OVERCOMING NORMATIVE AND REGULATORY BARRIERS HAMPERING PHOTOVOLTAIC HOSTING CAPACITY ENHANCEMENT IN EUROPEAN DISTRIBUTION GRIDS

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ABSTRACT

The PV GRID project has the ultimate objective to promote the large-scale integration of photovoltaic (PV) systems in distribution grids across Europe. In a first step towards this goal, the project consortium has identified the most effective technical solutions available for increasing the distribution grid hosting capacity. Successively, the barriers hampering their adoption in European distribution networks have been analysed and discussed, leading to a set of normative and regulatory recommendations aimed at stimulating the European and national debates on distribution grid integration of PV and other distributed generation resources. An overview of these barriers and recommendations, together with a structured approach for how they should be taken into account in the different European national contexts is presented in this paper.

INTRODUCTION

In May 2012, a consortium initially composed by 21 partners from 15 European countries has started the PV GRID project, pursuing the objective of preparing the grounds for the large-scale integration of PV systems in distribution grids across Europe and bringing forward concrete suggestions on how this can be achieved. The work started from the identification of the most appropriate technical solutions available to address the technical issues that arise in distribution grids when the penetration levels of distributed generations become significant.
Successively, the barriers affecting the adoption of the identified solutions have been researched and discussed in four focus countries (Germany, Spain, Italy and Czech Republic). Taking these initial results as a starting point, the PV GRID consortium has initiated an ongoing process of analysing the existing barriers in the 15 participating countries, involving in the discussion the key national stakeholders: electricity regulators, policymakers and DSOs.

In this paper, at first the identified technical solutions are listed and categorised. Then, a selection of the barriers towards their adoption is briefly analysed, providing general recommendations that can be used for their mitigation. Finally, a structured approach for the utilisation of the PV GRID results, consisting in a practical roadmap for national stakeholders, is presented.

TECHNICAL SOLUTIONS ENHANCING DISTRIBUTION GRID HOSTING CAPACITY

Concerning the increase of PV hosting capacity in distribution grids, voltage limitation is the most common constraint. Another limiting factor is the thermal limitation due to high current flow through electrical devices such as transformers. This issue is often indicated as congestion. If these local problems are solved, higher shares of PV can be integrated, as discussed in [1], [2], [3]. However, more global issues related to system stability or security of supply may also occur, but they are out of the scope of PV GRID.
During its work, the project consortium has focused on the first two challenges, dealing with the identification, based on a thorough review of existing literature, of the technical solutions available to solve voltage and thermal limitations, both at low voltage and medium voltage levels in distribution grids. The suitability and effectiveness of the technical solutions has then been analysed by involving the expertise of distribution grid operators (DSOs) and other experts. These solutions (presented in Figure 1) can be used to increase the PV hosting capacity in the distribution networks. They have been classified in DSO solutions, PROSUMER solutions and INTERACTIVE solutions. DSO solutions are installed and managed on the grid side and do not require any interaction with the consumers or the PV plants. PROSUMER solutions are installed behind the meter, i.e. on the PV operator’s premises, and react based on the grid characteristics at the point of common coupling, without any communication with the DSO.

The INTERACTIVE category requires a communication infrastructure linking the hardware located in different grid locations, involving both the prosumer and the DSOs.

Category	Technical solution
DSO	Network Reinforcement On Load Tap Changer for MV/LV transformer Advanced voltage control for HV/MV transformer Static VAr Control DSO storage Booster Transformer Network Reconfiguration Advanced Closed-Loop Operation
PROSUMER	Prosumer storage Self-consumption by tariff incentives Curtailment of power feed-in at PCC Active power control by PV inverter P(U) Reactive power control by PV inverter Q(U) Q(P)
INTERACTIVE	Demand response by local price signals Demand response by market price signals SCADA + direct load control SCADA + PV inverter control (Q and P) Wide area voltage control

Figure 1 - Technical solutions enhancing distribution grid hosting capacity

European distribution integration operators within their current operating mandates can in general implement any of the DSO solutions, with the exception of DSO storage. Dissimilarly, the PV GRID consortium has shown that the implementation of PROSUMER and INTERACTIVE solutions, when it is feasible from a technical readiness point of view, is often impaired by the existence of normative and regulatory barriers [4].

