

# ITER - Earthing

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Earthing of electrical installations is mainly governed by security rules. Electromagnetic compatibility also deals with earthing, among others circuit characteristics. Tokamaks are large-scale electrical installations that are known to generate large and low frequency magnetic fields as well as large and high frequency electrical fields. Four European Tokamak installations have been investigated, from the earthing point of view, to identify the best possible techniques to earth the electrical equipments and to provide the lowest possible electromagnetic interferences with the measurement circuits. But none of these existing installations looks like ITER, no even remotely. The plasma current range, the superconducting coils, the thick and continuous vacuum vessel, the cryostat, the very high voltage of its neutral beam injectors, the available amount of auxiliary heating power, the sensitivity of its magnetic measurements required for long pulses, the size of the site and the powerful supply utility grid do all affect the plant earthing. Based on these investigations and the ITER specificities, a layout of the ITER site electrical supply grid and of the related earthing grid is proposed. Basic rules to reduce the electromagnetic noise at its sources and to improve the measurements immunity are also suggested.

Keywords: Tokamak plants, Earthing, Grounding, Electromagnetic compatibility.

## 1. Introduction

End of 2007, EFDA contracted the CRPP for a task named "Engineering for the grounding of the ITER components inside the tokamak, diagnostics and tritium plant buildings and the assembly hall" under EFDA reference "TW6-TES-TKGND" with number 07-1601.

The EU is responsible for the SSEPN (Steady State Electrical Power Network) system design and installation. The delivery of the components will be shared between USA and EU. The grounding of the equipment is considered as a part of the SSEPN and therefore, has to be designed by the EU.

Within this frame, the main goal of the task is to propose to the ITER Organization a conceptual design of the machine grounding system. The task has been organized in three separate subtasks, each of them being finalized by an intermediate report.

As a first step, the earthing system of three European tokamaks was analyzed in order to identify a State of the Art. Tore-Supra in Cadarache (France), JET in Culham (England) and Asdex Upgrade in Garching (Germany) were selected. Since some of the authors has been involved in the design and construction of the TCV tokamak (Switzerland) and its buildings, the earthing system of this last machine was also commented.

The aim of the second subtask was to propose a conceptual design for the ITER earthing system together with a collection of directives.

The third step consisted of writing a specification for the engineering design work of the earthing.

## 2. State of the art in Europe

Some intrinsic properties of Tokamaks, such as

generation of large and low frequency magnetic fields as well as large and high frequency electrical fields make them very different from actual nuclear fission reactors. Moreover, the tokamak operation relies on very sensitive measurements (microvolt range) located in its core, which is not the case in fission cores. The electrical engineers should not apply the usual security earthing rules without paying specific care and attention. Preventing the electromagnetic fields from endangering the device integrity and from polluting signal measurements requires extensive engineering studies.

These problems are well known inside the fusion community. The fusion laboratories have approached them in many different ways and have arrived to a number of different philosophies, some of them, perhaps, with better results than others.

ITER is facing exactly the same issues. Moreover, it will generate higher magnetic fluxes and higher electrical fields (1MV Neutral Beam injectors) than the tokamaks built in the eighties.

### 2.1 JET

JET recorded its first plasma in 1983. From the dimensions and performance point of view, JET is the closest machine to ITER. Its power is supplied from a 400kV utility grid through a substation located near the site. The distribution takes place at 33kV. At this voltage level the earth fault current is limited to 5A.

In the 400kV substation site, the measured soil resistivity was approximately 50ohm\*m at 20cm and 20ohm\*m at 1m depth.

The buildings are erected over a grid made of copper cables with a mesh width of 10m. Those grids are interconnected with copper conductors. However, no

connection exists to the earthing grid of the 400kV substation. Copper risers connected to the building grids and to the reinforcement steel are available inside the buildings, typically every 15m. These copper risers are interconnected by means of copper bars, thus forming a general purpose Local Earth inside the buildings.

The tokamak components are connected, star wise, to an earthing collector, the Machine Earth, which is in turn connected to the building grid. Remote equipment, such as diagnostics and coil power supplies are referred, always star wise, to the Machine Earth collector. It has to be reminded that JET has a magnetic core that should leave little flux to cross the earthing grids.

## 2.2 Tore-Supra

Tore Supra, which started operation in 1988, was selected as reference machine because it is the only one in Europe that has superconducting coils as ITER will have. Moreover, the machine is designed for long plasma pulses, which is also an important similarity with ITER.

