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Overcoming the barriers that hamper a large-scale integration of solar photovoltaic power generation in European distribution grids

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ABSTRACT

Solar photovoltaic is increasingly seen as a key technology for low-carbon electricity generation. However, the deployment of growing shares of this technology is not without important challenges for their efficient integration in power systems. This paper aims to contribute to overcoming the barriers that hamper a large-scale integration of photovoltaics in the electricity distribution grids. The methodology followed is problem oriented. The paper firstly reviews the technical solutions available to integrate distributed photovoltaics, classifying them in three areas: Distribution System Operator (DSO) solutions, prosumer solutions and interactive solutions. Then, the set of barriers that hinder the implementation of the solutions in a European context are identified, assessing the relevance of each barrier in different countries. Four major barriers are discussed in detail: (1) DSO regulation does not promote smart grid investments, (2) rules limiting PV curtailment, (3) missing frameworks enabling DSOs to access advanced PV inverter capabilities, and (4) regulation hampering storage solutions. Finally, recommendations to overcome these barriers are presented, highlighting that DSO regulation should shift the focus from a short-term to a long-term cost assessment and revenue setting framework, equalizing the treatment of capital and operational expenditures, and implementing specific incentives for DSO innovation. Moreover, a fair debate on the definition of the boundary conditions for the use of renewable curtailment when the other technical solutions cannot be applied or are not economically optimal is required. Regarding the provision of services to DSOs by prosumers and the deployment of distributed storage, the roles, rights and limitations of the different stakeholders need to be clearly defined.

1. Introduction

Future energy scenarios foresee an important growth in the participation of solar photovoltaics (PV) in the electricity generation mix (BNEF, 2016; IEA, 2016, 2014; Shell, 2013). In fact, several countries have already experienced significant penetrations of PV installations, which have been primarily driven by economic incentives for renewables (RES) such as feed-in tariffs or direct investment support (Barbose and Darghouth, 2016; Campoccia et al., 2014; CEER, 2015a). The significant cost reduction that has been achieved over the last decades, as well as the fact that this decreasing trend is expected to continue, have undoubtedly contributed to its current level of deployment and the aforementioned expected growth (Barbose and Darghouth, 2016; EPIA, 2011; EPRI, 2009; Jones and Glachant, 2010). Indeed, some institutions have stated that solar PV may become fully competitive in the absence of additional economic support in the short term (Eclareon, 2014; UBS, 2013).

However, the connection of increasing levels of PV, similarly to other intermittent distributed generation (DG), has manifold impacts on power systems both from a technical and an economic perspective (ICER, 2012; J.a.P. Lopes et al., 2007). Despite the fact that the whole electricity supply chain is bound to be affected, it is the distribution network that will experience the most immediate and relevant impact. This has been analyzed by many authors from different perspectives, with the impact on voltage profiles, voltage control strategies, harmonic distortion, fault detection and protection coordination, impact on energy losses and distribution investment deferral being some of the most important aspects to be considered (Méndez et al., 2006; Ochoa et al., 2008; Passey et al., 2011; Quezada et al., 2006; Walling et al., 2008).

The specific impact caused by DG units greatly depends on a number of factors particular to each distribution area such as load

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concentration, DG technologies, DG penetration, feeder length, local consumption profile, voltage level at the point of connection, etc. In the end, all these parameters will determine the extent to which local generation and consumption balance both in terms of location and time (Cossent et al., 2011; Gil and Joos, 2008; Maciel et al., 2012; Ochoa et al., 2008, 2006; Passey et al., 2011).

In order to mitigate the impacts of PV and ensure an efficient integration, distribution system operators (DSOs) may need to carry out significant investments in order to ensure a safe and reliable grid operation, especially in areas with high penetration levels (Cossent et al., 2011; Eurelectric, 2014). Nonetheless, the need for conventional grid reinforcements can be reduced through different technical solutions such as voltage control, selective PV generation curtailment or storage. However, the implementation of these solutions is frequently hampered by existing regulation (Cossent et al., 2009; Eurelectric, 2013a; Joode et al., 2007; Lo Schiavo et al., 2013; Niesten, 2010).

When compared to other DG technologies, solar PV shows some particularities, the most relevant being the following: most production happens during the central hours of the day, PV facilities are usually small-sized (from a few kW to a few MW) and the fact that PV installations are often connected to the lower voltage levels or even at the consumers' premises. Consequently, the impact of PV on the distribution network also presents some particularities that require specific technical solutions.

Due to the relevance that this technology will have in the future in many countries, it is important to further evaluate the particular solutions and whether regulation should be adapted accordingly. For instance, the barriers related to individual decision-making for the adoption of residential solar PV are assessed in California (Rai et al., 2016). Likewise, possible existing barriers and challenges at policy and regulatory level are identified in Australia (Byrnes et al., 2013) and India (Punia Sindhu et al., 2016).

