EMC Issues in Grid-Connected Photovoltaic Systems

The Brazilian Regulatory and Standardization Scenario

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Abstract. Exponential growth of photovoltaic systems connected to the grid has been observed over the last decade in Brazil concurrently with concerns about the power quality and operational compliance of related equipment. In the past decades, there has been much research and debate regarding the definition of electromagnetic compatibility requirements. Since Brazil has both government and private entities responsible for the product certification and homologation process, it is important to discuss and analyze these entities' roles from an electromagnetic compatibility viewpoint in photovoltaic systems connected to the network. Thus, it is our aim to amplify current discussions on the Brazilian scenario. This work provides, first, an analysis of the origin and propagation of conducted and radiated electromagnetic interference in grid-connected photovoltaic systems, highlighting such concepts as symmetrical and asymmetrical noise and unintended antenna effects. Finally, the standardization framework is investigated based on the Brazilian scenario and current standards.

Keywords: Electromagnetic compatibility · Grid-connected photovoltaic systems · Electromagnetic interference · EMC standards

1 Introduction

Traditionally, there are concerns regarding electromagnetic compatibility (EMC) in the various types of photovoltaic power generation systems, given that connection of various

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items of electronic equipment to the network may give rise to disturbances not only in distribution lines, as seen in [1], but also electronic devices in the vicinity, as addressed in [2].

In recent years, the investigation of conducted and radiated electromagnetic interference (EMI) from photovoltaic power generation systems has become more active in Brazil [3]. According to the Brazilian Solar Photovoltaic Energy Association (ABSOLAR) [4], the cumulative operational capacity of distributed photovoltaic energy generation has recently reached 3GW, driven by the exponential growth of grid-connected installations in the last decade. Moreover, with the advent of smart cities, IoT (Internet of Things), and cloud computing, electromagnetic environments (EME) have become even more present, with the coexistence of a wide range of systems and wireless communication technologies [5].

In [6], it is stated that the EMC with grid-connected photovoltaic systems might be achieved based on an understanding of the EME. Attempts should be made to identify and characterize EMI sources, electrical equipment items that are susceptible to emitting or receiving EMI, and relevant non-electrical conditions from an EMC viewpoint, e.g., distance, humidity, and triboelectricity [7]. Such an understanding of the EME, together with the EMI requirements proposed in international standards, is normally necessary to ensure that systems are safe, correct, and reliable.

However, as suggested [8], the identification of possible violations may show a lack of EMC standards specific to the various items of equipment that comprise grid-connected photovoltaic systems, principally the photovoltaic (PV) inverter. Usually, such standards as CISPR 11, EN 55011, and EN 55022 are used for PV inverters, i.e., these devices are treated as household appliances [9] or as items of information technology equipment (ITE) in CISPR 22 [10].

Therefore, aiming to expand the current discussion regarding the Brazilian regulatory and standardization scenario, this work provides an overview of the EMI effect and investigates the scope of EMC's Brazilian regulation in grid-connected photovoltaic systems.

2 Electromagnetic Environment

As also observed in [6, 11, 12], Fig. 1 illustrates a PV inverter which, although essential to the installation, may give rise to EMI emissions since it operates in a non-linear manner based on switching and high-frequency clock signals [13, 14]. As a result, high *dv/dt* and *di/dt* occur, injecting conducted disturbances on both the DC and AC sides, comprising residential loads and the distribution network [1, 6, 9].

As indicated by [3, 11], the conducted EMI circulates via cables and elements, creating a parasitic reactance condition in the form of ground loops. According to [9, 15, 16], these loops could also make the grid-connected photovoltaic system operate as unwanted antennas in the EME, irradiating electromagnetic fields via radiofrequency waves (Fig. 1).

