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ITER Electrical Design Handbook Earthing and Lightning Protection

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ITER Electrical Design Handbook

Earthing and Lightning Protection

- Introduction
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Introduction

Abstract

This manual is provided for the use of all Departments of the ITER Organization and is addressed to system specifiers, designers and users of electrical components in otherwise non-electrical plant systems.

This is an initial version of this document that has been reviewed in accordance with the ITER MQP. Review comments have in part been addressed and others will be considered in detail and addressed at the next revision.

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1 Introduction

This document will be published in the Baseline documentation folder of the ITER Document Management (IDM) System and will be the subject of continual review and revision throughout the lifetime of the ITER project.

This handbook is provided for the use of all Departments of the ITER Organization and is addressed primarily to system specifiers, designers and users of electrical components in otherwise non-electrical plant systems, rather than to designers of the power supply systems. The latter shall in addition comply with many other standards, instructions and industrial practices that are beyond the scope of this handbook.

Standardisation Guides

All electrical components and plant systems used or installed at ITER shall comply with the requirements set out in this EDH.

In particular, voltage and current ratings must be selected for connection to the ITER standard nominal system voltages that have been selected from the IEC standards as given in the Section on Standard Voltages.

The related test voltages are given in the Section on Standard Test Voltages.

1.1 Standard Voltages

1.1.1 Applicable IEC standards

IEC 60038 IEC Standard Voltages

International Standard **IEC 60038** defines a set of standard voltages for use in low voltage and high voltage AC electricity supply systems.

The definition of voltage levels is as follows:

IEC voltage range	AC	DC	defining risk
Extra-low voltage	< 50 V_{rms}	< 120 V	low risk
Low voltage	50–1000 V_{rms}	120–1500 V	electrical shock
High voltage	> 1000 V_{rms}	> 1500 V	electrical arcing

Table 1.1 IEC Definition of Voltage Levels

1.1.2 Low Voltage, single & 3 phase, 50Hz

The 230V/400V level (in bold text) is that adopted for use by ITER:

	rms voltage between a phase and the neutral connector	Corresponding rms voltage between two phases. Four-wire (with neutral) or three-wire (without neutral) systems
LV	**230 V**	**400 V**
	400V	690V
	1000V	-

Table 1.2 Low Voltage (LV) used at ITER

1.1.3 *High Voltage, 3 phase, 50 Hz*

Whilst defined by IEC as being **High Voltage**, i.e. > 1000 V_{rms}, the following voltage levels shall be referred to within ITER as **Medium Voltage (MV)**, i.e. 1 kV < V_r ≤ 35 kV, **Intermediate Voltage (IV)**, i.e. 35 kV < V_r ≤ 230 kV or as **High Voltage (HV)**, i.e. 230 kV < V_r ≤ 800 kV.

The levels in bold are those adopted for use by ITER:

	Highest voltage for equipment *V_m kV	Nominal system voltage ☒V_r kV (± 10%)
MV	3.6	3.3
	7.2	**6.6**
	12	11
	17.5	-
	24	**22**
IV	**72.5**	**66**
	123	110
	145	132
HV	245	220
	420	**400**

Table 1.3 Medium Voltages (MV), Intermediate Voltage (IV) and High Voltage (HV) used at ITER

1.2 Standard Test Voltages

1.2.1 *Applicable IEC standards*

IEC 60060 High-Voltage Test Techniques

International Standard **IEC 60060** defines a set of tests on equipment having its highest voltage for equipment V_m above 1kV, i.e. in the case of components and plant systems used or installed at ITER, any that are to be connected to a supply voltage higher than that classed as low voltage, must be subjected to testing.

This standard is applicable to:

- dielectric tests with direct voltage;
- dielectric tests with alternating voltage;
- dielectric tests with impulse voltage;

* V_m represents the dielectric strength of an equipment, device or system for which it is designated

☒ V_r represents the nominal or rated system voltage at which an equipment, device or system shall usually operate

- tests with impulse current;
- tests with combinations of the above.

Highest voltage for equipment V_m kV	Standard short-duration power frequency withstand voltage kV (rms value)	Standard lightning impulse withstand voltage
7.2	**20**	**40/60**
24	**50**	**95/125/145**
36	70	145/170
72.5	**140**	**325**
245	(275)/(325)/360/395/460	(650)/850/950/1050

Note: If values in brackets are considered insufficient to prove that the required phase-to-phase withstand voltage are met, additional tests are needed.

Table 1.4 Test Voltages

1.3 Voltage Classes

The voltage class of a power circuit defines the degree of availability of the power delivery. The following classification of the power delivery circuits have been adopted at ITER:

Class I	Uninterruptible DC (up to 250 V)	DC battery supplies; batteries charging when AC supply is available. AC supply may be Class III or Class IV depending on Safety Level
Class II	Uninterruptible AC (230/400 V)	Provided from UPS systems, will switch to alternate supply. Alternate AC supply may be Class III or Class IV depending on Safety Level
Class III	Temporarily interruptible AC (230/400 V and 6.6 kV)	Provided from diesel motor generators, interruption for 30 s while generators start up
Class IV	Indefinitely interruptible AC (230/400 V and 6.6 kV).	Directly provided from the electrical supply network

Table 1.5 Voltage Classes

1.4 Insulation Coordination

1.4.1 Applicable IEC standards

IEC 60071 IEC Insulation Coordination

The following table shows standard insulation levels for range I (1kV < V_m = 245 kV)

Highest voltage for equipment (V_m) kV (rms value)	Standard rated short- duration power-frequency withstand voltage kV (rms value)	Standard rated lightning impulse withstand voltage kV (peak value)
7.2	20	40 60
24	50	95 125 145
36	70	145 170
72.5	140	325
245	(275) (325) 360 395 460	(650) (750) 850 950 1050

Note: If values in brackets are considered insufficient to prove that the required phase-to-phase withstand voltage are met, additional tests are needed.

Table 1.6 Insulation Withstand Voltages

1.5 Standard Current Ratings

1.5.1 Applicable IEC standards

IEC 60059 IEC Standard Current Ratings

This standard specifies standard current ratings for electrical devices, apparatus, instruments and equipment and should be applied to the designing or utilisation of systems or equipment as well as to operating characteristics. This standard does not apply to current ratings of components and parts used within electrical devices or items of equipment.

Standard current ratings in amperes have been fixed by the IEC as follows:

1	1.25	1.6	2	2.5	3.15	4	5	6.3	8
10	12.5	16	20	25	31.5	40	50	63	80
100	125	160	200	250	315	400	500	630	800
1000	1250	1600	2000	2500	3150	4000	5000	6300	8000
10000	12500	16000	20000	25000	31500	40000	50000	63000	80000
100000	125000	160000	200000						

Table 1.7 IEC Standard Current Ratings

Terminology & Acronyms

Abstract

This part lists all terms, definitions and acronyms that may be referenced when specifying an electrical component, device or system for use by the ITER Organization.

This is an initial version of this document that has been reviewed in accordance with the ITER MQP. Review comments have in part been addressed and others will be considered in detail and addressed at the next revision.

Contents

1 Terminology

This part of EDH (Electrical Design Handbook) outlines the terminology adopted by the ITER Organization for specific electrical components, devices or systems.

For components, devices and systems not covered by this document, the following references shall be considered to identify the proper terminology:

1. IEC dictionaries and glossaries (http://www.electropedia.org)

2. Electrical Installations Handbook, Executive Editor: Gunter G. Seip, John Wiley and Sons, ISBN 0-471-40435-6

In case of inconsistency between the above documents, requests for clarification shall be submitted to the ITER Electrical Implementation Division.

The ITER Organization has adopted the International System of Units, universally known as the **SI** (from the French *Système International d'Unités*), see http://www.bipm.org/en/si/si_brochure. The SI prefixes are given in the table below:

Factor	Name	Symbol		Factor	Name	Symbol
10^{1}	deca	da		10^{-1}	deci	d
10^{2}	hecto	h		10^{-2}	centi	c
10^{3}	kilo	k		10^{-3}	milli	m
10^{6}	mega	M		10^{-6}	micro	µ
10^{9}	giga	G		10^{-9}	nano	n
10^{12}	tera	T		10^{-12}	pico	p
10^{15}	peta	P		10^{-15}	femto	f
10^{18}	exa	E		10^{-18}	atto	a
10^{21}	zetta	Z		10^{-21}	zepto	z
10^{24}	yotta	Y		10^{-24}	yocto	y

Table 1.1 SI Prefixes

1.1 Main Definitions from IEC Standards

1.1.1 *Nominal System Voltage*

The voltage by which a system is designated.

1.1.2 *Rated Voltage/Current of Equipment*

The voltage/current assigned generally by a manufacturer, for a specified operating condition of a component, device or equipment.

1.1.3 *Highest System Voltage*

The highest value of voltage which occurs under normal operating conditions at any time and any point on the system. It excludes voltage transients, such as those due to system switching, and temporary voltage variations.

1.1.4 *Highest Voltage for Equipment*

The highest rms value of phase-to-phase voltage for which the equipment is designed in respect of its insulation as well as other characteristics which relate to this voltage in the relevant equipment standards.

The highest voltage for equipment is the maximum value of the "highest system voltage" (see above) for which the equipment may be used.

1.1.5 *Insulation Coordination*

The selection of the dielectric strength of equipment in relation to the voltages which can appear on the system for which the equipment is intended and taking into account the service environment and the characteristics of the available protective devices. The process is determined from the known characteristics of voltage surges and the characteristics of surge arresters.

1.1.6 *The Standard Short-Duration Power Frequency Voltage*

A sinusoidal voltage with frequency between 48 Hz and 52 Hz, and duration of 60 s. The voltage level is determined for specific tests.

1.1.7 *The Lightning Impulse Voltage*

An impulse voltage having a front time of 12 μs and a time to half-value of 50 μs. The voltage level is determined for specific tests.

2 Common Definitions Adopted for ITER

2.1.1 *AC/DC Charger*

A battery cahgher converting alternating current (AC) power into DC power, being the converter section of a UPS which charges batteries and supplies DC to the inverter.

2.1.2 *Batteries*

One or more cells fitted with devices necessary for use, for example case, terminals, marking and protective devices. A battery stores and supplies electrical energy to an electrical circuit when the normal power supply of that electrical circuit is interrupted.

2.1.3 Busbar

Conductors fabricated from thick strips of copper or aluminium to conduct electricity within a switchboard, distribution board, substation, or other electrical apparatus.

2.1.4 Bus Coupler

Inbuilt mechanical interlocking which connects busbar systems, where position change is via the OFF position, ensuring downstream distribution in case of failure of upstream lines. In a substation a circuit-breaker located between two busbars and which permits the busbars to be coupled; it may be associated with selectors in case of more than two busbars

2.1.5 Cable

Assembly of one or more conductors and/or optical fibres, with a protective covering and possibly filling, insulating and protective material

2.1.6 Cable Tray

a unit or assembly of units or sections and associated fittings forming a rigid structural system used to securely fasten or support cables and raceways. Cable trays are used to support and distribute cables.

2.1.7 Circuit Breaker

A switching device, capable of making, carrying and breaking currents under normal circuit conditions and also making, carrying for a specified time and carrying for a specified time during abnormal circuit conditions such as a short circuit.

2.1.8 Converter

A functional unit which changes the representation of information. Examples of converters are: analog-digital converter, digital-analog converter, code converter, parallel-serial converter, serial-parallel converter.

2.1.9 Current Transformer

A device that reduces current values at a point in a network where they are connected, to proportional and manageable values, whilst separating measuring instruments, meters, relays, etc. from the medium or low voltage circuit.

2.1.10 Diesel Generator

A diesel generator is the combination of a diesel engine with an electrical generator (often called an alternator) to generate electrical energy. Diesel generating sets are used as emergency power-supply if the grid fails. There are four 6.6kV diesel generator sets, two seismic qualified to feed SR loads and two non-seismic qualified for IP loads.

2.1.11 Disconnector

A mechanical switching device which provides, in the open position, an isolating distance in accordance with specified requirements. A Mechanical switching device which, in the open position, disconnects all the poles of an electrical circuit and is equipped with a reliable contact position indicator. A closed disconnector is capable of carrying currents under normal circuit conditions and carrying for a specified time currents under abnormal conditions such as those of short circuit.

2.1.12 Earth Switch

Mechanical switching device for earthing parts of an electrical circuit, capable of withstanding for a specified duration, electric currents under abnormal conditions such as those of a short-circuit, but not required to carry electric current under normal conditions of the electrical circuit

2.1.13 Electrical Interlock

Type of circuit in which the auxiliary contacts of various devices are switched in such a ways that the circuit states are interdependent. This makes it impossible to switch on one switching device if another is already switched on.

2.1.14 Insulators

A device designed to support and insulate a conductive element. A device intended for electrical insulation and mechanical fixing of equipment or conductors which are subject to potential differences.

2.1.15 Inverter

Electrical energy converter that changes direct current to single-phase or polyphase alternating current

2.1.16 Load Centre

The load voltage load centres are connected to the secondary 22 kV distribution switchgear through the MV/LV transformers.

They are mainly used at the load level. They are used for:

- Protecting persons and property
- Protecting electrical loads
- Protecting cables and electric lines
- Overvoltage protection
- Safety disconnection
- Monitoring and signalling
- Open and closed-loop control
- Metering, measuring and display purposes

This load centres are composed of:

- Incoming circuit breakers and coupler circuit breaker (interlocked function)
- 400V copper strip semi-busbars.
- Outgoing draw-out circuit breakers to the Local Panels and MCC.

2.1.17 Load Tap Changer

The on-load tap changer is used to change the tapping connection of the transformer winding while the transformer is energized. A connection made at some intermediate point in a winding. It is used to control the voltage over the SSEN

2.1.18 Main Busbar

The busbar is an assembly necessary to make a common connection for several circuits. A low-impedance conductor, to which several electric circuits can be connected

2.1.19 Main Distribution Board

Assembly containing different types of switchgear and control gear associated with one or more outgoing electric circuits fed from one or more incoming electric circuits, together with terminals for the neutral and protective conductors.

They are used for up 6300 A. They are used first and foremost for:

- Safety disconnection
- Coupling busbar sections
- Protecting busbars
- Selectivity vis-à-vis upstream protection equipment

They are primarily equipped with:

- Circuit-breakers and non-automatic circuit-breakers
- Tie circuit-breakers
- Fuses

2.1.20 Motor Control Centre

MCC is a low-voltage withdrawable-unit-type switchgear station for motor feeders with a main switch and door interlock. The MCC will consist of individual cubicles housed in the correspondent switchgear placed as close as possible of the LV motors zone. The MCC shall include:

- Motor protection systems.
- Monitoring & Control devices.
- Starter devices if applicable.

