TECHNICAL SOLUTIONS FOR INCREASING DER HOSTING CAPACITY IN DISTRIBUTION GRIDS IN THE CZECH REPUBLIC IN TERMS OF EUROPEAN PROJECT INTERFLEX

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ABSTRACT

The paper describes proposed, implemented, tested and verified technical solutions supporting distributed energy resources (DER) integration in the distribution grids. The solutions are implemented by CEZ Distribuce, the largest Distribution System Operator (DSO) in the Czech Republic, in terms of Horizon 2020 InterFlex project. New approaches for PV inverters control are introduced in a way that DER integration is less limited by voltage constraints or other grid issues. Different approaches for LV and MV grids are explained. Smart solutions including autonomous functions of PV inverters, remote control or energy storage are presented to show the future potential for successful DER grid integration.

INTRODUCTION

CEZ Distribuce as a European DSO has to be prepared for future expected development of DER in the Czech Republic. The official document called Czech National Action Plan for Smart Grids [1] published in 2015 by Czech Ministry of Industry and Trade presents a reference scenario of future expected development of DER where PV installations have a major share. Currently, the total installed capacity of PV in the Czech Republic is about 2.1 GWp which represents approximately 10 % of total installed capacity of all generations in the country (22 GW). Reference scenario assumes approx. 6 GWp of total PV installed capacity in year 2040 where most of PV installations are expected to be connected to LV grids.

This could result in non-economical massive investments on strengthening the distribution grid as it is shown in Fig. 1 where most regions are expected to have insufficient DER hosting capacity (coloured in pink). In order to find a cost effective solution for PV integration, secure supply and power quality for customers, CEZ Distribuce focuses on innovative smart solutions which have a strong potential for wide scale development.

On LV level, the solution is based on autonomous Q (V) and P (V) functions of PV inverters and use of energy storage at customer premises. On MV level, the solution is based on Q control based on required voltage set point. The solutions are tested within European project InterFlex.

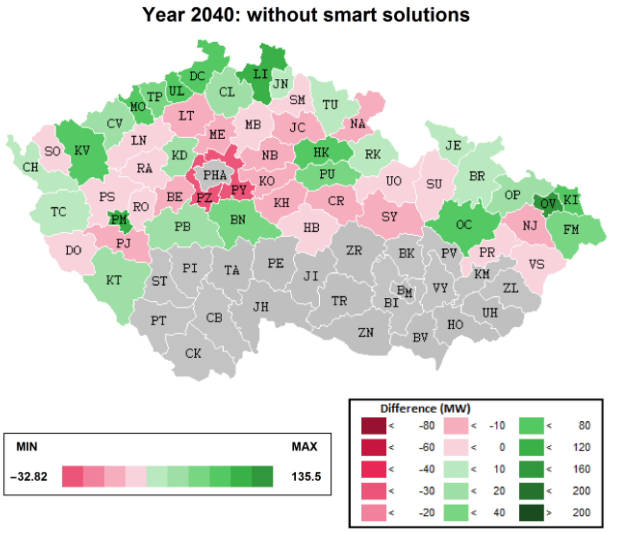

Fig. 1: Expected lack of DER hosting capacity in LV grids in 2040 in case that smart grid solutions are not implemented

INTERFLEX PROJECT IN CEZ DISTRIBUCE

Supported by the European Commission, in the framework of the biggest EU Research and Innovation Programme Horizon 2020, the smart grid project InterFlex was launched on January 1st, 2017. Its motto is “Interactions between automated energy systems and flexibilities brought by energy market players”. The 3-year 22.8 M€ project includes 20 partners who are exploring new ways to use various forms of flexibilities with the aim to optimize electric power systems on a local scale [2], [3].

The Czech demonstration project WP6 is located in several areas in the Czech Republic where CEZ Distribuce operates its distribution grid. The demonstration is not focused only on one area in order to prove replicability and interoperability of designed solutions and is divided into 4 Use cases (UC) [4]:

1) Increase DER hosting capacity of LV distribution networks by smart PV inverters
2) Increase DER hosting capacity in MV networks by volt-var control
3) Smart EV charging (*not in the scope of this paper*)
4) Smart energy storage