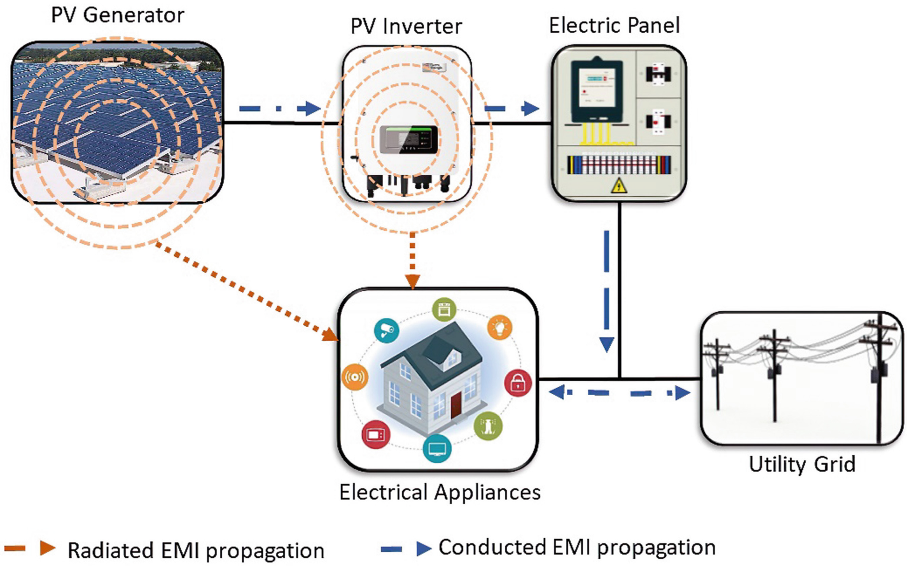

Fig. 1. Possible propagation paths for conducted and radiated EMI.

3 Electromagnetic Interference

Normally, EMI in the grid-connected photovoltaic system occurs in a conducted or radiated manner, such that propagation of one may generate the other, based on indirect emissions, as seen in [6, 17]. As observed by [8, 9], these disturbances are often divided into two types, according to frequency range: i) 150 kHz–30 MHz, in which conducted EMIs are normally addressed; and ii) 30 MHz–200 MHz, in which radiated EMI phenomena are constantly observed.

3.1 Symmetrical and Asymmetrical Conducted EMI

A conducted EMI analysis is normally made based on common and differential mode interference, as noted by [11]. According to [18], common-mode (CM) or asymmetrical interference originates from PV inverter switching processes, propagating oscillating voltage levels via DC cables and returns as ground currents from parasitic capacitance couplings. This is due to the fact that the cables behave electrically as undesirable inductors and the grounded modules as undesirable capacitors.

In general, the CM interference path is considered to be from the PV inverter to the load via circuit grounding. Furthermore, as indicated by [11, 17], there is an indication that the EMI couplings may occur with the photovoltaic solar modules interface in empirical proof processes. In this context, Fig. 2 illustrate the possible paths for CM current and floating electrostatic capacitance (C_{CM}) for a typical grid-connected photovoltaic system with a single-phase PV inverter.

Normally, as illustrated in Fig. 2, the transistors switches are high-frequency EMI sources due to their rapid switching process, generating CM voltages, represented as

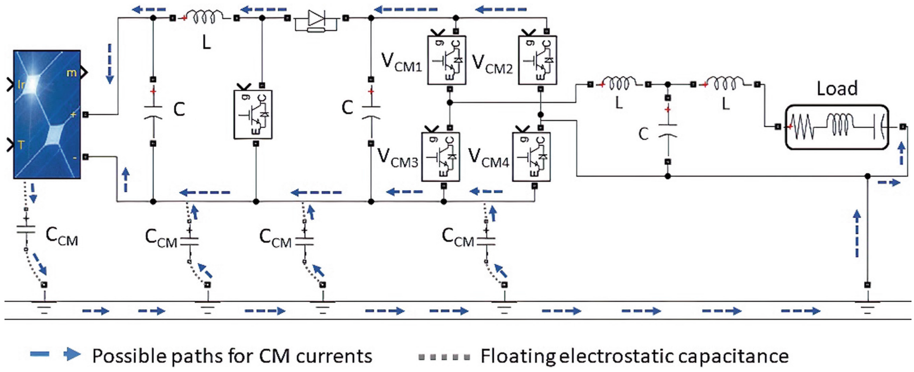

Fig. 2. CM currents possible paths for a typical grid-connected photovoltaic system with a single-phase PV inverter.

