section 5.4 - HV switchgear, for example RCB5	A (Prescribed re-use)
57	HR617	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.06.32	Circuit breaker for TF Power Supply transformer, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	One of the circuit breakers described in the section 5.4 - HV switchgear, for example RCB6	A (Prescribed re-use)

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category
58	JR618	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.12.32	Main circuit breaker for GG2, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	MCB1 or MCB2, see 5.4 - HV switchgear	A (Prescribed re-use)
Converters					
59	1RU01	Thyristor converter rack cabinet, see section 6.5.5	TFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)
60	2RU02	Thyristor converter rack cabinet, see section 6.5.5	TFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)
61	3RU03	Thyristor converter rack cabinet, see section 6.5.5	TFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)
62	4RU04	Thyristor converter rack cabinet, see section 6.5.5	TFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)
63	5RU05	Thyristor converter rack cabinet, see section 6.5.5	TFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)
64	6RU06	Thyristor converter rack cabinet, see section 6.5.5	TFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category
65	7RU07	Thyristor converter rack cabinet, see section 6.5.5	TFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)
66	8RU08	Thyristor converter rack cabinet, see section 6.5.5	TFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)
67	9RR09	Rack cabinet with control units of the thyristor converters	Control system of the existing TFPS	The rack cabinet must not be used in the new PSS; similar functionality is required from the PSS control system (the part controlling the TFPS) delivered by the Contractor.	C (Do not re-use)
68	ARU10	Thyristor converter rack cabinet, see section 6.5.5	EFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)
69	BRU11	Thyristor converter rack cabinet, see section 6.5.5	EFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)
70	CRU12	Thyristor converter rack cabinet, see section 6.5.5	SFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)
71	DRU13	Thyristor converter rack cabinet, see section 6.5.5	MFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category
72	ERU14	Thyristor converter rack cabinet, see section 6.5.5	MFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)
73	FRU15	Rack cabinet with the MFPS shaper circuit	MFPS shaper circuit (see chapters 6.2, 6.5)		C (Do not re-use)
74	GRU16	Frame with the capacitor bank used in the shaper circuit of the PF Power Supply	MFPS shaper circuit capacitor bank (see chapters 6.2, 6.5)		C (Do not re-use)
75	HRU17	Frame with the crowbar	MFPS crowbar (see chapters 6.2, 6.5)		C (Do not re-use)
Choke coils					
76	Choke coils details: see 6.5.5 - Converters and Accessories, general schematics “2018_Energetic_tokamak_en.pdf” and technical datasheet in “Accompanying documentation.zip”, specifically in ”COMPASS_existing_Power_Supply_system_Technical_documentation.zip”				
77	1TL31, 2TL32, 3TL33, 4TL34	Choke coil, type TLV 57/37	Balancing of the 24-pulse thyristor converter in the TF Power Supply		Category B (Free re-use)
78	TLF1, TLF2, TLF3, TLF4	Choke coil, type TLV 56/37	Additional inductance for the LC filter		Category B (Free re-use)

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category
79	TLF5, TLF7	Choke coil, type TLV 56/29	Additional inductance for the LC filters		Category B (Free re-use)
80	TLF6	Choke coil, type TLV 70/29	Additional inductance for the LC filter		Category B (Free re-use)
81	5TL41, 6TL42	Choke coil, type TLV 54/21	Balancing of the 12-pulse thyristor converter in the EF Power Supply		Category B (Free re-use)
82	7TL51, 8TL52	Choke coil, type TLV 58/21	Balancing of the 12-pulse thyristor converter in the SF Power Supply		Category B (Free re-use)
83	9TL61, ATL62	Choke coil, type TLV 61/21	Balancing of the 12-pulse thyristor converter in the MF Power Supply		Category B (Free re-use)

6 Background information for the technical requirements

6.1 Introduction and organization of the background information

The main purpose of the chapter **6 - Background information for the technical requirements** is to provide text description of the intended use and physics background information for the Power Supply System for COMPASS-U Tokamak.

The chapter **6 - Background information for the technical requirements** is **divided into these main parts**:

1. **Chapter 6.2** is named **General description of the background of the intended Power Supply System use**. In order to introduce the intended use of the Power Supply System and to identify available resources, the status of the Power Supply System of the COMPASS tokamak is briefly described (more details can be found in chapter 6.5 - Existing Power Supply System). The energy requirements of the COMPASS-U tokamak are presented. The flywheel generators, transformers and Power Supplies are explained and discussed.

2. **Chapter 6.3** is named **Description of the Poloidal Field coils behaviour**. The chapter contains figures with expected current, voltage, power and energy waveforms of the individual Power Supplies, explanation of the difference between theoretical (ideal) current waveforms and practical realization of these waveforms and information about plasma disruptions.

3. **Chapter 6.5** is named **Existing Power Supply System**. It contains detailed technical description of the existing Power Supply system.

4. **Chapter 6.6** is named **Description of the available space in the buildings**. It contains description of the assumed available space for the Power Supply System.

6.2 General description of the background of the intended Power Supply System use

6.2.1 Introduction

The Institute of Plasma Physics of the Czech Academy of Sciences has successfully received a formal grant agreement for funding of the COMPASS-U project in the frame of Operational Programme Research, Development and Education (OP RDE), in the call “Excellent research”. The COMPASS-U project started in December 2017 and it is planned to continue until December 2022.

The purpose of the project is to build a new high magnetic field tokamak called COMPASS-U with all auxiliary systems, which include the Power Supply System. The COMPASS-U tokamak will replace the COMPASS tokamak, which is presently operated within the Tokamak Department of IPP (the Client).

The COMPASS-U tokamak should achieve significantly higher plasma parameters than the existing COMPASS tokamak:

- Major tokamak radius will be 89.4 cm (presently in COMPASS 56 cm)
- Main Toroidal Field will be 5 tesla (presently 2.1 T)
- Maximal plasma current will be 2 MA (presently 350 kA)
- Duration of the plasma discharge will be more than 2 seconds (presently approx. 500 ms)

These higher parameters infer significantly higher energy requirements – energy stored in the magnetic field corresponds to the square of the magnetic field ($E_{mag} \sim B^2$, $E_{mag} \sim I_{pl}^2$). It is not possible to achieve these higher plasma parameters only by upgrading of the existing Power Supply System of the COMPASS tokamak. The COMPASS-U tokamak will be operated at cryogenic conditions (approximately - 200 °C, 77 K, liquid nitrogen temperature), where the ohmic losses in the tokamak coils are at least 5x lower than at the room temperature. Even when employing this solution, it will be necessary to extend significantly the capacity of the tokamak Power Supply System: both the power and the amount of usable energy.

In the frame of the COMPASS-U project, we plan to procure a new Power Supply System, which will utilize a large part of the existing Power Supply System (see 5.12 - Requirements for the utilization of the existing Power Supply System). The new Power Supply System is described in the sections 2 - Power Supply System for COMPASS-U: Extent of delivery, 4 - General schematics of the Power Supply System for COMPASS-U and 5 - Technical requirements table.

This chapter (6.2 - General description of the background of the intended Power Supply System use) contains a **general technical description of the background and physics requirements** for the new Power Supply System.

The **exact technical requirements** for the COMPASS-U Power Supply System are in the section **5 - Technical requirements table**.

6.2.2 Present Status of the existing Power Supply System

The presently operated COMPASS tokamak uses Power Supply System that was designed and manufactured in the period 2006-2008. The preliminary analysis is described in the article [2], two review articles of the installed system were published in Fusion Engineering and Design [3] and in Czech journal ELEKTRO [1] (the references to the articles can be found in the section 6.4 - References).

Power from the public electric distribution system available to the buildings of the Tokamak department of the IPP Prague is limited to the maximum of 2 MW (1 MW is presently installed). The energy demands of the existing COMPASS tokamak are therefore met by using two flywheel generators. One of the generators satisfies the demands of the main Toroidal Magnetic Field (TF); the second one satisfies the demands of the Poloidal Field (PF) coil circuits and additional heating systems.

Each of the flywheel generators provides up to 50 MVA (35 MW with cos phi = 0.7) power and usable energy ~50 MJ ($1/2I\omega^2$ is 56.6 MJ). The nominal pulsed operational range of the rotation speeds is between 1700 rpm and 1300 rpm.

The flywheel generators provide energy for two independent 6 kV three-phase high voltage grids. If only one generator is operated, the grids are connected together by a junction. Converters of individual tokamak coil circuits have separate transformers with specific voltages. There are two transformers available for the TF circuit (24 MVA each), two transformers for the flywheel generator exciters (1.3 MVA each) and six different transformers with power ratings from 0.75 MVA to 18 MVA for PF circuits and additional heating systems (names: MFPS, EFPS, SFPS, FFPS, Kly, NBI).

The COMPASS tokamak was designed in the United Kingdom in such a way that each PF circuit controls an independent physical plasma parameter (radial position, vertical position, plasma current and plasma shape). This approach enables plasma control to be simple and it also decreases the number of independent converters. The disadvantage is the decreased flexibility of the plasma control. Modern tokamaks use a system where each PF coil has its own independent Power Supply. COMPASS-U will use the same modern design with separate converters used for each of the individual PF coils (or for circuit created from two closely located PF coils).

The COMPASS tokamak Power Supply System uses two different types of converters (see references [2], [3]):

1. 24-pulse thyristor converters – TFPS - Toroidal Field Power Supply (0 ÷ 91 kA, 500 V).
2. 12-pulse thyristor converters – three power supplies with -18 ÷ 16 kA and voltages up to 800 V for the magnetizing field (MFPS), equilibrium field (EFPS) and shaping field (SFPS) circuits.

These thyristor converters were part of the original delivery of the COMPASS tokamak Power Supply System.

During the operation of the COMPASS tokamak in the years 2008-2019, the Institute of Plasma Physics designed and manufactured in-house three additional types of the Power Supplies for specific purposes (special magnetic coils, separate control system ...):

1. Fast amplifiers (FA) based on the MOSFET type transistors, H-bridge with switching frequency 40 kHz and +/- 5 kA current.
2. Vertical Kicks Power Supply (VKPS) based on the IGBT type transistors with intermittent frequency up to 4 kHz, +/- 5 kA current and operational voltage 1.2 kV.
3. Resonant Magnetic Perturbations (RMP) Power Supplies based on MOSFET transistor, H-bridge with switching frequency 40 kHz and +/- 4 kA current. The design is similar to the Fast Amplifiers, but the used transistors enable a higher operational voltage (up to 190 V).

These three types of Power Supplies are not considered to be part of the COMPASS Power Supply System and will not be incorporated into the new Power Supply System for COMPASS-U as a part of its delivery. Nevertheless, they can be used for technological inspiration.

6.2.3 Energy Requirements for COMPASS-U

The COMPASS-U tokamak with its 5 T toroidal magnetic field and 2 MA plasma current will have significantly higher energy requirements than the existing COMPASS tokamak. The ohmic losses will be decreased by cooling of TF and PF coils to the temperature of liquid nitrogen, effectively lowering the resistivity of the copper coils five times.

The COMPASS-U tokamak assembly (TF coils, PF coils, Vacuum Vessel and Support Structure), was subject to the Conceptual Design Review by an international panel of experts in fusion engineering and physics in November 2018. The panel recommended to review the advantages and disadvantages of placing the tokamak Central Solenoid coils in or outside of the toroidal magnetic field area. The recommendation did not specifically rule either of the solutions out.

It was not possible to postpone the public tender for the Power Supply System after the completion of the review of Central Solenoid placement. Therefore, the Institute of Plasma Physics (the Client) launched the public tender with two versions of the tokamak coil placing (different parameters of the loads for the COMPASS-U Power Supply System).

The names of the two versions, which will be used throughout the document, are **tokamak version 3.1 (v3.1)** and **tokamak version 4.1 (v4.1)**. The version may refer to the tokamak, PF coils or TF coils, depending on context.

The technical specifications of the Power Supply System are identical for both tokamak versions. The differences between the two versions are on the side of the load (tokamak) and are summarized as follows:

1. The **flywheel generators** power and energy requirements are **same for both versions**.
2. Thyristor **Toroidal Field Power Supply** for TF coils has **the same current and voltage rating** for both tokamak versions, even though the TF coils consumed **energy is different** (magnetic and ohmic energy).
3. Twelve **transistor-based H-bridge converters** have **the same voltage and current rating** for both tokamak versions, even though the electric parameters (**resistance and inductance**) of the connected Poloidal Field coils **are different**.
4. The **requirement to have possibility to be extended by adding two** transistor-based H-bridge **converters is same for both tokamak versions**. The additional converters would be used either to improve control capabilities of the plasma shape (v4.1) or to allow full plasma performance (v3.1). The two additional converters are not part of the Power Supply System delivery (or this tender).
5. The **power and energy** reserved for the **additional heating systems** is **same for both tokamak versions**.

6.2.3.1 Toroidal Field Coils

The calculations performed by the Institute of Plasma Physics show that two presently existing flywheel generators (2x 50 MVA, 2x ~50 MJ) cannot provide enough energy for the COMPASS-U TF coils. The required energy delivered to the TF coils to reach the magnetic field 5 T is at least 220 MJ for tokamak version v3.1 and at least 290 MJ for tokamak version v4.1. Therefore, the newly built flywheel generators (one in Basic configuration and one in Extended Option) coupled together are assumed to provide energy for the TF coils.

Figure 6.2.1 shows 16 TF coils, each with 7 turns. The coils are connected in series and one Toroidal Field Power Supply provides 199.5 kA in order to achieve magnetic field in the centre of the vacuum vessel (major radius R = 0.894 m) 5 tesla. Version 3.1 is shown; version 4.1 is similar, with a larger volume of the toroidal magnetic field.

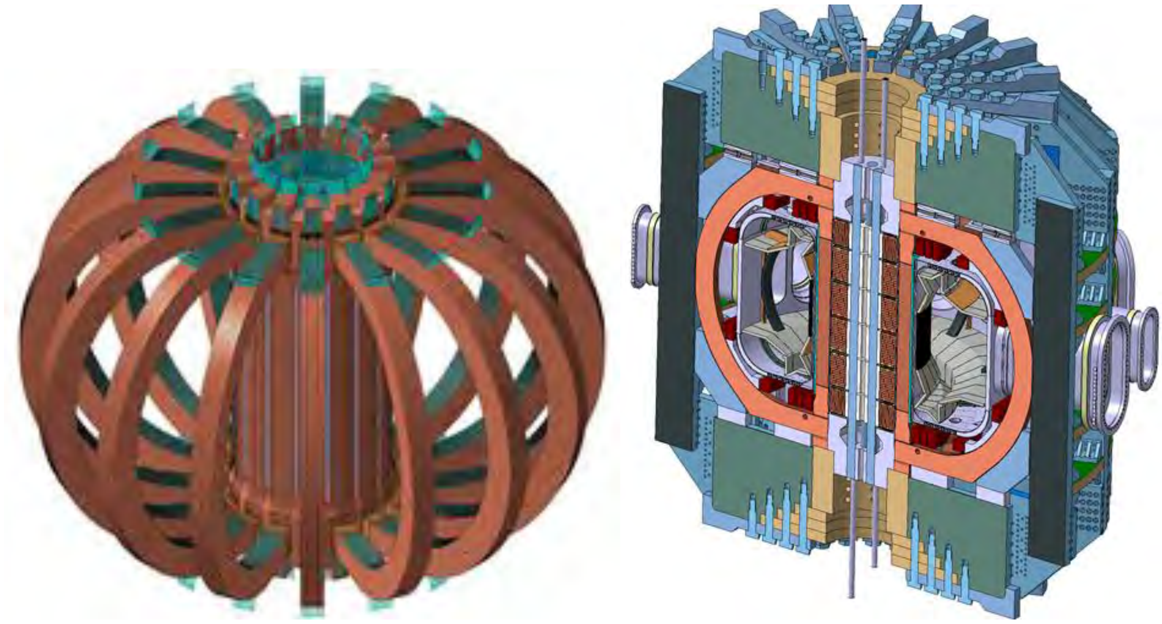


Figure 6.2.1: COMPASS-U Toroidal Field coils reference design, v3.1. 16 TF coils, 7 turns in each are shown in the left panel. TF coils nested in the Support Structure are shown in the right panel.

Toroidal Field Power Supply demands for the **tokamak version v3.1** are shown in the Figure 6.2.2. The figure shows a temporal evolution of the current, voltage, power and consumed energy.

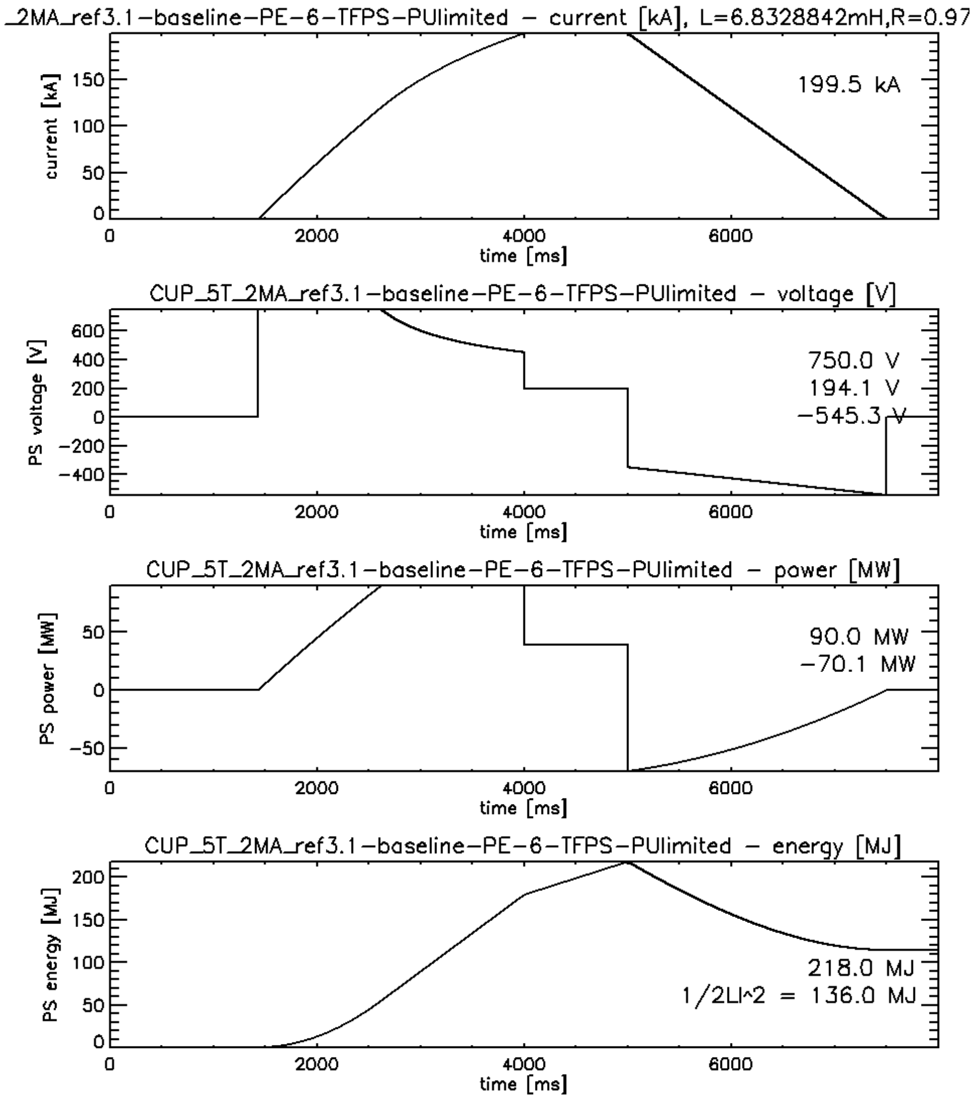


Figure 6.2.2: Simulation of the power and energy requirements to reach 5 T in the TF coils, v3.1. Energy stored in the magnetic field is 136 MJ, ohmic losses until t = 5000 ms are 82 MJ. The total maximal energy in the magnetic field, in the ohmic losses of the TF coils and of the inlet cables (without the losses in the converters, transformers and generators) is 218 MJ. The simulation assumes recuperation of the energy stored in the magnetic field back to the generators during the current ramp down. For this simulation, available PS power is limited to 90 MW and DC voltage to 750 Volts. The self-inductance of the TF coils is L = 6.83 mH and resistance is R = 0.97 mΩ for v3.1.

Power Supply demands for **tokamak version v4.1** are shown in Figure 6.2.3.

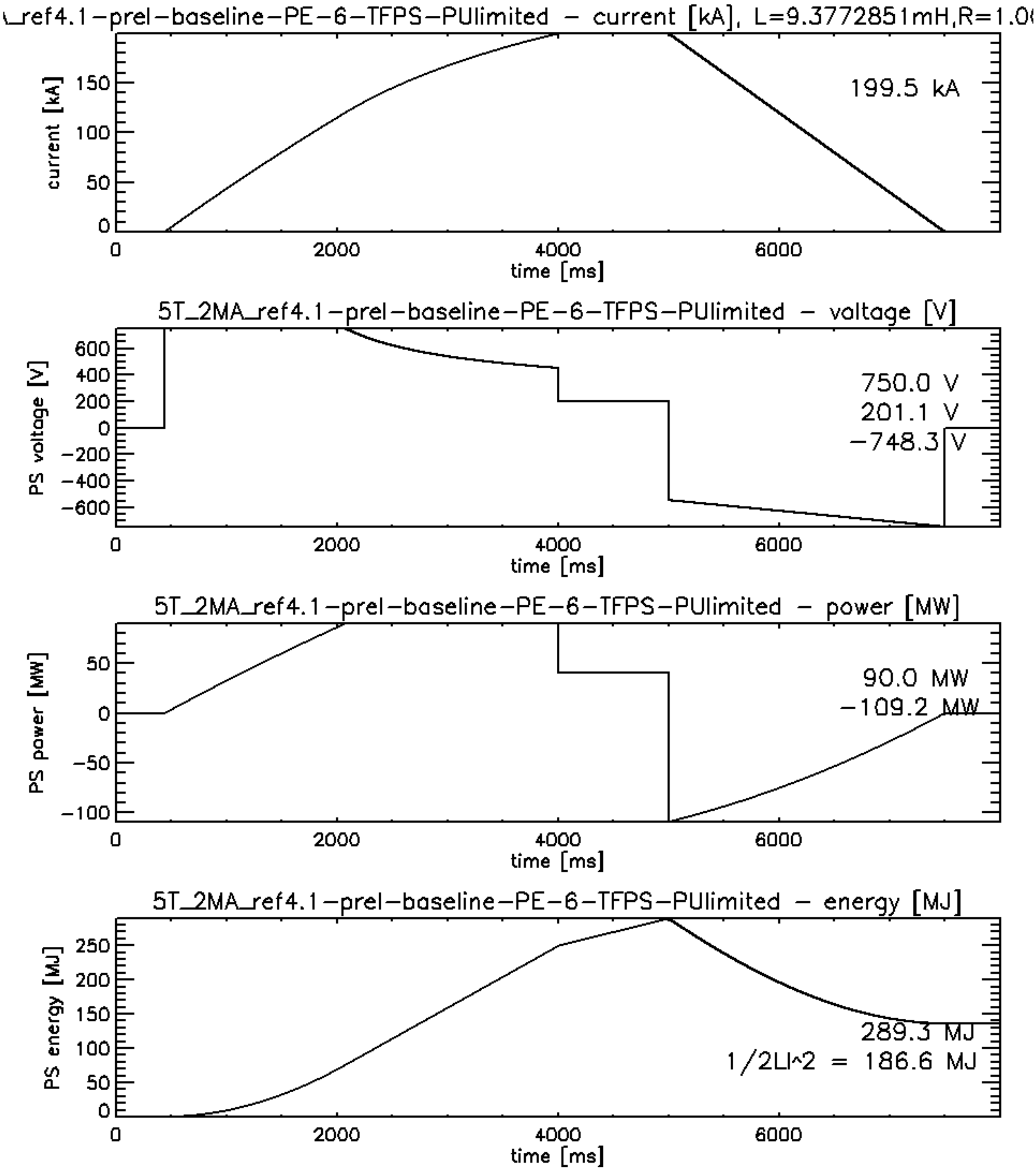


Figure 6.2.3: Preliminary simulation of the power and energy requirements to reach 5 T in the TF coils, v4.1. Energy stored in the magnetic field is 186.6 MJ, ohmic losses until t = 5000 ms are 102.7 MJ. The total maximal energy in the magnetic field, in the ohmic losses of the TF coils and of the inlet cables (without the losses in the converters, transformers and generators) is 289.3 MJ. The simulation assumes recuperation of the energy stored in the magnetic field back to the generators during the current ramp down. For this simulation, available PS power is limited to 90 MW and DC voltage to 750 Volts. The self-inductance of the TF coils is L = 9.4 mH and resistance is R = 1.08 mΩ for v4.1.

Figure 6.2.2 and Figure 6.2.3 should be understood as an example input for the possible solutions of the TF coils Power Supply.

- 90 MW shown in the figures is around the lowest acceptable power for the TFPS, because the ohmic losses for 200 kA flat-top reach around 40 MW. The possible proposed solution of a system flywheel generators -> transformers -> Power Supply can provide higher power during the Toroidal Field ramp-up. Then the ohmic losses during the TF ramp-up would be lowered and the energy could be used for other purposes (e.g. to lower the energy required from the flywheel generator or for additional heating systems ...).

- The ohmic losses at the output of the TFPS reach around 40 MW for 200 kA, even with cryogenically cooled TF coils. Therefore, the resistance of the transformers, converters, choke coils and cables is an important issue in the design of the Power Supply System - it must be kept sufficiently low (e.g. a combined resistance of 0.2 mΩ would add another 10 MW of ohmic losses).
- The DC voltage 750 V at the output of the TFPS can be increased for similar reasons. The maximal acceptable value is around 1 kV. The limiting factor is the breakdown voltage of the TF coils inlets placed in the vacuum cryostat and necessity to ramp-up the TF coils current slowly in order to assure current distribution in the TF coil conductor.
- The power used in the recuperation of the energy from the TF coils into the flywheel generator used in the simulation in the Figure 6.2.2 and Figure 6.2.3 is arbitrarily chosen to be above the minimal required (see section 5.5 - Converters for Toroidal Field coils).

It should be stated that the important feature of the Toroidal Field Power Supply is its capability to reach 5 tesla for at least 1 second. Longer duration of the 5 T flat-top is beneficial.

See specified requirements on the Toroidal Field Power Supply in the section **5.5 - Converters for Toroidal Field coils** and requirements on the transformers in the section **5.3 - Transformer requirements**.

6.2.3.2 Poloidal Field Coils

The performed calculations show that **combined energy and power requirements** for all of the COMPASS-U PF coils are:

- 80 MJ of usable energy provided from the flywheel generators,
- flywheel generators with power rating up to 100 MW,
- 13-15 individual transistor-based Power Supplies with controlled current waveforms transferring energy either to the tokamak coils or from them (ratings of *12 PF coils Power Supplies which are part of the delivery of the Power Supply System* are in the section **5.6 - Converters for Poloidal Field coils, capacitor bank and energy dissipator**),
- controlled energy dissipation from the DC-interlink with up to 200 MW power rating (see exact values required as part *of the delivery of the Power Supply system* in the section **5.6 - Converters for Poloidal Field coils, capacitor bank and energy dissipator**),
- common DC-interlinks with capacity to store > 0.5 MJ (or > 1.0 MJ with Extended Options) for voltage change between no-load and full-load voltage. There should be one or two common DC-interlinks.

These values are **valid for tokamak version v3.1**; version v4.1 has lower power requirements for the flywheel and energy dissipation.

The two presently existing flywheel generators (2x 50 MVA, 2x 35 MW, 2x ~50 MJ) are expected to be used to provide energy for the PF coils. The flywheel generators have sufficient energy content, even without extending the rotation speed range. The power rating 2x50 MVA (i.e. limitation 35 MW at *cos* ϕ = 0.7 for assumed thyristor converter as load) allows up to 2x50 MW if the uncontrolled diode rectifier or the controlled thyristor rectifier is used to provide energy for the DC-interlink.

6.2.3.2.1 PF coils geometry and name convention

The COMPASS-U tokamak will have every Poloidal Field coil supplied by an independent converter. Figure 6.2.4 contains the names of the individual PF coils of the COMPASS-U tokamak.

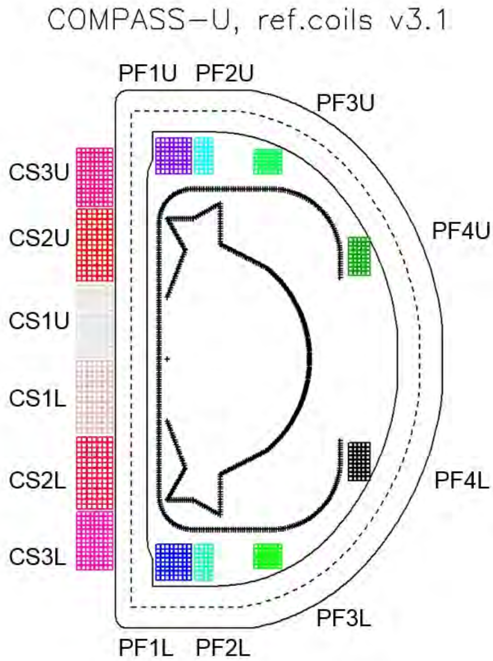


Figure 6.2.4: Names of the Poloidal Field coils are: CS1-3 (Central Solenoid) U and L (Upper and Lower) and PF1-4 (Poloidal Field). Multiple black crosses show the contour of the vacuum vessel and Plasma Facing Components. Black lines (and a dashed line) show the contours of the TF coils. These are the reference PF coils, version 3.1. The version v4.1 will have 8 CS coils located inside of the magnetic field area of the TF coil. One additional coils circuit (VSU+VSL - Vertical Stability Upper/Lower) for vertical stabilization of the plasma is not shown - it will be placed near one of the PF1-4 coils.

There are 16 Poloidal Field coils in the version v3.1 (6xCS, 8xPF, 2xVS), to be supplied by 15 Power Supplies (VSU and VSL are connected in series into a circuit).

There are 18 Poloidal Field coils in the tokamak version v4.1 (8x CS, 8xPF, 2xVS), to be supplied by 13 Power Supplies (VSU and VSL are connected in series into a circuit, 4 supplies for 8 CS coils).

Note that **only 12 Poloidal Field coils Power Supplies** (and 1 Power Supply for Toroidal Field coils) **are part of the delivery** of the “Power Supply System for COMPASS-U tokamak”.

6.2.3.2.2 Typical Poloidal Field coils waveforms

In a simplified manner, it can be said that there are three main tasks for the Poloidal Field coils:

- provide voltage for the plasma column
- control the plasma shape
- control the plasma position

Firstly, the voltage for the plasma column should be explained. The plasma column can be viewed as a 2 MA single turn coil in the middle of the PF coils. The Central Solenoid and PF1-4 act together as a primary winding in the air-core transformer, where the plasma column is a short-circuited secondary winding. The voltage for the plasma column is provided by changing the PF coils current from a negative maximum to a positive maximum in a feedback loop from the plasma current measurement (see Figure 6.2.5). All of the PF coils form a so-called virtual magnetizing field (VMF) circuit for this purpose - current waveforms in the individual coils are determined by a ratio from 0 to 1 from the current in the VMF circuit.

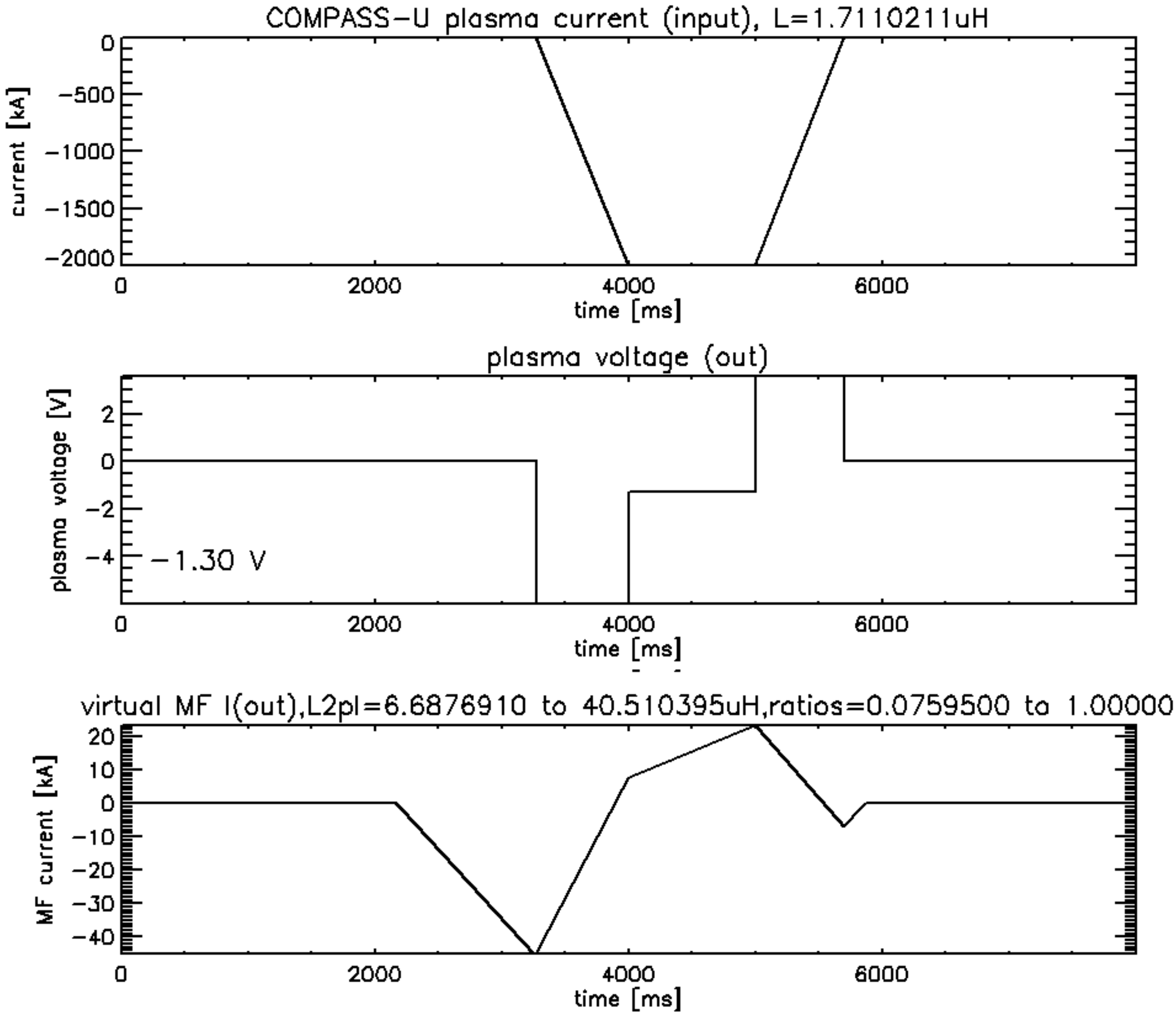


Figure 6.2.5: Nominal baseline plasma current waveform for tokamak v3.1 (top panel). Inductive voltage applied to the plasma from the virtual magnetizing circuit (middle panel). Current waveform $I_{magnetizing}$ in the virtual magnetizing circuit (bottom panel).

Secondly, the control of the plasma geometrical shape should be explained. The basic shape of the plasma column is circular. In order to change and control the shape, the PF coils require a current that is directly proportional to the immediate plasma current and depends on the required plasma shape.

Thirdly, the plasma position control should be explained. The plasma column position is unstable in the external magnetic field. It requires a feedback control of both radial and vertical position. This is provided by vertical and radial magnetic field, which is created by PF coils.

Therefore, the **typical current waveform of one of the PF coils** can be viewed as a sum of the three previously explained components:

$I_{PF,i}$ [A] (t) = $k_{magnetizing,i}$ * $I_{magnetizing}$ [A] (t) + $k_{shaping,i}$ * I_{plasma} [A] (t) + position control contribution

As a representative example, Figure 6.2.6 shows a current waveform in the CS1U coil (strong magnetizing component, sizeable shaping component) and in the PF4U coil (small magnetizing component, strong shaping component). Note that the position control contribution is not included in these predicted / simulated waveforms. The real current waveform can vary significantly, depending on the plasma behaviour and position control – **see section "6.3.2 - Real life temporal evolution of**

currents on the COMPASS tokamak" for examples of difference between theoretical and real-life current waveforms.

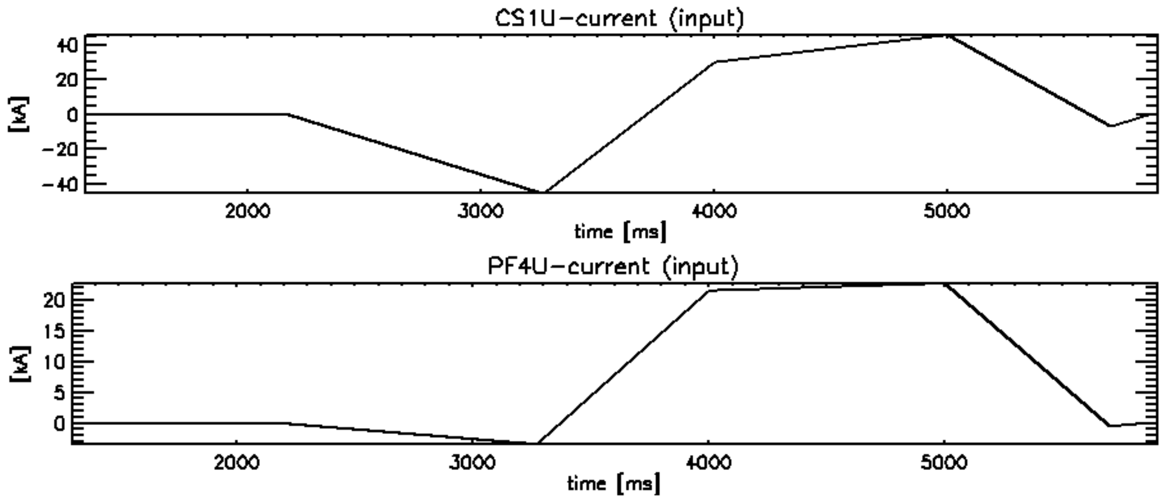


Figure 6.2.6: CS1U (top panel) and PF4U (bottom panel) current waveform example for v3.1, nominal baseline scenario.

In the case that the control of the plasma column is lost, plasma disruption occurs. During the plasma disruption, the 2 MA plasma current is decreased to 0 A within the time scale of ~ 5 ms. This induces additional current into the PF coils. The Power Supplies must be protected against this event.

The **detailed analysis of the current, voltage, power, consumed energy and disruption induced over-current** for the individual coils for both tokamak versions v3.1 and v4.1 is provided in Section **6.3 - Description of the Poloidal Field coils** behaviour.

The specific **rating of the individual converters, which are part of the delivery of the Power Supply System,** is provided in Section **5.6 - Converters for Poloidal Field coils, capacitor bank and energy dissipator**.

6.2.3.2.3 Combined PF coils energy and power requirements

The combined (=summed) power and energy requirements for the tokamak version v3.1 are in the Figure 6.2.7 (nominal baseline scenario) and Figure 6.2.8 (fastest plasma current ramp-up scenario).

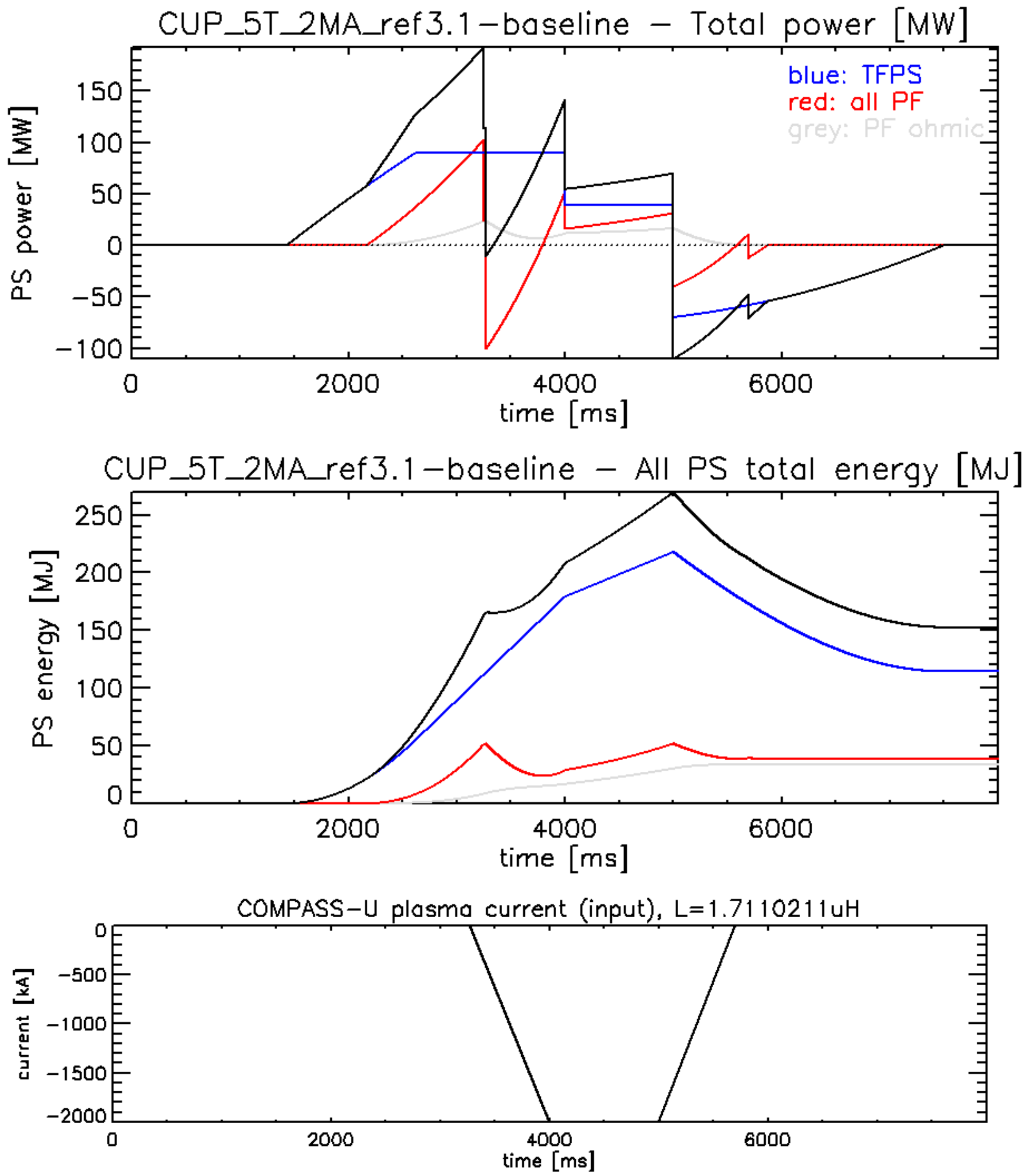


Figure 6.2.7: Nominal baseline plasma scenario (2 MA plasma current with flat-top duration 1 second, plasma current ramp-up rate 2.75 MA/s), tokamak version v3.1.

Figure 6.2.7 shows power and energy requirements for all combined PF coils for the nominal baseline plasma scenario, tokamak version v3.1. This is a scenario with standard plasma current ramp-up rate (2.75 MA/s), maximal plasma current (2 MA) and nominal plasma flat-top duration (1 second). Longer plasma current flat-top duration is possible, but it is limited by tokamak coils temperature change (< 80 kelvin allowed).

The PF coils (primarily CS coils) currents are ramped to the negative maximum in time 2200 ms – 3300 ms, draining energy from the flywheel generators with power up to 100 MW, usable energy drain is ~50 MJ. During the period t = 3300 ms – 4000 ms, the plasma current is ramped up, while the current in the PF coils is decreased. The energy previously stored in the PF coils magnetic field (~40 MJ) is first decreased as well, necessitating energy dissipation from the DC-interlink (/-s) with power ~100 MW. The plasma current flat-top lasts from 4000 ms to 5000 ms - the PF coils power requirements are modest, energy is used to cover the ohmic losses in the coils and to provide voltage for the plasma column. The plasma current ramp-down is between 5000 ms and 5700 ms. Energy from the PF coils should be again dissipated.

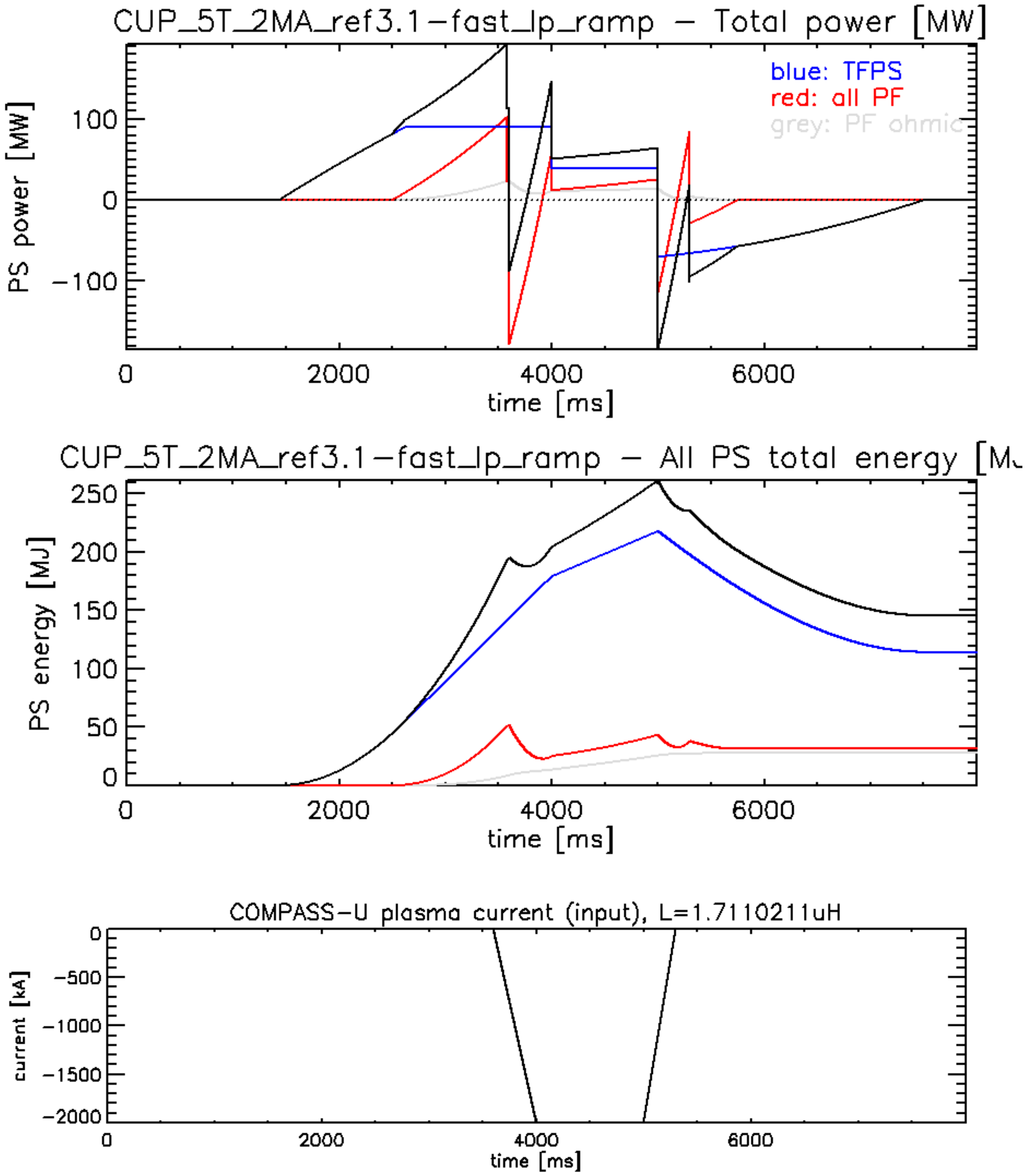


Figure 6.2.8: Fastest plasma current ramp-up scenario (2 MA plasma current with flat-top duration 1 second, plasma current ramp-up rate 5 MA/s), tokamak version v3.1.

It should be specifically noted that the total magnetic energy in the PF coils and in the plasma is <~40 MJ. Furthermore, the ohmic losses in the PF coils are significant (the cross-section of the turns is significantly lower than in the TF coils).

Figure 6.2.8 shows power and energy requirements for all combined PF coils for the fastest plasma current ramp-up scenario, tokamak version v3.1. This is the scenario with the fastest plasma current ramp-up rate (5 MA/s), maximal plasma current (2 MA) and nominal plasma flat-top duration (1 second). Longer plasma current flat-top duration is possible, but it is limited by tokamak coils temperature change (< 80 kelvin allowed). The difference compared to the baseline scenario is that the PF coils energy dissipation requirement during plasma current ramp-up is increased to 180 MW. The energy requirements for the PF coils remain similar as well as the power drained from the flywheel generators.

The combined power and energy requirements for the tokamak version v4.1 are in the Figure 6.2.9 (nominal baseline scenario) and Figure 6.2.10 (fastest plasma current ramp-up scenario).

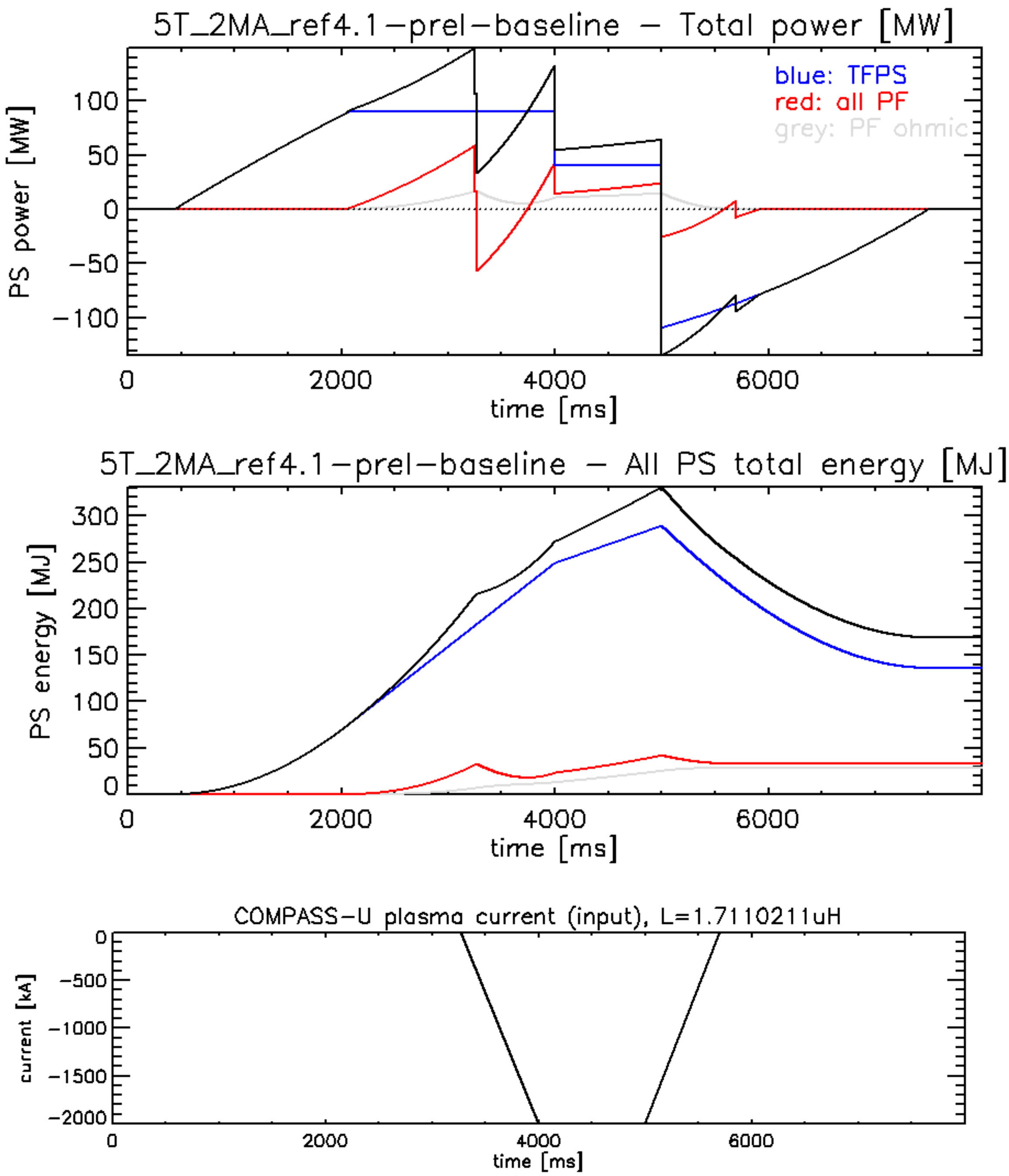


Figure 6.2.9: Nominal baseline plasma scenario (2 MA plasma current with flat-top duration 1 second, plasma current ramp-up rate 2.75 MA/s), tokamak version v4.1.

Figure 6.2.9 shows that the PF coils power requirements for the nominal baseline plasma scenario, tokamak version v4.1, are roughly 2x lower than for the tokamak version v3.1. This is caused by different positions of the Central Solenoid coils. Effectively, this means that the Central Solenoid coils can be ramped to the negative maximum 2x faster if full 100 MW available from the existing flywheel generators is used, saving ohmic losses and, therefore, lowering temperature change of the CS coils and allowing longer plasma flat-top phase.

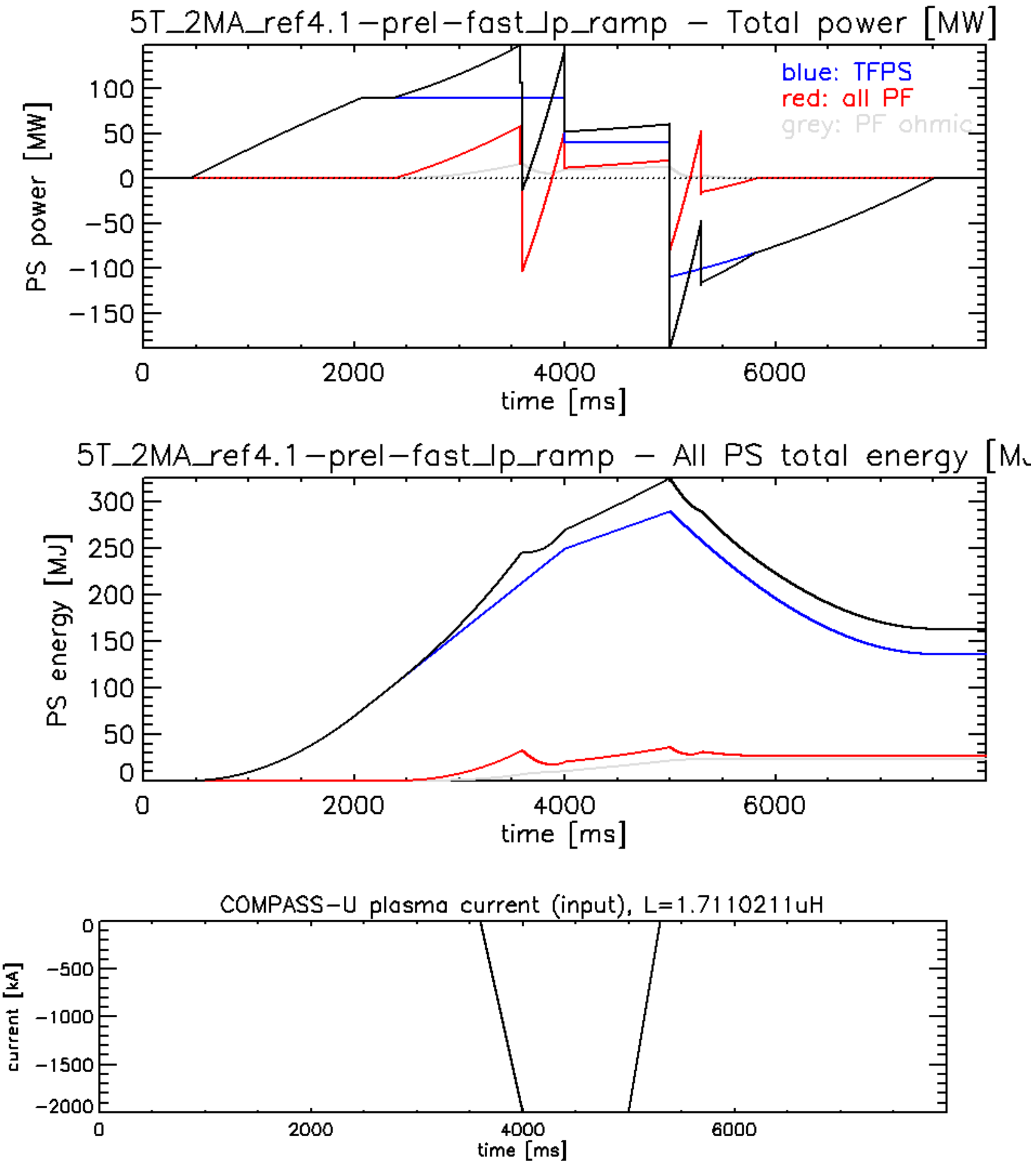


Figure 6.2.10: Fastest plasma current ramp-up scenario (2 MA plasma current with flat-top duration 1 second, plasma current ramp-up rate 5 MA/s), tokamak version v4.1.

The detailed analysis for the tokamak version v4.1 is preliminary. The preliminary conclusion, from the point of view of the Power Supply System, is:

- TF coils energy demand increases to 290 MJ (v4.1) from 220 MJ (v3.1)
- Flywheel generators power for the PF coils is 50-100 MW (v4.1), lowered from 100 MW (v3.1)

- Flywheel generators energy required for the PF coils remain 80 MJ (both v4.1 and v3.1)
- Energy dissipation long pulse (hundreds of ms or longer) power rating is lowered to ~100 MW (v4.1) from ~200 MW (v3.1)

6.2.3.3 Additional Heating Systems

In the frame of the COMPASS-U project, the Institute of Plasma Physics assumes the following additional (auxiliary) tokamak heating systems:

1. 2 x 0,5 MW heating by Neutral Beam Injection (NBI) using the existing NBI injectors
2. 4 x 1 MW heating by newly built NBI injectors
3. (1-4) MW heating by Electron Cyclotron Resonance Heating (ECRH)

The total power delivered to plasma by these additional heating systems will be 6-9 MW. Electrical efficiency of the heating systems is 30-40 %. Therefore, the required input power reserved for the additional heating was selected to be at least 25 MW. The duration of the heating at maximal parameters is expected to be 1-2 seconds, therefore, the energy consumption is 50 MJ (see **exact values required as a part of the Power Supply System delivery** in the sections **5.7 - Additional heating systems and other loads** and **5.1 - General requirements**).

Considering the effort to assure the upgradeability of the COMPASS-U tokamak in the following decades, **the values** 25 MW and 50 MJ for additional heating systems **should be considered as minimal**. The Power Supply System should be designed with the possibility of upgrade for the case of approximately double power and energy requirements of the additional heating systems.

The requirement for the Power Supply System Contractor is to:

- provide power and energy reserved in the flywheel generator/s (see section 5.7 - Additional heating systems and other loads)
- provide HV breakers in the switchgear for transformers, include the additional heating systems into the PSS protection (see sections 5.4 - HV switchgear and 5.8 - Control system requirements)
- incorporate the transformers for the additional heating systems into the system (see 5.3 - Transformer requirements).

6.2.4 Flywheel generators

The total energy required for COMPASS-U at the output of the Power Supply System is at least 420 MJ (TF coils: 290 MJ, PF coils: 80 MJ, additional heating: 50 MJ). This is a minimal number. For the operation of the COMPASS-U tokamak, it would be useful to increase it up to ~650 MJ (TF: 450 MJ, PF: 100 MJ, heating 100 MJ), but higher increase is no longer beneficial for the tokamak. The losses in the Power Supply System - energy used for excitation of flywheel generators, ohmic losses in the flywheel generators, transformers and Power Supplies - are not included in these numbers.

The above-mentioned physics considerations are the basis for the **Annex No. 5 – Evaluation matrix** (which is annex of the Tender documentation), where **the requirement for the mechanical energy stored in the new (additional) flywheel generators and its influence on the tender evaluation can be found**. The values listed in the Evaluation matrix are the above mentioned minimal and maximal output energy, with existing flywheel energy subtracted and with anticipated system losses added.

There are multiple available options how to provide the required energy for the COMPASS-U tokamak and how to organize the individual loads to the flywheel generators.

6.2.4.1 Existing generators (2 x 50 MVA, 2 x 50 MJ)

The two existing flywheel generators have nominal (i.e. nominal pulsed) rating 50 MVA, ~50 MJ (each) for rotation speed change 1700 rpm to 1300 rpm. Their field (primary, exciter) winding in rotor is excited by two 1.3 MVA transformers. They provide energy into two electrically separated three-phase

6 kV grids.

The moment of inertia of each generator is 8600 kg.m^2 (1700 kg.m^2 generator and 6900 kg.m^2 flywheel). Therefore, the nominal available kinetic energy is 56.6 MJ. The 6.6 MJ difference compared to the nominal energy is assumed to be used for excitation and covering the losses in the existing Power Supply System.

The operational limits of the existing flywheel generators are:

- Upper rotation speed limit: ~1750 rpm. According to the consultations with the designer of the flywheel generators, this is the maximal achievable rotation speed. The flywheel is mechanically connected to the shaft only by friction. There is a concern that it would slip if centrifugal force were increased by higher rotation speed.

- Lower rotation speed limit: 1300 rpm for nominal (pulsed) power. It can be decreased if torque between the flywheel and the shaft is not increased. The flywheel could slip on the shaft if the power drained from the generator were kept at nominal value at lower rotation speed. The rate of change of rotation speed dω is increasing with decreasing rotation speed in order to keep the same power ($P \sim \omega \times d\omega$), increasing torque.

- The nominal (pulsed) output current limit. The power delivered by the flywheel generators is limited at 50 MVA by the maximal allowed nominal (pulsed) current 4.8 kA. Maximal short circuit current Ic_{MAX} is 29,5 kA.

The existing flywheel generators will be used in the Power Supply System for COMPASS-U Tokamak with nominal (pulsed) power and energy rating.

The extension of the operational rotation speed was considered (e.g. rotations speed range 1750-1100 rpm would provide 2x 76 MJ of usable energy), but it was decided that this possibility should not be pursued in this public tender and it should serve as a reserve for the future. This possibility would require appropriate solution to ensure the safe operation, including accident situations (e.g. limitation of the power at lower rotation speed, pyro-breaker for accident scenarios …).

6.2.4.2 Additional generators

The COMPASS-U project will require installation of at least one additional flywheel generator (as required in “Power Supply System for COMPASS-U tokamak - Basic Configuration”). The maximal allowed number of the additional generators is two (Basic Configuration and Extended Option “Second new flywheel generator and its auxiliary systems”; more generators can be used in future upgrades).

The output voltage of the additional flywheel generators is preferred to be three-phase, 6 kV, in order to allow redundancy in case of maintenance of one of the flywheel generators (using lower power and energy for the tokamak). However, different voltage or number of phases is allowed.

The additional flywheel generator / generators are not required to maintain the output voltage during the rotation speed decrease (the existing flywheel generators maintain the output voltage during the rotation speed decrease). The disadvantages of this possibility (e.g. necessity to use converters that are more expensive in the additional heating systems) are taken into account by penalization in the public tender evaluation, see Annex No. 5 – Evaluation matrix (annex of the Tender documentation).

The auxiliary systems of the generators (exciter, transformer for the motor power supply, ventilation, cooling, oil management, control…) must be included in the delivery of the Power Supply System (in both Basic configuration and Extended Option separately).

See section **5.2 - Requirements for flywheel generators** for exact requirements on the flywheel generators.

6.2.5 Transformers

The requirements for the transformers for the Power Supply System for COMPASS-U Tokamak are described in the section **5.3 - Transformer requirements**. The majority of the requirements were selected to satisfy the requirements of the power supplies whose requirements are in sections 5.5 - Converters for Toroidal Field coils and 5.6 - Converters for Poloidal Field coils, capacitor bank and energy dissipator.

It should be noted that the requirements listed in the section "5.3 - Transformer requirements" are minimal public tender requirements. The actual size, power and current rating of the transformers must be selected by the Contractor in order to allow proper functionality of the connected sub-systems of the Power Supply System. For example, the transformers for Toroidal Field Power Supply may require higher "nominal pulsed current" and lower "relative short circuit test voltage" for proper functionality (proper switching of the thyristors) of the Toroidal Field Power Supply.

The key element of the transformers are ohmic and magnetizing losses. These should be minimized due to the tense energy balance of the COMPASS-U tokamak. Inductive reduction of voltage on the secondary winding decreases the transferred power, but does not consume energy from the generator.

It is in the interest of the Client to re-use the existing transformers, **see chapter "5.12 - Requirements for the utilization of the existing Power Supply System" for exact re-use requirements**. The **list of the existing transformers** is in the **section 6.5.4 - Transformers**.

6.2.6 Power Supplies

IPP requires utilization of the existing thyristor power supplies (26 blocks in 13 rack cabinets, each block capable of delivering 6 kA DC in pulsed operation; see 6.5 - Existing Power Supply System; requirement is listed in the chapter 5.12 - Requirements for the utilization of the existing Power Supply System) for the TF coils. It is possible either to increase the current rating by exchanging the thyristors or to supplement the converters by building more blocks.

Furthermore, installation of new transistor-based converters for the PF coils is expected.

The assumed (though not guaranteed) usage of the Power Supplies included in the delivery of the Power Supply System is as follows:

Tokamak version v3.1 – assignment of the Power Supplies to the tokamak coils			
Number	Tokamak coil name	Power Supply name	Comment
0	TF coil	TFPS	Toroidal Field coil
1	CS1U	CS PS1	Central Solenoid coils – 6 coils, only 4 Power Supplies => the Power Supplies can be assigned to any of the CS coils
2	CS1L	CS PS2	
3	CS2U	CS PS3	
4	CS2L	CS PS4	
5	CS3U	Not part of the PSS delivery	

6	CS3L	Not part of the PSS delivery	
7	PF1U	PF1U PS	
8	PF1L	PF1L PS	
9	PF2U	PF2U PS	
10	PF2L	PF2L PS	
11	PF3U	PF3U PS	
12	PF3L	PF3L PS	
13	PF4U	PF4U PS	
14	PF4L	PF4L PS	
15	VSU+VSL	Not part of the PSS delivery	Vertical Stability coils, connected in series

Tokamak version v4.1 – assignment of the Power Supplies to the tokamak coils			
Number	Tokamak coil name	Power Supply name	Comment
0	TF coil	TFPS	TFPS
1	CS1U + CS1L	CS PS1	Central solenoid coils – 8 coils connected in pairs in series to 4 Power Supplies
2	CS2U + CS2L	CS PS2	Above and below midplane
3	CS3U + CS4U	CS PS3	Two top coils of CS
4	CS3L + CS4L	CS PS4	Two bottom coils of CS
5	PF1U	PF1U PS	PF1U PS
6	PF1L	PF1L PS	PF1L PS
7	PF2U	PF2U PS	PF2U PS
8	PF2L	PF2L PS	PF2L PS
9	PF3U	PF3U PS	PF3U PS
10	PF3L	PF3L PS	PF3L PS
11	PF4U	PF4U PS	PF4U PS
12	PF4L	PF4L PS	PF4L PS

13	VSU+VSL	Not part of the PSS delivery	Vertical Stability coils, connected in series

6.2.6.1 Power Supply for the Toroidal Field Coils

The Toroidal Field coils do not require a feedback control from the point of view of the tokamak control system; the current changes are slow and can be pre-programmed. Thyristor power supplies are therefore more suitable than transistor based ones.

