

15 Pulsed and Steady-State Power Supplies

15.1 Functions, Basic Configuration and System Boundaries

15.1.1 Basic Configuration

The pulsed and steady-state power supplies (P&SS PS) consist of the following four major systems:

- pulsed power distribution system (PPDS);
- coil power supplies (CPS);
- heating and current drive (H&CD) power supplies (H&CD PS);
- steady-state electric power network (SSEPN).

The PPDS will supply AC power to the CPS and H&CD PS, while the SSEPN will provide AC power to different loads (mainly motors) within the plant systems, such as water-cooling system, cryoplant etc. The CPS and H&CD PS will supply their loads, magnet coils and H&CD systems respectively, with DC (with a few exceptions) power.

15.1.2 Basic Functions

The main general functions of these systems are:

- to supply the ITER machine and ITER plant systems with electric power;
- to protect them in case of electric faults;
- to provide proper grounding of the machine and power supply components.

More detailed description of these functions is given in the DRG1, section 2.12.

A specific function of the PPDS is to match the ITER pulsed loads with the HV grid capability.

15.1.3 System Boundaries

The system boundaries have been outlined as follows.

a) On the side of AC power sources:

- in the PPDS and SSEPN the interfaces with the site high voltage (HV) grid occur at the inputs of the corresponding circuit breakers, associated with disconnectors, which are connected to the primary winding of the corresponding main step-down transformers;
- in the CPS and H&CD PS, which receive AC power from the PPDS, this interface occurs at the end terminations of the cables connected to the 72 kV and 24 kV AC distribution busbars.

b) On the load side:

- in the CPS the interface with the coils occurs at the connection of the normal busbars to the coil terminal boxes located outside the cryostat;
- in the H&CD PS the interface with the radio frequency (RF) generators occurs at the output of the DC disconnectors isolating the generators from the power supplies. The interface with the NB H&CD occurs at the flange connecting the HV transmission

line and the HV bushing.

- in the SSEPN the interface location for the medium (11 kV and 3.3 kV) voltage loads occurs at the place of the power supply cable connections to the load (electrical motors) input terminals. For the components supplied with the low voltage the interface occurs at the output of the low voltage distribution boards which include the circuit breakers for protection.

15.2 Specific System-Internal Requirements

15.2.1 Electrical

Since the P&SS PS is an essentially a service system, the majority of the electrical (functional) requirements represent its interfaces with the other ITER plant systems - consumers of electric power. Therefore, these requirements are given in the DRG1 (sections 1.8, 10, 1.17 and 1.27). The additional requirements not included in the DRG1 are described below.

15.2.1.1 Limitations related to HV Grid Capability

The ITER plant shall be connected to a powerful HV grid capable of producing the large pulsed power needed to feed the superconducting coils and the H&CD systems. The HV grid is assumed to provide large active (positive or negative transfers from the grid) and reactive power, as well as fast power variations and occasional power steps (see below).

The HV grid shall also provide, through separate transmission lines, the steady-state power for the various ITER plant systems. The major consumers of the steady-state power are the cooling water and cryoplat and cryodistribution systems, which together require about 80% of the total amount of power.

Pulsed power

The power demand due to the combined loads of the magnet and H&CD systems in normal operating conditions shall remain within the limits of the reference HV grid. These limits are defined by the "Site Requirements and Assumptions" in the ITER document ¹, as follows:

- | | |
|---------------------------|-------------|
| • Peak active power *,** | 500 MW |
| • Peak reactive power | 400 Mvar |
| • Active power derivative | 200 MW/s |
| • Active power step ** | 60 MW |
| • Fault level | 10 - 25 GVA |

Notes:

- * From which up to 400 MW is a quasi-steady-state load during the sustained burn phase, while the remaining 100 MW has essentially pulse character for plasma shape control with a maximum pulse duration of 5 – 10 s and an energy content in the range of 250 – 500 MJ.
- ** These power parameters are to be considered both positive and negative. Positive

¹ " Plant Design Specification", section I.1.4

refers to power from the grid, while negative refers to power to the grid. Power variations will remain within the limits given above for the maximum power and for the power derivatives.