V_{CM}, [19]. Once the V_{CM} starts to flow through a parasitic ground, it may return by a capacitive coupling, generating various loop currents [16–19].

On the other hand, studies [3, 9–11, 15–19] indicate differential mode (DM) currents propagate in opposite, symmetrical directions, i.e., from the photovoltaic solar modules to the PV inverter (Fig. 3). The parasitic elements as series-equivalent inductance and resistance (X_{DM}), illustrated in the Fig. 3, are also sources of conducted EMI. As a result, the X_{DM} may provide EMI through DC cabling [20].

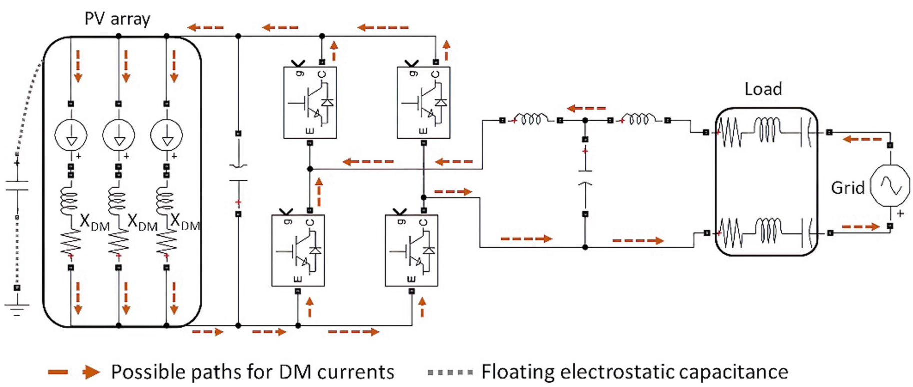

Fig. 3. DM currents paths propagation for a typical grid-connected photovoltaic system with a single-phase PV inverter.

Figure 3 illustrates the DM currents generated by photovoltaic solar modules that may flow through the AC side, propagating through the load and even to the grid [20]. However, as suggested [21], an EMI filter may filter the DM currents, traditionally dominant in high-frequency operations, if connected with a PV inverter.

3.2 Unintended Antenna Effects

Devices that unintentionally radiate electromagnetic energy are normally identified as active unintended antennas, e.g., cables conducting alternating current or openings/slots in the screens of devices that conduct radiofrequency (RF) currents [3]. On the other hand, devices that emit some type of EMI, in an unwanted manner, in the transmission and propagation of an electromagnetic signal are known as passive unintended antennas.

In the context of a grid-connected photovoltaic system, the modules are normally compared to active unintended antennas since the CM and DM emissions are generated with the interface of photovoltaic solar modules [15, 16]. Furthermore, as indicated in [17, 18], the DC side of a grid-connected photovoltaic system may operate as a resonant circuit, normally characterized in the EME as unintended inductors, and the photovoltaic solar modules as unintended capacitors, due to such parasitic elements as distributed longitudinal inductance and distributed transversal capacitance in DC cabling. Therefore, as proposed by [3, 18, 22], a cable-generator setup is highly desirable, as resonant frequencies generally reduce ground impedance on eliminating reactive impedances.

4 Brazilian EMC Standardization Framework

Although IEC standards regulate the production of photovoltaic equipment in Brazil, installers and consumers should be aware of additional Brazilian EMC standards. The National Telecommunications Agency (ANATEL) is responsible for mandatory regulation of telecommunications services in Brazil. Also, the Brazilian Technical Standards Association (ABNT) provides equipment certification based on international standards, aiming to unify Brazilian requirements. At the same time, research centers and institutions may conduct equipment tests and conformity certification, which will later be accredited by the National Institute of Metrology, Quality, and Technology (INMETRO), recognized as the Official Brazilian Accreditation Agency.

