TECHNICAL SOLUTIONS SUPPORTING THE LARGE SCALE INTEGRATION OF PHOTOVOLTAIC SYSTEMS IN THE FUTURE DISTRIBUTION GRIDS

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ABSTRACT

In 2012 a consortium of 21 partners from 16 EU countries launched the PV GRID project having as objective to reduce barriers hampering the large-scale integration of photovoltaic systems in distribution grids across Europe. This goal will be pursued through an analysis of barriers and solutions and the formulation of regulatory and normative recommendations. In a first step, technical solutions for increasing the grid hosting capacity have been identified. The suitability of the technical solutions has then been analyzed. The methodology for this analysis is presented in this paper.

INTRODUCTION

In 2012 a consortium of 21 partners from 16 EU countries started the PV GRID project with the objective to prepare the grounds for the large-scale integration of photovoltaic (PV) systems in distribution grids across Europe and bring forward concrete suggestions on how this can be achieved. To integrate higher shares of PV and other distributed energy resources (DER) in saturated distribution grids, voltage and congestion limitations need to be overcome by technical measures.
In a first step of the PV GRID project, the most appropriate technical solutions have been identified. The suitability of the technical solutions has then been analyzed by involving the expertise of distribution grid operators (DSOs) and other experts. Based on these results, the PV GRID consortium will investigate normative and regulatory actions that will allow a swifter and more economical implementation of the most promising technical solutions.
An outline of the identified technical solutions and the evaluation method used for their assessment is presented in this paper, while first results will be shown during the CIRED conference.

TECHNICAL SOLUTIONS FOR ENHANCING THE GRID CAPACITY FOR PV INTEGRATION

In order to increase the hosting capacity for PV generators, firstly voltage rise mitigation and secondly congestion reduction should be addressed in distribution grids [1] [2] [3].
The subsequent list of technical solutions for enhancing the grid capacity for PV integration has been identified in the literature and within the PV GRID consortium as the most relevant for the current and future electrical distribution networks. Depending on where they can be implemented, the technical measures are categorised in *DSO*, *Prosumer* 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. The *Prosumer* solutions are installed beyond the point of common coupling and react on loads or generation units, without any communication need with the DSO. The category *Interactive* requires a communication infrastructure linking the hardware located in different grid locations.

DSO solutions

Network reinforcement
Further grid hosting capacity is provided by additional cable and transformer capacity installations.
On Load Tap Changer (MV/LV transformer)
The OLTC device is able to adjust the lower voltage value of an energized transformer.
Advanced voltage control (HV/MV transformer)
This solution includes new control methods for existing HV/MV transformers with already installed OLTC.
Static VAR Control
Utilizing Static VAR Compensators (SVC) enables to provide instantaneously reactive power under various network conditions.
DSO storage
Storing electricity with a central storage situated in a suitable position of the feeder enables to mitigate voltage and congestion problems.
Booster Transformers
Boosters are MV-MV or LV-LV transformers which are

used to stabilize the voltage along a long feeder.

Network Reconfiguration

Revising network operational conditions by reconfigurations, in particular the boundaries between feeders in MV networks, is a method to enhance the voltage profiles in distribution networks.

Advanced Closed-Loop Operation

Two feeders are jointly operated in a meshed grid topology controlled by a Smart Grid architecture to decrease the circuit impedance while increasing the short circuit power.

Prosumer solutions

Prosumer Storage

Storing electricity at prosumer level enables to mitigate voltage and congestion problems if a reduction of the feed-in peaks can be ensured.

Self-consumption by tariff incentives

With a fixed tariff structure (e.g. feed-in price lower than consumption price), the prosumer is motivated to shift its electricity consumption in order to reduce its injected PV energy. A maximum feed-in power based tariff (e.g. kWh price set to zero or to negative values above some feed-in power limits) could further help in reducing injected PV peak power.

Guaranteed self-consumption

The meter at the customer's site controls that the feed-in power is never above the contracted maximum power or above a fixed value (e.g. 70% of the installed PV capacity as implemented in the German Renewable Energy Act). This solution requires the meter to be able to control down the PV production or to activate a dump load.

Indirect Voltage control by PV inverter Q(P)

Providing reactive power as an increasing function of active power limits the voltage rise caused by distributed generators.

Direct Voltage control by PV inverter Q(U), P(U)

Providing reactive power and in the second step reducing active power as a function of the local voltage value (measured by the PV inverter), limits the voltage rise caused by distributed generators.

Interactive solutions

Demand response by market price signals

Demand response is triggered by electricity market price signals, which are identical for all consumers wherever they are located.

Demand response by local price signals

Demand response is triggered by local price signals available only to consumers located in feeders which experience voltage and/or congestion problems.

SCADA + direct load control

In critical grid situations, DSOs or energy aggregators are allowed to remotely activate (or curtail) dedicated consumer loads, based on agreed contract.

SCADA + PV inverter control (Q only)

The level of reactive power provision by dedicated PV inverters is remotely controlled by a feeder supervisory control system.

SCADA + PV inverter control (Q and P)

The level of reactive power provision and the active power reduction of dedicated PV inverters are remotely controlled by a feeder supervisory control system.