2.1.21 Outlet/Connector

Device which provides connection and disconnection to a suitable mating component. Conductor of electricity used for carrying current between components in an electric circuit

2.1.22 Penetration

A cable transit assembly designed to implement safely the passage of cables lines through walls , floors or ceilings of areas with various environmental conditions, maintaining their integrity

2.1.23 Soft Starters

The combination of the switching means necessary to start and stop a motor in combination with suitable overload protection.

2.1.24 Raceway

An enclosed channel of metallic or nonmetallic materials designed expressly for holding wires, cables or busbars. Examples are electrical metallic tubing (EMT), flexible metallic tubing and nonmetallic rigid conduit.

2.1.25 Relay

Switching device which brings about sudden predetermined changes in one or more electric output circuits when specific conditions that control the device arise in the electric input circuit.

2.1.26 Sockets

Connector attached to an apparatus or to a constructional element or the like. Contact members of a socket may be socket contacts, pin contacts or both.

2.1.27 Static Transfer Switch

Device which transfers load automatically and without disturbance between inverter and utility power

2.1.28 Sub-Distribution Board

Part of an electrical installation for distributing energy to downstream loads or groups of loads

They are used up for 2500 A. They are used for:

- Safety disconnection
- Switching electrical loads, e.g. lighting systems and motors
- Protecting cables, electric lines and loads
- Back-up protection and selectivity vis-à-vis upstream and downstream protection equipment
- Overvoltage protection
- Control, metering and measuring purposes

The following devices are integrated in order to carry out these functions:

- Circuit-breakers, switch-disconnectors and fuse switch-disconnectors.
- Miniature circuit-breakers
- Fuses
- Modular built-in equipment for control, metering and measuring purposes

2.1.29 Surge Arrester

A protective device designed primarily for connection between a conductor of an electrical system and earth to limit the magnitude of transient overvoltages on equipment.

2.1.30 Switchgear

Electrical equipment switching devices for the purpose of carrying out one or more of the following functions: protection, control, isolation, switching and their combination with associated control, measuring, protective and regulating equipment Also assemblies of such devices and equipment with associated interconnections, accessories, enclosures and supporting structures, intended in principle for use in connection with generation, transmission, distribution and conversion of electric energy.

2.1.31 Transformers

A device that is used to change the voltage in an alternating current (AC) circuit. Three kinds of transformers are identified taking into account the voltage level: The four main step down transformers which transform from HV (400 kV) to MV (22 kV) Oil transformers, which transform from MV (22 kV) to MV (6.6 kV) and located outside of buildings and dry transformers which transform from MV (6.6 kV) to LV (0.4 kV) and located inside buildings.

2.1.32 UPS

An uninterruptible power supply (UPS) system is designed to provide conditioned power which offsets the effects of adverse normal power. A static UPS consists of:

- a battery to provide continuous source of electrical power;
- a rectifier/charger to maintain battery charge and to provide input to inverter when utility power is available;

- an inverter to provide power to load during normal operation;
- a static switch ,to transfer load automatically and without disturbance between inverter and utility power,
- a manual switch to bypass the static switch for maintenance;
- input and output isolation transformers and filters to provide appropriate isolation and disturbance attenuation; and monitors, sensors, and control circuits.

2.1.33 *Voltage Transformers*

These reduce the voltage values from the point in the network where they are connected to proportional and manageable values, whilst separating measuring instruments, meters, relays etc. from the medium or low voltage circuit.

3 Acronyms

A complete list of Acronyme used within ITER Organization is available at ITER Abbreviations (ITER_D_2MU6W5), here follows a list of those frequently used in EDH:

AC	Alternating Current
BO	Blackout
CB	Circuit Breaker
CC	Control Cubicle
CD	Current Drive
CMF	Common Mode Failure
CT	Current Transformer
CWS	Cooling Water System
D/G	Diesel Generator
DC	Direct Current
DDD	Design Description Document
DP	Distribution Panel for 400 V loads located within buildings
EDG	Emergency Diesel Motor Generator
EDH	Electrical Design Handbook
EHV	Extra High Voltage, > 275 kV, not used at ITER
ELV	Extra Low Voltage, <50 V_{rms} or < 120 V DC (IEC Definition)
EM	Electromagnetic
EPS	Emergency Power Supply
EPSS	Emergency Power Supply System

FDS	Fire Detection and alarm System
FFS	Fire Fighting System
FO	Fibre Optic
FPS	Fire Protection System
FSS	Fire Suppression System
H&CD	Heating & Current Drive
HV	High Voltage, > 1000 V_{rms} or > 1500 V (IEC Definition), 400 kV level on ITER
HVAC	Heating, Ventilation and Air Conditioning
HVDC	High Voltage Direct Current
I&C	Instrumentation and Control
IAEA	International Atomic Energy Agency
ICD	Interface Control Document
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IET	Institution of Engineering and Technology
IO	ITER Organization
IP	Investment Protection
IPEG	Integrated Plant Earth Grid
IV	Intermediate Voltage, 66 kV level on ITER
LC	Load Centre
LCC	Local Control Cubicle
LEP	Local Electrical Panel
LOSP	Loss of Off-Site Power
LTM	Construction/Long Term Maintenance
LV	Low Voltage, 5 – 1000 V_{rms} or 120 – 1500 V DC, 400 V level on ITER
MCC	Motor Control Centre
MP	Main 400V Distribution Panel located in LC
MPCB	Magnet Power Conversion Building
MPSSN	Magnet Power Supply Switching Network
MV	Medium Voltage, 6.6 kV and 22 kV levels on ITER

NBI	Neutral Beam Injection
NBPS	Neutral Beam Power Supply
OL	Ordinary Load
P&ID	Process and Instrumentation Diagram
PA	Procurement Arrangement
PBS	Plant Breakdown Structure
PEC	Prefabricated Electric Centre
PF	Power Factor
PHTS	Primary Heat Transport System
PID	Proportional, Integral and Differential Control
PID	Project Integration Document
PINI	Positive Ion Neutral Injector
PLC	Programmable Logic Controller
POS	Pulse Operation State
PP	Procurement Package
PPEN	Pulsed Power Electrical Network
PS	Power Supply
PSH	Plant System Host
QA	Quality Assurance
RCC-E	Règles de Conception et de Construction des matériels Electriques des îlots nucléaires
RF	Radio Frequency
RPC	Reactive Power Compensation
RPC&HF	Reactive Power Compensation and Harmonic Filtering system
RTE	Réseau de Transport d'Electricité (French Transmission Grid Operator)
SCADA	Supervisory Control And Data Acquisition
SCS	Supervisory Control System
SF6	Sulphur Hexafluoride
SIC	Safety Important Component
SIC	Safety Important Classification
S-ICD	System Interface Control Document

SR	Safety Relevant
SRD	System Requirements Document
SSEN	Steady State Electrical Network
SSPD	Steady State Power Distribution
SSS	Steady State 400 kV Substation
STM	Short term Maintenance
STS	Short Term Standby
TBC	To Be Confirmed
TBD	To Be Defined
TCR	Thyristor Controlled Reactor
TCS	Test and Conditioning State
UPS	Uninterruptible Power Supply
VT	Voltage Transformer
WBS	Work Breakdown Structure

4 Reference and Bibliography

Electrical Installations Handbook, 3rd Edition Ed. Günter G. Seip Pub. John Wiley & Sons ISBN 0-471-49435-6
Transformer Handbook Pub. ABB Power Technologies Business Unit Power Transformers

Earthing and Lightning Protection

Contents

1 Purpose

The scope of this part of the Electrical Design Handbook is to ensure personal safety and protection of equipment and installations against electrical hazards. For this aim, this section includes the guidelines for the design and construction of the ITER site integrated earthing grid and the earthing methodology to be followed for the earthing of all plant systems components used or installed at ITER project. In addition, this document includes the rules for the lightning protection system for ITER buildings.

2 Scope

This part of the Electrical Design Handbook is intended to be observed by designers, installers and users at ITER project.

3 Definitions

IO	ITER Organization
ISEG	ITER Site Earthing Grid
LPS	Lightning Protection System
PPEN	Pulsed Power Electrical Network
SSEN	Steady State Electrical Network

For a complete list of ITER abbreviations see: ITER_D_2MU6W5 - ITER Abbreviations

4 References

[1] Document JACOBS: "Site Investigation Interpretative Report, Phase 1 and 2, Contract ITER/CT/07/533" (ITER_D_2M3XEC)

5 Introduction

The primary goal of an earthing system is to assure personal safety and protection of installations against damages. The secondary goal of an earthing system is to serve as a common voltage reference and to contribute to the mitigation of disturbances in installations with sensitive and interconnected electronic and electrical system. The facility earthing network is then composed by four major electrically interconnected subsystem, that are be designed to shunting the unwanted power-frequency and high-frequency currents, and lowering the voltage difference between two points of the systems:

- The earth electrode subsystem (ITER Site earthing grid)
- The power subsystem
- The lightning protection system
- The signal reference subsystem.

The document describes the earth electrode system, the power subsystem and the lightning protection system.

6 The earth electrode subsystem

An Earth Grid is defined as a set of buried interconnected conductors which is in intimate electrical contact with the Earth. The Earth is at the reference potential (ZERO) and is supposed to conduct current without generating potential differences. An Earth Grid and its connections to the Earth are in turn more realistically considered as presenting potential differences when an electrical current flows.

So, the earth electrode subsystem is a network of electrically interconnected rods, mats or grids installed in the Earth for the purpose of establishing the facility ground reference for lightning and shock hazard. It is designed to provide a low-impedance contact with the general mass of the Earth to ensure that lightning and power fault currents are effectively reduced below hazardous levels. The earth grid also provides a low impedance mat within the facility to limit potential differences below hazardous level under 400 kV fault conditions and during a lightning strike.

6.1 Integrated site earthing grid (ISEG)

The purpose of the earthing grid is to provide an electrical path for the ground fault currents and the lightning surges in order to reduce potential gradients in the ITER site to values that people can withstand without injury and to limit potentials to which equipment and apparatus are exposed.

There is no specific IEC standard to calculate the earthing grid, so IEEE 80 shall be used in order to develop ITER earthing grid. This standard is a widely used method for earthing calculation and, above all, is the standard considered in the CDEGS[1] software tool (computer tool recommended by IO for sizing the ITER earthing grid)

The safety of a person depends on limiting the worst-case voltage between two accessible points before the earth short-circuit is cleared and the system de-energized. In order to design the earthing grid, step[2] and touch[3] voltage distribution in the whole area in the event of an earth fault at the ITER plant facilities must be calculated and must be verified that their maximum values are within safety limits defined by common industrial practice in electrical installations and standards (IEC 60479-1 and 60479-2).

The maximum driving voltage of any accidental circuit should not exceed the limits for step and touch voltage indicated in the standard IEEE 80. As the most conservative value, a body weight of 50 kg must be considered in the equations.

As a result of preliminary earthing grid simulations carried out with CDEGS software, it has been decided that, although there are some reasons to propose separated earthing grids for the 400 kV substation grid and the rest of the ITER site grid, finally **a common earthing grid for the whole area** shall be executed because has better results in the aspect of human safety (lower maximum values of step and touch voltages). So both earthing grids shall be connected to each other in order to get an equipotential surface which minimizes the potential gradient on the earthing grid limits.

The earthing conductor sizing shall be calculated according equations indicated in standard IEEE 80 with the earth fault current, the fault clearing time and the characteristics of the conductor. The minimum size of the conductors, according their material, shall be 25 mm^2 for copper, 35 mm^2 for aluminium and 50 mm^2 for steel.

ITER earthing grid design input parameters shall be:

- Earth fault current at the ITER plant area of 40 kA
- Fault clearing time of the back-up protective devices of maximum 0.4 sec
- Soil characteristics according on site Electrical Resistivity Tests Report ([1] or any more recent measurement)

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[1] CDEGS: Current Distribution Electromagnetic Interference Grounding & Soil Structure Analysis computer program developed by SES (Safe Engineering Services & technologies Ltd

[2] Step Voltage: voltage between two points on the Earth's surface that are 1 m distant from each other, which is considered to be the stride length of a person (IEC 195-05-12)

[3] Touch Voltage: voltage between conductive parts when touched simultaneously by a person or an animal (IEC 195-05-11)

The current (if1 in the figure 2.1-1) that must be considered for the step and touch voltage is the one that goes to earth. So, in the analysis it must be considered the current reduction because of:

- Fault current that returns to the fault point through the neutral of ITER transformers (both Steady State system and Pulsed system) (if2 in the figure 2.1-1)
- Induction on the overhead earth wire of the incoming Over Head Lines (if4 in the figure 2.1-1)
- Fault current that returns through the earthing of the nearest electrical tower of the incoming lines (if3 in the figure 2.1-1)

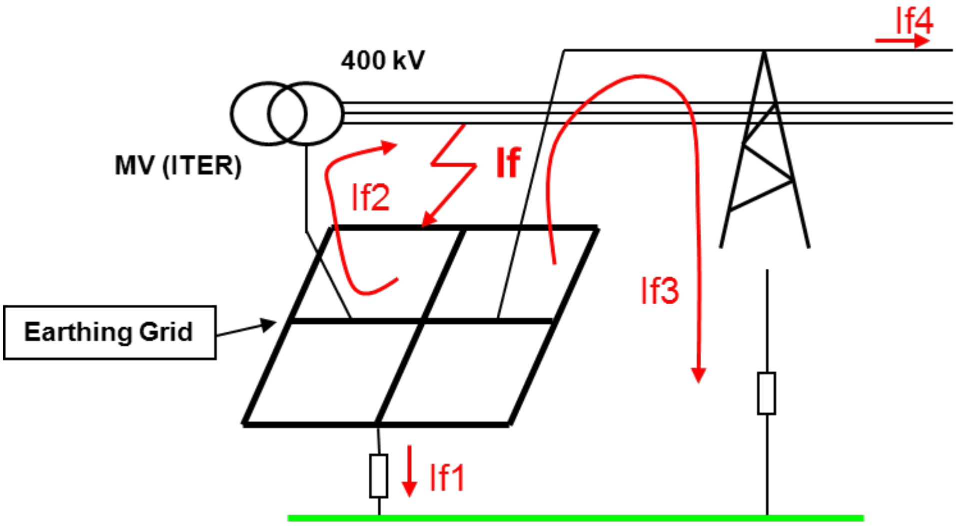


Figure 6-1 Fault earthing currents schematic

All metallic pipes or other long metallic structures **leaving** the ITER earthing grid area shall be isolated at the point of leaving the earthing grid area to avoid hazardous potential transmission along the pipes in order to avoid transferred voltages. The isolation method shall be done accordingly to IEC 62305.