The acceptable voltage distortion due to the operation of thyristor converters should be less than 1% and 0.5% for the total and single harmonic content respectively. The minimum fault power level of 10 GVA shall be used to determine the voltage drop/distortion performance. The maximum fault power level to be used to determine the short-circuit withstand capability of the CPS and H&CD PS is assumed to be 35 GVA.

The design of the CPS and H&CD PS shall accommodate the possible variation of the grid voltage in the range of 0.9 - 1.05 of nominal voltage.

Steady-state power

The ITER site shall have the capability of providing up to 120 MW active power required by the plant loads (see Table 1.27-4 in the DRG1). The PPDS shall receive this power through two independent transmission lines.

The system capacity shall include margins for uncertainty and growth; reasonable space and cable routing for future extension should be foreseen.

Reactive power compensation shall be added to increase the power factor to 0.95.

15.2.1.2 Grounding and Insulation

The grounding system shall ensure personnel safety and preserve the functional performance of all powered equipment. Equipment grounding shall be in conformance with local standards at the site of the ITER construction and with the relevant IEC recommendations.

Each individual power supply system shall be connected to ground at one point only: the "machine ground". In the PPDS soft grounding via high resistance will be provided for all the coils. The grounding scheme shall be designed so as to balance the voltage to ground at each coil terminal to one half of the voltage across the coil, under nominal conditions. In the H&CD PS, connection to ground will take place at the load end.

In order to permit safe access to the ITER machine and electrical equipment, power supply systems disconnectors and grounding switches shall be provided:

- in the magnet coil circuits to isolate and ground the coil circuits;
- at the primary windings of each rectifier transformer and DC output of each thyristor rectifier;
- at the incoming AC feeders of reactive power compensation and harmonic filtering (RPC&HF) system capacitors;
- in the AC input and DC output of each H&CD PS unit.

Components shall be insulated in accordance with the relevant IEC recommendations. For DC components with operating voltage of 14 kV and less, the nominal insulation voltage must not be less than 17.5 kV AC.

15.2.5 Seismic

The P&SS PS components must be designed to meet the seismic design specifications adopted by the project (see below).

All components, which do not have safety functions, shall be designed to withstand SL-0 earthquakes with 0.05 g peak horizontal and vertical ground acceleration¹.

The seismic requirements for the subsystems or components with safety functions is given in the document ². Such components and their auxiliaries must be designed to withstand SL-2 earthquakes with 0.2 g peak horizontal and vertical ground acceleration. More detail on the seismic requirements is given in ³.

15.2.6 Instrumentation and Control (I & C)

The ITER CODAC system is structured in a hierarchy composed of the supervisory control system and individual dedicated plant control subsystems to ensure the integrated control of the whole ITER plant.

Each major component or subsystem of the PPDS, CPS, H&CD PS and SSEPN will be provided with its own local control cubicle (LCC). The main functions of the LCCs are:

- real time operation control and monitoring;
- emergency operation requests;
- personnel safety interlocks.

If more than one LCC is necessary for a component/subsystem, one will act as the LCC supervisor. Moreover, these LCCs, themselves, will operate under supervision of higher level LCCs related to the individual PS systems, e.g. TF coil PS, ICH&CD PS etc. Finally, the four, top-level (for local control), LCCs will deal with the four major systems: PPDS, CPS, H&CD PS and SSEPN.

All signals from and to the component in the field will be made available at the terminal boxes in the LCCs. The LCCs will have the necessary functional ability to operate the subsystems. PLCs are to be used for this purpose and to perform the interface to CODAC cubicles. The operation of the component "in local" will be organised according to "state machine" logic. Enough information, among that available to the LCCs, will be transferred to CODAC to allow the correct operation of the subsystems in "remote". A local to remote change-over switch will allow control of the subsystems to be transferred from its LCCs to CODAC. In addition, the LCCs must be able to receive, from CODAC, the appropriate signals for the integrated remote control.

I&C functions (such as interlocks for system protection and access control for personnel safety) shall be grouped in different categories and designed accordingly.