Wide area voltage control

All controllable equipment (like transformers with OLTC, static VAR compensators, dedicated loads and PV inverters) are coordinated to optimize voltage and power factor in the whole DSO area. Smart grid technologies are applied to measure the voltage and power factor at several points, controlling the equipment, coordinating and optimizing the generation and load.

METHOD FOR THE EVALUATION OF TECHNICAL SOLUTIONS

In contrast to grid simulations which allow a direct comparison of different technical solutions but have the disadvantage of representing assumptions of predefined grid topologies, the method presented in this paper aims for a holistic trans-national outcome.

The qualitative approach for the evaluation of technical solutions is based on a country wise assessment by DSOs from Italy, Spain, Germany and Czech Republic and the assessment of the involved PV industry associations. However, technical solutions might not be applicable in every grid situation. The method was chosen to point out fundamental needs for action in terms of existing technical barriers and the surrounding regulatory framework.

Technical solutions have been evaluated considering two grid types (LV and MV) against the following five criteria:

- Investment costs
- Impact on voltage
- Impact on congestion
- Technology readiness
- Applicability within existing regulations

The five criteria are evaluated with 5 score levels (Table II). Based on the evaluation results with the different criteria, two performance indicators have been calculated for each solution in each table:

1. Techno-economic indicator

The techno-economic indicator represents weighted evaluations including the score results from the investment cost, the impact on voltage and the impact on congestion. As grid hosting capacity limitations are usually linked to voltage limitation violations [4], a higher weight is put on this impact.

Table I: Regulatory priority indicator

Regulatory priority	Technology available	Regulation needed	Recommendation
1	YES	YES	Urgency to adapt regulations
2	NO	YES	Urgency for regulatory changes depends on technology maturity
3	NO	NO	Technology is not mature
4	YES	NO	Should be applied where problems occur

2. Regulatory priority indicator

In contrast, the regulatory priority indicator indicates regulatory barriers and the urgency to remove this barrier. This indicator is defined in Table I considering the following thresholds:

- A "Technology readiness" score which is higher than 2 denotes that the technical solution is not available.
- A score for "Applicable within existing regulations" which is higher than 1 denotes that regulatory barriers are to be investigated.

Table II: Definitions of evaluation criteria

Criteria	1	2	3	4	5
Investment cost	Virtually no cost	Low cost	Average cost	High cost	Very high cost
Technology readiness	Commercial product	Successful in pilot grid demonstration	Successful in the laboratory	Early research	Only concepts are available
Impact on voltage quality and reproducibility	Can solve any voltage deviation problem through appropriate sizing AND Can be applied in any location of the related grid category	Can solve many voltage deviation problems through appropriate sizing AND Can be applied in many locations	Can solve many voltage deviation problems through appropriate sizing AND Can be applied in a limited number of locations	Can solve only limited number of voltage deviation problems AND Can be applied in a limited number of locations	Nearly useless or not reproducible
Impact on congestion and reproducibility	Can solve any congestion problem through appropriate sizing AND Can be applied in any location of the related grid category	Can solve many congestion problems through appropriate sizing AND Can be applied in many locations	Can solve many congestion problems through appropriate sizing AND Can be applied in a limited number of locations	Can solve only limited number of congestion problems AND Can be applied in a limited number of locations	Nearly useless or not reproducible
Applicable within existing regulations	Can be done by any operator	Do not know	Do not know	Do not know	Requires change in regulation

CONCLUSION

In order to increase the grid hosting capacity for PV integration, the main limitation is the voltage increase along the feeders due to higher generation power than demand. Within the PV GRID project, 19 technical solutions have been identified in order to increase the hosting capacity of existing distribution grids.

For comparing the relative impacts of the technical solutions in different grid categories, an evaluation methodology has been defined. In a first step, the solutions are compared against the investment costs, the impact on voltage, the impact on congestion, the technology readiness and the applicability within existing regulations. Different composite indicators (techno-economic, urgency to investigate regulatory barriers) are then derived from the initial results. Based on these indicators, the PV GRID consortium will investigate normative and regulatory actions that will allow a swifter and more economical implementation of the most promising technical solutions. Preliminary results will be shown during the CIRED conference.

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REFERENCES

[1] Deutsche Energie Agentur GmbH (ed.), 2012, *Dena-Verteilnetzstudie,* Dena, Berlin, Germany, 9.

[2] T. Stetz, M. Braun, 2011, “Decentralized approaches for voltage rise mitigation in low voltage grids – a case study”, Elektrotechnik & Informationstechnik, vol. 128/4, 105-109.

[3] M. Braun, A. van Oehsen, Y.M. Saint-Drenan, T. Stetz, 2012, “Vorstudie zur Integration großer Anteile Photovoltaik in die elektrische Energieversorgung“, Fraunhofer IWES, Kassel, Germany, 64-117.

[4] D. Mende, Y.T. Fawzy, D. Premm, S. Stevens, 2012, “Increasing the Hosting Capacity of Distribution Networks for Distributed Generation Utilizing Reactive Power Control - Potentials and Limits”, *2nd International Workshop on Integration of Solar Power into Power Systems*, Portugal.

[5] PV GRID website: www.pvgrid.eu