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ITER – Earthing

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ABSTRACT

Earthing of electrical installations is mainly governed by safety rules. Electromagnetic compatibility also deals with earthing, among other 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 electric fields. Four European Tokamak installations have been investigated, from the earthing point of view, to identify appropriate techniques to earth the electrical equipment and to provide the lowest possible electromagnetic interference with the measurement circuits. But none of these existing installations looks like ITER, not 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 grid 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 measurement immunity are also suggested.

1. Introduction

The EU is responsible for the SSEPN (Steady State Electrical Power Network) design and installation. The earthing of the equipment is considered to be part of the SSEPN and therefore, has to be designed by the EU.

EFDA has 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 the reference "TW6-TES-TKGND" with number 07-1601.

Within this frame, the main goal of the task was to propose to the ITER Organization a conceptual design of the tokamak earthing 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 have been involved in the design and construction of the TCV Tokamak (Switzerland) and its buildings, the earthing system of this last tokamak 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 the generation of large and low frequency magnetic fields as well as large and high frequency electric fields make them very different from present nuclear fission reactors. Moreover, 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 therefore apply the usual safety earthing rules [3] 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 at a number of different philosophies, some of them, perhaps, with better results than others.

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

2.1. JET

JET created 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 400 kV utility grid through a substation

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located near the site. The distribution takes place at 33 kV. At this voltage level the earth fault current is limited to 5 A.

In the 400 kV substation, the soil resistivity was around 50 Ω m at 0.2 m and 20 Ω m at 1 m depth.

The buildings are erected over a grid made of copper cables with a mesh width of 10 m. Those grids are interconnected with copper conductors. However, no connection exists to the earthing grid of the 400 kV substation. Copper risers connected to the building grids and to the steel reinforcement bars (rebars) are available inside the buildings, typically every 15 m. These risers, interconnected by means of copper bars, form 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 noted that JET has an iron core that should ideally leave little flux to link to the earthing grids.

2.2. Tore Supra

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

The equipment is installed in five adjacent buildings or areas situated 100 m away from the 400/63 kV substation that supplies the experiment. A 15 kV/400 V transformer located outside the 400 kV 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 400 kV 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 63/20 kV 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 95 mm^2 steel cables with a mesh of about 7 m. Vertical conductors, connected to the earth mat and to the rebars, 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 tokamak iron 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 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 300 m 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 buildings, 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.

As shown in Fig. 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 isolation steps are implemented, mainly when leaving the torus hall and next, before entering the control room where final signal treatment takes place.

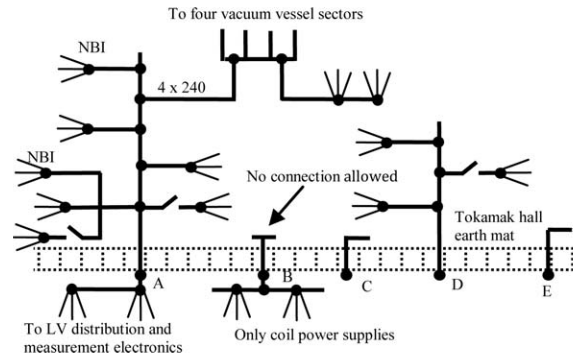

Fig. 1. Earthing scheme in the Asdex Upgrade tokamak hall.

2.4. TCV

TCV is, compared with 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 was designed to investigate plasmas with high vertical 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 dedicated to a 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 (5–10 m) rods and also to the concrete rebars. The steel profiles are brought inside the building for earthing of metallic structures or equipment. There are no special features for the tokamak hall.

An earthing grid made of copper bars runs 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 laid according to the star wise principle as shown in Fig. 2. All the power connections to the coils are located on the same

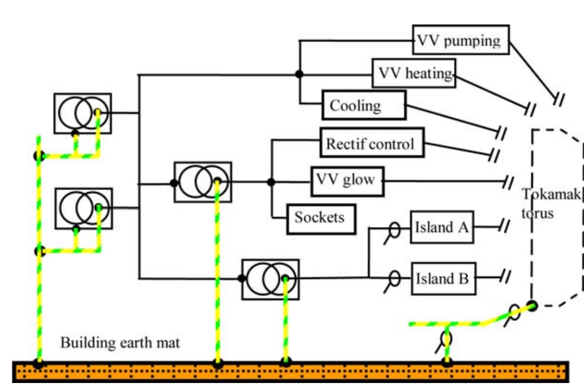

Fig. 2. Earthing scheme in the TCV tokamak hall.

machine sector. This sector and the incoming power cabling define a radial line that cannot be crossed by any kind of cabling on any floor.

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 subjective, depending on 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 prescriptive concept:

- Protect from electrical dangers any person inside or outside the ITER site, near or far away from any equipment, 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 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 shall host only negligible currents and provide stable potential references.

A previous study [1], which develops earthing and EMC concepts for fusion experiments, has been of great help for the development of the present concept.

3.1. High, medium and low voltage distribution

The 400 kV grid that will supply the ITER site is rigidly earthed, thus allowing large earth currents and voltages (tenths of kA, kV). Its earthing grid therefore shall be separated from the ITER site earthing grid.