It is possible to use either 12- pulse or 24-pulse converter setting. The 24-pulse setting is not required because the current will be smoothed by high self-inductance of the TF coil, switching noise will be smoothed by the vacuum vessel with a long time constant. 6-pulse converter is not allowed because of the uneven loading of the transformers (at any moment, only two out of three phases carry current).

See sections **5.5 - Converters for Toroidal Field coils** and **5.3 - Transformer requirements** for exact requirements.

6.2.6.2 Power Supplies for the Poloidal Field Coils

Currents in the Poloidal Field coils have to be feedback-controlled based on the plasma behaviour. IGBT transistor based H-bridge Power Supplies with switching frequency 500 - 2000 Hz are required. The required control schemes are: 1/ PWM (pulse width modulation) and 2/ bang-bang control (specifically three-state bang-bang with dead zone: -max V, 0 V, + max V; with 0 V realized by alternating upper and lower transistors of the H-bridge). The switching frequency should be adjustable within 500 - 2000 Hz range.

The Power supplies must have output filter with time constant c. 5 µs to evenly distribute voltage around the turns of the coil during the transistor switching. This output filter must be part of the Power Supply System.

According to IPP calculations, the inertial cooling is not suitable to be used for transistor modules, active cooling is advised. The potential suppliers are advised to keep the distance between module heatsink surface and cooling channel < 1 cm and to use thermal grease with >3 W(m.K).

The list of the Poloidal Field coils Power Supplies included in the delivery of the Power Supply System, their exact current and voltage rating, including decision one/two voltage levels, sizing of the capacitor banks of the DC-interlink and rating of the energy dissipator are in the section **5.6 - Converters for Poloidal Field coils, capacitor bank and energy dissipator.**

6.2.6.3 Power Supplies for the Additional Heating Systems

The NBI heating systems (5 MW to plasma, approx. 17 MW input electrical power) will have their own high voltage (~80 kV) switching power supplies delivered by their manufacturer. From the point of view of the COMPASS-U Power Supply System, only the transformer/transformers integration and HV circuit breakers for protection are needed, see sections **5.7 - Additional heating systems and other loads**, **5.4 - HV switchgear** and **5.3 - Transformer requirements**.

The ECRH heating systems use similar type of HV switching power supplies. The ECRH is presently in the state of planning, therefore, from the point of the COMPASS-U Power Supply System, only a dedicated HV circuit breakers, reserves in the control and protection system and reserved space for transformers are required.

6.3 Description of the Poloidal Field coils behaviour

This section is divided into three parts:

1) Chapter **6.3.1 - Time-trace waveforms (current, voltage, power, energy) of PF coils and Power Supplies, v3.1 and v4.1** provides graphs with overview, geometry, current, voltage, power and energy waveforms for “nominal baseline” and “fast Ip ramp-up” scenarios for both versions of the tokamak (v3.1 and v4.1). The provided voltage waveforms show voltage averaged over Power Supply control period.
2) Chapter **6.3.2 - Real life temporal evolution of currents on the COMPASS tokamak** shows practical difference between theoretical (ideal) current waveforms and practical realization of these waveforms on example of the presently existing tokamak COMPASS.
3) Chapter **6.3.3 - Protection of the Power Supplies against plasma disruptions** provides information about fast ending of the plasma current (so called “disruption”). The Power supplies have to deal with instantaneous (5-15 ms) and significant (hypothetically up to 2 MA-turns for one coil and therefore on one Power Supply) current change induced from the decaying plasma current into the tokamak coils.

6.3.1 Time-trace waveforms (current, voltage, power, energy) of PF coils and Power Supplies, v3.1 and v4.1

This section provides graphs with overview, geometry, current, voltage, power and energy waveforms for “nominal baseline” and “fast Ip ramp-up” scenarios for both versions of the tokamak (v3.1 and v4.1). The provided voltage waveforms show voltage averaged over Power Supply control period.

6.3.1.1 Basic electrical parameters of the PF coils (resistance, self-inductance, turn count) and their assigned Power Supplies

Table 6.3.1: Basic parameters of the PF coils and their respective Power Supplies for the tokamak version v3.1.

COMPASS-U PF coils ref 3.1

Coil description			
Coil name	R [mΩ]	L [mH]	Turn count, N
CS1U	1.68	3.51	98
CS1L	1.68	3.51	98
CS2U	1.68	3.51	98
CS2L	1.68	3.51	98
CS3U	2.37	4.38	104
CS3L	2.37	4.38	104
PF1U	4.54	7.2	64
PF1L	4.54	7.2	64
PF2U	2.76	2.65	32
PF2L	2.76	2.65	32
PF3U	4.84	5.27	36
PF3L	4.84	5.27	36
PF4U	6.62	9.59	40
PF4L	6.62	9.59	40

Note: the resistance at LN2 temperature.

Power Supply System	
Power Supply name	Assigned PF coil
CS PS1	CS1U
CS PS2	CS1L
CS PS3	CS2U
CS PS4	CS2L
---	CS3U
---	CS3L
PF1U PS	PF1U
PF1L PS	PF1L
PF2U PS	PF2U
PF2L PS	PF2L
PF3U PS	PF3U
PF3L PS	PF3L
PF4U PS	PF4U
PF4L PS	PF4L

Table 6.3.2: Basic parameters of the PF coils and their respective Power Supplies for the tokamak version v4.1.

COMPASS-U PF coils ref 4.1

Coil description			
Coil name	R [mΩ]	L [mH]	Turn count, N
CS1U	0.81	1.05	30
CS1L	0.81	1.05	30
CS2U	0.81	1.05	30
CS2L	0.81	1.05	30
CS3U	0.81	1.05	30
CS3L	0.81	1.05	30
CS3U	0.81	1.05	30
CS3L	0.81	1.05	30
PF1U	4.54	7.2	64
PF1L	4.54	7.2	64
PF2U	2.76	2.65	32
PF2L	2.76	2.65	32
PF3U	4.84	5.27	36
PF3L	4.84	5.27	36
PF4U	6.62	9.59	40
PF4L	6.62	9.59	40

Note: the resistance at LN2 temperature.

Power Supply System	
Power Supply name	Assigned PF coil
CS PS1	CS1U + CS1L
CS PS2	CS2U + CS2L
CS PS3	CS3U + CS4U
CS PS4	CS3L + CS4L
PF1U PS	PF1U
PF1L PS	PF1L
PF2U PS	PF2U
PF2L PS	PF2L
PF3U PS	PF3U
PF3L PS	PF3L
PF4U PS	PF4U
PF4L PS	PF4L

6.3.1.2 Overview of the power and energy requirements, without additional heating

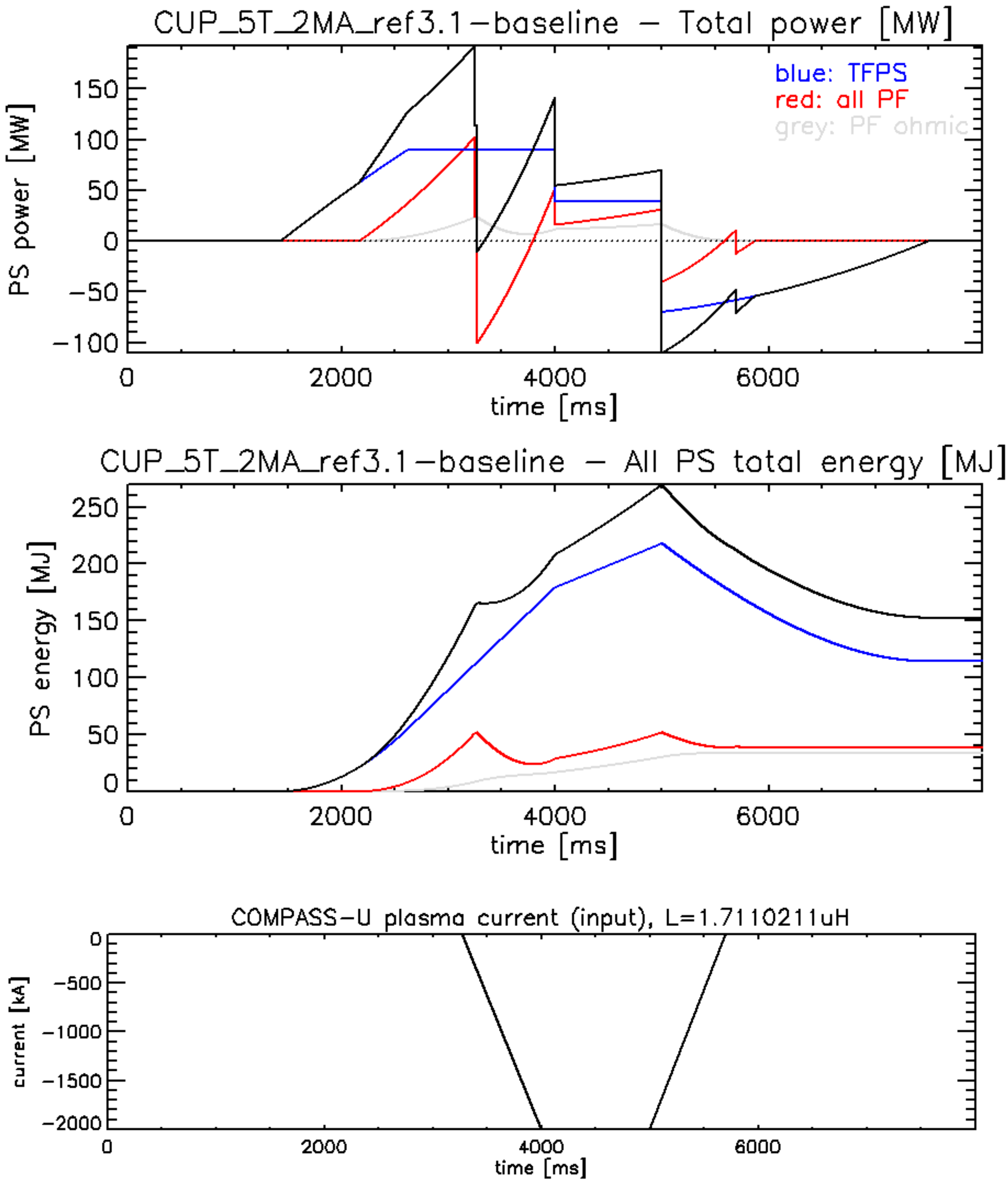


Figure 6.3.1: Overview of the total powers and energies (without additional heating) required from the Power Supply System for the "nominal baseline scenario" for the tokamak version v3.1.

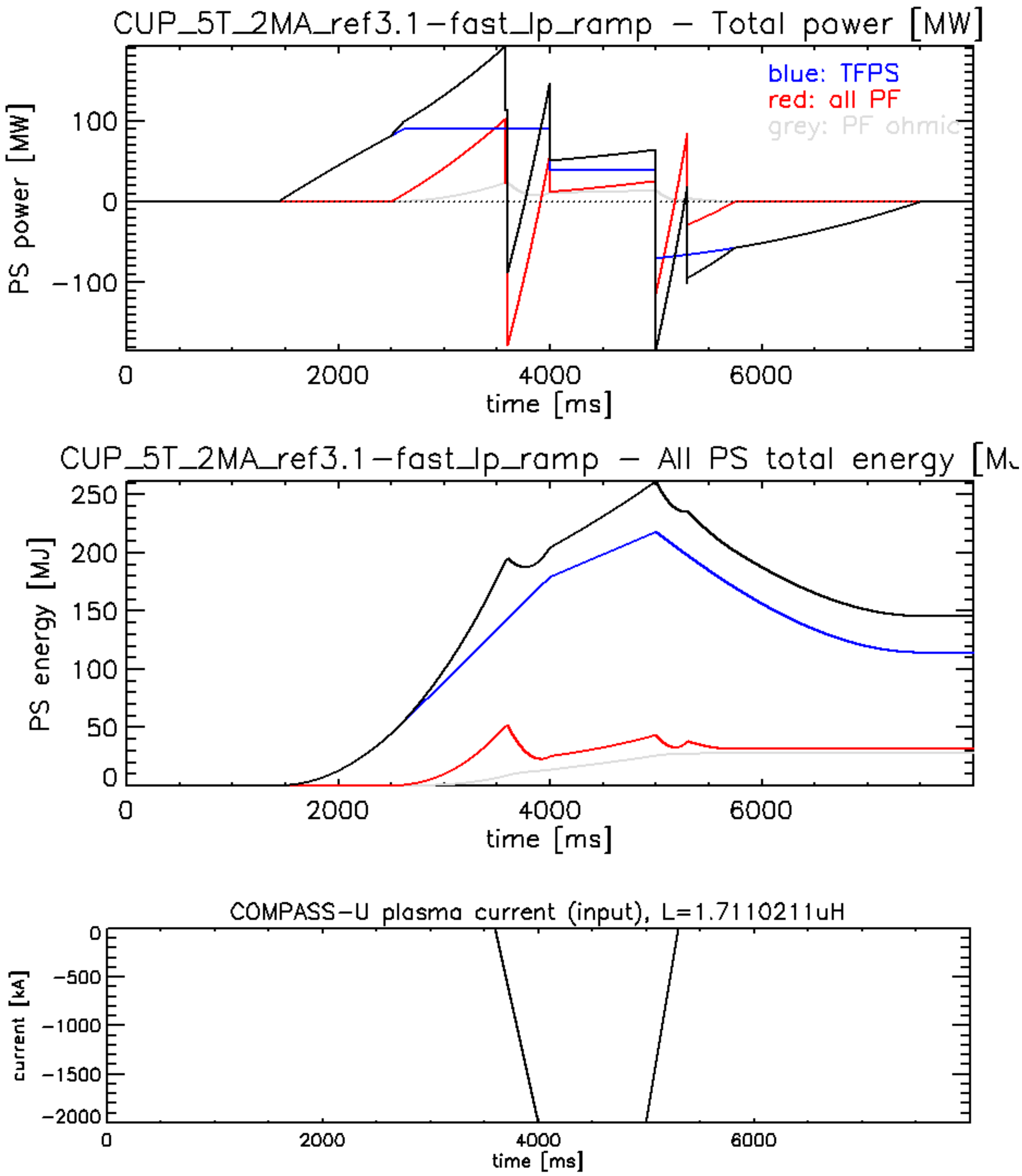


Figure 6.3.2: Overview of the total powers and energies (without additional heating) required from the Power Supply System for the “fast Ip ramp-up” scenario for the tokamak version v3.1.

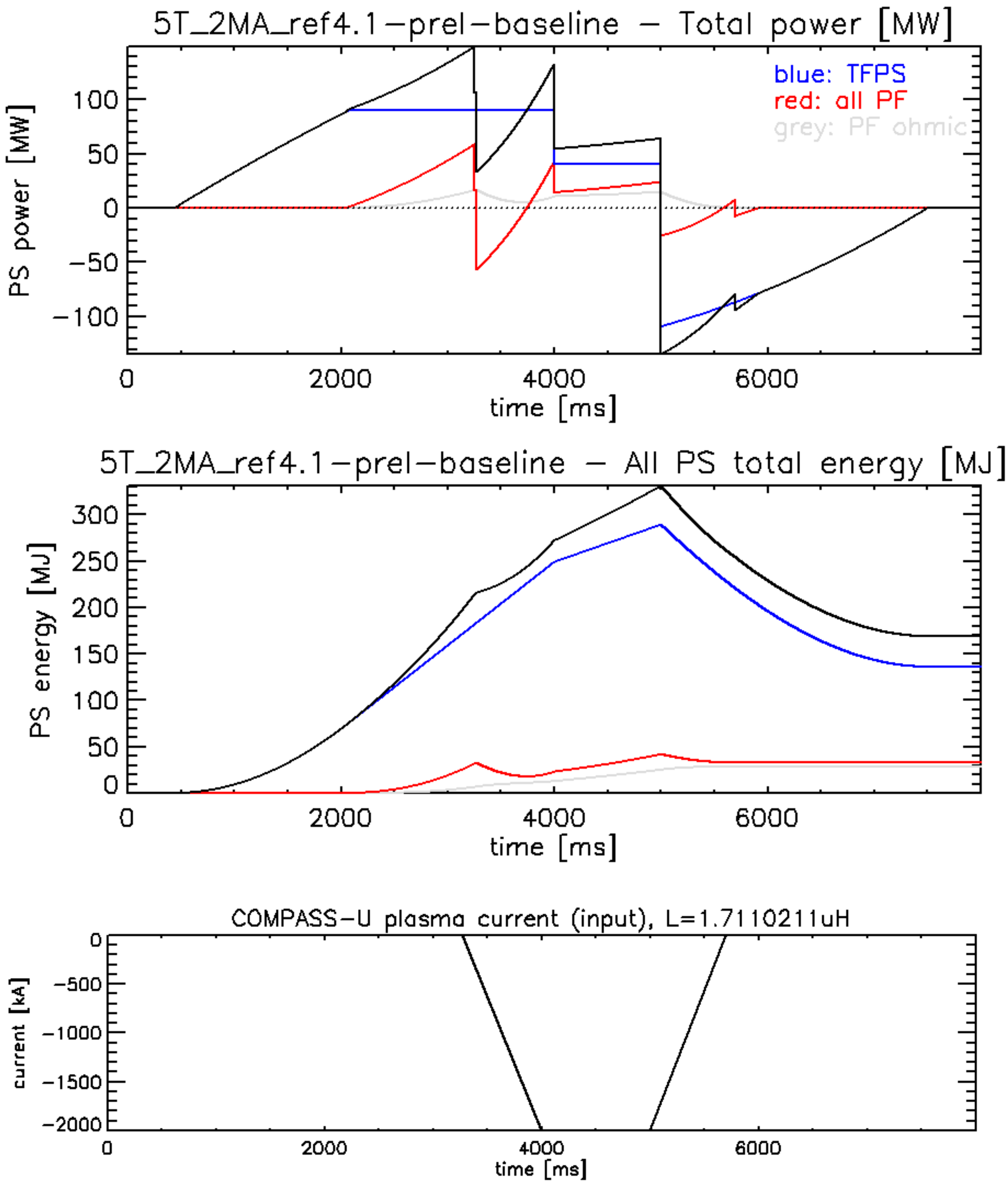


Figure 6.3.3 Overview of the total powers and energies (without additional heating) required from the Power Supply System for the "nominal baseline scenario" for the tokamak version v4.1 (8 Central Solenoid coils).

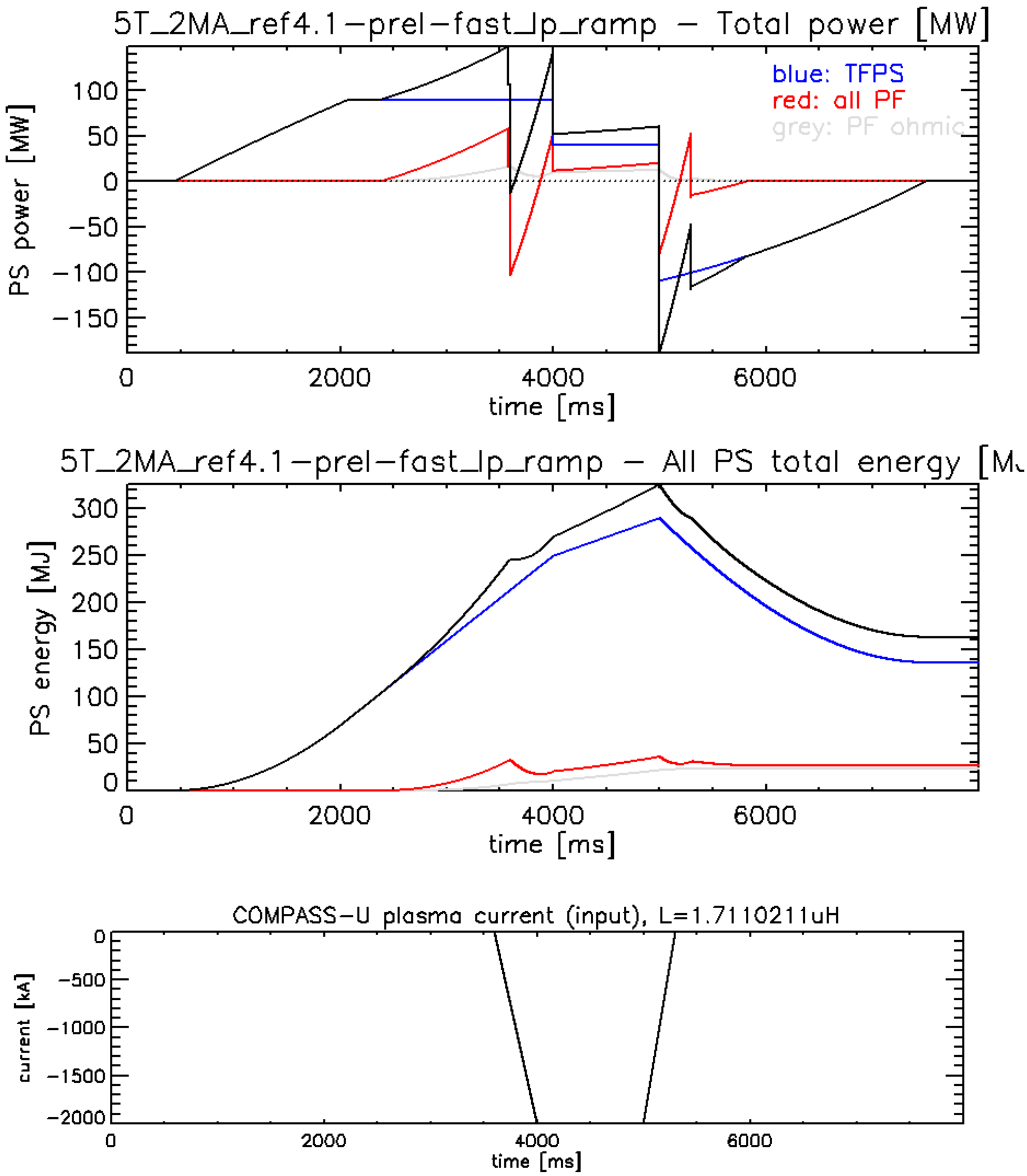


Figure 6.3.4 Overview of the total powers and energies (without additional heating) required from the Power Supply System for the “fast Ip ramp-up” scenario for the tokamak version v4.1 (8 Central Solenoid coils).

6.3.1.3 Indicative geometry

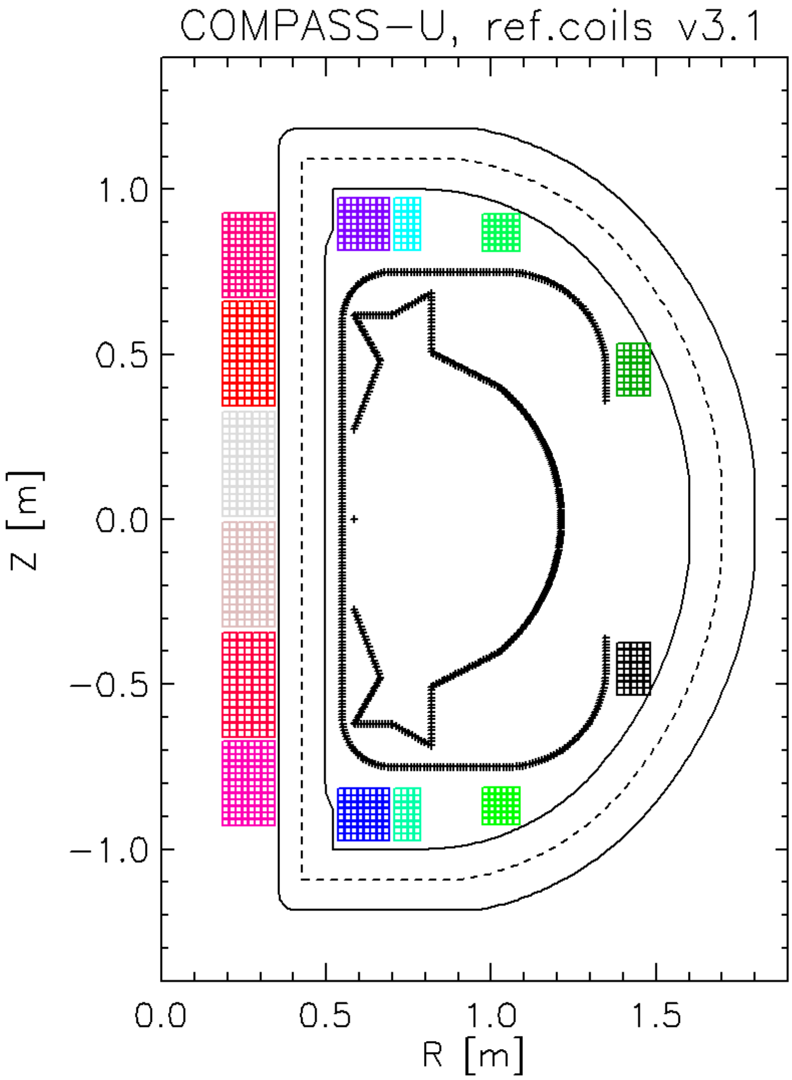


Figure 6.3.5 Geometry of the TF (black solid and dashed contours) and PF coils (colour squares) with depicted PF coil turns, vacuum vessel (black crosses) and the first wall (black crosses) for the tokamak version v3.1.

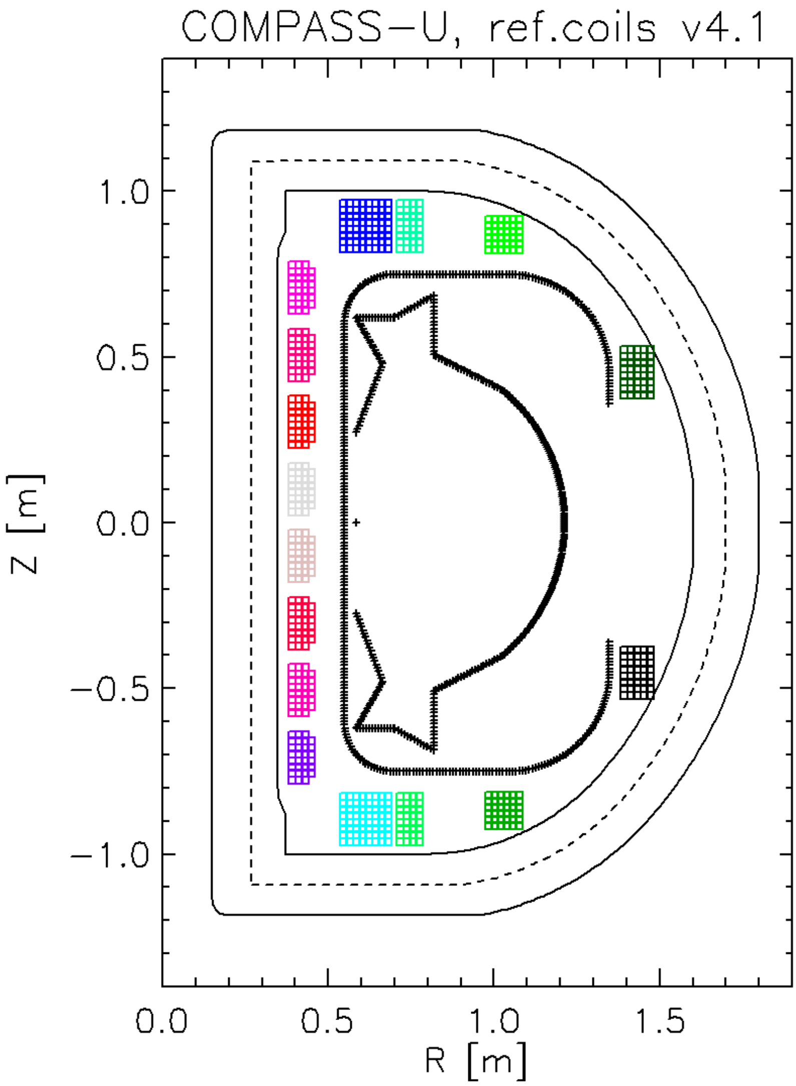


Figure 6.3.6 Geometry of the TF (black solid and dashed contours) and PF coils (colour squares) with depicted PF coil turns, vacuum vessel (black crosses) and the first wall (black crosses) for the tokamak version v4.1.

6.3.1.4 Current and voltage in plasma

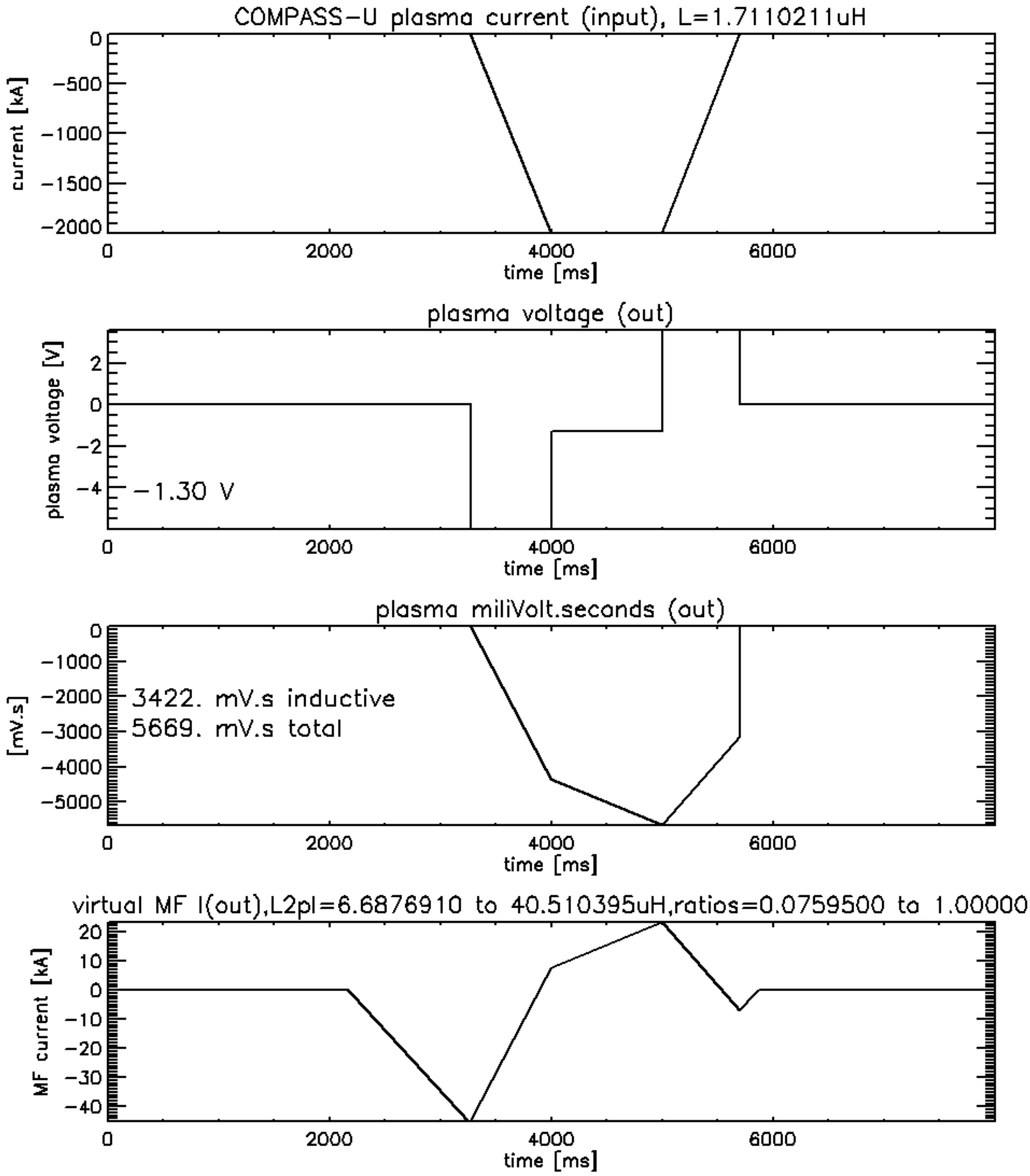


Figure 6.3.7 Waveforms of the plasma current, plasma voltage, consumed Volt-seconds and current in the VMF (Virtual Magnetizing Field) circuit for the “nominal baseline scenario” for the tokamak version v3.1.

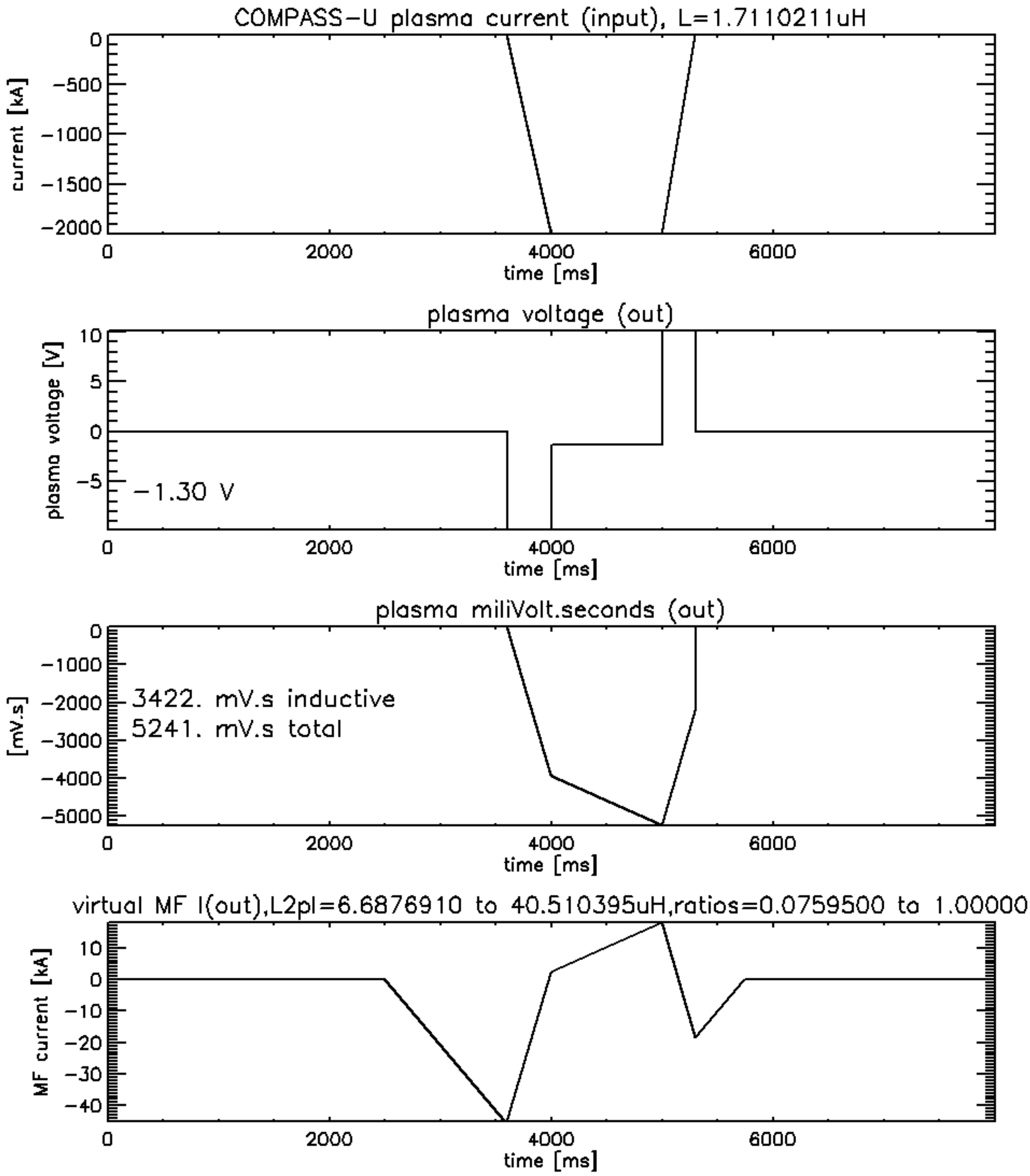


Figure 6.3.8 Waveforms of the plasma current, plasma voltage, consumed Volt-seconds and current in the VMF (Virtual Magnetizing Field) circuit for the "fast Ip ramp-up scenario" for the tokamak version v3.1.

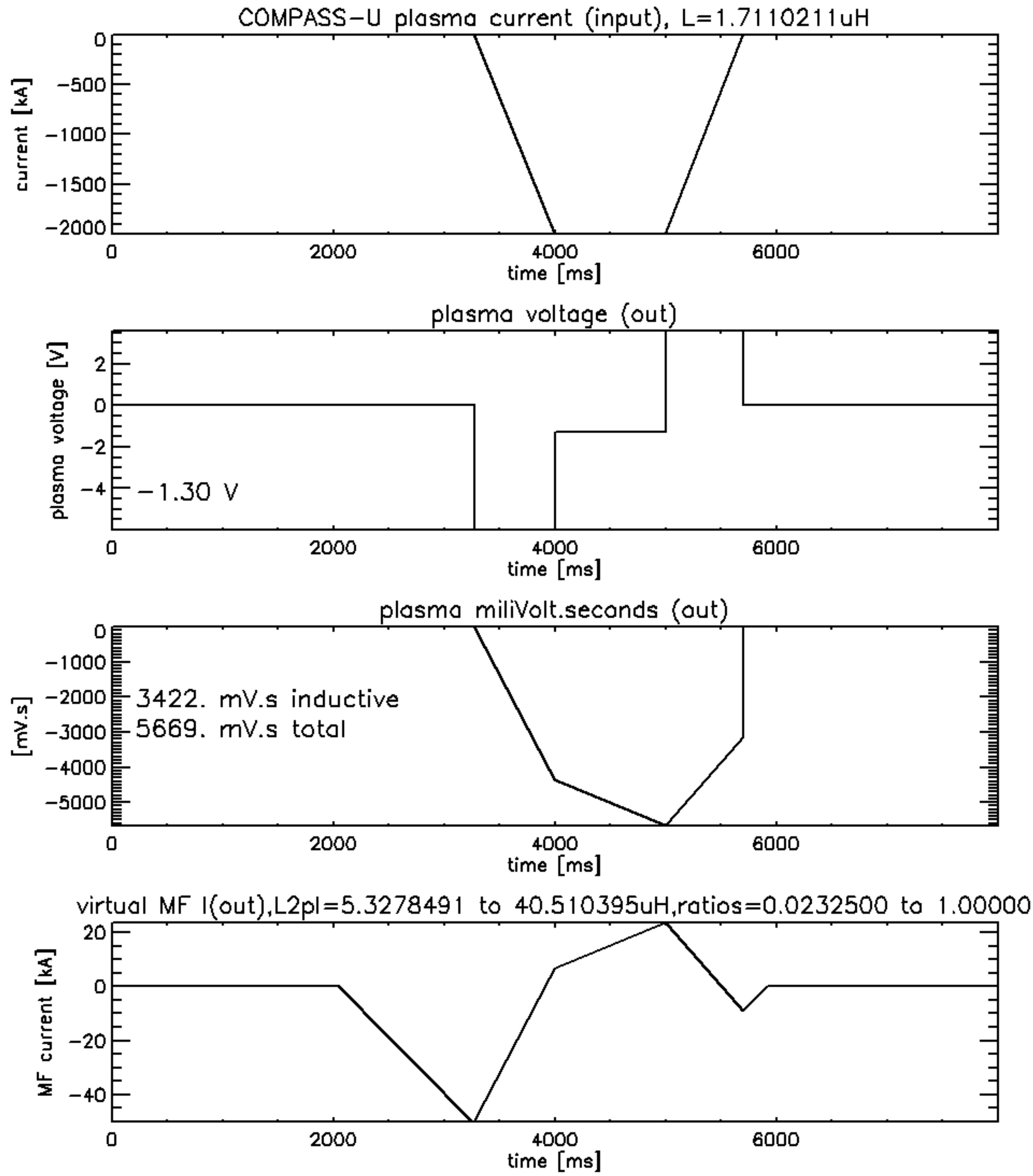


Figure 6.3.9 Waveforms of the plasma current, plasma voltage, consumed Volt-seconds and current in the VMF (Virtual Magnetizing Field) circuit for the "nominal baseline scenario" for the tokamak version v4.1.

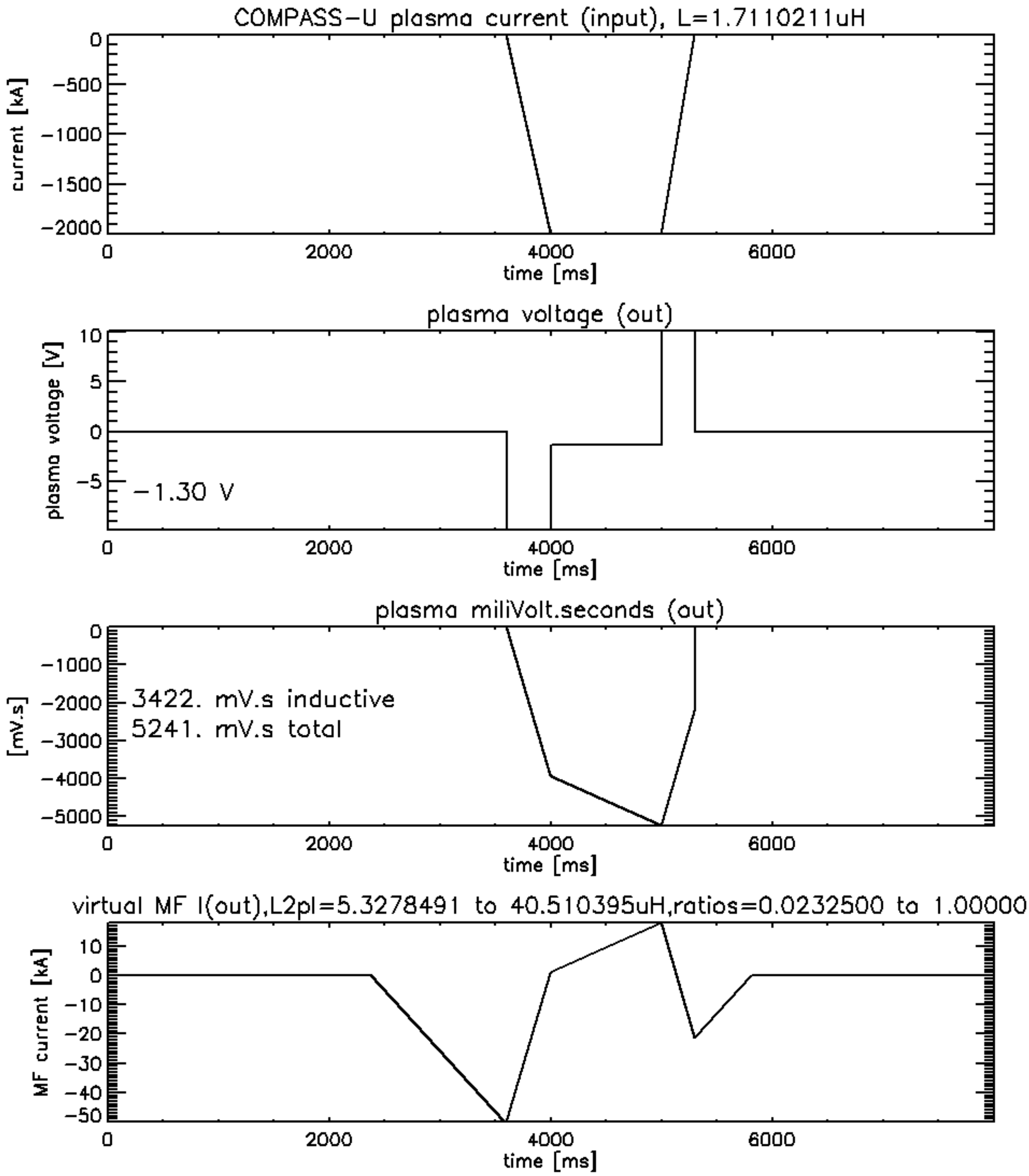
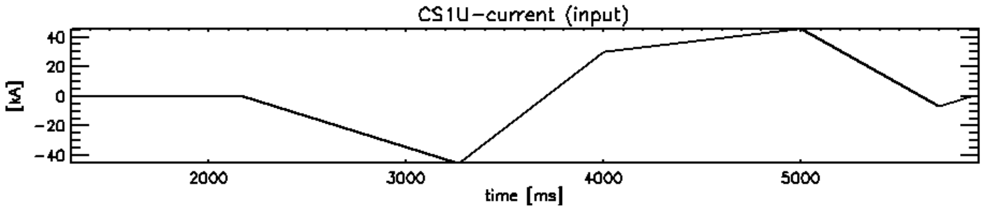
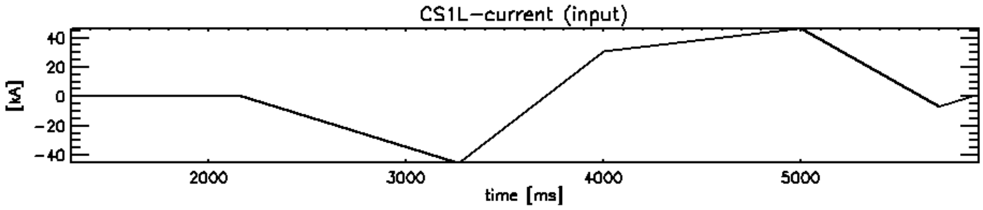
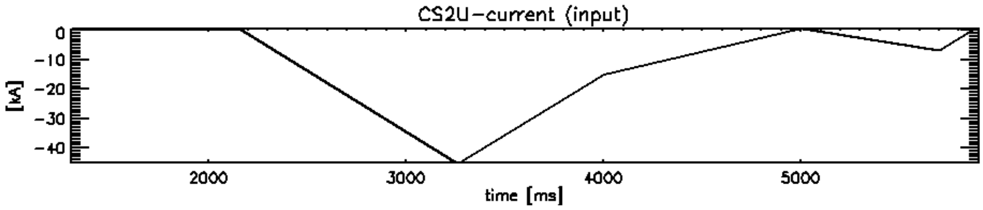


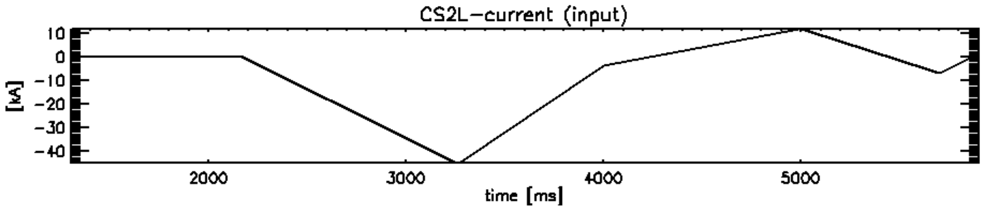
Figure 6.3.10 Waveforms of the plasma current, plasma voltage, consumed Volt-seconds and current in the VMF (Virtual Magnetizing Field) circuit for the "fast Ip ramp-up scenario" for the tokamak version v4.1.

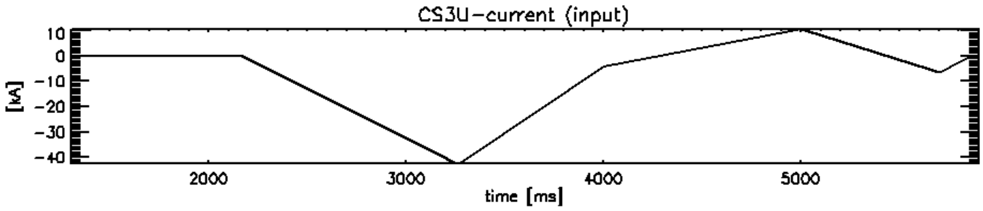
6.3.1.5 Currents in the PF coils

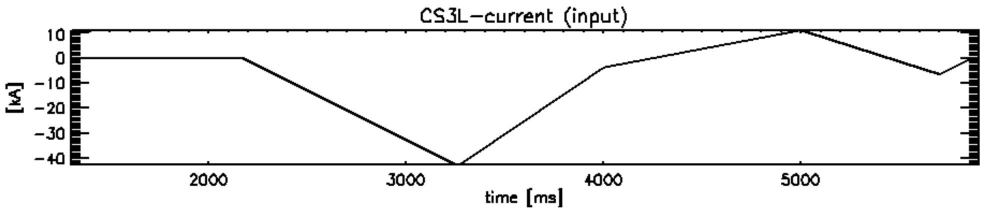


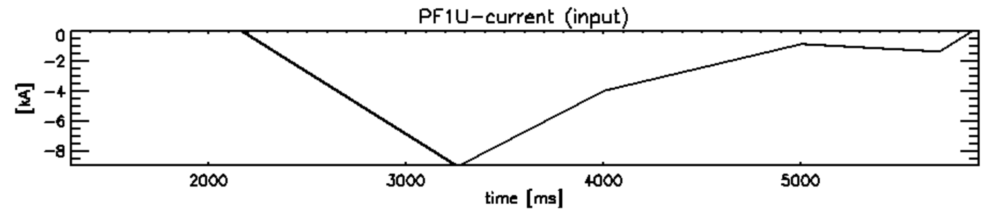












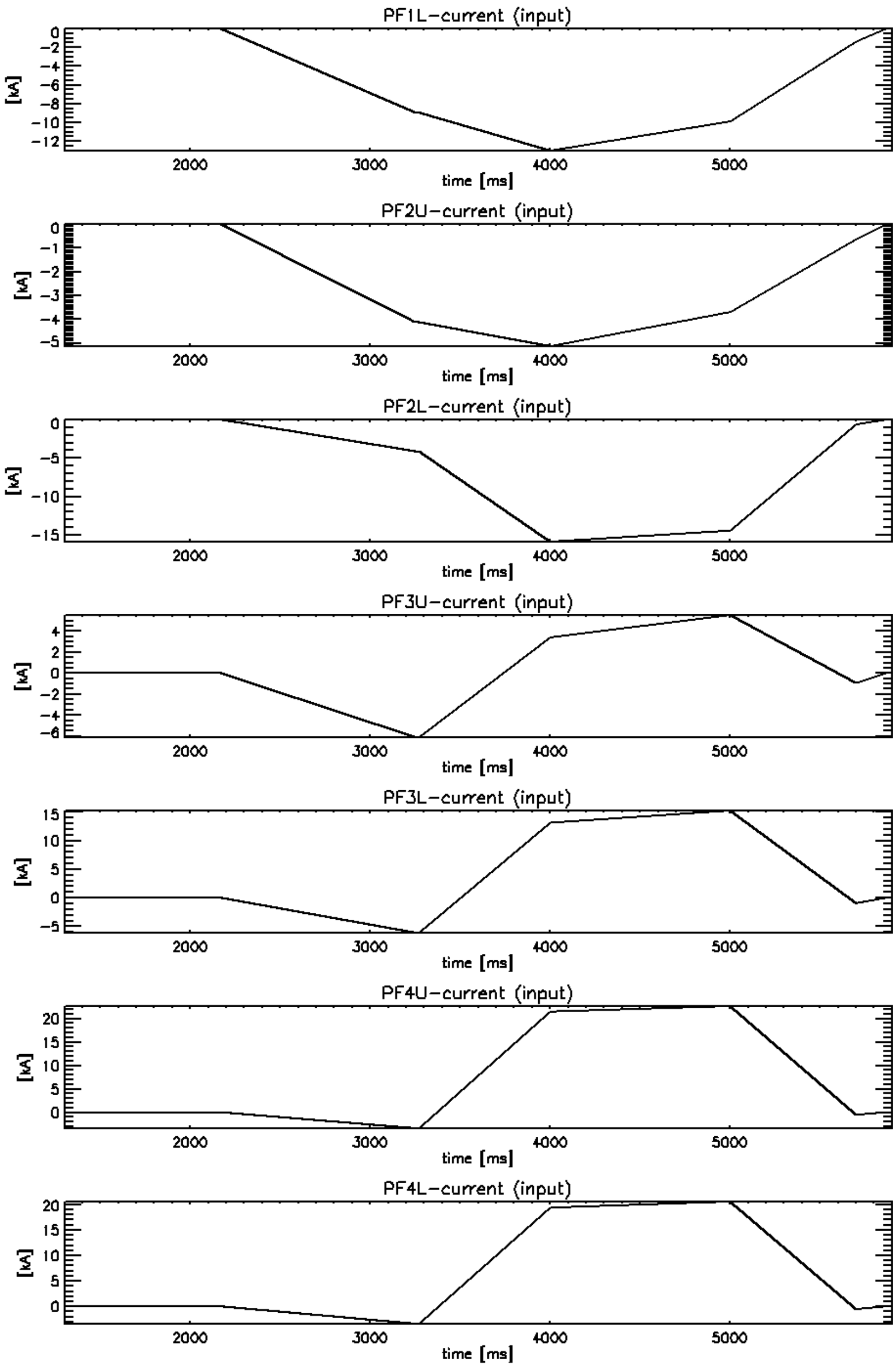
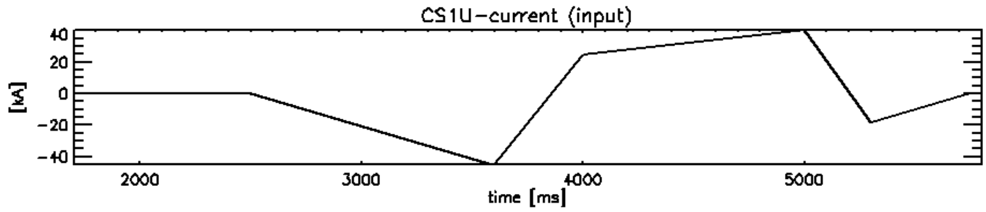
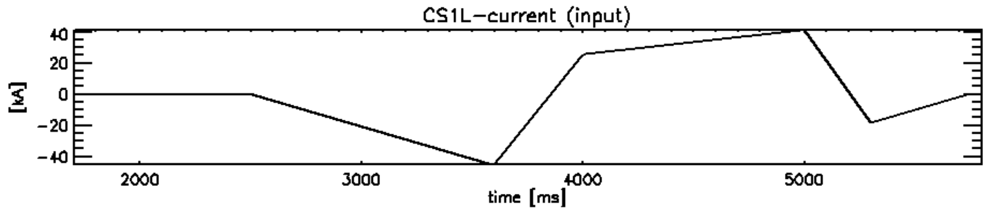
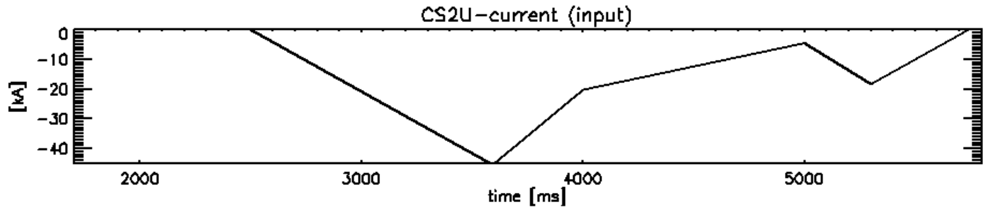
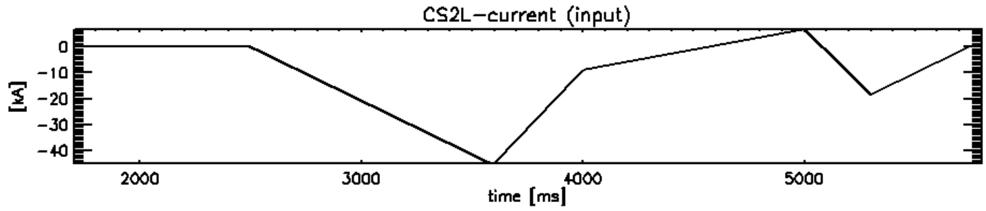


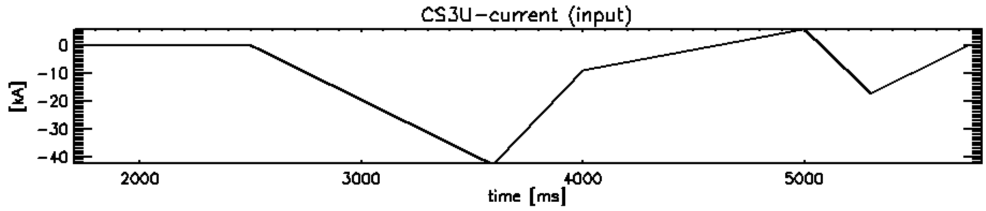
Figure 6.3.11 Waveforms of the PF coil currents for the "nominal baseline scenario" for the tokamak version v3.1.

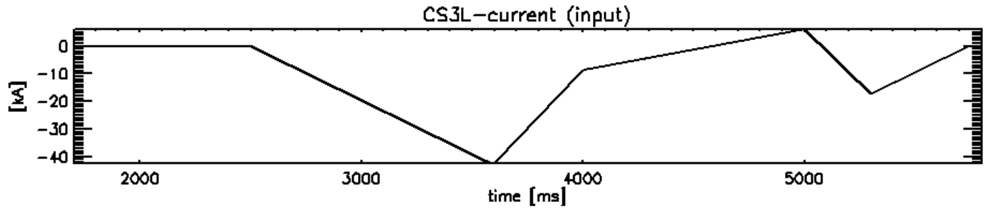

CS1U−current (input)
[kA]
40
20
0
−20
−40
2000
3000
4000
5000
time [ms]

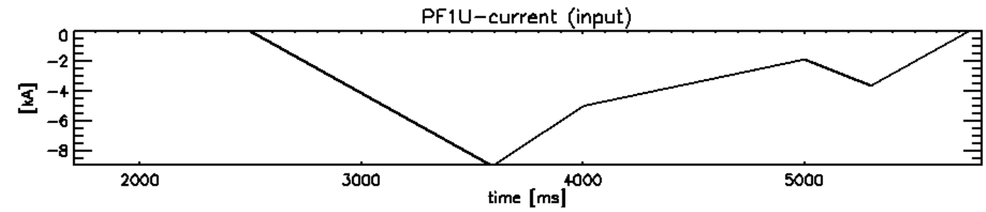

CS1L−current (input)
[kA]
40
20
0
−20
−40
2000
3000
4000
5000
time [ms]


CS2U−current (input)
[kA]
0
−10
−20
−30
−40
2000
3000
4000
5000
time [ms]


CS2L−current (input)
[kA]
0
−10
−20
−30
−40
2000
3000
4000
5000
time [ms]


CS3U−current (input)
[kA]
0
−10
−20
−30
−40
2000
3000
4000
5000
time [ms]


CS3L−current (input)
[kA]
0
−10
−20
−30
−40
2000
3000
4000
5000
time [ms]


PF1U−current (input)
[kA]
0
−2
−4
−6
−8
2000
3000
4000
5000
time [ms]

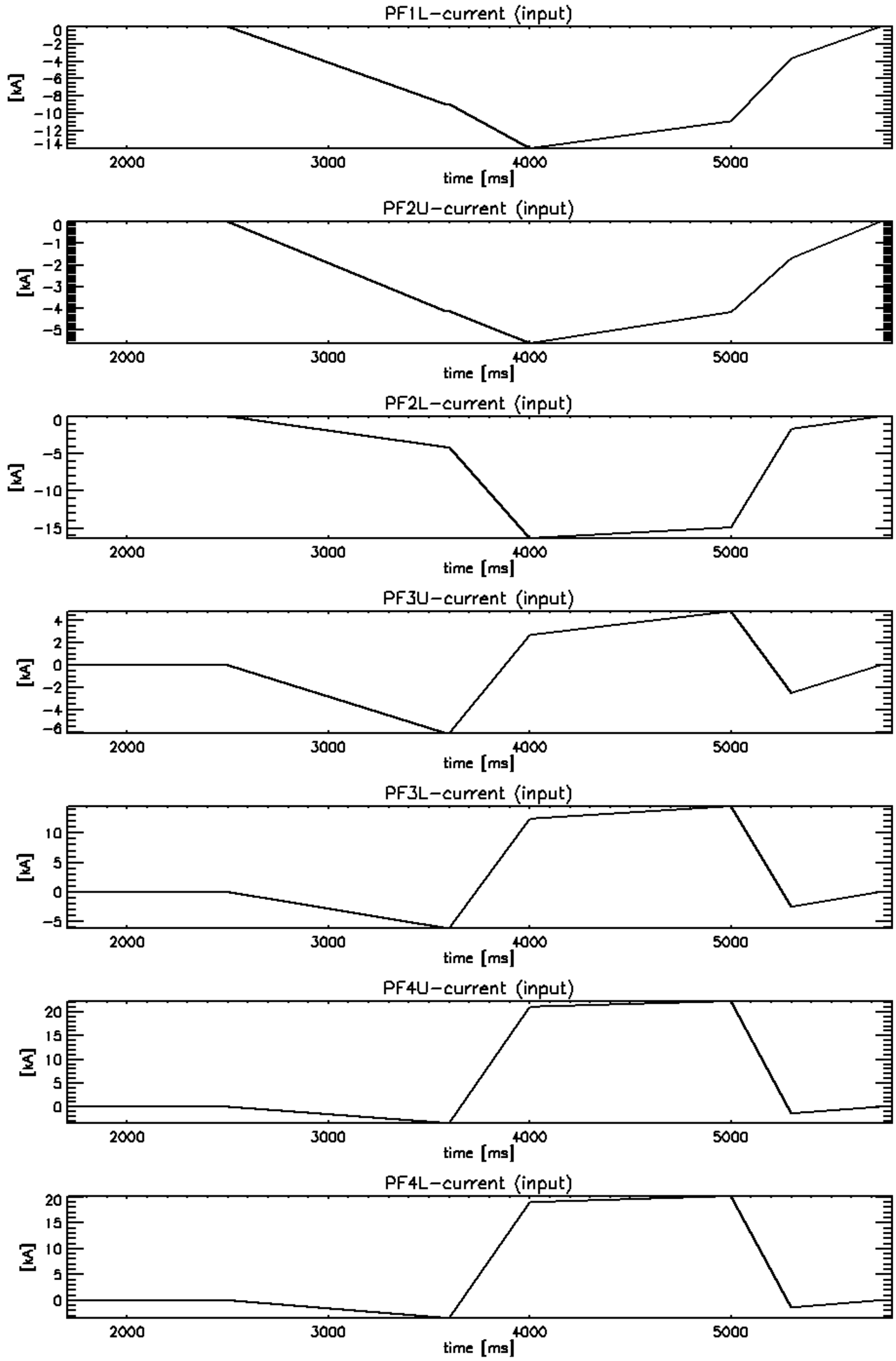
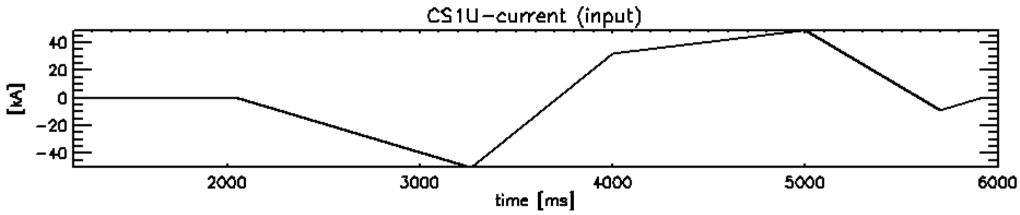
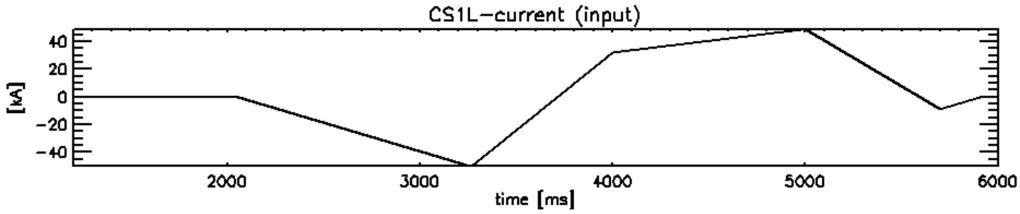
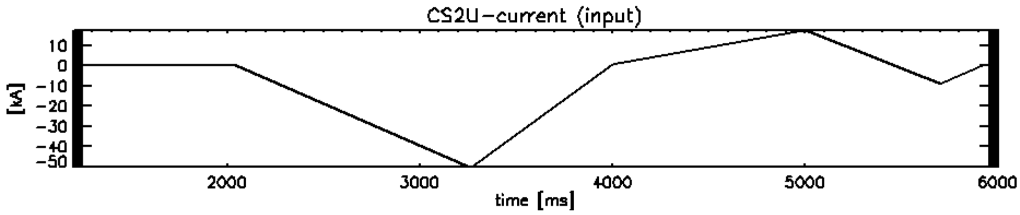
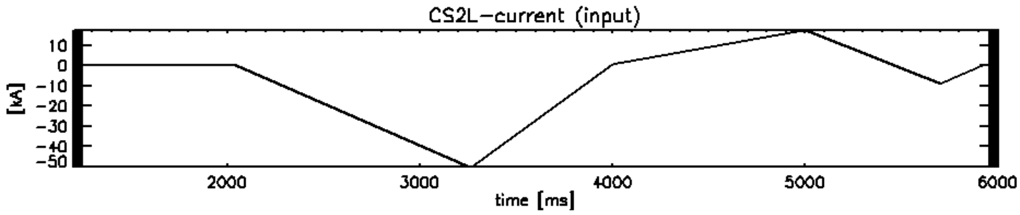


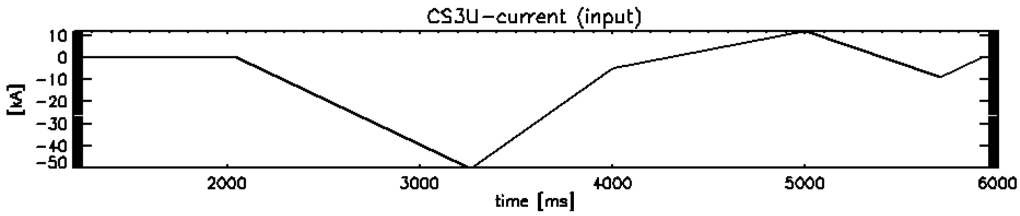
Figure 6.3.12 Waveforms of the PF coil currents for the "fast Ip ramp-up scenario" for the tokamak version v3.1.