BARRIERS HAMPERING THE ADOPTION OF IDENTIFIED TECHNICAL SOLUTIONS

The discussion on the implementation of the identified technical solutions in the project's four focus countries has led to the identification of a series of barriers at national level, either general (affecting all technical solutions identified) or specific (affecting mainly one or a few of the solutions identified). The identified barriers include:

- Rules forbidding RES energy curtailment except for security issues
- Insufficient self-consumption frameworks
- Insufficient DSO access to advanced PV inverter capabilities
- Insufficient frameworks for prosumer and DSO storage
- Insufficient frameworks for demand response
- Incoherent metering frameworks
- Regulatory frameworks discouraging "smart grids" development.

In the next sections, a selection of these barriers is described together with general recommendations for mitigating them.

Rules forbidding RES energy curtailment except for security issues

Priority access and dispatching rules embedded in the RES Directive [5] foresee the possibility to curtail renewable energy only for system security and security of supply reasons. Hence, the RES Directive does not allow DSOs to curtail PV electricity for distribution grid planning and/or managing purposes.
however, some of the technical solutions identified to increase the hosting capacity of the distribution networks involve interference with the natural production pattern of PV installations. The relationship among these technical solutions, their usability to support distribution grids and the general philosophy of the RES Directive and of national laws with regards to RES priority dispatching involve a certain element of conflict. Amongst these solutions, curtailment can make sense from a technical point of view as the real production of a PV system only seldom reaches values that are close to its installed capacity. The peak power (of consumption and production) is the main driver for network investments. As peaks in consumption or production will only occur during a few hours of the year, curtailment of these peaks may imply significant savings. However, without some form of compensation for the loss of revenues, curtailment is a measure that entails considerable risks for the planning security of RES investors and hence has high potential to slow down the growth of PV installations.
The PV GRID consortium believes that a fair debate on the use of PV electricity curtailment would require the determination of 1) a national cost-benefit analysis methodology, 2) the boundary conditions for its application and 3) adequate compensation rules for PV agents in case of curtailment exceeding the agreed boundary conditions. In general, DSO driven curtailment should be utilised as little as possible, and only be allowed when congestion or voltage problems arise in the local network and all other available measures cannot be used. From the DSO's point of view, PV curtailment would be beneficial in many circumstances, even if PV agents are reimbursed for unpredicted losses of revenues. As a general and overriding rule the annuitized savings in avoided investments from curtailment should be larger than the compensation paid to the PV agent. Otherwise, the network should be expanded. As it was already mentioned, curtailment can put RES market growth at risk, bringing investment insecurity. Therefore, it should only apply to new installations.

Insufficient DSO access to advanced PV inverter capabilities

Modern inverters are able to provide many functionalities to support network operation. Although some of these solutions are already available from a technical point of view, in some countries DSOs cannot exploit such functionalities, as they do not have access to the PV inverter or the inverters' advanced capabilities. In countries where DSO access is allowed, other barriers may be a lack of experience and clear rules, as well as the absence of standards. In addition, PV GRID recognises that in the future other ancillary services may be provided by DG operators. However, further details still need to be defined in order to provide a sufficient regulatory framework for such services.

The PV GRID project consortium agrees that DSOs should be provided with access to advanced PV inverter capabilities and that the boundary conditions for the selected technical solutions should be defined by the competent national authorities. Further, the trade-off between the obligatory capabilities (established by grid codes) and capabilities that can be offered on a voluntary basis needs to be recognised and analysed further by all stakeholders. Finally, mechanisms to avoid conflict of interests with the TSOs and energy providers shall be put in place.

Insufficient Frameworks for Prosumer and DSO Storage Solutions

PV electricity production is subject to fluctuations associated with weather phenomena, such as cloud coverage and its changes, air temperature and others. These fluctuations contribute to a situation where the power output of these installations is not easily predictable and subject to spikes. Electricity storage solutions, implemented either (on the prosumer's premises) in combination with PV generators, or more centrally in the distribution network infrastructure, may allow for mitigating and controlling the aforementioned fluctuations. Storage integrated with PV generators, from a market point of view, increases the ability of PV to "produce" a predictable profile even in rapidly changing weather conditions. Additionally, from a network point of view, storage may be a means to control the maximum load that any PV generator can actually deliver to the network: i.e., production spikes above a certain power threshold can be kept in the storage device and not delivered to the network (peak shaving).

National regulatory frameworks should therefore allow prosumer storage solutions, while their connection and operation requirements should ensure that prosumer storage does not pose a security problem to the system or interfere with the metering of DG production.