The touch and step voltages for fences on the boundary of the ITER grid shall be analysed in detail. Fence earthing is of major importance because the fence is accessible to the general public and installed near the edge of the earthing grid. So, the ITER facilities earthing grid design should be such that the touch potential on the fence is within the calculated tolerable limit. Step potential is usually not a concern at the perimeter, but it also should be checked to verify that a problem does not exist.

In case of step and touch voltages over the norm limits, there shall be added at least one conductor (same size and characteristics as earthing conductor) one meter away from the outside part of the fence. This conductor shall be connected to the buried earthing grid.

If there is a section of the boundary fence that leaves the meshed grounding grid area and that won't be connected to the general grounding grid, it shall be isolated from the grid by means of appropriate insulating material and distance.

The high security fence around the nuclear perimeter is isolated from the earth, and it is out of the scope of this handbook.

6.2 Around Building Foundations

Every building will be encircled by a continuous copper conductor laid at the building foundation depth but at least at the same depth than ITER earthing grid (Ring Earth Electrode).

The ITER earthing grid (ISEG) will be connected to the Ring Earth Electrode, always via at least two separate routes thus forming additional loops.

Earth electrodes will be connected to the Ring Earth Electrode so that no point of the encircling conductor is more than 10 meters from an earth electrode, i.e. an earth electrode at least every 20 meters. Vertical Electrodes must also be installed at each acute angle formed by the encircling conductor. Large radius arcs are preferred to acute angles.

The conductor material, its cross-section, the depth of the electrodes and the distance between electrodes shall be defined according to the applicable rules (IEC 62305-3, Protection Against Lightning).

The outdoor vertical lightning protection conductors shall be terminated to the earth electrodes. The earth electrodes shall be connected to the Ring Earth Electrode.

Conductors connected to the Ring Earth Electrode will be made available above the surface, in the zones dedicated to host the low voltage supply transformers and load centres. At least one conductor every 25 m² of dedicated surface or one conductor every 10 m in length will be installed. The minimum number of available conductors will be 2. These conductors will be used to earth the transformers neutral conductors and the distribution cubicles.

Additional conductors, also connected to the Ring Earth Electrode, will be made available for the building foundations (foundation embedded loop as indicated in next section). The number of conductors will be at least 2 for a foundation surface of 25 m² or less. For every 25 m² of additional surface, one more conductor must to be planned. The conductors will be installed in a distributed manner all along the foundation periphery. One conductor for every 10 m in length is sufficient for large foundations. They will be used to earth the concrete reinforcement bars and internal metallic structures.

All the connections embedded in the concrete or in the ground must be rigidly screwed and protected against corrosion or preferably welded.

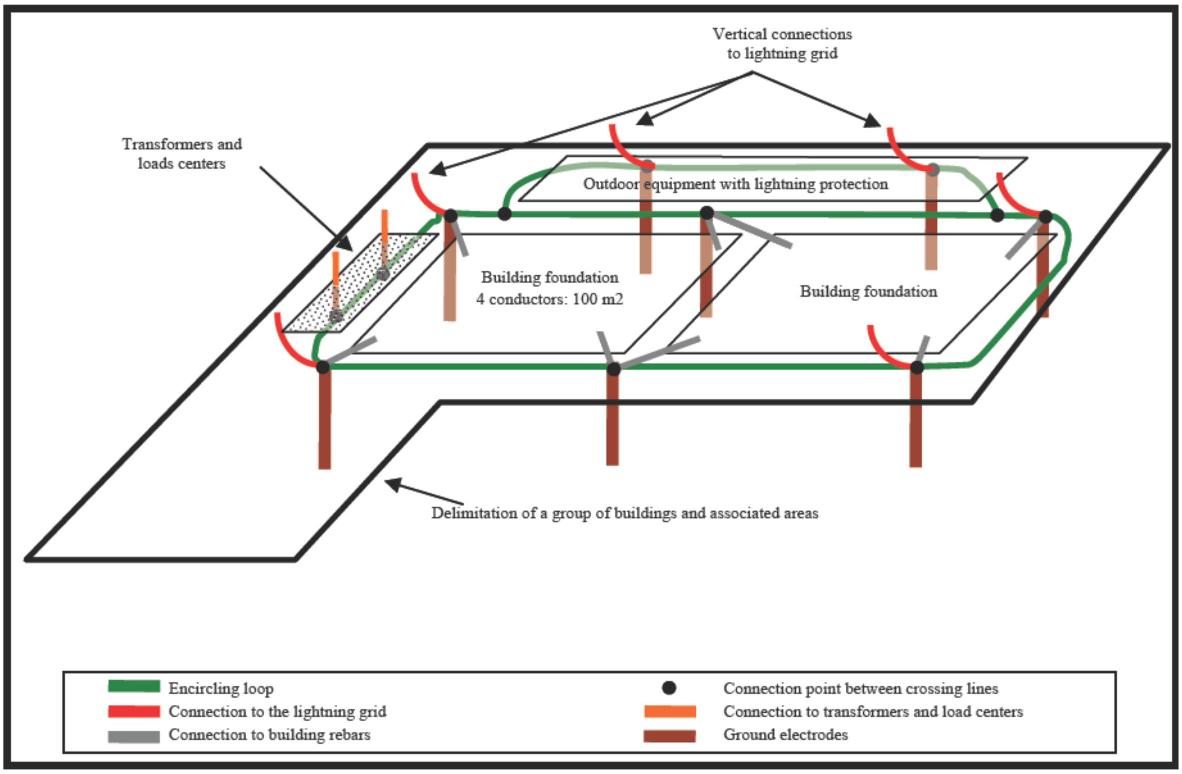


Figure 6-2 Embedded Ring Earth Electrode Around Foundations

6.3 Summary of equipment and structures earthing

6.3.1 Outdoor Equipment

All exposed metal parts of switches, structures, transformer tanks, metallic walkways, fences, switchboards, instrument-transformer secondary windings, etc., must be adequately earthed to the Ring Earth Electrode to ensure personnel protection. This means that each individual piece of equipment and each structural column have reliable electrical connection to the ISEG. Moreover, a visible protection conductor will connect all these elements and run along the supply lines up to power source.

As far as possible, the lightning protection conductors placed on top of or nearby outdoor equipment will be directly connected earthing rods (minimum length and cross-sections are defined at 8.7.1).

6.3.2 Indoor Equipment

Equipment for indoor installation is connected to fixed bonding terminals (or specific embedded plates bonded to the building re-bars) provided inside the buildings on each floor (see details for the Tokamak complex in ITER_D_97ZQ3R). The minimum cross-sections and other properties of the earthing conductors are defined in IEC 60364-5-54.

An earth busbar is provided inside each electrical equipment cabinet.

Shields and armours in power cables must be earthed at both ends.

6.3.3 Tunnels and Cable Trays

All non-current carrying metallic parts in the tunnels must be connected to the ISEG through earthing busbars or earth cables running along the tunnels.

Metallic cable trays are required. Sections of the conducting cable trays will have to be bridged to guarantee low impedance connection.

Separated trays are required for power cables and for control and instrumentation (see ITER_D_34GBZB - SRD-44 (Cable Trays)).

Every cable tray will have a protection conductor electrically bonded to the tray, running all along the one. This conductor shall be electrically bonded to the tray at regular intervals (~5 m), and it shall be terminated at the Earth Ring Electrode.

Metallic cable trays must be earthed at least at both ends. The tray sections have mutual connections along the tray. Multiple earthing conductors connect each tray with the ISEG.

6.4 Earthing in Tokamak Building

6.4.1 Foundations

The Tokamak, Diagnostic and Tritium buildings are in fact three zones of a single building laid on a large foundation of approximately 115 x 80 metres. This foundation will support around 600 seismic dampers on which the building will be constructed.

The document Interaction of Tokamak Building Structures with ITER Magnetic field (ITER_D_2FGN9P) presents the calculations of the eddy currents induced in the building structures and concrete reinforcement bars in the case of the maximum field variation which can occur from the poloidal coils (plasma breakdown). According to its recommendations (part 5), these eddy currents do not present problems with regard to forces or to heating of the structures of the building itself.

The grid at the bottom of the foundation will be around 8 metres mesh.

The embedded grid at the top of the foundation will form a grid with 5 metres mesh size. Its conductors will be screwed or welded to the nearby or crossing reinforcement bars once every one metre. The same will apply for the thick vertical walls surrounding the basements of the Tokamak complex building.

The connection terminals for equipment and frames are not required here. Nevertheless, interconnection between the foundation embedded grid and the tokamak complex building is required as well as earthing of the seismic dampers. Connection terminals will be made available on the foundation floor. They will be used for earthing of the metallic bases of the seismic dampers and their location coordinated with the position of the dampers.

6.4.2 Interconnection between Foundation and Building Basemat

The earthing interconnection between foundation and damped building basemat presents a specific challenge since relative horizontal displacements of up to +/- 200 mm and vertical ones of up to +/- 50mm must to be considered without endangering the earthing integrity.

According to the rules, one vertical earthing conductor per 25 m² of slab surface should be provided. Since the tokamak complex surface is of 9000 m², 360 vertical conductors would be needed.

According to preliminary analysis which describes the seismic system, 550 bearings with a total contact surface of 445 m² will be installed. We would have one vertical conductor for every 1.2 m² of seismic bearing contact surface. The minimum cross-sections of these bonding connections between basemat and foundation shall be calculated according to the lightning protection studies (IEC 62305-3 and 62305-4).

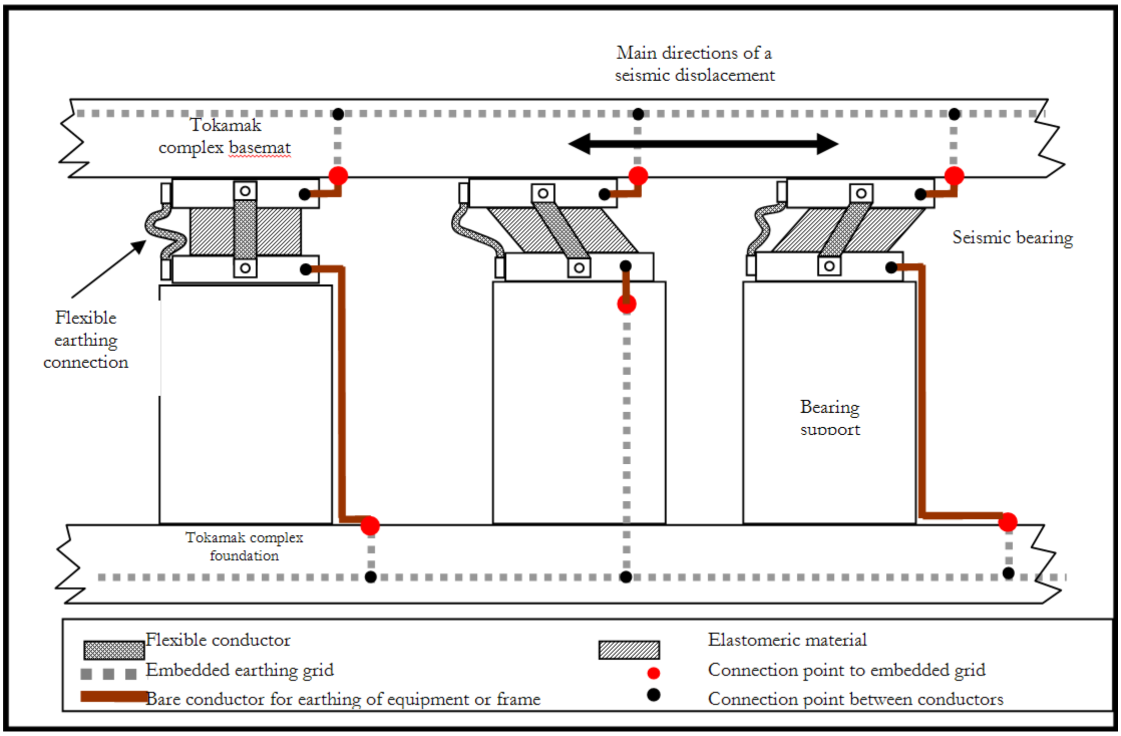


Figure 6-3 Earthing of Tokamak Basemat with Flexible Interconnections

As the elastomeric material used for the seismic bearings may not be engineered for low resistivity, foundation and basemat will have to be interconnected with flexible conductors designed for the expected displacements. As any other metallic component, the structural elements of the bearings will have to be earthed. The lower bearing supports will be connected to the foundation embedded grid each with its vertical conductor and the same will apply for the bearing upper support.

6.4.3 Building Basemat. Embedded Earthing Grid

At the bottom of the basemat, one earthing connection point per seismic bearing will be available. All these connection points will first be interconnected (screwed or welded), creating a 5 m mesh.

All the building re-bars in the walls, pillars and slabs of the Tokamak complex shall be connected, creating a mesh (as indicated in EDH Electromagnetic Compatibility (EMC), ITR-20-006).

On the walls and pillars of the tokamak zone, connection points for earthing of equipment and frames will be made available (details in EDH Electromagnetic Compatibility (EMC), ITR-20-006).

7 The Power system earthing

Equipment earthing is required to guarantee personnel safety in normal operation as well as in case of equipment failure, to minimise EMC noise generation and to improve the reliability and the service continuity of the plant

The power earthing subsystem refers to a system in which the neutral point of transformer or generator windings are intentionally grounded, either solidly or through impedance. This section describes the earthing scheme for Pulsed Power Electrical Network (PPEN) and Steady State Electrical Network (SSEN).

The ITER switchyard integrates both the Steady State and the Pulsed Power Supplies systems. It comprises seven cross bays:

- Four cross bays to feed the SSEN loads
- Three cross bays to feed the PPEN loads

The one line diagrams for the PPEN and SSEN systems are in the IDM documents “41.PP- One-Line Diagram General PPEN Distribution” - ITER_D_35RMBK (PPEN) and “ITER_430000_SLD_000: ITER SSEN One Line General Diagram” - ITER_D_RH3V2M (SSEN).