The equipment is installed in five adjacent buildings or areas situated 100m away from the 400/63kV substation that supplies the experiment. A 15kV/400V transformer located outside the 400kV substation and the tokamak building zones provides the low voltage distribution. The soil of the Tore Supra site is calcareous and particularly dry, thus highly resistive.

The 400kV substation equipment is earthed by means of interconnected rods distributed around the substation. This grid is connected to the Tore Supra buildings, including their specific 63/20kV substation, by means of an insulated conductor.

The foundations of the buildings and transformer zones are laid on a single and wide earth mat made of 95mm<sup>2</sup> steel cables with a mesh of about 7 meters. Vertical derivations, connected to the earth mat and to the reinforcement steel bars, are brought up to the building basements for equipment earthing.

The earthing mat of the tokamak hall is laid according to the specific hexagonal geometry of the machine magnetic core. Six earthing collectors situated just below the tokamak may be connected either to the earth mat, to the rebars or to both.

## 2.3 Asdex Upgrade

Asdex Upgrade went into operation in 1991 and is, in Europe, the most recent fusion device of these dimensions.

The equipment, such as the flywheel generators, the coil power supplies and the high voltage power supplies for auxiliary heating, are located in separate buildings, with distances up to 300m between them. The site land is flat, made of coarse gravel and is humid due to the presence of ground water, thus presenting low resistivity.

It has not been possible to identify, if and how, the concrete steel bars of the older buildings are connected to the surrounding ground.

In more recent building, hosting the high voltage

power supplies for auxiliary heating, the lightning protection grid is connected, outside the building, to the zinc-coated steel bars coming out of the foundation. These connections are available inside the building.

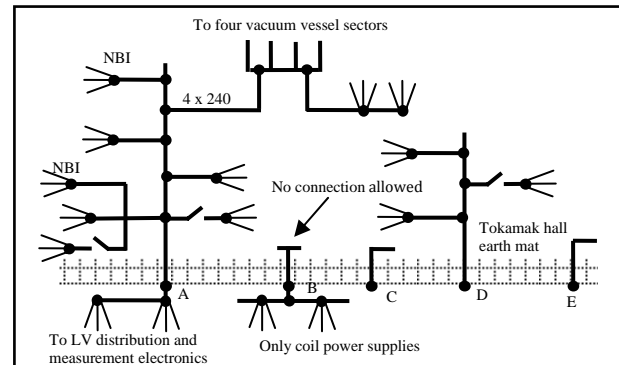


Fig.1 Earthing scheme in the Asdex Upgrade tokamak hall.

As showed in figure 1, the equipment located in the machine hall is star-wise earthed to the building embedded grid. The cabling of the instrumentation has been very carefully designed and many galvanic insulation steps are implemented, mainly when leaving the torus hall and next, before entering the control room where signal final treatment takes place.

## 2.4 TCV

TCV is, compared to the three selected machines, a small tokamak which went into operation in 1992. It has little similitude with ITER but is nevertheless exploring operation domains of high interest for ITER. It has been designed to investigate plasmas with high growth rates. Controlling this kind of plasmas requires precise magnetic signals, high bandwidth and high signal to noise ratio. Thus, the earthing of the machine and its auxiliaries was carefully designed.

The equipment is located in two adjacent buildings, one of them being dedicated to the flywheel generator which supplies the power equipment. The layout within the two buildings is such that the power equipment is located at the opposite side of the control and acquisition electronics with the tokamak in between.

The site land is a clay moraine and the underground water level is three meters below land surface. Its resistivity is low.

No earth mat is laid underneath the foundations. Steel profiles are laid around both building foundations, connected to deep (5 - 10m) rods and also to the concrete reinforcement steels. The steel profiles are brought inside the building halls for connection to the earth of metallic structures or equipment. There are no special features for the tokamak hall.

An earthing grid made of copper bars is running along all the power cabling trays. It is connected to all the nearby connection points of the embedded grid and to the power equipment frames and structures.

The control and instrumentation cabling within the tokamak hall is made according to the star wise principle as shown in figure 2. All the power connections to the

coils are located on the same machine sector. This sector and the incoming power cabling define a radial boarder that cannot be crossed by any kind of cabling.

