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EDH Guide C: Electrical Installations for EPS Client Systems

Guide on Standardisation of Electrical Components for EPS Client Systems in ITER.

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1 Introduction

1.1 Purpose

Electrical components and systems used in ITER must meet the required standards specified in the EDH. The general definition of a component and a system is as follows:

- A component is standalone and is connected directly to the electrical network; it is self-protecting and has no other interface. A typical component is an electrical heating element or a light bulb. Each must be correctly rated for connection to ITER power supplies. The protection of an electrical component is typically a fuse, which is rated to interrupt the supply in the event of fault.
- A system is likely to be an integrated collection of components and will normally have multiple interfaces, e.g. with other components and systems such as CODAC. A typical example is a vacuum pumping system. The overall system must be correctly rated for connection to its power supply but it can signal various systems to request response, e.g. to switch off in a controlled manner as well as directly tripping its supply in the event of serious fault.

This part of the EDH details the requirements for, and recommendations on, all electrical components and plant systems to be used or installed at ITER and to be connected to the EPS.

In general, EPS loads, much similar to SSEN loads, are not ITER pulse related but of a continuous nature, e.g. cryogenics plant, vacuum plant, heating, cooling, ventilation and lighting systems, etc.

This guide provides practical design guidance further than EDH Guide A: Electrical Installations for SSEN Client Systems (ITER_D_2EB9VT) to EPS consumers. Most design guideline described in the EDH Guide A will be applicable to EPS loads as well, unless specifically described otherwise in this guide.

In regard to the cabling requirements, e.g. cable design requirement; raceway design requirement; interface requirement for cabling and wiring, IO cabling rules (ITER_D_335VF9) will govern plant wide ITER cabling engineering and construction.

1.2 Abbreviations

Abbreviation	Full Description
ac	Alternate Current
ALARA	As Low As Reasonably Achievable
dc	Direct Current
EDG	Emergency Diesel Generator
EMI	Electro-magnetic Interference
EMC	Electro-magnetic Compatibility
EPS	Emergency Power Supply
HF	Human Factor
IP	Investment Protection
LOSP	Loss of Offsite Power
LV	Low Voltage
MV	Medium Voltage
PBS	Physical Breakdown Structure
SIC	Safety Importance Classification
SSEN	Steady State Electrical Network

Abbreviation	Full Description
UPS	Uninterruptible Power Supply

2 General Characteristics of EPS system

Emergency Power Supply (EPS) system shall be designed to feed all emergency loads, which are important to safety, classified into SIC, and which are relevant to ITER machine protection, classified into IP. Even in the event of LOSP (loss of off-site power), the Emergency Power Supply (EPS) system provides the emergency loads with reliable electricity with sufficient capacity and duration for their due performance.

As defined in SRD-43 (Steady State Electric Power Supply Networks), in terms of the degrees of service availability, steady state power distribution system is classified into 4 power supply classes: Class I thru Class IV. Among the classes, Class I thru Class III power supplies are included in the Emergency Power Supply (EPS) system.

In addition, as briefly described above, the EPS system is divided into two different electrical systems: one is the safety EPS system dedicated to supplying electrical power to SIC (SIC-1 and SIC-2) loads and the other is the IP EPS system dedicated to supplying electrical power to loads which demand more reliable power supply from the perspective of ITER investment protection.

Electrical loads to be supplied by EPS system, so called EPS loads, shall be determined according to emergency load determination criteria addressed in Appendix A (Policy for SSEN Power Supply to Consumers) of this document.

In each power supply class of the EPS system, there are two separated and independent distribution systems, train A and train B for safety and IP EPS distribution system.

2.1 Class I Power Supply

The Class I power distribution system provides reliable, uninterruptible DC power for various plant control and instrumentation systems and other specific loads such as emergency DC motor, solenoid valve, emergency lighting, etc. of several PBS clients.

The Class I power supply include dc power sources and associated distribution systems needed to supply control power to the Consumers. Batteries and ac/dc converters, called also battery chargers, are used as the power sources for the Class I power supply system.