7.1 Electrical Network Description

7.1.1 Pulsed Power Electrical Network

ITER 400 kV Pulsed Power Substation (PPS) switchyard is an outdoor, air-insulated switchgear based on SF6 circuit breakers. The step-down transformers are connected to the Switchyard by means of overhead line conductors. These transformers are 400 / 66 – 22 kV step-down transformers. The main function of these transformers is to transform the network voltage in order to feed the 66 kV MV main distribution busbars (coil power supply, reactive power compensation and harmonic filtering) and the 22 kV MV main distribution busbars (heating and current drive components).

The 66 kV switchyard is an outdoor, air-insulated switchgear formed by three-phase busbars, which connects the 66 kV transformer side to the 66 kV loads. These busbars are fed from the 400/66-22 kV transformers by means of incoming circuit breakers. The 66 kV busbars are coupled by means of disconnector switches (only for maintenance). Normal 66 kV system configurations will be busbars fed from transformers with the maintenance coupler disconnector switches open.

Harmonic Filtering and Reactive Power Compensation shall be equipped in every 66 kV busbar.

The 22 kV distribution switchgears comprise busbars that feed phases I and II loads and also extended phase loads. In normal operating conditions, every 400/66-22 kV transformer will feed two 22 kV busbars by means of two incoming circuit breakers (one busbar for phases I and II loads and another busbar for extended phase loads).

Disconnectors are foreseen to couple the 22 kV busbars. Normal configuration will be with all the coupler disconnector switches open. These coupler disconnector switches are for maintenance.

The 22 kV cabinets will be located inside building 32 (Magnet Power Conversion Building 1).

7.1.2 Steady-State Electrical Network

The SSEN consists of three main power supply subsystems as follows:

- The 400kV Steady-State Substation (SSS)
- The Steady State Power Distribution (SSPD)
- The Emergency Power Supply System (EPSS)

ITER 400 kV Steady-State Substation (SSS) switchyard is an outdoor, air-insulated switchgear based on SF6 circuit breakers. The step-down transformers are connected to the Switchyard by means of overhead line conductors. The main function of these transformers is to transform the network voltage in order to feed the 22 kV main distribution busbars.

These 22 kV busbars feed the SSEN MV and LV distributed load centres through outgoing circuit breakers. Main switchgears are installed in the MV distribution building 36 close to the Main step-down transformers.

The Steady State Power Distribution (SSPD) is designed to perform the power distribution to all Class IV SSEN consumers. It will be formed by:

- MV distributed load centres, composed by 22/6.6 kV transformers and its corresponding 6.6 kV busbars,
- And LV distributed Load Centres, formed by 22 kV sub-distribution busbars, 22/0.42 kV transformers and 400 V/230 V busbars.

The function of the MV sub-distribution switchgears is to perform the distribution of MV power supply close to the consumers. For 6.6 kV sub-distribution, the power from 22 kV main distribution is transformed in 6.6 kV by means of step-down transformers

The 22/0.42 kV step-down transformer has a phase connection group Dyn11.

400/230 V Low Voltage Main Distribution Board is destined to supply all ITER LV loads of Class IV grouped in Load Centres installed inside the plant, optimally close to the consumers.

The system consists of sub-distribution panels for miscellaneous services spread inside the ITER plant according to the needs of the consumers and supplied from LV LCs.

Emergency Power Supply (EPSS) system is designed to perform the power distribution to:

- Class I, II and III SIC SSEN loads. (see document SRD-43 Steady State Electric Power Supply Networks, for class definition)
- Class I, II and III IP & SR SSEN loads.

Due to their important function in the safety of the plant, SIC (Safety Important Component) emergency power supply is composed by two trains totally redundant (SIC-A and SIC-B). All components of IP Emergency Power System (IP and SR loads) are divided in two bars (IP-A and IP-B).

Each SIC EPS train will be composed by 6.6 kV emergency busbars including 6.6 kV Emergency Diesel Generators (EDG), 6.6/0.42 kV transformers, 400 V emergency busbars, 230 Vac UPS systems, and Vdc systems.

Each IP EPS system will be composed by 6.6 kV emergency busbars including 6.6 kV Emergency Diesel Generators (EDG), 6.6/0.42 kV transformers, 400 V emergency busbars, 230 Vac UPS systems, and Vdc systems.

The power of 22 kV is transformed in 6.6 kV and supplied to the switchgears, by means of step-down transformers. The 6.6 kV main emergency busbars switchgears distribute Class III power supply to MV motors and load centres.

Each LV load centre is connected to its corresponding 6.6 kV switchgear by means of step-down transformers.

Load centres distribute power supply to Class III LV loads, and to Class I and II systems.

7.2 Earthing of Medium Voltage Substations

7.2.1 Purpose

Earthing and bonding system shall be provided for ensuring personnel safety and preserve performance of electrically powered equipment:

- Limiting potential between non-current-carrying conductive parts of plant components
- Providing low impedance return path for earth fault currents
- Providing insulation monitoring and earth fault detection
- Eliminating floating potentials
- Minimising EMC noise voltage generation and EMC noise current propagation
- As far as possible and without endangering personnel, allowing service continuity in case of earth fault

The most important goal of an earthing concept is to guarantee, under normal operation as well as during fault conditions, the security of any person staying inside or outside of the site, near or far away of the equipment. The human body is endangered if electrical current flows through it or if it is submitted to voltage gradients.

The rules agree on the voltage limits below which no danger exists. For long application times, the voltage limits are of 50 V @ 50 Hz and 120 V for DC. Since the current is a consequence of the voltage gradient and the body resistance, only the limit voltages are usually mentioned. For short periods of time, the limit voltages are higher than for continuous application (for dry skin and small area of skin contact.).

In addition to the security aspects, the proposed concept embraces additional goals; to limit the EMC sources of perturbation, to improve the reliability and availability of the plant and to guarantee service continuity.

To prevent voltage being applied to a person (touch, contact, and step) one first impedes the person from making contact with active parts by means of an insulation distance and if technically possible, also a separation screen connected to earth. Thus, even in case of insulation fault, the screen maintains the persons out of danger. Earthing is basically making sure that the voltage applied to accessible elements presents to earth a much lower resistance than the body itself. The current then flows outside the human body and the potential difference decreases. Two parameters are essential, the applied voltage and the resistance existing in parallel to the body.

Finally, the availability of the plant is related to the amount of possible faults, their probability and also to the consequences of the faults. Short circuits between phases will always lead to large currents since the fault represents a very low load appearing in parallel to the supplied one and that the source has low impedance in order to present good efficiency. Short circuits will always result in a fast interruption of the supply, thus affecting the reliability of the system. As far as possible and without endangering personnel, it should be allowing service continuity in case of earth fault (regardless its location).

7.2.2 Pulsed Power Medium Voltage System Earthing

The step-down transformers shall transform the voltage from 400 kV input on the primary winding to an intermediate level of 66 kV and to a medium level of 22 kV on the two secondary windings, suitable for distribution to the loads and to provide an impedance which limits the current deliverable to faults on the secondary sides in a manner which is coordinated with the downstream equipment.

The Y-neutral connection on the 400 kV side shall be solidly earthed or through an impedance (400 kV National Grid operator requirement).

The 66 kV and 22kV system neutral must be low-resistance earthed.

For the low resistance option, the Y-neutral on the intermediate voltage side of the transformers (star winding type) shall be connected to earth by a resistor in order to limit the earth fault current. In case of medium voltage secondary winding (delta winding type) to allow a current path for zero sequence, an earthing transformer should be planned.

The one line diagram of the PPEN distribution is in “41.PP- One-Line Diagram General PPEN Distribution” - ITER_D_35RMBK.

7.2.2.1 Secondary Star Windings (66 kV system)

In the case of a secondary star winding type (66 kV system case) and low-resistance option, the earthing resistor will have to be located at the 66 kV winding of the 400/66/22 kV transformers, inside the boundary of the ITER substation earthing grid and earthed to it.

So, the winding on the intermediate voltage side of the transformer (66kV) shall be connected to earth by a resistor in order to limit the line-to-earth short-circuit current to 500 A (10 sec.). The reason to consider this configuration is to allow the system to disconnect the faulted circuit in case of an earth fault within a short time (less than one second).

If cabling between 400/66/22 kV transformers and the ITER site area are made with cables, their screen must be connected to earth at both ends. Nevertheless, all the 66kV cables laid inside the ITER site area should have their screens earthed at both ends.

7.2.2.2 Secondary Delta Windings (22 kV system)

In case of a transformer secondary of delta type (22 kV system case), no neutral line is required between the substation area and the ITER site area. The system is then intrinsically floating.

So, as we have a delta connected secondary and the low resistance option is recommended, earthing of the 22 kV distribution busbars is made by means of a neutral point earthing transformer that limit the fault current to 500 A (10 sec.). In this case, the distribution busbars should be implemented with an auxiliary earthing transformer, one on each of the 22 kV busbars. The secondary winding of these transformers will provide the path for the zero sequence current and will limit it.

22kV network cables shall have their screens connected to earth at both ends.

7.2.3 Steady State Medium Voltage System Earthing

The earthing scheme for the Steady State Electrical Network is shown in the IDM single line diagram.

The one line diagram of the SSEN distribution is in "ITER_430000_SLD_000: ITER SSEN One Line General Diagram"- ITER_D_RH3V2M (SSEN).

7.2.3.1 22 kV system

The main step-down transformers 400kV / 22kV have their primary windings firmly bonded to the earth grid through their neutrals (solid earthing or through impedance as per PPEN). The secondary windings of the main transformers have a Y-neutral connection through a low impedance connection to earth, as well as all other components of 22 kV distribution system, including transformers, distribution busbars, switchgear etc. This does not apply to the earth switches, normally opened, which provide safe access to the electric components and circuits during the shutdown period for maintenance.

So, the winding on the medium voltage side of the 400 kV / 22 kV shall be connected to earth by a resistor in order to limit the line-to-earth short-circuit current to 500 A (10 sec.). The reason to consider this configuration is to allow the system to disconnect the faulted circuit in case of a line-to-earth short-circuits within a short time (less than one second). In order not to trip in case of a line-to-earth short-circuit an increase the reliability of the system an isolated system or a high-resistance neutral system could be considered, but we must bear in mind the current to earth caused by the capacitances to ground of the 22 kV cables (more than 60 A). This current could be dangerous for people so the faulted circuit must be always disconnected as quickly as possible.

The transformer tank shall be earthed through at least two terminals on opposite sides.

The 22kV cables have to be shielded. If single phase cables are used, each phase conductor will be surrounded with its own screen. The cables will have to be laid in trefoil configuration. If more than one cable per phase is needed, the trefoil arrangements will contain one cable of each phase. Nevertheless, the use of three phase cable with an overall screen in addition to the phase conductor screens shall be preferred.

The 22 kV cables laid inside the ITER site area should have their screens earthed at both ends.

Every conductor screen or three phase cable screen will be earthed to the transformer tank (with 360 degrees) or to a copper earthing collector located on the transformer with a low impedance conductor.

7.2.3.2 6.6 kV system: class IV loads

The class IV transformers 22kV / 6.6kV have their primary windings delta connected (isolated from earth). The secondary windings of these transformers have a Y-neutral connection through a low value impedance, as well as all other components of 6.6 kV distribution system, including transformers, distribution busbars, switchgear, motors etc. This does not apply to the earth switches, normally opened, which provide safe access to the electric components and circuits during the shutdown period for maintenance.

Therefore the winding on the low voltage side of the 22kV / 6.6kV shall be connected to earth by a resistor in order to limit the line-to-earth short-circuit current to 500 A (10 sec.). The reason to consider this configuration is to allow the system to disconnect the faulted circuit in case of an earth fault within a short time (less than one second).

The transformer tank shall be earthed through at least two terminals on opposite sides.

The 6.6 kV cables have to be shielded. If single phase cables are used, each phase conductor will be surrounded with its own screen. The cables will have to be laid in trefoil configuration. If more than one cable per phase is needed, the trefoil arrangements will contain one cable of each phase. Nevertheless, the use of three phase cable with an overall screen in addition to the phase conductor screens shall be preferred.

The 6.6 kV cables laid inside the ITER site area should have their screens earthed at both ends.

Every conductor screen or three phase cable screen will be earthed to the transformer tank (with 360 degrees) or to a copper earthing collector located on the transformer with a low impedance conductor.

7.2.3.3 6.6 kV system: class III loads

This network will supply the Safety Important Components of the plant and backup autonomous sources will be installed.

In this system, as in the class IV system, the step-down transformers 22kV / 6.6kV have their primary windings delta connected (isolated from earth) and the secondary windings of these transformers have a Y-neutral connection through low value impedance. As in the aforementioned system, the winding on the low voltage side of the 22kV / 6.6kV shall be connected to earth by a resistor in order to limit the line-to-earth short-circuit current to 500 A (10 sec.).

There is an important difference between both 6.6 kV systems because the last one feeds the SIC loads and the Investment Protection loads and they have diesel generators installed.

As under emergency situation the loads must remain on service connected to the diesel generator, a high-resistance earthing (line-to-earth short-circuit current limited to 5 A) is proposed for the generator. In this situation, in case of a line-to-earth short-circuit, although an alarm is sent to the operator, the system remains on service increasing the reliability of the emergency loads. The same concerns applies to the IP system. So in this case, the line - to - earth short - circuit current will be limited to 5 A, and in case of line – to – earth fault only alarm is given in order to guarantee the continuity of the service.

In case of diesel generator test, the generator remains connected to the external grid. In this situation, if a line-to-earth short-circuit occurs, the current would be limited to 500 A and the protection system will disconnect the faulted component.

Earthing of the 6.6 kV cables screens and transformers tank earthing will be equal to that described for class IV loads.

7.3 Earthing of Low Voltage Substations

Contrary to medium voltage earthing, the low voltage (400/230 V) distribution is essentially a solidly earthed (neutral) system according to IEC-50601. The 22 kV/400 V transformers in the Load Centres have the earthed neutral on the secondary side.

7.3.1 Purpose

In a similar way as for medium voltage networks, the main purpose of the earthing grid is to guarantee personal security both in normal operation and in case of equipment electrical failure. Since the use of the electrical energy delivered at this voltage level is widely spread over a large spectrum of equipment and applications, it is of concern for a much larger category of personal as is for the high and medium voltage equipment. The risk of accidents is consequently much higher.

Moreover, the low voltage network is aimed to provide electrical power at two voltage levels, the phase to neutral voltage (230V) and the phase to phase voltage (400V). As a result, the neutral voltage is required by the loads and it may drive some current. The neutral has then to be considered as ”active” conductor.

The 230 / 400V voltage level being reachable by personnel who are not always electrical specialists, impose to comply with rules and standards approved in many countries in order to ensure personal safety. At ITER project, the French rule NF C 15-100 Low-Voltage Electrical Installations is applied for all the low voltage installation in ITER site.