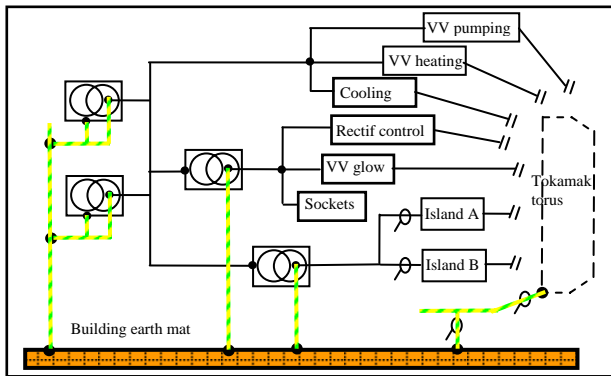


Fig.2 Earthing scheme in the TCV tokamak hall.

## 2.5 State of the art: Summary

Unfortunately, it has not been possible to identify clear concepts that would have been unanimously accepted and implemented. Moreover, when asking if problems related to earthing have been experienced and if signal quality is as good as expected, the answers were often depending of the interviewee. Finally, it has been noticed that the main actors of those earthing systems are no longer professionally active and when asking why some choices were made, the obtained answers are now uncertain.

## 3. ITER site earthing concept

The following goals drive the proposed concept:

- Protect from electrical dangers any person staying inside or outside the ITER site, near or far away from the equipments, during normal operation or fault conditions.
- Limit the electromagnetic perturbation sources and improve the reliability, the availability and the service continuity of the plant.
- Implement a power and signal cabling concept, as the one developed in [1], which provides immunity to electromagnetic perturbation.
- Induced and earth fault currents have to flow back to their sources through low impedance paths connected in parallel to the earthing grids. As a consequence, the earthing grids should host only negligible currents and provide stable potential reference.

### 3.1 High, medium and low voltage distribution

The 400kV grid that will supply the ITER site is rigidly earthed, thus allowing for important earth currents and voltages. Its earthing grid has to be separated from the ITER site earthing grid.

The medium voltage networks installed inside the ITER site should be earthed through high impedances thus as to limit the earth fault currents to the ampere range. Three phase cables should be used and the conductor shields earthed at both ends. Metal clad equipment should be preferred to surface consuming outdoor equipments and conductors which radiate electromagnetic fields.

The 400V networks have to be rigidly earthed. The layout of the sources and of the consumers should be designed so that each network occupies the smallest possible surface. The 400V cabling should be made with shielded cables each containing the normal current return path (neutral) and protection conductors. They have to be laid in closed metallic trays whose current conducting capability would be improved with bare copper conductors running along them. The protection conductors, cables trays and bare conductors should be earthed at least at both ends.

### 3.2 Loads and consumers

Any electrical load will be earthed through its connection to the protection conductors provided with the supply cables, through the shielding of the cables and to the building earthing grids. The control and signal cabling should be based on shielded twisted pairs, with shields earthed at both ends. The proposed configuration allows for power and control cabling to be laid in the same trays if care is taken in separating both categories.

## 4. ITER earthing grid

Applying the rules presented above allows for a simplification of the earthing grids to be laid deep in the ground and below the buildings. The importance of the earthing grid vertical path up to the ground (soil) is reduced if the horizontal paths of the grid are reinforced and also made accessible at any time, allowing for easy checks, modifications and improvements.

The soil resistivity has been measured in different occasions. The resistances vary between 400 ohm\*meter for early measurements down to 80 ohm\*meter recently measured after site preparation. In any case, the soil resistivity is to be considered as high to very high.

### 4.1 Overall site

No overall earthing grid, covering the over 250'000 m<sup>2</sup> surface of the ITER site, is required. The buildings or groups of nearby buildings should be surrounded by a copper conductor connected to rods, to the concrete reinforcement structures and to the building steel structures, thus forming an embedded earthing grid. The inner walls of the building halls will be fitted with connection points to the embedded grid. These points will be used for connection to the earthing grid formed by bare copper conductors, cabling trays, protection conductors, cable screens and equipment frames.

### 4.2 Tokamak building

Because of the stray magnetic poloidal field generated by the tokamak and its high time derivative, the rules presented above should be applied very carefully or even modified. A study provided by the US ITER Project Office [2] shows that the tokamak will generate important but acceptable induced currents into the building steel structures as long as the current is distributed over all the steel elements. As shown in figure 3, the embedded grid located in the outer parts of the tokamak complex may be designed according to the general rules stated above, but the grid situated just

below the machine as well as the walls surrounding it must provide an embedded grid where all the rebars and steels structural elements are electrically interconnected.