In principle, storage solutions may also be used by DSOs to address the variability of DG. However, the concept of unbundling implies that DSOs are not allowed to own, operate or use storage. The reason is that DSO use of storage solutions would have (positive or negative) implications in the electrical market, due to the difference in prices between the instant of charging and the instant of discharging. As a consequence, both at European policy-making level and within each national regulatory framework, taking into account the network operation benefits that can be made available by DSO storage, there should be a reflection on how to activate this potential.

Regulatory Frameworks discouraging "Smart Grids" Development

The RES Directive [5] establishes that Member States shall take the steps to develop intelligent networks, i.e. network structures that are commonly referred to as "smart grids". Some of the technical solutions evaluated in PV GRID require more advanced system services and online monitoring of grid operating conditions, including an intensive use of communication systems and technologies.

The aim to develop smart grids at a European level is often in conflict with national regulations, which establish the specific conditions under which DSOs recover their investments and operate their networks. Basically, the national frameworks tend to implement regimes that include elements of incentive regulation, which has the main objective of promoting only efficient investments, with the underlying assumption that this reduction in investment and/or operational expenditure will ultimately imply a reduction of prices for the consumer. These types of regulations are adequate for promoting efficiency. However, as incentive regulations decouple the revenues from the real investments, they are a disincentive to investment; in addition they are mostly inefficient in steering investments into certain technologies. In fact, smart grid solutions typically rely on electronic components that have shorter useful lives and/or are not fully proven yet. Consequently, DSOs could discard their implementation due to the technological uncertainties. Under these conditions, national regulators should consider setting specific incentives to adopt and test innovative solutions.

A "smart grid" can bring about many advantages, such as a more sustainable, efficient and secure electricity supply to customers. However, each of these benefits is accompanied by significant costs related to the purchase, operation and maintenance of the required components. Careful consideration of both costs and benefits will be required.

National regulators should discuss with all relevant stakeholders the adaptation of regulatory frameworks in order to concretely promote "smart grid" investments. A stable and transparent regulatory framework (avoiding frequent changes), and an ex-ante approach should also

be established in order to favour such evolution.
If the conclusion of careful analysis suggests the implementation of smart grids to support integration of renewables and where necessary, explicit (pecuniary) incentives should also be established:

- Incentives can apply to innovative projects in smart grids, approved by the national regulators;
- In case that these incentives are to be generalised it would be required to clearly define a "smart grid" in terms of what are the services it has to provide and its architecture.

A ROADMAP FOR INCREASING PV INTEGRATION IN DISTRIBUTION GRIDS

In the previous section, we have offered a selection of the barrier analysis and recommendations contained in the PV GRID European Advisory Paper [6], part of a stakeholder consultation process that is currently taking place in the 15 countries participating in the project. In fact, the discussion of barriers and of such recommendations cannot take place without considering the peculiarities of each national context, and in particular the political willingness of developing PV as an electricity generation technology providing a certain share of national electricity supply within the framework of European objectives for RES development.

PV support measures and technical solutions

It should be recognised that there is a general correlation between the type of RES support schemes and the type, technology and size (load) of PV that will be generated. These correlations are shown in Figure 2.

Type of investor/ Regime	Large Investor	Small Investor	Electricity Suppliers
Tender	Utility-size	--	--
Quota	Utility-size and commercial	--	Utility-size and Commercial
Feed-in Tariff	Utility-size and Commercial	Commercial and Residential	--
Net Metering	--	Commercial and Residential	--

Figure 2 - Correlation between support schemes and PV system development

The point is that a certain support scheme will not only attract certain types of investors, but it will also largely determine the average size of PV installations that will be developed. Using a simple example that is also presented in the table, it is more likely that a tender regime will lead to rather large utility-size PV systems. In the same way, net-metering regimes tend to create a certain advantage in self-consuming PV produced electricity and probably imply somewhat smaller residential or commercial segment systems, whose size is "related" to amount of energy used on-site.
Due to the general technical characteristics of electricity networks, the type and capacity of a PV installation will to a large extent determine the network level it will be connected to, and this level determines the applicability and relative advantage of the technical solutions identified by PV GRID:

- **Utility-size PV systems** are typically installed in high voltage (HV) and, to a lesser extent, in medium voltage (MV) networks.
- **Commercial PV systems** in most cases are installed in MV networks. In this case, either a new connection is built or an existing one is enlarged.
- **Residential PV systems** are typically installed in low voltage (LV) and sometimes MV networks.

Therefore, it is useful to analyse the current and future set-up of PV support schemes and the network infrastructure as well as the regulatory and normative framework to determine in advance whether the technical solutions as identified by PV GRID are useful in the current or upcoming situation (as they might help to avoid or delay network expansion) and applicable in the current regulatory and normative framework (as they might be hindered by some of the barriers that were identified by PV GRID).