This rule allows different distribution schemes and also imposes security concepts. In order to take in consideration the peculiarities of the ITER site, mainly with regard to electromagnetic noise, specific requirements will also have to be complied with.

Finally, measures to ensure a good quality of the earth potential and to prevent it to become a vector of electromagnetic conducted noise have to be taken.

7.3.2 Recommendations

The ITER steady state network “Conceptual Design Review” and “Preliminary Design Review” state that the low voltage 230/400V networks will be provided by step down transformers fed from the 22kV network. The transformers and distribution centres, called Load Centres, will be located as close as possible to the buildings to be supplied. We will took advantage of this de-centralisation philosophy to define effective earthing networks within the supplied building and intending to prevent or reduce transmission of EM noise and perturbations to neighbour buildings and installations.

7.3.3 Earthing of the Step down Transformers

The primary cables (22kV) have to be shielded. If single phase cables are used, each phase conductor will be surrounded with its own screen. The cables will have to be laid in trefoil configuration and twisted regularly along the cable raceway. If more than one cable per phase is needed, the trefoil arrangements will contain the three phases in the arrangement. Nevertheless, the use of three phase cable with an overall screen in addition to the phase conductor screens shall be preferred.

Every conductor screen or three phase cable screen will be earthed to the transformer tank or to a copper earthing collector located on the transformer.

The secondary winding of all the low voltage transformers shall be star or zigzag connection when the primary winding is delta connection. Since the transformers will supply single phase loads they shall be designed for asymmetric loads and present an adequate zero sequence impedance.

At least two visible earthing connections must be available between transformer lid and transformer tank.

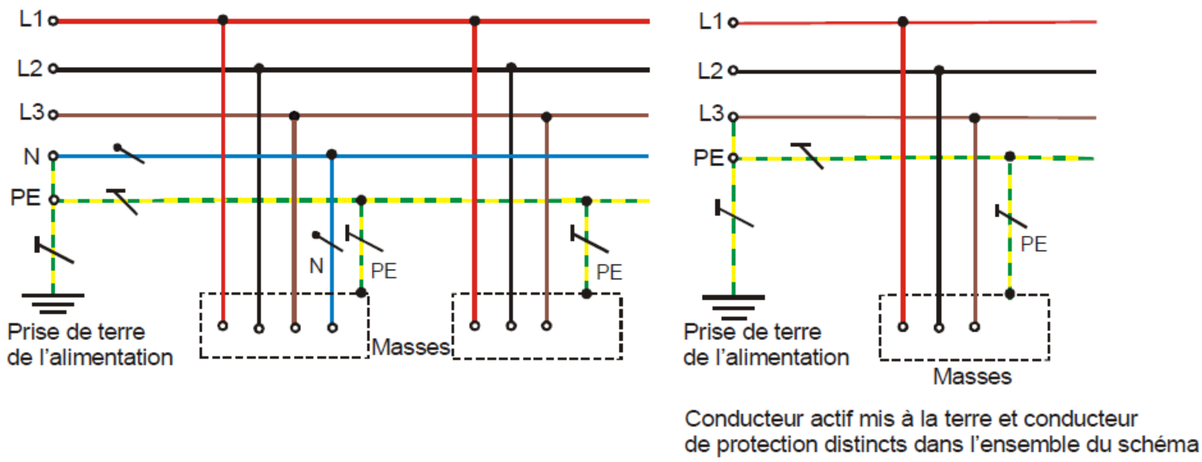
The transformer tank will be earthed at two visible places.

Finally, the transformer neutral feed through will be rigidly earthed at the transformer proximity.

For the connection at the transformer secondary TN-S scheme shall be considered according schemes specified in the standard NF C 15-100:

- TN-S scheme

A five (5) bars configuration is required to feed the power centre (three phases plus a protection bar plus a neutral bar).



French	English
Prise de terre de l'alimentation	Earthing of system
Masses	Exposed-conductive-parts
Conducteur actif mis à la terre et conducteur de protection distincts dans l'ensemble du schéma	Separate earthed phase conductor and protective conductor throughout the system

Figure 7-1 Earthing of Low Voltage Transformer. TN-S Scheme (Figure 312A NF C 15-100)

In case of low voltage cables from transformer to the distribution switchgears, the cables (or non-segregated busbars) must be made of 5 conductors (according to scheme selected) with an overall screen. One of the conductors will be the protection conductor and identified as such according to the NF C 15-100 rule (yellow/green). Its cross-section must be identical to the phase conductor cross-section. The screen cross-section must be higher than 10% of the phase conductor cross-section. The cables will be laid in metallic trays forming a galvanic continuity all over the cable way.

7.3.4 Earthing of Distribution Substations

The low voltage distribution has to be made according the TN-S scheme as described in the NF C 15-100 rule and shown in Figure 7-1.

Any distribution cubicle supplied with low voltage cables from a low voltage transformer, shall include an earthing copper bar whose cross-section shall be equivalent to the cross-section of the supply phases. The protection earth conductors, the screens, the tray and the possible copper bar laid in the cable tray shall be connected to the cubicle earthing bar. This connection has to be made in the vicinity of the main incoming connections. The neutral distribution bar shall be physically connected to the incoming cable. The earthing bar shall be available at each distribution cubicle supplied from the same power cable.

The earthing bar cross-section may be reduced in the cubicles whose rated current has been de-rated compared to the main incomer. However, the cross-section reduction is not allowed in the cubicle where the de-rating current takes place.

All metallic components of the distribution cubicles (doors, walls, etc...) shall be connected to the earthing copper bar located in the cubicles.

The earthing bar installed in the distribution cubicles shall be as well connected to the building earth connection points available in the building rooms and /or around the buildings.

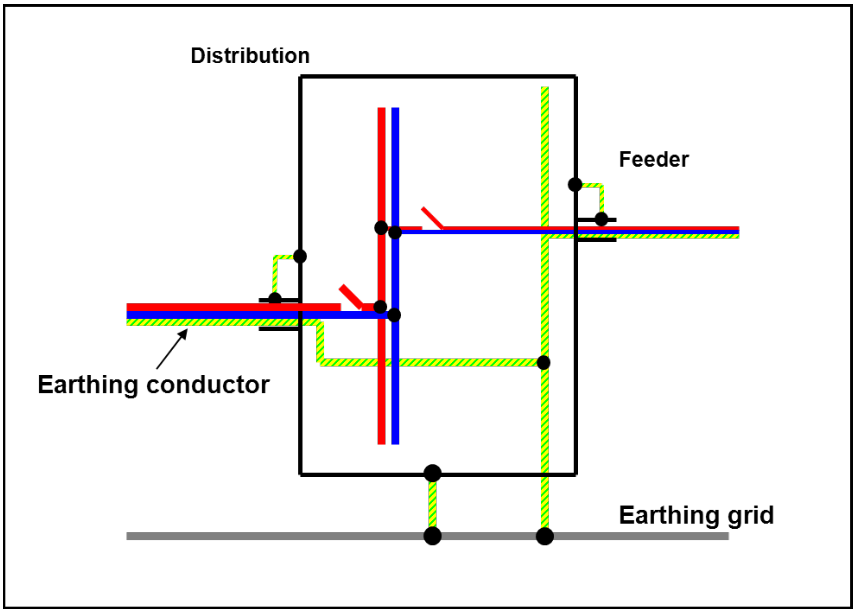


Figure 7-2 Earthing of Low Voltage distribution substations

The distribution busbar shall be a TN-S earthing scheme, 3PH+N+PE for three-phase circuits and 1PH+N+PE for single-phase circuits. Neutral wire (N) could not be distributed if it is not used by the load; in this case, a 3 phase circuit breaker is sufficient. The 230 /400V power cables shall always include a protection conductor and an overall screen; both will be earthed at both ends.

All LV outgoing feeders from the distribution cubicles shall be laid by means of 3, 4 or 5 conductor cables (L1,N,PE; L1, L2, L3, PE or L1, L2, L3, N, PE) according to the TN-S scheme as defined in the NF C 15-100 rule. The cross-section of the protection conductor must be equivalent to the phase conductor cross section. The cables will have a screen over the 3, 4 or 5 conductors. The screens will be connected at both ends to the earthing bar available in the distribution cubicles.

7.4 Earthing of Low Voltage Loads or Consumers

7.4.1 Purpose

As mentioned earlier, the main goal of an earthing concept is to protect the persons from the electric hazards.

The NF C 15-100 rule states:

- that direct contact to the dangerous active parts must not be possible,
- that the conducting elements which may be touched must not present dangerous voltages in normal operation as well as under fault conditions.

Since the fusion research machines are surrounded by many electrical equipment generating DC or low frequency magnetic fields as well as high frequency electromagnetic fields, the earthing concepts has also to deal with these peculiarities. Its design has to take into consideration the Electro Magnetic Compatibility between the noise generators and the victims. This aspect is analysed in EDH part 4.

7.4.2 Loads Earthing

All the low voltage cables will be surrounded by a screen and shall include a protection conductor.

Because of the presence of a lightning protection concept, earthing of the electrical loads installed outside the buildings shall not be carried out as for the loads situated inside the buildings.

The earthing path through the power cables (PE conductor) issued to ensure the personal safety from electric hazards. An additional earthing path through the building reinforcement bars and buried grid shall be implemented in order to increase personal safety.

7.4.3 Loads Inside Buildings

At the load side, both protection conductor and screen will be connected to the metallic parts of the load which may be touched (i.e. frames, enclosures, etc...). If the load consists of many metallic elements which are not mechanically and galvanic interconnected, these parts shall be interconnected by means of an accessible protection conductor (PE). The cross-section of these interconnections is at least as high as the one available in the LV supply cable.

Any conductive (metallic) component part of the same equipment which does not contain an electrical supply but it is located at less than 2.5 meters from electrical part of the equipment shall be also interconnected to the same point of the equipment. If the metallic component of the equipment is surrounded by several electrical equipment, it shall be interconnected to all of them.

All the conductive (metallic) parts or groups of interconnected parts, even if they are not hosting electrical loads, shall be connected in addition to the building earthing grid.

7.4.4 Loads Outside Buildings

The conducting (metallic) parts of the electrical loads installed outside the buildings and exposed to outdoor conditions shall be earthed through a protection conductor in the power cable. Additional bonding is recommended (and may be necessary according to the lightning protection system).

8 Lightning protection

ITER buildings, and very likely discrete installations, on the ITER site may be struck by lightning.

All buildings shall be fitted with a Lightning Protection System (LPS), designed and fitted in accordance with IEC 62305-3 and 62305-4.

This shall include air terminations (for the lightning discharge) connected to down-conductors (routed directly downwards to follow the shortest route), concrete reinforcement and connected to earth electrodes (metal rods and earthing mesh directly into the ground).

8.1 ITER buildings

The ITER buildings shall be designed and constructed to comply with all four parts of the lightning protection standard IEC 62305.

This version only includes the lightning protection mesh for Tokamak complex. The meshes for the other buildings will be designed after the risk analysis according with IEC 62305-2 is performed.

8.1.1 *Protection of equipment*

For the equipment contained within these buildings, the buildings' lightning protection systems shall provide the following protections against:

a) Pulsed magnetic fields caused by lightning events.
b) Overvoltages and overcurrents (usually called surges) on their electrical power distribution and signal cables caused by lightning events of all possible types, whether the strikes attach to:
   - Any parts of the buildings' air termination networks
   - Any parts of the sides of the buildings that could possibly experience lighting side-flashes
   - The ground outside the buildings, or any other structures near to the buildings, that could possibly experience direct lightning strikes

8.1.2 *Lightning protection mesh for Tokamak complex*

The lightning protection mesh for the tokamak complex is shown in the following picture, according with the analytical studies performed at document ITER_D_9AYWRJ:

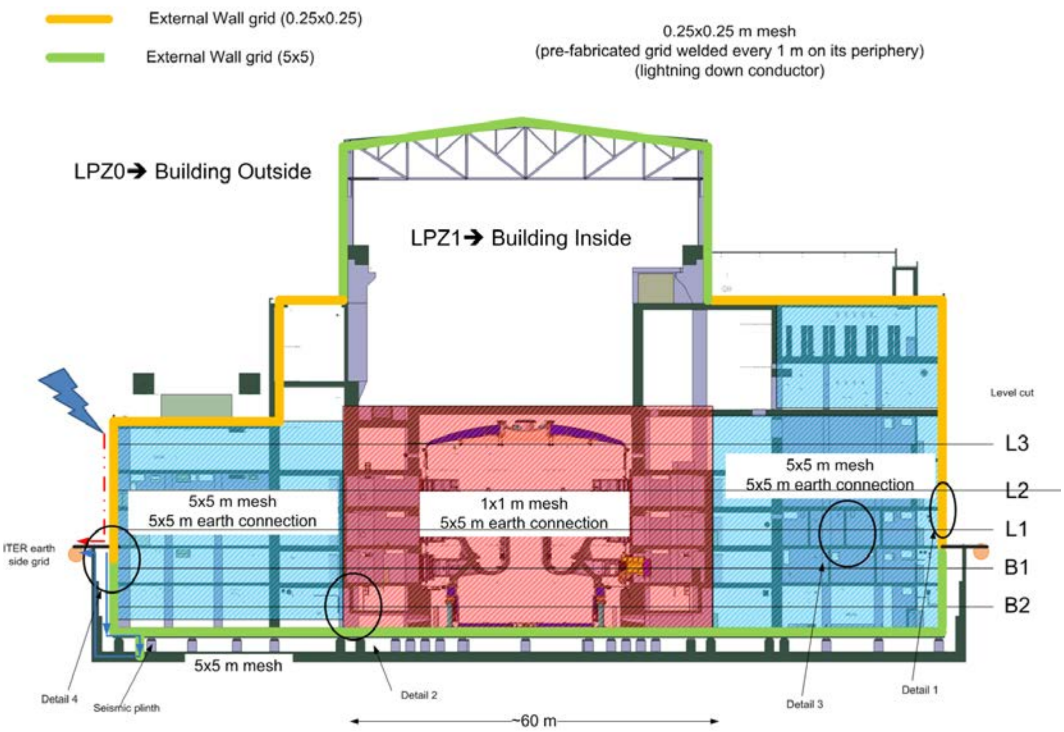


Figure 8.1- Lightning protection mesh for the Tokamak complex. There is an external mesh of 0.25x0.25 m on the areas where a direct lightning impact could be produced, and where electrical and electronic equipment is located. This covers the roof of the Diagnostics and Tritium building, and the external walls of the Tokamax complex from L5 to L1. A pre-fabricated grid of 0.25x0.25 m could be used welded on its periphery every 1 m. The external mesh of 0.25x0.25 m is ended on its upper side at the bottom of the Tokamak cladding (bardage), where it is welded every 1 m on the periphery, and at least 0.5 m below the metallic plate that covers the Tokamak isolation pit (a grounding fix terminal shall be located in this area of 0.25x0.25 m below the plate covering the Tokamak isolation pit). The metallic plate covering the Tokamak isolation pit shall be bonded to the building and to the ITER earthing side grid, as it is part of the lightning down conductor. There is an area around of the Tokamak machine with a mesh of 1x1 m in the internal walls, floor and ceiling covering the port cells and the Neutral Beam Cell (ITER_D_97ZQ3R v1.3). The rest of areas of the tokamak complex will have a mesh 5x5 m.