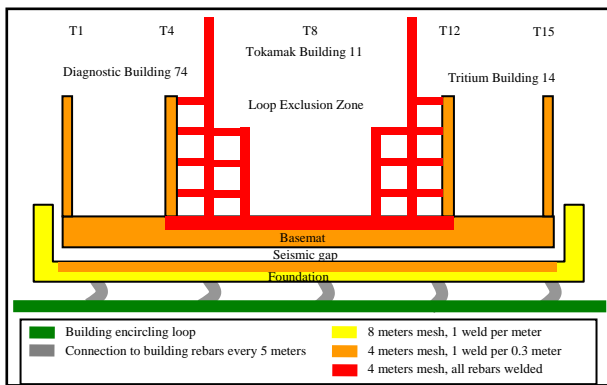


Fig.3 Embedded earthing grid in the ITER tokamak complex.

### 4.3 Loop exclusion zone

Unlike the building structural components, the cabling and equipment installed in the tokamak hall may be very sensitive to induced currents and forces. In this hall, the equipment and cabling layout must not generate large conductive loops, the worst ones being those centered on the machine axis. A radial border, centered on the machine axis and whose crossing would be highly forbidden, must be early decided, before the equipment layout around the tokamak is designed. Small conductive loops would be allowed, and even recommended, to improve the signal cabling immunity. Nevertheless, the pickup surface of these small loops should be limited to a minimum by means of an adequate layout of the equipments and of the cabling routes. The usual concept, namely Star-Wise or Single Point earthing, is not found to be the most appropriated since it may allow for induced voltages between equipments and provides poor shielding.

### 5. Tokamak earthing

As for all equipment hosting electrical loads, the tokamak has to be earthed. Since no electrical insulation is planned in the base plate of the cryostat, in the toroidal coils supporting ring and in the supports of this ring, it is proposed to improve the contacts between machine and floor with 18 vertical copper conductors (one per sector) connected to the cryostat and to the embedded grid situated just below the machine.

The cryostat and the vacuum vessel are a kind of focal points for a large part of the electrical power installed on the site, it is commonly agreed that the vacuum vessel and cryostat, despite being earthed, may host fast and large potential transients presenting a danger for the persons and equipment in contact with them. As a general rule, no conductive component connected to the machine should be available outside the Loop Exclusion Zone. In case exceptions are required, these conductive components should be insulated from earth and made inaccessible similarly to live electrical conductors.

There are two possible earthing schemes for the

control and instrumentation cabling and equipment situated near the machine. In one case, the equipment is fully insulated from the machine and its cabling can be brought outside the loop exclusion zone. In that case, an optimal shielding of the cabling is not possible. In the other case, the equipment is in galvanic contact with the machine, shielding is optimal but the cabling can't be brought outside the zone without presenting some galvanic insulation. The later configuration, presented in figure 4, is recommended.

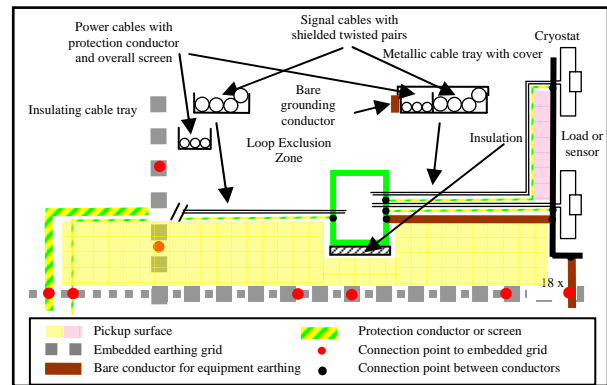


Fig.4 Earthing concept in the ITER tokamak hall.

### 6. Conclusions

Despite the earthing of tokamak plants has always been considered as an important matter, it has been poorly described, documented and discussed. The valuable know-how which was available in the eighties has dim. Moreover, ITER is very different from the machines constructed 20 to 30 years ago.

Completion with the security rules and standards is not a challenge if consideration of the signal quality is left to the signal transmission and treatment specialists.

The presented work suggests an earthing concept which would provide the security level required by the rules together with careful attention to the signal quality which will be required to operate ITER successfully.

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