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Review of advanced grid requirements for the integration of large scale photovoltaic power plants in the transmission system

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ABSTRACT

The installation of large scale photovoltaic power plants connected at transmission level has increased during the last years. There are some challenges that these power plants have to overcome regarding the operation and control while dealing with the solar energy variability and uncertainty. Today, few countries are aware of the importance of this source of energy as part of the utility system and how it can affect the operability. Thus, this paper discusses about the trend of large scale photovoltaic power plants around the world and the importance of the development of grid codes for its integration. Then, the paper addresses a comparison of the grid codes of Germany, US, Puerto Rico, Romania, China and South Africa considering: fault ride through capability, frequency and voltage regulation, as well as active and reactive power support. In addition, a broad discussion about the challenges that the large scale photovoltaic power plants have to overcome is presented together with the compliance technology and future trend.

Contents

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1. Introduction

A centralized system that performs the functions to supply power to the electrical system and not to a particular customer is known as a power plant. Its main aims are to function independently and to comply the needs of the electrical system under some regulations [1]. Grid codes and standards define the requirements of these power plants connected to the transmission or distribution grids to enhance its reliability, stability and security. These grid codes were traditionally developed to permit the interconnection of power plants, based on synchronous generators, with the grid. The use of renewable energy to produce electricity was initially very low in comparison with conventional power plants, but this has changed drastically in the last years. Thus, it is becoming more important to develop grid codes for power plants that use renewable generation as the main source to avoid any problem with the electrical system operation. In this sense, wind power plants have stepped up the path for grid codes development. However, for large scale photovoltaic power plants (LS-PVPPs) and very large scale PVPPs (VLS-PVPPs) connected to the transmission system, grid codes have recently been developed and further analysis is needed. Thus, this paper addresses a comprehensive discussion about the trend of LS-PVPPs around the world together with the importance of grid codes development. Then, an analysis of the main grid code regulations for LS-PVPPs connected to the transmission system is developed. This analysis is conducted by a comparison of the main requirements related to frequency and voltage control, active and reactive power regulation, and fault conditions. After this comparison, a discussion about the challenges that operators of PVPPs have to face is deeply discussed. Further, the analysis of the compliance technology used and researched so far is analysed and summarized.

A short comparison between the grid codes of China, Germany and US for PVPPs connected to the distribution or to the transmission system, considering also the electrical standards IEEE 1547 and EN 50160 is developed in [2]. As Germany was the first technical grid code launched for PVPPs connected to medium and high voltage transmission network, there are some publications analysing these requirements like [3,4]. These focus on the response of the PVPP when there are disturbances. A similar study developed by Jiao and Gao considers Chinese grid code [5]. A scope of the challenges for large scale PV integration in the distribution and transmission level is developed by Shah et al. [6], comparing some grid code requirements given by Germany and US. The work developed by Obi and Bass [7] compares and analyses the requirements given by some electrical standards for the distribution system as: IEEE 1547, IEEE 519 and IEEE 929. They also analyse the challenges and the trends of the PV systems interconnection with the distribution level. But this work does not consider the grid code requirements for the interconnection of LS-PVPPs with the transmission system. In the case of WPPs a deeper analysis of the most important grid codes is developed by [8], however a similar study for LS-PVPPs' grid codes is still missing.

In this paper, the grid codes analysed are the ones that up today are accepted by the transmission system operators of Germany, US, Puerto Rico, South Africa, China and Romania which have been used for the current PVPPs installed in those countries. This paper attempts to assist PVPPs developers, operators, researchers in the understanding of today's grid codes in order to set and to improve the operation, design and technology used in LS-PVPPs.

This paper is organized as follows. Section 2 analyses the current trend of PVPPs around the world. Section 3 compares different grid codes that consider the integration of LS-PVPPs. Section 4 analyses the challenges to integrate LS-PVPPs in the transmission system. The compliance technology to overcome the challenges imposed by the grid codes is discussed in Section 5. Finally, the conclusions are drawn in Section 6.

2. Current trend of PVPPs development in the world

PV power generation was first introduced to the distribution system, where the power generated was less than 1 MW. These PV systems were installed in houses, neighbourhoods, buildings and industries, representing a total power installed of 106.2 GW around the world by 2014 (Fig. 1). During 2014, 19 GW were installed worldwide and it is expected that in 2019 37 GW will be added to the existing capacity [1,9].

The main reason why the consumers were attracted to this type of installation was the economic incentives given by some countries to the citizens for the installation of PV system. These incentives consist specially in the feed in tariff that is defined as a payback for the PV system installation. The countries that have succeeded by the adoption of this policy are Germany, Spain, Italy, US, Australia, and Canada [10–13]. Because of these incentives, Europe leads the residential, commercial and industrial market with a power capacity of around 40–50% of the global market by 2014 [9]. However, due to the reduction of feed in tariffs in this region, a slower rate of growth in the upcoming years is expected. But the Asian-Pacific countries will lead the residential and commercial market in the future years as the price of the technology reduces [14]. The reduction of prices of PV modules and inverters

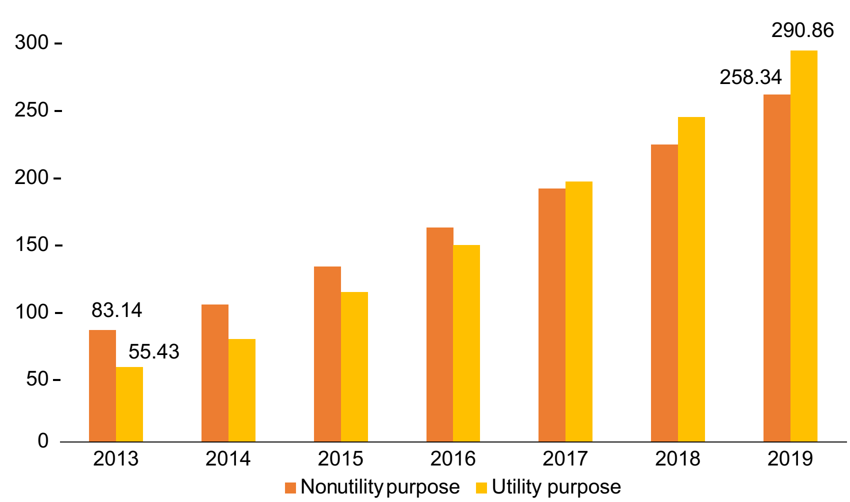

Fig. 1. Global utility and non-utility cumulative power (GW) up to 2019 [1,9].