8.1.3 Protection against overvoltages on electrical power distribution networks

The lightning protection systems shall provide a level of protection against the effects of lightning strikes so that the overvoltages created on electrical power distribution networks within the buildings do not exceed the levels of risetime, voltage or energy specified by the relevant tests in EN 61000-6-2 (i.e. ±2kV line-to-earth and ±1kV line-to-line when tested using the IEC 61000-4-5 test method).

8.1.4 Verification of the design, and validation of the construction

The level of overvoltage protection achieved by the design shall be verified by analysis or simulations of the lightning protection system performed, prior to construction, for each building.

8.2 LPS design flow diagram

In accordance with the IEC 62305, the design of the LPS for ITER buildings must be achieved by treating all the following points:

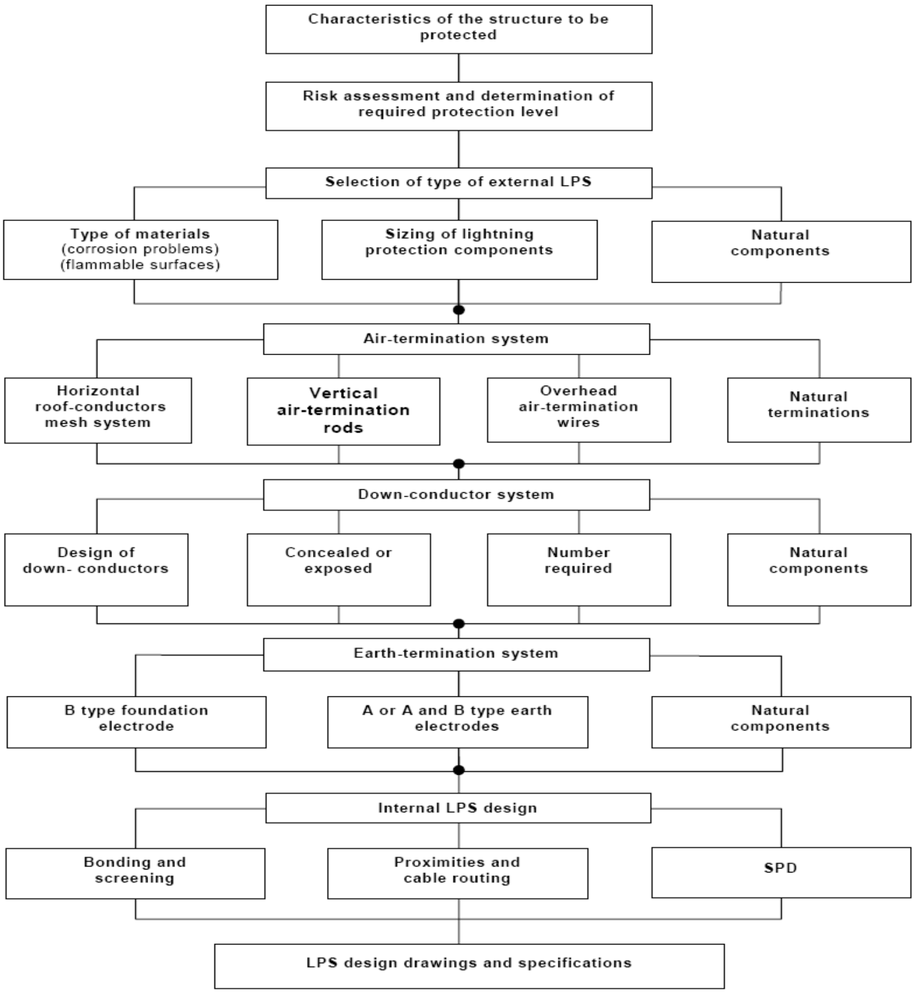


Figure 8-2 LPS design flow diagram

8.3 Characteristics of the structure and risk assessment

Before any detailed design work on the LPS is commenced, the lightning protection designer should, where reasonably practical, obtain basic information regarding the function, general design, construction and location of the structure for each buildings of the ITER structure:

- Tokamak building,
- Tritium building,
- Diagnostic building.

In the design and construction stages of the ITER structure, the LPS designer, LPS installer and all other persons responsible for installations in the structure or for regulations pertaining to the use of the structure (e.g. purchaser, architect, and builder) should be in consultation regularly.

Regarding the risk assessment, the contractor may propose a Lightning Risk Analysis for the Diagnostic building, but the maximum level will be taken necessary for the Tokamak and the Tritium buildings.

8.4 Selection of type of external LPS

8.4.1 Characteristics of LPS

In accordance with the IEC 62305-3-§4, each class of LPS is characterized by the following:

- data dependent upon the class of LPS
  - lightning **parameters** (see Tables 3 and 4 in IEC 62305-1),
  - rolling **sphere** radius, mesh size and **protection angle** (see IEC 62305-3-§ 5.2.2),
  - typical **distances** between down-conductors and between ring conductors (see IEC 62305-3-§ 5.3.3),
  - **separation** distance against dangerous sparking (see IEC 62305-3-§ 6.3),
  - minimum length of **earth electrodes** (see IEC 62305-3-§ 5.4.2).
- data not dependent upon the class of LPS
  - lightning **equipotential bonding** (see IEC 62305-3-§ 6.2);
  - minimum **thickness of metal** sheets or metal pipes in air-termination systems (see IEC 62305-3-§ 5.2.5);
  - **LPS** materials and conditions of use (see IEC 62305-3-§ 5.5);
  - material, configuration and minimum dimensions for **air-terminations**, **down-conductors** and **earth-terminations** (see IEC 62305-3-§ 5.6);
  - minimum dimensions of **connecting conductors** (see IEC 62305-3-§ 6.2.2).

8.4.2 Isolated external LPS

An **isolated external LPS** should be considered when the thermal and explosive effects at the point of strike may cause damage to the structure or to the contents. Typical examples include structures with combustible covering, structures with combustible walls and areas at risk of explosion and fire. This LPS may also be considered when the susceptibility of the contents warrants the reduction of the radiated electromagnetic field associated with the lightning current pulse in the down-conductor.

8.4.3 Non-isolated external LPS (natural components)

A technically and economically optimized design of an LPS is possible especially if the steps in the design and construction of the LPS are coordinated with the steps in the design and construction of the structure to be protected. So, the design of the structure itself should utilize the metal parts of the structure as parts of the LPS ; it's a **non-isolated system to use natural components**.

If the reinforcement of the concrete and any other steel constructions of a structure are connected both externally and internally so that the electrical continuity conforms to IEC 62305-3-§4.3, effective protection may be achieved against physical damage.

The current injected into the reinforcing rods is assumed to flow through a large number of parallel paths. The impedance of the resulting mesh is thus low and, as a consequence, the voltage drop due to the lightning current is also low. The magnetic field generated by the current in the reinforcing steel mesh is reduced as the inverse of the mesh width due to the low current density and the parallel current paths generating opposing electromagnetic fields. Interference with neighbouring internal electrical conductors is correspondingly reduced.

Reinforced concrete structures are considered to be electrically continuous. The electrical continuity of the reinforcing bars shall be determined by electrical testing between the uppermost part and ground level. The overall electrical resistance should be less than 0.2 Ω, measured using test equipment suitable for this purpose (4 wires Kelvin probes). If this value is not achieved, or it is not practical to conduct such testing, the reinforcing steel shall not be used as a natural down-conductor in accordance with IEC 62305-3.

Regarding the ITER buildings, there is no need to define an isolated external LPS if the potentially internal explosive areas are in accordance with the internal LPS criteria (See IEC 625305-3 §6) and the natural components can be used. The contractor shall carry out this analysis of risk for potentially explosive areas and reduction of radiated EM field.

The design documentation of an LPS shall contain all the information necessary to ensure correct and complete installation.

8.5 Air termination system

8.5.1 Elements

The probability of structure penetration by a lightning current is considerably decreased by the presence of a properly designed air-termination system: rods, catenary wires and meshed conductors.

8.5.2 Positioning

Air-termination components installed on a structure shall be located at corners, exposed points and edges (especially on the upper level of any facades) in accordance with one or more of the following methods of the IEC 62305-3 and the IEC annex A:

- **The protection angle method**. For protection level I, the protective angle corresponds to the air-termination height, to height of 20 m (highest possible of protection level I) the protective angle is 23° and height of 10 m is 45° (See Table 2 of the IEC 62305-3 §5.2.2),

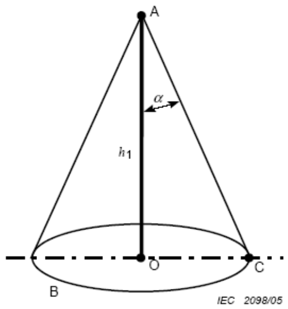


Figure 8-1 Volume protected by a vertical air-termination rod

Key:

A : Tip of on air-termination rod

B : reference plane

OC : radius of protected area

h1 : height of an air-termination rod above the reference plane of the area to be protected

α : protective angle according to table 2 of the IEC 62305-3 §5.2.2

- **The mesh method**; is suitable for horizontal and inclined roofs with no curvature. For protection level I, the maximum mesh size is 5 x 5 m
- **The rolling sphere method**; the positioning of the air-termination system is adequate if no point of the structure to be protected comes into contact with a sphere with radius 20 m (protection level I)

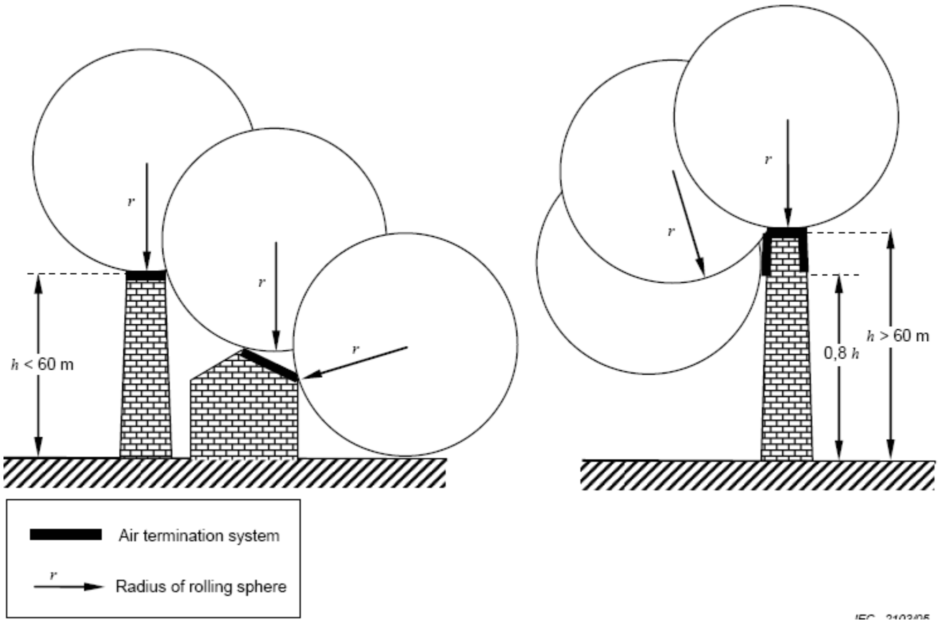


Figure 8-2 Design of an air-termination system according to the rolling sphere method

On structures taller than 60 m, flashes to the side may occur, especially to points; corners and edges of surfaces.

An air-termination system shall be installed to protect the upper part of tall structures; typically the topmost 20 % of the height of the structure, and the equipment installed on it. For the structures taller than 120 m, all parts witch may be endangered above 120 m should be protected.

For the ITER project, the Contractor shall specify the positioning of an Air Termination System that is appropriate for the height of each building.

8.5.3 Natural components

The following parts of a structure should be considered as natural air-termination components and part of an LPS:

- Metal sheets covering the structures to be protected, the thickness of the metal sheet is not less than the values given in Table 3 of the IEC 62305-3 §5.2.5,

- Metal components of roof construction underneath non-metallic roofing,
- Metal parts such as ornamentation, railings, pipes, coverings of parapets, etc.
- Metal pipes and tanks on the roof with thicknesses and cross-sections in accordance with Table 6 of the IEC 62305-3 §5.6.2,
- Metal pipes and tanks carrying readily-combustible or explosive mixtures provided that they are constructed with thickness not less than the appropriate values given in Table 3 of IEC 62305-3 §5.2.5 and that the temperature rise of the inner surface at the point of strike does not constitute a danger (for detailed information, see Annex E of the IEC 62305-3).

A thin coating of protective paint or about 1 mm asphalt or 0.5 mm PVC is not regarded as an insulator.

8.5.4 Examples of air-termination constructions

This figure contains examples of air-termination constructions which protect the roof fixtures of conducting and isolating material enclosing electrical installations.