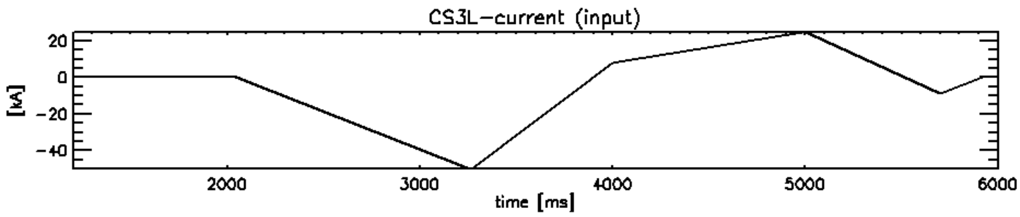

CS1U−current (input)
40
20
0
−20
−40
[kA]
2000
3000
4000
5000
6000
time [ms]

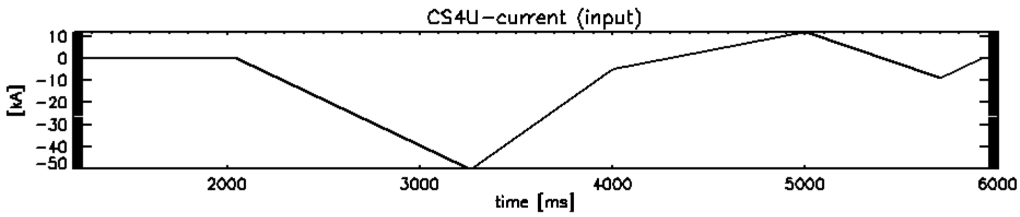

CS1L−current (input)
40
20
0
−20
−40
[kA]
2000
3000
4000
5000
6000
time [ms]

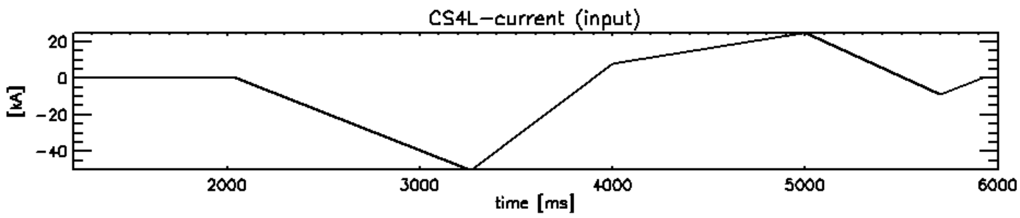

CS2U−current (input)
10
0
−10
−20
−30
−40
−50
[kA]
2000
3000
4000
5000
6000
time [ms]


CS2L−current (input)
10
0
−10
−20
−30
−40
−50
[kA]
2000
3000
4000
5000
6000
time [ms]


CS3U−current (input)
10
0
−10
−20
−30
−40
−50
[kA]
2000
3000
4000
5000
6000
time [ms]


CS3L−current (input)
20
0
−20
−40
[kA]
2000
3000
4000
5000
6000
time [ms]


CS4U−current (input)
10
0
−10
−20
−30
−40
−50
[kA]
2000
3000
4000
5000
6000
time [ms]


CS4L−current (input)
20
0
−20
−40
[kA]
2000
3000
4000
5000
6000
time [ms]

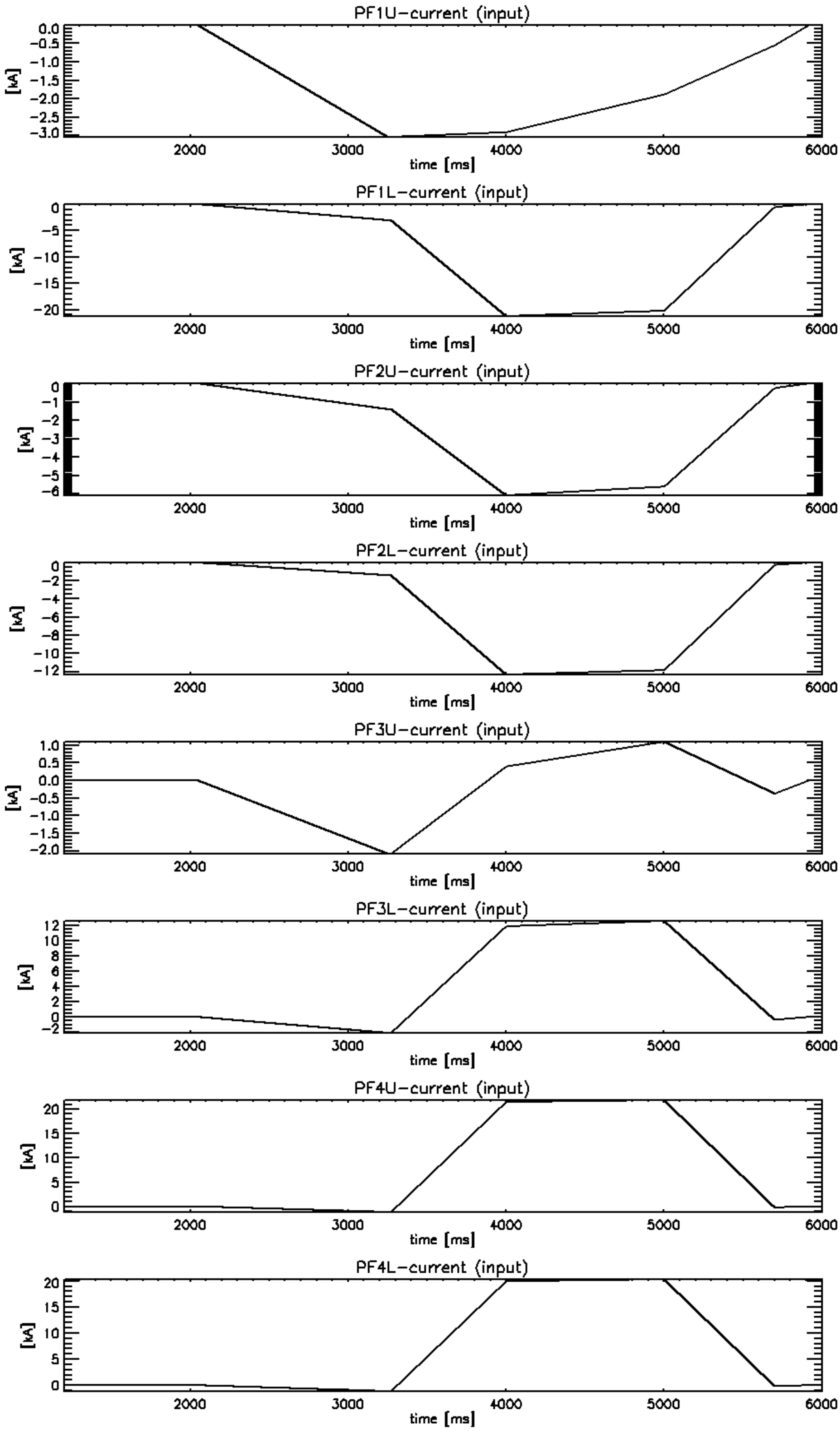
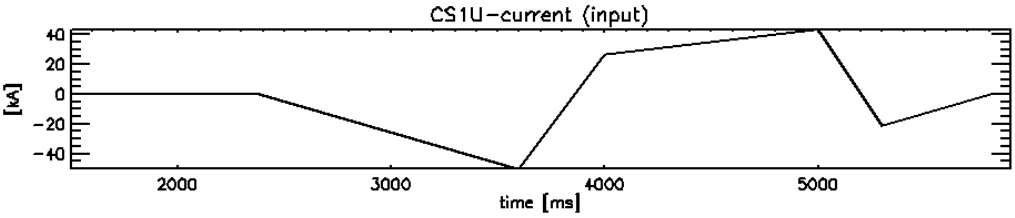
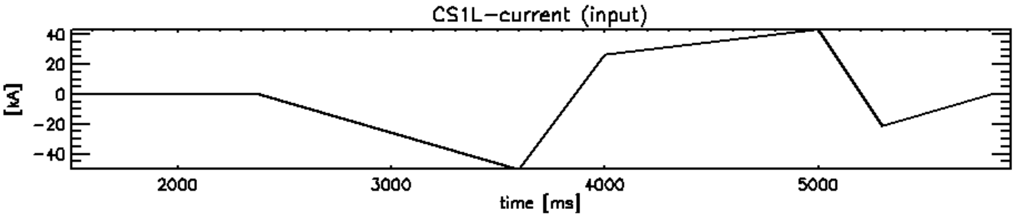
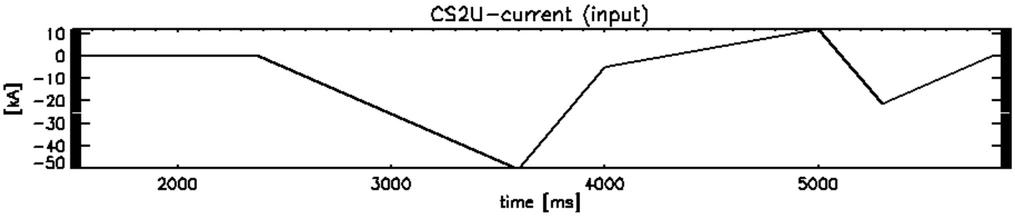
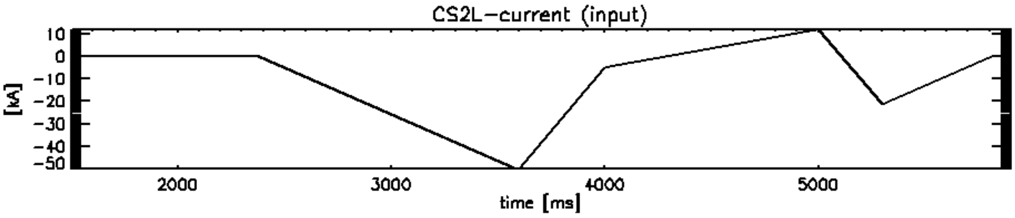


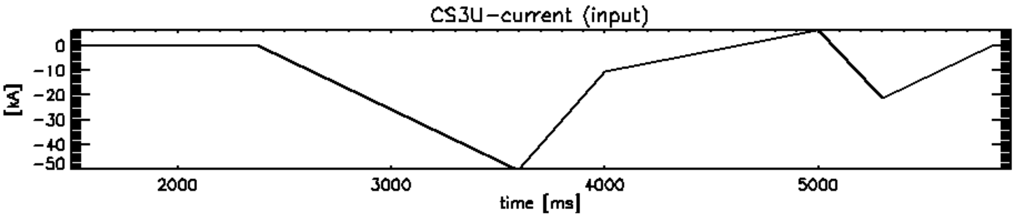
Figure 6.3.13 Waveforms of the PF coil currents for the "nominal baseline scenario" for the tokamak version v4.1.

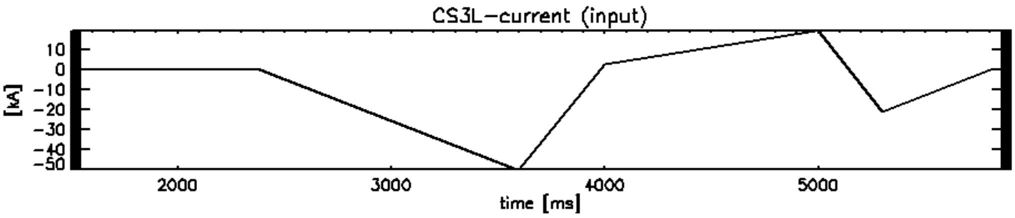

CS1U−current (input)
[kA]
40
20
0
−20
−40
2000
3000
4000
5000
time [ms]

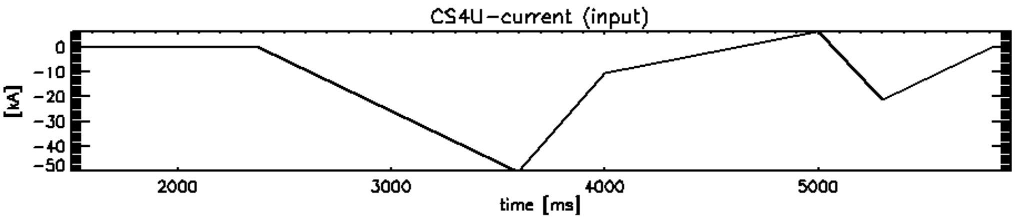

CS1L−current (input)
[kA]
40
20
0
−20
−40
2000
3000
4000
5000
time [ms]

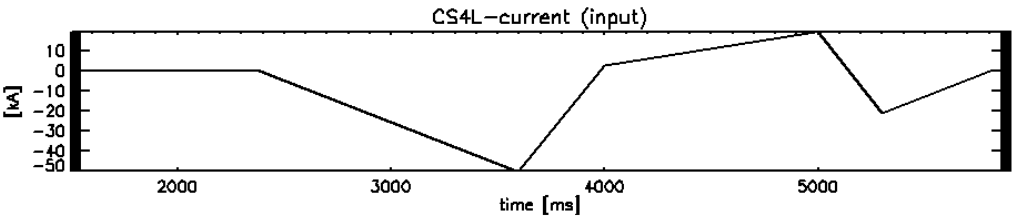

CS2U−current (input)
[kA]
10
0
−10
−20
−30
−40
−50
2000
3000
4000
5000
time [ms]


CS2L−current (input)
[kA]
10
0
−10
−20
−30
−40
−50
2000
3000
4000
5000
time [ms]


CS3U−current (input)
[kA]
0
−10
−20
−30
−40
−50
2000
3000
4000
5000
time [ms]


CS3L−current (input)
[kA]
10
0
−10
−20
−30
−40
−50
2000
3000
4000
5000
time [ms]


CS4U−current (input)
[kA]
0
−10
−20
−30
−40
−50
2000
3000
4000
5000
time [ms]


CS4L−current (input)
[kA]
10
0
−10
−20
−30
−40
−50
2000
3000
4000
5000
time [ms]

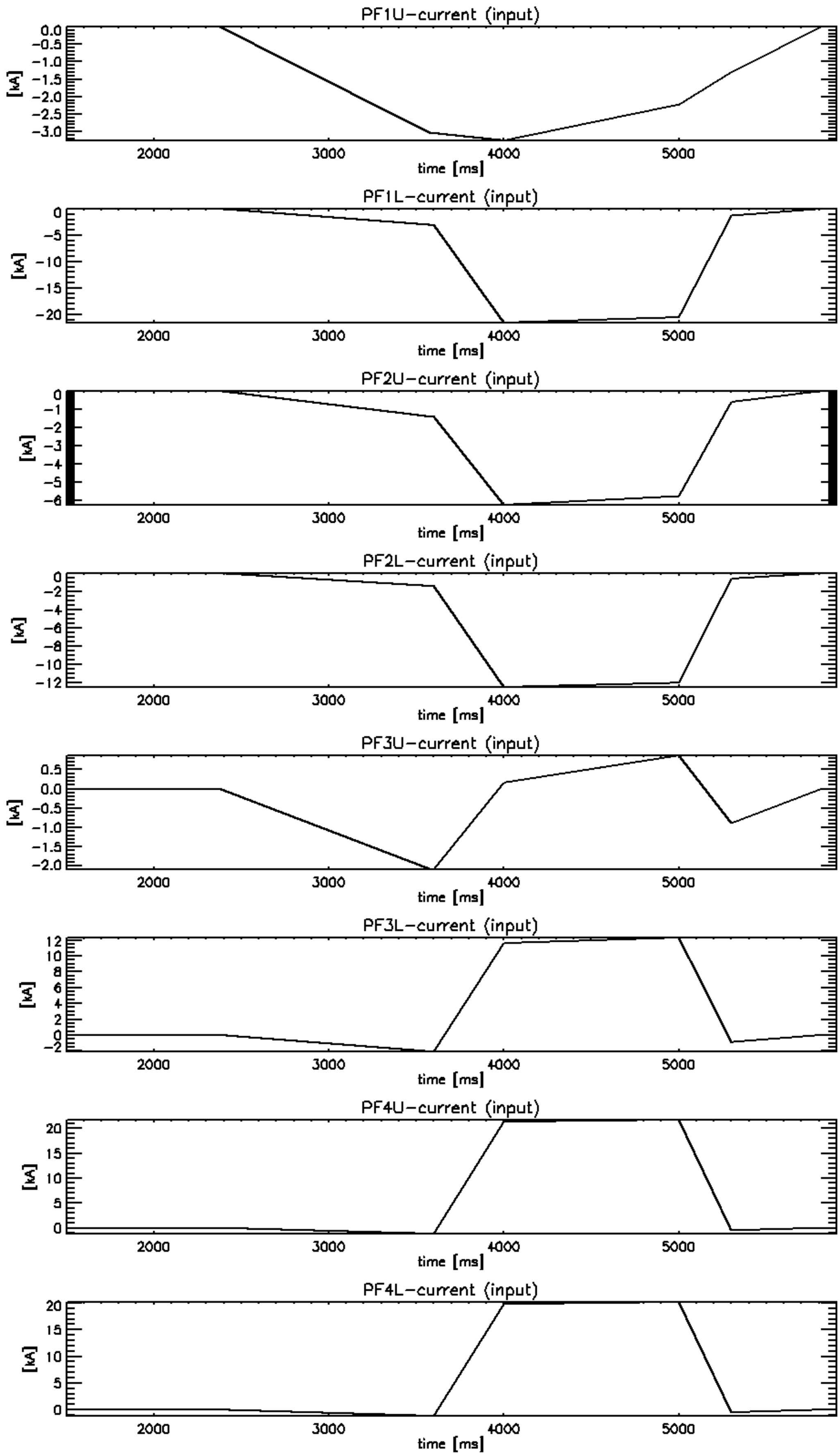
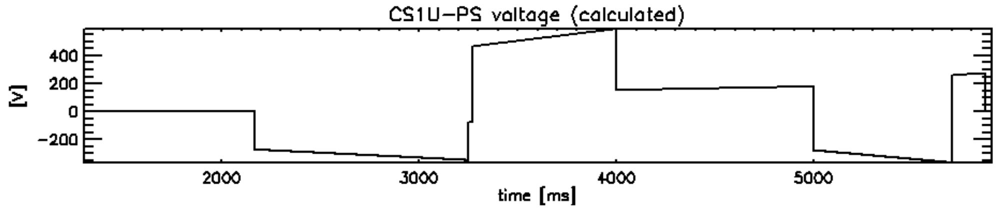
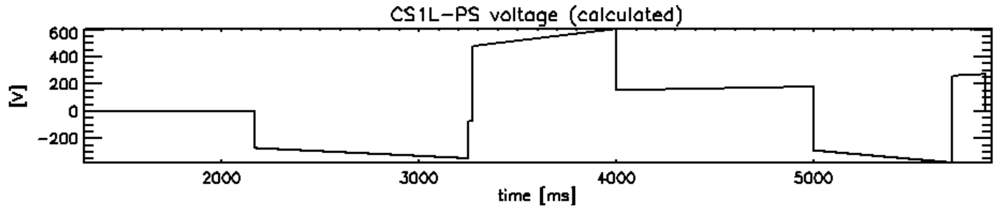


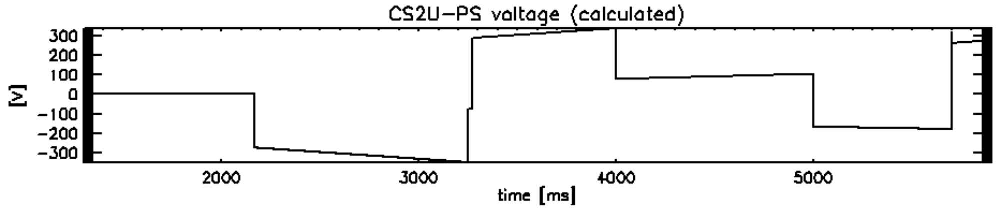
Figure 6.3.14 Waveforms of the PF coil currents for the "fast Ip ramp-up scenario" for the tokamak version v4.1.

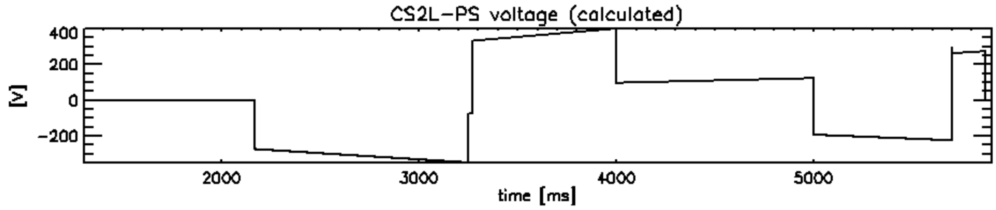
6.3.1.6 Voltage in the PF coils

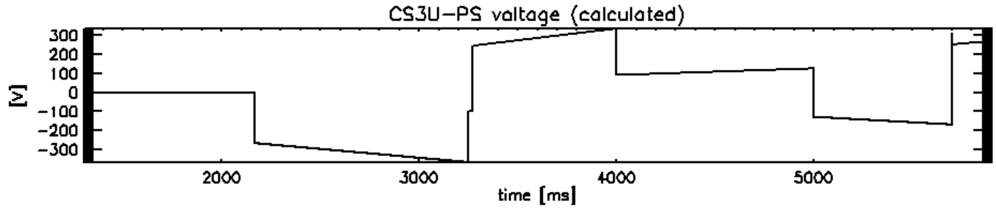
The provided voltage waveforms show voltage averaged over Power Supply control period.

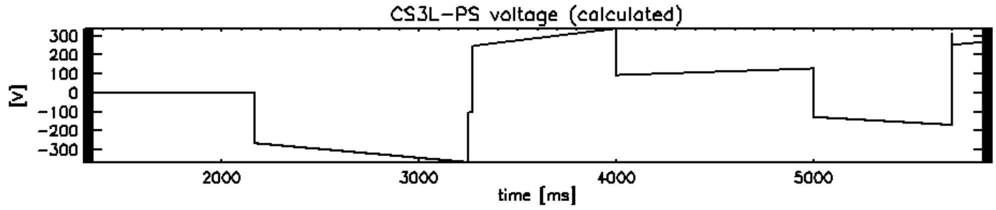


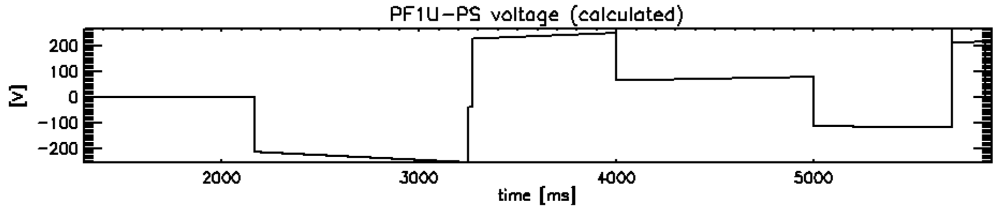












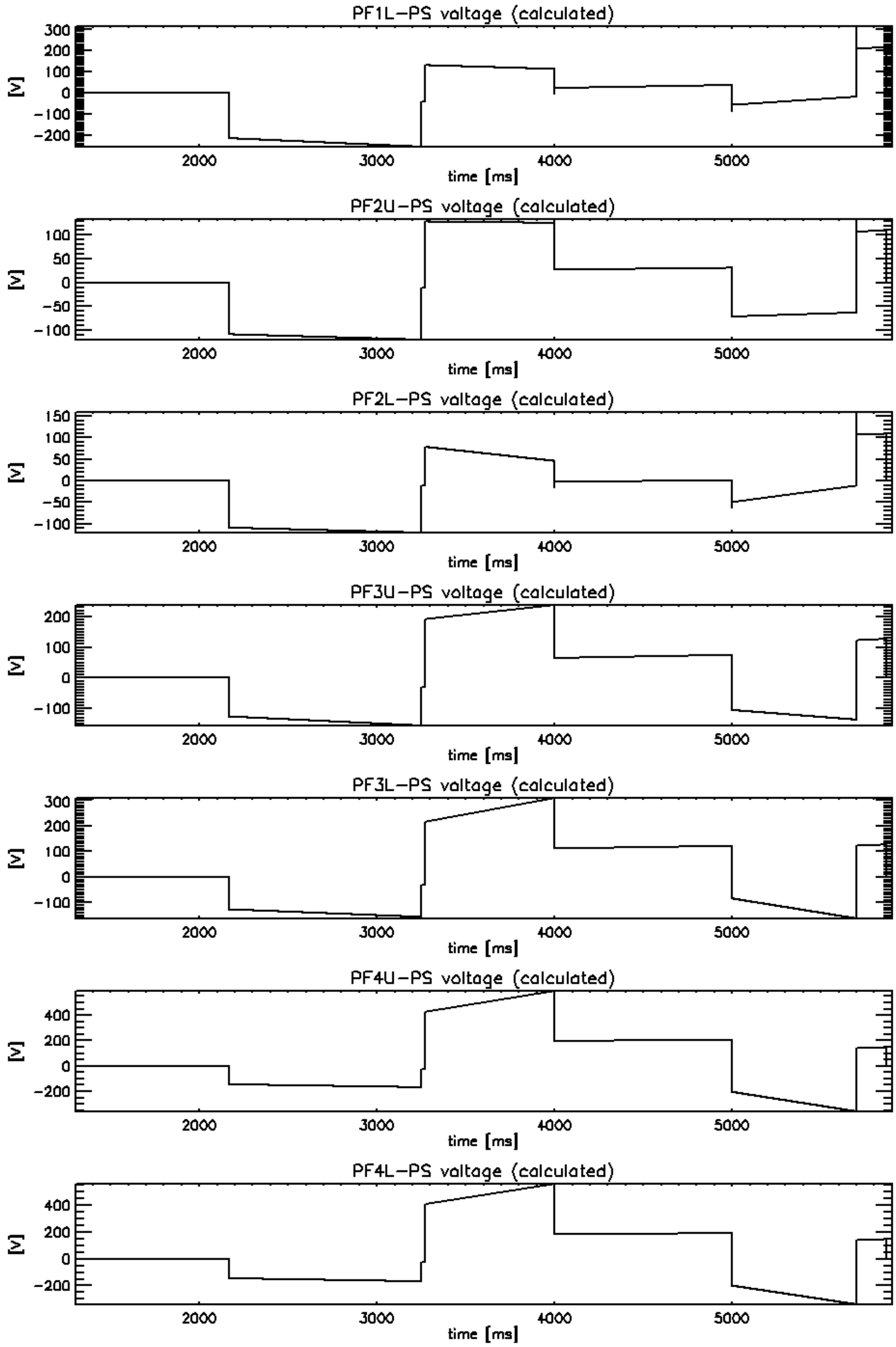
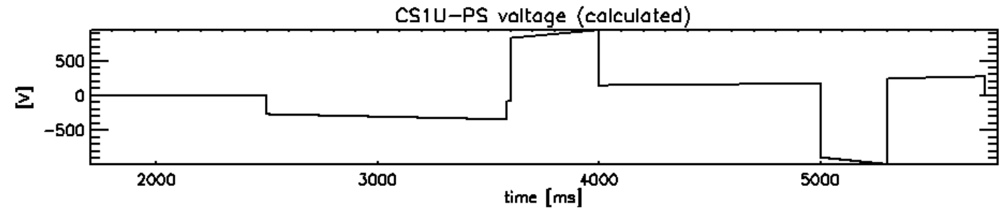
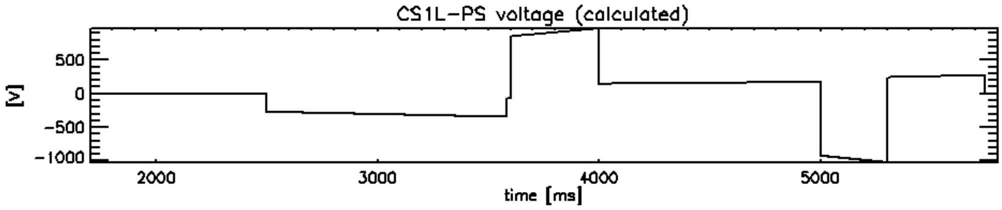
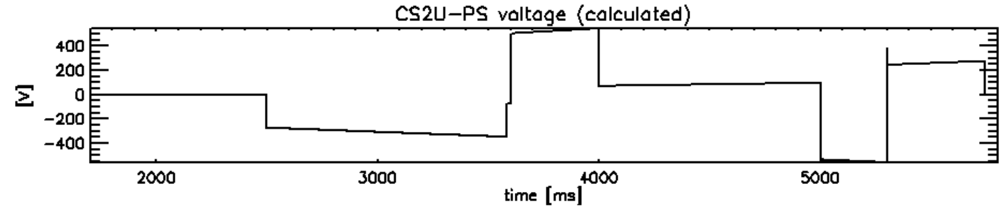
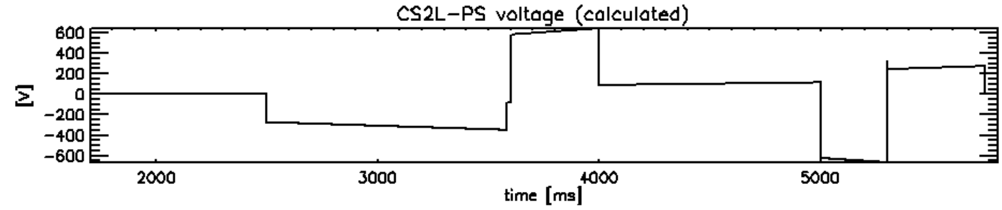


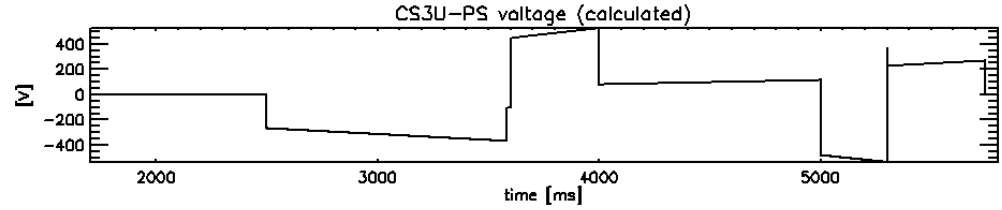
Figure 6.3.15 Waveforms of the PF coil voltages for the “nominal baseline scenario” for the tokamak version v3.1.

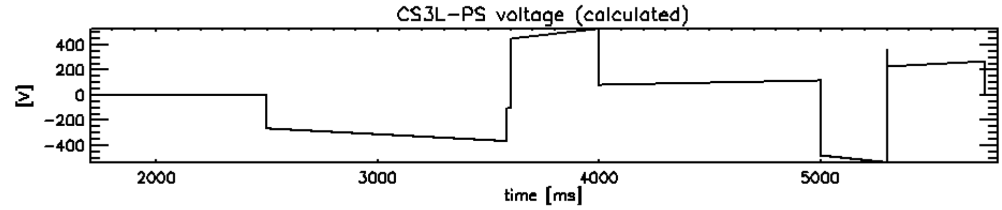

CS1U−PS voltage (calculated)
[V]
500
0
−500
2000
3000
4000
5000
time [ms]

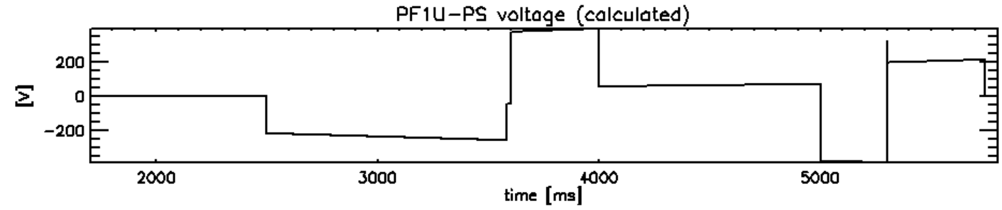

CS1L−PS voltage (calculated)
[V]
500
0
−500
−1000
2000
3000
4000
5000
time [ms]


CS2U−PS voltage (calculated)
[V]
400
200
0
−200
−400
2000
3000
4000
5000
time [ms]


CS2L−PS voltage (calculated)
[V]
600
400
200
0
−200
−400
−600
2000
3000
4000
5000
time [ms]


CS3U−PS voltage (calculated)
[V]
400
200
0
−200
−400
2000
3000
4000
5000
time [ms]


CS3L−PS voltage (calculated)
[V]
400
200
0
−200
−400
2000
3000
4000
5000
time [ms]


PF1U−PS voltage (calculated)
[V]
200
0
−200
2000
3000
4000
5000
time [ms]

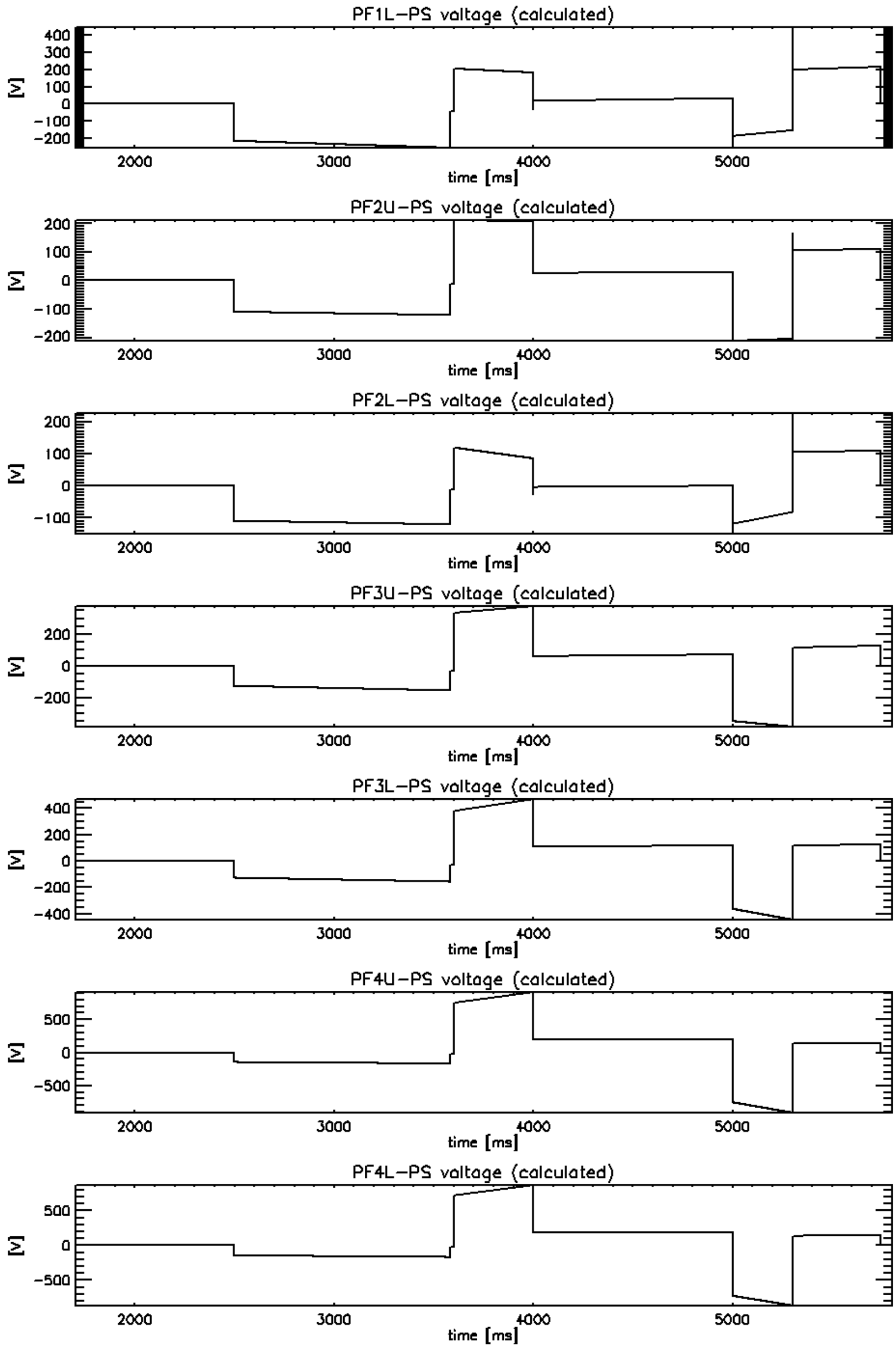
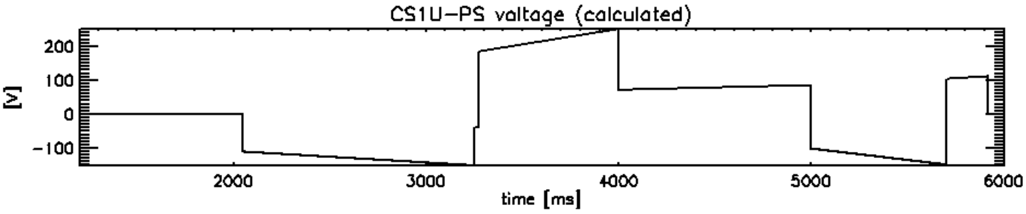
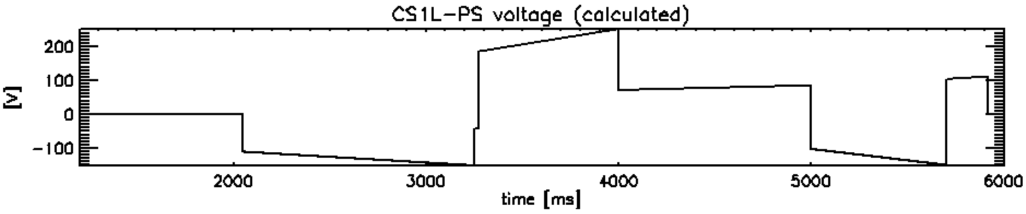
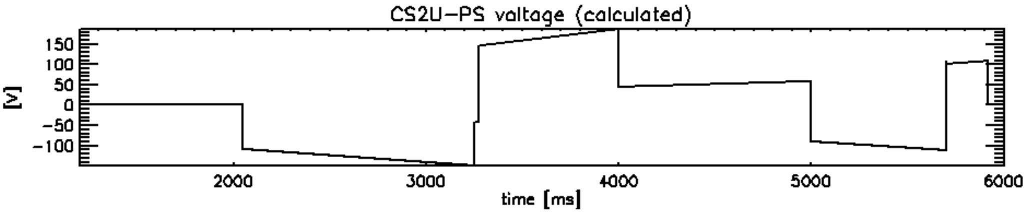
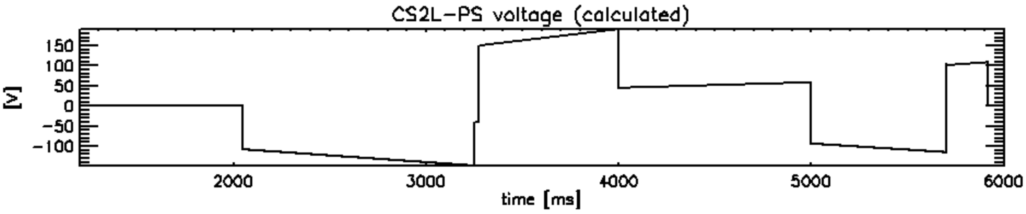


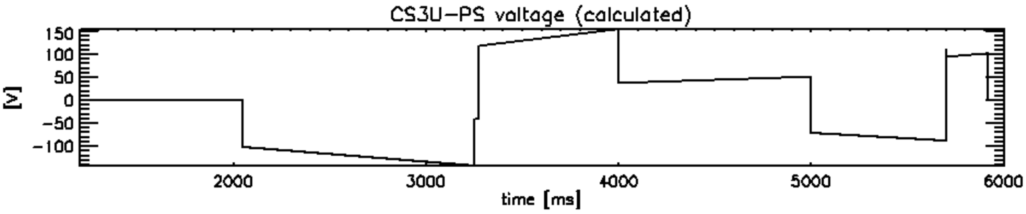
Figure 6.3.16 Waveforms of the PF coil voltages for the "fast Ip ramp-up scenario" for the tokamak version v3.1.

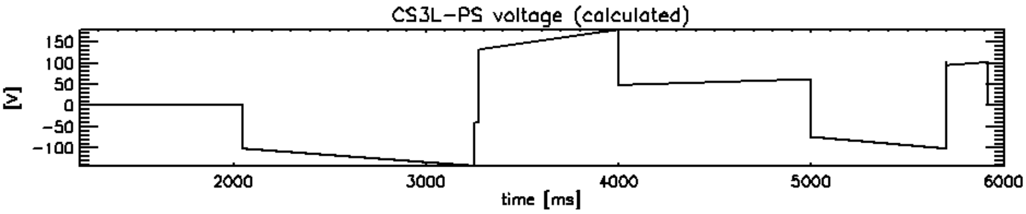

CS1U−PS voltage (calculated)
[V]
200
100
0
−100
2000
3000
4000
5000
6000
time [ms]

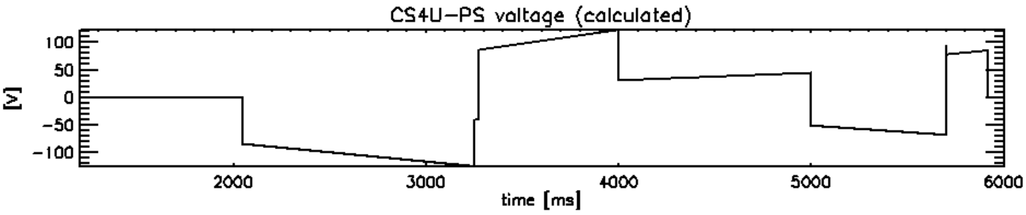

CS1L−PS voltage (calculated)
[V]
200
100
0
−100
2000
3000
4000
5000
6000
time [ms]

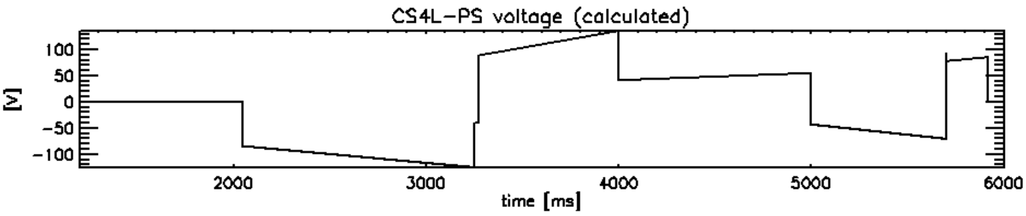

CS2U−PS voltage (calculated)
[V]
150
100
50
0
−50
−100
2000
3000
4000
5000
6000
time [ms]


CS2L−PS voltage (calculated)
[V]
150
100
50
0
−50
−100
2000
3000
4000
5000
6000
time [ms]


CS3U−PS voltage (calculated)
[V]
150
100
50
0
−50
−100
2000
3000
4000
5000
6000
time [ms]


CS3L−PS voltage (calculated)
[V]
150
100
50
0
−50
−100
2000
3000
4000
5000
6000
time [ms]


CS4U−PS voltage (calculated)
[V]
100
50
0
−50
−100
2000
3000
4000
5000
6000
time [ms]


CS4L−PS voltage (calculated)
[V]
100
50
0
−50
−100
2000
3000
4000
5000
6000
time [ms]

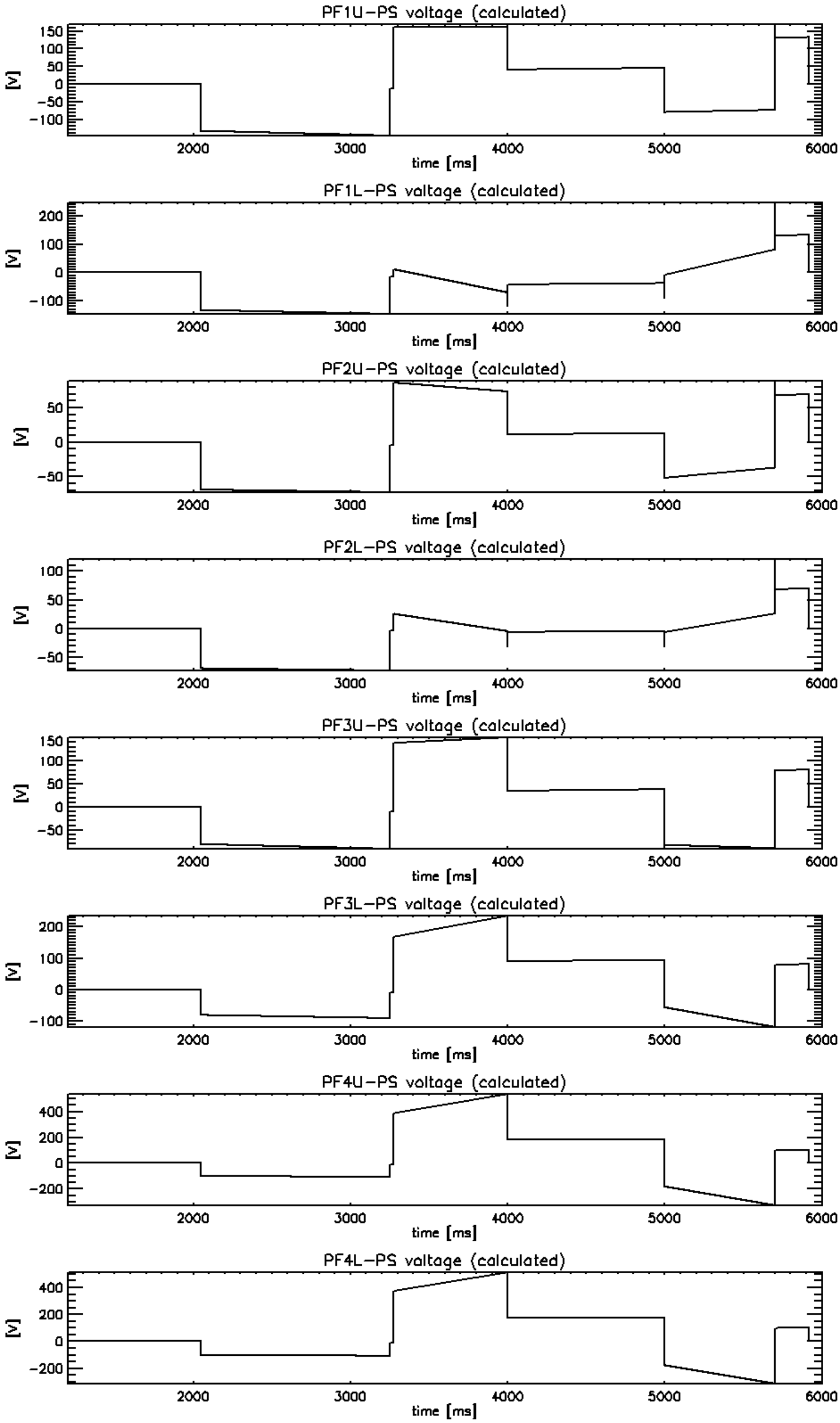
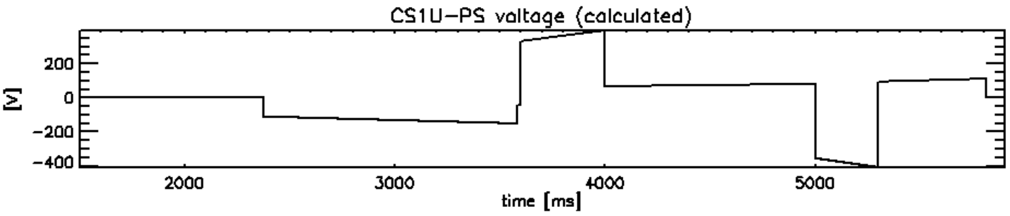
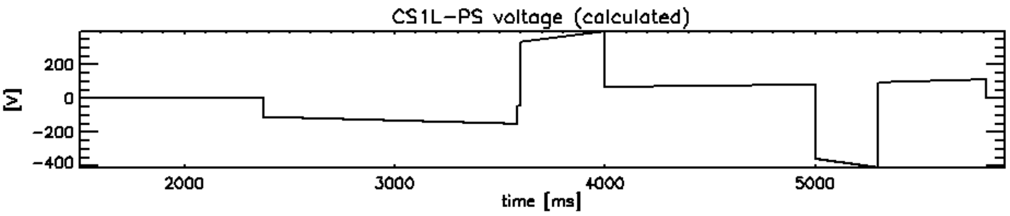
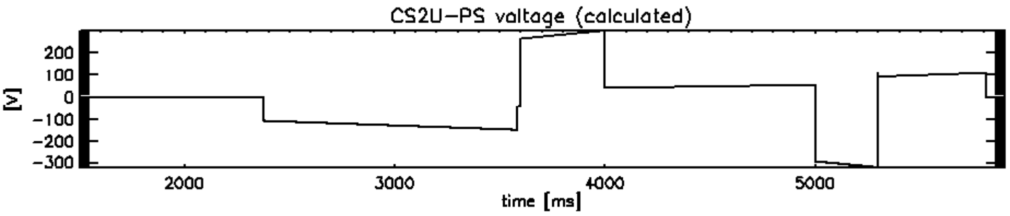
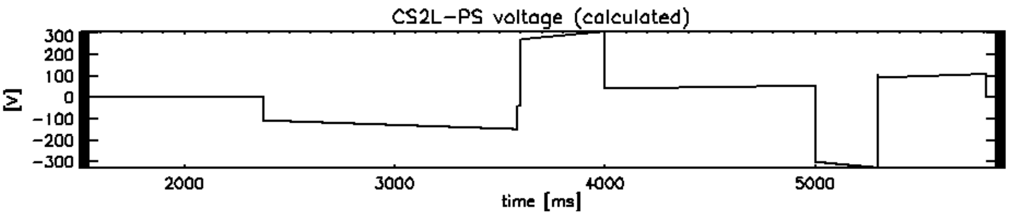


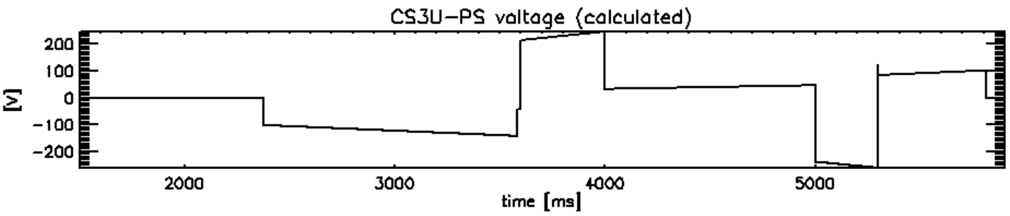
Figure 6.3.17 Waveforms of the PF coil voltages for the "nominal baseline scenario" for the tokamak version v4.1.

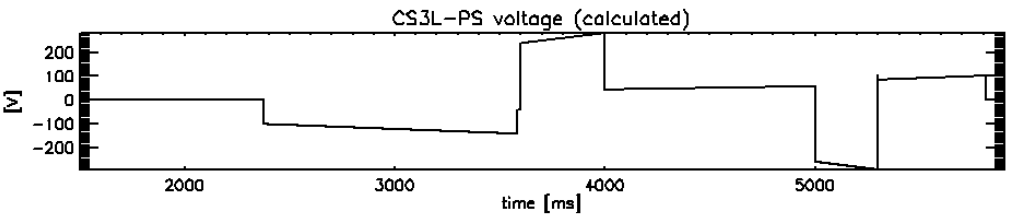

CS1U−PS voltage (calculated)
[V]
200
0
−200
−400
2000
3000
4000
5000
time [ms]

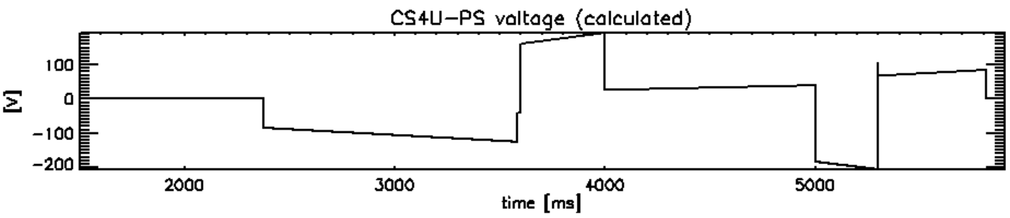

CS1L−PS voltage (calculated)
[V]
200
0
−200
−400
2000
3000
4000
5000
time [ms]

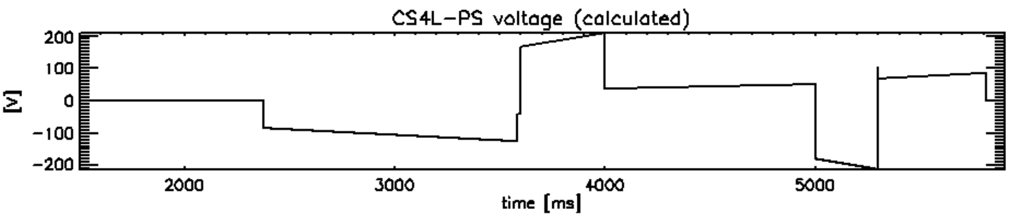

CS2U−PS voltage (calculated)
[V]
200
100
0
−100
−200
−300
2000
3000
4000
5000
time [ms]


CS2L−PS voltage (calculated)
[V]
300
200
100
0
−100
−200
−300
2000
3000
4000
5000
time [ms]


CS3U−PS voltage (calculated)
[V]
200
100
0
−100
−200
2000
3000
4000
5000
time [ms]


CS3L−PS voltage (calculated)
[V]
200
100
0
−100
−200
2000
3000
4000
5000
time [ms]


CS4U−PS voltage (calculated)
[V]
100
0
−100
−200
2000
3000
4000
5000
time [ms]


CS4L−PS voltage (calculated)
[V]
200
100
0
−100
−200
2000
3000
4000
5000
time [ms]

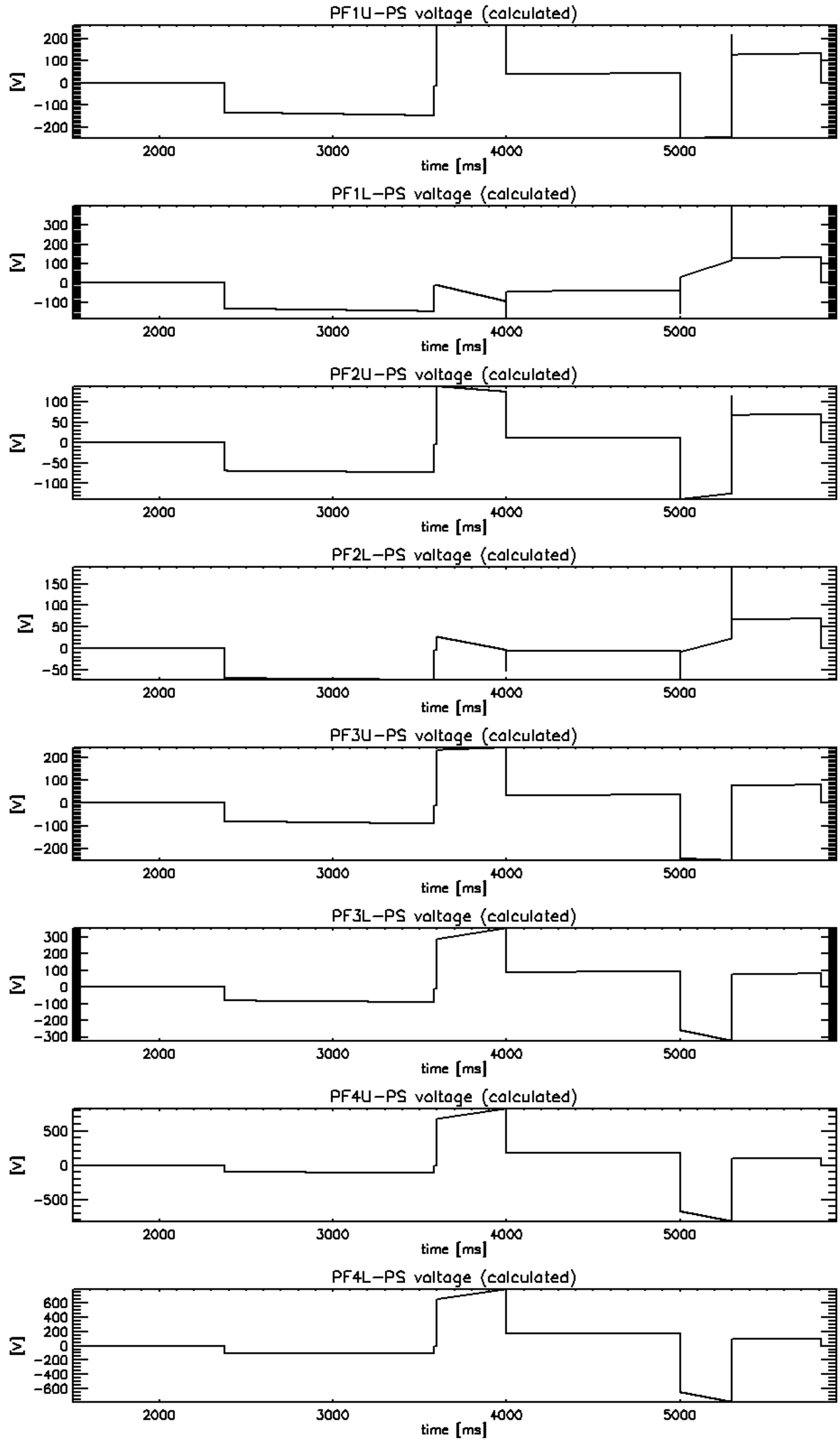
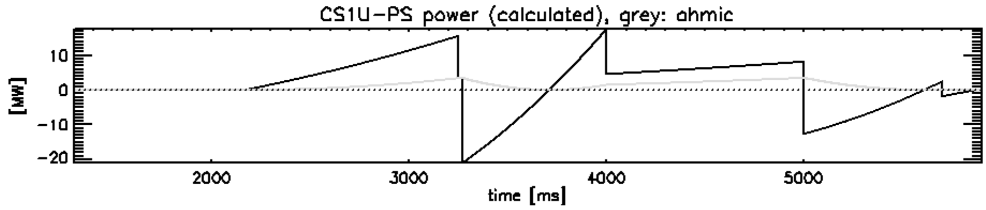
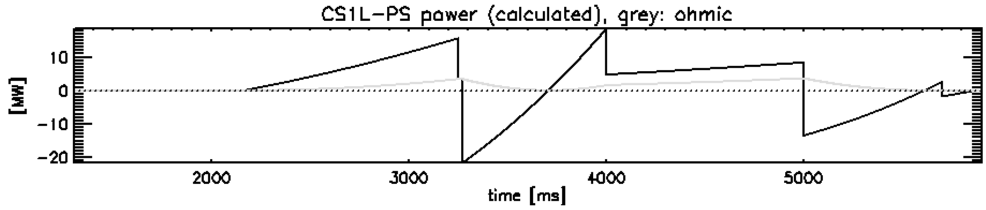
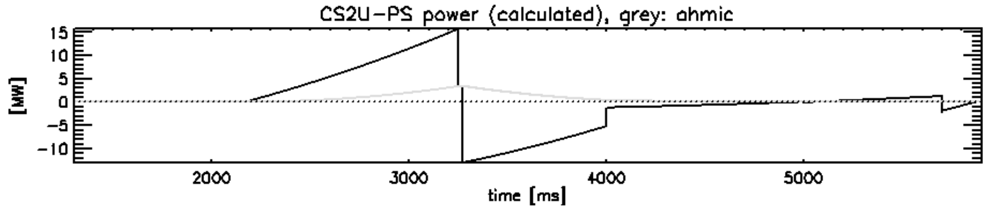


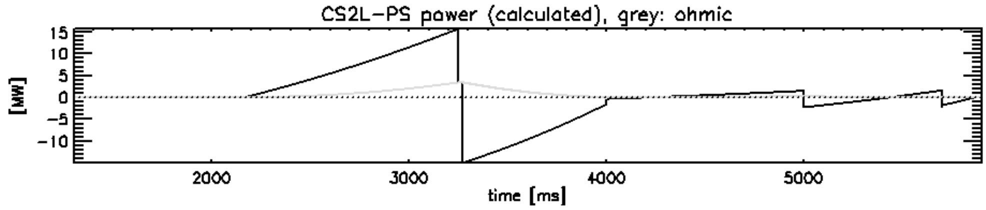
Figure 6.3.18 Waveforms of the PF coil voltages for the “fast Ip ramp-up scenario” for the tokamak version v4.1.

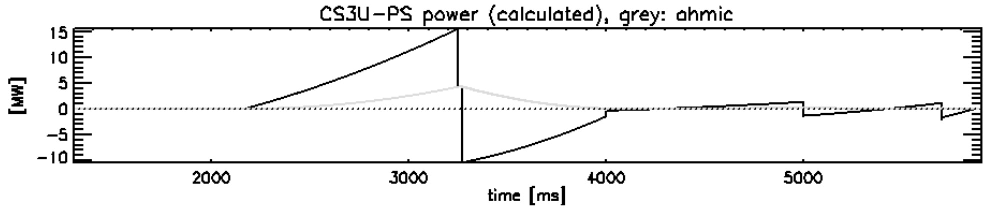
6.3.1.7 Power of the PF coils (total and ohmic)

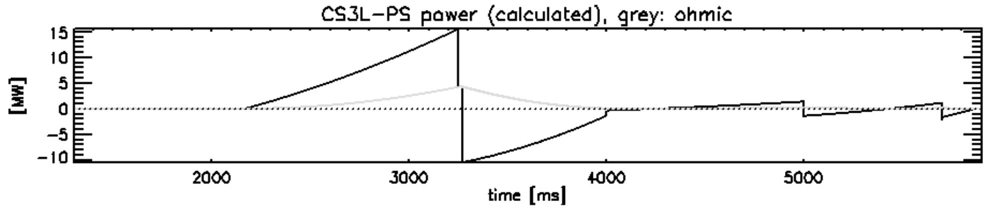


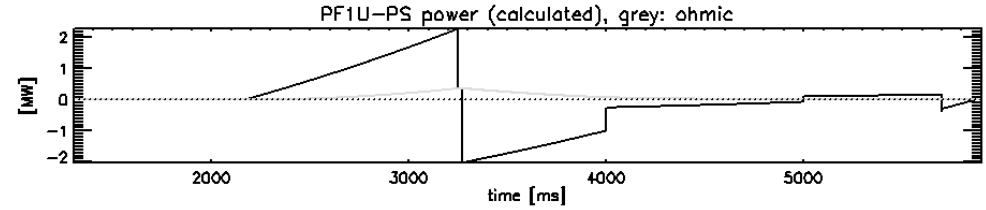












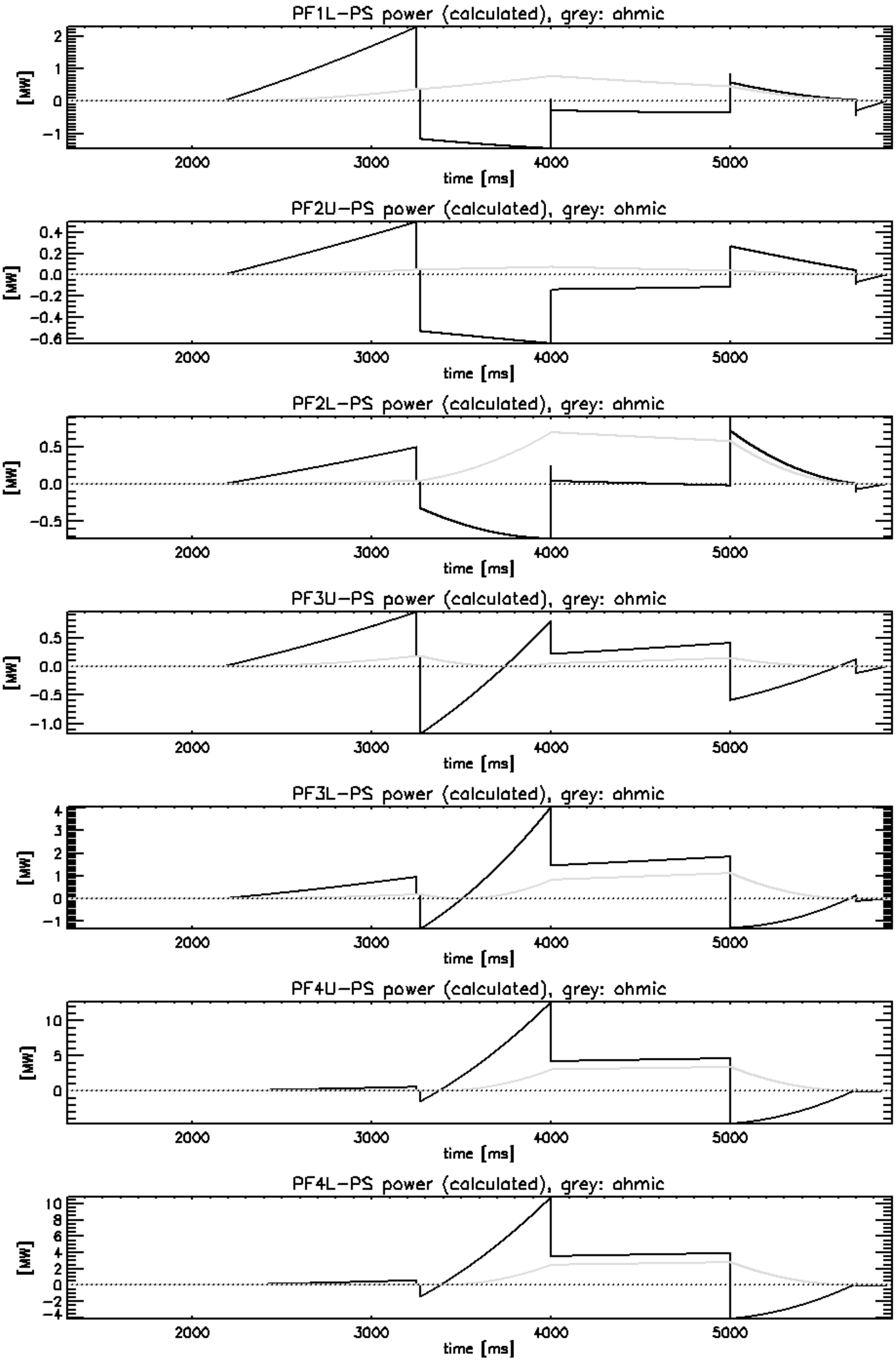
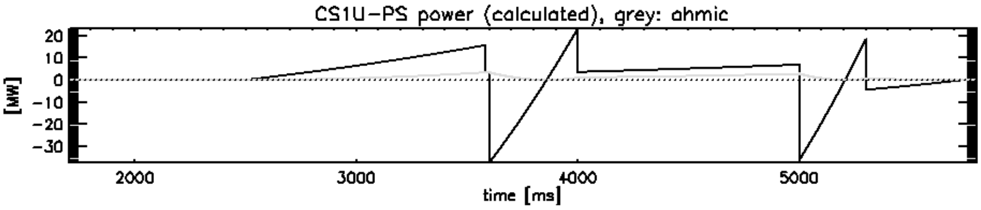
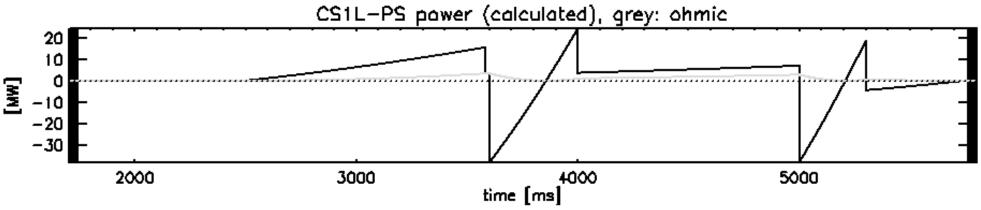
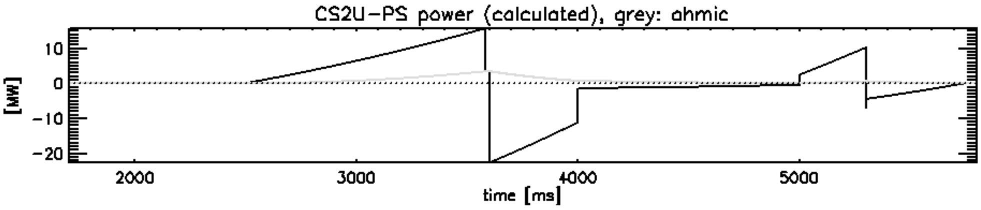
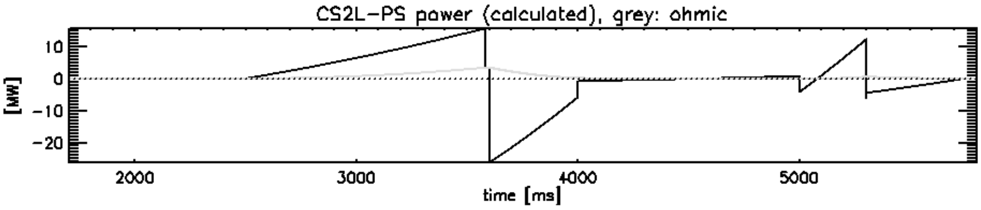


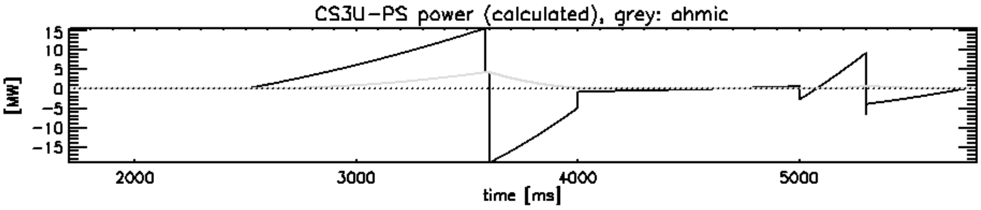
Figure 6.3.19 Waveforms of the PF coil power requirements and ohmic losses for the "nominal baseline scenario" for the tokamak version v3.1.