Each class I power distribution system includes of two different voltage levels: one is 48 Vdc and the other is 110 Vdc.

The sources of power to the Class I power supply are configured as follows:

a) Preferred source: Class I ac/dc converter energized by class III power
b) Alternate source: station batteries discharge autonomously for predestined duration (4 hours) with sufficient load capacity and voltage characteristics.

Batteries and Class I power distribution system is ungrounded. Automatic means of detecting and/or locating earthing fault will be provided.

For every Class I load, short circuit current contribution from the Class I power supply source, ac/dc converter and battery, should be taken into account such that the load should withstand the maximum available short current within the fault clearing time required by protective device of client's own. The protective devices in Class I power distribution take into account only feeder cables.

The short circuit current contribution from Class I power supply will be determined in detailed design phase.

2.2 Class II Power Supply

The Class II power distribution system supplies uninterruptible, reliable, regulated AC power to various plant instruments and control equipment which require uninterrupted AC power for their reliable operation.

The Class II power distribution system is composed of UPS's and distribution boards, (automatic and/or manual) bypasses.

Each distribution board receives power from its associated UPS (or inverter) with bypass. The UPS is the normal and preferred power source and the bypass serves as an alternate source in case of failure or unavailability of power supply from UPS.

The sources of power to the Class II power supply are configured as follows:

a) Preferred source: Class II UPS (or inverter) energized by Class III power
b) Alternate source: station batteries discharge and transformed to regulated ac power via inverter (module) for predestined duration (1 hour for IP and SIC loads) with sufficient load capacity and voltage characteristics.
c) Bypass source: directly fed from Class III power supply

The Class II power distribution system produces 400 Vac-3ph (230 Vac-1ph), 50 Hz output.

In case power supply from the UPS output module (or inverter module) is no more available, the power to the distribution panel is transferred to alternate Class III 400Vac/230Vac power through bypass, which also prevents the parallel operation of incoming supplies.

The bypass, make-before-break type or switching within ¼ cycles, transfers total load from the UPS to the Class III ac power source.

The Class II power distribution system shall be of TN-S earthing system in accordance with NF C15-100 (corresponding to IEC 60364).

The Class II power distribution boards shall be provided with 2-pole (for single phase loads) and 3-pole (for 3 phase loads) thermal-magnetic type circuit breakers for the circuits of load side.

For every Class II load, short circuit current contribution from the Class II power supply source, UPS (or inverter) or bypass Class III power supply, should be taken into account for the design features of the load such that the load should withstand the maximum available short current within the fault clearing time required by protective device of client's own.

The protective devices in Class II power distribution take into account only feeder cables.

The short circuit current contribution from Class II power supply will be determined in detailed design phase.

2.3 Class III Power Supply

The Class III power distribution system provides a reliable source of power to all emergency AC loads in ITER plant.

The class III power distribution system supplies electric power to the loads which require very reliable power though tolerate interruptions, which could occur during changeover of power supply from the preferred source to the alternate source, in the event of LOSP (loss of off-site power).

The sources of power to the Class III power supply are configured as follows:

a) Preferred sources: Class III MV switchgears energized by Class IV power via 22/6.6 kV step-down transformers
b) Alternate sources: Under a LOSP (loss of off-site power) scenario, the diesel generators shall supply the class III power distribution bus bars.

In addition, during periods of maintenance, outage or generator failure, the Class III power supply of each safety train shall be powered manually by the 15kV CEA network through 15kV cable link via 15kV/6.6kV step down transformers and by cable link with 6.6kV IP (investment protection) bus.

The Class III power fed from alternate sources shall be transformed in low-voltage class III loads through four (or sic) 6.6/0.4kV transformers per each train or division.

The diesel generators shall be ready to accept SIC and IP loads within 30 seconds from the onset of the LOSP event.

All Class III loads shall be fully operational within 90 seconds from the onset of the LOSP event.

