**Design of Grounding / Earthing System in a Substation Grid**

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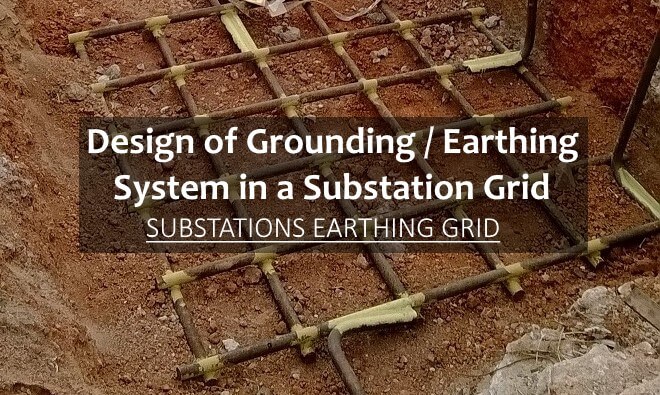
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**Introduction to Substation Earthing Grid**

In **high and medium voltage**[[1]](https://www.electricaltechnology.org/2018/02/design-earthing-grounding-substation-grid.html#1)*Air Insulated Substations* (**AIS**) the [**electromagnetic field**](https://www.electricaltechnology.org/2014/08/basic-magnetic-terms-definition-formulas.html), *which causes are the static charges of bare cable and conductors and by the atmospheric conditions* (**surges**), **induce voltages** at **no-live parts** of the installation that create [**potential differences**](https://www.electricaltechnology.org/2012/03/what-are-fundamental-differences.html) *between metallic parts and ground and also between different points of the ground*.

Similar situations can occur when there are *faults between live parts of the installation and no-live parts*, for example in **phase-to-earth short circuit**.

[](https://www.electricaltechnology.org/wp-content/uploads/2018/02/Design-of-Grounding-Earthing-System-in-a-Substation-Grid-Substation-earthing-grid.jpg)

These *potential differences* give origin to **step potential** and **touch potential**, or a *combination of both*, that can lead **to circulation of an electric current through the human body**, that can **cause hazardous** to people.

**Touch voltage (*E*t)** can be defined as the maximum potential difference that exists between an earthed metallic structure capable to be touched by the hand and any point of the ground, when a [fault current](https://www.electricaltechnology.org/2015/03/fault-current-limiter-current-limiting-reactors.html) flows.

*It is usual to consider a distance of 1 m between the metallic structure and the point on the ground.*

**Step voltage (*Es*)** is defined as the maximum potential difference that exists between the feet when a fault current flows.

*It is usual to consider a distance of 1 m between the feet.*

A particular case of *step voltage* is the **Transferred voltage (*Etrrd*)**: where a voltage is transferred into or out of the substation from or to a remote point external to the substation site.

* Related Post: [**Earthing and Electrical Grounding Installation | A Complete Guide**](https://www.electricaltechnology.org/2015/05/earthing-and-electrical-grounding-types-of-earthing.html)

**Other concepts are**:

* **Ground potential rise (*GPR*):**The maximum electrical potential that a substation grounding grid may attain relative to a distant grounding point assumed to be at the potential of remote earth. This voltage, GPR, is equal to the maximum grid current times the grid resistance.
* [**Mesh voltage**](https://www.electricaltechnology.org/2015/01/supermesh-circuit-analysis-step-step-solved-example.html)**(*Em*):**The maximum touch voltage within a mesh of a ground grid.
* **Metal-to-metal touch voltage (*Emm*):**The difference in potential between metallic objects or structures within the substation site that may be bridged by direct hand-to-hand or hand-to-feet contact.