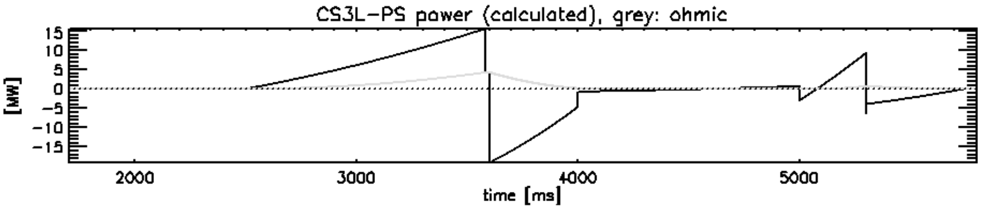

CS1U−PS power (calculated), grey: ohmic
[MW]
20
10
0
−10
−20
−30
2000
3000
4000
5000
time [ms]

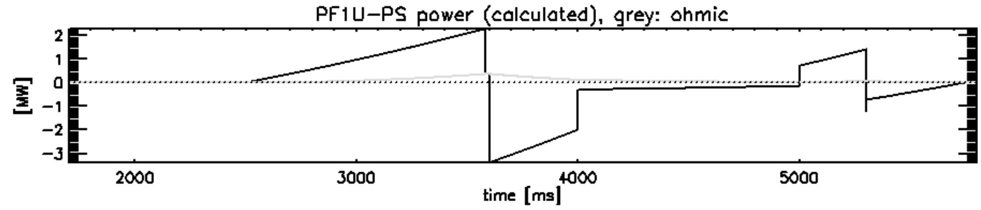

CS1L−PS power (calculated), grey: ohmic
[MW]
20
10
0
−10
−20
−30
2000
3000
4000
5000
time [ms]


CS2U−PS power (calculated), grey: ohmic
[MW]
10
0
−10
−20
2000
3000
4000
5000
time [ms]


CS2L−PS power (calculated), grey: ohmic
[MW]
10
0
−10
−20
2000
3000
4000
5000
time [ms]


CS3U−PS power (calculated), grey: ohmic
[MW]
15
10
5
0
−5
−10
−15
2000
3000
4000
5000
time [ms]


CS3L−PS power (calculated), grey: ohmic
[MW]
15
10
5
0
−5
−10
−15
2000
3000
4000
5000
time [ms]


PF1U−PS power (calculated), grey: ohmic
[MW]
2
1
0
−1
−2
−3
2000
3000
4000
5000
time [ms]

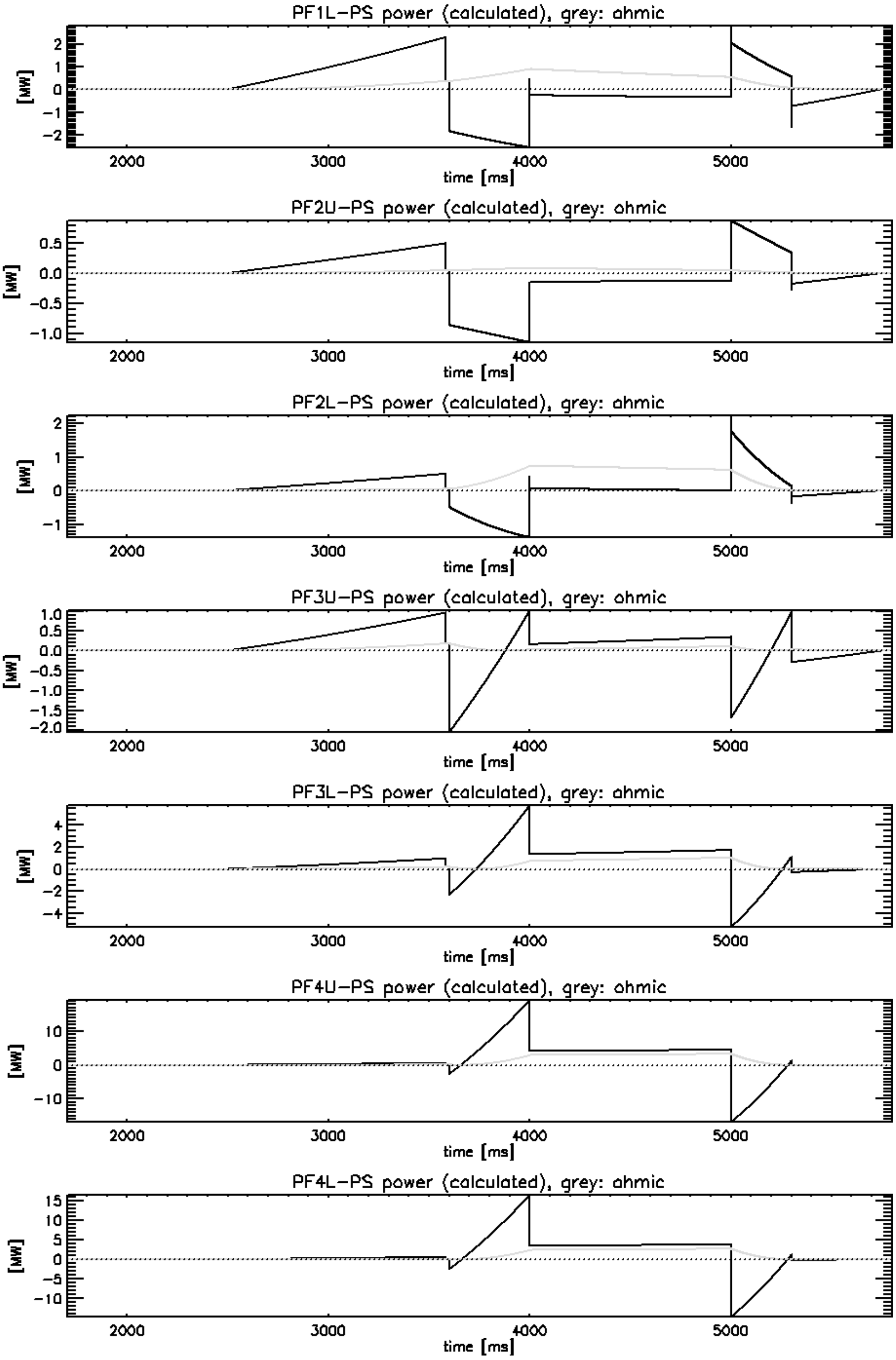
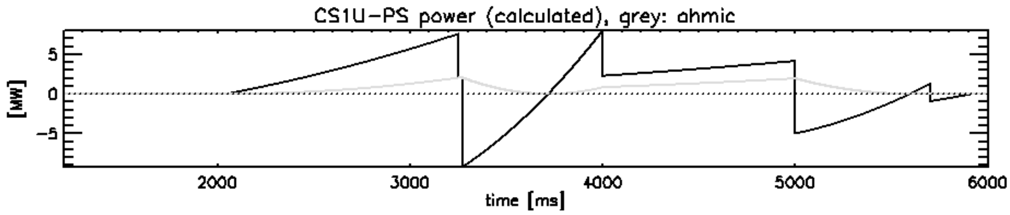
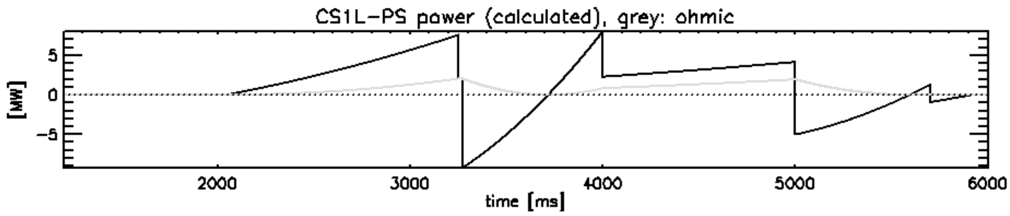
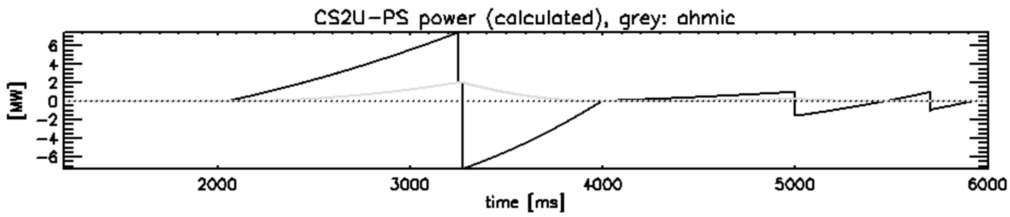
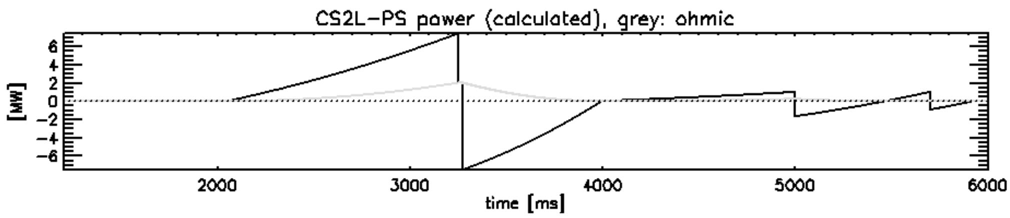


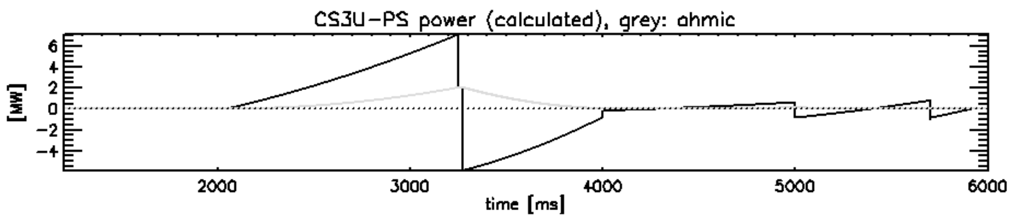
Figure 6.3.20 Waveforms of the PF coil power requirements and ohmic losses for the “fast Ip ramp-up scenario” for the tokamak version v3.1.

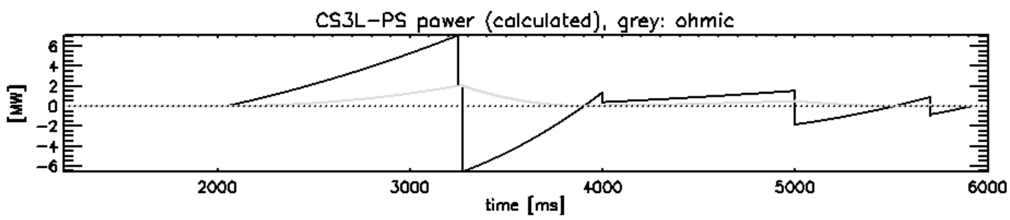

CS1U−PS power (calculated), grey: ohmic
[MW]
5
0
−5
2000
3000
4000
5000
6000
time [ms]

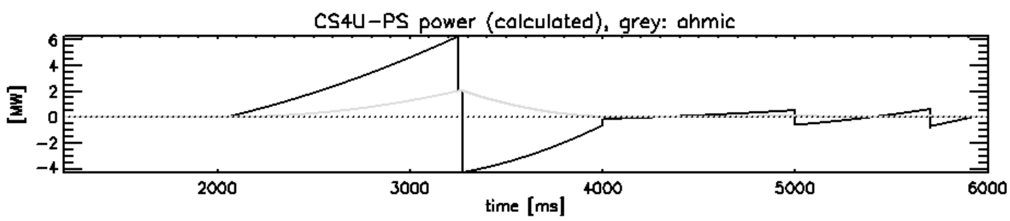

CS1L−PS power (calculated), grey: ohmic
[MW]
5
0
−5
2000
3000
4000
5000
6000
time [ms]

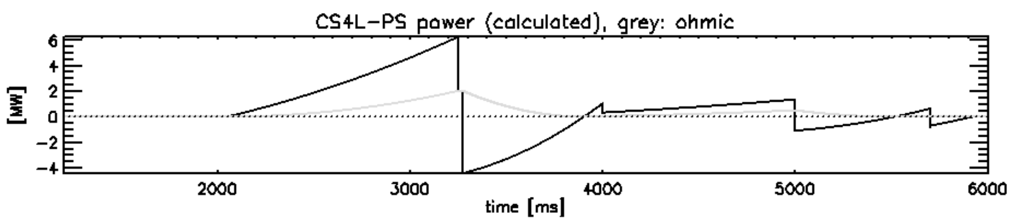

CS2U−PS power (calculated), grey: ohmic
[MW]
6
4
2
0
−2
−4
−6
2000
3000
4000
5000
6000
time [ms]


CS2L−PS power (calculated), grey: ohmic
[MW]
6
4
2
0
−2
−4
−6
2000
3000
4000
5000
6000
time [ms]


CS3U−PS power (calculated), grey: ohmic
[MW]
6
4
2
0
−2
−4
2000
3000
4000
5000
6000
time [ms]


CS3L−PS power (calculated), grey: ohmic
[MW]
6
4
2
0
−2
−4
−6
2000
3000
4000
5000
6000
time [ms]


CS4U−PS power (calculated), grey: ohmic
[MW]
6
4
2
0
−2
−4
2000
3000
4000
5000
6000
time [ms]


CS4L−PS power (calculated), grey: ohmic
[MW]
6
4
2
0
−2
−4
2000
3000
4000
5000
6000
time [ms]

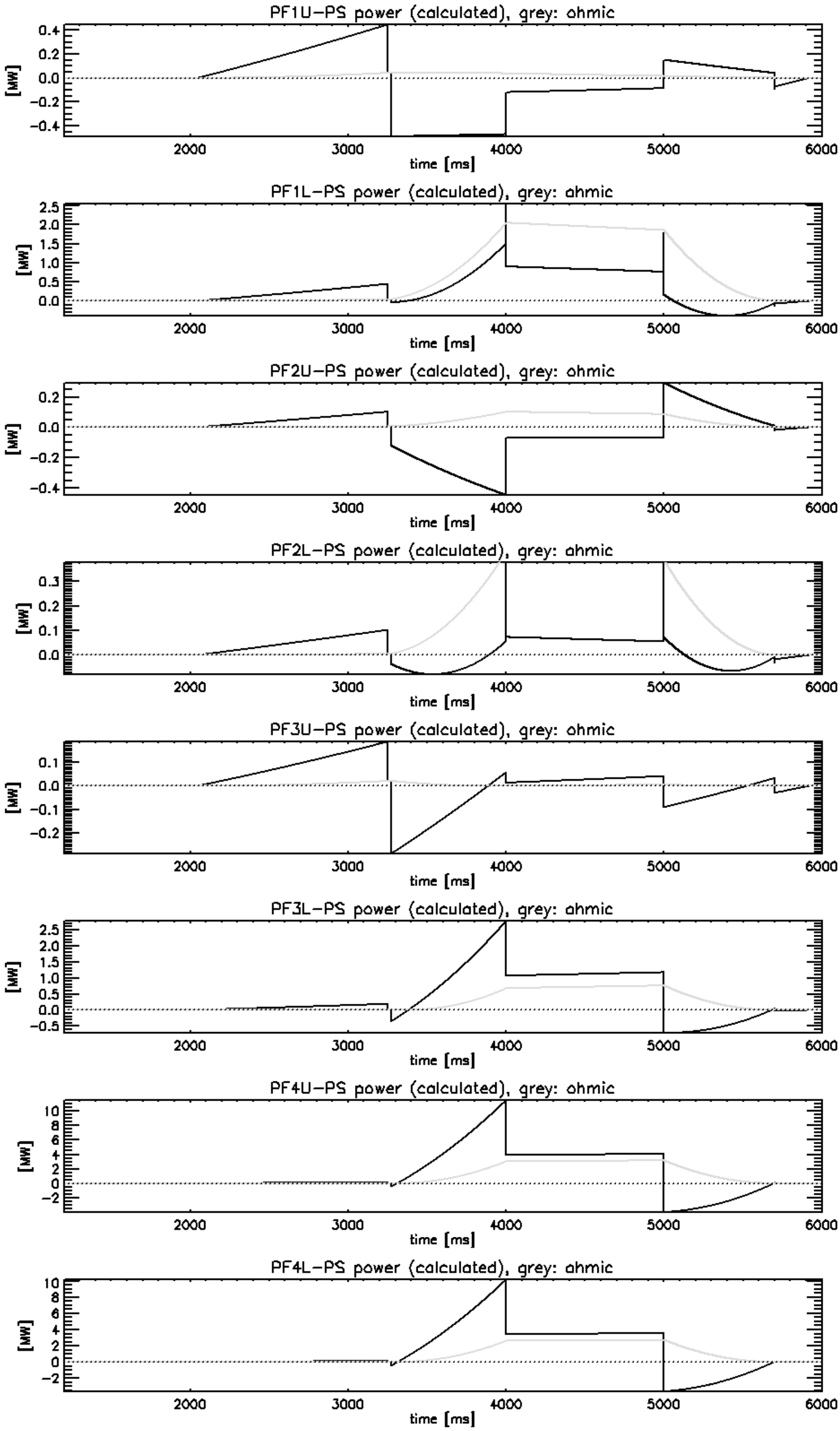
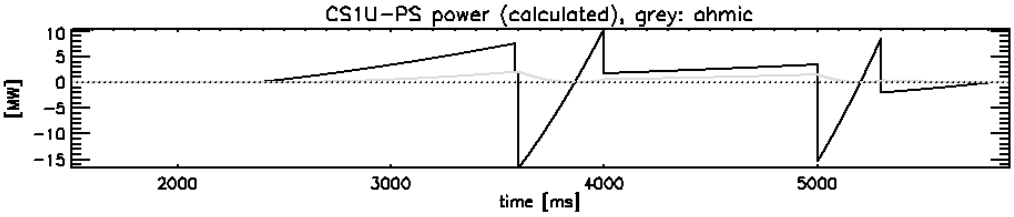
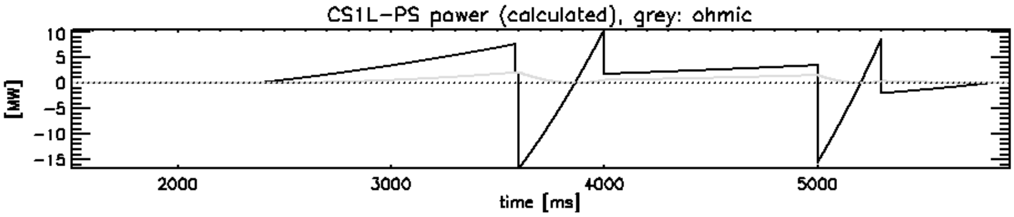
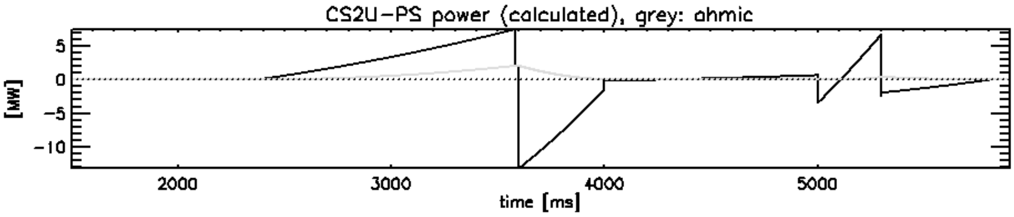
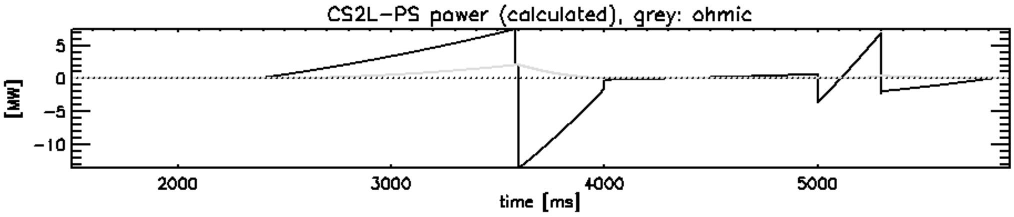


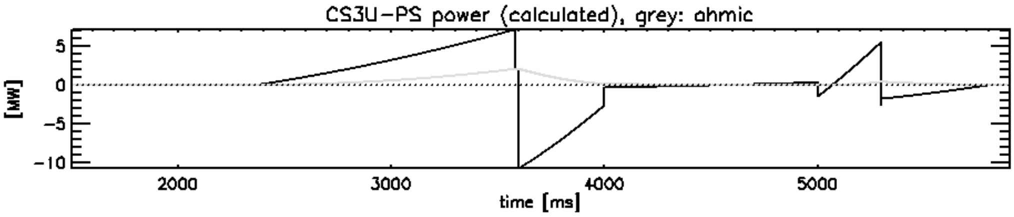
Figure 6.3.21 Waveforms of the PF coil power requirements and ohmic losses for the "nominal baseline scenario" for the tokamak version v4.1.

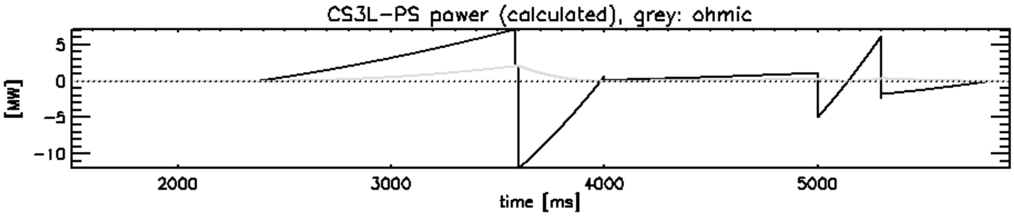

CS1U−PS power (calculated), grey: ohmic
10
5
0
−5
−10
−15
[MW]
2000
3000
4000
5000
time [ms]

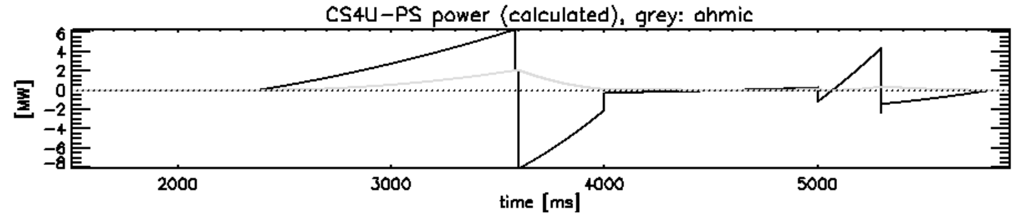

CS1L−PS power (calculated), grey: ohmic
10
5
0
−5
−10
−15
[MW]
2000
3000
4000
5000
time [ms]

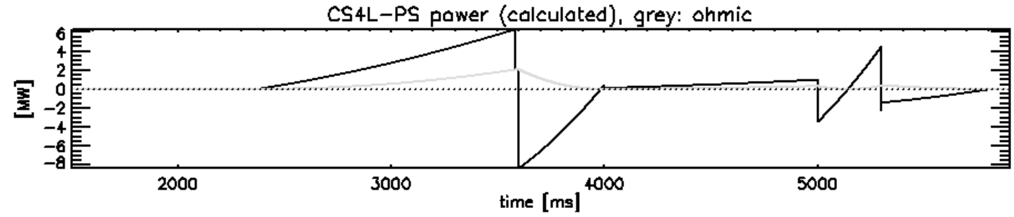

CS2U−PS power (calculated), grey: ohmic
5
0
−5
−10
[MW]
2000
3000
4000
5000
time [ms]


CS2L−PS power (calculated), grey: ohmic
5
0
−5
−10
[MW]
2000
3000
4000
5000
time [ms]


CS3U−PS power (calculated), grey: ohmic
5
0
−5
−10
[MW]
2000
3000
4000
5000
time [ms]


CS3L−PS power (calculated), grey: ohmic
5
0
−5
−10
[MW]
2000
3000
4000
5000
time [ms]


CS4U−PS power (calculated), grey: ohmic
6
4
2
0
−2
−4
−6
−8
[MW]
2000
3000
4000
5000
time [ms]


CS4L−PS power (calculated), grey: ohmic
6
4
2
0
−2
−4
−6
−8
[MW]
2000
3000
4000
5000
time [ms]

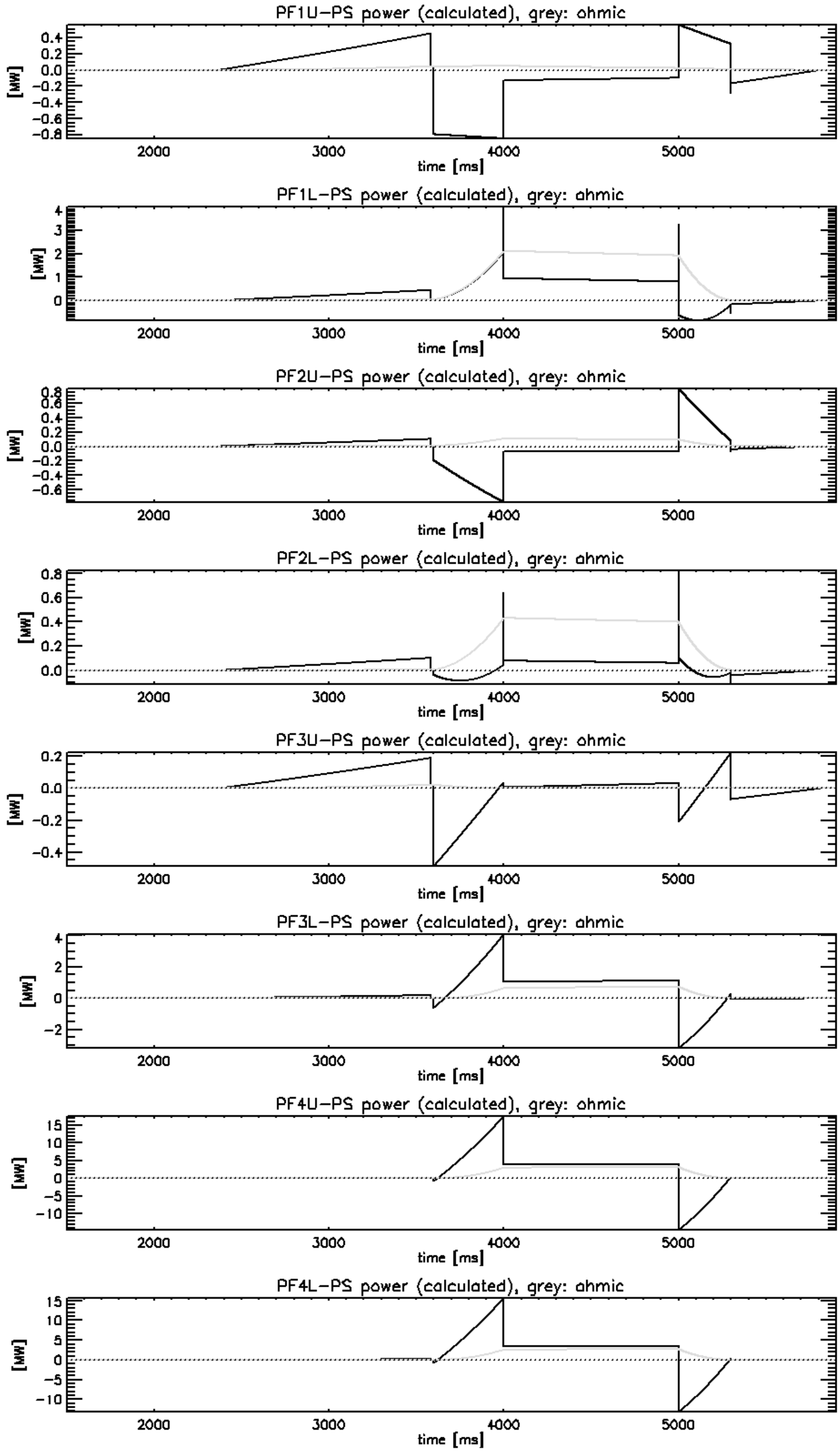
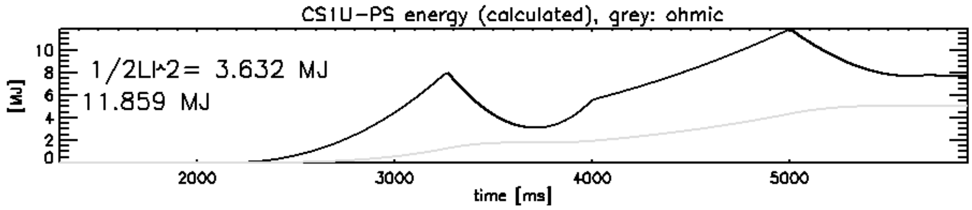
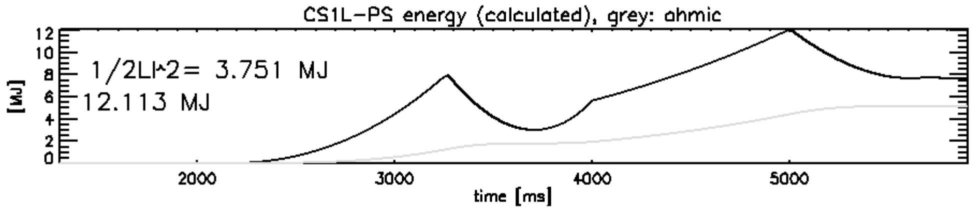
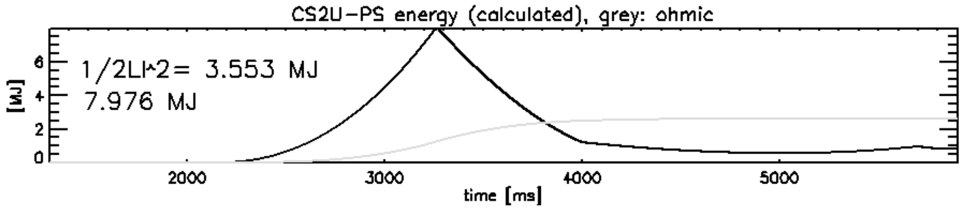


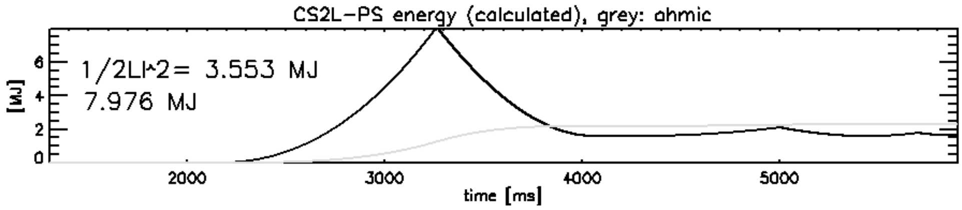
Figure 6.3.22 Waveforms of the PF coil power requirements and ohmic losses for the “fast Ip ramp-up scenario” for the tokamak version v4.1.

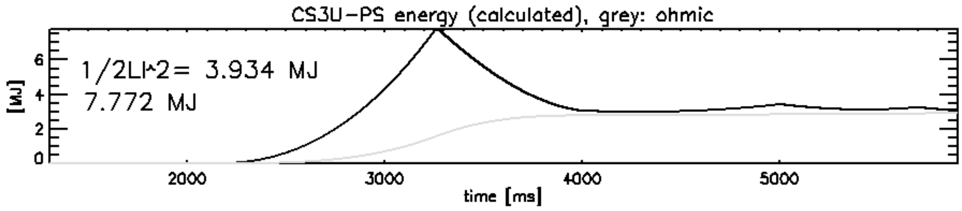
6.3.1.8 Energy of the PF coils (total and ohmic)

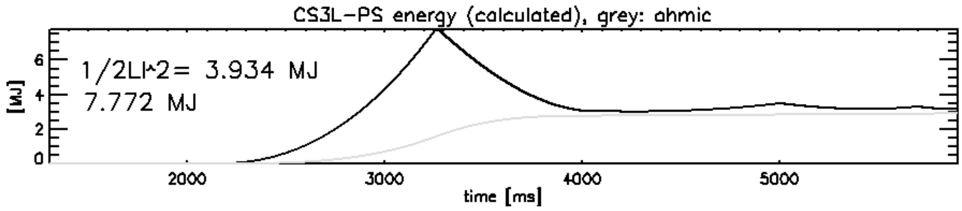


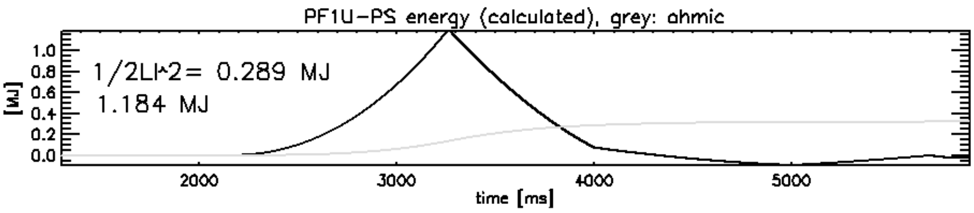












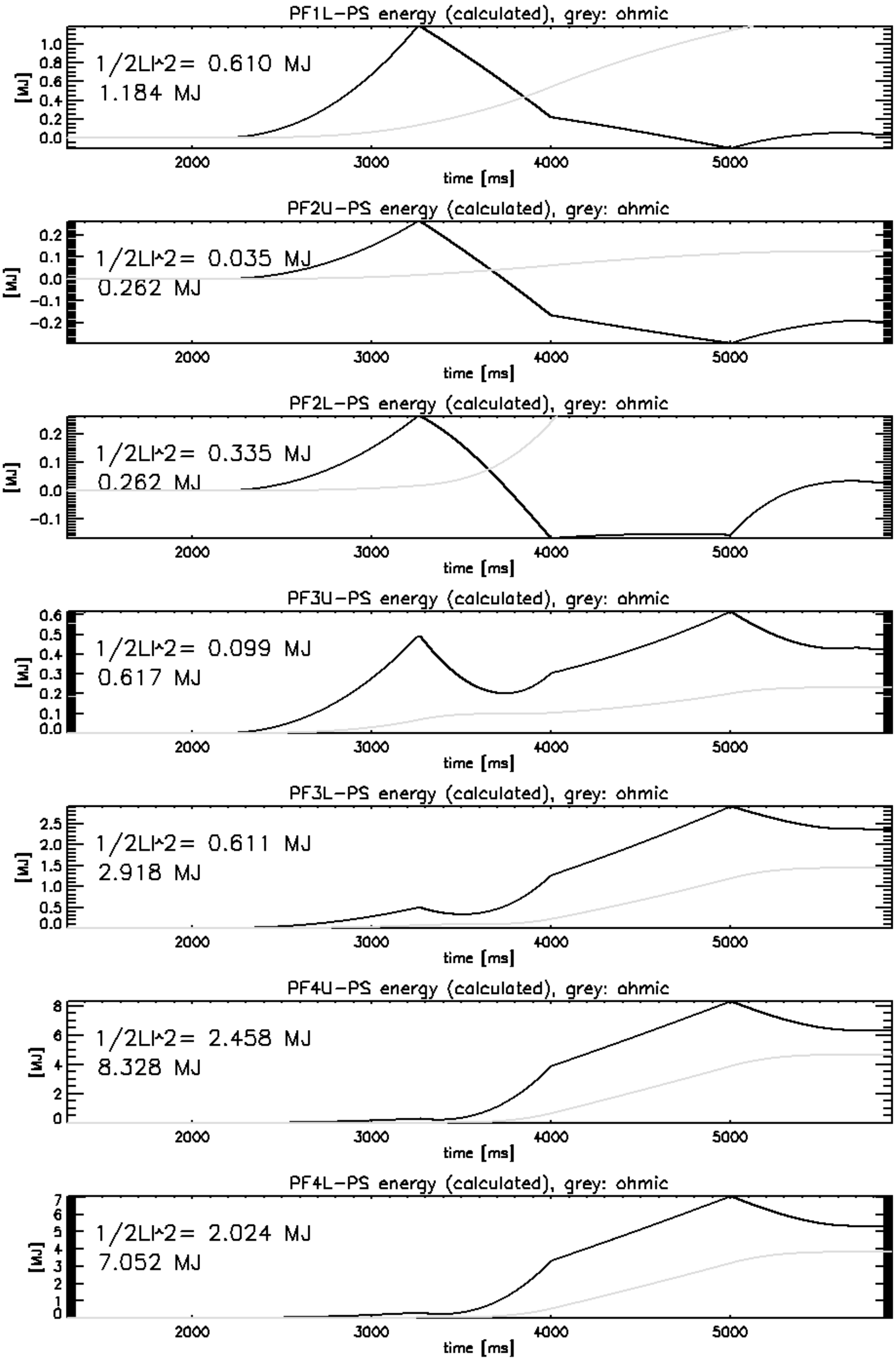
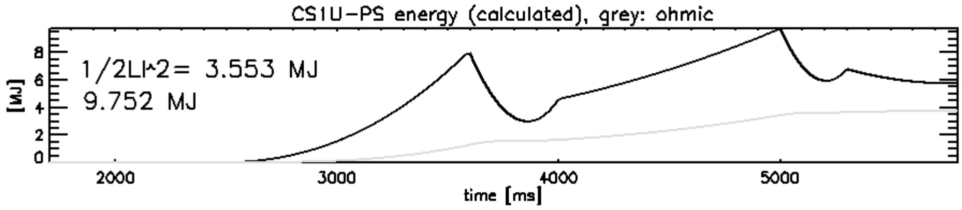
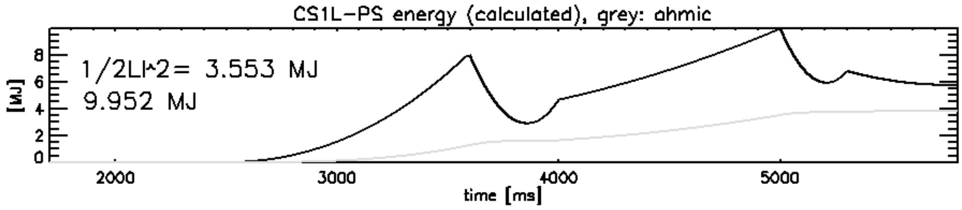
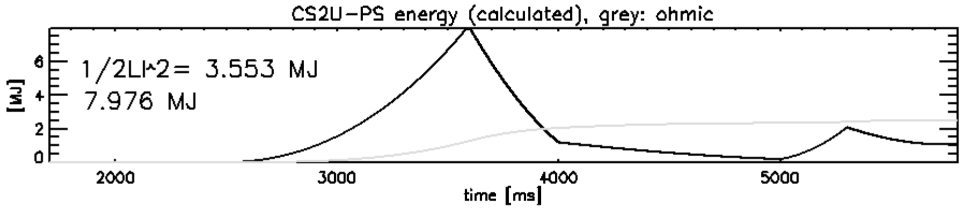
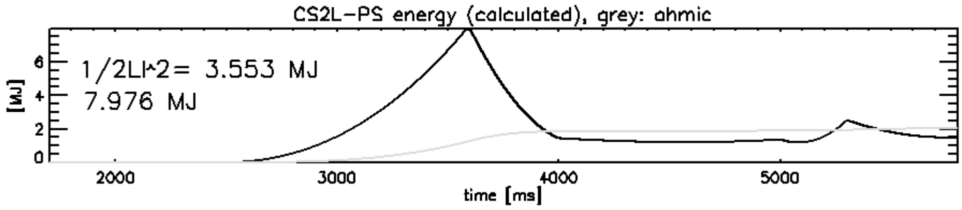


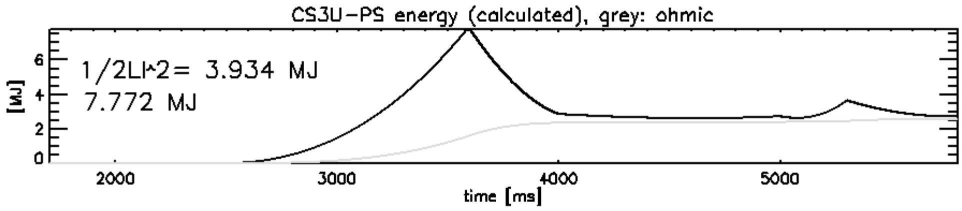
Figure 6.3.23 Waveforms of the PF coil energy requirements and ohmic losses for the "nominal baseline scenario" for the tokamak version v3.1.

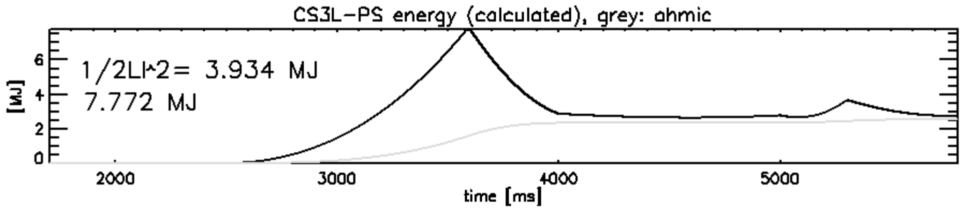

CS1U-PS energy (calculated), grey: ohmic
1/2LI^2= 3.553 MJ
9.752 MJ
[MJ]
time [ms]

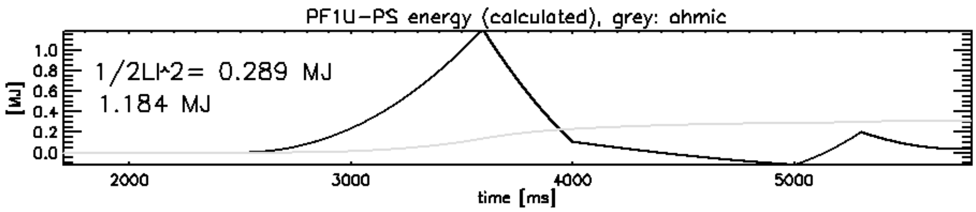

CS1L-PS energy (calculated), grey: ohmic
1/2LI^2= 3.553 MJ
9.952 MJ
[MJ]
time [ms]


CS2U-PS energy (calculated), grey: ohmic
1/2LI^2= 3.553 MJ
7.976 MJ
[MJ]
time [ms]


CS2L-PS energy (calculated), grey: ohmic
1/2LI^2= 3.553 MJ
7.976 MJ
[MJ]
time [ms]


CS3U-PS energy (calculated), grey: ohmic
1/2LI^2= 3.934 MJ
7.772 MJ
[MJ]
time [ms]


CS3L-PS energy (calculated), grey: ohmic
1/2LI^2= 3.934 MJ
7.772 MJ
[MJ]
time [ms]


PF1U-PS energy (calculated), grey: ohmic
1/2LI^2= 0.289 MJ
1.184 MJ
[MJ]
time [ms]

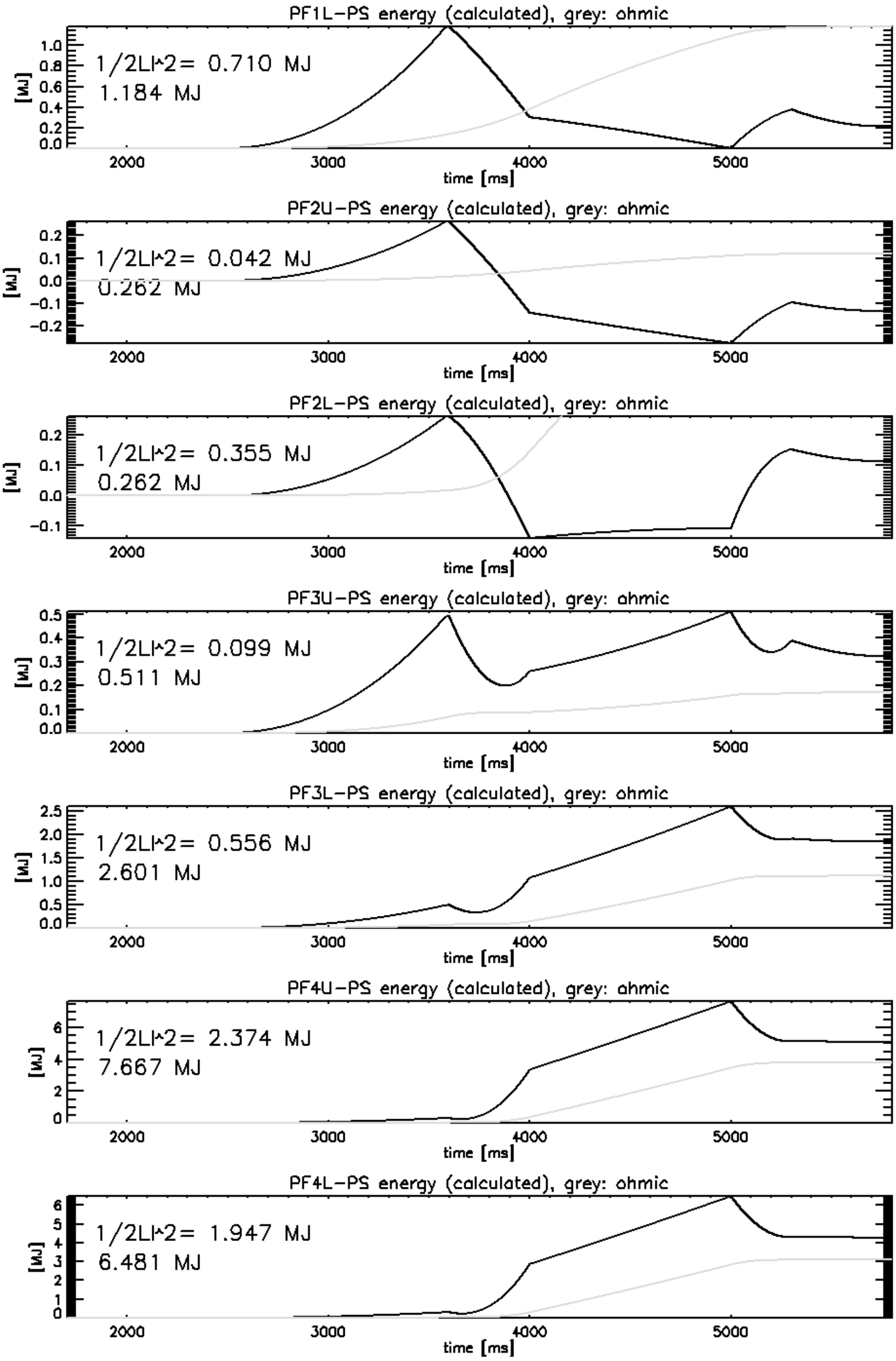
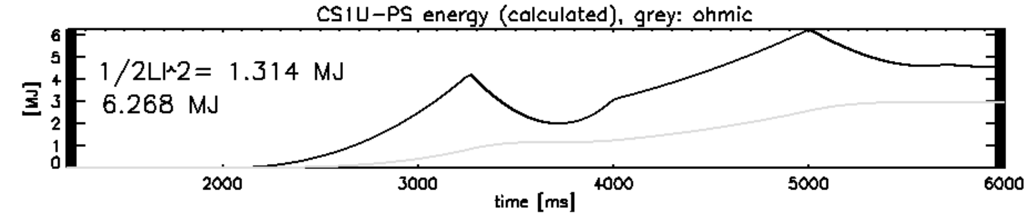
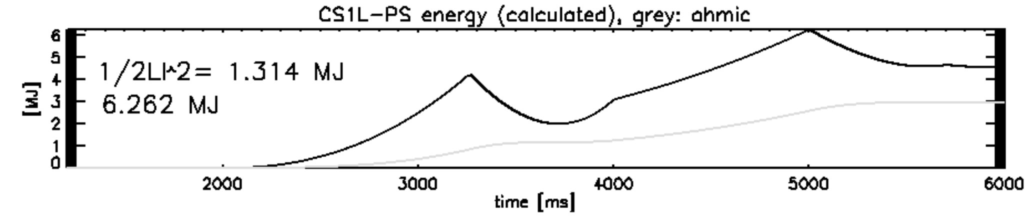
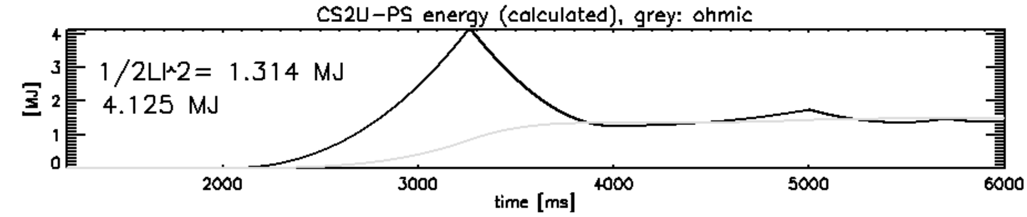
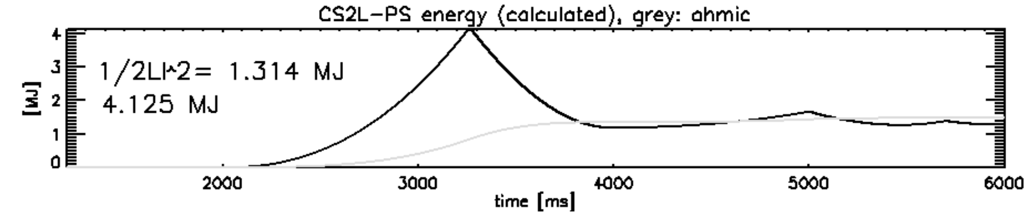


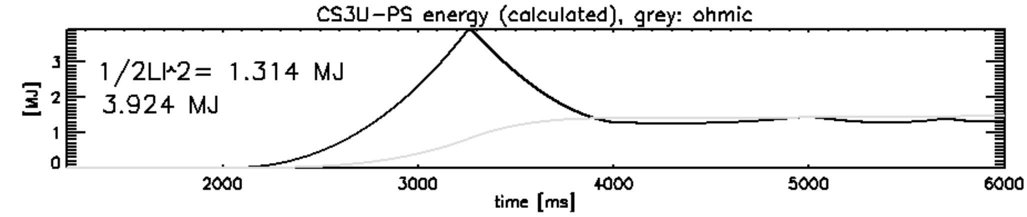
Figure 6.3.24 Waveforms of the PF coil energy requirements and ohmic losses for the "fast Ip ramp-up scenario" for the tokamak version v3.1.

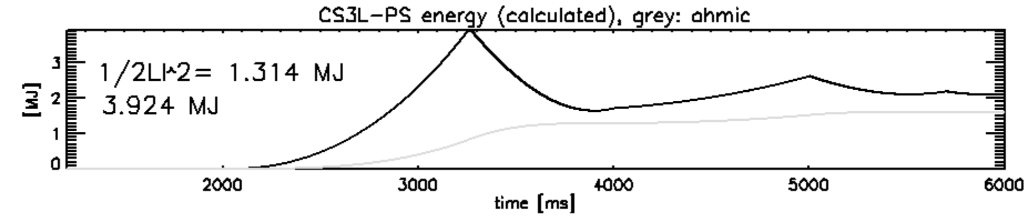

CS1U–PS energy (calculated), grey: ohmic
1/2LI^2= 1.314 MJ
6.268 MJ
[MJ]
time [ms]

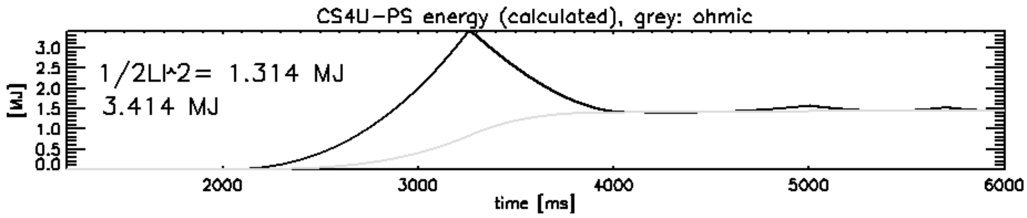

CS1L–PS energy (calculated), grey: ohmic
1/2LI^2= 1.314 MJ
6.262 MJ
[MJ]
time [ms]

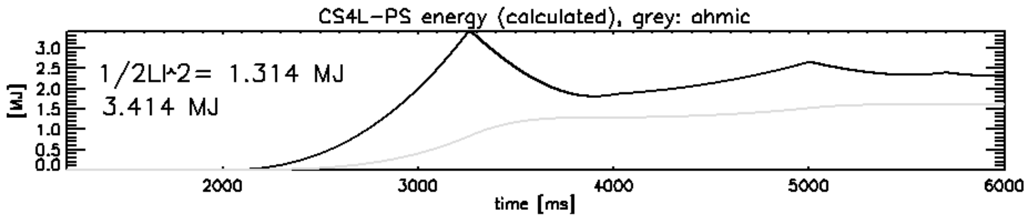

CS2U–PS energy (calculated), grey: ohmic
1/2LI^2= 1.314 MJ
4.125 MJ
[MJ]
time [ms]


CS2L–PS energy (calculated), grey: ohmic
1/2LI^2= 1.314 MJ
4.125 MJ
[MJ]
time [ms]


CS3U–PS energy (calculated), grey: ohmic
1/2LI^2= 1.314 MJ
3.924 MJ
[MJ]
time [ms]


CS3L–PS energy (calculated), grey: ohmic
1/2LI^2= 1.314 MJ
3.924 MJ
[MJ]
time [ms]


CS4U–PS energy (calculated), grey: ohmic
1/2LI^2= 1.314 MJ
3.414 MJ
[MJ]
time [ms]


CS4L–PS energy (calculated), grey: ohmic
1/2LI^2= 1.314 MJ
3.414 MJ
[MJ]
time [ms]

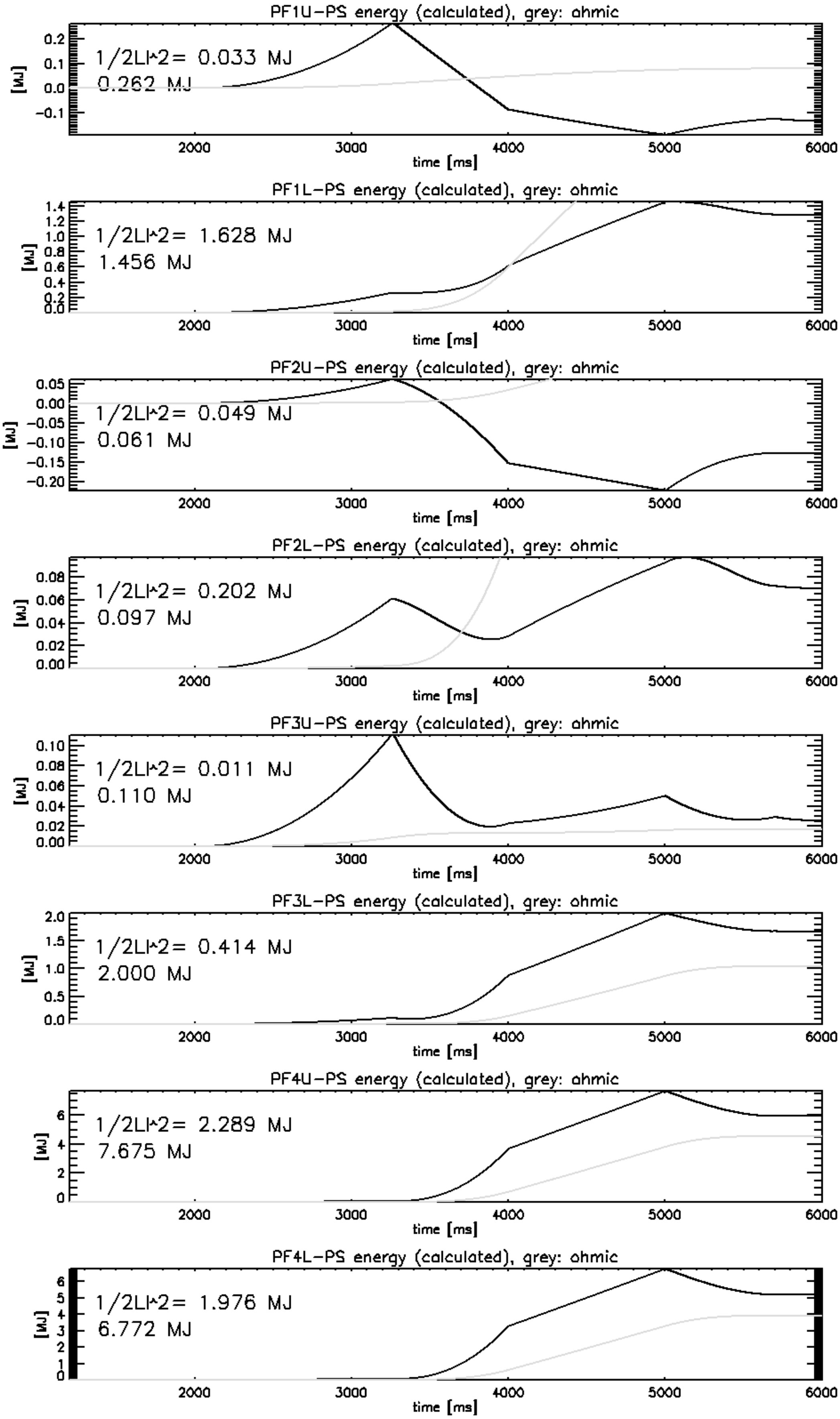
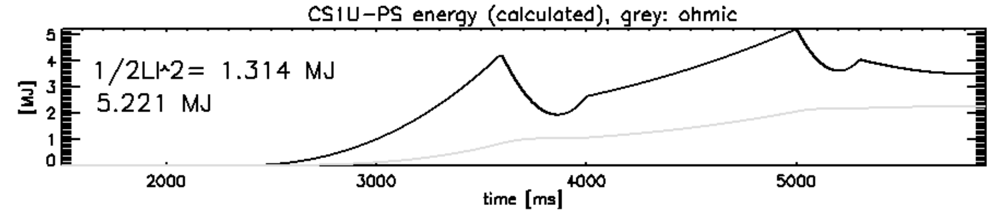
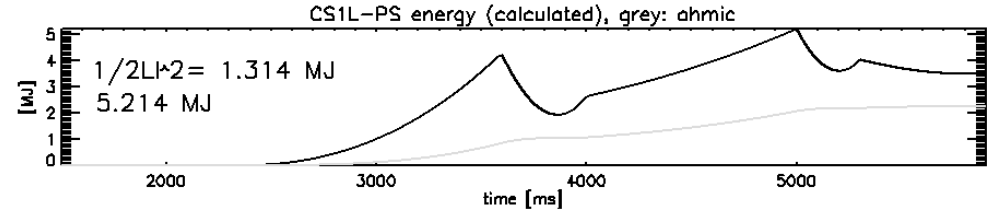
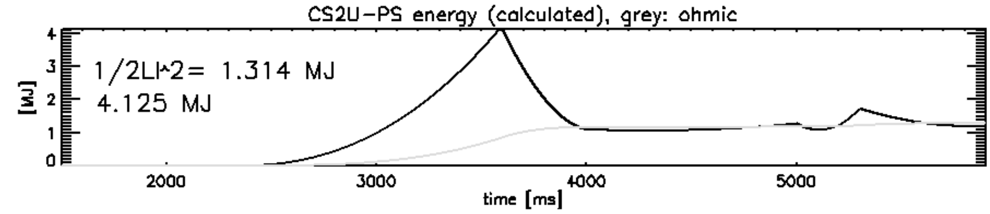
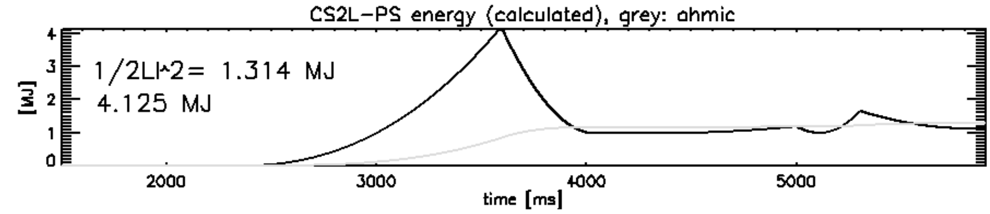


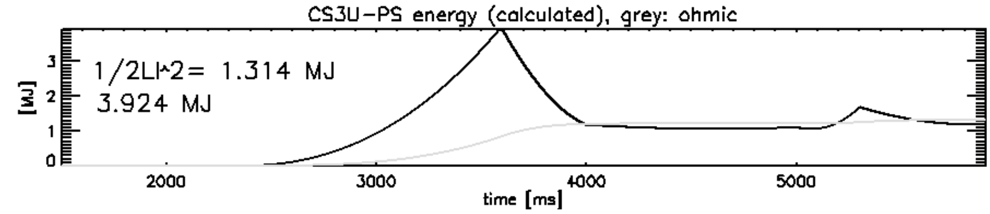
Figure 6.3.25 Waveforms of the PF coil energy requirements and ohmic losses for the "nominal baseline scenario" for the tokamak version v4.1.

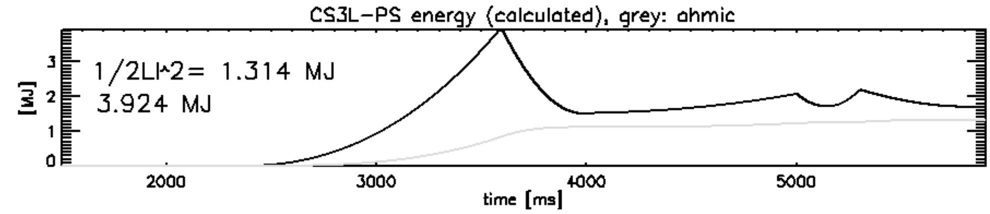

CS1U-PS energy (calculated), grey: ohmic
1/2LI^2= 1.314 MJ
5.221 MJ
[MJ]
time [ms]

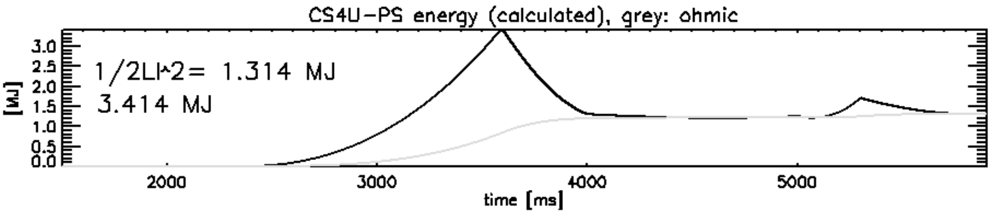

CS1L-PS energy (calculated), grey: ohmic
1/2LI^2= 1.314 MJ
5.214 MJ
[MJ]
time [ms]

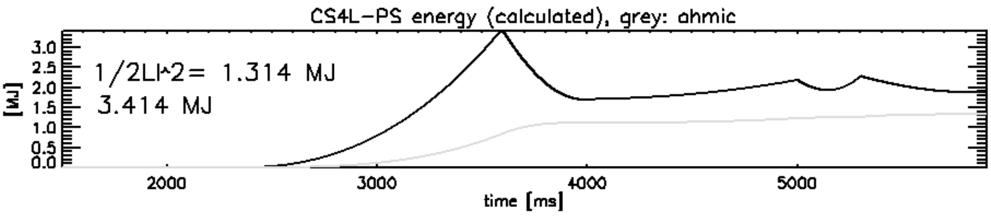

CS2U-PS energy (calculated), grey: ohmic
1/2LI^2= 1.314 MJ
4.125 MJ
[MJ]
time [ms]


CS2L-PS energy (calculated), grey: ohmic
1/2LI^2= 1.314 MJ
4.125 MJ
[MJ]
time [ms]


CS3U-PS energy (calculated), grey: ohmic
1/2LI^2= 1.314 MJ
3.924 MJ
[MJ]
time [ms]


CS3L-PS energy (calculated), grey: ohmic
1/2LI^2= 1.314 MJ
3.924 MJ
[MJ]
time [ms]


CS4U-PS energy (calculated), grey: ohmic
1/2LI^2= 1.314 MJ
3.414 MJ
[MJ]
time [ms]


CS4L-PS energy (calculated), grey: ohmic
1/2LI^2= 1.314 MJ
3.414 MJ
[MJ]
time [ms]

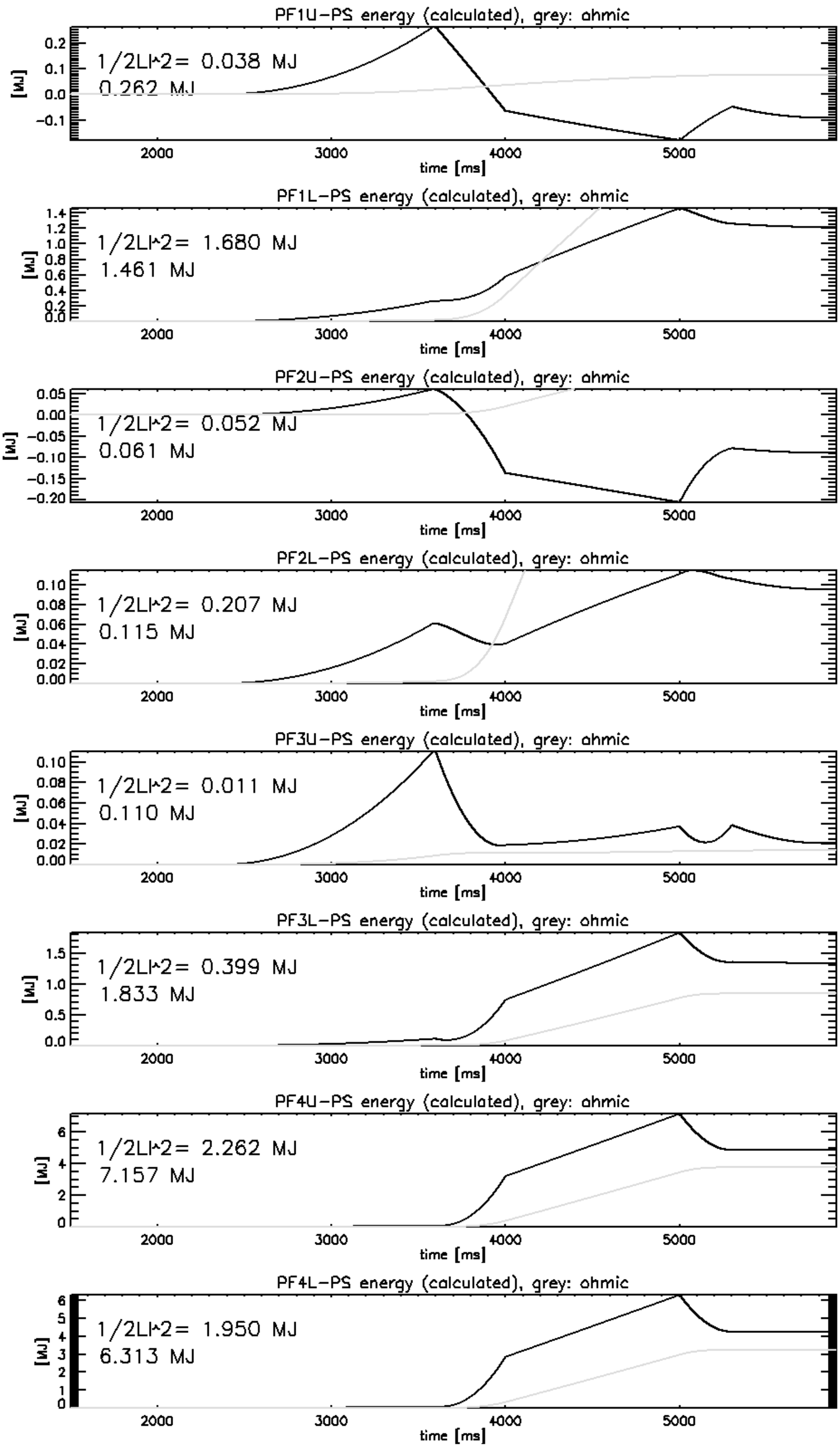


Figure 6.3.26 Waveforms of the PF coil energy requirements and ohmic losses for the “fast Ip ramp-up scenario” for the tokamak version v4.1.

6.3.2 Real life temporal evolution of currents on the COMPASS tokamak

The purpose of this section is to show practical difference between theoretical (ideal) current waveforms and practical realization of these waveforms on example of the presently existing tokamak operated in the Institute of Plasma Physics – tokamak COMPASS.