PV GRID Roadmap

With the aim of providing guidance and advice to member states that either anticipate a significant increase in PV penetration or are planning for such an increase, a roadmap for increasing PV integration in distribution grids in a given national context is illustrated in Figure 3. Together with the technical solutions, the roadmap can be used to identify gaps in the national regulatory and normative frameworks. To this end, it can support member states in their PV and overall RES strategy, as it gives an indication whether and how the technical solutions identified to increase the hosting capacity of existing grids should be exploited.
Based on a country's RES objectives and policies for increasing PV penetration, is there a need for action regarding the distribution grid hosting capacity? If so, policymakers, making use of broad stakeholder input, need to determine whether PV is supposed to be installed uniformly distributed, or only in certain regions. In case available regional hosting capacities should be used first, it may be necessary to introduce regulatory and normative steering instruments offering incentives or other forms of facilitation for PV systems in those regions with hosting capacity available. If not enough grid hosting capacity is available, stakeholders need to identify why capacity is limited and on what voltage level. PV GRID is addressing two main problems: voltage and congestion issues. Other

problems are out of the project's scope and hence, not addressed in the roadmap.

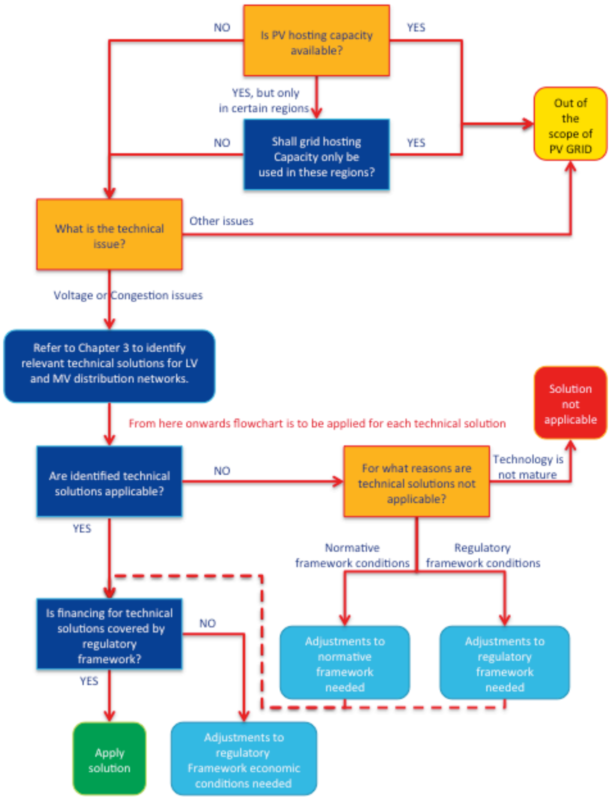

Figure 3 - PV GRID Roadmap for Increasing PV integration in distribution networks

Successively, DSOs in collaboration with other stakeholders need to check which of the technical solutions identified by PV GRID best suit the task of handling the particular situation in a certain region, thereby identifying the optimal mix of solutions to address the problems. Then, it needs to be checked whether those solutions are actually applicable. This step involves the analysis of barriers highlighted by PV GRID in [6]. If barriers are found, necessary changes in the normative and regulatory framework conditions need to be identified and all stakeholders should work together towards implementing them.

The final test is whether the most suitable solutions identified above can be financed, either by DSOs or by other stakeholders (e.g., prosumer storage solutions by consumers). If existing financial incentives are not sufficient to stimulate the application of technical solutions, stakeholders should work together towards adjusting the regulatory framework and setting the economic conditions in order to allow for adequate financing to apply the optimal mix of technical solutions.

CONCLUSIONS

The results of the PV GRID project indicate a set of effective technical solutions available to address the technical constraints induced by an increasing penetration of PV on distribution grids, and highlight the regulatory and normative barriers that need to be removed in order to allow for the application of these solutions. However, the PV GRID consortium's work also shows that addressing the large-scale integration of PV in distribution grids requires that policy makers, regulators, DSOs, PV associations and all other national stakeholders work in close cooperation and address several interlinked issues, and in the first place the political willingness of national authorities in establishing PV as a significant source of electricity generation.

In order to provide national stakeholders with a structured approach, the PV GRID consortium has prepared a roadmap that can be used to analyse these factors in an organised, step-by-step fashion, allowing to select the most tailored technical solutions, and identify the barriers that impede their implementation or their financial sustainability.

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