Some aspects of electromagnetic interference, electromagnetic compatibility and geomagnetic induced currents

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Abstract. Electromagnetic compatibility is studied in special environments represented by renewable energy systems of two types, namely wind power farms and large photovoltaic parks. First, the sources of interference are identified which can be internal or external to these systems. Then suggestions of how to mitigate these effects are proposed. In addition, geomagnetic induced currents are also described as rare events but relevant sources of interference for both systems. The focus is on immunity of these systems to internal and external sources, but emissions and their effects on external equipment/installations will also be mentioned.

1. Introduction

The future of a modern society is highly dependent on the efficiency and reliability of the power network. In this respect, the inclusion of renewable energies has brought several improvements. Yet, at the same time new problems have emerged. For example in wind power (WP) and solar photovoltaic (PV) systems, electromagnetic interference (EMI) can be produced at various frequencies, from 50/60 Hz harmonics up to MHz order and propagate via cables or field emissions. Typical sources of EMI are solid-state converters and connecting cables. In the latter case, wiring in large PV systems (e.g. solar parks of over MW power) can act as antennas injecting disturbances into the power grid or causing serious interference in parts of the PV system itself. Solving such problems by applying computational tools in electromagnetism and performing experimental validation, with further implementation, makes it possible to reach the state of electromagnetic compatibility (EMC) for these systems [1,2].

EMI in power systems can also be generated by natural phenomena, for example lightning, a major source of disturbance, or by coronal mass ejections (CME) from the sun, which under certain conditions are able to create ionospheric intense currents which couple to long wiring ground connections inserting geomagnetic induced currents (or GICs) into large transformers, saturating the core and generating destructive overheating that may, in the worst case, produce a black out. This work is a sample of the investigations of various CIGRE working groups to which the author has contributed [3-7].
2. Electromagnetic compatibility (EMC)

The topic of EMC describes, firstly, the ability of an electronic or electric equipment to operate correctly in its electromagnetic environment, also known as immunity, which may relate to another nearby (or external) equipment or, in a wider sense, it may involve natural causes (such as lightning or GICs), all these being sources of interference. Secondly, EMC also describes the possibility that the initially considered equipment could cause interference on another equipment, also known as victim, which can be observed in figure 1. For the purpose of illustrating the concepts, a source of unwanted interference and various “victims” have been located for each type of interfering interaction. Thus, we have electromagnetic or radiative type (victim 1), via cables or conductive (victim 2), electric or capacitive (victim 3) and magnetic or inductive (victim 4).

![Figure 1. Simplified illustration of various types of EMI produced by an artificial or a natural source (e.g. lightning).](image)

It is important to point out that these interferences are due to natural, stray or unintended emissions from the source. However, intentional electromagnetic interference (IEMI) has recently been subject of intense investigation due to increasing awareness of attacks on cybersecurity, high power microwave (HPM) devices, high altitude electromagnetic pulse (HEMP) attacks and other related risks [8]. Yet, these topics are outside the scope of this paper.

3. EMC in wind energy systems

Wind energy systems, both types, onshore and offshore are increasingly being produced and developed, providing not only energy but also stability to the main grid. The more powerful, the higher and larger the wind turbines are. This fact creates a potential for lightning strikes and interference (figure 2). Lightning
protection is designed to “guide” the impulsive incursion through a conductor (located in each blade) then the impulse is transmitted via the nacelle, where sensitive equipment and controls are located, down to the bottom part of the tower where controls are also located. The impulse current is finally distributed to reach the ground in a specially designed conductive mesh (copper) that will avoid any destructive effect on the foundations. The traveling impulse is able to produce serious disturbances in the operation of controls, thus robust design and shielding of such equipment must be carefully applied in order to mitigate these effects.

**Figure 2.** A wind power farm connected to the network grid showing sources of EMI with disturbances propagating inside the turbine, to other turbines, to the grid or to external installations.
The mitigation designs should allow the equipment to comply with standards of lightning protection for wind turbines such as IEC 61400-24 and IEC 62305-4 [5]. Another source of EMI is the high-frequency emissions by converters. The power flow starts with a rotational energy/torque from the blades transformed into AC electric output by an induction generator, which then goes to an AC/DC/AC converter that has two parts: the rotor side converter and the grid-side converter. Both are voltage-source converters that use forced-commutated power electronic devices (IGBT’s) to synthesize an AC voltage from a DC voltage source. These fast switching operations tend to emit high frequency (kHz to MHz or even more) disturbances that couple to wires and can be radiated and affect sensitive parts of the system. These emissions can also propagate outside and reach other wind turbines via connecting cables, at the same time they can reach the network grid. Protection techniques such as HF filters and dampers have to be implemented. An IEC EMC standard that can be applied to a WT is IEC 61800-3 as suggested in [5]. Furthermore, radiative emissions can reach the network grid and other sensitive installations/equipment located externally, for example mobile communication base stations, airports, and radio-telescopes, as shown in figure 2.

A source of EMI which is typical for wind energy systems is caused by electrostatic charging of the components of these systems. Specifically large rotor blades, which are made from composites, build up charges while in relative motion with air. There is not an easy way to discharge the blades during that process. Eventually a source of interference is created, which subsequently produces flash-over discharges (ESD) to various parts of the wind turbine, especially those with metallic sharp edges. ESD processes can be damaging to nearby electronics.