During the period, all SIC loads will be sequentially loaded to safety emergency diesel generators by automatic load sequencer. Interval between each loading should be determined taking into account starting time of large motors and voltage & frequency recovery capability the generators. The time interval between each loading step is tentatively estimated 5s, which is determined considering 3s of motor starting time and 2s for generator voltage and frequency stabilizing and marginal period. In case the starting period of MV motors require more than 3s, the step interval will be increased as much as the time excess of 3s.

Loads receiving power from Class III IP distribution will be loaded sequentially by the operation of automatic load sequencer and/or operator's manual loading manipulation.

Upon restoration of ac power to its emergency bus, each of safety or IP generators is manually shutdown after being synchronized to upstream Class IV power source.

In Class III power supply, there are two different voltage levels are available for various station loads. One is 6.6 kV and another is 400/230 V. Large motors rated 200 kW or larger are destined to be supplied at a voltage level of 6.6 kV.

In case where the size of a particular load other than electrical motor is too huge to be fed from LV distribution from the perspective of technical and economic efficiency, it could be supplied at a voltage level of 6.6 kV.

The others are to be supplied at a voltage level of 400/230 V.

3 Power Quality of Emergency Power Supplies

3.1 General

This section gives the main characteristics of voltage and frequency at the terminals in LV(low voltage) including dc power, and MV(medium voltage) Emergency Power Supply (EPS) network under normal and abnormal operating conditions, and it also gives the limits or values within which customer can expect the voltage characteristics to maintain.

3.2 Power Quality of EPS Network

Power quality of EPS follows requirements of SRD-43 (Steady State Electric Power Supply Networks) and other industrial standards such as IEC 61225, IEC 62040-3, IEC 61000-2-4 and IEC 61000-4-17 as delineated below.

3.2.1 Power Quality of Class I Power Distribution

Design limit of voltage variation of Class I power supply during normal operation is around nominal voltage +15/-10%. However, accurate voltage variation of class I power supply will be determined taking into account the voltage characteristics of batteries and ac/dc converters, both servicing dc loads.

Examples of the voltage tolerances at supply terminal are as follow.

- Nominal voltage: 110 V / 48 V
- No. of battery cells: 55 /24
- Nominal voltage per cell: 2.0 V (lead-acid type)
- Final discharge voltage per cell: 1.8 V
- Battery equalizing voltage per cell: 2.33 V
- Voltage tolerance: 99 ~ 128 V (90% ~ 116%) / 43.2 ~ 55.9 V (90% ~ 116%)

Utilization voltage ranges should be far lower than that of supply terminal, taking into account significant voltage drop arising across the cables feeding dc loads, e.g. control relays, protective relays, solenoids, etc.

The minimum operating voltage of each dc load shall be informed to PBS 43 so that the feeder cable should be adequately sized.

During normal operation, dc power delivered by Class I system will include approximately 2% rms (2.2 V on 110V basis, 1V on 48V basis) ripple, which correspond to test level 1 according to IEC 61000-4-17, when operating connected to Class I batteries.

In order to attain lower level of the voltage ripple for particular dc load, the Clients should apply dedicated filter at the load side.

3.2.2 Power Quality of Class II Power Distribution

The power quality of Class II output with preferred or alternate source shall not be worse than the following:

a) Frequency: ± 2%
b) Voltage (steady state): ± 2.5%
c) Voltage (dynamic response): ± 10% in response to a step load change of 100% rated output and shall be restored to within steady state limits within 1 sec.
d) Total harmonic voltage distortion (THD): less than 3%/5% (linear load/non-linear load)

Utilization voltage range should be within 400 V/230 V ± 10% according to IEC 61000-2-4.