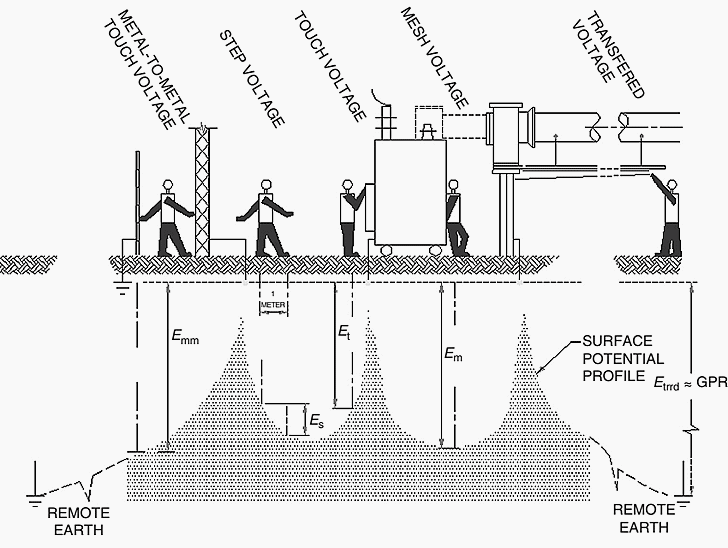
**The diagram in Figure 1 shows the phenomena referred above**.[](https://www.electricaltechnology.org/wp-content/uploads/2018/01/Figure-1.png)

Figure 1 – Touch, step and transferred voltages

In order to *minimize* to *acceptable values* of the **currents through the human body**, to **ensure electrical safety** for *people working within or near the installation*, and also to **limit any eventual electrical interference with third-party equipment**, *AIS*must be provided with an [**earthing** (or *grounding*) **system**](https://www.electricaltechnology.org/2015/05/earthing-and-electrical-grounding-types-of-earthing.html), to which **all metallic non-live parts of the installation must be connected**, such as *metallic structures, earthing switches, surge arresters, enclosures of switchboards and motors,*[*transformers*](https://www.electricaltechnology.org/2012/02/working-principle-of-transformer.html)*rails and metallic fences*.

Since earthing has an influence on the **levels of**[**power system**](https://www.electricaltechnology.org/2013/05/typical-ac-power-supply-system-scheme.html)**overvoltages and fault current**, and the definition of protection systems, earthing system must be designed to ensure that there is proper operation of the protective devices such as **protective relaying and surge arresters**.

Design and construction of [earthing system](https://www.electricaltechnology.org/2015/05/earthing-and-electrical-grounding-types-of-earthing.html) must assure that system performs for the expected life of the installation and it must therefore take into account future additions and the maximum fault current for the ultimate configuration.

*Earthing system* is made of a **mesh of buried bare copper cable**, with **additional**[**earth rods**](https://www.electricaltechnology.org/2015/12/size-of-earth-conductor-earthing-lead-earth-electrodes.html), and shall be calculated, being recommended to use *IEEE Std. 80-2000*.

* **Related Post:**[**Difference Between Grounding, Earthing and Bonding**](https://www.electricaltechnology.org/2020/07/difference-between-grounding-earthing-bonding.html)

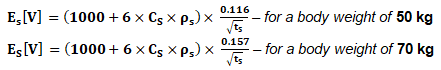
**Important formulas for Designing a Substation Grid Earthing System**

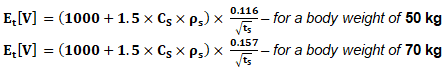
The **cross section** of the *buried cable* should calculated in accordance with the value of the **phase-to-earth short circuit current**, but it is common to use the [**three phase short-circuit current**](https://www.electricaltechnology.org/2018/02/short-circuit-currents-and-symmetrical-components.html) for this purpose.

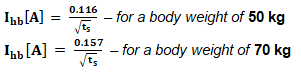
**For this calculation the following formula must be used**:https://www.electricaltechnology.org/wp-content/uploads/2018/01/Screenshot_9.pngWhere:

* *I”K1* is the phase-to-earth short-circuit current [**A**]
* *ts* is the duration of the fault [**s**]
* *Δθ* is the maximum admissible temperature rise [**°C**] – for bare copper **Δθ = 150 °C**

According to the referred *IEEE Standard* **maximum tolerable step and touch potential and maximum tolerable current through the human body** (**Ihb**) and the **resistance** of the *earth grid* (**Rg**) are calculated by the formulas:

**Maximum tolerable step potential**

**Maximum tolerable touch potential**

**Maximum tolerable current through the human body**

**Resistance of the Earth GridResistance of the earth grid**

Where:

* *Cs*is the surface layer derating factor and is calculated by the formula:https://www.electricaltechnology.org/wp-content/uploads/2018/01/Screenshot_14.png
* *ts*is the duration of the fault [**s**]
* *ρs* is the surface material resistivity [**Ω.m**]*–*typical value for *wet crushed rock/gravel:***2,500 Ω.m**
* *ρ* is the resistivity of the earth beneath the surface material [**Ω.m**]
* *hs*is the thickness of the surface material [**m**]
* *A* is the area occupied by the ground grid [**m2**]
* *lT* is the total buried length of conductor, including the earth rods [**m**]