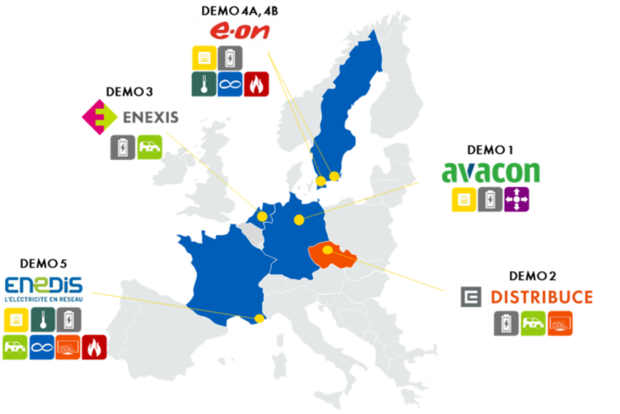

Fig. 2: European DSOs involved in InterFlex project

WP6 is focused on the implementation of technical solutions which are not so far disseminated in distribution grids but which have a strong potential for future roll out. The tested solutions cover the most urgent challenges of DSOs - increasing DER hosting capacity, EV charging stations integration and energy storage. WP6 also aims to propose grid codes and standards updates in order to secure future smoother integration of the smart solutions.

USE CASE 1: INCREASE DER HOSTING CAPACITY OF LV DISTRIBUTION NETWORKS BY SMART PV INVERTERS

UC1 is focused on testing and implementation of advanced smart PV inverters equipped with Q (V) and P (V) control functions which should allow increasing DER hosting capacity in LV grids. These functions work autonomously without the need of communication to DSO. CEZ Distribuce carries out field tests in 2 areas.

Both functions are used for voltage stabilization in LV grids and thus for significant increasing DER hosting capacity. In case voltage is higher than a threshold, PV inverter switches to the under-excited (inductive) mode thanks to Q (V) function as it is shown on Fig. 3. In case the voltage slopes up even more, PV inverter starts to curtail active power generation thanks to P (V) function – see Fig. 4. In case voltage is lower than a threshold, PV inverter switches to the over-excited (capacitive) mode thanks to Q (V) function. The inverter voltage measurement input for both functions is based on several seconds moving average.

Standard inverters are usually able to be operated with symmetrical active and reactive powers in all three phases today. The inverters equipped with the mentioned control functions work autonomously, i.e. the functions curves are set inside each inverter setup menu (but uniform over the distribution area). Q and P are controlled locally only according to voltage conditions in the point of the inverter connection without any command from the dispatch centre or elsewhere.

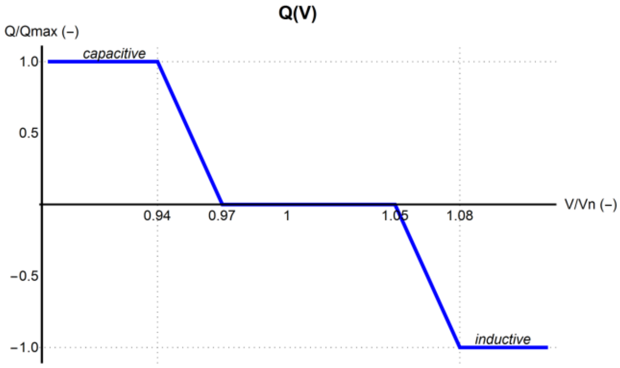

Fig. 3: Autonomous Q (V) function of smart PV inverter

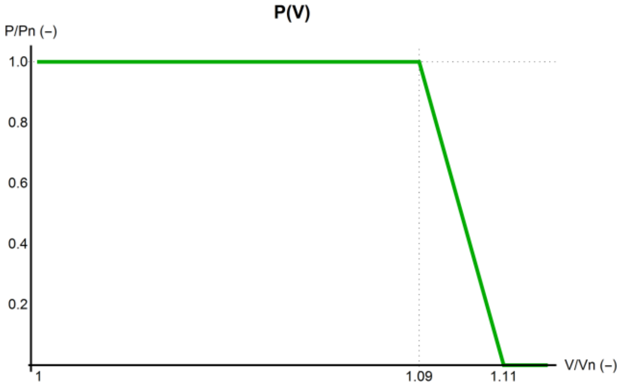

Fig. 4: Autonomous P (V) function of smart PV inverter

Micro-generation plants are obliged to be equipped with Q (V) and P (V) control functions according to technical standards (EN 50438:2013) and Distribution grid code in the Czech Republic. It means relevant prosumers have to provide this grid supporting control as a condition of connecting to the grid. Their benefit is higher generation power connectable to the grid without any intensive need to curtail their energy production.