3.2.3 Power Quality of Class III Power Distribution

The power quality of Class III output shall not be worse than the following:

3.2.3.1 Normal Operation (preferred source)

The power quality of Class III output during normal operation is no different from that of Class IV.

a) Nominal ac power frequency: 50 Hz ± 1%,
b) Design limits of power source: 6.6 kV ± 6%, 400 V ± 6% (lighting and sockets), 400V ± 8% (motors)
c) Utilization voltage range : 6.6 kV ± 10%, 400 V ± 10%

3.2.3.2 Start-up, Loading, Unloading and Steady State Operation of Safety and IP Diesel Generators (alternate source)

For each reloading step (or reconnection sequence), the following performance levels must be assured:

a) Frequency shall not fall below 95% of its rated value.
b) Voltage at 6.6kV bus shall not fall below 90% of its rated value.
c) Frequency is restored to 98 % of its rated value within less than 60 % of the time interval between the beginning of the sequential loading and the beginning of the following one (i.e., 3 seconds).

At full voltage, medium voltage motors draw a starting current of about five times its rated full load current, and step-down transformers draw instantaneously huge in-rush current larger than ten times of rated full load current. These sudden large increases in current drawn from the diesel generator as a result of the start-up of induction motors or initial magnetization of iron core of transformers can result in substantial voltage reduction. This low voltage could prevent a motor from starting (i.e., accelerating its load to rated speed in the required time), or could cause a running motor to coast down or stall and other voltage-sensitive loads might also be lost because of low voltage or if their associated contactors drop out.

Hence, every motor which is fed from the safety emergency diesel generator shall be capable of accelerating the equipment to the rated speed without damaging, overheating or slipping when running at 75% (for SIC) or 80% (for non-SIC) of nominal voltage during sequential loading period. Detail operation requirements of motors are addressed in EDH Guide A: Electrical Installations for SSEN Client Systems (ITER_D_2EB9VT).

In steady-state operations, the frequency shall be maintained within ± 1% and the voltage within ± 5% of their rated values at the safety diesel generator terminals. In addition, safety EPS network should be so designed that EPS client loads may obtain the voltage range, not worse that Class IV power supply during normal operation.

Even under the accidental conditions, e.g. largest load rejection; full load rejection; etc., over-speed of diesel generators shall not exceed 115% of nominal speed. Over-speed beyond 115% shall be protected by mechanical over-speed trip device. Maximum transient voltage deviation after 100% sudden power decrease shall not exceed 120% of nominal voltage (6.6 kV).

During emergency condition, e.g. loss of off-site power, the safety emergency diesel generators shall not trip except for the following conditions;

- Mechanical over-speed (115%)
- Internal faults detected by only differential relay
- Remote (emergency) trip command
- Manual (local) stop lever

4 Electromagnetic Compatibility (EMC)

The general rules and concept of EMI/EMC to be placed on electrical components are described in EDH Part 4: Earthing, EMC and Lightning Protection (ITER_D_2ELREB) and component oriented application guidance and requirements of EMI/EMC for the electrical components are delineated in EDH Guide A: Electrical Installations for SSEN client Systems (ITER_D_2EB9VT).

In addition, as for the DC magnetic field qualification, ITER Policy on EEE in Tokamak Complex (ITER_D_6ZX6S3) and Guidance for EEE in Tokamak Complex (ITER_D_7NPFMA) provide further detailed policy and guide.

5 Special Considerations

5.1 Qualification Requirements for SIC components

Qualification of SIC electrical components, including instrumentation and control, shall be performed in a manner that assures its operability when subjected to equivalent conditions which would be foreseen during and after the postulated plant conditions as specified in the PA of the driven devices.

5.1.1 Environmental Qualification

Environmental conditions (normal, incidental and accidental) within which these components operate while providing the functions important to safety shall be identified, considering the following:

Environmental conditions during normal operation

- Radiation dose rate (Gy/h) and integrated dose (Gy) during normal operation
- Radiation dose rate: Gr/h
- Temperature (maximum excursion range in the room)
- Humidity (maximum excursion range in the room)
- Pressure
- Electromagnetic interference (EMI)
- Magnetic field and derivative magnetic field

Environmental conditions during incidents/accidents

- Radiation dose rate (Gy/h) and integrated dose (Gy) during an accident
- Seismic floor response spectra (Refer to 5.1.2)
- Temperature (peak and duration)
- Humidity (peak and duration)
- Pressure (peak and duration)
- Magnetic field and derivative magnetic field

Information on the environmental conditions for the components to be qualified is given in Environmental Conditions Room Book (2UUZ23 v2.1) and Radiological Zoning (3P4FAF).