6.3.2.1 Power supplies for individual coil systems on the COMPASS tokamak

- **TFPS** – Toroidal Field Power Supply – Power Supply for toroidal magnetic field coils, which generate main magnetic field in the toroidal direction, used for principal confinement of plasma.

- **MFPS** – Magnetizing Field Power Supply – Power supply for poloidal magnetic field coils, which are responsible for magnetization of the plasma column, induction of plasma current and initialization of plasma breakdown in the gas. It is a circuit of the coils – the coils act as the primary winding of the air-core transformer, where plasma column acts as the secondary winding in short-circuit.

- **EFPS** – Equilibrium Field Power Supply – Power supply for the poloidal magnetic field coils, which are used to maintain the plasma equilibrium using vertical magnetic field. The vertical magnetic field creates together with plasma current radial force ($\vec{F} = \vec{j} \times \vec{B}$), which counters the hoop force of the plasma itself.

- **SFPS** – Shaping Field Power Supply – Power supply for the poloidal magnetic field coils, which are used to control the plasma shape.

- **BR** – Fast Amplifier power supply for the poloidal magnetic field coils, which are used to control the vertical position of the plasma column.

- **BV** – Fast Amplifier power supply for the poloidal magnetic field coils, which are used to control the radial position of the plasma column.

6.3.2.2 Description of the typical COMPASS discharge

The typical tokamak COMPASS discharge can be most conveniently described using time traces of the fundamental plasma parameters together with the current evolution in individual coil systems (listed above). Plasma current and loop voltage (*U_loop*) are fundamental plasma parameters, which describe the current flowing in the plasma column in the toroidal direction and voltage on a single turn of the secondary transformer (tokamak) winding, whose primary winding is constituted by the MFPS coil system. Secondary winding is created by the plasma column itself, thus, has only one turn.

The typical discharge length on the COMPASS tokamak ranges from 300 to 400 ms. Its initialization and termination is distinguished from the time trace of plasma current and is marked by the vertical dashed lines in Figure 6.3.27. The discharge can be further divided into three stages according to the plasma current evolution, namely *ramp-up phase*, *flat-top phase* and *ramp-down phase*. In the first phase, the current is increasing from zero value, then it is kept constant at given value and in the last phase decreases back to zero value. Most of the physics scientific experiments are focused on the flat-top phase, when the plasma physical parameters of the plasma are stabilized. In order to achieve high-quality results, it is required to achieve as long phase with stabilized plasma physics parameters as possible.

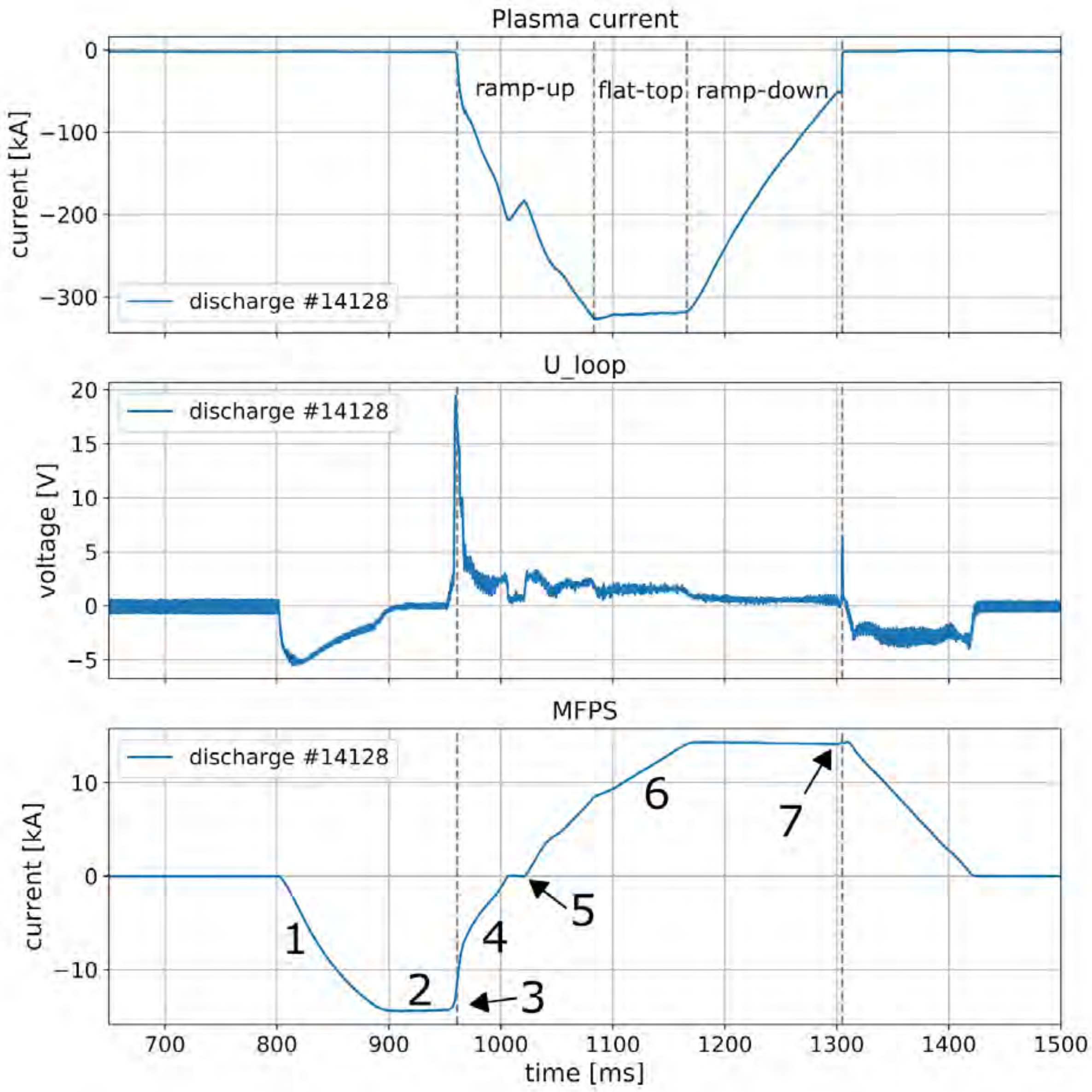


Figure 6.3.27 Time traces of fundamental parameters of the typical discharge on the COMPASS tokamak. Top to bottom: Plasma current, loop voltage (U_loop) and current in the magnetizing field coils (MFPS).

The bottom plot in Figure 6.3.27 represents the time trace of the current in the magnetizing field coils (MFPS). Typical shape of the time trace can be further divided into several phases. The plasma current (secondary winding in air-core transformer) is induced by the change of the electrical current flowing through the MFPS circuit (primary winding). The maximal current in these coils is set to ±15 kA. In order to utilize the full range of applicable current of the coils, firstly, the maximal negative current (-15 kA) is driven to the MFPS coils during **phase 1**. In order to achieve zero loop voltage before the plasma breakdown (see the middle graph in Figure 6.3.27), MFPS current is held constant in the **phase 2**. In the moment marked as **3**, breakdown of a discharge in the neutral working gas inside the tokamak vessel is generated. Electrical current is induced in plasma, thus, causing further ionization of the medium and increase of the plasma current. Sufficiently high loop voltage (> 10 V) is required for the plasma breakdown, which is induced by a rapid current increase in the MFPS coils. In the **phase 4**, the current in the MFPS coils is rising, thus, inducing more current in the plasma column, using the loop voltage values of few volts. The moment, when the MFPS current reaches zero value marked as **5**, introduces characteristic feature in the plasma current evolution, when the plasma current decreases by several percent, due to the lack of current swing in the MFPS circuit. Changing of the current polarity (from negative to positive current values) in the MFPS coils requires approximately 5-15 ms. In the **phase 6**, previously described as the flat-top phase, after the requested plasma current is reached, a active feedback determined rate of increase of the MFPS current is maintained in order to keep the plasma current flat-top. The change of the MFPS current generates enough voltage on the plasma column to compensate ohmic losses in the plasma. When the maximum value of MFPS current is achieved, the flat-top phase is terminated and the plasma current starts to decrease, while the current in the MFPS coils is kept constant. In this particular case, the plasma discharge is not terminated ideally, when a sudden drop in the plasma current occurs soon after 1300 ms. This moment marked as **7** is called plasma disruption and may be caused by various mechanism. The remaining plasma current is suddenly discharged to the tokamak vessel, after the plasma column touches vacuum vessel wall.

The toroidal magnetic field, which plays a key role in plasma confinement, is generated by toroidal magnetic field coils, which are supplied by TFPS (Toroidal Field Power Supply) system. Toroidal magnetic field is generated and maintained at given value (0.9 – 1.65 T) during the whole discharge, therefore the current in TFPS is maintained constant during the plasma discharge as seen on Figure 6.3.28.

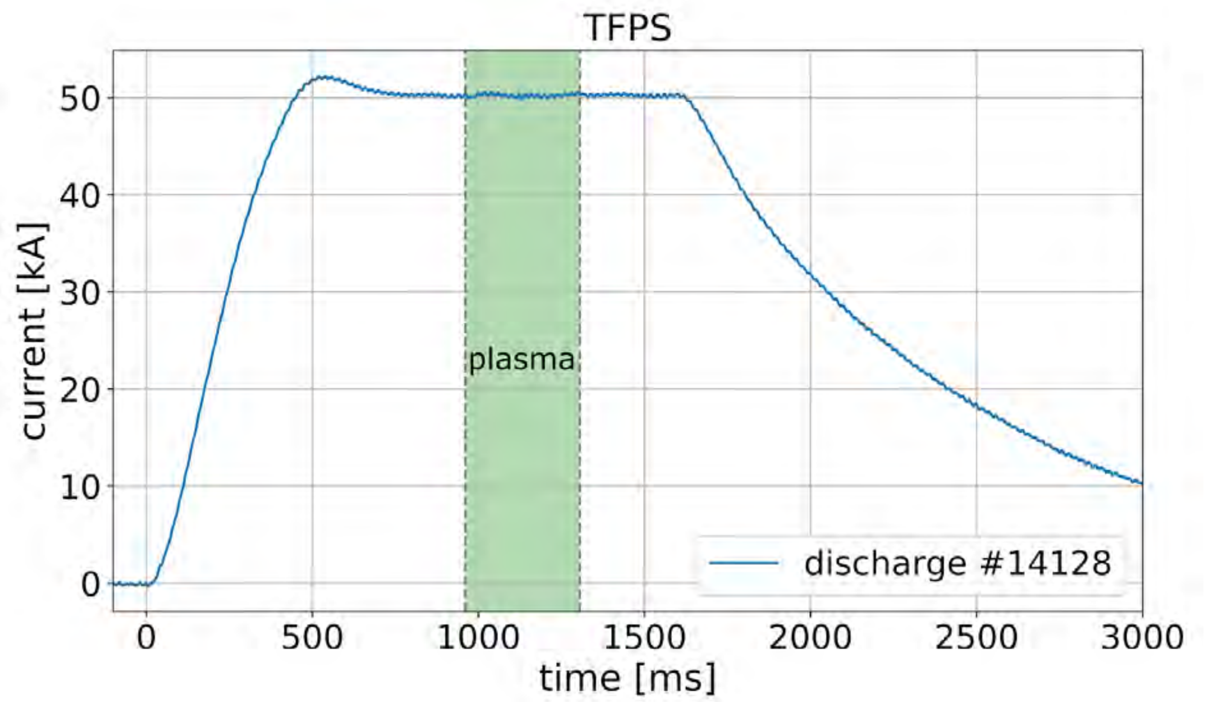


Figure 6.3.28 Current evolution in toroidal field coils (TFPS). The period of plasma discharge is marked by a green region.

6.3.2.3 Time-trace waveforms of the individual coil systems of the COMPASS tokamak – comparison between the ideal and practical waveforms

In order to evaluate real-life performance of the magnetic field coils systems, the requested currents in the main magnetic field coils and the resulting simulated plasma currents are compared with the real ones generated by the COMPASS real-time control system and measured by diagnostic tools.

Measured data from three chosen tokamak discharges from the last five years of operation (solid lines) are compared in Figure 6.3.29, together with calculated currents from ideal scenario simulation for the COMPASS tokamak (dashed lines). Discharges with similar parameters were chosen to be comparable. During each of these discharges (numbers #5936, #12960, #14128) the maximal current of 330 kA was achieved, while the toroidal magnetic field was set to 1.15 T on the magnetic axis, major radius R = 56 cm.

As can be easily observed, presented real-life currents in key coil systems are significantly different from the simulated ones. Considering plasma current, the initial plasma current ramp-up is substantially steeper to be able to reach requested plasma current in a given time. Correspondingly, the current increase in the MFPS and EFPS coils is deviated from the modelled discharge to enable appropriate increase of the plasma current. Moreover, the current in MFPS is ramped to the maximal negative current. The moment when zero current is flowing in magnetization coils (MFPS) is one of the reasons for such steep ramp-up. As described in the previous section, the time necessary for changing the polarity of the current in MFPS coils is up to 15 ms, during which the plasma current decreases. Characteristic oscillation in the current evolution can be distinguished on EFPS and SFPS in addition to MFPS and plasma current.

During the flat-top phase, when the plasma current is maintained constant, the simulation properly matches the experimental data. When the maximum current in the magnetizing coils is reached, the flat-top phase is terminated and the current ramp-down is initiated, as indicated by the gradual decrease of the plasma current.

In various discharges, the existence of the plasma column is terminated by a sudden event called *plasma disruption*, during which the column of plasma touches the tokamak vessel wall and both the electric current and the energy confined within the plasma is transferred to the vessel. The disruption event is indicated by a sudden drop of the plasma current and highlighted by vertical dashed lines on individual plots in Figure 6.3.29. Apart from the massive thermal and electromagnetic load of the tokamak vessel caused by a disruption, the current is being induced into each of the magnetic field coil systems. This can be observed in the discharge #12960, where a sudden change of the MFPS coils current can be seen after the disruption. In addition, for the two other discharges, there is a significant increase in the EFPS current just after the disruption. This effect can potentially cause serious damage to coils and their power supplies if not protection is included in the power supply design, especially for COMPASS-U, where the plasma current reaches up to 2 MA.

The two bottom plots in Figure 6.3.29, namely BR and BV, describe the current in the magnetic field coils responsible for the stabilization of the vertical and radial position (feedback controlled system). In these cases, the dashed lines represent the maximum (both negative -5 kA and positive +5 kA) current applicable for these coils. In most cases, currents in these coils required to ensure proper plasma position are within the boundary limit. However, for the discharge #12960 a saturation current in the radial position coil (BV) is observable.

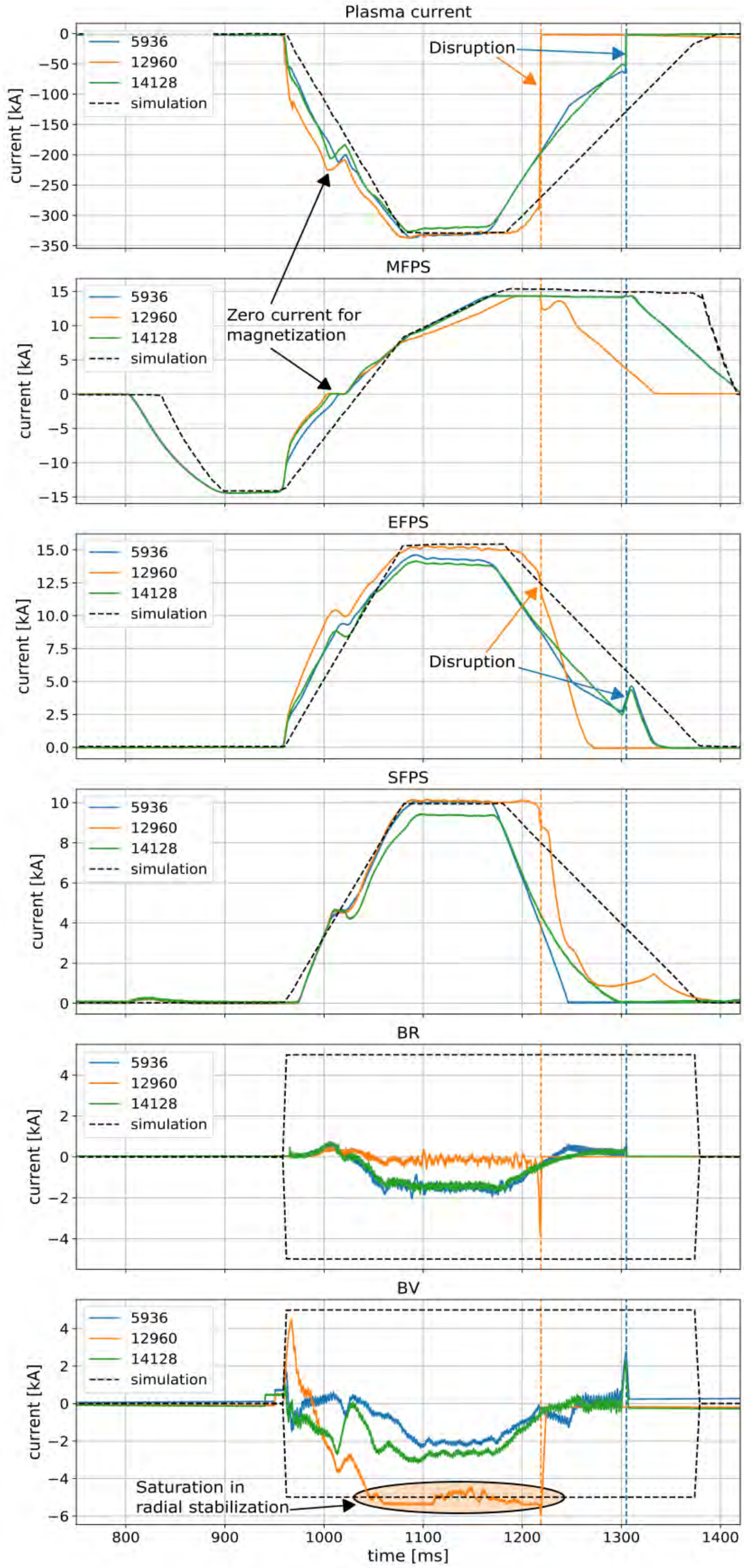


Figure 6.3.29 Measured temporal evolutions of currents in the main COMPASS magnetic field coils power supplies compared to their respective simulations during plasma discharges on the COMPASS tokamak.

6.3.3 Protection of the Power Supplies against plasma disruptions

The disruption is an event when control of the plasma column is lost, resulting into uncontrolled movement of the plasma column (≤ 2 MA) to the vacuum vessel wall and to the fast decrease of the plasma current. Both the plasma column movement and the decrease of the plasma current induce significant voltage into the neighbouring conductors – vacuum vessel and the PF coils. The plasma disruption is a common event in the tokamaks used for scientific experiments – the development of the new operational scenarios for the plasma, as well as "pushing the boundary" leads to significant fraction of the tokamak pulses ending with disruption. The COMPASS-U tokamak should perform approximately up to 50 000 discharges during its life (2500 discharges per year). It is expected that up to 20 - 50 % of these discharges will end with disruption.

The vacuum vessel is placed between the plasma and the PF coils. Therefore, the time constant of the magnetic field change on the PF coils is either the duration of the plasma current decay or the time constant of the vacuum vessel, whichever is longer. The plasma current (up to 2 MA) can decay with rate up to 10 MA/ms, inducing current into the vacuum vessel. The COMPASS-U vacuum vessel will have time constant $\tau = L/R$ in the range 5-15 ms. The change of the magnetic field generated by the plasma current disruption will be "seen" by the PF coils with time constant of vacuum vessel. Therefore, 5-15 ms is the fastest feasible time for the current change generated in the PF coils from the plasma disruption. The current induced in the PF coils will then decay according the time constant of the PF coils (up to 1-2 seconds) and voltage applied by the connected Power Supply or activated crowbar.

If the Power Supply connected to the PF coil (or more PF coils in series) has very small or negligible self-inductance with respect to the PF coil, then the disruption should not produce extraneous voltage, which could damage the Power Supply. The transistor based H-bridge converter should be constructed with minimized internal inductance between the transistors and the DC-interlink. Therefore, the disruption-induced voltage should not be of concern. The caution should be exercised only if choke coils are used in the construction of the transistor based PS.

The magnitude of the current induced from the disruption in the PF coils can damage the connected Power Supply if it is not designed to survive the sudden current change or if it is not protected by crowbar. The possible crowbar (circuit used to shot-circuit the PF coil and thus protect the Power Supply) must have resistor with a) sufficiently low self-inductance, b) energy capacity suitable for the PF coil, c) resistance, which allows safe extraction of the magnetic field energy from the tokamak PF coils system, and d) redundant triggering from the over-current.

For the purpose of the Power Supply System protection dimensioning, the upper boundary (envelope) of the disruption induced current must be found for each PF coil. Three possible methods how to determine the upper boundary of the induced current can be used:

1) Assume that 2 MA of current in plasma is perfectly coupled via mutual inductance to each of the PF coils and can induce 2 MA-turns in 5 ms.

2) Assume the system with plasma column represented by thin wire on realistic position inside the vacuum vessel, neglect the effect of vacuum vessel currents and assume that there is only one PF coil, to which the current is induced during the disruption.

3) A variety of models with all PF coils present, vacuum vessel induced currents and with many ways, how to describe plasma column movement and current decay, can be used.

The three methods are listed in order with the increasing complexity of the calculation and precision of the result. The second method was used, with first method used as simple check. **The results are summarized in the Table 6.3.3**. The method is described in detail in the following section **6.3.3.1 - Estimation of the upper boundary of currents induced in the PF coils during disruption.**

COMPASS-U PF coils, v3.1

Coil name	Maximal disruption induced current I=M/L*Ip [kA]
CS1U	13
CS1L	13
CS2U	12
CS2L	12
CS3U	7
CS3L	7
PF1U	11
PF1L	11
PF2U	19
PF2L	19
PF3U	15
PF3L	15
PF4U	17
PF4L	17

COMPASS-U PF coils, v4.1

Coil name	Maximal disruption induced current I=M/L*Ip [kA]
CS1U	39
CS1L	39
CS2U	38
CS2L	38
CS3U	34
CS3L	34
CS4U	25
CS4L	25
PF1U	11
PF1L	11
PF2U	19
PF2L	19
PF3U	15
PF3L	15
PF4U	17
PF4L	17

Table 6.3.3: Overview of the maximal possible induced currents (absolute value – both current directions are possible) for the PF coils, for the tokamak version v3.1 and v4.1.

6.3.3.1 Estimation of the upper boundary of currents induced in the PF coils during disruption

The method of determination of the upper boundary of the induced current in the PF coils is as follows:

- Plasma is represented by a thin wire carrying -2 MA current.
- The plasma is placed on the separatrix line (see red line in Figure 6.3.30 and Figure 6.3.31). The exact position is selected to have maximal mutual inductance (coupling) between the plasma and the investigated individual PF coil. Found positions of maximal coupling are listed in the Table 6.3.4 and Table 6.3.5.
- Vacuum vessel is neglected.
- There are no other coils than the one investigated (e.g. CS1U is close to CS1L, so in reality the current will be induced into both of them) => estimated induced current can be considered to be upper limit, with sufficient reserves.
- Resistance of the PF coils is neglected. This is reasonable assumption, the time constant of the PF coils is much longer than duration of the disruption (seconds vs tens of ms, see Table 6.3.4 and Table 6.3.5 for the time constants of the PF coils).
- The movement of the plasma from the vacuum vessel centre to the position on separatrix is neglected. This does not invalidate the calculation of the induced current envelope. The mutual inductance $M_{PF\text{-}plasma}$ is changing up to 2x – 2.5x between the vacuum vessel centre and the selected position on separatrix. The movement of the plasma column to the separatrix induces coil current in the opposite direction to the plasma current, followed by the plasma current decrease, which induces coil current in the same direction as the plasma current. Therefore, the PF coil will experience current excursion in both current polarities. The envelope of the induced current is given by the plasma current decrease, because it is always valid that Ip,max x dL/dt < Lmax x dIp/dt (where dL = Lmax-Lmin, dIp = Ip,max).
- If one Power Supply supplies two coils in series (as is expected for Central Solenoid for

COMPASS-U v4.1), the current induced to the Power Supply will be same or lower than higher from two “Maximal disruption induced currents” in the individual coils. This is valid for Central Solenoid coils, where CS coils self-inductance is equal between the coils. The induced current is $I_{PF} = \frac{M1+M2}{L1+L2} I_{plasma}$.

The maximal possible current induced in the PF coil can be calculated from the equation $I_{PF} = \frac{M}{L} I_{plasma}$, where M is mutual inductance between the plasma column and PF coil and L is PF coil self-inductance. The results are summarized in the Table 6.3.3, while the details, including simplified method (2 MA.turns / turn count) for check, are described in the Table 6.3.4 and Table 6.3.5.

The analysis was performed using IDL (Interactive Data Language) code “disruption_induced_currents.pro” with tokamak geometry input from file

z:\Users\havlicek\COMPASS-Upgrade\Power_Estimation_Code\COMPASS-U_3.1.txt

and

z:\Users\havlicek\COMPASS-Upgrade\Power_Estimation_Code\COMPASS-U_4.1-temp.txt.

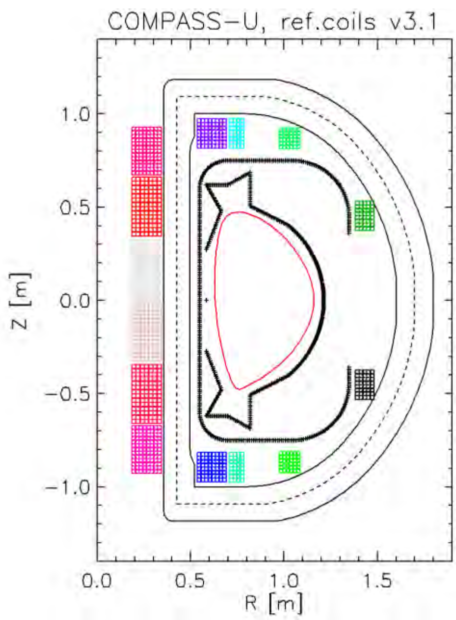


Figure 6.3.30: COMPASS-U PF coils v3.1 with individual turns shown. The plasma separatrix is marked by red line inside of the vacuum vessel.

COMPASS-U PF coils, v3.1										
Power Supply name	Turn count, N	R [mΩ]	Self-inductance, L [uH]	Time constant L/R [s]	Mutual inductance to plasma represented by thin wire at R=0.894m, Z=0m, M [uH]	Mutual inductance between the PF coil and plasma at position R, Z, which is the point on separatrix where mutual inductance to PF coil is maximal			Plasma current divided by turn count (-2MA/N) [kA]	Maximal disruption induced current I=M/L*Ip [kA]
						R [m]	Z [m]	M [uH]		
CS1U PS	98	1.68	3509	2.10	15.0	0.63	0.182	22.905	-20.41	-13.05
CS1L PS	98	1.68	3509	2.10	15.0	0.64	-0.131	22.347	-20.41	-12.74
CS2U PS	98	1.68	3509	2.10	10.3	0.66	0.405	20.909	-20.41	-11.92
CS2L PS	98	1.68	3509	2.10	10.3	0.71	-0.419	19.650	-20.41	-11.20
CS3U PS	104	2.37	4375	1.85	6.7	0.72	0.467	15.365	-19.23	-7.02
CS3L PS	104	2.37	4375	1.85	6.7	0.74	-0.468	15.191	-19.23	-6.94
PF1U PS	64	4.54	7202	1.59	16.3	0.78	0.471	37.539	-31.25	-10.42
PF1L PS	64	4.54	7202	1.59	16.3	0.76	-0.477	37.614	-31.25	-10.45
PF2U PS	32	2.76	2653	0.96	11.1	0.83	0.458	25.017	-62.50	-18.86
PF2L PS	32	2.76	2653	0.96	11.1	0.78	-0.468	24.524	-62.50	-18.49
PF3U PS	36	4.84	5268	1.09	19.3	0.94	0.392	39.920	-55.56	-15.16
PF3L PS	36	4.84	5268	1.09	19.3	0.94	-0.373	38.454	-55.56	-14.60
PF4U PS	40	6.62	9589	1.45	40.5	1.12	0.174	78.733	-50.00	-16.42
PF4L PS	40	6.62	9589	1.45	40.5	1.11	-0.183	77.601	-50.00	-16.19

Table 6.3.4: PF coils parameters used for calculation of the maximal possible induced currents. Tokamak version v3.1.

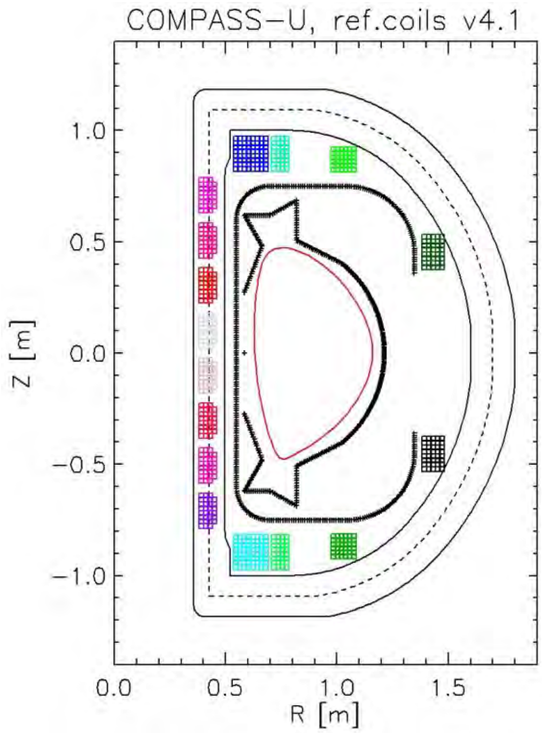


Figure 6.3.31: COMPASS-U PF coils v4.1 with individual turns shown. The plasma separatrix is marked by red line inside of the vacuum vessel.

COMPASS-U PF coils, v4.1										
Coil name	Turn count, N	R [mΩ]	Self-inductance, L [uH]	Time constant L/R [s]	Mutual inductance to plasma represented by thin wire at R=0.894m, Z=0m, M [uH]	Mutual inductance between the PF coil and plasma at position R, Z, which is the point on separatrix where mutual inductance to PF coil is maximal			Plasma current divided by turn count (-2MA/N) [kA]	Maximal disruption induced current I=M/L*Ip [kA]
						R [m]	Z [m]	M [uH]		
CS1U	30	0.813	1051	1.29	12.4	0.63	0.094	20.288	-66.67	-38.59
CS1L	30	0.813	1051	1.29	12.4	0.64	-0.097	19.777	-66.67	-37.62
CS2U	30	0.813	1051	1.29	10.2	0.64	0.303	19.670	-66.67	-37.42
CS2L	30	0.813	1051	1.29	10.2	0.67	-0.272	18.412	-66.67	-35.02
CS3U	30	0.813	1051	1.29	7.5	0.68	0.430	17.548	-66.67	-33.38
CS3L	30	0.813	1051	1.29	7.5	0.72	-0.441	16.281	-66.67	-30.97
CS4U	30	0.813	1051	1.29	5.3	0.72	0.467	12.938	-66.67	-24.61
CS4L	30	0.813	1051	1.29	5.3	0.74	-0.468	12.721	-66.67	-24.20
PF1U	64	4.54	7202	1.59	16.3	0.78	0.471	37.539	-31.25	-10.42
PF1L	64	4.54	7202	1.59	16.3	0.76	-0.477	37.614	-31.25	-10.45
PF2U	32	2.76	2653	0.96	11.1	0.83	0.458	25.017	-62.50	-18.86
PF2L	32	2.76	2653	0.96	11.1	0.78	-0.468	24.524	-62.50	-18.49
PF3U	36	4.84	5268	1.09	19.3	0.94	0.392	39.920	-55.56	-15.16
PF3L	36	4.84	5268	1.09	19.3	0.94	-0.373	38.454	-55.56	-14.60
PF4U	40	6.62	9589	1.45	40.5	1.12	0.174	78.733	-50.00	-16.42
PF4L	40	6.62	9589	1.45	40.5	1.11	-0.183	77.601	-50.00	-16.19

Table 6.3.5: PF coils parameters used for calculation of the maximal possible induced currents. Tokamak version v4.1.

6.4 References

[1] Pavelka, J., R. Hauptmann, J. Šimek, P. Pavelka, Tokamak, in ELEKTRO, Odborný časopis pro elektrotechniku, 2015, 2, pp. 6-13.

[2] Zajac, J., F. Zacek, V. Lejsek, Z. Brettschneider, Short-term power sources for tokamaks and other physical experiments, Fusion Engineering and Design, 2007, 82(4), pp. 369-379.

[3] Zajac, J., R. Pánek, F. Žáček, J. Vlček, M. Hron, A. Křivská, R. Hauptmann, M. Daněk, J. Šimek, J. Prošek, Power supply system for COMPASS tokamak re-installed at the IPP, Prague, Fusion Engineering and Design, 2009, 84(7–11), pp. 2020–2024.

6.5 Existing Power Supply System

The existing Power Supply System of the COMPASS tokamak consists of the following technological parts:

- flywheel generators
- Low-voltage switchgear
- High-voltage switchgear
- Transformers
- Power thyristor converters and accessories
- Connection to the tokamak

Electrical drawings are provided in the compressed file “Accompanying documentation.zip”, specifically in:

”COMPASS_existing_Power_Supply_system_Technical_documentation.zip”.

The main power supply for the tokamak building is provided by a 1 MW transformer from a 22 / 0.4 kV public electricity network, which is supplied to the main rack cabinet 0RH00 in the low-voltage switchgear (LVS). The main rack cabinet provides voltage supply of 3 x 400 V to technological units of the administrative building, support facilities in the tokamak experimental hall (not the tokamak itself), UPS batteries, static exciters and frequency converters for the generator start-up. The COMPASS tokamak is connected to a second network of 3 x 400 V from RH04 and this network is used for backup power in the event of blackout of the main grid.

The main rack cabinet 0RH00 powers the frequency converters 1RM01 and 1RM02, which take care of the spinning-up of the electric motors (200 kW) which provide a flywheel generator spin through the clutch. When the generator reaches the required / selected rotation speed of 1400-1700 rpm (it takes about 40 minutes to spin up from zero to 1700 rpm), the tokamak discharge sequence is ready to start. The requested energy is taken from the flywheel and transformed into electrical power. The output voltage of one generator is 6 kV, the nominal (i.e. nominal pulsed) output current is 4800 A. Static exciters 0RB01 and 0RB02 provide stabilization of the output voltage of both generators via 1TR2A and 2TR2B transformers. The flywheel generators are located outside of the tokamak building in their own external acoustically shielded container. Generators are equipped with a lubrication station, which is located in the cable compartment below LVS (low-voltage switchgear).

From the generator terminals, the energy is fed to a high-voltage switchgear (HVS), which is equipped with high-power vacuum switches (mostly circuit breakers) capable of interrupting the passing current in the event of any fault. Generator 1 (G1 or GG1) is connected via breaker 1RB601 and Generator 2 (G2 or GG2) is connect via breaker JR618 and have to supply a busbar separately (G1 is used for the poloidal field coils and the rest of the loads, G2 is used only for the toroidal field coils). The switches are controlled by a computer interface, where we can select individual switches to connect a particular circuit. HVS substation is usually switched without current and voltage loads. From the busbar, the energy is distributed to individual transformers for the respective loads (tokamak coils / windings) that transform voltage from 6 kV to the respective voltages and currents of the individual coils.

Transformers have the appropriate number of power semiconductor converters for the individual circuits. For the toroidal field, there are 16 converters that are located in eight rack cabinets (1RU01-8RU08). The 09RR09 rack cabinet includes a thyristor driver control for all converters. The ARU10 and BRU11 rack cabinets contain Equilibrium Field Power Supply converters, and CRU12 contains Shaping Field Power Supply. Magnetizing Field Power Supply is located in the rack cabinets DRU13, ERU14, FRU14 and GRU16 (commutator switch). These converters convert the energy for each winding according to the specified waveforms (e.g. shown by black dashed lines in **Figure 6.3.29** in section **6.3.2.3** - **Time-trace waveforms of the individual coil systems of the COMPASS tokamak – comparison between the ideal and practical waveforms**). Behind the converters outputs, there are the smoothing choke coils, LC filters, crowbar protection and specific transformers T11 and T12 (decoupling transformers used to suppress mutual inductance of the poloidal field coils) according to the requirements of the individual windings. The TF power supply is then connected directly to the tokamak, the PF power supplies goes through the so-called "linkboard" where it is possible to change the connection of the individual tokamak PF coils.

The disposition plan of the ground floor is provided in Figure 6.6.1 in section 6.6 - Description of the available space in the buildings, on page 227, scaled 1: 100.

6.5.1 Technological Part of Flywheel Generators

- 2 x synchronous generator – label 0GG01 and 0GGO2
- 2 x Siemens electric motor type 1LG6317 - 4AA60 - ZA60L27G17H72 – label 0RM01 and 0RM02
    - Shape IMM3, IP55, size 315L, motor specially designed for synchronous drive operation
    - Nominal motor power is 200 kW at 1490 rpm and 690 volts, engine efficiency 96.1%
- 2 x Siemens frequency converter - label 1RM01 and 1RM02
    - Type Siemens AGA5E00280268

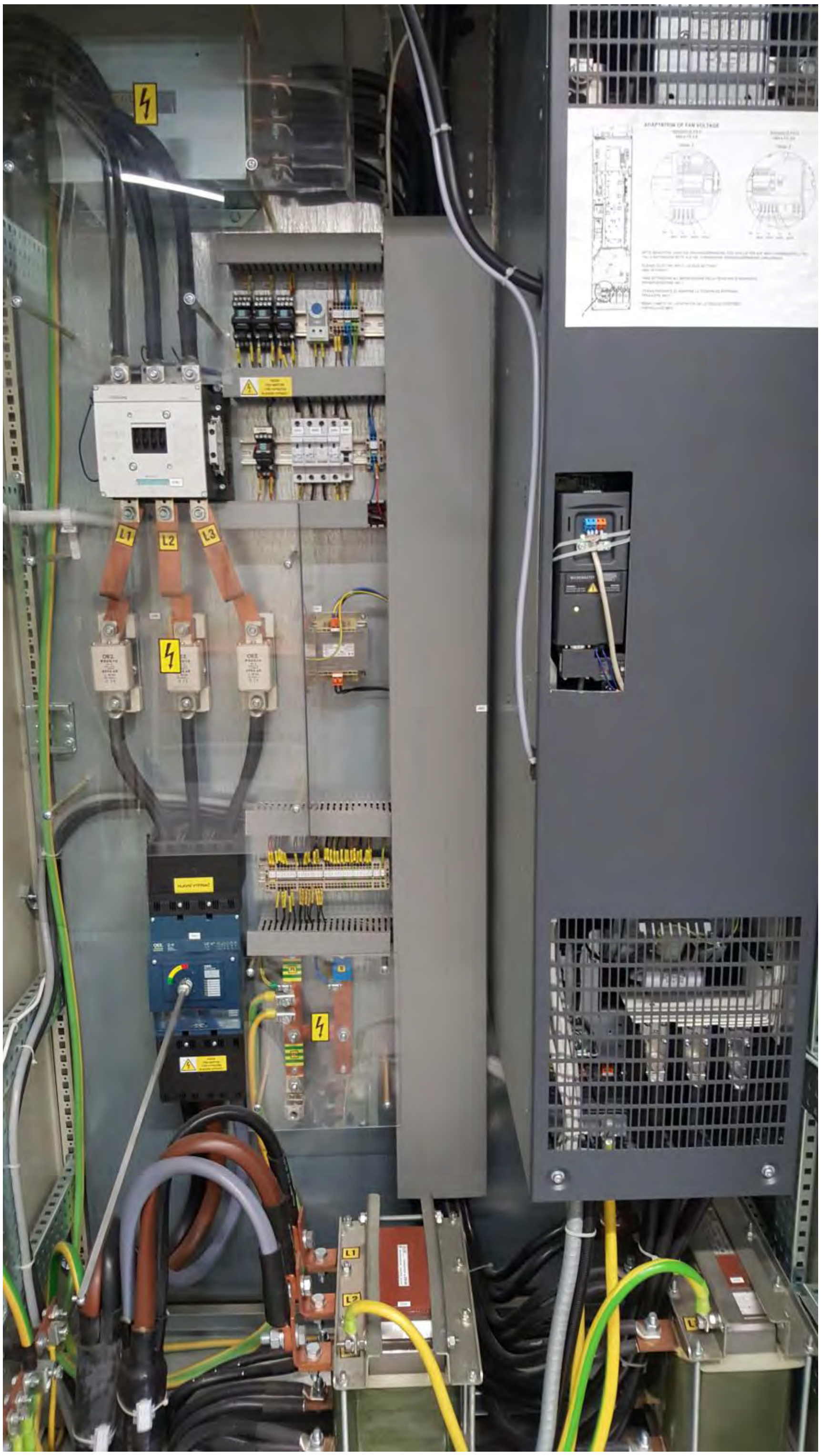


Figure 6.5.1 display of the frequency converter rack cabinet

- 2 x static driver powered from the 400V building electrical grid (left side of Figure 6.5.2) and 2 x static driver powered by the generator (right side of the Figure 6.5.2)– label 0RB01 and 0RB02

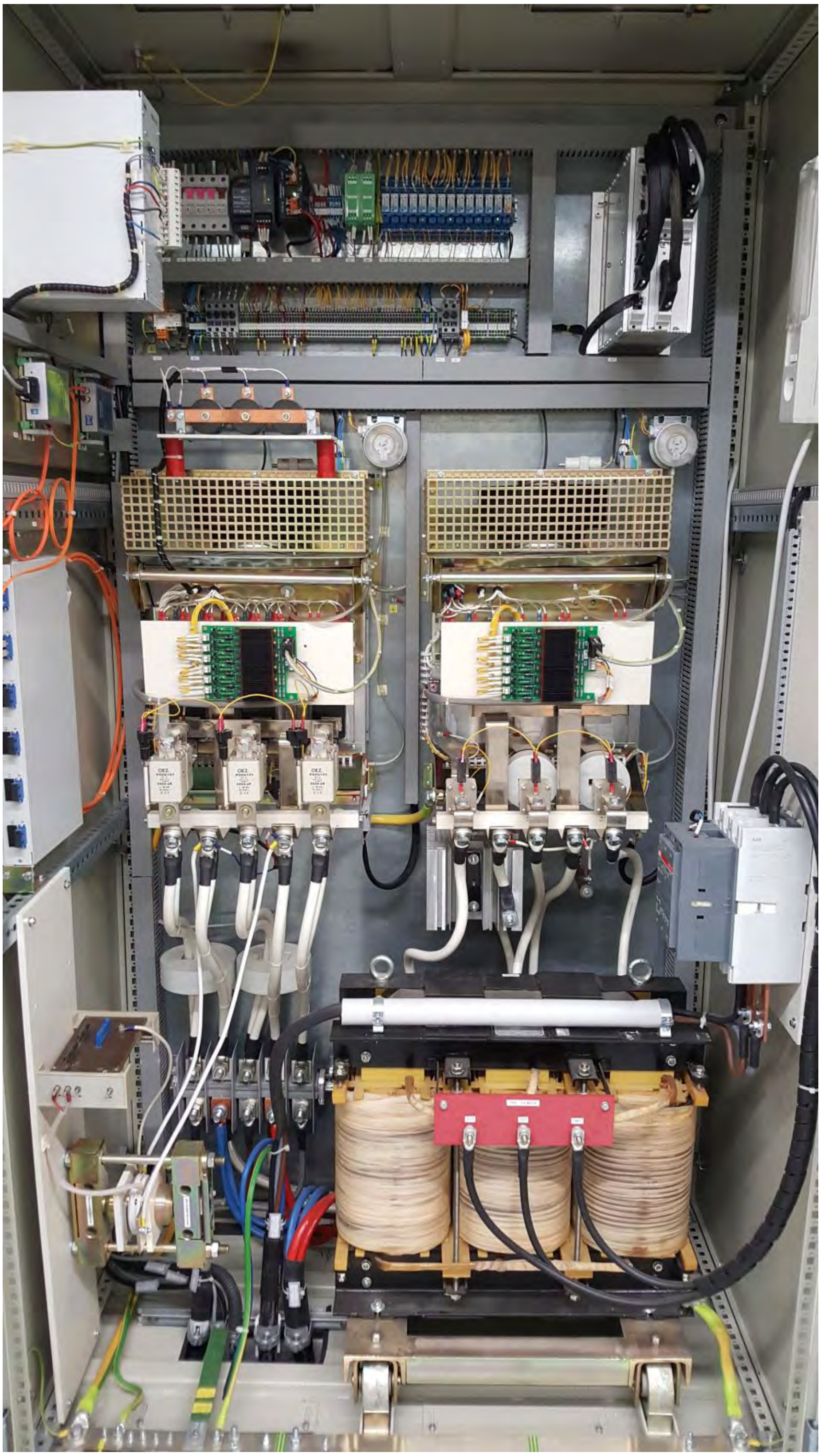


Figure 6.5.2 display of the exciter rack cabinet

- 2 x motor-generator clutch
- Soundproof external generator container
- Lubrication unit 0MM03

Table 6.5.1: Synchronous generator parameters

Manufacturer	ČKD NOVÉ ENERGO, a.s.	Nominal frequency	85 ± 2 % Hz
Generator type	5A286-06H	Nominal power factor (cos phi)	0,7
Number of poles	6	Nominal speed	1700 rpm
Quantity	2	Test maximal speed	2040 rpm
Nominal apparent power	50000 kVA	Exciter	Static
Nominal active power	35000 kW	Total loss at nominal power	1500 ± 10% kW
Nominal voltage	6000 ± 5 % V	Moment of inertia	1700 + 6900 kg.m2
Nominal current	4800 A	Connection of stator	Y
Nominal torque	205 kNm	Technical standards	ČSN, ČSN EN, IEC
Maximal short circuit current	29,5 kA		

Detailed parameters are provided in “Accompanying documentation.zip”, specifically in: ”COMPASS_existing_Power_Supply_system_Technical_documentation.zip”.

6.5.2 Low-voltage Switchgear

Low-voltage switchgear includes frequency converter drives and static exciters for the generators. It also contains protective elements of the electric power supply, backup power supply, generator control and the power supply to HVS.

- Main rack cabinet 0RH00
  - main power supply to the tokamak building, circuit breakers and fuse switch

disconnectors

- Compensation rack cabinet 0RK00
  - reactive power compensation for the tokamak building
- Construction rack cabinet 0RS00
  - circuit breakers for the administration building
- Generator accessories rack cabinet 0RG00
  - generator control, UPS for the converter control, generators exciter, HV switchgear control, generator accessories
- Insulation transformer TR19 for the tokamak hall
  - used for galvanic separation of the power supply and the supply of auxiliary devices in the tokamak hall
- Rack cabinet 1RT17
  - main switch for the tokamak hall
- Rack cabinet 1RT18
  - circuit breaker for UPS
- Rack cabinet 6RC01
  - communication unit
- Rack cabinet 7RC02
  - protection of the power supply systems
- Rack cabinet 0RZ00
  - backup power supply for the lubrication station

6.5.3 High-voltage switchgear

High-voltage switchgear is equipped with UniGear ZS1 arrays by ABB company that contain high-power vacuum switches, protection, bar-to-bar junction and grounding mechanism.

There are 18 arrays of UniGear ZS1:

- 2x vacuum circuit breaker VD4 / P 12.12.32 P150 ABB
  - generator circuit breaker 1R601 and JR618 I_n = 1250 A
- 10x vacuum circuit breaker VD4 / P 12.06.32 P150 ABB (2R602, 3R603, 4R604,5R605,6R606, 7R607, 8R608, 9R609)
  - Circuit breaker for EFPS, 2xTFPS, SFPS, MFPS / OH, FFPS, NBI, RMP and 2x reserve
- 2x bridge (AR610. FR615)
- 1x junction BR611

- 1x isolating truck TE1212-31 (junction) ER614
- 2x vacuum contactors VSC / P7 CS0 for transformer of the generator exciter (CR612, DR613)

6.5.4 Transformers

All of these transformers were specifically designed for pulse load with high relative short-circuit test voltage (<20% at 85 Hz) and working frequency range 65-85 Hz. They were manufactured by Starkstrom-gerätebau GmbH (SGB). (The required usage of some of the transformers is described in the section **5.3 - Transformer requirements** and depicted in the **Figure 4.1.1.**)

- 1TR2A and 2TR2B transformers for the generator exciter, power 1.3 MVA, voltage 6 / 0.75 kV, current 125/1001 A
- 0TR10 transformer for RMP, power 1.5 MVA, voltage 6 / 0.4 kV, current 144 / 2165 A
- 3TR3A and 4TR3B transformers for TFPS, power 24 / 12 / 12 MVA, voltage 6 / 0.37 kV, current 2309/18725/18725 A
- 9TR09 transformer for NBI, power 1.5 MVA, voltage 6 / 0.4 kV, current 144 / 2165 A
- 8TR08 transformer for Fast Feedback (FF), power 0.75 MVA, voltage 6 / 0.072 kV, current 72 / 6000 A
- 5TR04 transformer for EFPS, power 7 / 3.5 / 3.5 MVA, voltage 6 / 0.28 / 0.28 kV, current 673/7217/7217 A
- 6TR05 transformer for SFPS, power 9 / 4.5 / 4.5 MVA, voltage 6 / 0.54 / 0.54 kV, current 866/4811/4811 A
- 7TR06 transformer for MFPS, power 18 / 9 / 9 MVA, voltage 6 / 0.7 / 0.7 kV, current 1732 / 7423 / 7423 A

General schematics and detailed parameters of the transformers are provided in “Accompanying documentation.zip”, specifically in:
”COMPASS_existing_Power_Supply_system_Technical_documentation.zip”.

6.5.5 Converters and Accessories

- 8x TFPS - converter rack cabinets 1RU01 TFPS - 8RU08 TFPS
  - Input 2 x 3 AC; max 85 Hz; 700 V / 7.4 kA / IT
  - Output 2 x 2 DC; 0-850 V; 7 kA / 2 s; 9 kA / 200 ms
  - Auxiliary voltage: 1 NPE AC; 50 Hz; 230 V; 3 A
  - Auxiliary voltage: 2 DC 24 V / IT; 1 A

- 3x EFPS, SFPS - converter rack cabinets ARU10, BRU11, CRU12
  - Input 2 x 3 AC; max 85 Hz; 700 V / 7.4 kA / IT
  - Output 2 x 2 DC; 0- 850 V; 7 kA / 2 s; 9 kA / 200 ms
  - Auxiliary voltage: 1 NPE AC; 50 Hz; 230 V; 3 A

- Auxiliary voltage: 2 DC 24 V / IT; 1 A

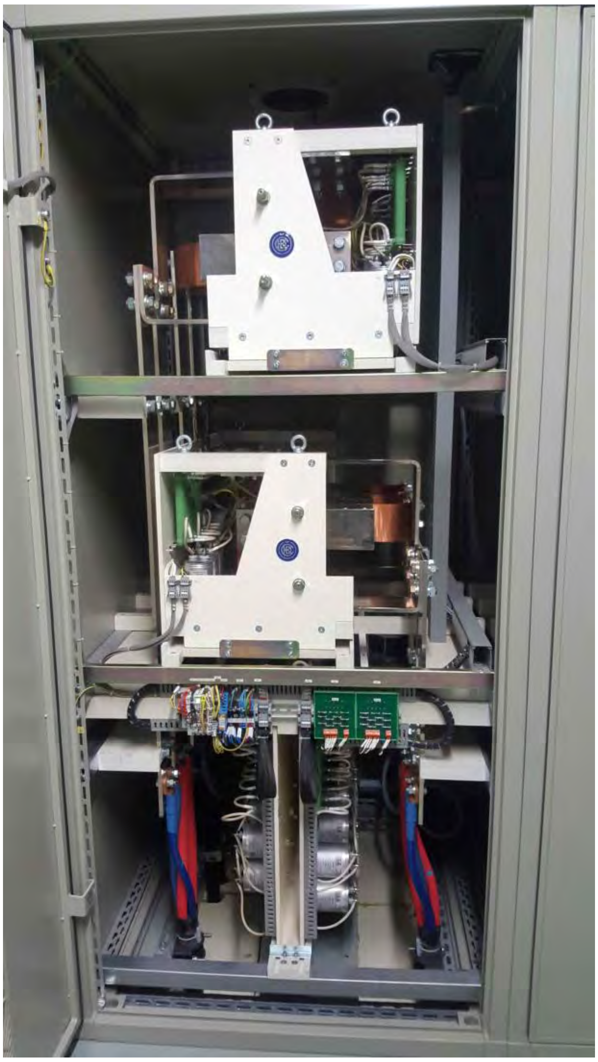
- 2 x MFPS / 1 x OH - converter rack cabinet DRU13, ERU14, FRU15
    - Input 2 DC; 0-850 V, 18 kA / 200 ms / IT
    - Output 2 DC; 0-850 V, 18 kA / 200 ms / IT
    - Auxiliary voltage: 3 NPE AC; 50 Hz; 230 V; 3 A TN-S
    - Auxiliary voltage: 2 DC 24 V / IT; 1 A
- 1x commutation switchboard GRU16
- 1x crowbar rack HRU17
- 1x converter control rack cabinet 9RR09
- 17 pieces of chokes - detailed parameters in “Accompanying documentation.zip”, specifically in ”COMPASS_existing_Power_Supply_system_Technical_documentation.zip”.
    - Name of choke in electric schema: 1TL31, 2TL32, 3TL33, 4TL34 – Name of choke from manufacturer (name in datasheet) TLV 57/37
    - TLF1, TLF2, TLF3, TLF4 – choke TLV 56/37
    - TLF5, TLF7 – choke TLV 56/29
    - TLF6 – choke TLV 70/29
    - 5TL41,6TL42 – choke TLV 54/21
    - 7TL51,8TL52 – choke TLV 58/21
    - 9TL61, ATL62 – choke TLV 61/21
- LC filters (LC filter with parallel resistance added, the added resistance lower impedance of the inductive load in order to have non-oscillating filter)
- 4x RMP power supply (These Power Supplies are not considered to be part of the COMPASS Power Supply System and are not available for incorporation into the new Power Supply System for COMPASS-U. It is listed only for information purpose.)
- 1x power supply for Fast Feedback (This Power Supply is not considered to be part of the COMPASS Power Supply System and are not available for incorporation into the new Power Supply System for COMPASS-U. It is listed only for information purpose.)
- 1x power supply for Vertical Kicks (This Power Supply is not considered to be part of the COMPASS Power Supply System and are not available for incorporation into the new Power Supply System for COMPASS-U. It is listed only for information purpose.)

Description of the COMPASS Power Supply System was published in journal Elektro (in Czech): http://www.odbornecasopisy.cz//flipviewer/Elektro/2015/02/Elektro_02_2015/index.html#p=6

6.5.5.1 Design of Controlled Converters

The power supplies for TF, EF and SF systems are designed as a modular system using identical thyristor blocks of three-phase converters. A thyristor block is rated for the working voltage of the MF/OH source, which is the highest. The block consists of a pull-down structure with six thyristors connected by copper bars, triggering units for thyristor control and RC relief circuitry. Thyristors are naturally (air) cooled without active elements. Two blocks are located in one rack cabinet and contain measuring current transformers for each phase for each module.

Thyristor used in TF, SF, EF is type TV989-2700-28.



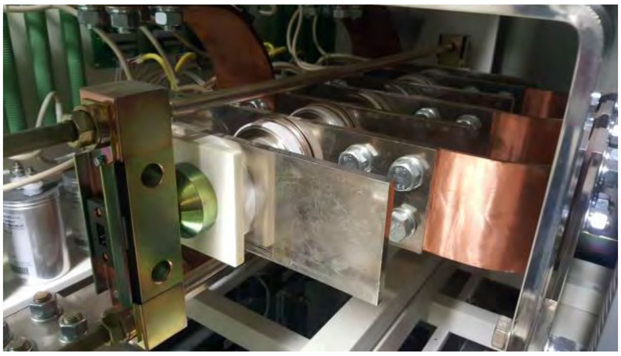


Figure 6.5.3 Picture of one TF converter rack and his detail

6.5.5.1.1 TF converter

The power supply is connected as a twenty-four-pulse converter and is connected via two three-wire transformers with different clock angles. The entire converter consists of a total of 16 basic thyristor blocks connected in parallel. The converter is made up of six-pulse rectifiers that are connected to the tokamak windings via 1TL31, 1TL32, 3TL34 and 4TL35 chokes. Additionally, four chokes were added to increase the inductance for the purpose of the LC filter, the LC filter has a resistor in parallel in order to prevent oscillation of the filter together with the tokamak coil. Each of the four six-pulse rectifiers is composed of four thyristor blocks, which are connected in parallel. Even distribution of the current between the four parallel blocks of each rectifier is achieved by the exactly same impedance of the connecting cables. During installation, it was checked that the supply cables tolerances were +/- 2 mm and that their layout was identical. For this reason, four parallel operating blocks are located in four switchboards. The whole source for the toroidal field consists of eight rack cabinets with sixteen thyristor blocks, i.e. 16 x 6 = 96 thyristors TV989-2700-28.

6.5.5.1.2 SF and EF converter

Both SF and EF power supplies are connected as twelve-pulse thyristor converter. Each six-pulse EF winding rectifier is composed of two directly connected blocks. In the SF and EF circuit, there is a "crowbar HRU17" overvoltage protection that protects the semiconductor components in the event of rapid extinction of the plasma current (typically ~>100 A / µs from a value of up to 360 kA). The "crowbar" consists of a series-connected thyristor and non-inductive resistor. The thyristor is energized by a circuit with a BOD diode, which switches on at a certain voltage on the thyristor.

6.5.5.1.3 MF / OH converter

The power supply is connected as a twelve-pulse reversing converter consisting of two reversing rectifiers, each powered by one of the 7TR06 transformer windings, with a 30° phase shift. Positive poles of the reverse rectifiers are connected via chokes. The source is complemented by a circuitry of so called “shaper” GRU16, which, after the magnetization of the central solenoid tokamak winding by a negative current, causes such a drop of the amplitude of this current that the critical magnetic field change inside the vacuum vessel is exceeded and plasma breakdown occurs.

Thyristor used in MFPS / OH - T2401N52

Three types of the **Power Supplies mentioned bellow are not considered to be part of the COMPASS Power Supply System and, therefore, are not listed in the chapter “5.12 - Requirements for the utilization of the existing Power Supply System” describing incorporation into the new Power Supply System for COMPASS-U**.

6.5.5.1.4 Fast Amplifiers power supply

The power supplies are based on MOSFET type transistors, H-bridge with a switching frequency of 40 kHz, current of +/- 5 kA and rated voltage of 100 V.

6.5.5.1.5 Vertical Kicks Power Supply

The power supply is based on IGBT type transistors, with irregular switching frequency up to 4 kHz, current +/- 5 kA and operating voltage 1.2 kV.

FA and VKPS are described in the following publication:

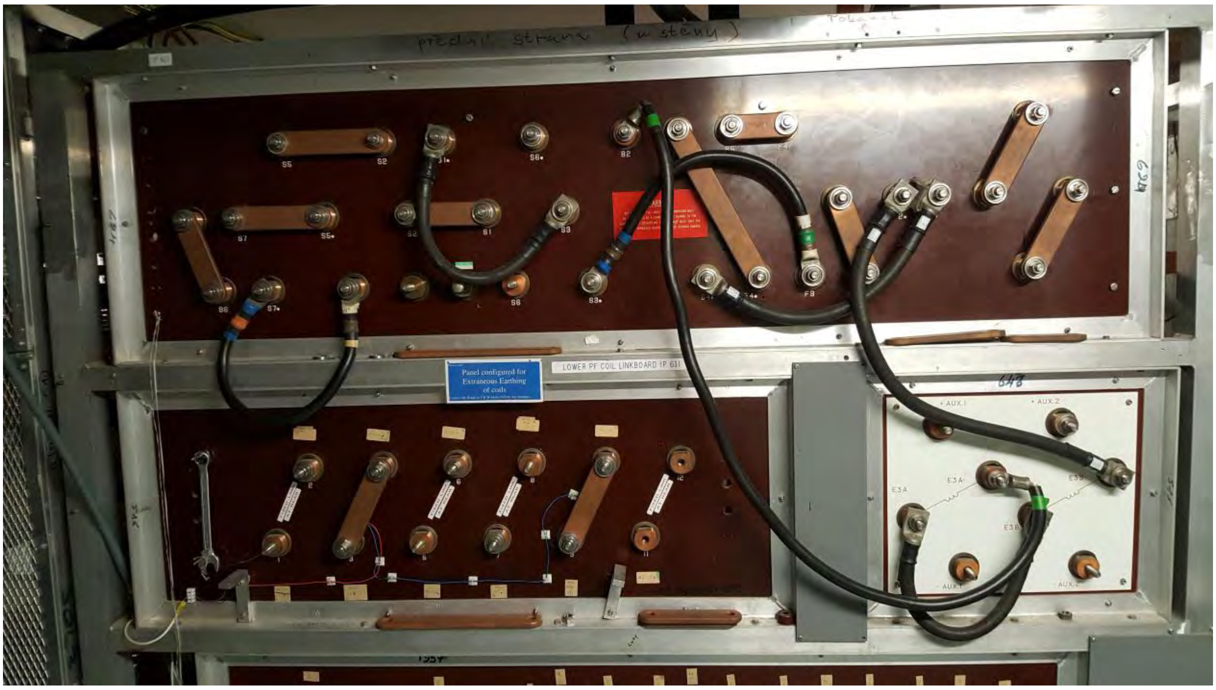
https://doi.org/10.1016/j.fusengdes.2013.02.040

6.5.5.1.6 Resonant Magnetic Perturbations Power Supply

The power supply is based on MOSFET type transistors, H-bridge with a switching frequency of 40 kHz and a current of +/- 4 kA. The design is similar to FA, but the used transistors allow higher operating voltages (up to 190 V).

6.5.6 Connection to Tokamak

Connection to the Poloidal Field coil windings is via linkboard, where it is possible to change the configuration of circuits for MF, SF, EF, BR and BV - see picture in Figure 6.5.4.



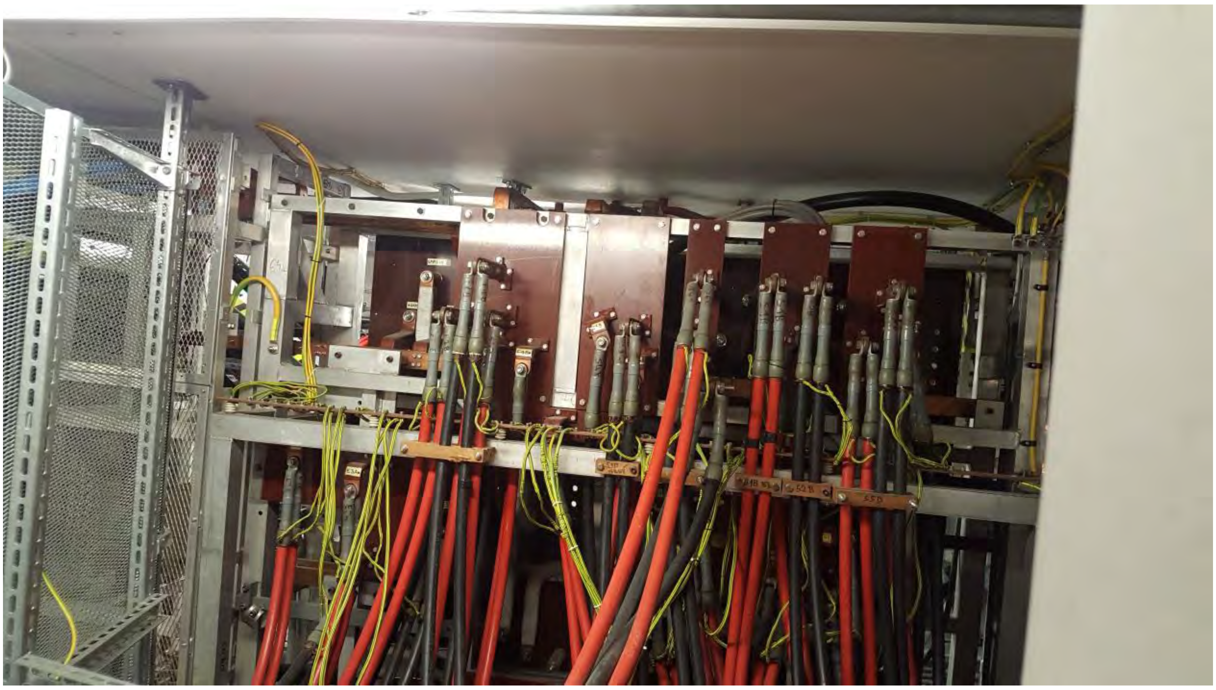


Figure 6.5.4: Picture of the connection point of the poloidal field coils

Connection for the Toroidal Field coil windings is realized by copper bars, which are used as terminals that distribute energy to the coils - see picture in Figure 6.5.5.

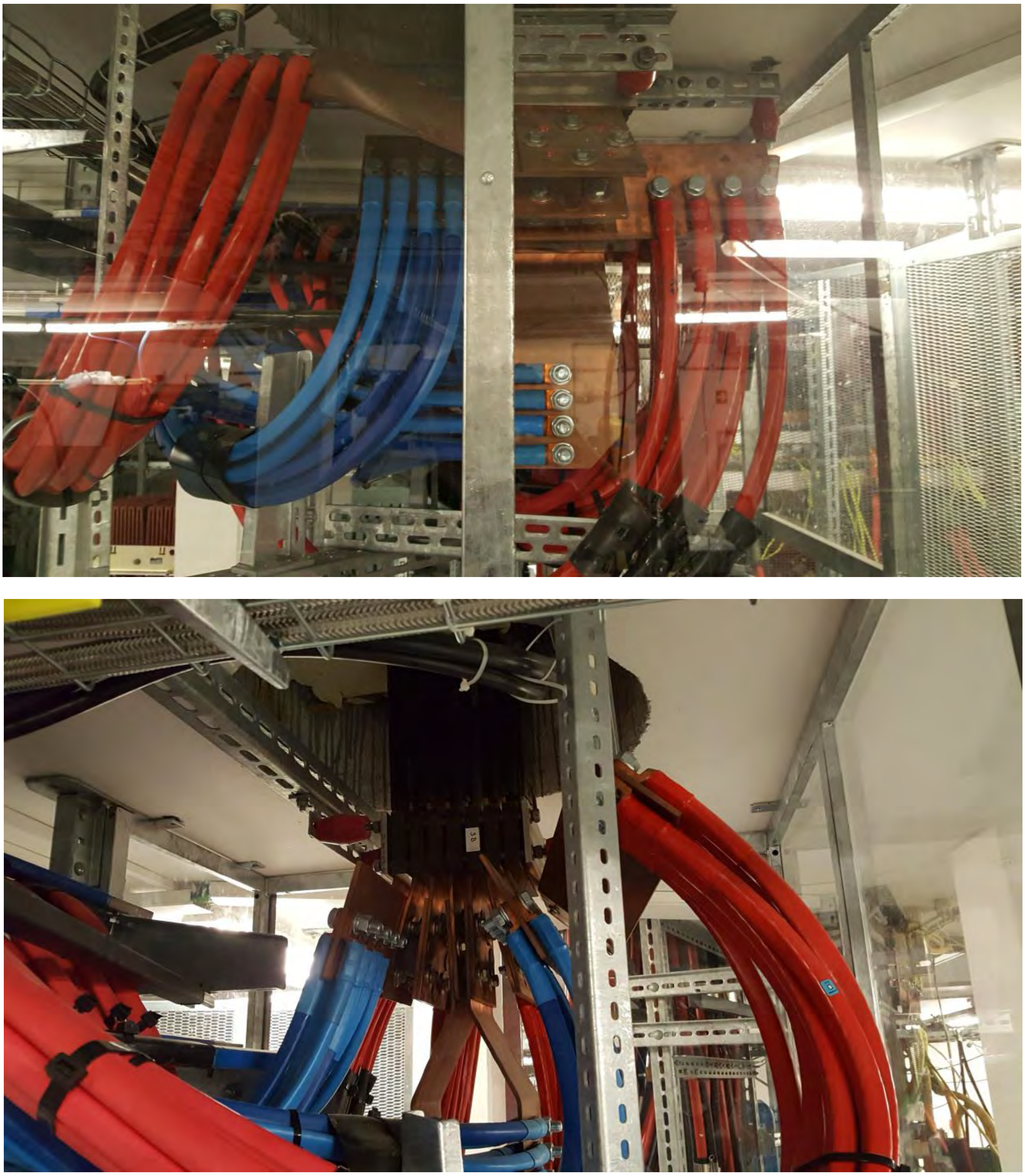


Figure 6.5.5: Connection point of the toroidal coils from all TF power converters

6.5.7 Control system

The control system consists of the following levels:

6.5.7.1 Lowest Level of Control

Works at fast EMADYN-D microprocessor emulators that generate control pulses for thyristors and directly control individual thyristor converters. EMADYN-D is the universal control system used by company ČKD-E. The EMADYN-D control system is a modular system consisting of a basic processor card and various interconnection cards. The individual cards are inserted into the Schroff construction kit cassette. Each thyristor module has its own EMADYN-D controller. In total, six separate controllers are used (2 for generator excitation and 4 for the individual tokamak windings, EF, MF, SF, TF). The control pulses for both thyristors and the serial communication lines are led by optical fibres to avoid interference with these signals.