Where:

1 Air-termination conductor

2 Metallic cover

3 Bonding conductor

4 Horizontal air-termination conductor

5 Electric equipment

6 Electric power junction box with SPD

7 Bonding joint to the conductive elements of the structure

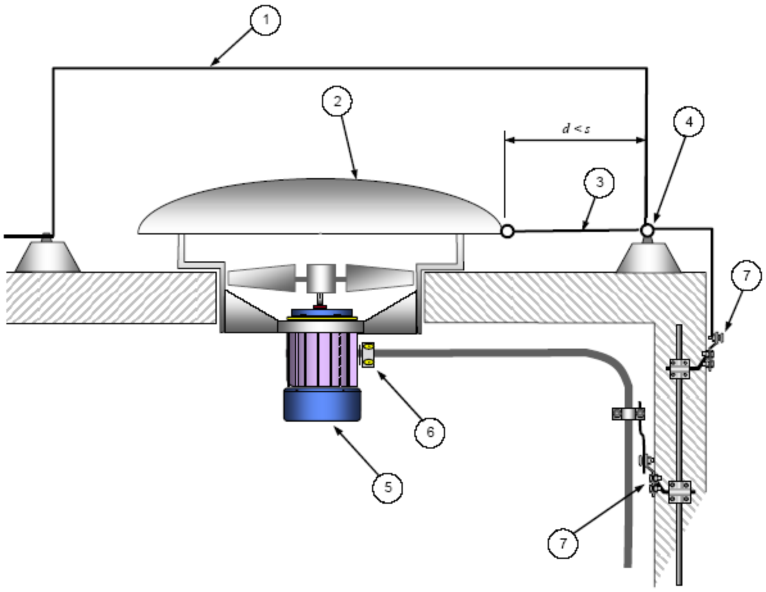


Figure 8-3 Metallic roof fixture protected against direct lightning interception, connected to air-termination system

8.6 Down Conductor system

8.6.1 Objectives

In order to reduce the probability of damage due to lightning current flowing in the LPS, the down-conductors shall be arranged in such a way that from the point of strike to earth:

- several parallel current paths exist;
- the length of the current paths is kept to a minimum;
- equipotential bonding to conducting parts of the structure is performed according to the requirements of the IEC 62305-3 §6.2.

8.6.2 Positioning for an isolated LPS

For ITER buildings, it does not seem necessary to install an isolated LPS. But, if the contractor shows the benefits of such protection, then it must apply the requirements in accordance with the IEC 62305-3 §5.3.2 and 6.3 for the separation distance

8.6.3 Positioning for a non-isolated LPS

Lateral connection of down-conductors at ground level and **every 10 m** of height are considered to be good practice. The number of down-conductors shall be not less than two and should be distributed around the structure perimeter to be protected.

When the distance from down-conductor to a combustible material cannot be assured, the cross-section of the conductor shall be not less than 100 mm². For the design calculation and the evaluation of the Kc coefficient, the contractor must apply method from IEC 62305-3 §Annex E4.2.4.

The following parts of the structure should be considered as **natural down-conductors** providing that continuity is assured and the resistance is checked between the connection point to the circuit capture and point of connection to the earth's natural component is carried out (resistance must be less than 0.2 Ω):

- The metal installations. Piping carrying ready-combustible or explosive mixtures shall not be considered as a down-conductor natural component if the gasket in the flange couplings in not metallic or if the flange-sides are not otherwise properly bonded. Only if the connections are in accordance with the IEC 62305-3 §5.5.2.
- The metal of the electrically-continuous reinforced concrete framework of the structure.
- The interconnected steel framework of the structure
- The facade elements, profile rails and metallic sub-constructions, provided that metal pipes thicknesses shall be not less than 0.5 mm and with extra requirements in accordance with the IEC 62305-3 §5.6.2.

Each down-conductor is joined to a control joint to measure the earth and is also compatible with the same material and the other conductors. This terminal must only be removable with a tool.

When the vertical continuity of the natural down-conductors, providing a straight path from roof to ground cannot be guaranteed, additional dedicated conductors should be used. These additional conductors should be lashed to the reinforcement steel.

To reduce the probability of a person standing under a cantilevered construction from becoming an alternate path for lightning current flowing in the down-conductor running on the cantilevered wall, the actual distance, d, in metres should satisfy the following condition:

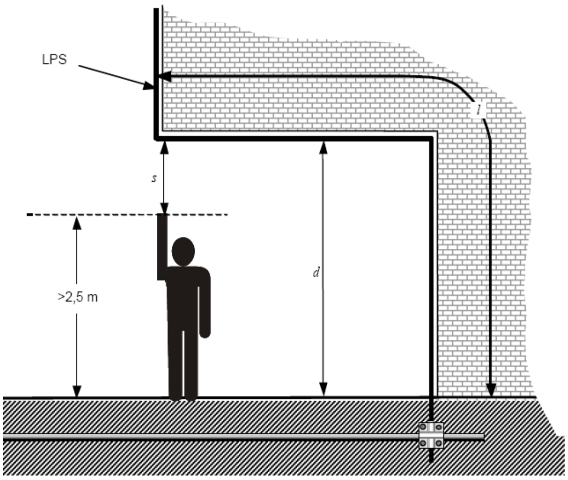


Figure 8-4 LPS design for a cantilevered part of a structure

$$d > 2.5+s$$

where:

s : the separation distance in metres calculated in accordance with IEC 62305-3 §6.3

d: Actual distance > s

l : length for the evaluation of separation distance s

***note**: the height of the person with raised hand is taken to be 2.5m*

8.7 Earth termination system

When dealing with the dispersion of the lightning current (high frequency behaviour) into the ground, whilst minimizing any potentially dangerous overvoltage, the shape and dimensions of the earth-termination system are the important criteria. In general, a low earthing resistance (if possible lower than 10 Ω when measured at low frequency) is recommended by the IEC 62305-3 §5.4. For the actual maximum resistance value, calculation can be done with data from 62305-3 §5.4.2.

For earth-termination systems of ITER, two basic types of earth electrode arrangements apply.

8.7.1 Type A arrangement: electrodes

This type of arrangement comprises horizontal or vertical earth electrodes installed outside the structure to be protected connected to each down-conductor.

The minimum length of each earth electrode at the base of each down-conductor is

- **l1** for horizontal electrodes, or
- **0,5 l1** for vertical (or inclined) electrodes,

Where l1 is the **minimum length** of horizontal electrodes shown in the relevant part of Figure 2 of the IEC 62305-3 §5.4.2 and cross section of table 6.

For combined (vertical or horizontal) electrodes, the total length shall be considered.

The earth electrodes shall be installed at a depth of upper end at least 0,5 m and distributed as uniformly as possible to minimize electrical coupling effects in the earth.

8.7.2 Type B arrangement: ring

This type of arrangement comprises either a ring conductor external to the structure to be protected, in contact with the soil for at least **80 % of its total length**, or a foundation earth electrode. Such earth electrodes will also be meshed with the earthing network.

For the ring earth electrode (or foundation earth electrode), the mean radius re of the area enclosed by the ring earth electrode (or foundation earth electrode) shall be not less than the **value l1** (where l1 is the same length of type A in accordance with figure 2 of the IEC 62305-3 §5.4.2).

However, when the required value of l1 is larger than the convenient value of re, additional horizontal or vertical (or inclined) electrodes shall be added in accordance with the IEC 62305-3 § 5.4.2.2.

The ring earth electrode should preferably be buried at a depth of at least 0,5 m and at a distance of about 1 m around the external walls.

And for bare solid rock, only type B earthing arrangement is recommended. And, for structures with extensive electronic systems or with high risk of fire (see IEC 62305-2), type B earthing arrangement is preferable.

So, for ITER project, the contractor will evaluate the two types of arrangement to achieve earth termination system, but **the type B is recommended.**

In both cases, the earth-termination system shall be installed to allow an inspection during construction.

Interconnected reinforcing steel in concrete foundations in accordance with IEC 63305-3 §5.6, or other suitable underground metal structures, should preferably be used as an earth electrode.

8.8 Components

Components of an LPS shall withstand the electromagnetic effects of lightning current and predictable accidental stresses without being damaged.

Components of an LPS shall be manufactured from the materials listed in Table 5 of the IEC 62305-3 §5.5 or from other materials with equivalent mechanical, electrical and chemical (corrosion) performance characteristics.

Material and its dimensions shall be chosen bearing in mind the possibility of corrosion either of the structure to be protected or of the LPS.

Configurations and minimum cross-sectional areas of **air-termination conductors, air-termination rods and down-conductors** are given in Table 6 of the IEC 62305-3 §5.6.

Configurations and minimum dimensions of **earth electrodes** are given in Table 7 of the IEC 62305-3 §5.6.

Industrial structures frequently comprise sections of reinforced concrete which are produced on site. In many other cases, parts of the structure may consist of prefabricated concrete units or steel parts.

Steel reinforcement in reinforced concrete structures conforming to IEC 62305-3 §4.3 may be used as a natural component of the LPS.

Such natural components must fulfil the requirements of:

- **down-conductors** according to IEC 62305-3 §5.3;
- **earth-termination** networks according to IEC 62305-3 §5.4.

Moreover, the conductive reinforcement of concrete, when properly used, should form the cage for potential equalization of the internal LPS according to IEC 62305-3 §6.2.

Furthermore, the steel reinforcement of the structure, if adequate, serves as an electromagnetic shield, which assists in protecting electrical and electronic equipment from interference caused by lightning electromagnetic fields according to IEC 62305-4.

If the reinforcement of the concrete and any other steel constructions of a structure are connected both externally and internally so that the electrical continuity conforms to IEC 62305-3 §4.3, effectively protects against physical damage.

Bonding conductors or grounding plates should be furnished in order to provide reliable electrical connection to the reinforcement steel. Conductive frames that, for example, are attached to the structure may be used as natural LPS conductors and as connection points for the internal equipotential bonding system.

A practical example is the use of foundation anchors or foundation rails of machines, apparatus or housings, to achieve potential equalization. This figure illustrates the arrangement of the reinforcement and the bonding bars in an industrial structure. The mesh-CBN (meshed Common Bonding Network) is the main part of this global network.

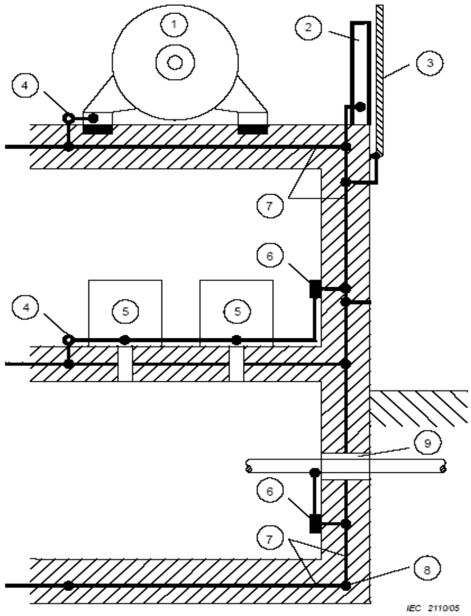


Figure 8-5 Equipotential bonding in a structure with a steel reinforcement

Where :

1 : Electrical power equipment

2 : Steel girder

3 : Metal covering of the facade

4 Bonding joint

5 Electrical or electronic equipment

6 Bonding bar

7 Steel reinforcement in concrete (with superimposed mesh conductors)

8 Foundation earth electrode

9 Common inlet for different services

8.9 Internal LPS design

Dangerous sparking may occur between the metal installations, the internal systems and the external conductive parts and lines connected to the structure.

An internal LPS prevents dangerous sparking within the structure using **either** equipotential bonding or a separation distance (and hence electrical insulation) between the external LPS components and other electrically conducting elements internal to the structure.

8.9.1 Lightning equipotential bonding

Equipotentiality is achieved by interconnecting the structural metal parts, metal installations (Mesh-CBN), internal systems and external conductive parts and lines connected to the structure.

Interconnecting means can be

- **Bonding conductors**, where the electrical continuity is not provided by natural bonding (in accordance with the Table 1 of the IEC62305-4),
- **Surge Protective Devices** (SPDs), where direct connections with bonding conductors are not feasible.

8.9.1.1 Lightning equipotential bonding for metal installations

In the case of a not isolated external LPS, the equipotential union shall be established in the next locations:

- In the basement or approximately at ground level.
- Where insulation requirements are not interconnected (See IEC 62305-3 §6.3)

Lightning equipotential bonding connections shall be made as direct and straight as possible.

The bonding conductors should be dimensioned for the proportion of lightning current flowing at the bonding point (see Tables below from the IEC 62305-3 §6.2.2).

Minimum dimensions of conductors connecting different bonding bars or connecting bonding bars to the earth-termination system :

Material	Cross-section mm²
Copper	14
Aluminium	22
Steel	50

Minimum dimensions of conductors connecting internal metal installations to the bonding bar :

Material	Cross-section mm²
Copper	5
Aluminium	8
Steel	16

If insulating pieces are inserted into gas lines or water pipes, inside the structure to be protected they shall, with the agreement of the water and gas supplier, be bridged by SPDs designed for such an operation (cf. §8.9.5).

8.9.1.2 Lightning equipotential bonding for external conductive parts

For external conductive parts, lightning equipotential bonding shall be established as near as possible to the point of entry into the structure to be protected.

Bonding conductors shall be capable of withstanding the part of the lightning current flowing through them evaluated in accordance with Annex E of IEC 62305-1.

If direct bonding is not acceptable, SPDs with the characteristics of the §8.9.5 shall be used

8.9.1.3 Lightning equipotential bonding for internal systems

If the internal systems conductors are screened or located in metal conduits, it may be sufficient to bond only these screens and conduits to earth termination system. The Mesh-CBD efficiently protects any internal equipment. If conductors of internal systems are neither screened nor located in metal conduits, they shall be bonded via SPD (See Annex B of IEC 62305-3). In TN systems, PE and PEN conductors shall be bonded to the LPS directly or with a SPD.

Bonding conductors and SPDs shall have the same characteristics as indicated in §8.9.5 or from IEC 62305-3 §6.2.2.

8.9.1.4 Lightning equipotential bonding for lines connected to the structure to be protected

Lightning equipotential bonding for electrical and telecommunication lines shall be installed in accordance with IEC 62305-3 §6.2.3.

All the conductors of each line should be bonded directly or with an SPD. Live conductors shall only be bonded to the bonding bar via an SPD. In TN systems, PE or PEN conductors shall be bonded directly or via SPD to the bonding bar.

If lines are screened or routed into metal conduits, these screens and conduits shall be bonded; lightning equipotential bonding for conductors is not necessary provided that the cross-section Sc of these screens or conduits is not lower than the minimum value Scmin evaluated in accordance with Annex B from the IEC 62305-3.

Lightning equipotential bonding of the cable screens or of the conduits shall be performed near the point where they enter the structure. Bonding conductors and SPDs shall have the same characteristics as indicated in IEC 62305-3 §6.2.3.

If protection against surges of internal systems connected to lines entering the structure is required, a “coordinated SPD protection” conforming to the requirements of IEC 62305-4, Clause 7 shall be used.