If no protective surface layer is used, then ***Cs =1*** and ***ρs*** ***= ρ***

**These calculations are usually done using specific software**.

**Substation Earthing Grid**

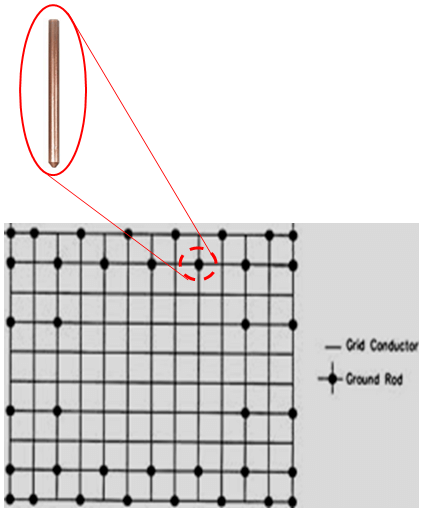
Figure 2 shows an example of the earth grid.

Figure 2 – Earth grid

**The most suitable methods for the connection of the earth grid connections are**:

**a.) Exothermic welding**

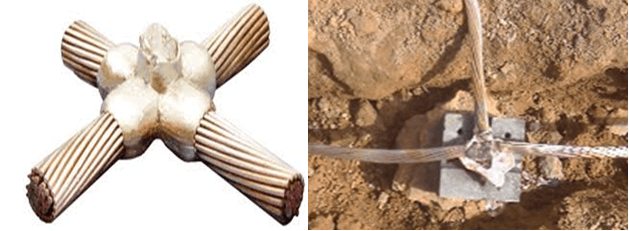


Figure 3 – Exothermic welding

*Exothermic welding* is **conductors’ permanent connection process** that uses *molten metal and molds*, which is based in a **chemical reaction** between **metal oxides** (*the conductor*) and **ignited aluminium powder**, which **acts as fuel**, with **heat energy release**. This *chemical reaction* is a **pyrotechnic composition** known as **thermite**.

**It must be assured that the number of exothermic welding done with each mold will not exceed the indications of the manufacturer.**

* Also read: [What is the Difference Between Neutral, Ground and Earth?](https://www.electricaltechnology.org/2015/08/difference-between-neutral-ground-and-earth.html)

**b.) C connector:**

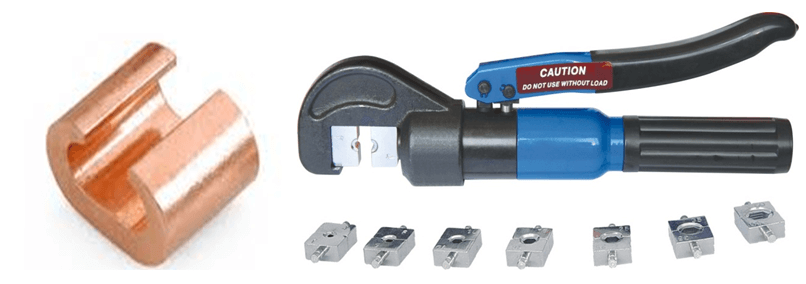
using a **hydraulic crimping tool and matrixes** with a **size suitable for the size of the connectors**.

Figure 4 – C connector and crimping tool

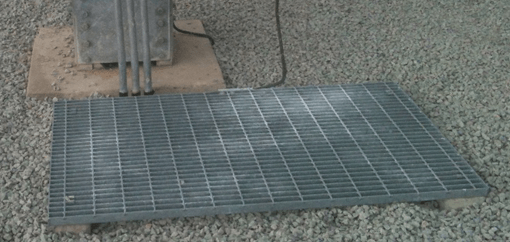
Close to the **control boxes** of *circuit breakers, switches and isolators* it must be installed a **metallic equipotential mat**, connected to the *earth system*, similar to the one shown in Figure 5.

Figure 5 – Metallic equipotential mat

**Good to know:**

[1] Being **Un** the rated voltage of the network: **HV** – **Un≥ 60 kV**; **MV** – **1 kV < Un ≤ 49.5 kV**.



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– Master Degree in Electrical and Computers Engineering (2017 – Faculdade de Ciências e Tecnologia/Nova University of Lisbon)  
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