4. EMC for large PV systems
In the last couple of decades, large PV systems have shown an exponential growth. Table 1 shows the currently largest solar parks in the world. Yet, the table in a few years may be very different, as every year new members will enter to this table. In fact some forecast gives a total worldwide PV installed capacity of 500 GW by 2020. Therefore, as in the case of wind energy systems, since PV is becoming such a relevant energy source, related EMC considerations are becoming increasingly relevant especially for large PV plants, connected to the grid.

| Name                          | Country | Capacity (MW) | Size (km²) |
|-------------------------------|---------|---------------|------------|
| Tengger Desert Solar Park     | China   | 1,547         | 43         |
| Datong Solar Power Top Runner Base | China     | 1,000         | 30         |
| Kurnool Ultra Mega Solar Park | India   | 1,000         | 24         |
| Longyangxia Dam Solar Park   | China   | 850           | 23         |
| Bhadla Solar Park            | India   | 746           | 40         |
| Kamuthi Solar Power Project  | India   | 648           | 10.1       |
| Pavgada Solar Park           | India   | 600           | 53         |
| Solar Star (I and II)        | US      | 579           | 13         |
| Topaz Solar Farm             | US      | 550           | 24.6       |
| Desert Sunlight Solar Farm   | US      | 550           | 16         |
The EMI/EMC issues are a bit different in PV systems (PVs) than in wind turbine systems (WTs). Since the height of PVs is not in the order of ~hundred meters, but just a few meters. Large PVs are not prone to lightning in the same way than WTs. In WTs, the highest top of the blade will attract lightning while in large PVs, lightning “sees” a large mesh of long conductors connecting the large set of modular panels. The lightning protection in WTs can be realized with dedicated receptors in the blades and a robust earthing mesh. In PVs this could be realized with lightning rods (with much simpler earth connections than in the WTs). Still, the emitted impulse field generated when the lightning strike goes through the rod is large and its effect on electronic equipment has to be considered at the design stage. The DC/AC inverters are also a major source of conductive interference being able to inject disturbances into the power grid. The EU directive and a few standards for PVs already exists, such as IEC 62305, while integration into the grid is causing several other standards to be considered and cross referred (e.g. IEC 62561, CLC 50539).

In terms of emission, in large PV parks, long cables act as antennas propagating coupled high frequencies (e.g. RF) from inverters. Thus radiated interference can reach as far as several km distance. Thus airports, radio observatories, base stations and radar sites could be affected by these RF emissions.

5. Geomagnetically induced currents (GIC)

One of the main characteristic of our sun is its activity, which include solar storms related to coronal mass ejections (CMEs) that are huge and highly energetic plasma expulsions from the sun. Figure 4 shows one detected in 2003. From time to time these ejections are able to reach earth going around the magnetosphere and penetrating through the Polar Regions to form in the ionosphere quasistatic currents of hundreds of km long and with an intensity of ~1 million amperes known as electro-jets. These intense currents couple with long conductors in the ground producing GICs which are able to penetrate the grid causing transformer core saturation and serious damage to the power grid in the worst case producing blackout. The most severe CME registered since the use of electricity is the Carrington event in Sept 1, 1859 which managed to overheat and destroy some telegraph lines and explode some powering batteries. The second largest event in recent times happened in March 1989 when GICs managed to knock out the power grid causing hundreds of millions in damage.
The effects of these natural phenomena can be so severe on the power grid, and therefore affecting our entire society, that serious investigations are currently being performed by various organizations [6, 9].

6. Conclusion
EMC for both, WTs and PVs, present some similarities. Being lightning and the DC/AC converters the most relevant sources of EMI. On the other hand, their electromagnetic environments are rather different, especially in relation with lightning protection. GIC is an extremely relevant topic for the reliability of the power grid and more efforts should be placed for finding mitigation techniques and devices.

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References
[1] Francesco Lattarulo, “Electromagnetic Compatibility in Power Systems”, Elsevier Science Ltd. 2006
[2] David Weston, “EMC – Methods, Analysis, Circuits, and Measurement”, CRC Press, (3rd edition) 2017
[3] CIGRE TB 320, “Characterization of ELF Magnetic Fields”, 2007
[4] CIGRE TB 535, “EMC in Power plants and substations”, 2013
[5] CIGRE WG C4.30, “EMC in Wind Power Systems”, 2017
[6] CIGRE WG C4.32, “Understanding Geomagnetically Induced Currents” 2018
[7] CIGRE WG C4.44, “EMC in Large Photovoltaic Systems”, established in 2017
[8] CIGRE WG C4.206, “Protection of High Voltage power network control electronics against Intentional Electromagnetic Interference (IEMI)”, 2015
[9] ABB Press Release, “ABB engineering protects power plant from solar storm” 20016-10-24 http://www.abb.com/cawp/seitp202/c99eb3b89e85b7b2c12571c6004579aa.aspx

Figure 4. Registration of a CME on October 29-30, 2003 by the geo-magnetic station located in Tromso, Norway. This event is also known as the Halloween storm. It caused a power blackout in the city of Malmö in Sweden.