In addition, threshold environmental condition for qualification of EEE (Electronics, Electrical and Electro-mechanical) components, condition and method of qualification tests are described in ITER Policy on EEE in Tokamak Complex (ITER_D_6ZX6S3) and Guidance for EEE in Tokamak Complex (ITER_D_7NPFMA) provide further detailed policy and guide.

The qualification program shall also address and consider equipment aging (i.e. radiation, thermal & cyclic) throughout the equipment lifetime. The qualification methods and procedures shall be in compliance with IEC 60780 and/or RCC-E.

5.1.2 Seismic Qualification

As described in ITER_D_347SF3 - Safety Important Functions and Components Classification Criteria and Methodology, all SIC components shall be designed to withstand the postulated seismic event and maintain the required capability. In addition, the collapse, falling, dislodgement or other spatial response of a component as a result of an earthquake shall not jeopardise the functioning of other components providing a safety function.

SIC electrical components, which are classified into either SIC-1 or SIC-2 according to the safety functions those components are designed to perform, are active ones such that those components shall be classified into SC1 (SF), which is defined as the following.

SC1(SF): Structural stability and required functional seismic safety performance maintained in the event of an earthquake, The respect of this level of requirement guarantees the level of safety as throughout the normal operation of the equipment. Nevertheless, taking into account seismic load characteristics, fatigue is not taken into account.

The seismic assessment levels correspond to reference earthquake spectra for the ITER Cadarache site in compliance with the Basic safety rule RFS 2001-01: the reference earthquakes for the design are defined by two seismic levels. The more severe is called Safe Shutdown Earthquake (SSE), defined as SL-2. A second (lower) level called SMHV also needs to be considered in the design. Moreover, ITER defines a less intense earthquake (SL-1) addressed in the facility design for investment protection. More detail information on the reference earthquake spectra is described in Load Specifications (LS) (ITER_D_222QGL).

SIC electrical components shall be appropriately qualified to demonstrate that the components meet the safety (functional and structural) requirements imposed on the seismic classification (SC1-SF)

The qualification methods and procedures shall be in compliance with IEC 60780 and/or RCC-E.

5.2 Human Factors

Each PBS shall apply Human Factors (HF) principles to (functional and physical) design, fabrication, assembly, operation, testing and maintenance in order to reduce the likelihood and consequence of human errors in all life cycles of ITER to ALARA, with particular attention to SIC components.

Each PBS will develop its own HF integration plan (System Human Factors Integration Plan), in line with the requirements defined in ITER Human Factor Integration Plan (2WBVKU). The System Human Factors Integration Plan shall specify all HF issues and plan required actions to properly address the issues. The System HFIP and resulting actions will be developed further during the PA phase by the Suppliers of ITER electrical systems and components.