6.5.7.2 Medium Level of Control

This is a special unit for data acquisition and input of setpoint currents for individual tokamak windings. The unit triggers new setpoint currents every 500 µs, simultaneously via four fast serial lines, into four different independent EMADYN-D controllers, synchronizes their operation and provides the required current flows in the TF, MF, SF, and MF / OH windings during the discharge.

6.5.7.3 Highest Level of Control

Here, the SIMATIC PLC is used, which mainly implements the logic control and control of the EMADYN-D controllers and other subordinate tokamak subsystems. For example, it controls the correct sequence of events in preparation for the discharge, including the rotation of the synchronous generators at the desired speed.

6.5.8 Cable installation

Tokamak experiments are very sensitive to interfering electromagnetic fields, therefore electromagnetic distractions need to be taken into account. The balancing air chokes of the individual sources were spatially distributed in a way that their magnetic fields generated near the tokamak vessel counter each other. Four-wire cable harnesses were used to connect the various parts of the power supply circuits. In each of the cables, the current is drawn away from the source by one pair of diagonally located conductors and back from the tokamak by the other pair. This reduces the magnetic field generated in the surrounding area.

The types and numbers of cables are provided in “Accompanying documentation.zip”, specifically in ”COMPASS_existing_Power_Supply_system_Technical_documentation.zip”.

6.6 Description of the available space in the buildings

The IPP has assembly hall available, where the Power Supply System for the existing COMPASS tokamak is located. The size of the assembly hall is not sufficient for the Power Supply System for COMPASS-U Tokamak. Therefore, the assembly hall will be extended to the north.

This extension is currently in the phase of planning. Therefore, **the information contained in this section** (6.6 - Description of the available space in the buildings**) must be considered as preliminary**. The exact size of the extension of the assembly hall is being still considered, same as the exact placement of the new flywheel generators GG3 and GG4. The new generators are expected to be placed in the separated building. **Regardless of the size of the assembly hall extension, the Power Supply System must fit into the offered installation floor area** - see appropriate requirement in the section 5.1 - General requirements.

Available space for the installation of the Power Supply System is described in this section. The ground plan of the individual floors of the building is presented in the figures below. Assumed possible locations for installation of the Power Supply System are marked in each figure. The figures are aligned so that the top part of each figure is directed to the north.

The offered installation (floor) area in this section does not include:

1. The floor area of the separated building used for the housing of the existing flywheel generators GG1 and GG2 (64 m^2). The building is located ~ 3 m west from the assembly hall.
2. The floor area for their cables leading to the assembly hall (2 m^2).
3. The floor area housing the lubrication unit for the existing generators (12 m^2; underground floor, west of the Location 4, see Figure 6.6.1)

The reason for exclusion of this floor area (64 + 2 + 12 m^2) is that the existing generators and lubrication unit are not supposed to undergo any reconstruction or movement during the Power Supply System installation.

The list of the assumed possible locations for installation of the Power Supply System are:

- **Location 1** - extension building of the assembly hall to the north is assumed **(~18 m × 23.5 m + 6 m × 8 m= 471 m^2**). The ground floor will have height of 3.5 m. The outer parts of the extension building are expected to be used for transformers. The assumed maximal floor weight load is 1000 kg/m^2.
- **Location 2** – new building of generators – available dimensions **~11 m × 17 m = 187 m^2** with expected height 4.5 m. Central part of the building will have significantly reinforced foundations in order to hold the generators, rest of the floors expected for weight load of 500 kg/m^2. It is assumed to prepare a limited floor area with lower height level to house the lubrication units.
- **Location 3** - existing ground floor corridor near the tokamak hall - north corridor with a height of 3.5 m and dimensions **~15 m × 2.5 m = 37.5 m^2**. Maximal load is 500 kg/m^2.
- **Location 4** - present place of the high-voltage switchgear with a height of 3.5 m and dimensions **~5 m × 8 m= 40 m^2**, maximal load 500 kg/m2
- **Location 5** - underground of the present assembly hall with a height of 2.2 m and dimensions **~7.5 × 12 +12 × 3 m^2= 126 m^2**, maximal load 500 kg/m^2

- **Location 6** - inside the tokamak hall, where a higher level of neutron radiation is expected (suitable for non-semiconductor elements like choke coils, etc.). Dimensions **~10 m x 4.2 m = 42 m²**, height of 2.9 m.

- The extension of the assembly hall and the hall of new flywheel generators will be connected with a trench with depth of 0.5 m. The distance between the buildings will be up to 9.5 m. Width will be adjusted to fit all the power cables and pipes with coolant from nearby chillers.

Location	Description	Height [m]	Dimensions [m]	Area [m2]	Radiation
1	Ground floor new building	3.5	18 × 23.5 + 6 x 8	471	no
2	New generator hall	4.5	11 x 17	187	no
3	Ground floor assembly hall north corridor	3.5	15 × 2.5	37.5	no
4	Ground floor assembly hall	3.5	5 × 8	40	no
5	Underground assembly hall	2.2	7.5 × 12 +12 × 3	126	no
6	Underground tokamak hall	2.9	10 × 4.2	42	yes
	Total			903.5	

6.6.1.1.1 Underground floor

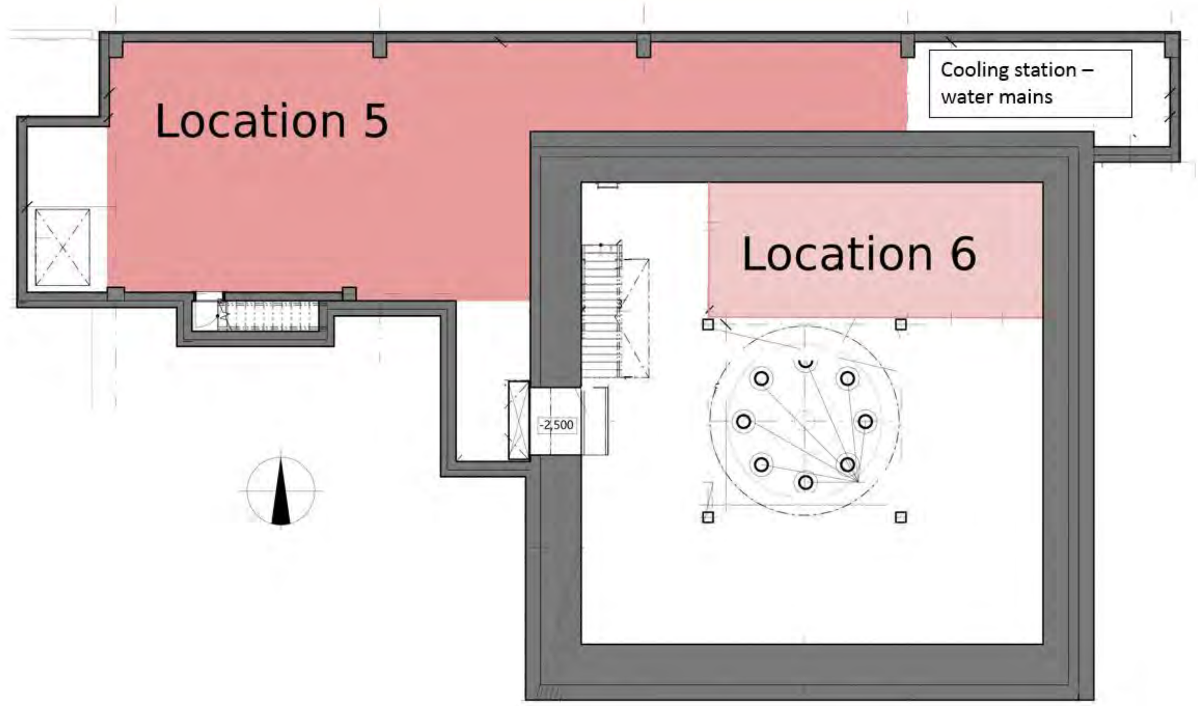


Figure 6.6.1 Plan of the underground floor at IPP (Client) site with highlighted possible locations for placement of the Power Supply System components.

6.6.1.1.2 Ground floor

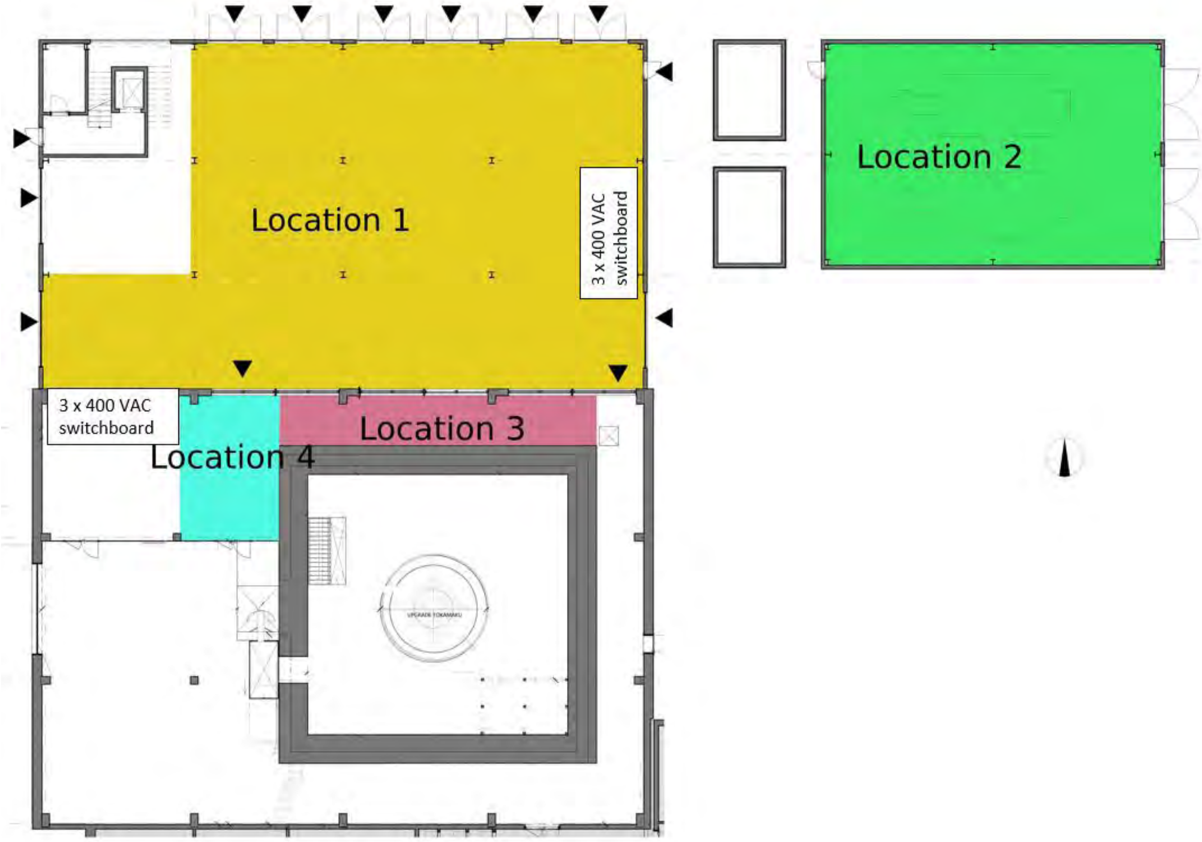


Figure 6.6.2 Plan of the ground floor at IPP (Client) site along with the planned additional building north of the assembly and tokamak hall and the new generator building. The assumed possible locations for placement of the Power Supply System components are highlighted.

TECHNICAL SPECIFICATION

Bid No: PE03127A

POWER SUPPLY SYSTEM FOR COMPASS-U TOKAMAK

Contractor:

ELEKTROTECHNIKA, a.s.
Kolbenova 936/5e
CZ-190 00 Praha 9

Business manager:
[redacted]

Technical manager:
[redacted]

Client:

Ústav fyziky plazmatu AV ČR, v. v. i.
Za Slovankou 1782/3,
182 00 Prague 8

Function/Represented by:
Doc. RNDr. Radomír Pánek, Ph.D.

1 CONTENT

2 GENERAL OVERVIEW

Basic Document describes the Power Supply System on General electric schema, attached Annex 1 of this technical bid description. All elementary performing Parts of Power Supply System are shown in Annex 1 including their internal interconnections up to each TOKAMAK`s coils. Furthermore all basic information about flywheel generator, power transformers and client`s requirements are provided. Also elementary Structure of Control system is given bellow.

In accordance with client`s requirements all devices and all specified purposed related parts have been re-used (See, Annex 1 Red highlighted). We are likely to use existing power-cable works as much as possible while respecting a floor`s layouts. Mainly the power cables and lines have been taken into the consideration.

The Power Supply System consists of following main parts:

2.1 LV auxiliary part

It consists of LV cabinets and devices connected to the 3-phase $400V_{AC}$ distribution system. Mainly it describes following: MAIN CABINET, FC CABINET for the frequency converter`s start and breaking supply, etc.

The devices of existing TOKAMAK installation should be preserved as much as possible.

2.2 Frequency Converters FC and Motors MC

Existing frequency converters FC1 and FC2 will be re-used in accordance with the client`s requirements. No adjustments will be made. In case of needy, the interface will be modified in a meaning to be compatible with new Control System.

Existing motors MG1 and MG2 will be re-used in accordance with the client`s requirements. No adjustments will be made.

The newly supplied frequency converter FC3 (FC4) will be able of 4-quadrant operation.

Time duration between the order to start the flywheel generator GG3 (GG4) to reach a maximal operational rotation speed using the newly supplied frequency converter FC3 (FC4) and MG3 (MG4) motor will be lower than 50 minutes.

The newly supplied frequency converter FC3 (FC4) will be capable of generator GG3 (GG4) stoppage, i.e. to reach of zero rotation speed, rotating at maximal operational rotation in time less than 50 minutes. FC3 (FC4) will be equipped with a braking resistor because the energy shall not be returned to the public power grid.

Time duration to increase flywheel generator GG3 (GG4) speed from minimal operational rotation speed to maximal operational rotation speed will be lower than 25 minutes.

Due to the fact; that requires the Power for the generator GG3 (GG4) rotation starts, it would be approximately 4-times higher than in case of existing flywheel generators GG1 and GG2, therefore a step-up transformer turn-on would need to be required before the frequency converters FC3 (GG4) would be connected.

2.3 Flywheel generators GG and excitation EG

The existing generators GG1 and GG2 including all accessories will be re-used in accordance with the client`s requirements. No adjustments will be made. The operational electronics is going to be changed for the new one, fully compatible to the new Control System on converters (rectifiers) of EG1 and EG2 excitation.

Newly supplied generator GG3 (GG4) is described in Annex 2. The excitation of EG3 (EG4) generators will be made similarly to the existing EG, via two converters. The first, less performing one will be supplied from 3x400V/50Hz grid and thus will used for the generator excitation while non-load running before pulse. The second one, its performance will be supplied from the generator during pulse.

For details see Annex 2.

2.4 MV switchboards GRID

The existing MV substations GRID1 and GRID2 will be re-used in accordance with the client`s requirements. MV substations will be dismounted and their checking and overhaul will be carried out in the producer`s facility (ABB). Two new switchboard`s cabinets, marked as GRID3,4 will be extended, in a meaning of its extension into switchboard GRID1 and GRID2. The new cabinets 1.A01 and 2.A01 will provide function of the couplers JU4+JU6 and JU2+JU5. The coupler JU6 between GRID1 and GRID4 is not required.

In remaining MV substations GRID1 and GRID2 a change of the cabinet sequence order will be probably carried out as mentioned in Annex 1.

MV substations GRID3 and GRID4 will be newly set. Manufacturer of it will be ABB, type UniGear ZS1 - IEC air insulated switchgear. The switchgear is manufactured worldwide and there are more than 200,000 panels currently installed. UniGear ZS1 is used to distribute electric power in a variety of demanding applications such as on off-shore platforms, in container or cruise ships, in mines as well as in utility substations, power plants or chemical plants. Panels are available as a single bus-bar, double bus-bar, back-to-back or double level solution.

Two fields will be equipped with pyrobreaker (I_S-limiter). There are two I_S-limiters planed in identical systems. These two systems are electrically not connected to each other.

In normal operation the I_S-limiter represents a solid bus-bar connection. In the event of a fault which would cause too high short-circuit contributions, the I_S-limiter rapidly trips and the short-circuit current will be limited. As tripping criteria the instantaneous value of the current (i) and the rate of rise of current (di/dt) will be used. Limitation of the short-circuit current occurs within about 0.6 ms after detection, i.e. during the first quarter cycle before short-circuit current reaches its peak value.

The purpose of protection is to limit the fault current downstream of the I_S-limiter to an acceptable level so that it can be safely interrupted by the VD4 circuit breakers. The I_S-limiter is offered in our standard design (no selectivity / no additional tripping criteria).

The switchboard controlling will be via communication protocol IEC 61850.

For details see Annex 4.

Figure 1. MV switchboard UniGear ZS1.

2.5 Power transformers PFTR and TFTR

The Power transformers for PF and TF coils will be newly produced. For PF and TF coils supply purposes two new identical transformers will be always used. Transformers will be equipped with two secondary windings, connected „y“ and „d“, to meet the requirement of 12-pulse rectifying conditions. Transformers PF1TR and PF2TR will be able to operate in a range of 60 up to 85 Hz frequency, in the same manner as the previous ones. The operation of transformers TF3TR and TF4TR are meant for ca 60 up to 85 Hz frequency. The short-circuit voltage will be always lower than 20% to meet the requirements, since such value is valid for 85 Hz frequency, i.e. during the dropping frequency during the pulse occurrence a value of the short-circuit voltage will also fall down. The load of the transformers is of pulse type.

Transformers will be of dry design – cast resin. The design enables a higher pulse load.

For details see Annex 3.

2.6 Rectifiers R1PF and R2PF

Power supply system for PF coils is designed as voltage supply with DC-link.

The rectifiers for PF will be of diode design. Contractor supposes to use pastille diodes. The rectifiers are of 12-pulse design, in which case those separate blocks will be made of 6-pulse bridges organised in two above each other, mounted on the frame or in the cabinet. Such execution is similar to the re-used thyristor rectifiers` designs TF coils. Each block will be supplied from a different secondary transformer winding.

A balanced arrangement of the load (current) among connected in parallel rectifiers` blocks will be done in the same way as during the previous TOKAMAK installation and with execution of the length on incoming and outcoming cables (oblique lines in Annex 1). Thanks to that identical impedance is arranged. Cables will be re-used; if possible however the client counts on with their partial replacement (see Annex 1).

Furthermore for the load (current) balancing purposes among rectifiers connected to a different secondary PF1TR or PF2TR transformer windings, probably the existing choke coils that have been used for existing design of TF power supply (see Annex 1, TL1.1, TL1.2, TL2.1 and TL2.2) are likely to be used again.

For details see Annex 6.

2.7 PF DC-link

The voltage of DC-link will level up to 1020 V_{DC} as requested during no-load operation. The optional capacitor bank will be connected probably directly into the DC-link (see Annex 1).

2.8 PF Power Supplies (PF PS)

Power supplies CS PS1, CS PS2, CS PS3, CS PS4, PF1U PS, PF1L PS, PF2U PS, PF2L PS, PF3U PS, PF3L PS, PF4U PS and PF4L PS will be executed in parallel order IGBT transistors inter-connected to H-bridge.

The ED and capacitor bank are always going to be pre-advanced connected into the H-bridge. Dischargers (EDs) will be designed in a way to withstand absorption of the energy charged within TOKAMAK magnetic poles of the coils without of dangerous over-voltage formation occurrence in DC-link and furthermore it discharges the energy in capacitors.

Charging of the capacitor banks (in DC-link) will be made concurrently with excitation of the flywheel generator GG1/GG2. The power transformer PF1TR/PF2TR and rectifier R1PF/R2PF, R2PF will be supplied by circuit breakers connected to flywheel generator. The excitation current will be increased and voltage at the output of the generator will rise. Voltage of the DC-link will grow-up up to rated value.

Power modules containing IGBT and fly back diode will be used. Nominal switching frequency will be 1 kHz. Water cooling will be implemented.

LC filters with time constant >5 μs will be installed at the output of the converter.

For details see Annex 6.

2.9 TF Power Supplies (TF PS)

Power supply system for TF coils is designed as current supply.

The existing thyristor rectifiers (13 cabinets) will be used in the Power supplies TF3PS and TF4PS while another three cabinets will be newly produced in accordance with the existing documentation. A producer of these rectifiers is the Contractor. The Power supplies will be fit with electronics compatible to the new Operational system.

The rectifiers are of 12-pulse design, in which case those separate blocks will be made of 6-pulse bridges organized in two above each other, mounted on the frame or in the cabinet. Each block will supplied from the secondary transformer winding.

Both rectifiers TF3PS and TF4PS working in parallel will look like 24-pulse rectifier.

A balanced arrangement of the load (current) among connected in parallel rectifiers` blocks will be done in the same way as during the previous TOKAMAK installation and with execution of the length on incoming and outcoming cables (oblique lines in Annex 1). Thanks to that identical impedance is arranged.

All rectifiers` blocks (32 blocks) will be equipped by fuses at the DC output (see Annex 1) according to client`s request.

The chokes for arrangement of time of 120° line of the electric thyristors of 12-pulse rectifier will be installed in between each of DC outputs of 6-pulse bridges (see Annex 1, TL3.1, TL3.2, TL4.1 and TL4.2).

For details see Annex 5 and Annex 12.

2.10 TF crowbar

TF crowbar unit will be constructed of several parallel junctions formed by serially ordered thyristor and resistor. Thanks to that minimal double powers switch and control electronics redundancy is made.

The switching-on of thyristors will be enabled either from the fastest Control System level or also in the Analog way while exceeding voltage via BOD diode.

2.11 TF current commutator

The current commutator (see Annex 1) will be used as a protection against loss of voltage on transformer or transformers for Toroidal Field Power Supply. The TF coil current will be redirected.

2.12 Additional heating systems and other loads

Re-used equipment for additional heating will be connected according to Annex 1.

For details see Annex 7.

2.13 Cabling

The cabling includes cables, cable trays, cable terminals, barriers etc. The cabling will withstand short circuit currents. The cables will be protected against leakage of coolant or water leak.

Four-wire cable harnesses will be used to connect the various parts of the power supply circuits on DC side. In each of the cables, the current will draw away from the source by one pair of diagonally located conductors and back from the tokamak by the other pair. This will reduce the magnetic field generated in the surrounding area.

2.14 Water cooling

Devices as described in chapter 2.8 will be cooled down with water. We suggest usage of independent closed systems filled with raw or demineralised water and equipped with automatic water re-filling for cases of slow water losses caused by the leakage through air-release degassing valves or via the microscopic unsealed spots leakage, etc.

The cooling circuits will be connected to main circuit via a heat exchanger. See following figure of water cooling cabinet produced by contractor. Except the heat exchange, the cabinet is furthermore fit with a pump, reverse valve, deionise tank with ion resin, sensors of the flow, pressure, temperature and conductivity of the demineralized water, etc.

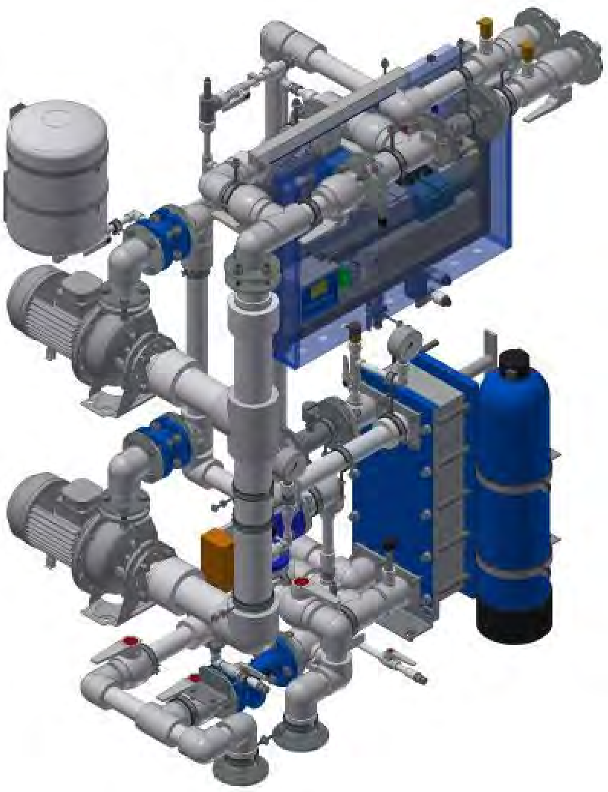


Figure 2. A picture of the water cooling cabinet manufactured by contractor.

2.15 Control system

Control system consists from HW and SW. High efficiency embedded industrial PC Beckhoff will be used as main controllers. Smart devices (independent PCB) are connected with PC Beckhoff via industrial bus-bar EtherCAT (100 Mb/s). Optical fibres are used for connection PC Beckhoff to all smart devices. PC CX2030 or CX2040 is mostly used as a main controller.

Smart devices are used for controlling and measurement, i.e. device control IGBT (pulses, feedback etc.) and simultaneously measure given signals (voltages, currents) and convert signals from analog to digital values (mostly is used sigma-delta modulation). Each smart device is equipped with FPGA and ARM processor. ARM processor is mostly used as a controller of communication via EtherCAT. Processor ATSAME70Q20B-CN with frequency 300MHz manufactured by Microchip is used. FPGA is used for controlling and measurement. FPGA produces company XILINX. Type of FPGA is XC6SLX16-3FTG256I. It is very powerful FPGA: 14500 logical cells, 232 user inputs/outputs, communication speed 3.2 Gb/s. Program loop is 3.2 μs. 24-bit A/D converters are used for very precise measurement.

For details see Annex 8.

2.16 Human Machine Interface (HMI)

Human Machine Interface (GUI) is usually multi-thread application developed by contractor. The programming language is C# of the development environment Visual Studio (Microsoft). Communication between HMI and control PC provides dynamic library (DLL) developed by Beckhoff. HMI uses access to the database. Operational data and events are stored in the database (MS SQL Server). Remote control / access via VPN will be available.

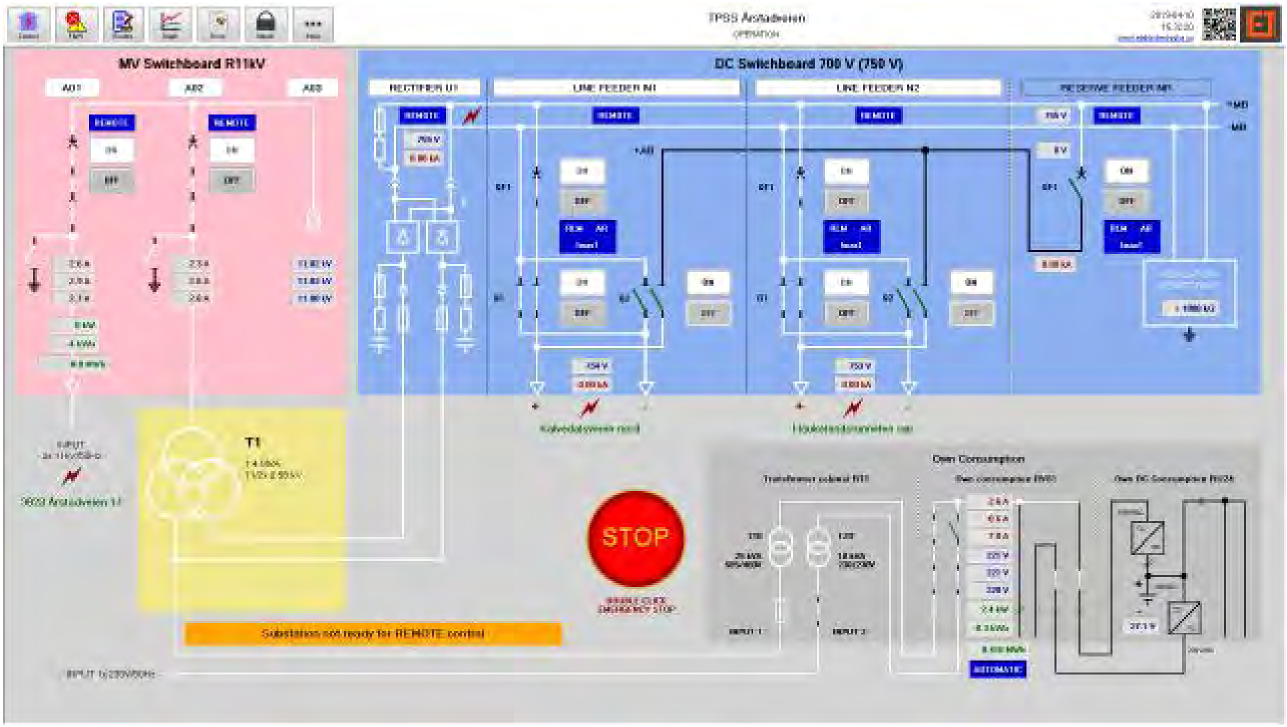


Figure 3. HMI for Traction Power Substation developed by contractor – line diagram.

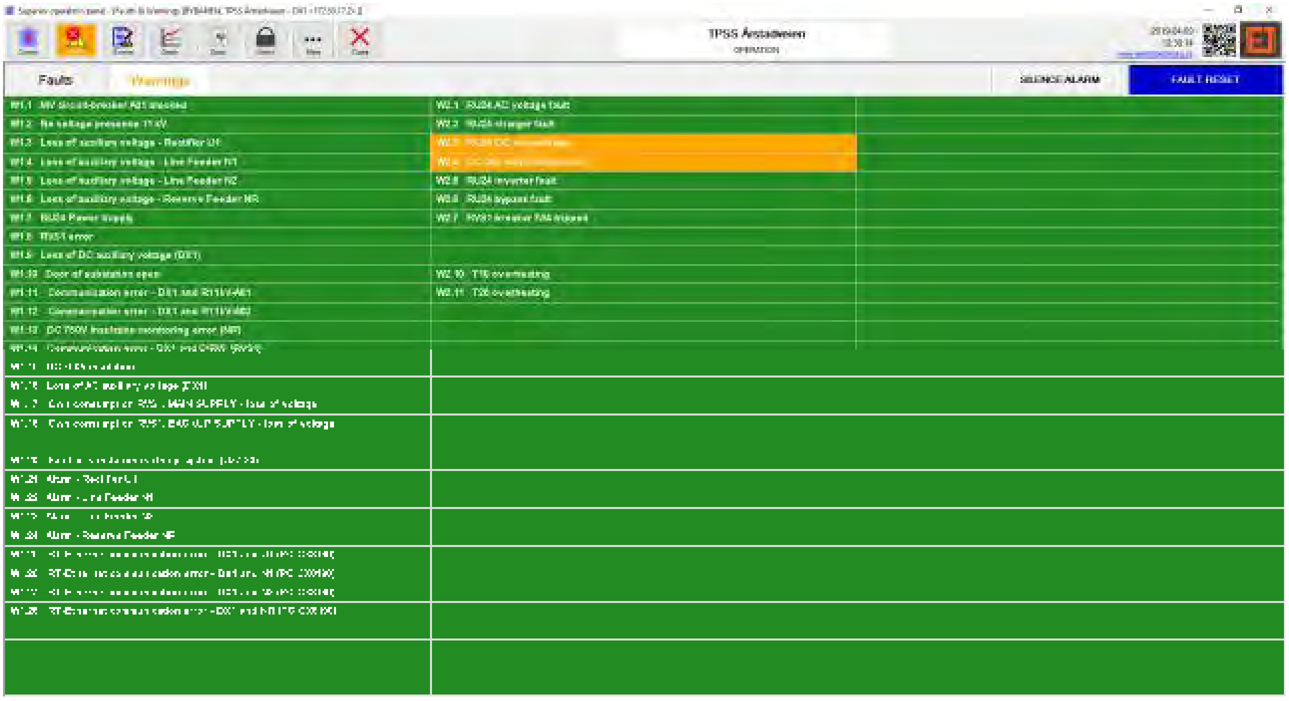


Figure 4. HMI for Traction Power Substation developed by contractor – faults and warnings.

2.17 Pre-project preparation

Pre-project cooperation with the client and assistance while preparation of the technical work will precede towards all related activities including civil works (for the purposes of the planned technological delivery, only). However such pre-preparation is going to be strictly limited to the technological (electrical) part of delivery. See also a subject of the tender.

2.18 Project documentation

See Annex 11.

2.19 Erection

Device placing, anchoring and fixing including the base frames in accordance with enclosed diagram and designer/documentation.

Inter Cable work of all connected devices and equipment.

2.20 Commissioning

Experts of all major components will be participated during the commissioning, i.e. flywheel generators, MV switchboards, power supplies, control system and assembly company.

2.21 Training of the Client’s employees

Training will be carried out during the installation process (a detail introduction) will be made during SAT and on client`s request.

3 DELIVERIES THAT ARE NOT SCOPE OF THE SUPPLIER’S DELIVERY

Basic configuration and/or Extended Option:

1. Advising and all design or proceedings of any civil work, civil work construction of the new building or adjustment of existing facility of the client.
2. Providing and work out of the civil work Engineering or design of the ground works, geological research, geometrical activity or work and other civil works activities.
3. Negotiation to all related Organs and Authorities of the Czech Republic which are related to all civil work proceedings and construction itself
4. Construction of the civil works/building or constructional adjustment of existing facility.
5. Demolition all in-facility road works or their temporary reconstruction, damage, change or any outside works
6. Demolition of any existing building or premises of the client which are related to the civil works.
7. Outer ground, fence or surrounding works and deliveries that around existing or new buildings and facilities.
8. Design, delivery, assembly, revisions, training and operation start of the new fully equipped independent transformer kiosk station in accordance with PRE/ČEZ standard and other approval input electrical increase or performance negotiation including any related financial compensations, fees or payments.
9. MV new incoming lines.

10. Dismantle work of existing devices and equipment installed on existing TOKAMAK installation which are not going to be re-used again and their loading, transport and environmentally friendly waste disposal.
11. Remove or moving of the existing GG1 and GG2 and other parts which are not planned to be removed.
12. Delivery, assembly, instalment and testing of new TOKAMAK unit and all related works including calculation, engineering, etc., All devices and cables - In accordance with enclosed diagram and designer/documentation – See Annex 1, lines in brown.
13. All other devices and cable lines and connections - in accordance with enclosed diagram and designer/documentation – See Annex 1, lines in blue.

4 TECHNICAL DETAILS AND PARAMETERS

No.	Name / description of the requirement	Allowed value / description	Contractor's offered value / description
General requirements			
1	The Power Supply System (excluding existing flywheel generators, their cables and lubrication unit; see details in Table 5.1.1: General requirements) must **fit into the allocated available installation space**.	Installation (floor) area for the Power Supply System is required to be from 800 m^2 to 1000 m^2.	985 m^2
2	Power Supply System must be **capable of simultaneously** (in one tokamak discharge) **delivering usable energy to its outputs** (see details in Table 5.1.1: General requirements).	TF coils output: > 290 MJ TF coils output in Basic Configuration (i.e. without 2nd new flywheel generator): > 145 MJ PF coils Power Supplies outputs: > 80 MJ additional heating or other loads outputs: >50 MJ	TF coils output: 341 MJ TF coils output in Basic Configuration: 166 MJ PF coils Power Supplies outputs: 90 MJ additional heating or other loads outputs: 58 MJ additional heating or other loads outputs in Basic Configuration: 33 MJ

No.	Name / description of the requirement	Allowed value / description	Contractor's offered value / description
		additional heating or other loads outputs in Basic Configuration (without 2nd new flywheel generator): > 30 MJ	
3	The offered Power Supply System fulfills all requirements in the Technical Specification for Power Supply System for COMPASS-U Tokamak.	Confirmation statement (for example "Yes")	YES - The offered Power Supply System fulfills all requirements in the Technical Specification for Power Supply System for COMPASS-U Tokamak.
4	The offered Power Supply System fulfills all requirements in the Technical Specification, chapter 5.1 - General requirements.	Confirmation statement (for example "Yes")	YES - The offered Power Supply System fulfills all requirements in the Technical Specification, chapter 5.1 - General requirements.
Requirements for flywheel generators			
5	**Power** available from the Power Supply System at the output (see details in 5.2 - Requirements for	>80 MW for PF coils > 90 MW for TF coils (>45 MW in Basic	Output for PF coils: 85 MW Output for TF coils: 136 MW

No.	Name / description of the requirement	Allowed value / description	Contractor's offered value / description
	flywheel generators).	Configuration, i.e. without 2nd new flywheel generator) > 25 MW for additional heating and other loads (>15 MW in Basic Configuration, i.e. without 2nd new flywheel generator) The Power Supply System must be capable of delivering these values simultaneously.	Output for TF coils, in Basic Configuration: 65 MW Output for additional heating or other loads: 38 MW Output for additional heating or other loads, in Basic Configuration: 22 MW
6	**Output voltage** and **number of phases** of the new flywheel generator / generators.	The values are not prescribed (preferred 6 kV and 3-phase for compatibility with existing flywheel generators).	New flywheel generators output voltage: 9 400 V New flywheel generators number of phases: 3
7	**Total mechanical energy** stored in the two new flywheel generators for rotation speed decrease from maximal operational to minimal operational rotation speed while	>360 MJ	Mechanical energy stored in the first flywheel generator (Basic Configuration) = 207 MJ Mechanical energy stored in the second flywheel generator (Extended Option) = 207 MJ Total mechanical energy stored in the two new flywheel generators =

No.	Name / description of the requirement	Allowed value / description	Contractor's offered value / description
	providing energy to the tokamak.		414 MJ
8	**Moment of inertia** of the new flywheel generators. Note that the value should include all rotating parts storing the energy – motor, flywheel (if applicable) and generator.	Any value is allowed.	Moment of inertia of the first flywheel generator (Basic Configuration) = 26 000 $kg.m^2$ Moment of inertia of the second flywheel generator (Extended Option) = 26 000 $kg.m^2$
9	**Operational rotation speed** of the two new flywheel generators usable when providing energy to the tokamak.	Any value is allowed.	Maximal operational rotation speed = 1 700 rpm Minimal operational rotation speed = 1 200 rpm
10	**The stability of the output voltage** of the two new flywheel generators during the pulse when generator provides nominal pulsed energy. Pulse in this context: rotation speed decrease from maximal operational to minimal operational rotation speed with nominal pulsed power load (TF	< 34%	New flywheel generators output voltage change: 11,1%

No.	Name / description of the requirement	Allowed value / description	Contractor’s offered value / description
	current and additional heating and other loads). For the purpose of the evaluation of the public tender (in this criterion!), the load cycle definition is: a) TF coils with self-inductance 9.5 mH and resistance 1.05 mOhm b) no losses on cables, choke coils, transformer or TF Power Supply c) TF Power supply provides for the TF coil <= 750 VDC and <90 MW (this determines the current ramp-up duration) d) for the duration of the TF current flat-top, the auxiliary heating system drains from the two new flywheel generators 25 MW (with cos		

No.	Name / description of the requirement	Allowed value / description	Contractor's offered value / description
	phi = 0.9) e) the duration of the TF current flat-top is selected in such a way that the flywheel generator/s reach minimal operational rotation speed at the end of the current flat-top		
11	Reference to the **section of the document and to the figures** describing the **model of the behavior of the two new flywheel generators** during the defined load cycle (above in the "The stability of the output voltage" requirement).	Reference to the document / section of the document and figures location (e.g. name of the figure and name of the document section).	Reference to the document or section of the document describing the model: see Annex 13 of this Technical specification. Reference to the figures with: 1. TF current: Annex 13 – chapter 3.1 2. TF voltage: Annex 13 – chapter 3.2 3. TF Power Supply cos phi: Annex 13 – chapter 3.3 4. Auxiliary heating power: Annex 13 – chapter 3.4
12	Reference to the required **readable tables describing the behavior of the two new flywheel generators**	Reference to the document or the file in the human readable format - ASCII / text (e.g.	Reference to the tables containing the time evolution of the flywheel generators: 1. Output voltage, line-to-line, (actual instantaneous value with ~ms

No.	Name / description of the requirement	Allowed value / description	Contractor's offered value / description
	during the defined load cycle (above in the "The stability of the output voltage" requirement).	name of the table and name of the document, or name of the file).	resolution): file name "PE03127A - Technical specification, Annex 13A - Matlab-Simulink TF model results - round 2.xlsx" 2. Output voltage, line-to-line, effective (RMS): file name "PE03127A - Technical specification, Annex 13A - Matlab-Simulink TF model results - round 2.xlsx" 3. Output current, line-to-line, (actual instantaneous value with ~ms resolution): file name "PE03127A - Technical specification, Annex 13A - Matlab-Simulink TF model results - round 2.xlsx" 4. Output current, line-to-line, effective (RMS): file name "PE03127A - Technical specification, Annex 13A - Matlab-Simulink TF model results - round 2.xlsx"
13	Reference to the required **figures describing the behavior of the two new flywheel generators** during the defined load cycle (above in the "The stability of the output voltage" requirement).	Reference to the figures location (e.g. name of the figure and name of the document section, or name of the file).	Reference to the figures containing the time evolution of the flywheel generators: 5. Output voltage, line-to-line, (actual instantaneous value with ~ms resolution): Annex 13 – chapter 3.5 6. Output voltage, line-to-line, effective (RMS): Annex 13 – chapter 3.5 7. Output current, line-to-line, (actual instantaneous value with ~ms

No.	Name / description of the requirement	Allowed value / description	Contractor's offered value / description
			resolution): Annex 13 – chapter 3.6 8. Output current, line-to-line, effective (RMS): Annex 13 – chapter 3.6
14	The offered Power Supply System fulfills all requirements in the Technical Specification, chapter 5.2 - Requirements for flywheel generators.	Confirmation statement (for example "Yes")	YES – The offered Power Supply System fulfills all requirements in the Technical Specification, chapter 5.2 - Requirements for flywheel generators.
Transformer requirements			
15	The offered Power Supply System fulfills all requirements in the Technical Specification, chapter 5.3 - Transformer requirements.	Confirmation statement (for example "Yes")	YES - The offered Power Supply System fulfills all requirements in the Technical Specification, chapter 5.3 - Transformer requirements.
HV switchgear			
16	The offered Power Supply System fulfills all requirements in the Technical Specification, chapter 5.4 -	Confirmation statement (for example "Yes")	YES - The offered Power Supply System fulfills all requirements in the Technical Specification, chapter 5.4 - HV switchgear.

No.	Name / description of the requirement	Allowed value / description	Contractor's offered value / description
	HV switchgear.		
Converters for Toroidal Field coil			
17	Type of the converter	Either 12-pulse thyristor converter or 24 pulse thyristor converter.	Type of the converter: 24 pulse
18	Toroidal Field Power Supply (TFPS) **nominal pulsed output current** (see details in 5.5 - Converters for Toroidal Field coils)	>199.5 kA DC in flat-top	TFPS nominal pulsed output current: 200 kA DC
19	**Energy deliverable to the TF coils by the TFPS.** This is a requirement for the capability of the toroidal Field Power Supply, transformers and connection (cables) between these parts (see details in 5.5 - Converters for Toroidal Field coils).	> 290 MJ	Energy deliverable to the TF coils by the TFPS: 341 MJ
20	The offered Power Supply System fulfills all requirements in the	Confirmation statement (for	YES - The offered Power Supply System fulfills all requirements in the

No.	Name / description of the requirement	Allowed value / description	Contractor's offered value / description
	Technical Specification, chapter 5.5 - Converters for Toroidal Field coils.	example "Yes")	Technical Specification, chapter 5.5 - Converters for Toroidal Field coils.
Converters for Poloidal Field coils, capacitor bank and energy dissipator			
21	The Contractor is required to choose whether to use two output voltage levels for the PF coils Power Supplies or whether to use only one voltage level. See details in 5.6 - Converters for Poloidal Field coils, capacitor bank and energy dissipator.	1 voltage level (1 kV DC with specified allowed range 920 – 1020 VDC, no load) or 2 voltage levels (1 kV DC and 660 V DC, specified allowed ranges 920 – 1020 VDC, 660 VDC +/- 5%, no load)	Number of voltage levels: 1
22	Power Supplies **nominal pulsed output current rating range** at nominal switching frequency 1 kHz, PWM switching. See details in 5.6 - Converters for Poloidal Field coils, capacitor bank and energy dissipator.	CS PS1, CS PS2, CS PS3, CS PS4: more or equal than +/-50 kA PF1U PS, PF1L PS, PF2U PS, PF2L PS, PF3U PS, PF3L PS: more or equal than +/-25 kA	CS PS1, CS PS2, CS PS3, CS PS4 (4 converters): ±50 kA PF1U PS, PF1L PS, PF2U PS, PF2L PS, PF3U PS, PF3L PS (6 converters): ±25 kA PF4U PS, PF4L PS (2 converters): ±30 kA

No.	Name / description of the requirement	Allowed value / description	Contractor's offered value / description
		PF4U PS, PF4L PS: more or equal than +/-30 kA	
23	Type of the PF coils Power Supplies (all of them).	H-bridge with IGBT transistors (i.e. four-quadrant converter)	Type of the PF coils Power Supplies: four-quadrant converter, full H-bridge IGBT transistors and fly-back diodes
24	The offered Power Supply System fulfills all requirements in the Technical Specification, chapter 5.6 - Converters for Poloidal Field coils, capacitor bank and energy dissipator.	Confirmation statement (for example "Yes")	YES - The offered Power Supply System fulfills all requirements in the Technical Specification, chapter 5.6 - Converters for Poloidal Field coils, capacitor bank and energy dissipator.
Additional heating systems and other loads			
25	The offered Power Supply System fulfills all requirements in the Technical Specification, chapter 5.7 - Additional heating systems and other loads.	Confirmation statement (for example "Yes")	YES - The offered Power Supply System fulfills all requirements in the Technical Specification, chapter 5.7 - Additional heating systems and other loads.

No.	Name / description of the requirement	Allowed value / description	Contractor's offered value / description
Control system requirements			
26	The offered Power Supply System includes control system, which fulfills all requirements in the Technical Specification, chapter 5.8 - Control system requirements.	Confirmation statement (for example "Yes")	YES - Power Supply System includes control system fulfills all requirements in the Technical Specification, chapter 5.8 - Control system requirements.
Safety and Protection requirements			
27	The offered Power Supply System fulfills all requirements in the Technical Specification, chapter 5.9 - Safety and Protection requirements.	Confirmation statement (for example "Yes")	YES - The offered Power Supply System all requirements in the Technical Specification, chapter 5.9 - Safety and Protection requirements.
Acceptance tests requirements			
28	The Contractor declares that the requirements in the Technical Specification in the chapter "5.10 - Acceptance tests requirements" will be followed.	Confirmation statement (for example "Yes")	YES - The requirements in the Technical Specification in the chapter "5.10 - Acceptance tests requirements" will be followed.

No.	Name / description of the requirement	Allowed value / description	Contractor's offered value / description
Documentation and SW backup requirements			
29	The Contractor declares that the requirements in the Technical Specification in the chapter "5.11 - Documentation and SW backup requirements" will be followed.	Confirmation statement (for example "Yes")	YES – The requirements in the Technical Specification in the chapter "5.11 - Documentation and SW backup requirements" will be followed.
Requirements for the utilization of the existing Power Supply System			
30	The Contractor declares that the requirements in the Technical Specification in the chapter "5.12 - Requirements for the utilization of the existing Power Supply System" will be followed.	Confirmation statement (for example "Yes")	YES – The requirements in the Technical Specification in the chapter "5.12 - Requirements for the utilization of the existing Power Supply System" will be followed.

5 STATEMENTS OF THE CONTACTOR

1. The parts of the offered Power Supply System fulfills all requirements in the Technical Specification for Power Supply System for COMPASS-U Tokamak (see chapter 4, rows no. 3, 4, 14-16, 20, 24-30).
2. The expected longevity of the offered Power Supply System excluding pyrobreakers is more than 30 000 TOKAMAK pulses with full performance parameters or at least 15 years – whichever from these two conditions is satisfied first.
3. The expected longevity of the offered TF crowbar resistors is more than 2 000 TOKAMAK pulses at 100% current load.
4. All parameters specified in this Technical Specification or its Annexes may be changed based on the results of simulations of the detailed PSS model in Matlab-Simulink (part of the delivery). Even if the parameters of the offered equipment will be changed, all evaluated criteria resulting from Annex No. 1 of the “Technical specification for Power Supply System for COMPASS-U Tokamak” will be fulfilled.

6 NOTICE

The Contractor has been the producer of the power semi-conductive sources and power supplies for existing TOKAMAK that were installed and delivered in period of 2007 up to 2008.

Legend:
G303 GG3 — new parts of delivery
1.A01 GG1 — existing (re-used) parts of delivery
C (capacitor bank) — new parts of delivery - option
NBI3 — existing devices excluded from delivery
TOKAMAK — parts of the TOKAMAK
>45MW (>90MW) — requirement of the submitter
(Value in bracket is valid for option with 2nd flywheel generator.)
FT CONTROL CABINET — control system cabinets (part of delivery)
COOLING — water cooling system (part of delivery)
GG1
GG2
GG3
GG4
GRID1
GRID2
GRID3
GRID4
Excitation switchboard
CODAC TOKAMAK CONTROL SYSTEM
INTERNET VPN
MAIN CONTROL CABINET
Current 0.4kV switchboard
RESERVE+ + ADDITIONAL HEATING+OTHER LOADS
RESERVE + ADDITIONAL HEATING
6 kV
> 90 kA (PF1TR+PF2TR)
> 1 s 100% load + 25 min 0% load
12-pulse
uK < 20%
uR < 4%
Note: Supply from generator or generators with output voltage not changing with generator rotation speed (e.g. existing generators GG1 or GG2).
FT CONTROL CABINET
> 141 kA (TF3TR+TF4TR)
> 780 V (LV)
> 7 s 100% load + 25 min 0% load
uK < 20%
uR < 4%
V3 x 780 x 141000/2 = 95.2 MVA
100 MVA/7 s
9.4/0.77 kV
Y/yd
TOKAMAK WATER COOLING SYSTEM
PF1TR
PF2TR
TF3TR
TF4TR
PF BUSBAR +
PF BUSBAR -
PF DC-link
Charger of the current commutator
TFPS current commutator
TFPS crowbar
> 255 MJ (> 420 MJ)
CS1 coil
CS2 coil
CS3 coil
CS4 coil
PF1U coil
PF1L coil
PF2U coil
PF2L coil
PF3U winding
PF3L coil
PF4U coil
PF4L coil
> 80 MJ
> 80 MW
> 2 seconds flat-top 100 % nominal pulsed current load + ramp-up and ramp-down, each 700 ms, followed by 25 minutes no load (0 %)
> 4 seconds flat-top 50% of nominal pulsed current load + ramp-up and ramp-down, followed by 25 minutes no load (0 %)
RMP1
NBI0
NB1
NB2
FA
NBI3
NBI4
ADDITIONAL HEATING PS
> 30 MJ (>50 MJ)
> 15 MW (> 25 MW)
TF coils
> 145 MJ (> 290 MJ); > 45 MW (>90 MW); > 460 V; (> 199.5 kA)
> 1 seconds 100 % flat-top current load + ramp-up and ramp-down, followed by 25 minutes no load (0 %) or
> 6 seconds 50% flat-top current load + ramp-up and ramp-down, followed by 25 minutes no load (0 %)
TOKAMAK COMPASS-U corpus
TOKAMAK COMPASS-U corpus
PE03127 AV CR TOKAMAK COMPASS-U
ges2
Datum
Zpracoval Pavel Justiz
Kontroloval Pavel Justiz
Schválil Pavel Justiz
Razítko
ELEKTROTECHNIKA
General electric schema - round 2
List: 1
Listů: 1
Rev. Změna Datum Název Orig. Náhrada Nahrazeno

ELEKTROTECHNIKA

TECHNICAL SPECIFICATION

Bid No: PE03127A

POWER SUPPLY SYSTEM FOR COMPASS-U TOKAMAK

ANNEX 2

DETAILS FOR FLYWHEEL GENERATORS

ROUND 2

Contractor:

ELEKTROTECHNIKA, a.s.
Kolbenova 936/5e
CZ-190 00 Praha 9

Business manager:
[redacted]

Technical manager:
[redacted]

Client:

Ústav fyziky plazmatu AV ČR, v. v. i.
Za Slovankou 1782/3,
182 00 Prague 8

Function/Represented by:
Doc. RNDr. Radomír Pánek, Ph.D.

1 CONTENT

2 SYNCHRONNOUS GENERATOR

The horizontal generator is designed to give power pulses at maximal active power ca 100 MW. The maximal pulse apparent power is 106 MVA.

The mechanical parts of the machine, including the flywheel mounting and mechanical connections, are designed for mechanical load 100 MW. Rotor and stator windings are electrically and mechanically designed and reinforced for pulse load.

Speed operation range is between 1700 and 1200 rpm.

The flywheel generators are able to recuperate (recover) energy from TF PS.

The generator is cooled by air - water heat exchanger, which is able safely cool down the internal generator parts.

The flywheel generators will be designed to allow future installation of an independent emergency braking system.

The excitation of the machine is taken from static source through slip rings. The generator is driven by an auxiliary asynchronous motor, which is powered from the frequency converter. The mechanical connection of the motor to the generator is via an isolated coupling.

Noise of the flywheel generators will be less than 70 dB at the distance 1 m from the generator cover, 1.5 m from the ground.

3 FLYWHEEL

The flywheel is made of forged steel and it is placed on the generator shaft. The flywheel is equipped with own cover with own air – water exchanger to cool down ventilation and mechanical losses from flywheel assembly.

Flywheel will be equipped with powerful brakes, which will be able stop the generator form speed 500 RPM in case of emergency, or from 10 % of the speed.

4 OIL LUBRICATION UNIT

Unit has to be located near the generator at a level at least 1.5 m below the level of the generator feet. The lubrication will be placed in safety basin to prevent oil leakage to the environment in case of failure of valves or pipes.

The unit will be equipped with oil heating and cooling, with instruments for control and monitoring, and with a backup pump to avoid any lubrication failures or outages in the event of a power failure.

The lubrication unit will be equipped as well with a high-pressure pump – hydraulic lifting of the rotors at starting and stopping of the machinery for bearing life time prolongation.

5 DRIVE - ASYNCHRONOUS MOTOR

The drive motor will be placed on a supporting frame with the generator and flywheel.

The drive motor is designed especially for operation with frequency converter. The connection of the motor with the generator will be carry with insulated flexible coupling.

The motor will be used as well for slow braking of the generator at normal operation.

6 TECHNICAL SPECIFICATION – SYNCHRONNOUS GENERATOR

Ratings and parameters of the generator

Author: Jiří Svoboda
Date: 23.09.2019

Type: GSV1120L6U9,4F85 **Quotation:** N1810697/8

Nominal Data:

Rating S_N :	106 000	kVA	P.F. $\cos\varphi$:	0,67	
Voltage U_N :	9 400	V	Frequency f_N :	85	Hz
Current I_N :	6 510,5	A	Speed n :	1700	min^{-1}
Connection :	Y				

Parameters	Symbol	Unit	Value	
Stator phase resistance (terminals U1-U2; 20°C)	R_{a20}	[Ω]	0,00465	
Field winding resistance (20°C)	R_{f20}	[Ω]	0,0907	
Stator phase resistance (terminals U1-U2; 75°C)	R_a	[Ω]	0,00565	
Field winding resistance (75°C)	R_f	[Ω]	0,1103	
Reference impedance	Z	[Ω]	0,834	
			saturated	unsaturated
Direct axis synchronous reactance	x_d	[p.u.]	1,571	1,752
Direct axis transient reactance	x_d'	[p.u.]	0,334	0,368
Direct axis sub-transient reactance	x_d''	[p.u.]	0,198	0,216
Quadrature axis synchronous reactance	x_q	[p.u.]	0,931	1,033
Quadrature axis transient reactance	x_q'	[p.u.]	0,931	1,033
Quadrature axis sub-transient reactance	x_q''	[p.u.]	0,178	0,193
Zero sequence reactance	x_0	[p.u.]	0,043	0,047
Negative sequence reactance	x_2	[p.u.]	0,188	0,204
Leakage reaktance	x_1	[p.u.]	0,090	0,090
Direct axis open-circuit transient time constant	T_{d0}'	[s]	1,927	2,148
Direct axis open-circuit sub-transient time constant	T_{d0}''	[s]	0,035	0,038
Direct axis short-circuit transient time constant	T_d'	[s]	0,409	0,451
Direct axis short-circuit sub-transient time constant	T_d''	[s]	0,021	0,022
Quadrature axis open-circuit transient time constant	T_{q0}'	[s]	-	0,179
Quadrature axis open-circuit sub-transient time constant	T_{q0}''	[s]	-	0,094
Quadrature axis short-circuit transient time constant	T_q'	[s]	-	0,161
Quadrature axis short-circuit sub-transient time constant	T_q''	[s]	-	0,018
Armature time constant	T_A	[s]	0,052	0,057
Zero sequence resistance	r_0	[p.u.]	0,003	
Negative sequence resistance	r_2	[p.u.]	0,020	
Stator phase resistance (terminals U1-U2; 20°C)	r_{a20}	[p.u.]	0,005578	
Short Circuit Ratio	SCR	[-]	0,636	
Saturation factor (S1.0)	S1.0	[-]	0,086	
Saturation factor (S1.2)	S1.2	[-]	0,271	
Open-circuit excitation voltage (air-gap line) of generator	U_{f0}	[V]	83,6	
Inertia constant (only rotor of the generator J=6859kg.m2)	H	[kW.s/kVA]	1,025	
Inertia constant (only rotor of the generator J=6859kg.m2)	H	[s]	1,531	
Type of rotor			salient	
Pole pairs (number of poles/2)			3	

Remarks:

- The above mentioned values are calculated!
- Parameters are calculated for winding temperature 75°C. (unless otherwise noted)

7 ERRECTION

This work will be covered by a team of TES specialists (2x installer, 2x electrician, 2x service worker).

8 COMMISIONING

TES service personnel will take part in commissioning.

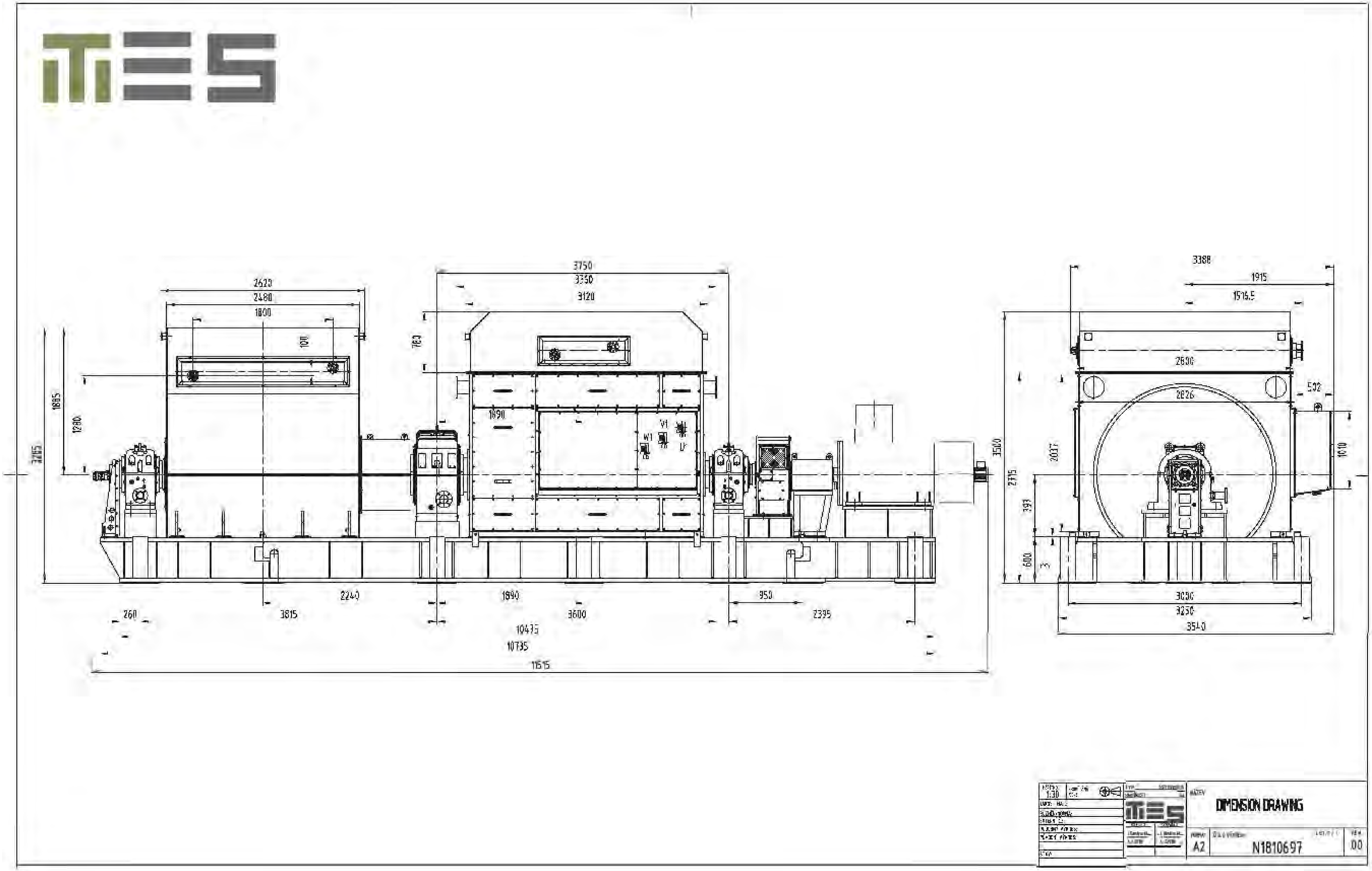


Figure 1. The flywheel generator – dimension drawing.

TECHNICAL SPECIFICATION

ELEKTROTECHNIKA

Bid No: PE03127A

POWER SUPPLY SYSTEM FOR COMPASS-U TOKAMAK

ANNEX 3

DETAILS FOR TRANSFORMERS

ROUND 2

Contractor:

ELEKTROTECHNIKA, a.s.
Kolbenova 936/5e
CZ-190 00 Praha 9

Business manager:
[redacted]

Technical manager:
[redacted]

Client:

Ústav fyziky plazmatu AV ČR, v. v. i.
Za Slovankou 1782/3,
182 00 Prague 8

Function/Represented by:
Doc. RNDr. Radomír Pánek, Ph.D.

1 CONTENT

2 GENERAL OVERVIEW

Cast resin transformers offer a range of features which, on the one hand, distinguish them from other cast resin transformers in terms of technology and, on the other hand, make them a highly reliable and extremely safe solution.

The operative benefits for you, our customer, are the following:

– Thanks to the multi-layer winding principle, high surge voltages and switching voltages are handled safely.

– Cooling ducts provide thermal reserves and allow for overload.

– Long service lives are ensured.

3 TECHNICAL SPECIFICATION

		TF3TR and TF4TR	PF1TR and PF2TR
Power	kVA	8 000 // 4 000 / 4 000	4 000 // 2000 / 2000
Load cycle		100 MVA for 7 s than 25 min pause	50 MVA for 3 s than 25 min pause
Higher voltage	V	9 400	6 000
Voltage level (Um/AC/BIL)	kV	12/28/60	12/28/60
Taps	%	±2x2,5	±2x2,5
Lower voltage	V	770 / 770	720 / 720
Voltage level (Um/AC/BIL)	kV	1,1/3/-	1,1/3/-
Frequency	Hz	60-85	60-85
Vector group		Yy0d1	Yy0d1
Protection class		IP00	IP00
Cooling		AN (AF)	AN (AF)
Impedance	%	2,3//16/16*	2,3/16/16*

* uk < 20% and ur < 4% in all frequency range

TECHNICAL SPECIFICATION

ELEKTROTECHNIKA

Bid No: PE03127A

POWER SUPPLY SYSTEM FOR COMPASS-U TOKAMAK

ANNEX 4

DETAILS FOR MV SWITCHBOARDS

ROUND 2

Contractor:

ELEKTROTECHNIKA, a.s.
Kolbenova 936/5e
CZ-190 00 Praha 9

Business manager:
[redacted]

Technical manager:
[redacted]

Client:

Ústav fyziky plazmatu AV ČR, v. v. i.
Za Slovankou 1782/3,
182 00 Prague 8

Function/Represented by:
Doc. RNDr. Radomír Pánek, Ph.D.