Over the last decade until mid-2017, ANATEL's standard 442 was used as one of the main references in conformance and EMC tests in order to regulate product certification based on IEC 61000-3-4, CISPR 11, and CISPR 22. In the context of grid-connected photovoltaic systems, ANATEL standard 442 was frequently used to measure the conducted EMI noise. Furthermore, for the measurement of radiated EMI noise, the CISPR 22 standard was used.

In 2018, ANATEL resolution 1120 was created to replace ANATEL standard 442. In addition, the ANATEL resolution 1120 establishes measurement and test method requirements for power supply equipment as sources, converters, inverters, and rectifiers, although it does not deal directly with the context of photovoltaic power generating systems.

Therefore, the main concept on which the Brazilian EMC standardization scenario is based assumes that ANATEL establishes the EMC requirements applicable to equipment subject to mandatory certification and in the absence of specific requirements. However, as indicated by [3], there are empirical cases in which photovoltaic power generating systems exceed the national limits imposed, which could be related to the fact that compulsory national standards do not specifically cover the EMC requirements and test methods for this kind of application.

Analogously, as indicated by [23], although INMETRO has recently submitted several quality tests and possible tests for conducted and radiated noise for photovoltaic inverters, there is no certification applicable for these items of equipment in its scope of accreditation. On the other hand, with regard to Brazilian voluntary certification, some standards have been considered by ABNT regarding EMC for photovoltaic equipment (Table 1).

Table 1. EMC standards applied in the certification of photovoltaic equipment in Brazil.

Standards	Description	Equipment covered	Tests performed
CISPR 22	Establishment of limits for radiofrequency disturbances as well as requirements for measurement methods and immunity of ITE equipment	Industrial, scientific, and medical (ISM) and ITE equipment	Conducted and radiated emissions
CISPR 11	Application of EMI limits for ISM equipment, requirements for photovoltaic semiconductor power converters (SPCs), and the introduction of a fully-anechoic room (FAR) for EMC measurements	ISM and photovoltaic PCEs	Radiated emissions; Conducted emissions input power
ANATEL 1120	Homologation of EMC certification based on requirements for EMI emissions, immunity, and resistibility. Application of test methods for converters, inverters, and rectifiers regarding EMC measurement	Telecommunication products	EMI conducted and radiated emissions; Immunity tests to electrical surges and noise; Resistibility measurement
IEC 62920	Provides classification and definition of PCEs and establish EMC requirements regarding emission limits and immunity for PCEs. Test conditions and measurement methods in relation to photovoltaic PCEs are also presented	Photovoltaic power conversion equipment (PCE)	Conducted and radiated emissions; Immunity tests to electrostatic discharge, surges, and transients; Direct/Indirect application of discharges to PCEs

5 Conclusions and Trends

This work provides an overview of the EMI effect and investigates the scope of the Brazilian regulation on EMC in grid-connected photovoltaic systems. As the standards that deal with EMC issues for the grid-connected photovoltaic system (Table 1) are voluntary, we can assume that the regulatory framework could be one of the causes that explains why there is still some irregular equipment sold in Brazil.

In this sense, although voluntary certification can add competitive value to a product, it generally increases its selling price, making the need for certification an unlikely proposal on the part of the supplier. Therefore, it is recommended that Brazilian standardization institutions, such as ANATEL, establish mandatory EMC requirements, especially with regard to the PV inverter.

In addition, it is reasonable to consider that this standard could also facilitate the implementation of technologies related to the concept of Smart Cities in Brazil since reducing the emission of EMI from grid-connected photovoltaic system installations would provide EMC, which can lead to improved cost-benefit for the EME in the long term.

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