The European Union energy targets set for 2020 and 2030, result in an increase of the shares of renewables, and in particular PV, in the distribution networks involving new challenges for the DSOs. This paper contributes to this new scenario with a thorough analysis to ensure that this distributed generation is integrated in an efficient way into the power system, by proposing a set of regulatory recommendations. These recommendations are aimed at removing the barriers that could hamper the adoption of the technical solutions required to achieve the final EU targets.

The remainder of this paper is organized as follows. Section 2 provides some background information about the current situation of PV generation and the distribution sector in European countries. Section 3 summarizes the methodology applied in the paper. Section 4 presents a review of the technical solutions identified to be the most promising for an efficient PV integration. Section 5 discusses the regulatory barriers that may hamper the implementation of the aforementioned technical solutions, presents a barrier assessment in a set of selected target countries in the European Union, and proposes recommendations to overcome the previous barriers. Finally, conclusions are drawn in Section 6.

2. Context: solar PV and distribution systems in Europe

The penetration of PV in European countries has been significantly increasing in recent years. Fig. 1 depicts an overview of the PV penetration in EU countries. Germany is the EU country which presents the highest share of installed PV capacity (over 17% in 2014), followed by Belgium, Italy and Greece (all of them with PV shares above 7%). These penetration levels can be expected to increase in the near future. According to a report by the European Solar Association,[1] an accelerated scenario would lead to 8% PV penetration in 2020 across EU countries, and a 15% PV penetration in 2030; while under a paradigm shift scenario up to a 25% PV penetration could be reached by 2030 (EPIA, 2012).

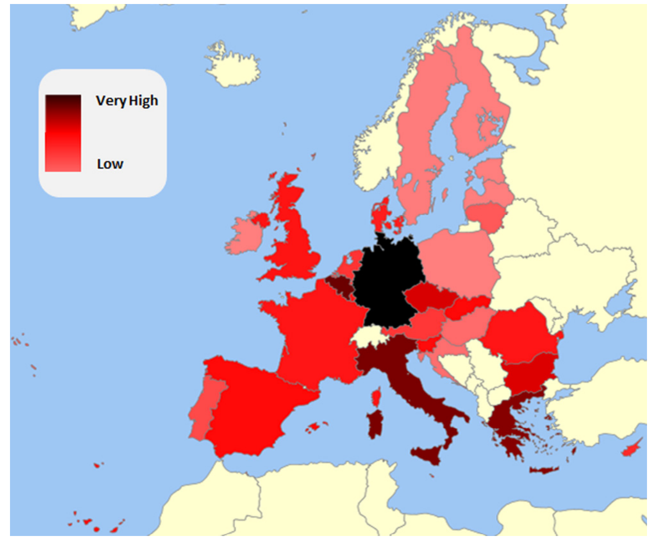

Fig. 1. PV penetration ratio (share of installed generation capacity) in 2014. Data from Eurostat.

PV units can be categorized into residential, commercial and industrial ground-mounted systems (utility-scale). The financing and administrative processes of the related projects can differ widely for each type of system and country.[2] For the distribution network, the different types of installations or PV segments may have different voltage levels at the point of connection and different sizes.

Another relevant aspect to bear in mind concerning PV integration in distribution grids in Europe is the fact that there is a great diversity of DSOs and distribution networks. Table 1 shows significant differences beginning with the number of DSOs per country, ranging from just 1 in Cyprus, Ireland or Slovenia, up to over 890 in Germany (Eurelectric, 2013b). Additionally, the length of the distribution networks can differ in several magnitude orders, as shown in Table 1, using the overall distribution circuit length[3] of the network as an indicator of the distribution area. Furthermore, distribution voltage levels, which are a key factor affecting PV integration, may vary significantly across countries. This is particularly important in medium voltage grids, where most medium-sized and large PV installations are normally connected.

To sum up, due to the key role of solar PV for power generation in the coming years, it is necessary to analyze the technical solutions that would enable the efficient integration of PV in the distribution networks. Furthermore, attention should be paid to the different conditions faced by DSOs in different countries.

3. Methodology

The methodology applied in this paper is problem oriented, and it is summarized in Fig. 2. First, the technical issues that may arise as a result of the connection of solar PV to the distribution networks are identified. Despite the fact that PV generation may also

[1] Old EPIA, nowadays Solar Power Europe.

[2] The public database developed within the PV-GRID project provides extensive data and indicators related to non-technical barriers for different types of PV installations and project phases. Further info at: http://www.pvgrid.eu/database.

[3] This circuit length includes the low, medium and high voltages of the distribution networks of both overhead and underground electrical lines.