MV Switchgear
UniGear ZS1

1 CONTENT

2 GENERAL SPECIFICATION SWITCHBOARDS GRID3+GRID4

UniGear type	Standard
Design	Complete
Application	Standard
Packing	Palette
FAT	Standard FAT
Installation for the sea level	Less than 1000 m

Rated Voltage	12 kV
Service Voltage	10 kV
Rated Frequency	50 Hz
AC withstand voltage at the sea level <= 1000 m	28 kV
Basic insulation level at the sea level <= 1000 m	75 kV
Short-time withstand current of the main circuit	31,5 kA - 1 s
Short-time withstand current for earthing	31,5 kA - 1 s
Dynamic withstand current	80 kA
Withstand current during internal arc (IEC 60298 appendix A)	31,5 kA - 1 s
Rated Bus-bar Voltage	4000 A
Main and T-offs bus-bar insulated	Yes
Bus-bar edge and Cu profile powder coating	No
Colour of shutters	Standard RAL7035
Bus-bar wall bushings	Each cabinet

Outer protection degree (acc. IEC 60529)	IP4X
Outer bushing protection degree (acc. IEC 60529)	IP2X
Surrounding temperature (acc. IEC 60694)	-5 up to +40 °C
Colour	RAL 7035
Colour proceeding	Standard
Mimic diagram	Mimic on the cabinet
Exhaust valve channel	Exhaust channel with valve
Execution of Exhaust valve channel	Output and flap
Device for failure limiting	UFES
Cable and secondary compartment door closing execution	Main door key
LV compartment door closing	Lock
Internal LV design	DIN bars (standard)
Floor fixing	Screw anchoring
Heating unit for condensation prevention	No
Internal light LV compartment	Yes, with IR sensor

Aux. Voltage for spring charging	230 VAC 50Hz
Aux. Voltage for operation	230 VAC 50Hz
Aux. Voltage for signalization	230 VAC 50Hz
Aux. Voltage for light and heating	230 VAC 50Hz
Aux. wire cross-section – operation circuits	1.5 mm^2
Aux. wire cross-section – voltage circuits	1.5 mm^2
Aux. wire cross-section – current circuits	2.5 mm^2
Aux. wire cross-section – earthing circuits	2.5 mm^2
Cable type	Self-extinguishing
Rated cable voltage	0.45/0.75 kV
Cable colour	Acc. IEC Standard
AC operational cable colour	Black/light blue
DC operational cable colour	Black
Current cable colour	Black

Voltage cable colour	Black
Earthing cable colour	Yellow /green

Cabinet operation	ABB IEDs
Communication protocol 1	IEC 61850 - circuit (HSR) + GOOSE
Communication protocol 2	MODBUS TCP
IEC 61850 Edition	1.0
Communication line	Iron

3 FIELDS GRID3+GRID4

10 kV; 4000 A; 31,5 kA/1 s

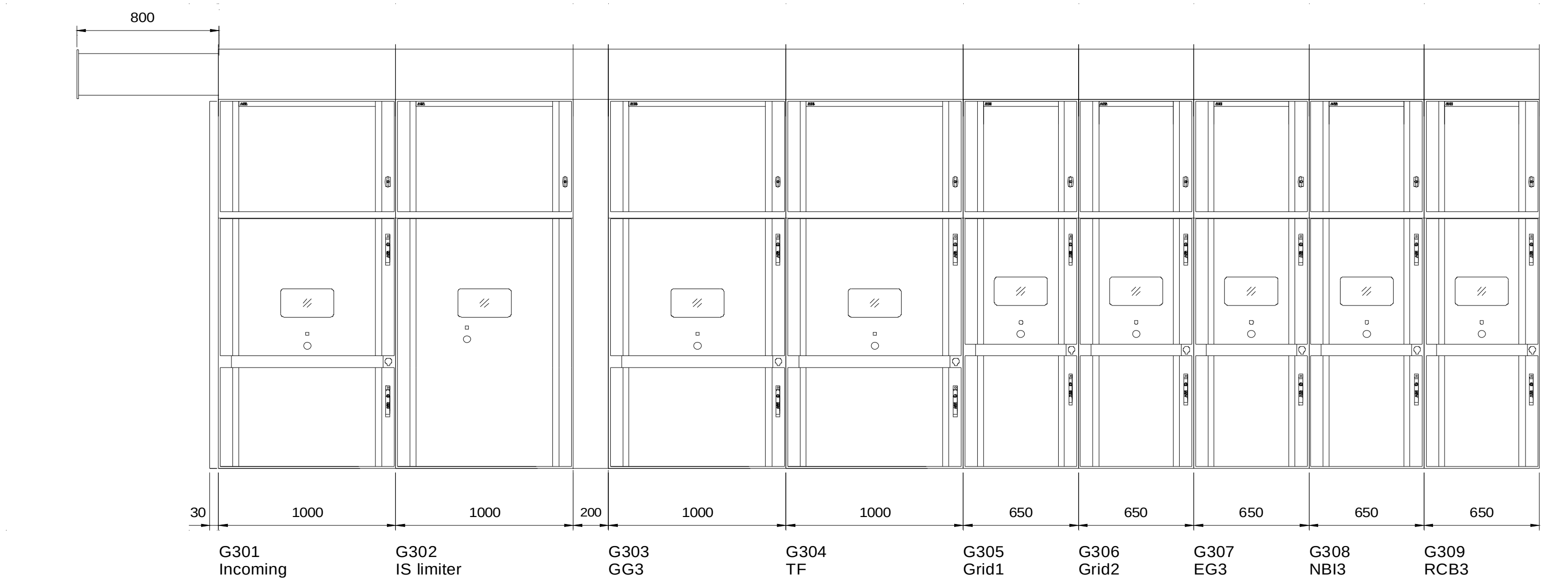
27 cabinets

Name of the cabinet	Product	Current [A]	Width [mm]	Weight [kg]	Count
Incoming	UniGear ZS1	4000	1000	1240	2
IS limiter	UniGear ZS1	4000	1200	1640	2
GG3	UniGear ZS1	4000	1000	1820	1
TF	UniGear ZS1	4000	1000	1600	2
Grid1, Grid2	UniGear ZS1	1250	650	970	4
EG3, EG4	UniGear ZS1	400	650	860	2
NBI3, NBI4, RCB3, RCB4, RCB5, RCB6	UniGear ZS1	630	650	970	6
RS3, RS4, RS5, RS6	UniGear ZS1	1250	650	790	4
Mereni3	UniGear ZS1	630	650	830	1
Spojka	UniGear ZS1	4000	1000	1820	1
Mereni4	UniGear ZS1	4000	800	1150	1
GG4	UniGear ZS1	4000	1000	1820	1

4 TOTAL DIMENSIONS AND WEIGHT GRID3+GRID4

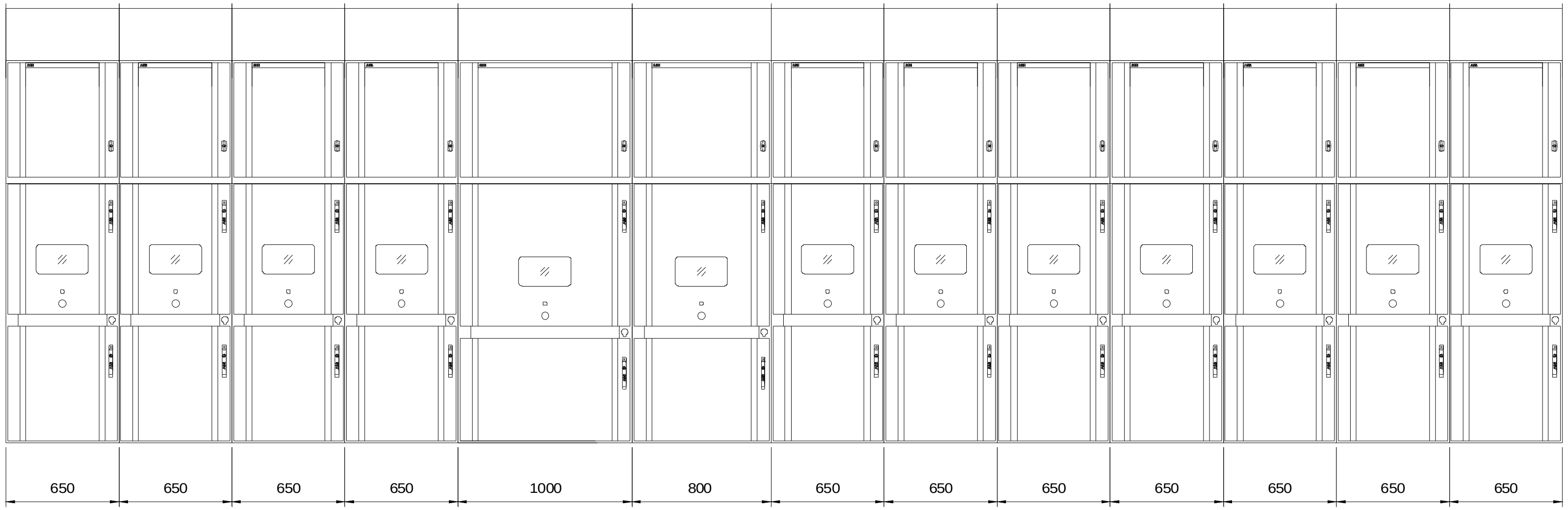
Total Height	2533 mm
Depth	1635 mm
Width	22710 mm
Minimal switchboard height	2700 mm
Brutto total weight incl. Accessories	34080 kg

5 DRAWINGS GRID3+GRID4



Width 21310 mm, Height 2533 mm

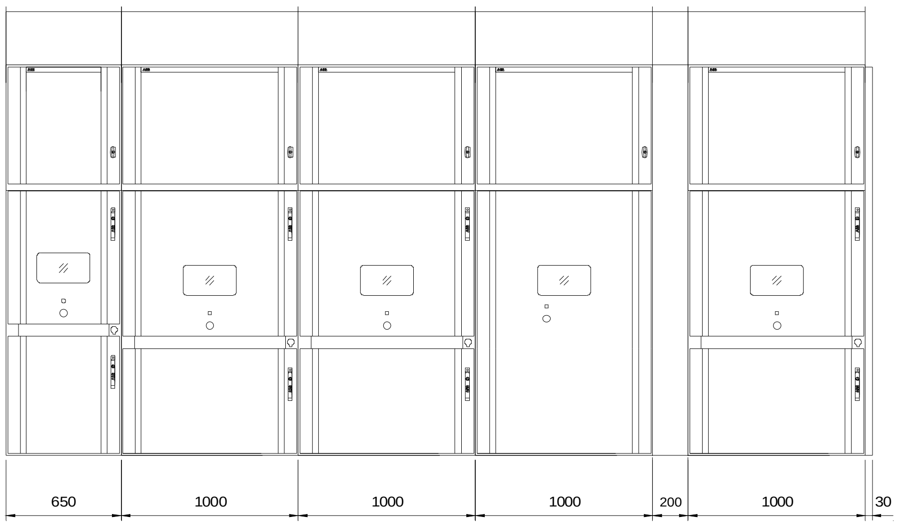
	Customer: ELEKTROTECHNIKA, a.s.	Prepared by: Martin Kloc	Name of switchgear: Switchgear 1	Rev Date: 2019-11-07	Quotation Date: 07.11.2019	No. of Sheets 14
	Project: PE0312 Speciální zdroje CR	ABB s.r.o.	Front view	Rev Number: 6	Quotation Number: QT-18-01295939	Sheet no. 1



G310	G311	G312	G313	G12	G413	G412	G411	G410	G409	G408	G407	G406
RCB5	RS3	RS4	Mereni3	Spojka	Mereni4	RCB4	RCB6	RS5	RS6	EG4	NBI4	Grid1

Width 21310 mm, Height 2533 mm

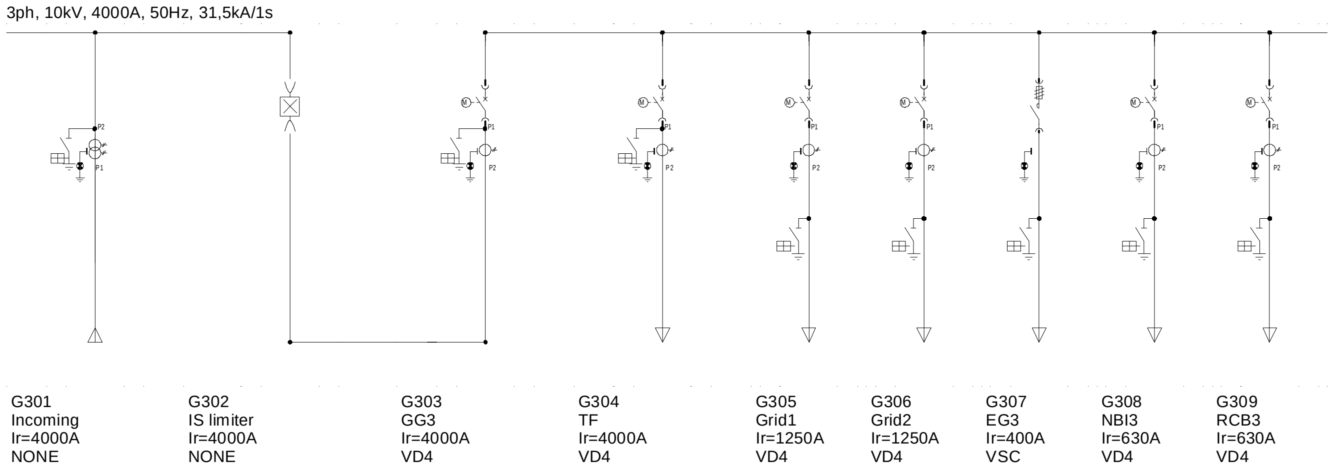
Customer: ELEKTROTECHNIKA, a.s.	Prepared by: Martin Kloc	Name of switchgear: Switchgear 1	Rev Date: 2019-11-07	Quotation Date: 07.11.2019	No. of Sheets 14
Project: PE0312 Speciální zdroje CR	ABB s.r.o.	Front view	Rev Number: 6	Quotation Number: QT-18-01295939	Sheet no. 2



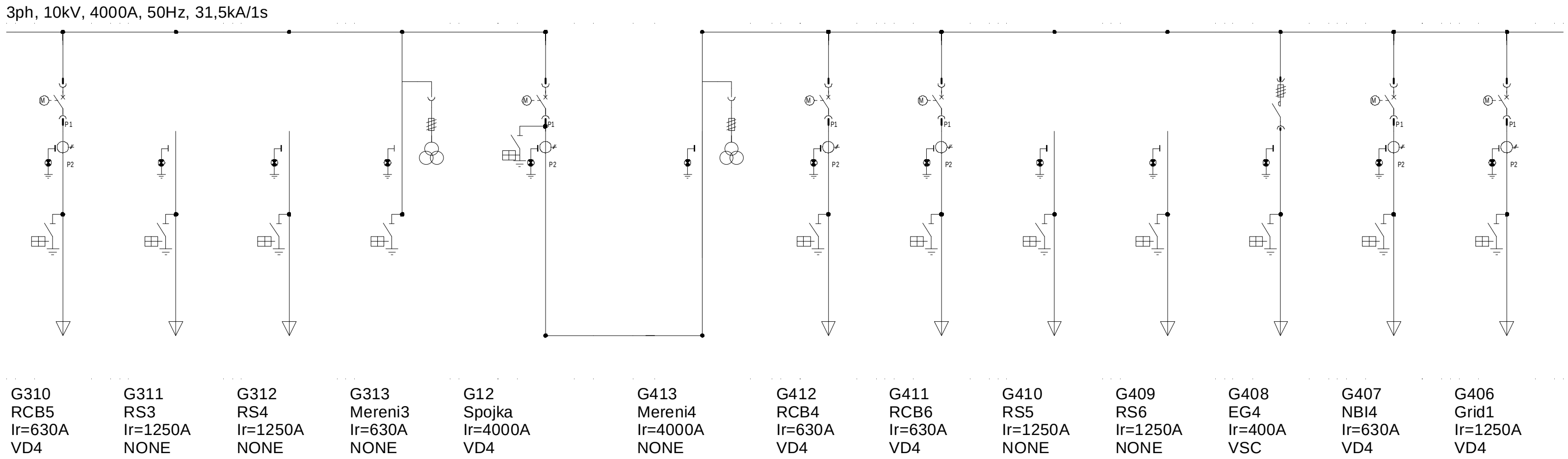
G405 Grid2 | G404 TF | G403 GG4 | G402 IS limiter | G401 Incoming

Width 21310 mm, Height 2533 mm

Customer: ELEKTROTECHNIKA, a.s.	Prepared by: Martin Kloc	Name of switchgear: Switchgear 1	Rev Date: 2019-11-07	Quotation Date: 07.11.2019	No. of Sheets 14
Project: PE0312 Speciální zdroje CR	ABB s.r.o.	Front view	Rev Number: 6	Quotation Number: QT-18-01295939	Sheet no. 3

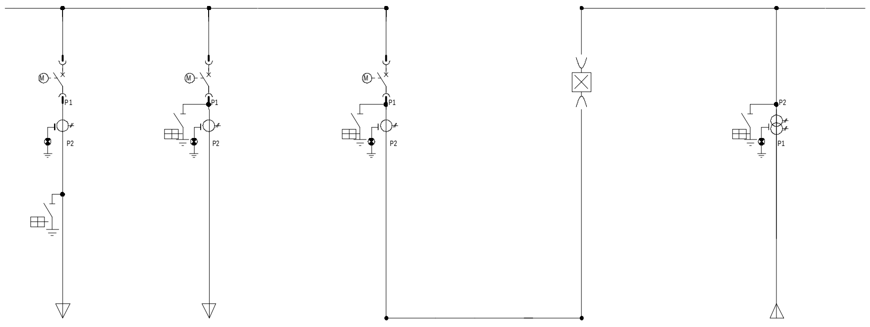


Customer: ELEKTROTECHNIKA, a.s.	Prepared by: Martin Kloc	Name of switchgear: Switchgear 1	Rev Date: 2019-11-07	Quotation Date: 07.11.2019	No. of Sheets 14
Project: PE0312 Speciální zdroje CR	ABB s.r.o.	Single line diagram	Rev Number: 6	Quotation Number: QT-18-01295939	Sheet no. 4



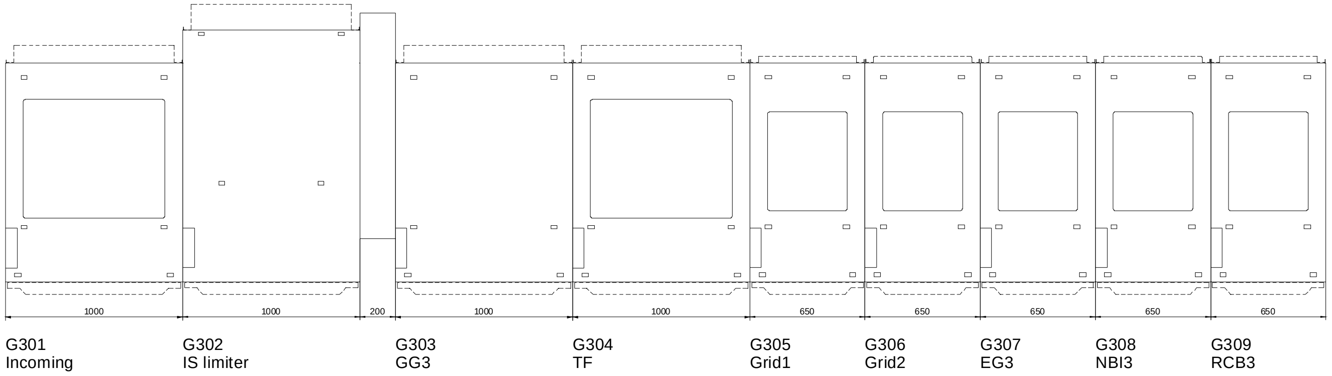
Customer: ELEKTROTECHNIKA, a.s.	Prepared by: Martin Kloc	Name of switchgear: Switchgear 1	Rev Date: 2019-11-07	Quotation Date: 07.11.2019	No. of Sheets 14
Project: PE0312 Speciální zdroje CR	ABB ABB s.r.o.	Single line diagram	Rev Number: 6	Quotation Number: QT-18-01295939	Sheet no. 5

3ph, 10kV, 4000A, 50Hz, 31,5kA/1s

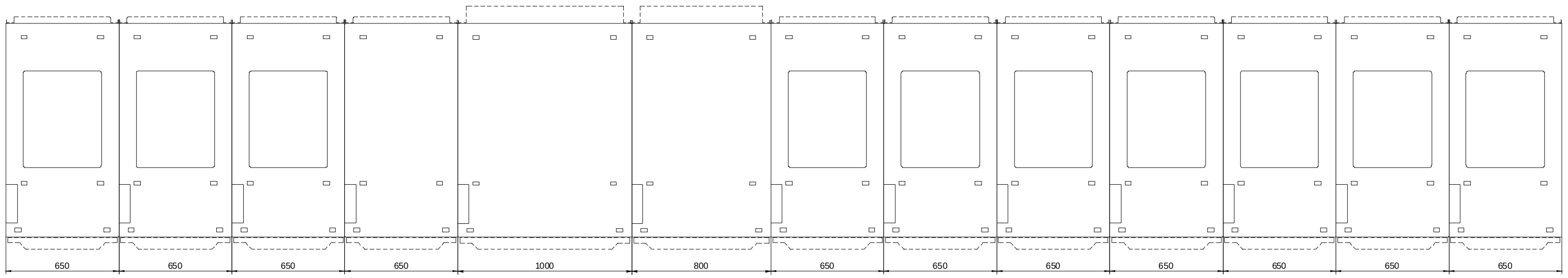


G405	G404	G403	G402	G401
Grid2	TF	GG4	IS limiter	Incoming
Ir=1250A	Ir=4000A	Ir=4000A	Ir=4000A	Ir=4000A
VD4	VD4	VD4	NONE	NONE

Customer: ELEKTROTECHNIKA, a.s.	Prepared by: Martin Kloc	Name of switchgear: Switchgear 1	Rev Date: 2019-11-07	Quotation Date: 07.11.2019	No. of Sheets 14
Project: PE0312 Speciální zdroje CR	ABB s.r.o.	Single line diagram	Rev Number: 6	Quotation Number: QT-18-01295939	Sheet no. 6

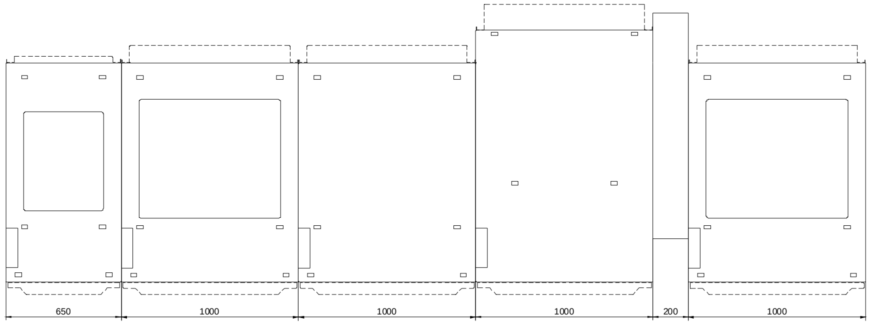


	Customer: ELEKTROTECHNIKA, a.s.	Prepared by: Martin Kloc	Name of switchgear: Switchgear 1	Rev Date: 2019-11-07	Quotation Date: 07.11.2019	No. of Sheets 14
	Project: PE0312 Speciální zdroje CR	ABB ABB s.r.o.	Top view	Rev Number: 6	Quotation Number: QT-18-01295939	Sheet no. 7



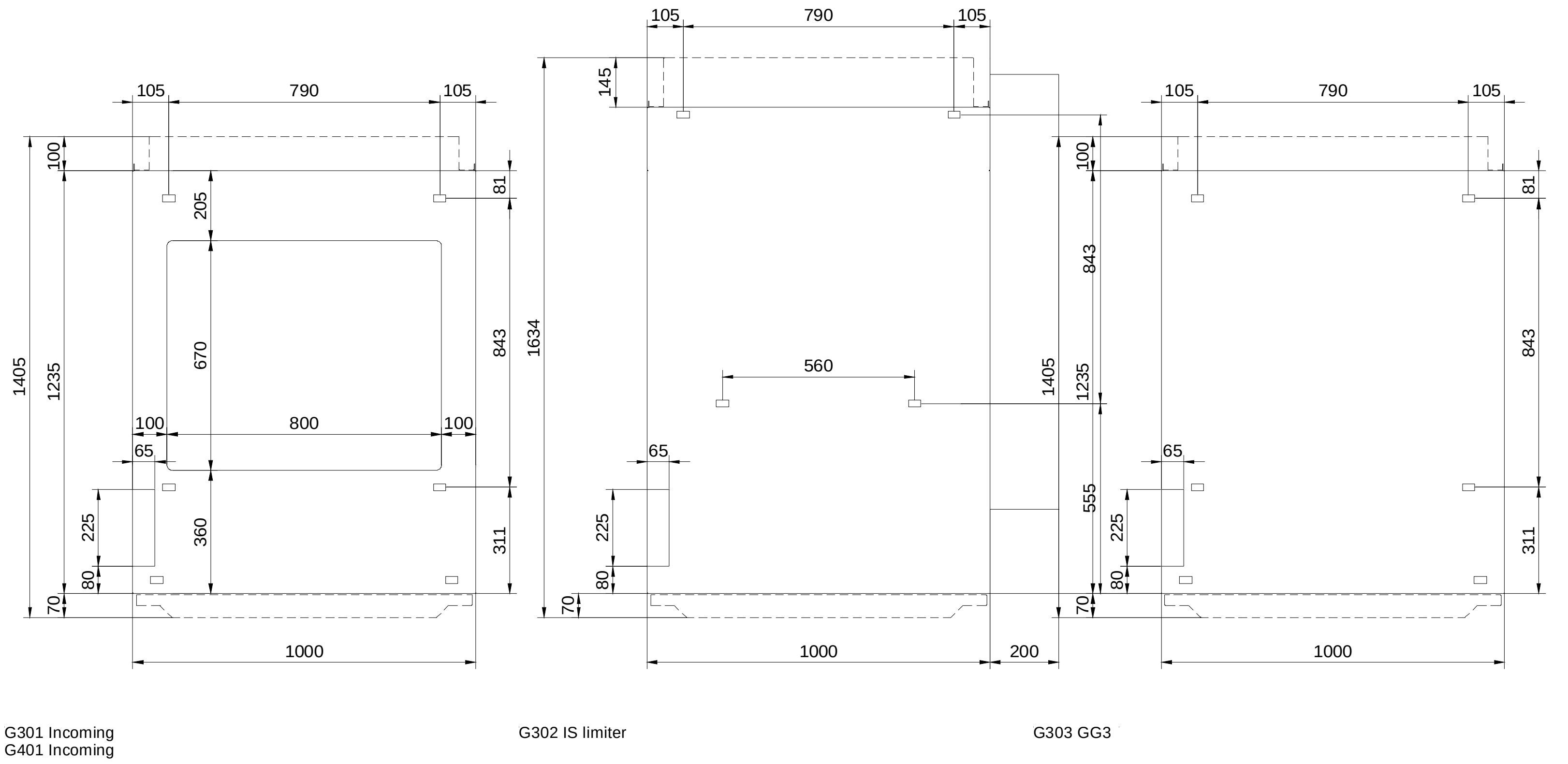
G310	G311	G312	G313	G12	G413	G412	G411	G410	G409	G408	G407	G406
RCB5	RS3	RS4	Mereni3	Spojka	Mereni4	RCB4	RCB6	RS5	RS6	EG4	NBI4	Grid1

	Customer: ELEKTROTECHNIKA, a.s.	Prepared by: Martin Kloc	Name of switchgear: Switchgear 1	Rev Date: 2019-11-07	Quotation Date: 07.11.2019	No. of Sheets 14
	Project: PE0312 Speciální zdroje CR	ABB s.r.o.	Top view	Rev Number: 6	Quotation Number: QT-18-01295939	Sheet no. 8

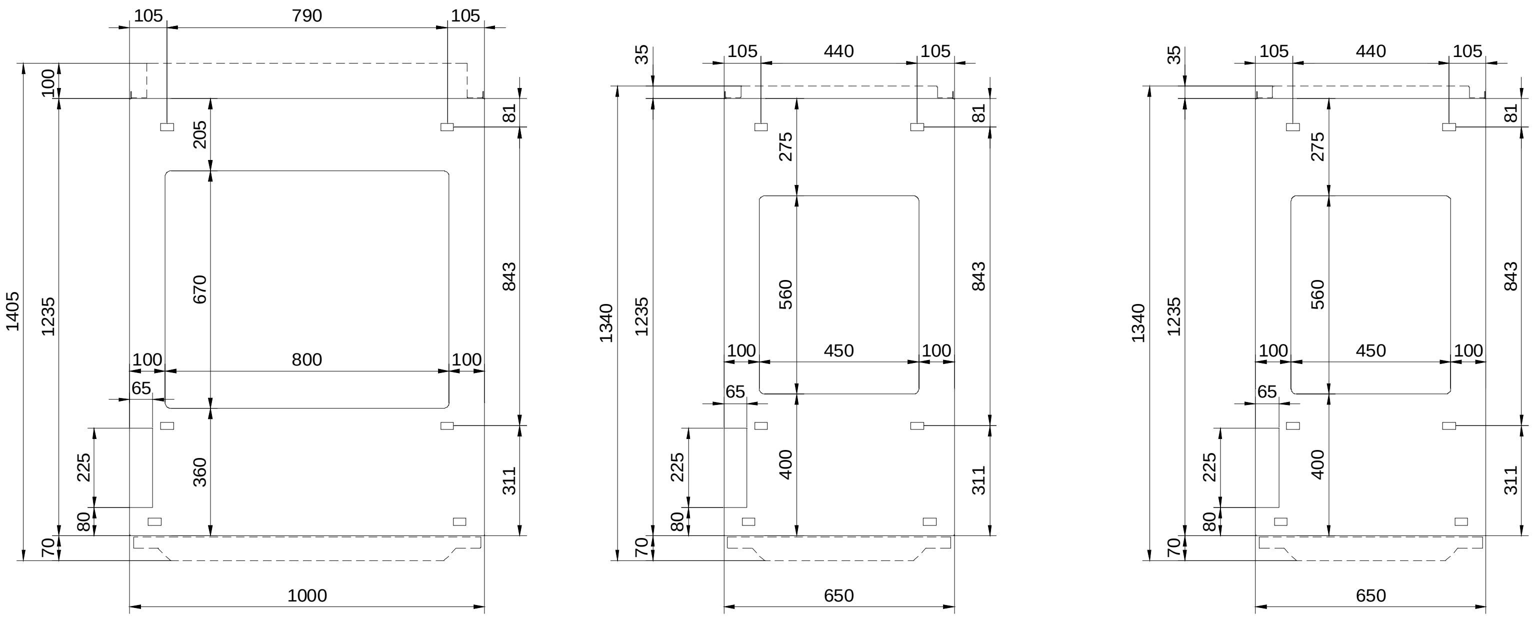


G405 Grid2 | G404 TF | G403 GG4 | G402 IS limiter | G401 Incoming

	Customer: ELEKTROTECHNIKA, a.s.	Prepared by: Martin Kloc	Name of switchgear: Switchgear 1	Rev Date: 2019-11-07	Quotation Date: 07.11.2019	No. of Sheets 14
	Project: PE0312 Speciální zdroje CR	ABB s.r.o.	Top view	Rev Number: 6	Quotation Number: QT-18-01295939	Sheet no. 9



	Customer: ELEKTROTECHNIKA, a.s.	Prepared by: Martin Kloc	Name of switchgear: Switchgear 1	Rev Date: 2019-11-07	Quotation Date: 07.11.2019	No. of Sheets 14
	Project: PE0312 Speciální zdroje CR	ABB s.r.o.	Detailed top views	Rev Number: 6	Quotation Number: QT-18-01295939	Sheet no. 10

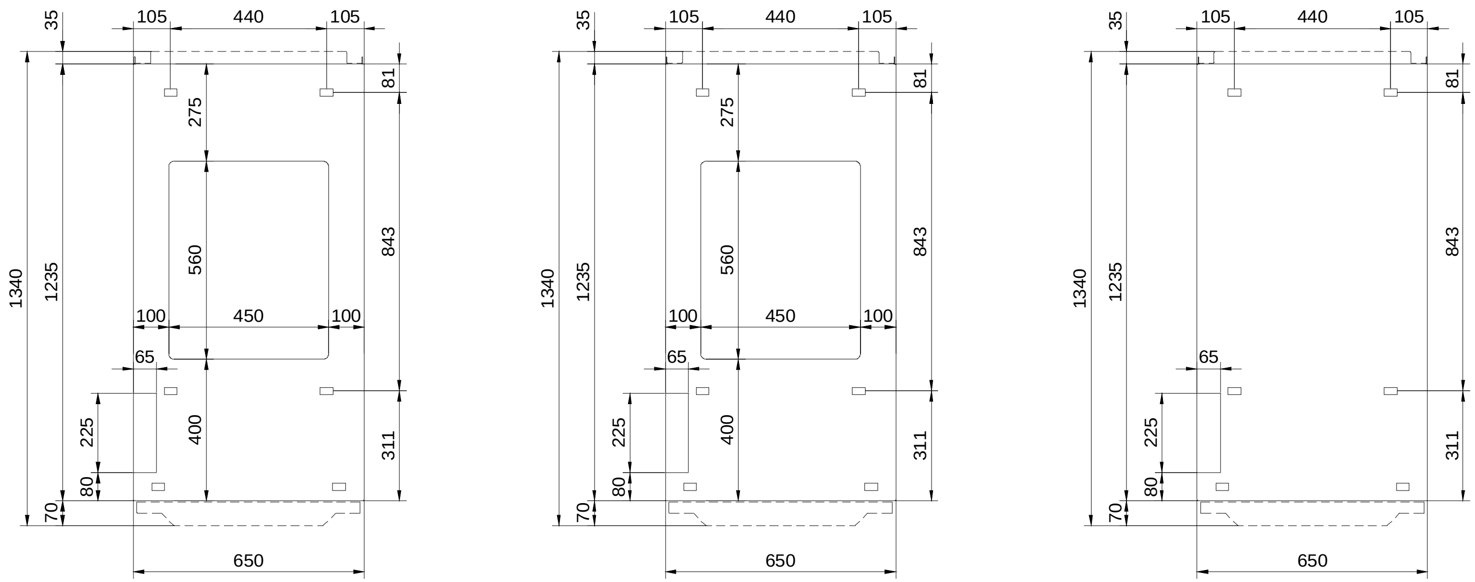


G304 TF
G404 TF

G305 Grid1
G306 Grid2
G406 Grid1
G405 Grid2

G307 EG3
G408 EG4

Customer: ELEKTROTECHNIKA, a.s.	Prepared by: Martin Kloc	Name of switchgear: Switchgear 1	Rev Date: 2019-11-07	Quotation Date: 07.11.2019	No. of Sheets 14
Project: PE0312 Speciální zdroje CR	ABB s.r.o.	Detailed top views	Rev Number: 6	Quotation Number: QT-18-01295939	Sheet no. 11

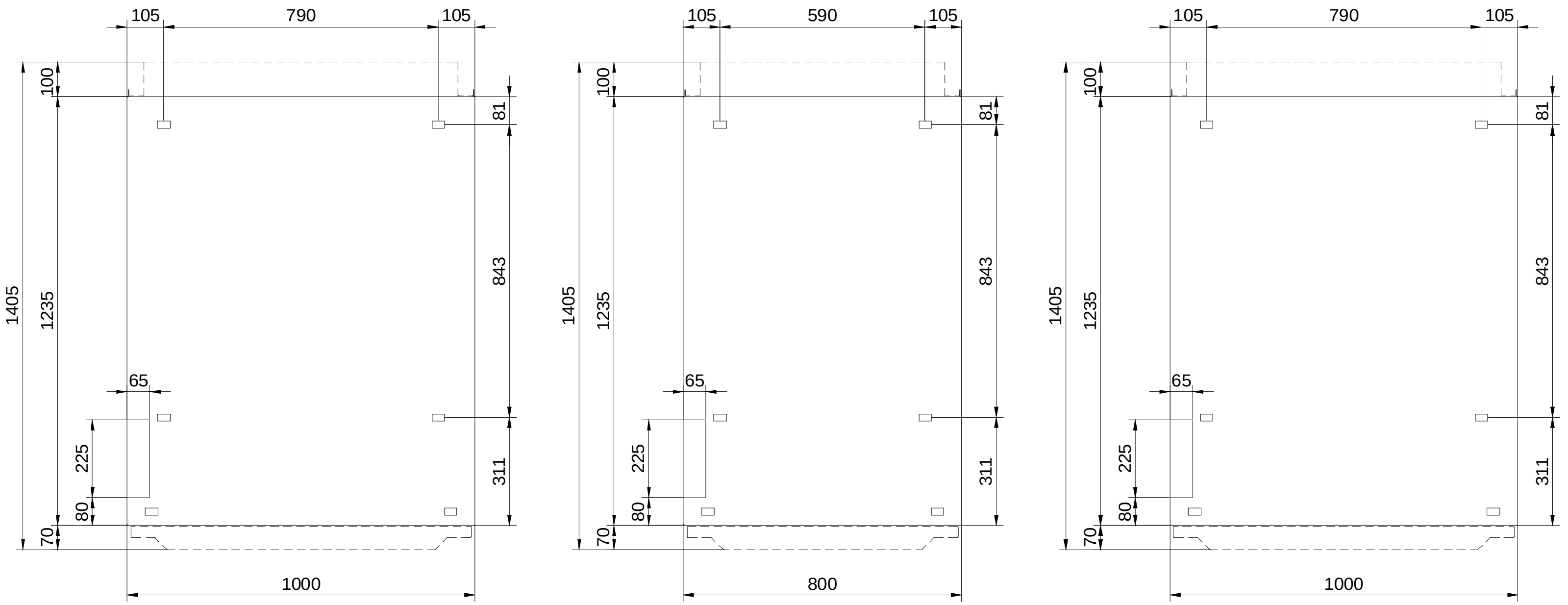


G308 NBI3
G309 RCB3
G310 RCB5
G412 RCB4
G411 RCB6
G407 NBI4

G311 RS3
G312 RS4
G410 RS5
G409 RS6

G313 Mereni3

Customer: ELEKTROTECHNIKA, a.s.	Prepared by: Martin Kloc	Name of switchgear: Switchgear 1	Rev Date: 2019-11-07	Quotation Date: 07.11.2019	No. of Sheets 14
Project: PE0312 Speciální zdroje CR	ABB s.r.o.	Detailed top views	Rev Number: 6	Quotation Number: QT-18-01295939	Sheet no. 12



G12 Spojka

G413 Mereni4

G403 GG4

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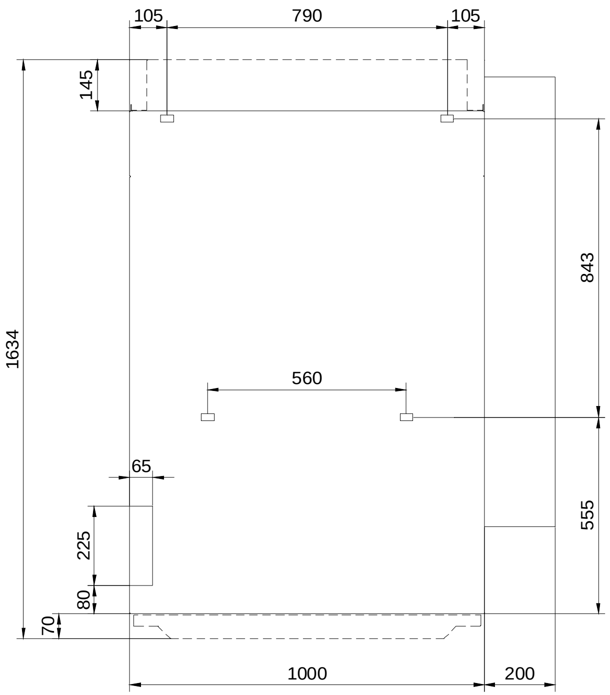
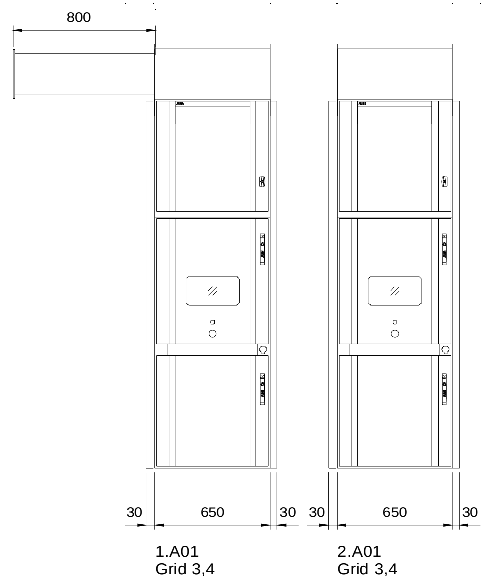
	Project: PE0312 Speciální zdroje CR	ABB s.r.o.	Detailed top views	Rev Number: 6	Quotation Number: QT-18-01295939	Sheet no. 13



G402 IS limiter

Customer: ELEKTROTECHNIKA, a.s.	Prepared by: Martin Kloc	Name of switchgear: Switchgear 1	Rev Date: 2019-11-07	Quotation Date: 07.11.2019	No. of Sheets 14
Project: PE0312 Speciální zdroje CR	ABB s.r.o.	Detailed top views	Rev Number: 6	Quotation Number: QT-18-01295939	Sheet no. 14

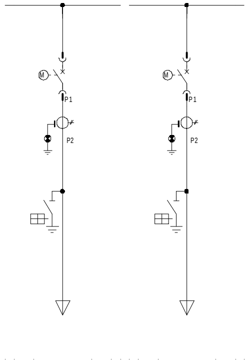
6 DRAWINGS GRID1+GRID2 – ADDED CABINETS



Width 1420 mm, Height 2533 mm
Width of section 1: 710 mm, Height: 2533 mm
Width of section 2: 710 mm, Height: 2533 mm

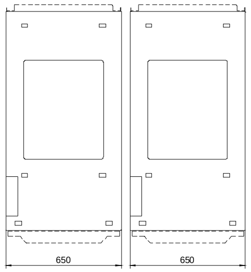
	Customer: ELEKTROTECHNIKA, a.s.	Prepared by: Martin Kloc	Name of switchgear: Switchgear 2 (extension)	Rev Date: 2019-11-07	Quotation Date: 07.11.2019	No. of Sheets 4
	Project: PE0312 Speciální zdroje CR	ABB s.r.o.	Front view	Rev Number: 6	Quotation Number: QT-18-01295939	Sheet no. 1

3ph, 6kV, 1250A, 50Hz, 31,5kA/1s



1.A01	2.A01
Grid 3,4	Grid 3,4
Ir=1250A	Ir=1250A
VD4	VD4

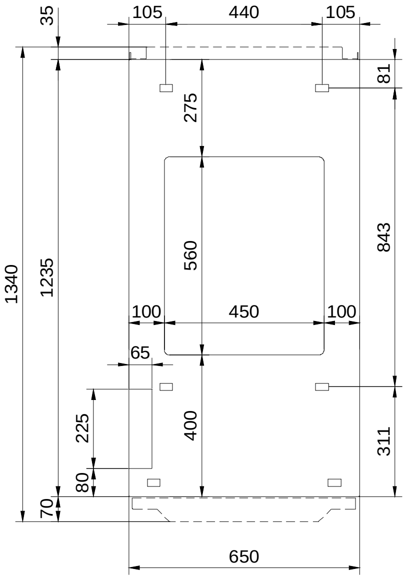
	Customer: ELEKTROTECHNIKA, a.s.	Prepared by: Martin Kloc	Name of switchgear: Switchgear 2 (extension)	Rev Date: 2019-11-07	Quotation Date: 07.11.2019	No. of Sheets 4
	Project: PE0312 Speciální zdroje CR	ABB s.r.o.	Single line diagram	Rev Number: 6	Quotation Number: QT-18-01295939	Sheet no. 2



1.A01
Grid 3,4

2.A01
Grid 3,4

Customer: ELEKTROTECHNIKA, a.s.	Prepared by: Martin Kloc	Name of switchgear: Switchgear 2 (extension)	Rev Date: 2019-11-07	Quotation Date: 07.11.2019	No. of Sheets 4
Project: PE0312 Speciální zdroje CR	ABB s.r.o.	Top view	Rev Number: 6	Quotation Number: QT-18-01295939	Sheet no. 3



1.A01 Grid 3,4
2.A01 Grid 3,4

	Customer: ELEKTROTECHNIKA, a.s.	Prepared by: Martin Kloc	Name of switchgear: Switchgear 2 (extension)	Rev Date: 2019-11-07	Quotation Date: 07.11.2019	No. of Sheets 4
	Project: PE0312 Speciální zdroje CR	ABB ABB s.r.o.	Detailed top views	Rev Number: 6	Quotation Number: QT-18-01295939	Sheet no. 4

ELEKTROTECHNIKA

TECHNICAL SPECIFICATION

Bid No: PE03127A

POWER SUPPLY SYSTEM FOR COMPASS-U TOKAMAK

ANNEX 5

DETALS FOR CONVERTERS FOR TOROIDAL FIELD COILS

ROUND 2

Contractor:

ELEKTROTECHNIKA, a.s.
Kolbenova 936/5e
CZ-190 00 Praha 9

Business manager:
[redacted]

Technical manager:
[redacted]

Client:

Ústav fyziky plazmatu AV ČR, v. v. i.
Za Slovankou 1782/3,
182 00 Prague 8

Function/Represented by:
Doc. RNDr. Radomír Pánek, Ph.D.

1 CONTENT

2 GENERAL OVERVIEW

TFPS will be consisting from two 12-pulse thyristor rectifiers. Both rectifiers TF3PS and TF4PS working in parallel will look like 24-pulse rectifier.

TFPS will be capable of generating controlled current waveforms into the TF coils.

New three cabinets will be manufactured according to original design.

The existing cabinets will be equipped with new electronics needed for new control system.

The clamping force will be checked before reusing of the power blocks.

TF crowbar unit will be constructed of several parallel junctions formed by serially ordered thyristor and resistor.

3 DESIGN

Two blocks of the performance part are going to be fit into the cabinet, each block form a single 6-pulse controlled rectifier within the bridge connection. Each block is equipped with independent side design cabinet outputs. The over-voltage protection will be placed for each block at the bottom of the cabinet. Blocks and the over-voltage protection will be withdrawable. A special lifting truck adopted for withdrawable block will be available for blocks` withdrawing. The pulses for thyristors will be transferred by the optical fibre from the control unit.

The component block is going to consist of a clamping construction of six thyristors connected into the 6-pulse bridge. The clamping construction will be front joined to a block clamped drawn frame. The block frame will be made from the insulation material plates. The block will furthermore consist of: RC snubber, optical units for pulses, supplying transformer for transmitting of the pulses. The clamping construction will be connected to the supplying circuit and to the output circuit via the flexible coupling. The auxiliary voltage will be 230V_{AC}.

4 TECHNICAL SPECIFICATION

Thyristor rectifier cabinet:

Type:	CX65
Input:	2x3AC; 85 Hz; 700V/7,4kA/IT
Output:	2x 2DC;±0-850V; 2x 7kA/2s, 2x 9kA/200 ms
Aux. voltage:	1NPE AC; 50Hz; 230V;3A
Protection code:	IP40
Weight:	700 kg
Cooling:	air

5 PICTURES

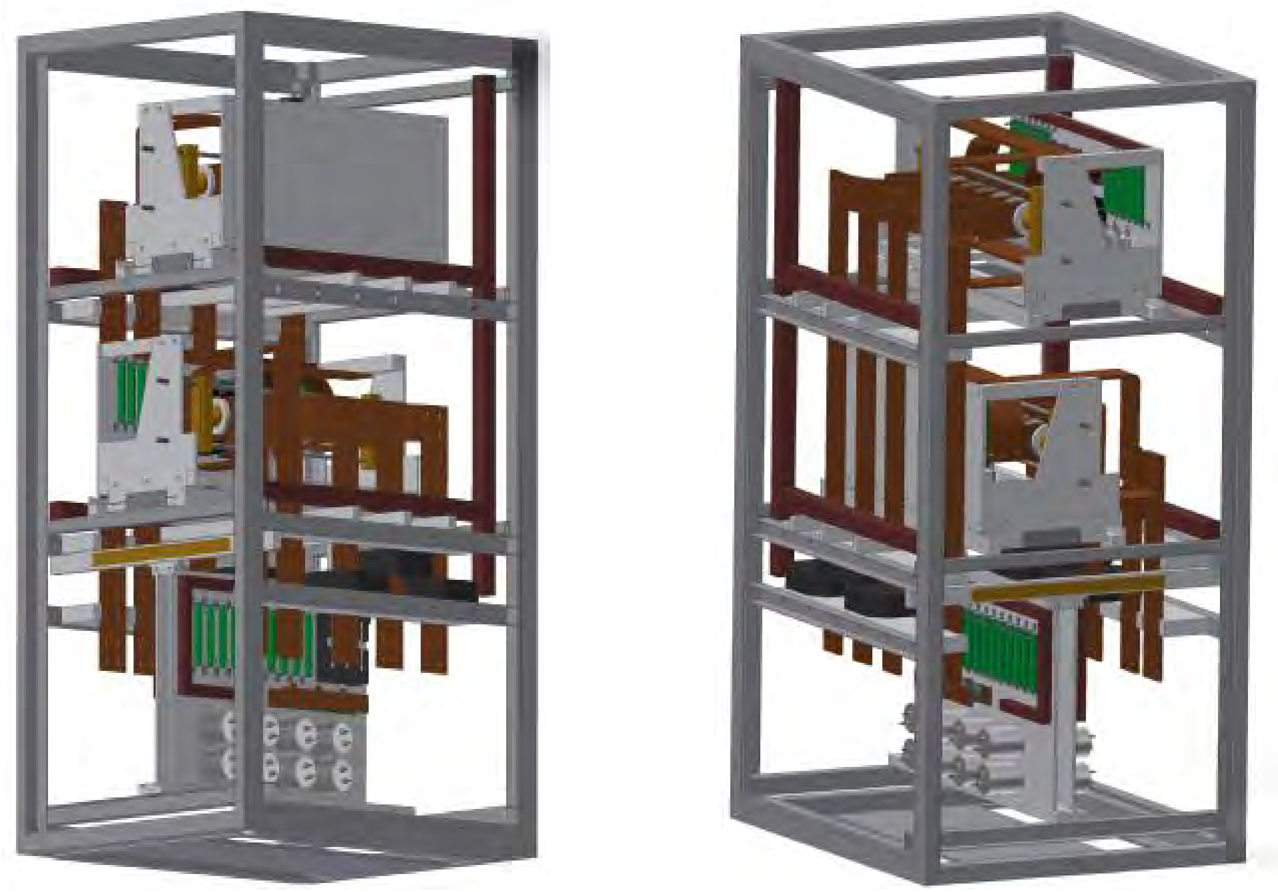


Figure 1. TF power supply cabinet / frame.

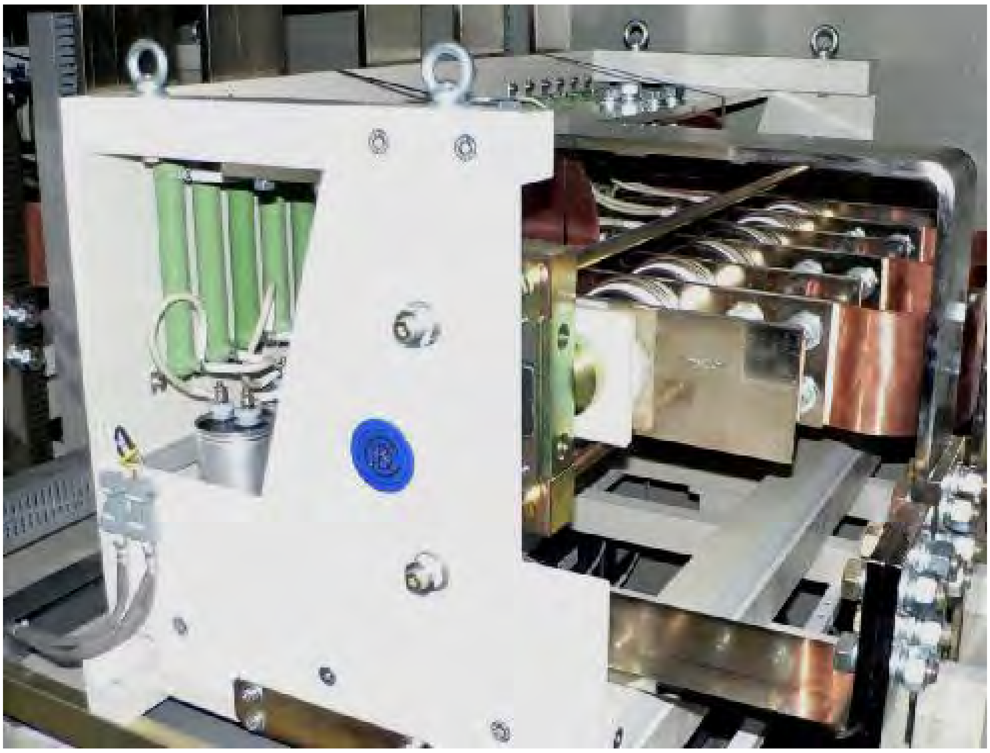


Figure 2. 6-pulse thyristor bridge in current power supply.

ELEKTROTECHNIKA

TECHNICAL SPECIFICATION

Bid No: PE03127A

POWER SUPPLY SYSTEM FOR COMPASS-U TOKAMAK

ANNEX 6

DETAILS FOR CONVERTERS FOR POLOIDAL FIELD COILS

ROUND 2

Contractor:

ELEKTROTECHNIKA, a.s.
Kolbenova 936/5e
CZ-190 00 Praha 9

Business manager:
[redacted]

Technical manager:
[redacted]

Client:

Ústav fyziky plazmatu AV ČR, v. v. i.
Za Slovankou 1782/3,
182 00 Prague 8

Function/Represented by:
Doc. RNDr. Radomír Pánek, Ph.D.

1 CONTENT

2 GENERAL OVERVIEW

PFPS will be consisting from:

1. diode rectifiers,
2. DC-link,
3. capacitor banks,
4. dischargers,
5. DC/DC converters.

Rectifier will be consisting from two 12-pulse diode rectifiers. Both rectifiers R1PF and R2PF working in parallel will look like 24-pulse rectifier.

Power supplies CS PS1, CS PS2, CS PS3, CS PS4, PF1U PS, PF1L PS, PF2U PS, PF2L PS, PF3U PS, PF3L PS, PF4U PS and PF4L PS will be done in parallel order IGBT transistors inter-connected to H-bridge (four-quadrant).

The ED and capacitor bank are always going to be pre-advanced connected into the H-bridge. Dischargers (EDs) will be designed in a way to withstand absorption of the Energy charged within TOKAMAK magnetic poles of the coils without of dangerous over-voltage formation occurrence in DC circuit and furthermore it discharges the charges in DC-link capacitors.

Charging of the capacitor banks (in DC-link) will be made in parallel with excitation of the flywheel generator(s) GG. The power transformer PF1TR/PF2TR and rectifier R1PF/R2PF, R2PF will be supplied by circuit breakers connected to flywheel generator. The excitation current will be increased and voltage at the output of the generator will rise. Voltage of the DC-link will grow-up up to rated value.

3 DESIGN

3.1. Diode rectifiers

Input:	2x3AC; 85 Hz; 720V/IT
Output:	2x2DC;1020V – no-load
	50kA
Cooling:	air

3.2. DC-link

Voltage:	1020V – no-load

3.3. DC/DC converters

Execution:	four-quadrant
Input:	2DC;1020V – no-load
Output:	2DC;±0-900V
	±50, ±30 or ±25kA
Cooling:	water

4 PICTURES

Figure 1. The IGBT air cooled converter using power modules manufactured by contractor.

ELEKTROTECHNIKA

TECHNICAL SPECIFICATION

Bid No: PE03127A

POWER SUPPLY SYSTEM FOR COMPASS-U TOKAMAK

ANNEX 7

DETAILS FOR ADDITIONAL HEATING SYSTEMS AND OTHER LOADS

ROUND 2

Contractor:

ELEKTROTECHNIKA, a.s.
Kolbenova 936/5e
CZ-190 00 Praha 9

Business manager:
[redacted]

Technical manager:
[redacted]

Client:

Ústav fyziky plazmatu AV ČR, v. v. i.
Za Slovankou 1782/3,
182 00 Prague 8

Function/Represented by:
Doc. RNDr. Radomír Pánek, Ph.D.

1 CONTENT

2 GENERAL OVERVIEW

The contractor will re-used parts of the additional heating of other loads according to requests of the client (see Annex 1).

The existing transformers NBI12TTR, RMP1TR and FATR will be installed again and their protection will be included into the control system of the Power Supply System.

The reserve cabinets will be available in MV switchboards GRID1, GRID2, GRID3 and GRID4 according to requests of the client.

TECHNICAL SPECIFICATION

Bid No: PE03127A

POWER SUPPLY SYSTEM FOR COMPASS-U TOKAMAK

ANNEX 8

DETAILS FOR CONTROL SYSTEM

ROUND 2

Contractor:

ELEKTROTECHNIKA, a.s.
Kolbenova 936/5e
CZ-190 00 Praha 9

Business manager:
[redacted]

Technical manager:
[redacted]

Client:

Ústav fyziky plazmatu AV ČR, v. v. i.
Za Slovankou 1782/3,
182 00 Prague 8

Function/Represented by:
Doc. RNDr. Radomír Pánek, Ph.D.

1 CONTENT

2 GENERAL OVERVIEW

Control system consists from HW and SW. High efficiency embedded industrial PC Beckhoff will be used as main controllers. Smart devices (independent PCB) are connected with PC Beckhoff via industrial bus-bar EtherCAT (100 Mb/s). Optical fibers are used for connection PC Beckhoff to all smart devices. PC CX2030 or CX2040 is mostly used as a main controller.

Smart devices are used for controlling and measurement, i.e. device control IGBT (pulses, feedback etc.) and simultaneously measure given signals (voltages, currents) and convert signals from analog to digital values (mostly is used sigma-delta modulation). Each smart device is equipped with FPGA and ARM processor. ARM processor is mostly used as a controller of communication via EtherCAT. Processor ATSAME70Q20B-CN with frequency 300MHz manufactured by Microchip is used. FPGA is used for controlling and measurement. FPGA produces company XILINX. Type of FPGA is XC6SLX16-3FTG256I. It is very powerful FPGA: 14500 logical cells, 232 user inputs/outputs, communication speed 3.2 Gb/s. Program loop is 3.2 µs. 24-bit A/D converters are used for very precise measurement.

Control systems established on Beckhoff technology are used in our company from year 2012.

3 BECKHOFF APPROACH

Beckhoff implements open automation systems based on PC Control technology. The product range covers Industrial PCs, I/O and Fieldbus Components, Drive Technology and automation software. Products that can be used as separate components or integrated into a complete and seamless control system are available for all industries.

4 ETHERCAT

EtherCAT is a real-time Industrial Ethernet technology originally developed by Beckhoff Automation. The EtherCAT protocol which is disclosed in the IEC standard IEC61158 is suitable for hard and soft real-time requirements in automation technology, in test and measurement and many other applications.

The main focus during the development of EtherCAT was on short cycle times (≤ 100 µs), low jitter for accurate synchronization (≤ 1 µs) and low hardware costs.

5 TWINCAT

The TwinCAT software system turns almost any PC-based system into a real-time control with multiple PLC, NC, CNC and/or robotics runtime systems.

6 SCOPE OF DELIVERY

1. Control of the Power Supply System.
2. Setting of the Power Supply System parameters.

The system parameters is possible to set from HMI or using by service application BVis.

3. Monitoring of the Power Supply System.
4. Storage of all measurements, operational states, errors - warning and faults logs, settings and access logs (for limited time).

   Operational (measured) data, operation states and events (i.e. warnings, fault, messages etc.) are stored in tables of the database in MS SQL Server.

5. Communication with external systems (systems that are not part of Power Supply System).
6. Communication with responsible personnel (graphical user interface, e-mail notice).

   Human Machine Interface (GUI) is multi-thread application developed by contractor. The programming language is C# of the development environment Visual Studio (Microsoft). Communication between HMI and control PC provides dynamic library (DLL) developed by Beckhoff. HMI uses access to database. Operational data and events are stored in the database. Remote control / access via VPN is available.

   There will be two places from where will be possible to control the Power Supply System. First will be in a control room of the tokamak COMPASS/COMPASS-U, second will be in suitable area in switchgear room. Both places will be used the same HMI.

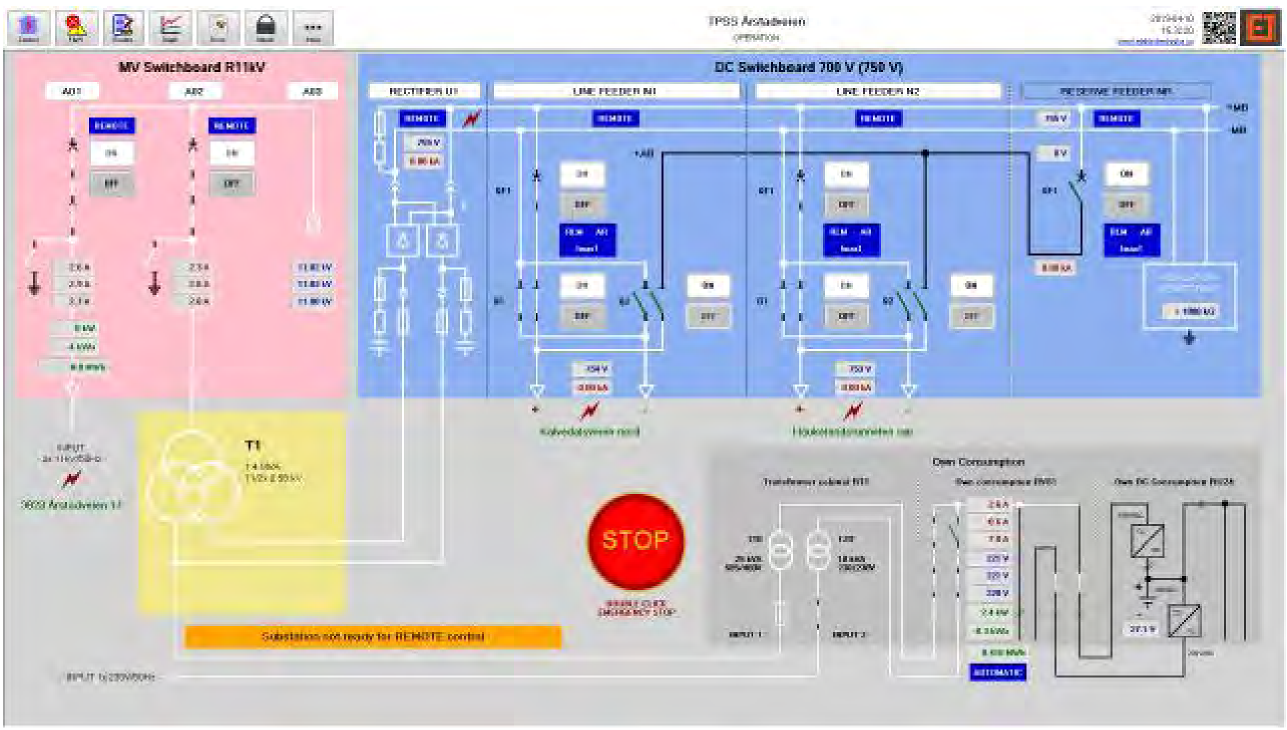


Figure 1. HMI for Traction Power Substation developed by contractor – line diagram.

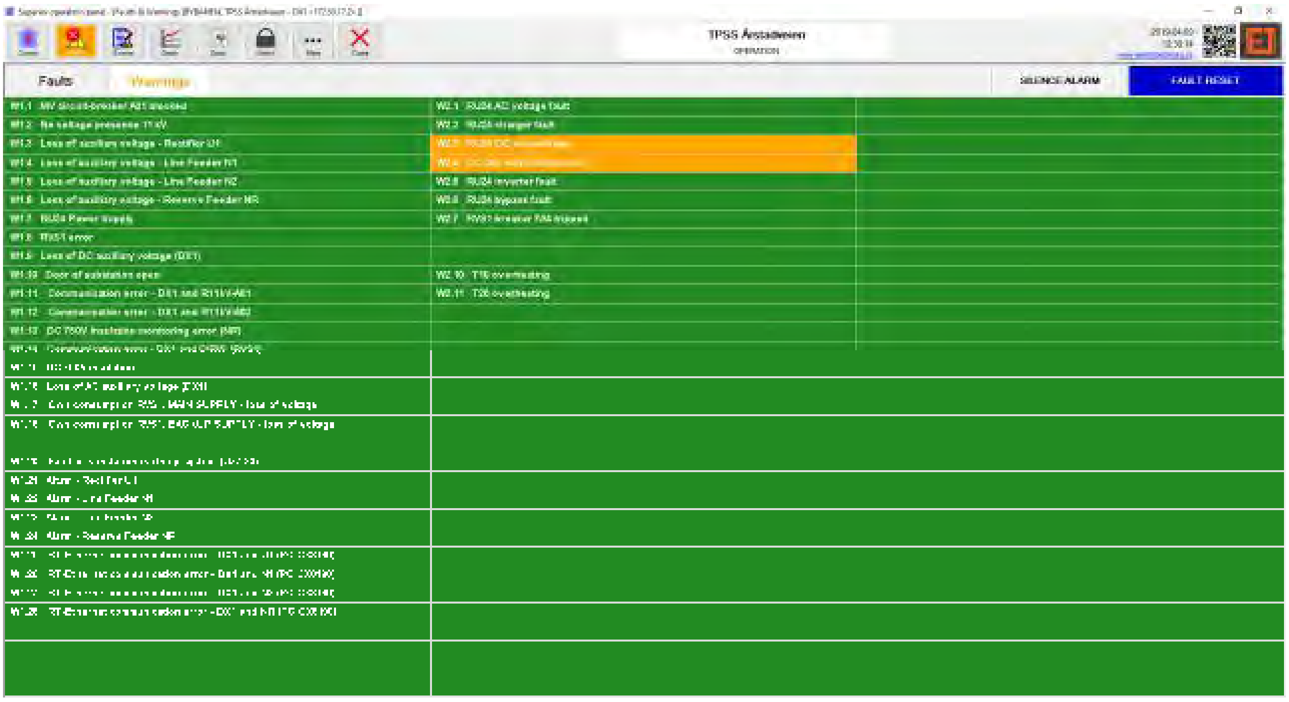


Figure 2. HMI for Traction Power Substation developed by contractor – faults and warnings.

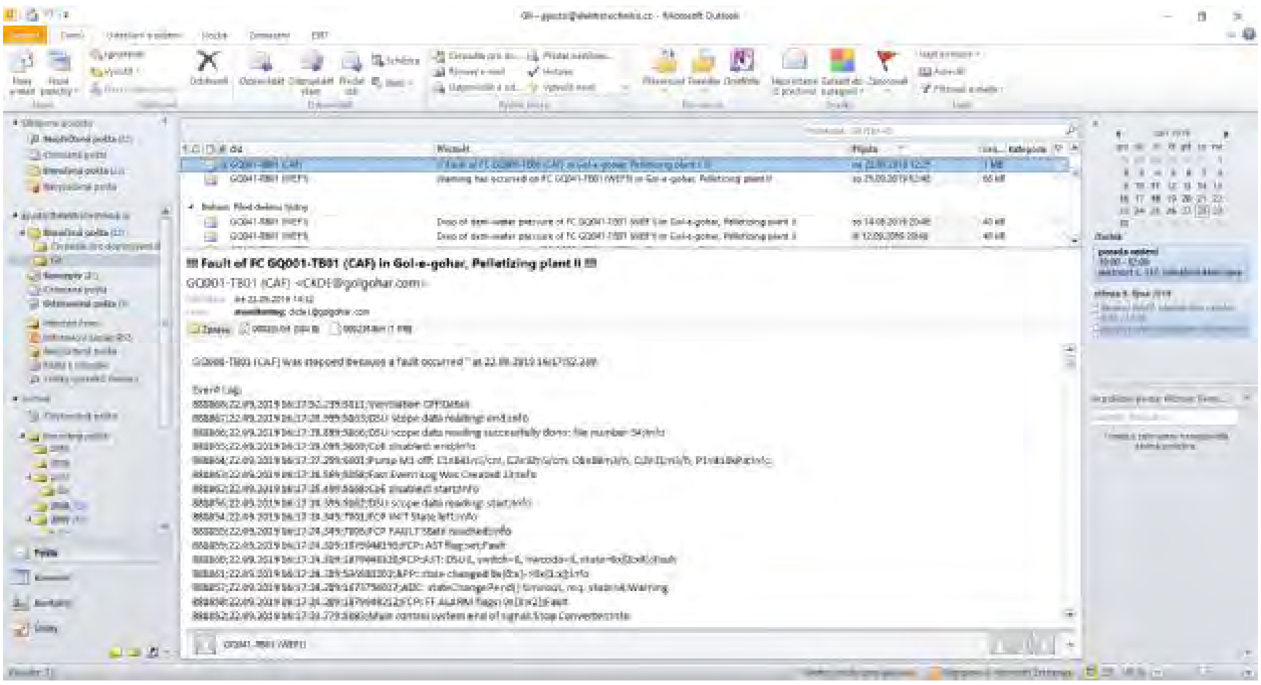


Figure 3. The example of the messages (e-mails) automatically send by control system in case of occurrence of the selected events – developed by contractor and used for MV drives on Pelletizing Plant.

7. Personnel safety - dangerous conditions or situations caused by Power Supply System or Power Supply System operation or faults will be safely handled.
8. Power Supply System safety – prevents damage or faults within Power Supply System.