8.9.2 Isolation of installation

The electrical insulation between the air-termination or the down-conductor and the structural metal parts, the metal installations and the internal systems can be achieved by providing a distance d between the parts greater than the separation distance s:

$$s = k_i \frac{k_c}{k_m} l$$

For the LPS class I:

Ki = ***0.08***

Kc = ***1/n*** *with n is the number of down-conductors (See Annex C of IEC 62305-3)*

Km = ***Air=1*** *or* **Concrete, bricks=0.5** *(When there are several insulating materials in series, it is good practice to use the lower value for Km)*

l =length*, in metres, along the air-termination or the down-conductor, from the point where the separation distance is to be considered, to the nearest equipotential bonding point.*

In the case of the lines or external conductive parts connected to the structure, it is always necessary to ensure lightning equipotential bonding (by direct connection or connection by SPD) at their point of entry in the structure.

An adequate separation distance, determined should be maintained between the external LPS and all conductive parts connected to the equipotential bonding of the structure.

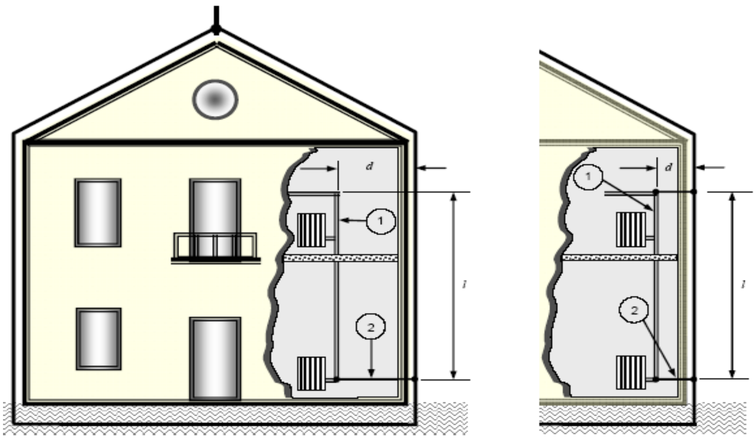


Figure 8-6 Calculated separation distances

Where:

1: Metal pipe

2: Equipotential bonding

d: Distance between a down-conductor and a metallic installation inside the building

l: Length for the evaluation of separation distance s

s: Separation distance

NOTE When the distance between a down-conductor and the internal installations cannot be increased above the calculated separation distance, bonding should be provided at the most distant point.

In structures with metallic or electrically continuous, connected, reinforced, concrete framework of the structures, a separation distances is not required in accordance with the IEC 62305-3 §6.3.

So, for ITER buildings, the contractor must prove that it is not required to impose separation distances.

When bonding of installations to the LPS is performed at the reference point and the furthest point, the separation distance is fulfilled along the whole path of the installation.

The following points are often critical and require particular consideration:

- In the case of larger structures, the separation distance between the LPS conductors and the metal installations is often so large that it cannot be implemented. This involves additional bonding of the LPS to these metal installations.
- Electromagnetic interference occurring as a result of these partial currents should be taken into account when planning the structure installations and designing the lightning protection electromagnetic zones inside the structure according to IEC 62305-4. The Mesh-CBN eases this demand.

8.9.3 Welding or clamping to the steel-reinforcing rods

Welding to the reinforcing rods is only permitted if the civil works designer consents. The reinforcing rods should be welded over a length not less than **30 mm**.

Where:

1 Reinforcing bars

2 Welded seam at least 30 mm long

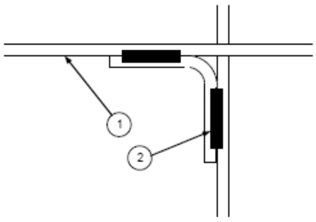


Figure 8-7 Welded joints of reinforcing rods in reinforced concrete

Where joints between the reinforcing rods in concrete and the bonding conductor are made by means of clamping, two bonding conductors should always be used for safety reasons; since the joints cannot be inspected after the concrete has set. If the bonding conductor and reinforcing rod are dissimilar metals, then the joint area should be completely sealed with a moisture inhibiting compound. Brazing or welding is preferred.

The connection to outside components of the lightning protection system should be established by a reinforcement rod brought out through the concrete at a designated location or by a connecting rod or ground plate passing through the concrete which is welded or clamped to the reinforcing rods.

Figures show clamps (two bonding conductor shaded in grey) used for joints for reinforcing rods and solid tape conductors.

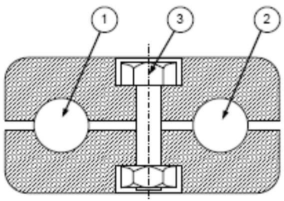


Figure 8-8 Circular conductor to a reinforcing rod

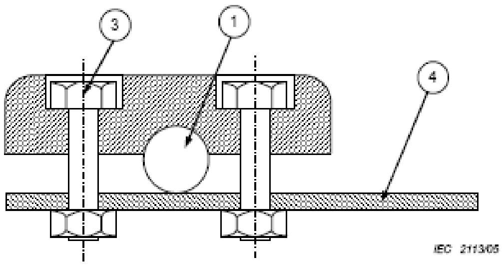


Figure 8-9 Solid tape conductor to a reinforcing rod

Where:

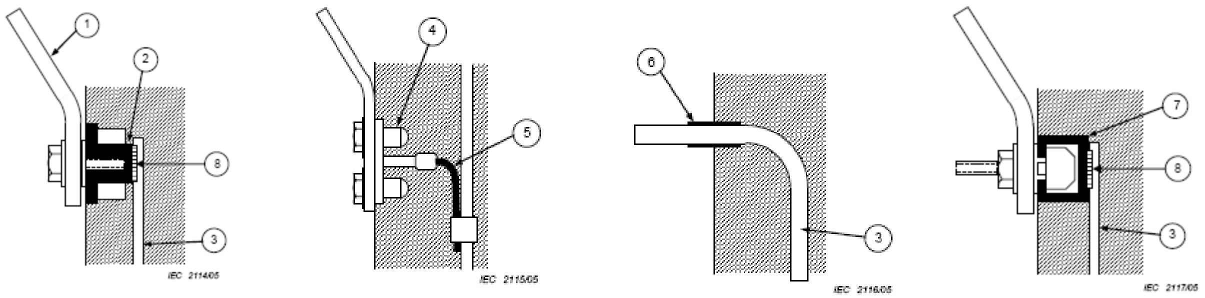
1: Reinforcing rod

2: Circular conductor

3: Screw

4: Tape conductor

Figures4.9.8 below show examples of details for connection of an external system to reinforcing rods:



Where:

1: bonding conductor

2: Nut welded to steel bonding connector

3: Steel-bonding connector

4: Cast in non-ferrous bonding point

5: Stranded copper bonding connector

6: Corrosion protection measure

7: C-steel (C-shaped mounting bar)

8: welding

8.9.4 Corrosion

Where steel reinforcement bonding conductors are brought through a concrete wall, particular attention should be paid to protection against chemical corrosion.

The simplest corrosion protection measure is the provision of a silicon rubber or bitumen finish in the vicinity of the exit point from the wall, e.g. 50 mm or more in the wall and 50 mm or more outside the wall (see figure on previous page).

Where copper bonding conductors are brought through the concrete wall, there is no corrosion risk if a solid conductor, proprietary bonding point, PVC covering, or insulated wire is used (see Figure on previous page). For stainless steel bonding conductors, in accordance with Tables 6 and 7 of the IEC 62305-3 §5.6, no corrosion prevention measures need to be used.

In the case of extremely aggressive atmospheres, it is recommended that the bonding conductor projecting from the wall be made of stainless steel.

NOTE Galvanized steel outside of the concrete in contact with reinforcement steel in the concrete may, under certain circumstances, cause damage to the concrete.

When cast-in type nuts or mild steel pieces are used, these should be protected against corrosion on the outside of the wall. Serrated lock washers should be used to make electrical contact through the protective finish of the nut (see Figure on previous page).

8.9.5 Surge Protective Device (SPD)

Surge protective devices (SPDs) should withstand the prospective part of the lightning current flowing through them without being damaged. An SPD should also have the ability to extinguish electrical power follow-on currents from the power supply if they are connected to the electrical power conductors.

SPDs shall have the following characteristics:

- class I test;
- Iimp ≥ kcI with kcI being the lightning current flowing along the relevant part of the external LPS (see Annex C of the IEC 62305-3);
- the protection level UP shall be lower than the impulse withstand level of insulation between parts,
- Iimp ≥ If with If being the lightning current flowing along the considered external conductive part (see Annex E of IEC 62305-1),
- Other characteristics conforming to **IEC 61643-12.**

Note: Where protection of internal systems against LEMP (Lightning Electro-Magnetic Pulse) is required, SPDs shall also conform to IEC 62305-4.

Surge protective devices (SPDs) should be provided as part of the LPS for all locations where explosive material is present. Where practicable, SPDs should be positioned outside locations where solid explosive material is present. SPDs positioned inside locations where exposed explosives or explosive dust is present should be of explosion-proof type or contained within explosion-proof enclosures.

For the protection of roof fixtures enclosing electrical or information processing equipment, if the fixtures need extra protection, SPDs on the active cables connected to it can be provided at roof level.

For buildings higher than 30 m, it is recommended to repeat the equipotential bonding at a level of 20 m and every 20 m above that. However, in all circumstances the separation distance should be maintained. This means that, at the very least, on those levels the external down-conductors, the internal down-conductors and metal parts should be bonded. Live conductors should be bonded via SPDs.

In the following figure, an example of bonding arrangement in a structure with multiple point entries of external conductive parts entering the structure above ground level.

With :

1 Electric power or communication line

2 External horizontal ring conductor

3 External conductive part

4 Down-conductor joint

5 Steel reinforcement in the wall

6 Bonding joint to construction steel

7 Bonding bar

8 SPD

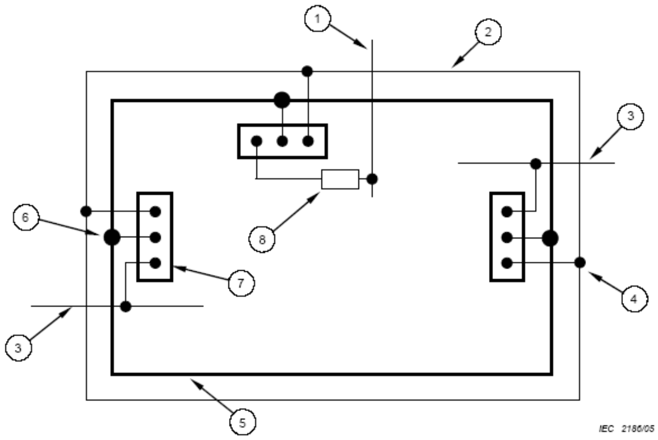


Figure 8-10 Example of bonding arrangement

If the services entering the building are not shielded, the partial lightning current will flow on the active conductors. In this case, SPDs with lightning current capabilities should be placed at the entry point. PE or PEN conductors may be connected to the bonding bar directly.

8.10 Inspection, Testing, Records and Maintenance

The object of the inspections is to ascertain that the LPS conforms to the design bases on this standard, all components of the LPS are in good condition and capable of performing their designed functions, and that there is no corrosion and any recently added services or constructions are incorporated into the LPS.

Inspections should be made according to:

- during the construction of the structure, in order to check the embedded electrodes,
- after the installation of the LPS,
- periodically at such intervals as determined with regard to the nature of the structure to be protected, corrosion problems and the class of LPS,
- after alterations or repairs, or when it is known that the structure has been struck by lightning.

During the **periodic inspection**, it is particularly important to check the following:

- deterioration and corrosion of air-termination elements, conductors and connections,
- corrosion of earth electrodes,
- earthing resistance value for the earth-termination system,
- condition of connections, equipotential bonding and fixings.

Periodicity is determined by the protection level and the local environment, like ground or corrosive atmosphere. For the protection level I for normal frequency is 2 years and increased frequency is 1 year.

The Lightning protection system shall be checked after all modifications, repairs or after lightning strike.

The following items shall be inspected **visually** as part of a periodic test:

- confirm that connections have not been subject to over-tightening and that there is no evidence of failure of the driver or its interfacing part
- ground and screen conductors are intact
- there aren't changes needing complementary protection
- there is no evidence of damage to the lightning protection components
- routing of cables is maintained
- security distances to screen are respected

After maintenance and inspection, all defects found shall be repaired immediately and if necessary, the technical documentation is shall be updated.

The lightning protection system must be maintained periodically in accordance with quality procedures to ensure that it continues to provide effective protection against lighting. The mechanical and electrical characteristics of the lightning protection system shall be maintained throughout its lifetime in order to meet the requirements of the standard.

8.11 Protection measures against injury to living beings due to touch and step voltages

8.11.1Protection measures against touch voltages

In certain conditions, the vicinity of the down-conductors of an LPS, outside the structure, may be hazardous to life even if the LPS has been designed and constructed according to the above-mentioned requirements.

The hazard is reduced to a tolerable level if one of the following conditions is fulfilled:

- the probability of persons approaching, or the duration of their presence outside the structure and close to the down-conductors, is very low;
- the natural down-conductor system consists of several columns of the extensive metal framework of the structure or of several pillars of interconnected steel of the structure, with the electrical continuity assured;
- the resistivity of the surface layer of the soil, within 3 m of the down-conductor, is not less than 5 kΩm.

If none of these conditions are fulfilled, protection measures shall be adopted against injury to living beings due to touch voltages as follows:

- insulation of the exposed down-conductor is provided giving a 100 kV, 1,2/50 μs impulse withstand voltage, e.g. at least 3 mm cross-linked polyethylene;
- physical restrictions and/or warning notices to minimize the probability of down-conductors being touched.

8.11.2 Protection measures against step voltages

In certain conditions, the vicinity of the down-conductors outside the structure may be hazardous to life even if the LPS has been designed and constructed according to the abovementioned rules.

The hazard is reduced to a tolerable level if one of the following conditions is fulfilled:

- the probability of persons approaching, or the duration of their presence in the dangerous area within 3 m from the down-conductors, is very low;
- the resistivity of the surface layer of the soil, within 3 m of the down-conductor, is not less than 5 kΩm.

If none of these conditions is fulfilled, protection measures shall be adopted against injury to living beings due to step voltages as follows:

- equipotentiality by means of a meshed earthing system;
- physical restrictions and/or warning notices to minimize the probability of access to the dangerous area, within 3 m of the down-conductor.

Protection symbols shall conform to the relevant standards (see ISO 3864-1).

References

This ITER Technical Report may contain references to internal technical documents. These are accessible to ITER staff and External Collaborators included in the corresponding ITER Document Management (IDM) lists. If you are not included in these lists and need to access a specific technical document referenced in this report, please contact us at ITR.support@iter.org and your request will be considered, on a case by case basis, and in light of applicable ITER regulations.