The medium voltage networks installed inside the ITER site shall be earthed through high impedances so as to limit the earth fault currents to the ampere range. Three phase cables shall be used and the conductor shields earthed at both ends. Metal clad equipment shall be preferred to outdoor equipment and conductors which radiate electromagnetic fields and take up a lot of space[4].

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

3.2. Loads and consumers

Any electrical load shall 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 shall be based on single or multiple twisted pairs, with independent or overall shields and earthed at both ends. The proposed configuration allows for power and control cabling to be laid in the same trays by taking care when separating both categories.

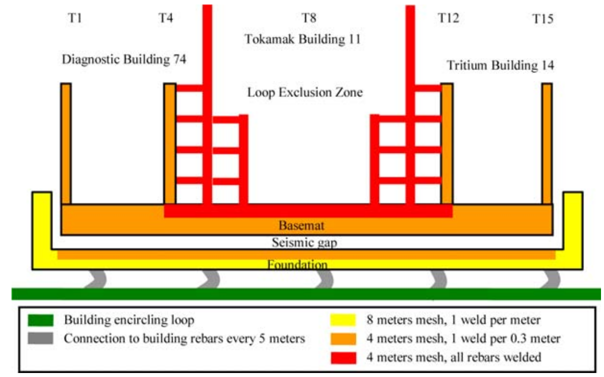

Fig. 3. Embedded earthing grid in the ITER tokamak complex.

4. ITER earthing grid

Applying the rules presented above allows 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 down to the ground (soil) is reduced by the horizontal paths of the grid being reinforced and also made accessible at any time, allowing easy checks, modifications and improvements.

The soil resistivity has been measured on different occasions. The resistances vary between 400 Ω m for early measurements down to 80 Ω m 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 250,000 m^2 area of the ITER site, is required. The buildings or groups of nearby buildings shall be surrounded by a copper conductor connected to rods, to the rebars and to the building steel structures, thus forming an embedded earthing grid. The inner walls of the building halls shall be fitted with connection points to that grid. These points shall 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 shall be applied very carefully or even enhanced. A study provided by the US ITER Project Office [2] shows that the tokamak will generate large induced currents into the building steel structures, which will be acceptable as long as the current is distributed over all the steel elements. As shown in Fig. 3, the embedded grid located in the outer parts of the tokamak complex can be designed according to the general rules stated above. However, the grid situated below the machine as well as the walls surrounding it shall provide an embedded grid where all the rebars and steel structural elements are electrically interconnected.

4.3. Loop exclusion zone

Unlike the building structural components, the cabling and equipment installed near the tokamak is endangered by induced currents and forces. A surface area (the Loop Exclusion Zone) shall be defined, in which the equipment and cabling layout shall

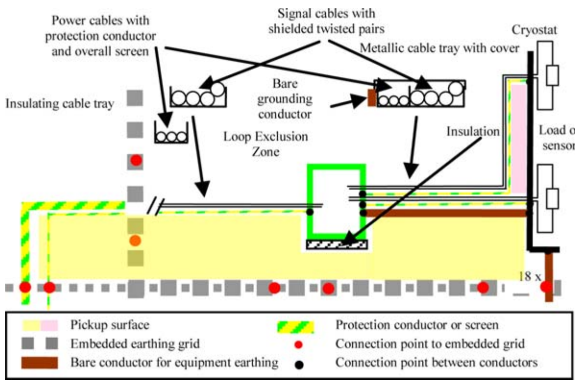

Fig. 4. Earthing concept in the ITER tokamak hall.

not generate large conductive loops, the worst ones being those centered on the tokamak axis. A radial line, centered on the tokamak axis and whose crossing would be highly forbidden, must be decided early, before the equipment layout around the tokamak is designed. The radial extent of this line has to be defined. Small conductive loops shall be allowed, and even recommended, to improve the signal cabling immunity. Nevertheless, within the Loop Exclusion Zone, the pickup area of these small loops shall be limited to a minimum by means of an adequate layout of the equipment and of the cabling routes. The usual concept, namely Star-Wise or Single Point earthing, is not found to be appropriate since it may allow induced voltages between equipment and provides poor shielding.

5. Tokamak earthing

As for all equipment hosting electrical loads, the tokamak itself must 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 accepted 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 tokamak shall be available outside the tokamak hall. In case exceptions are required, these conductive components shall 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 tokamak. In one case, the equipment is fully insulated from the tokamak and its cabling can be brought outside the hall. In that case, an optimal shielding of the cabling is not possible. In the other case, the equipment is in galvanic contact with the tokamak, shielding is optimal but the cabling shall not be brought outside the hall without providing galvanic isolation. The later configuration, shown in Fig. 4, is recommended.

6. Conclusions

Despite the importance of the earthing of tokamak plants, it has been poorly described, documented and discussed. The valuable know-how which was available in the eighties has dimmed. Moreover, ITER is very different from the machines constructed 20 years ago.

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

The work presented proposes an earthing concept which provides 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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