15.2.7 Testing

¹ " Plant Design Specification", sections I.1.3 and I.1.4

² " Plant Safety Requirements", annex to the DRG1

³ " Load Specification and Combination", annex to the DRG1

15.2.7.1 Factory Tests

Certain component and system tests will be accomplished at the manufacturer's site. These tests will include:

- the routine and type test in agreement with the appropriate IEC recommendations;
- special tests quoted in the technical specifications.

15.2.7.2 Site Tests

The following acceptance tests shall be performed at the ITER site after the installation:

- insulation tests (in agreement with the appropriate IEC recommendations);
- functional tests;
- tests of protection;
- tests on dummy loads (if applicable);
- integrated tests (if applicable).

The functional tests shall include:

- end to end tests of all signals (digital and analogue) from the transducers in the field to the terminal blocks in the LCCs and in the CODAC cubicles;
- operation of active components;
- operation of interlocks;
- injection of signals at the transducer level to simulate thresholds.

The integrated tests shall include operational tests performed under LCCs control, with dummy loads.

15.2.7.3 Dummy Loads

Dummy loads shall be provided to allow testing of components of the CPS and H&CD PS without the coils and the H&CD generators as a load.

15.2.8 **Operation and Maintenance**

The operation of the PPDS, CPS, H&CD PS and SSEPN systems requires a distributed computerised control and monitoring system under the supervision of CODAC.

Periodic maintenance cycles are required for AC and DC power equipment and busbars. A preventive maintenance program will be implemented to ensure that all equipment is maintained in accordance with the manufacturers' recommendations. This preventive maintenance system will be periodically updated to take an account of operational experience.

After maintenance the equipment will be tested according to agreed procedures, before operation starts again.

15.3 **Codes and Standards**

All components utilised in the P&SS PS shall be designed, manufactured and tested in compliance with the latest issues of the standards published by the International

electrotechnical commission (IEC). Some IEC standards relevant for the design of the components of these systems are given in Table 15.3-1.

Table 15.3-1 IEC Standards relevant for the PS system design

IEC	Tech. Comm.	Title
38	TC 8	IEC standard voltages
50	TC 1	International electrotechnical vocabulary
56	SC 17A	High-voltage alternating-current circuit-breakers
59	TC 8	IEC standard current ratings
60	TC 42	High-voltage test techniques
71	TC 28	Insulation co-ordination
76	TC 14	Power transformers
99	TC 37	Surge arresters
129	SC 17A	Alternating current disconnectors (isolators) and earthing switches
146	SC 22B	Semiconductor converters
168	SC 36C	Tests on indoor and outdoor post insulators of ceramic material or glass for systems with nominal voltage greater than 1000 V
183	SC 20A	Guide to the selection of HV cables
185	TC 38	Current transformers
186	TC 38	Voltage transformers
265	SC 17A	High-voltage switches
273	SC 36C	Characteristics of indoor and outdoor post insulators for systems with nominal voltages greater than 1,000 V
287	SC 20A	Calculation of the continuous current rating of cables
289	SC 14C	Reactors
300	TC 56	Reliability and maintainability management
331	SC 20C	Fire resisting characteristics of electrical cables
332	SC 20C	Test on electric cables under fire conditions
364	TC 64	Electrical installations in buildings
438	TC 36	Test and dimensions for high-voltage d.c. insulators
529	TC70	Degrees of protection provided by enclosures
617	TC 3	Graphical symbols for diagrams
728	SC 12G	Cable distribution systems
754	SC 20C	Tests on gases involved during combustion of electric cables
801	SC 65A	Electromagnetic compatibility for industrial-process measurement and control equipment
853	TC 20	Calculation of the cyclic and emergency current ratings of cables
871	TC 33	Shunt capacitors for a.c. power systems having a rated voltage above 660 V
919	SC 22F	Performance of high-voltage d.c. (HVDC) systems
947	SC 17B	Low-voltage switchgear and controlgear
1000	TC 77	Electromagnetic compatibility

Table 15.3-1 IEC Standards relevant for the PS system design (cont'd)

IEC	Tech. Comm.	Title
1010	TC 66	Safety requirements for electrical equipment for measurement, control, and laboratory use
1131	SC 65B	Programmable controllers
1140	TC 64	Protection against electric shock. Common aspects for installation and equipment