9. Interface for communication with CODAC (slow, real-time and optical interlock signals).

   Access for reading data from the database will be provided for superior control system CODAC.

   Status and control words will be used for data exchange between PSS control system and CODAC.

7 IMPORTANT FEATURES

1. The control system will block commands and setting parameters, which compromise personnel safety, which can damage any part of the Power Supply System or which are out of the defined limits.
2. The control system will ensure safe turn-off of the whole Power Supply System in the case of Power Supply System failures or power outage.
3. The control system will allow for unambiguous identification of the fault causes in the case of Power Supply System failures (see chapter 6 paragraph 6).
4. The control system will allow access to all stored information (settings, measurements, logs etc.) in standardized way (see chapter 6 paragraph 4).
5. The HMI will indicate state of Power Supply System, allow set parameters of Power Supply System, inform about warnings, errors and faults and allow access to all measurements (see chapter 6 paragraphs 2, 4 and 6).

8 DESIGN

Contractor supposes to use 5 or 6 embedded PCs for control of the Power Supply System (see Annex 1).

All embedded PCs will be connected to the LAN for service purpose.

All embedded PCs will be equipped by integrated UPS for safety shutdown.

Figure 4. The smart devices used for controlling of the PS of the similar TOKAMAK developed according to order of the contractor.

9 REMOTE ACCESS (VPN)

The part of delivery is VPN router for remote access of the contractor (service) and client (remote control).

10 BACKUP

The database will be regularly backup.

TECHNICAL SPECIFICATION

ELEKTROTECHNIKA

Bid No: PE03127A

POWER SUPPLY SYSTEM FOR COMPASS-U TOKAMAK

ANNEX 9

DETAILS FOR SAFETY AND PROTECTION SYSTEMS

ROUND 2

Contractor:

ELEKTROTECHNIKA, a.s.
Kolbenova 936/5e
CZ-190 00 Praha 9

Business manager:
[redacted]

Technical manager:
[redacted]

Client:

Ústav fyziky plazmatu AV ČR, v. v. i.
Za Slovankou 1782/3,
182 00 Prague 8

Function/Represented by:
Doc. RNDr. Radomír Pánek, Ph.D.

1 CONTENT

2 GENERAL OVERVIEW

The Power Supply System will fully protect itself and connected systems in case of faults. This includes protection against incorrect use or commands or settings.

The Power Supply System will ensure safe operation regarding personnel safety and will minimize chance and handle dangerous situations and faults.

The Power Supply System control, monitoring system and all other systems that will be able to turn-off safely Power Supply System (e.g. flywheel generators lubrication units, PFPS drivers, energy dissipator, crowbars) in case of power outage.

All important devices will be supplied from UPS. The minimal time UPS operation will be at least 30 minutes.

3 SAFETY OF THE STAFF

The areas with restricted access will be bordered by a protection fence or protected by other protections (e.g. cabinet rack with sensor for opening and automatic discharging). The access to the restricted areas will be controlled by control system.

4 DESIGN

The Power Supply System will withstand short circuit in each Power Supply device including short circuit in tokamak coils.

The cabling will withstand short circuit currents (acting forces, thermal stress).

The Power Supply System including cabling will be protected against leakage of coolant or water leak from the other sources.

ELEKTROTECHNIKA

TECHNICAL SPECIFICATION

Bid No: PE03127A

POWER SUPPLY SYSTEM FOR COMPASS-U TOKAMAK

ANNEX 10

DETAILS FOR ACCEPTANCE TESTS

ROUND 2

Contractor:

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Kolbenova 936/5e
CZ-190 00 Praha 9

Business manager:
[redacted]

Technical manager:
[redacted]

Client:

Ústav fyziky plazmatu AV ČR, v. v. i.
Za Slovankou 1782/3,
182 00 Prague 8

Function/Represented by:
Doc. RNDr. Radomír Pánek, Ph.D.

1 CONTENT

2 GENERAL OVERVIEW

All tests of the equipment will be done according to the relevant Czech and European rules and regulations.

The Quality Plan (list of the tests) will be prepared by contractor.

Key tests specifically required by the Client will be done according to client request.

3 FACTORY ACCEPTANCE TESTS (FAT)

FAT of individual Power Supply System components will be performed at the site of the Contractor or at the site of the third party (ABB, TES etc.). After the FATs are successfully performed, the tested Power Supply System components are cleared to be accepted by the Client.

As a part of all FATs, the Contractor will provide technical documentation (drawings, electrical schematics, datasheets, and test protocols of the components …) which proves that the tested part of the Power Supply System fulfils the required overall parameters.

4 SITE ACCEPTANCE TESTS (SAT)

SATs of the installed part of the Power Supply System will be performed after its installation at the Client site.

5 FULL PERFORMANCE TEST

Power Supply System Full Performance Tests will be performed during the warranty period at the request of the Client, with the Contractor’s technical support (including staff on-site).

TECHNICAL SPECIFICATION

ELEKTROTECHNIKA

Bid No: PE03127A

POWER SUPPLY SYSTEM FOR COMPASS-U TOKAMAK

ANNEX 11

DETAILS FOR DOCUMENTATION AND SW BACKUP

ROUND 2

Contractor:

ELEKTROTECHNIKA, a.s.
Kolbenova 936/5e
CZ-190 00 Praha 9

Business manager:
[redacted]

Technical manager:
[redacted]

Client:

Ústav fyziky plazmatu AV ČR, v. v. i.
Za Slovankou 1782/3,
182 00 Prague 8

Function/Represented by:
Doc. RNDr. Radomír Pánek, Ph.D.

1 CONTENT

2 DOCUMENTATION

Contractor will provide the necessary documentation for successful operation, maintenance and repairs even after a long period of operation for all Power Supply System components in a range of:

1. Documentation “CID” (of power supply system, only) for approval for submission to the client in a range as specified by the contract, only.
2. Approved documentation “ABD” (of power supply system, only) for realisation and construction in a range as specified by the contract, only.
3. As-built documentation “AD” (of power supply system, only) in a range as specified by the contract, only.
4. The documentation will be submitted in the electronic media (2x CD) and hard copy (4x) in accordance with the signed contract, as specified.
5. Time schedule of design delivery, cable lines networks, dismantle, assembly work, erection on site, FAT, SAT presence, commissioning, protection relay setting calculations and settings, site testing, revisions providing and handing over of the work to the client.
6. Cooperation in pre-preparatory, preparatory, electro-technical design stage with a chosen civil work project designer/engineering and Construction Company in a meaning to enable the easiest and technically suitable way technology instalment.
7. Cooperation with the client.
8. All necessary certificates, test reports and other document release.

All documents will be in Czech.

3 SW BACKUP

Current version of all SW will be backed up to CD.

ELEKTROTECHNIKA

TECHNICAL SPECIFICATION

Bid No: PE03127A

POWER SUPPLY SYSTEM FOR COMPASS-U TOKAMAK

ANNEX 12

DETAILS FOR UTILIZATION OF THE EXISTING POWER SUPPLY SYSTEM

ROUND 2

Contractor:

ELEKTROTECHNIKA, a.s.
Kolbenova 936/5e
CZ-190 00 Praha 9

Business manager:
[redacted]

Technical manager:
[redacted]

Client:

Ústav fyziky plazmatu AV ČR, v. v. i.
Za Slovankou 1782/3,
182 00 Prague 8

Function/Represented by:
Doc. RNDr. Radomír Pánek, Ph.D.

1 CONTENT

2 UTILIZATION OF THE EXISTING PARTS

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category	Notice of the Contractor
General						
1	GG1	Existing flywheel generator	GG1 (see chapters 6.2, 6.5)	GG1 (see 2.1 - Extent of delivery and 4.1- General Schematics)	A (Prescribed re-use)	**YES** **(see Annex 1)**
2	GG2	Existing flywheel generator	GG2 (see chapters 6.2, 6.5)	GG2 (see 2.1 - Extent of delivery and 4.1- General Schematics)	A (Prescribed re-use)	**YES** **(see Annex 1)**
3	MG1	Motor of the flywheel generator	MG1 (see chapters 6.2, 6.5)	MG1 (see 2.1 - Extent of delivery and 4.1- General Schematics)	A (Prescribed re-use)	**YES** **(see Annex 1)**
4	MG2	Motor of the flywheel generator	MG2 (see chapters 6.2, 6.5)	MG2 (see 2.1 - Extent of delivery and 4.1- General Schematics)	A (Prescribed re-use)	**YES** **(see Annex 1)**
5	Lubrication unit 0MM03	Lubrication unit and cooling unit	Unit provides lubrication, pressurization and cooling of the bearing oil of the existing generators GG1 and GG2	Same function as in the existing PSS. The Contractor will control the lubrication unit and provide safe emergency stop of the generators (see 5.9 - Safety and Protection requirements).	A (Prescribed re-use)	**YES** **Lubrication system will be controlled by new Control System.**
6	GG1 and GG2 air cooling system	The existing generators draw the air from outside of the assembly hall. This air is used for their cooling. The air cooling system decides whether the warm exhaust air is ejected outside of the	Air cooling of the GG1 and GG2.	Same function as in the existing PSS. Incorporate / interface the control of the generator's air cooling system into the control system of the new PSS.	A (Prescribed re-use)	**YES**

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category	Notice of the Contractor
		assembly hall or inside of the assembly hall (in order to support its heating during the winter). The decision is provided by control of 2x2 shutters.				
7	GG1 and GG2 braking system	The braking of the generators from the operational rotation speed to the 0 rpm is provided by 3 means: 1) generator is exciting itself (speed > 700 rpm), 2) generator is excited from the electric grid (100-700 rpm), 3) active braking by the motor (0-100 rpm), with energy being dissipated in the resistors.	Braking of the generators GG1 and GG2	Braking of the generators GG1 and GG2	A (Prescribed re-use)	**YES**
8	Power cables	Power cables used in the existing Power Supply System	Connection between parts of the existing Power Supply System		Category B (Free re-use)	**YES** **The existing power cables will be used as much as possible.**
9	Cable trays	Cable trays used in the existing Power Supply System	Support for the cables connecting parts of the existing Power Supply System		Category B (Free re-use)	**YES** **The existing power trays will be used as much as possible.**
Transformers						
12	1TR2A	See section 6.5 - Existing Power Supply System, particularly 6.5.4 - Transformers	Excitation transformer for GG1	Excitation transformer EG1TR for GG1 (see 5.3 - Transformer requirements)	A (Prescribed re-use)	**YES** **(see Annex 1)**

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category	Notice of the Contractor
13	2TR2B	See section 6.5 - Existing Power Supply System, particularly 6.5.4 - Transformers	Excitation transformer for GG2	Excitation transformer EG2TR for GG2 (see 5.3 - Transformer requirements)	A (Prescribed re-use)	**YES** **(see Annex 1)**
14	0TR10	See section 6.5 - Existing Power Supply System, particularly 6.5.4 - Transformers	Transformer for the RMP Power Supplies	Transformer RMP1TR for the existing converters RMP PSs (the converters are not part of the Power Supply System), see 5.3 - Transformer requirements	A (Prescribed re-use)	**YES** **(see Annex 1)**
17	9TR09	See section 6.5 - Existing Power Supply System, particularly 6.5.4 - Transformers	Transformer for existing Neutral Beam Injectors NBI1 and NBI2	Transformer NBI12TR for existing Neutral Beam Injectors 1 and 2 (the NBI1 and NBI2 are not part of the Power Supply System), see 5.3 - Transformer requirements	A (Prescribed re-use)	**YES** **(see Annex 1)**
18	8TR08	See section 6.5 - Existing Power Supply System, particularly 6.5.4 - Transformers	Transformer for Fast Amplifier FAPS	Transformer FATR for existing converter Fast Amplifier Power Supply FAPS (the converter is not part of the Power Supply System), see 5.3 - Transformer requirements	A (Prescribed re-use)	**YES** **(see Annex 1)**
LV switchgear						
22	1RM01	frequency converter for motor, see section 6.5.1 - Technological Part of Flywheel Generators	frequency converter for motor MG1	frequency converter FC1 for motor MG1; assumed to stay on the same place in the LV switchgear area	A (Prescribed re-use)	**YES** **Frequency converter will be controlled by new Control System.**

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category	Notice of the Contractor
23	2RM02	frequency converter for motor, see section 6.5.1 - Technological Part of Flywheel Generators	frequency converter for motor MG2	frequency converter FC2 for motor MG2; assumed to stay on the same place in the LV switchgear area	A (Prescribed re-use)	**YES** **Frequency converter will be controlled by new Control System.**
24	0RB01	Converter for excitation of flywheel generator GG1, see section 6.5.1 - Technological Part of Flywheel Generators	EG1	Converter EG1 for excitation of flywheel generator GG1; assumed to stay on the same place in the LV switchgear area	A (Prescribed re-use)	**YES** **Frequency converter will be controlled by new Control System.**
25	0RB02	Converter for excitation of flywheel generator GG2, see section 6.5.1 - Technological Part of Flywheel Generators	EG2	Converter EG2 for excitation of flywheel generator GG2; assumed to stay on the same place in the LV switchgear area	A (Prescribed re-use)	**YES** **Frequency converter will be controlled by new Control System.**
HV switchgear						**The existing MV switchgear will be disassembly and checked in manufacturer factory.**
40		The switchgear rack cabinets can be physically moved from their existing position in the HV switchgear area, if required by the layout of the new Power Supply System.				**Position will be determined according to dispositions of a new design.**
41	1R601	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.12.32	Main circuit breaker for GG1, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	MCB1 or MCB2, see 5.4 - HV switchgear	A (Prescribed re-use)	**YES** **(see Annex 1)**
42	2R602	Medium voltage switchgear UniGear ZS1 + circuit breaker	Circuit breaker for EF Power Supply transformer, see	One of the circuit breakers described in the section 5.4 -	A (Prescribed re-use)	**YES** **(see Annex 1)**

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category	Notice of the Contractor
		VD4/P 12.06.32	2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	HV switchgear, for example RCB1		
43	3R603	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.06.32	Circuit breaker for SF Power Supply transformer, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	One of the circuit breakers described in the section 5.4 - HV switchgear, for example RCB2	A (Prescribed re-use)	**YES** **(see Annex 1)**
44	4R604	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.06.32	Circuit breaker for MF Power Supply transformer, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	One of the circuit breakers described in the section 5.4 - HV switchgear, for example RCB3	A (Prescribed re-use)	**YES** **(see Annex 1)**
45	5R605	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.06.32	Circuit breaker for FA Power Supply transformer, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	One of the circuit breakers described in the section 5.4 - HV switchgear, for example NBI0CB	A (Prescribed re-use)	**YES** **(see Annex 1)**
46	6R606	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.06.32	Circuit breakers for Neutral Beam Injectors 1 and 2 transformer, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	One of the circuit breakers described in the section 5.4 - HV switchgear, for example NBI12CB	A (Prescribed re-use)	**YES** **(see Annex 1)**
47	7R607	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.06.32	Circuit breakers for RMP Power Supplies transformer, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	One of the circuit breakers described in the section 5.4 - HV switchgear, for example RMP1CB	A (Prescribed re-use)	**YES** **(see Annex 1)**

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category	Notice of the Contractor
48	8R608	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.06.32	Reserve, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	One of the circuit breakers described in the section 5.4 - HV switchgear, for example FACB	A (Prescribed re-use)	**YES** **(see Annex 1)**
49	9R609	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.06.32	Reserve, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	One of the circuit breakers described in the section 5.4 - HV switchgear, for example RCB4	A (Prescribed re-use)	**YES** **(see Annex 1)**
50	AR610	Medium voltage switchgear UniGear ZS1 + internal electrical connection	Bridge 1, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear		Category B (Free re-use)	**The designer will make decision about the re-usage of the cabinet.**
51	BR611	Medium voltage switchgear UniGear ZS1 + internal electrical connection	Junction 1, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear		Category B (Free re-use)	**The designer will make decision about the re-usage of the cabinet.**
52	CR612	Medium voltage switchgear UniGear ZS1 + contactor VSC7/P SC0; 80A	Contactor for generator GG1 excitation transformer, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	EG1CB or EG2CB, see 5.4 - HV switchgear	A (Prescribed re-use)	**YES** **(see Annex 1)**
53	DR613	Medium voltage switchgear UniGear ZS1 + contactor VSC7/P SC0; 80A	Contactor for generator GG2 excitation transformer, see 2018_Energetic_tokamak_en.pdf and section 6.5.3 - High-voltage switchgear	EG1CB or EG2CB, see 5.4 - HV switchgear	A (Prescribed re-use)	**YES** **(see Annex 1)**
54	ER614	Medium voltage switchgear UniGear ZS1 + Isolating truck TE 1212-34	Junction 2 (disconnectable), see 2018_Energetic_tokamak_en.	Junction JU1 between the grids, see 5.4 - HV switchgear	A (Prescribed re-use)	**YES** **(see Annex 1)**

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category	Notice of the Contractor
			pdf and section 6.5.3 - High-voltage switchgear			
55	FR615	Medium voltage switchgear UniGear ZS1 + internal electrical connection	Bridge 2, see 2018_Energetic_tokamak_en. pdf and section 6.5.3 - High-voltage switchgear		Category B (Free re-use)	**The designer will make decision about the re-usage of the cabinet.**
56	GR616	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.06.32	Circuit breaker for TF Power Supply transformer, see 2018_Energetic_tokamak_en. pdf and section 6.5.3 - High-voltage switchgear	One of the circuit breakers described in the section 5.4 - HV switchgear, for example RCB5	A (Prescribed re-use)	**YES**
57	HR617	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.06.32	Circuit breaker for TF Power Supply transformer, see 2018_Energetic_tokamak_en. pdf and section 6.5.3 - High-voltage switchgear	One of the circuit breakers described in the section 5.4 - HV switchgear, for example RCB6	A (Prescribed re-use)	**YES**
58	JR618	Medium voltage switchgear UniGear ZS1 + circuit breaker VD4/P 12.12.32	Main circuit breaker for GG2, see 2018_Energetic_tokamak_en. pdf and section 6.5.3 - High-voltage switchgear	MCB1 or MCB2, see 5.4 - HV switchgear	A (Prescribed re-use)	**YES**
Converters						**The existing thyristor converters will be disassembly and checked in manufacturer factory.**
59	1RU01	Thyristor converter rack cabinet, see section 6.5.5	TFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)	**YES** **(see Annex 1)**
60	2RU02	Thyristor converter rack cabinet, see section 6.5.5	TFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)	**YES** **(see Annex 1)**

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category	Notice of the Contractor
61	3RU03	Thyristor converter rack cabinet, see section 6.5.5	TFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)	**YES** **(see Annex 1)**
62	4RU04	Thyristor converter rack cabinet, see section 6.5.5	TFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)	**YES** **(see Annex 1)**
63	5RU05	Thyristor converter rack cabinet, see section 6.5.5	TFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)	**YES** **(see Annex 1)**
64	6RU06	Thyristor converter rack cabinet, see section 6.5.5	TFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)	**YES** **(see Annex 1)**
65	7RU07	Thyristor converter rack cabinet, see section 6.5.5	TFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)	**YES** **(see Annex 1)**
66	8RU08	Thyristor converter rack cabinet, see section 6.5.5	TFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)	**YES** **(see Annex 1)**
68	ARU10	Thyristor converter rack cabinet, see section 6.5.5	EFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)	**YES** **(see Annex 1)**
69	BRU11	Thyristor converter rack cabinet, see section 6.5.5	EFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)	**YES** **(see Annex 1)**
70	CRU12	Thyristor converter rack cabinet, see section 6.5.5	SFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)	**YES** **(see Annex 1)**
71	DRU13	Thyristor converter rack cabinet, see section 6.5.5	MFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)	**YES** **(see Annex 1)**
72	ERU14	Thyristor converter rack cabinet, see section 6.5.5	MFPS (see chapters 6.2, 6.5)	TFPS, see 5.5 - Converters for Toroidal Field coils	A (Prescribed re-use)	**YES** **(see Annex 1)**

No.	Part name	Brief description	Function in the existing PSS	Function in the new PSS	Re-use category	**Notice of the Contractor**
Choke coils						
76	Choke coils details: see 6.5.5 - Converters and Accessories, general schematics "2018_Energetic_tokamak_en.pdf" and technical datasheet in "Accompanying documentation.zip", specifically in "COMPASS_existing_Power_Supply_system_Technical_documentation.zip"					
77	1TL31, 2TL32, 3TL33, 4TL34	Choke coil, type TLV 57/37	Balancing of the 24-pulse thyristor converter in the TF Power Supply		Category B (Free re-use)	**Some of the existing choke coils will may be used for balancing PF diode converter (see Annex 1).**
78	TLF1, TLF2, TLF3, TLF4	Choke coil, type TLV 56/37	Additional inductance for the LC filter		Category B (Free re-use)	
79	TLF5, TLF7	Choke coil, type TLV 56/29	Additional inductance for the LC filters		Category B (Free re-use)	
80	TLF6	Choke coil, type TLV 70/29	Additional inductance for the LC filter		Category B (Free re-use)	
81	5TL41, 6TL42	Choke coil, type TLV 54/21	Balancing of the 12-pulse thyristor converter in the EF Power Supply		Category B (Free re-use)	
82	7TL51, 8TL52	Choke coil, type TLV 58/21	Balancing of the 12-pulse thyristor converter in the SF Power Supply		Category B (Free re-use)	
83	9TL61, ATL62	Choke coil, type TLV 61/21	Balancing of the 12-pulse thyristor converter in the MF Power Supply		Category B (Free re-use)	

ELEKTROTECHNIKA

TECHNICAL SPECIFICATION

Bid No: PE03127A

POWER SUPPLY SYSTEM FOR COMPASS-U TOKAMAK

ANNEX 13

MATLAB-SIMULINK TF MODEL RESULTS

ROUND 2

Contractor:

ELEKTROTECHNIKA, a.s.
Kolbenova 936/5e
CZ-190 00 Praha 9

Business manager:
[redacted]
[redacted]1
[redacted]

Technical manager:
[redacted]

Client:

Ústav fyziky plazmatu AV ČR, v. v. i.
Za Slovankou 1782/3,
182 00 Prague 8

Function/Represented by:
Doc. RNDr. Radomír Pánek, Ph.D.

1 CONTENT

2 MATLAB-SIMULINK MODEL

The model of the TF circuit was created for Basic configuration. Results provided by this model were used for Option configuration. The basic model is shown on Figure 1. Model of the offered flywheel generator is shown on Figure 2.

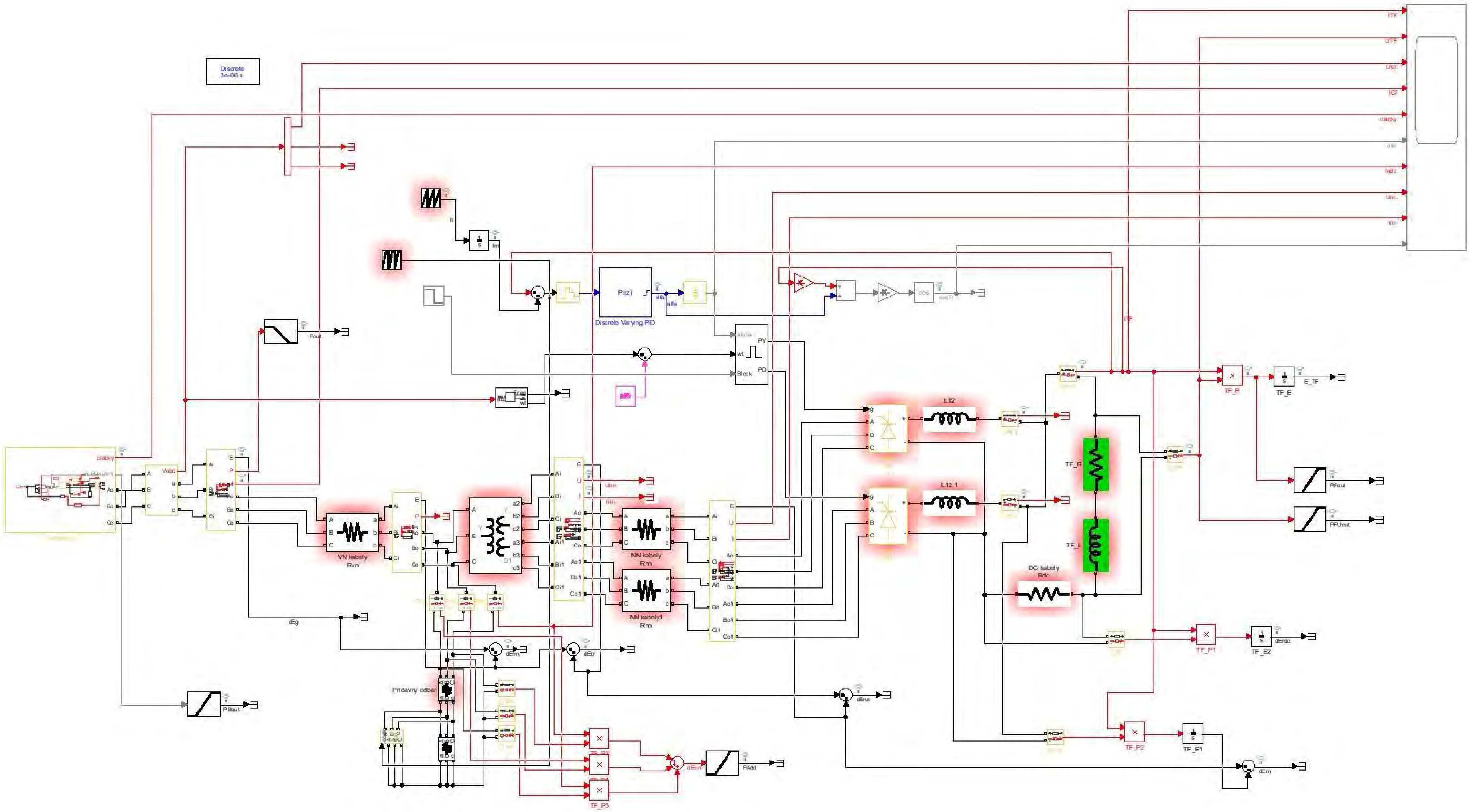

Figure 1. Basic Matlab-Simulink model of the TF circuit.

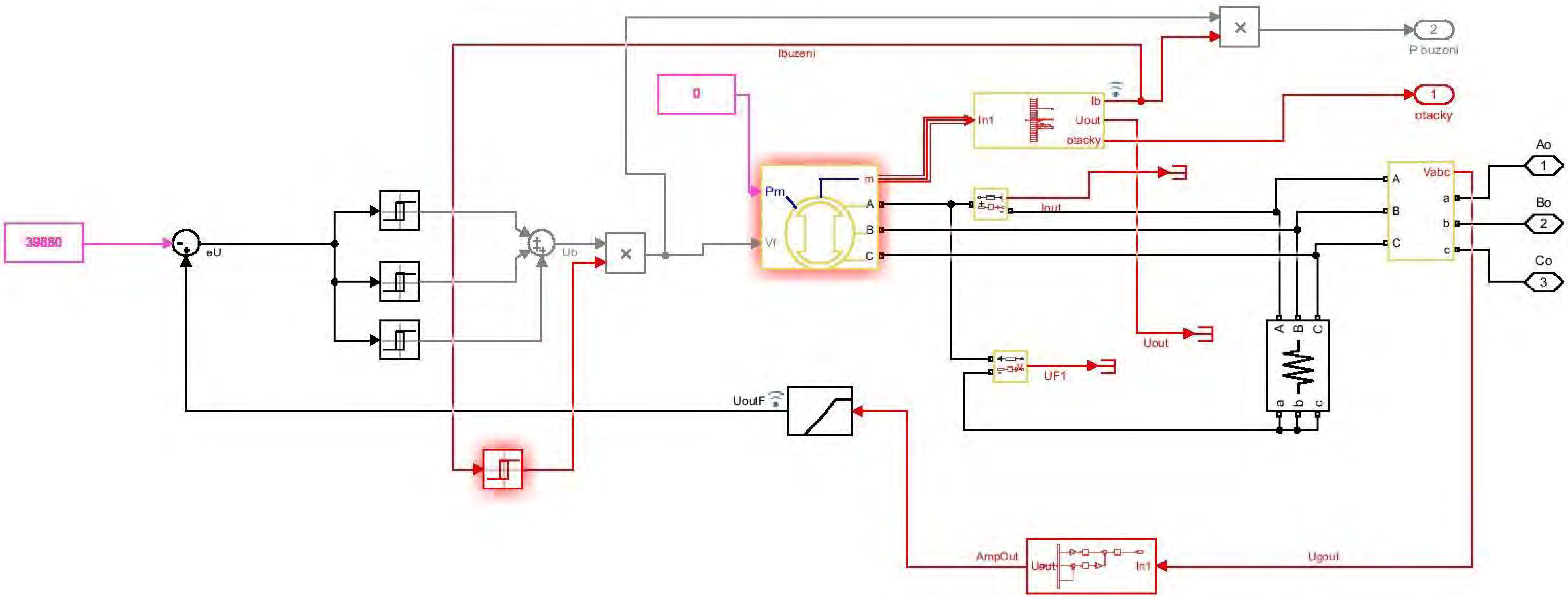

Figure 2. Model of the offered flywheel generator.

3 RESULTS OF THE SIMULATION

The results of the simulation are shown on following figures.

Flat-top border are indicated by orange dashed lines in the figures. The duration of the TF current flat-top is selected in such:

- TF coil current reaches requested value,
- flywheel generator/s reach minimal operational rotation speed.

The human readable data are stored in file “PE03127 - Technical specification, Annex 13A - Matlab-Simulink TF model results.xlsx”.

3.1. TF coil – current waveform

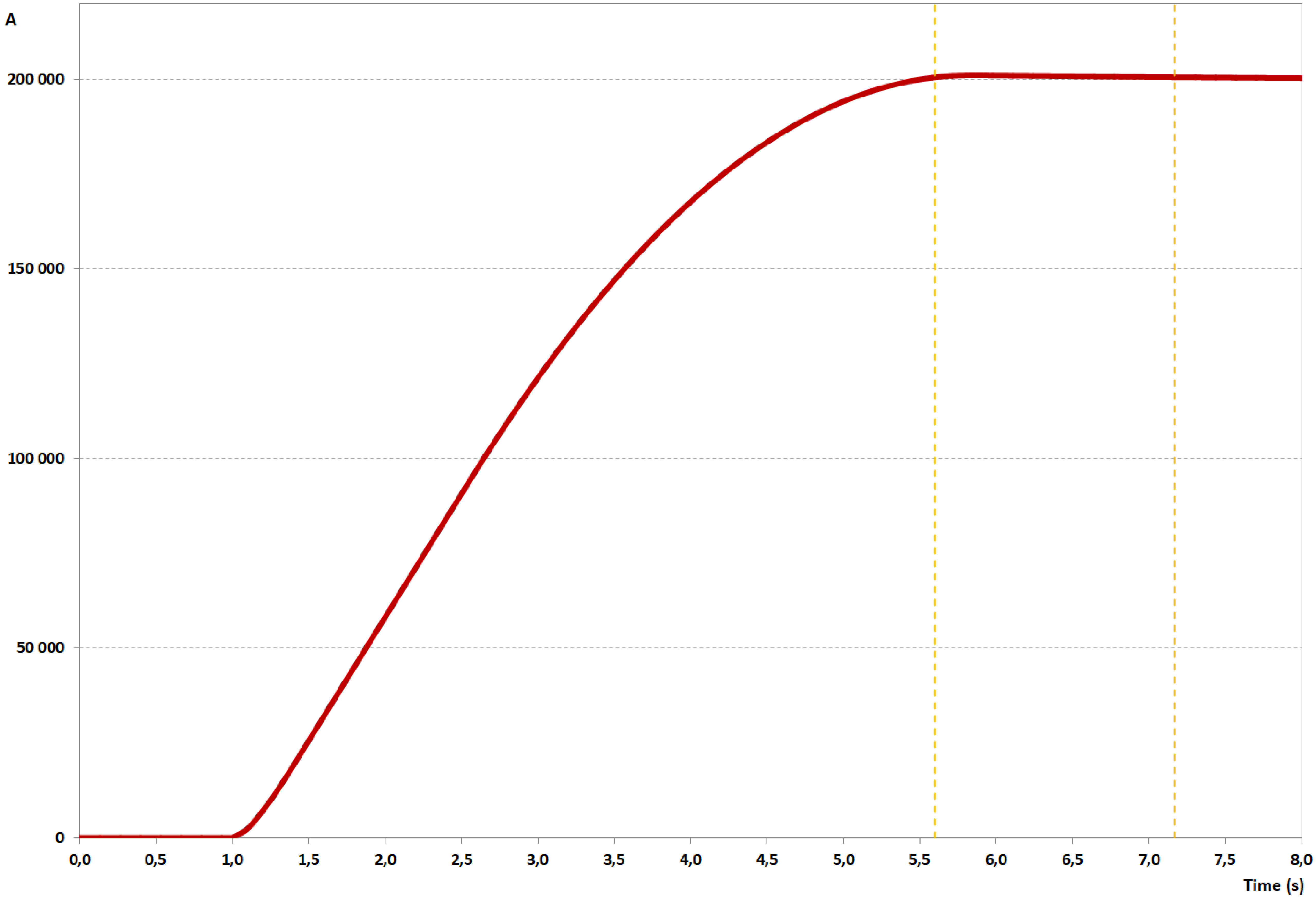

Figure 3. TF coil current.

3.2. TF coil – voltage waveform

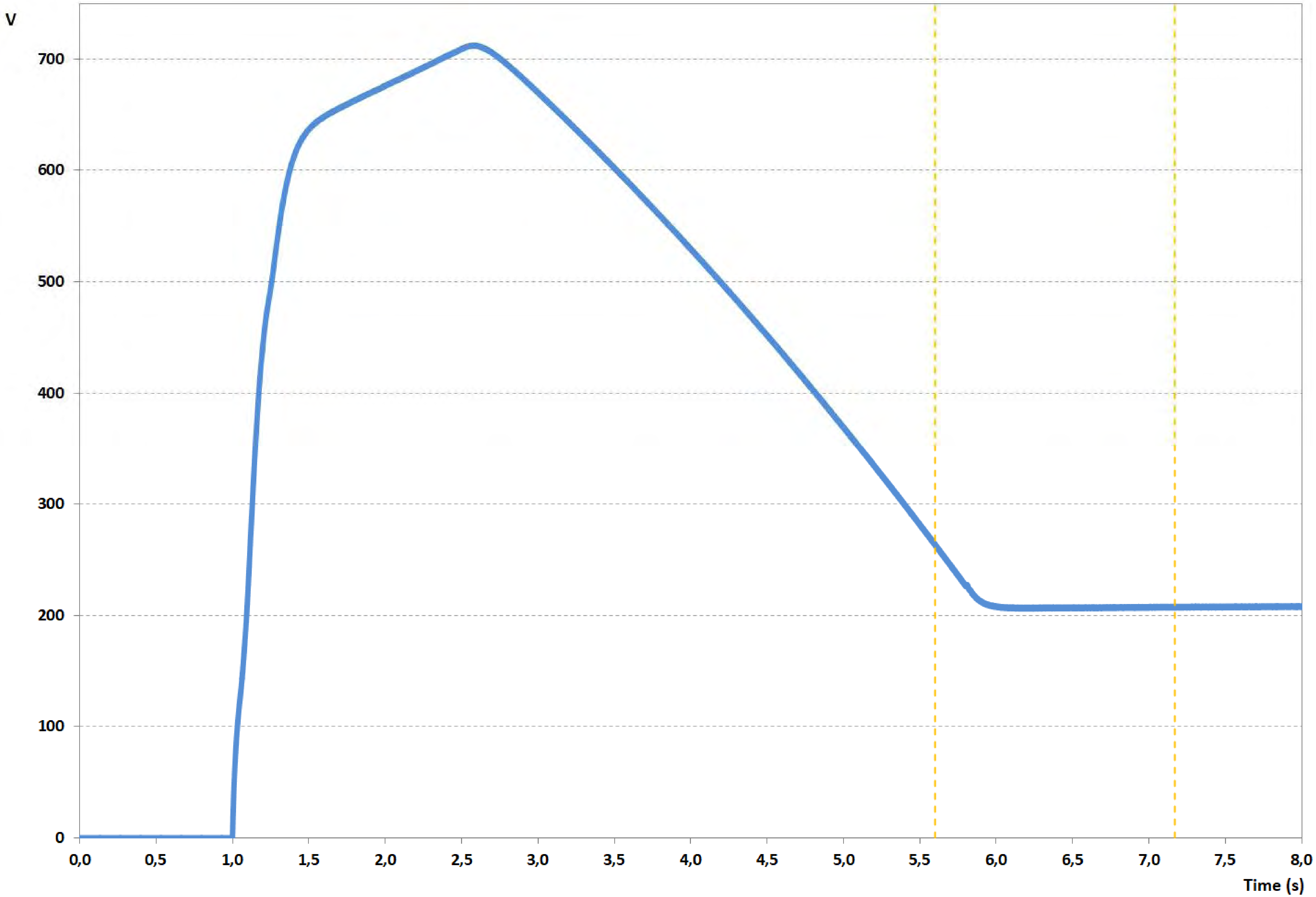

Figure 4. TF coil voltage.

3.3. TF PS power factor (cosφ)

Figure 5. TF PS power factor.

3.4. Auxiliary heating power

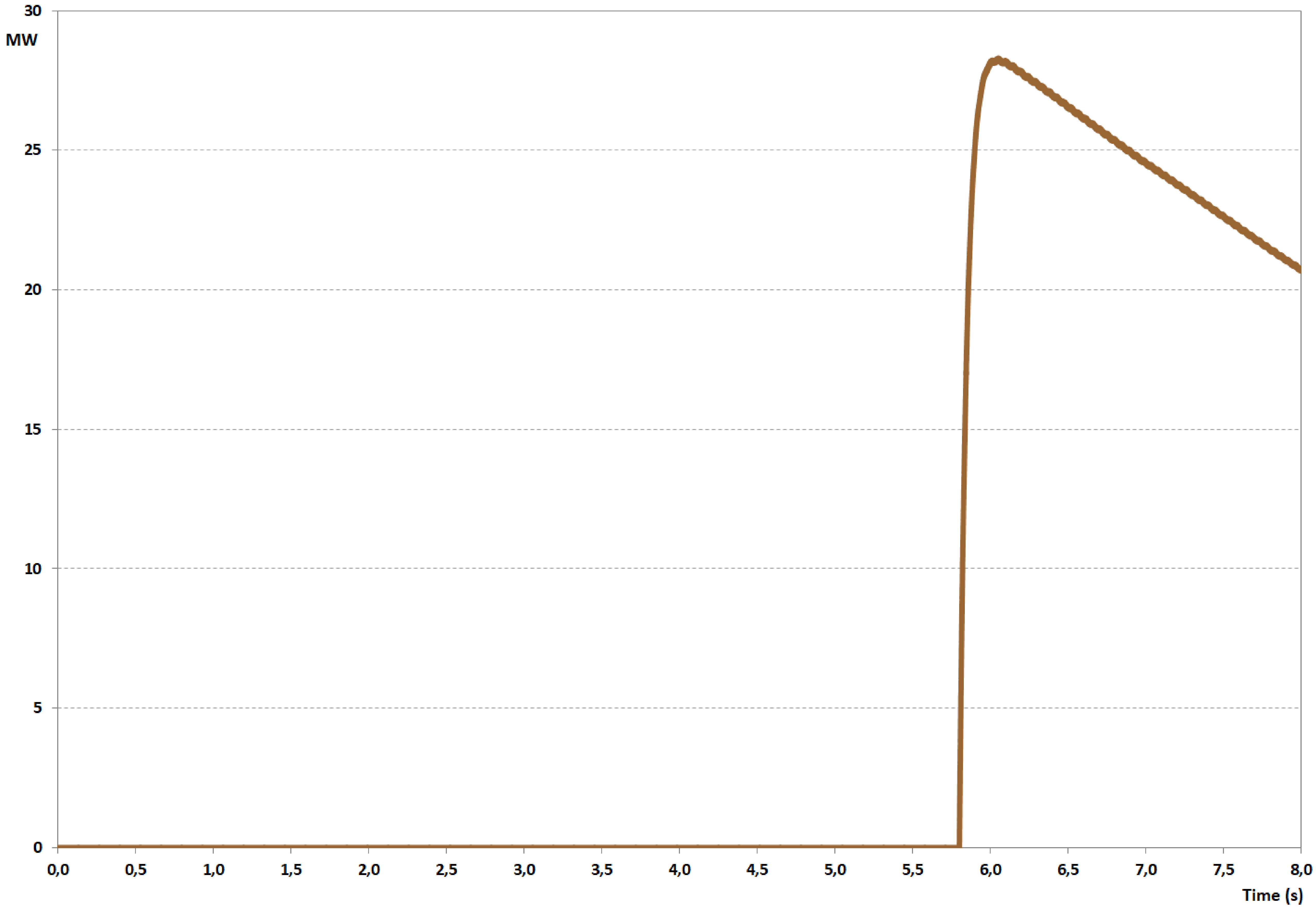

Figure 6. Auxiliary heating power.

3.5. New flywheel generator – output line-to-line voltage

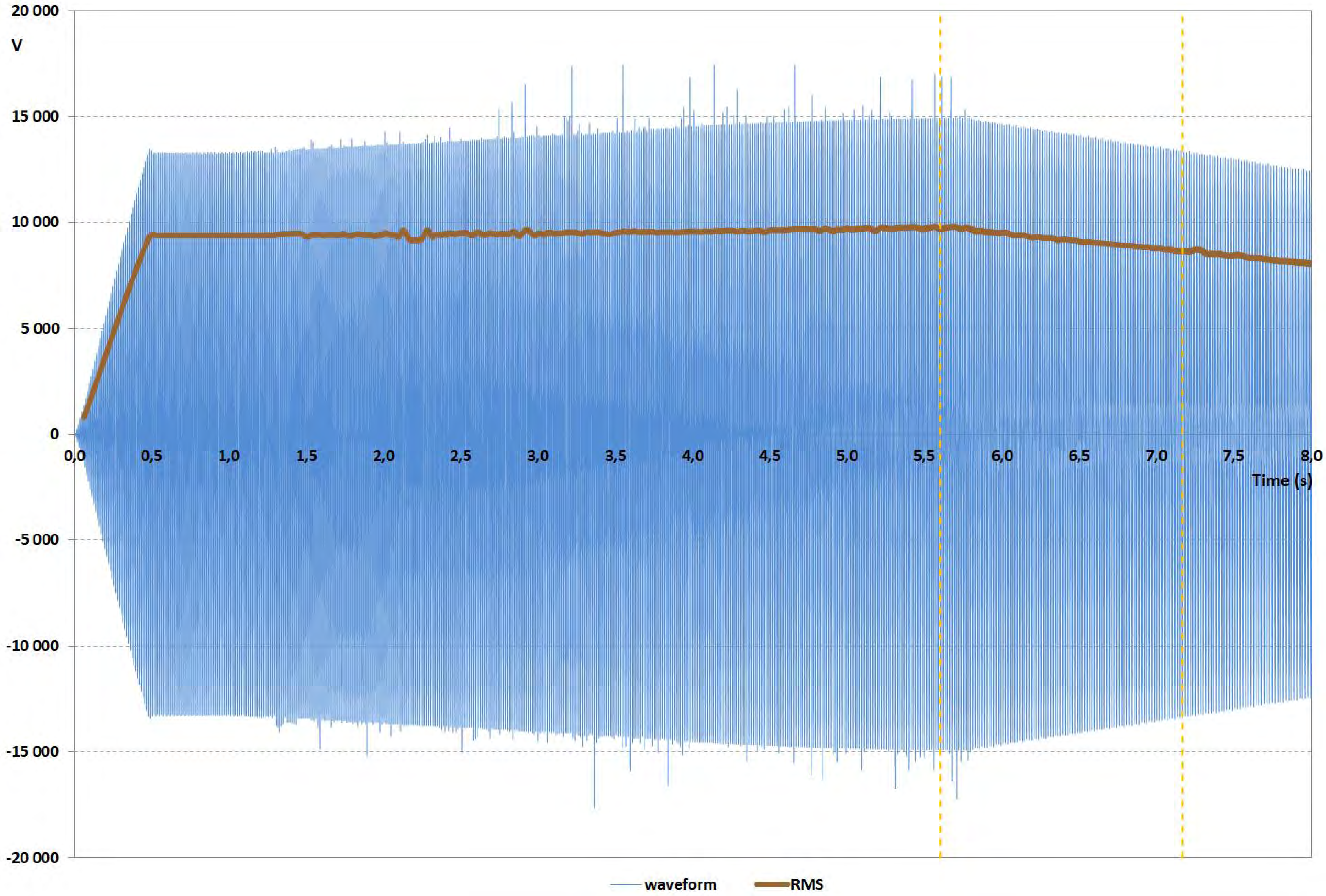

Figure 7. New flywheel generator – output line-to-line voltage.

3.6. New flywheel generator – output current

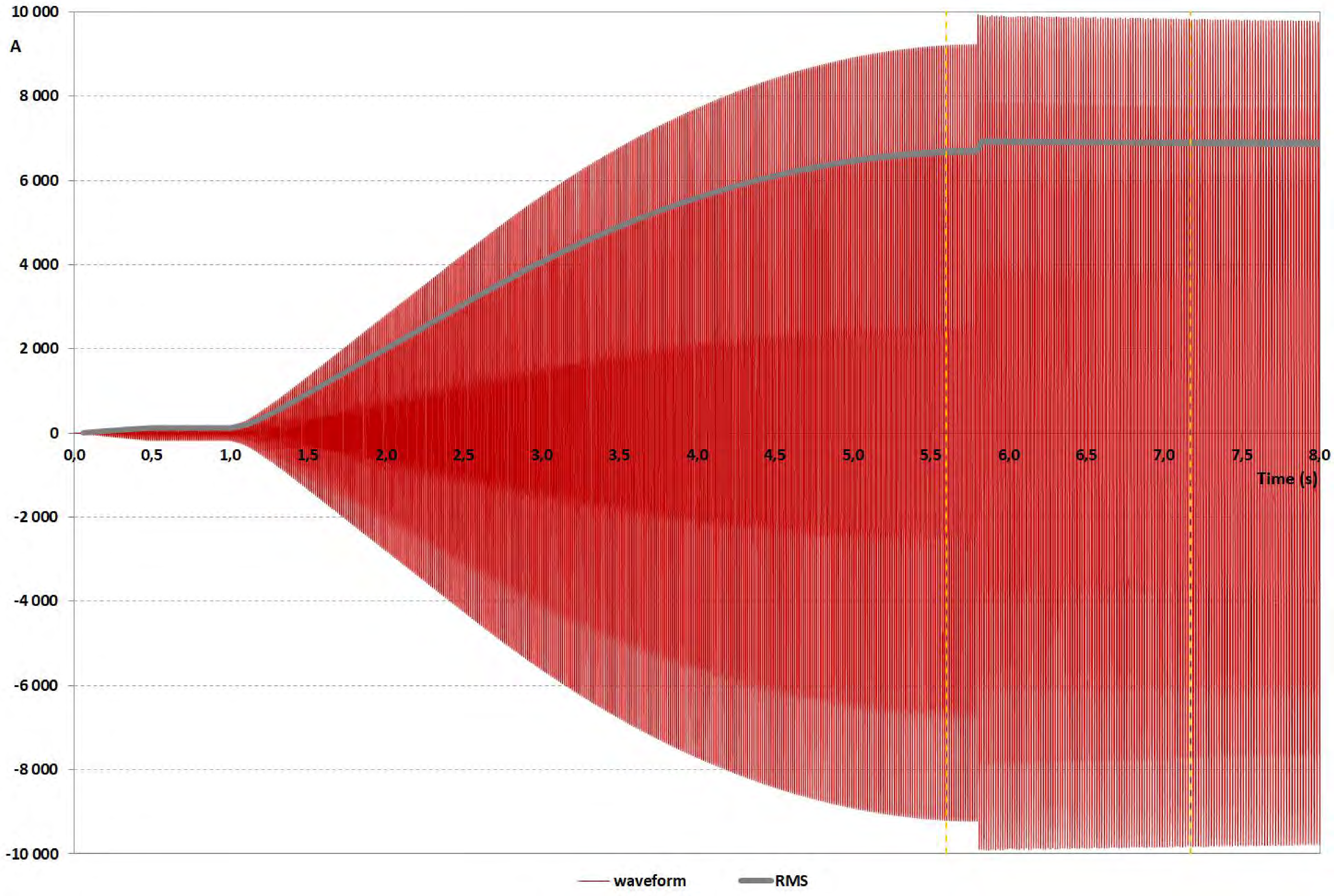

Figure 8. New flywheel generator – output current.

Detail zprávy Re: Clarification Request No. 2

Zpráva

Odesílatel	[redacted] (D0010231 - ELEKTROTECHNIKA, a.s.)
Předmět	Re: Clarification Request No. 2

Project: Power Supply System for COMPASS-U Tokamak – Round 2
Subject: Answers for Clarification No.2 request
Public Contract: Z2019-036594 - pursuant to Sec. 46 (1) of Act No. 134/2016 Coll., the Public Procurement Act (the ”PPA”)
ET ref. No.: PE03127A

To whom it may concern,

Based on your Clarification Request No. 2, please be learnt about following answers, as follows:

1/
The Contractor (company ELEKTROTECHNIKA, a.s.) herewith can confirm, that we are going to solve a described problem in accordance with the recommendation, i.e. usage of transformers TFTR of changed ratio from 9.4/0.77 kV to 9.4/ca 0.60 kV.

2/
The Contractor (company ELEKTROTECHNIKA, a.s.) can herewith furthermore state: such change of transformers TFTR usage will not affect negatively the total Bid price, i.e. no price increase will occur.

Yours Sincerely

[redacted]

[redacted]

[redacted]

http://www.elektrotechnika.cz

Dne 29.11.2019 10:34:47 odesílatel Mgr. Jan Dudák (Z0000464 - Ústav fyziky plazmatu AV ČR, v. v. i.) napsal:

Dear Supplier,

please find attached a Clarification Request concerning the Technical Specification in your Bid for the tender "Power Supply System for COMPASS-U Tokamak – Round 2".

Kind regards,

HOLEC, ZUSKA & PARTNEŘI advokátní s.r.o.

[redacted]

On behalf of:

Ústav fyziky plazmatu AV ČR, v. v. i.

Doplňující údaje

Odesláno	03.12.2019 15:59:02
Typ zprávy	Odpověď
Číslo jednací	
ID zprávy	914503
Zakázka	VZ0079165 - Power Supply System for COMPASS-U Tokamak - Round 2

Detail zprávy Re: Clarification Request No. 3

Zpráva

Odesílatel	[redacted] (D0010231 - ELEKTROTECHNIKA, a.s.)
Předmět	Re: Clarification Request No. 3

Project: Power Supply System for COMPASS-U Tokamak – Round 2
Subject: Answers for Clarification No.3 request
Public Contract: Z2019-036594
ET ref. No.: PE03127A

To whom it may concern,

With regards to your submitted request for Clarification No. 3 please, be learnt about clearance of the internal conflict regarding the fulfilment of the technical specification, i.e. Transformer requirements requirement meet, as follows:

Having studied mentioned technical issue in detail, we can herewith state that:

1/ We are going to solve the problem by the increase of the nominal (pulsed) rating of the transformers and increase the impedance (e.g. from 16% up to 18%). In such execution the same transformer can be used.

2/ Herewith we can confirm that such change of transformers` ratings will not affect negatively the total Bid price, i.e. no price increase or change will occur.

3/ Furthermore we can herewith state that such transformers` ratio change will not have an influence to the other values as mentioned in the submitted Evaluation Criteria chart (Annex No.5).

In case of your further inquiries and/or clarifications` requests, please contact us.

Yours Sincerely

[redacted]

[redacted]

[redacted]

Dne 05.12.2019 13:50:09 odesílatel Mgr. Jan Dudák (Z0000464 - Ústav fyziky plazmatu AV ČR, v. v. i.) napsal:

Dear Supplier,

we are sending to you Clarification Request No. 3 (see attached). It concerns the Technical Specification submitted in your Bid for the tender "Power Supply System for COMPASS-U Tokamak – Round 2".

Kind regards,

HOLEC, ZUSKA & PARTNEŘI advokátní s.r.o.
[redacted]

On behalf of:
Ústav fyziky plazmatu AV ČR, v. v. i.

Doplňující údaje

Odesláno	06.12.2019 08:46:49
Typ zprávy	Odpověď
Číslo jednací	
ID zprávy	918487
Zakázka	VZ0079165 - Power Supply System for COMPASS-U Tokamak - Round 2

Template List of qualified persons - Annex No. 7 to the Tender Documentation
To be attached as Annex No. 3 to the Contract for Work

List of qualified persons

The Supplier ELEKTROTECHNIKA, a.s. hereby declares that the following persons will be involved in the performance of the Public Contract:

	Identification data (Name and Surname)	Function and assumed role within the performance of the Public Contract	Professional qualifications or experience in services similar to the Public Contract's subject
1.	[redacted]	Project leader	5 years of experience in a field of heavy-current electronics; 1 participation on a project in a field of heavy-current electronics as project leader
2.	[redacted]	Chief designer of accumulation source	5 years of experience in a field of generators; 1 participation on a project in a field of design of generator as chief designer
3.	[redacted]	Chief designer of heavy-current electronics	5 years of experience in a field of heavy-current electronics; Participated on a project in a field of heavy-current electronics as chief designer – COMPASS Tokamak
4.	[redacted]	Technician with responsibility for testing the accumulation source	5 years of experience in testing of asynchronous generators; 1 participation on a project in testing of asynchronous generators as a technician with responsibility for testing the accumulation source;
5.	[redacted]	Technician with responsibility for testing heavy-current electronics	5 years of experience in testing heavy-current electronics; 1 participation on a project in the testing of heavy-current electronics as a technician with responsibility for testing heavy-current electronics
6.	[redacted]	Quality control technician	5 years of experience in a field of quality control; Participation on a project as a quality control technician COMPASS Tokamak

[redacted]

Annex 4: Documentation

Contractor’s Implementing Documentation (hereinafter the "CID")

1. The Contractor undertakes to prepare full-scale, complete and executable CID (including all implementing projects for the technology part of the Work, workshop documentation etc.) within deadlines and under the terms defined in the Contract. The Contractor shall be responsible for the correctness and completeness of all parts of the CID.

2. The Contractor shall comply with the following obligations when preparing, submitting and seeking approval for the CID:

   a) Comply with requirements and terms defined in the Technical Specification. The Contractor shall be authorized to deviate from Technical Specification only with a prior consent in writing from the Client;

   b) Organize regular (at least once a month) project inspection days (hereinafter the "PID") during CID preparation process, and to invite the Client to these PIDs. In order to organize a PID, the Contractor shall be obliged to prepare all necessary documentation in writing and to submit these documents to the Client at least two (2) days prior to planned PID date, unless the Parties agree otherwise. In case the Client request the Contractor, the Contractor shall be obliged to organize extraordinary inspection days, within deadlines specified by the Client. PIDs shall take place in the offices of the Client unless the Parties agree otherwise.

3. Completed partial CID segments shall be submitted by the Contractor to the Client for inspection for sections allowing verification of functional contingencies in four (4) copies in hardcopy and in electronic format in two (2) copies on CD/DVD. The submitted partial CIDs shall be handed over in electronic format in *.pdf files as well as in open formats such as *.dwg or *.dxf, and any text in the *.doc, *.xls or *.txt formats.

4. The Client reserves the right to demand modifications or alternative technical solutions for the Work within the framework of partial CIDs submissions by the Contractor.

5. The complete draft CID shall be submitted by the Contractor to the Client for review no later than within 5 months from the signature of the Contract in four (4) copies in hardcopy and in electronic format in two (2) copies on CD/DVD. The submitted partial CIDs shall be handed over in electronic format in *.pdf files as well as in open formats such as *.dwg or *.dxf, and any text in the *.doc, *.xls or *.txt formats. The Client shall inform the Contractor, within ten (10) business days from the receipt of CID, whether he considers CID as falling into one of the three following categories:

   a) "A": There are no comments to CID and it is eligible for the execution of the Work, or

   b) "B": CID lacks certain essentials but on the whole, with certain reservations or limitations, it is eligible for the execution of the Work, or

   c) "C": CID is to be returned to the Contractor for readjustment. Such documentation cannot be used by the Contractor for execution of the Work in any extent.

   Any CID passing the Client’s review may be considered only documentation receiving an "A" category verdict. Once the review will have been passed, the CID becomes the basis for the execution of the Work hereunder and binding upon the Contractor.

Should documentation be classified as a "B" or "C", the Contractor shall be obliged to rectify any shortcoming therein within ten (10) business days and submit it again to the Client for review. This process shall be repeated until the Client considers it an "A" provided that the Client does not exercise its right to withdraw from the Contract prior. Any reviews of the CID undertaken by the Client does not in any way substitute vendor inspection on the part of the Contractor itself, and shall not release the Contractor from his full liability for the correctness, completeness and complete execution of the Work.

6. CID shall meet all requirements defined in generally applicable legislation and the relevant Czech Technical Standards.
7. The procedure for submission and approval of CID defined above, including deadlines, terms and conditions, shall apply mutatis mutandis to submission and approval of Quality Plan specified under Article XIII Paragraph 5 of the Contract.
8. The Client reserves the right to request PID even if the CID documentation received an "A" category verdict, at any time during the execution of the Work until its final handover and acceptance; the extent of activities and obligations of the Contractor during these PID and their time interval (schedule) shall be specified by the Client and does not need to be subject to amendments hereof.
9. The Client reserves the right to request cooperation from the Contractor, i.e. in providing necessary information and technical documentation that may be necessary for preparation of simultaneously running projects or public tender. Specifically, this concerns construction / project activities and work related to the preparation of the site for installations stemming from the Work.
10. The Client will require that the Contractor submits, within three (3) months from the signature of the Contract, the exact specification of construction preparedness for installations of generators, as well as specifications for construction requirements concerning planned future electro-installations stemming from the Work for the purposes of preparing documentation for construction work.

As-built Documentation (hereinafter the "ABD")

1. The Contractor shall prepare and submit to the Client for approval, no later than within thirty (30) days prior to the planned signature of the Final Acceptance Protocol, four (4) copies of the complete ABD that documents the Contractor’s work in executing the Work in detail. ABD shall be also handed over in electronic format, in two (2) copies on CD/DVD in *.pdf files as well as in open formats such as *.dwg or *.dxf, and any text in the *.doc, *.xls or *.txt formats. ABD shall clearly specify all approved and executed modifications. ABD shall comply with the actual state of the Work as of the date of the Final Acceptance Protocol.
2. Any partial ABDs shall be submitted by the Contractor to the Client on continuous basis, once each phase of assembly of the Work will have been completed; partial ABDs shall be submitted in two (2) copies in hardcopy and simultaneously in electronic format in one (1) copy on CD/DVD in *.pdf files as well as in open formats such as *.dwg or *.dxf, and any text in the *.doc, *.xls or *.txt formats. Should the Client fail to inform the Contractor within ten (10) business days from receipt of any partial ABD whether it is considered approved or not, it shall be considered approved by the Client. The Contractor shall be obliged to address any potential comments of the Client within a

deadline specified by the Client. All partial ABDs shall clearly specify and delineate all approved and executed modifications (clear specification/delineation shall be understood as clear delineation of all modified information – for example at the report's title page, in the drawings stamp etc. – and inside of each individual information simultaneously, delineating each executed modification in comparison to CID).

3. The Contractor shall be obliged to update the ABD as of the date of signature of the Final Acceptance Protocol, and submit this updated ABD to the Client in the extent and under the terms defined in the Contract.

4. ABD shall meet all requirements defined in generally applicable legislation and the relevant Czech Technical Standards.

5. The Contractor shall be obliged to provide the Client with complete production documentation for new flywheel generator and its auxiliary systems as part of ABD for the purpose of its service, maintenance and production of spare parts that may be necessary.

Accompanying Documentation (hereinafter the "AD")

1. AD shall describe in detail primarily all operating and maintenance instructions for the Work and its technical equipment including maintenance plans of the Work. AD shall be prepared on the level, that the Client's employees shall be able to individually operate the Work in its entirety and individually perform its management and maintenance.

2. The Contractor shall submit to the Client for approval, no later than within sixty (60) days prior to the planned signature of the Final Acceptance Protocol, the complete AD, in four (4) copies in hardcopy and in two (2) copies in electronic format on CD/DVD in *.pdf files as well as in open formats such as *.dwg or *.dxf, and any text in the *.doc, *.xls or *.txt formats.

3. Any partial ADs shall be submitted by the Contractor to the Client for approval, always when a specific part of the Work will have been completed, in two (2) copies in hardcopy and in one (1) electronic copy on CD/DVD in *.pdf files as well as in open formats such as *.dwg or *.dxf, and any text in the *.doc, *.xls or *.txt formats. Should the Client fail to inform the Contractor within twenty (20) business days from receipt whether he approves such partial AD or not, its shall be understood that that particular partial AD had been approved by the Client. The Contractor shall be obliged to address any potential comments of the Client within a deadline specified by the Client.

4. Within the framework of AD concerning maintenance, the Contractor shall define, while preparing CID, a list of components requiring regular maintenance as well as schedule for such maintenance and financial requirements thereof, and schedule for maintenance of individual components. The Contractor shall also specify recommended product range and volume of any spare parts that may be necessary for the operation of the Work; these spare parts shall be considered to form a part of the Work hereunder and the Contractor shall be obliged, within the Price defined in the Contract, to provide such spare parts in agreed volume and under the terms specified in the Contract. Additional requirements for spare parts and maintenance of the Work are defined in detail in the Technical Specification.

5. AD shall also include operating documentation (i.e. primarily a draft of operating rules and regulations for all technology, safety manuals including risk analysis, calibration protocols, service instructions, operation manuals, manuals for repairs and maintenance of the System).
6. AD shall meet all requirements defined in generally applicable legislation and the relevant Czech Technical Standards.
7. The Contractor shall submit to the Client the complete AD, primarily all manuals for repairs and maintenance of the System, in Czech or English version.
8. Along with the AD, the Contractor shall be obliged to submit to the Client any keys and other instruments / accessories that are necessary to operate the Work, especially its technological parts.

Additional documentation

1. In order to avoid any doubt, the Parties declare that the Contractor shall be obliged to provide, within the framework of executing the Work hereunder, in addition to CID, ABD and AD defined above, additional documentation foreseen herein, including but not limited to:
   a) Documentation of the quality of the Work, including the Quality Plan (containing validation and verification plans etc. – in detail please refer to the Technical Specification),
   b) Documentation of all required tests (in detail please refer to the Technical Specification),
   c) Calibration protocols for the relevant parts of the Work (in detail please refer to the Technical Specification),
   d) Protocols concerning preparedness for assembly and assembly completion protocols,
   e) Protocols concerning complex tests and Final Acceptance of the Work
   f) All initial revision reports (inspection records), necessary permits, certificates, accreditation protocols,
   g) Copies of all warranty certificates.
2. In order to avoid any doubt, the Parties declare that the Contractor acknowledges that the list of documentation provided herein cannot be considered the complete list, and that the Contractor shall be obliged, in order to execute the Work properly and completely, to provide any and all documentation specified herein directly or indirectly, as well as any documentation which may not be defined directly or indirectly herein, but whose preparation may be assumed or stipulated in any generally applicable legislation or in the Czech Technical Standards and that this documentation will be prepared and provided without any effect on the Price.
3. All reports and protocols shall be clearly structured and prepared in sufficient detail, so that any professional in this particular field is able to evaluate correctness of the actions taken by the Contractor when executing the respective part of the Work. The Client shall not be obliged to verify correctness of any results, reports, outcomes, certificates, protocols etc. or details pertaining to technical solutions during the handover procedure.
4. Any approval of any documentation or information or any parts thereof by the Client shall not in any way release the Contractor from his full liability for the correctness, completeness and complete execution of any documentation of information.
5. Any submitted documentation or its part specified hereof may be amended or modified exclusively in the written form signed by the authorized representatives of the Parties. The proposal of such

modification or new version of documentation of one Party shall clearly specify all implemented changes (if applicable using function of track changes or by highlighting of all modified information for example on the cover page of an information, in a drawing or in its stamp, etc. alongside with specification of all changes in such information) in order to be able to compare it with the original documentation. Any approval or refusal of the proposed change by other Party shall be executed in the same form as its proposal.

The Basic Configuration

The mandatory terms and conditions of the tender									Price offered by contractor
Category	Phase of delivery	Part. Performance	Delivered parts/Completed tasks	Delivery period for the item after contract signature [months]	Percentage cost value of item from the total cost of the Power Supply System for COMPASS-U tokamak - The Basic Configuration [%]	Maximum allowed advance payment (percentage of price for the item) [%]	Date of the advance payment	Price cap	Offered price excluding VAT [CZK]
Production	1st phase of delivery	a	Contractor's Implementing Documentation	6	8	40	after signing the contract	The total price offered by the Contractor for the Basic Configuration is capped at CZK 225 million excl. VAT as maximum.	18 000 000,00
		b	First new flywheel generator	18	24	40	after signing the contract		54 000 000,00
		c	High voltage switchgear	12	4,5	40	after signing the contract		10 125 000,00
		d	Low voltage switchgear	12	2	40	after signing the contract		4 500 000,00
		e	Transformers for TF coils	12	4,5	40	after signing the contract		10 125 000,00
		f	Transformers for PF coils	12	3	40	after signing the contract		6 750 000,00
		g	Prototype of Power Supplies for PF coils (IGBT transistor based), including the successful tests specified in the Technical Specification (Article 5.10 Acceptance tests requirements / Tests 8 - 12)	14	1,5	40	after signing the contract		3 375 000,00
		h	PF coils capacitor bank	14	2,5	40	after signing the contract		5 625 000,00
		i	Power Supplies for PF coils (IGBT transistor based)	24	23	40	20 % after signing the contract, 20 % after delivery of prototypes of power supplies for PF coils		51 750 000,00
		j	Power Supplies for TF coils (Thyristor based)	24	3,5	40	after signing the contract		7 875 000,00
		k	Auxiliary systems (cables, chokes, protections, filters, lubrication unit, etc.)	24	3,5	40	after signing the contract		7 875 000,00
Delivery and Commissioning	2nd phase of delivery	l	Control system, SW	24	1	70	after 1st milestone is met (assumed 18 months after the date of contract signing)		2 250 000,00
		m	Final assembly	The delivery period is governed by Article VI. paragraph 4 of the Contract for Work.	14	70	20 % after 1st milestone is met (assumed 18 months after the date of contract signing), 50 % after installation starts		31 500 000,00
		n	Commissioning and acceptance tests	The delivery period is governed by Article VI. paragraph 4 of the Contract for Work.	5	70	after delivery of all components of 1st phase of delivery		11 250 000,00
					Total Offered Price of The Basic Configuration excluding VAT [CZK] (The total price offered by the Contractor for the Basic Configuration is capped at CZK 225 million excl. VAT as maximum.)				225 000 000,00

This cell is completed by the contractor

The Extended Options

The mandatory terms and conditions of the tender									Price offered by contractor
Category	Phase of delivery	Option number	Delivered parts/Completed tasks	Delivery period for the item (in months after Client's call for the option) [months]	Deadline for the Client´s call (in months after contract signature) [months]	Maximum allowed advance payment (percentage of price for the item) [%]	Date of the advance payment	Price cap	Offered price excluding VAT [CZK]
Production, Delivery and Commissioning	3rd phase of delivery	1	Second new flywheel generator and its auxiliary systems	24	36	30	after Clien's call for the option	The price for the option is capped at 58 million CZK excl.VAT as maximum.	58 000 000,00
		2	Increase of the capacitor bank(s) energy by +0.5 MJ	12	36	30	after Clien's call for the option	The price for the option is capped at 6 million CZK excl.VAT as maximum.	6 000 000,00
Tests		3	Short circuit test at full nominal pulsed voltage of a selected transformer	6	24	No advance payment	None	The price for the option is capped at 1 million CZK excl.VAT as maximum.	1 000 000,00

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