6 References

1) Preliminary Safety Report (RPrS) - Version 2.0 (ITER_D_3ZR2NC)
2) SRD (System Requirements Document) of PBS 43 : Steady State Electrical Network (ITER_D_28B6Y9)
3) ITER_D_347SF3 - Safety Important Functions and Components Classification Criteria and Methodology
4) EDH Part 1: Introduction (ITER_D_2F7HD2)
5) EDH Part 2: Terminology & Acronyms (ITER_D_2E8QVA)
6) EDH Part 3: Codes & Standards (TER_D_2E8DLM)
7) EDH Part 4: Earthing, EMC and Lightning Protection (ITER_D_2ELREB)
8) EDH Guide A: Electrical Installations for SSEN Client Systems (ITER_D_2EB9VT)
9) IO cabling rules (ITER_D_335VF9)
10) ITER Policy on EEE in Tokamak Complex (ITER_D_6ZX6S3)
11) Guidance for EEE in Tokamak Complex (ITER_D_7NPFMA)
12) Load Specifications (LS) (ITER_D_222QGL)
13) ITER Human Factor Integration Plan (2WBVKU)
14) RCC-E (2005), Design and construction rules for electrical equipment of nuclear islands
15) NF C15-100, Low-voltage electrical installations
16) IEC 60038, IEC standard voltages
17) IEC 60364, Low-voltage electrical installations
18) IEC 60780, Nuclear power plants – Electrical equipment of the safety system – Qualification
19) IEC 61225, Nuclear power plants – Instrumentation and control systems important to safety – Requirements for electrical supplies
20) IEC 62040-3, Uninterruptible power systems (UPS) -Part 3: Method of specifying the performance and test requirements
21) IEC 61000-2-4, Electromagnetic compatibility (EMC) Part 2-4: Environment – Compatibility levels in industrial plants for low-frequency conducted disturbances
22) IEC 61000-4-17, Electromagnetic compatibility (EMC) Part 4-17: Testing and measure tech Ripple on DC input power port immunity test

Appendix A

Policy for SSEN Power Supply to Consumers

A1. SIC Power Supply (Class I[i]/ Class II / Class III)

SIC loads whose nuclear safety function relies on electric power shall be supplied by SIC (Class I[i], Class II or Class III) power supply.

A2. IP Power Supply (Class II / Class III)

Loads whose investment protection function relies on electric power shall be supplied by IP (Class II or Class III) power supply if any of the following criteria apply.

- **Criterion 1**: Class III-IP power will be supplied in the cases where the loads require prolonged operation after loss of Class IV and Class III (temporarily interruptible with DG back-up) power prove to be required to mitigate IP (investment Protection) risk to acceptable level by IP risk assessment.. Other ordinary loads can be provided with Class III-IP upon written agreement between PBS 43 and the client PBS with specific endorsement from safety or operation division.

- **Criterion 2**: I&C loads which function associated with Class III-IP powered equipment or prove to be required to remain active status, through IP risk assessment, during loss of Class IV power condition to mitigate IP (investment Protection) risk to acceptable level should be powered by Class II-IP.

Rationale: In the case where no investment protection concern arises during power outage on the component, Class II-IP power need not be served. (e.g., equipment with fail-safe operation characteristics)

- **Criterion 3**: I&C components, which do not fall into the components fulfilling Criterion 2, can be powered by Class II-IP only in the following cases upon written agreement between PBS 43 and the client PBS with specific endorsement from safety or operation division.

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[i] Due to the voltage drop characteristics of DC power sources – battery terminal voltage could decrease to 90% and huge voltage drop occurs across the feeder cables between sources and loads – PBS 43 recommends Class I power supply need to be supplied only to the components which require more than 1 hour battery autonomy (due to regulatory reason) without EDG back-up.

(1) During loss of Class IV power condition, the load is required to remain active status for longer period than outage duration while waiting for power recovery (typically 30min.) for purposes of status reporting to central I&C system, data archiving and shutdown **or**
(2) A local back-up power source cannot be provided due to restrictions of local UPS (or battery) installation in the area where the load is situated.

Rationale: Basically, Class II-IP is not provided for ordinary loads including plant control I&C cubicles, for which the load consumers can provide their own back-up source (UPS with battery) to orderly archive data and shut down in the event of power outage. However, there are some exceptional cases such as where continuous control & monitoring is required even during the LOSP, e.g. access control, environmental monitoring, etc. (which falls into case 1 of criterion 3) or where local installation of back-up power source is prohibited due to an explosion hazard or other inevitable technical reasons (which falls into case 2 of criterion 3).

A3. Class IV Power Supply

Non-SIC loads which do not meet the above Criteria shall be powered by Class IV. In cases where uninterruptible power is required for the loads, the load consumer shall provide their own back-up power supply.