Q (V) and P (V) functions were tested in the lab of Austrian Institute of Technology in Vienna for Fronius and Schneider Electric PV inverters in order to prove their behaviour before field implementation. Both tests showed very good results with only minor deviations from expected characteristics. See Fig. 5 and 6 for steady-state characteristics test results.

If active power is equal to 100 % of Sn (inverter rated power) and Q (V) function needs to be activated, the PV inverter has to reduce its active power in order to be able to produce/absorb any reactive power without overloading the PV inverter’s components. The tested settings with minimal power factor equal to 0.9 results in active power curtailment to 90 % of Sn. It must be mentioned that such behaviour results in a negligible annual energy production losses of the PV system.

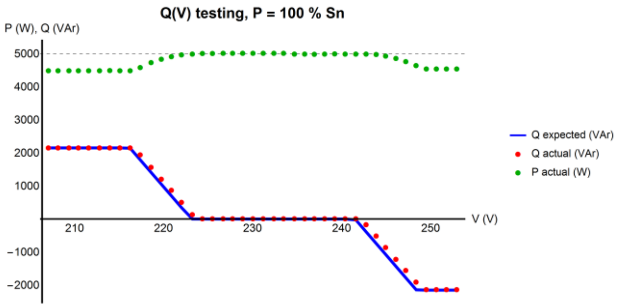

Fig. 5: Q (V) function lab test results for Fronius PV inverter

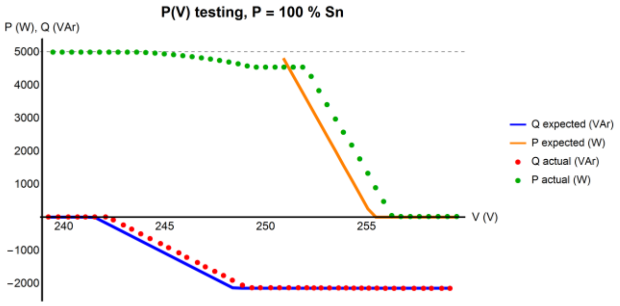

Fig. 6: P (V) function lab test results for Fronius PV inverter

The inverter functions dynamic behaviour should follow technical standard EN 50438:2013 requirements. It defines that control dynamics must correspond to the first-order filter with a settable time constant in the range from 3 to 60 seconds. Successful lab tests results are shown in Fig. 7 for the settings with the time constant 5 s for both Q (V) and P (V) function.

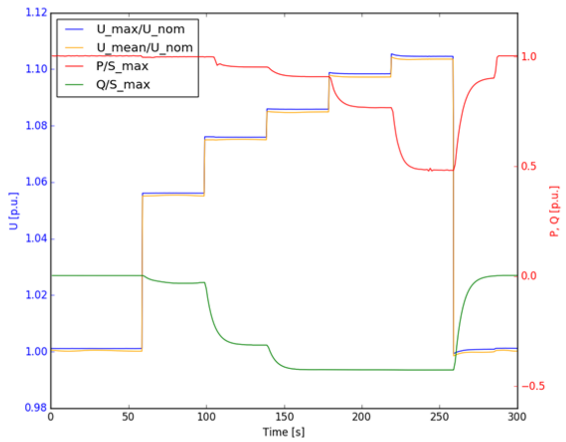

Fig. 7: Control dynamic behaviour for Fronius PV inverter

There were carried out some previous theoretical studies (e.g. [5]) or practical tests [6] of smart PV inverters to increase DER hosting capacity in LV grids. InterFlex project respects the previous results and focuses on long-term field testing with stabilized control function settings. The aims are to quantify the hosting capacity increase, to verify this by means of field installations in different distribution areas, to check voltage quality issue (EN 50160:2011) at the customers and finally to implement received knowledge into distribution grid codes.

Several rooftop PV installations with smart inverters were commissioned during winter and spring season 2018. The first interesting results from the demonstration are already available, the others for the entire solar season will be obtained during 2019. Fig. 8 shows an example of behaviour of 10 kWp PV system on 7th May 2018. Data are measured directly at the inverter AC output, all samples are 1 minute average values. Due to the fact that all PV systems are installed in distribution grids with very limited DER hosting capacity (long feeders with thin cross-sections), the PV active power production increases grid voltage significantly. Q (V) function switches to the inductive (under-excited) mode if the average voltage (blue samples) exceeds 1.05 Vn (red dashed line) and is fully activated if the average voltage exceeds 1.08 Vn (red dot-dashed line). The active power curtailment is activated only if maximal phase-to-neutral voltage exceeds 1.09 Vn and active power is high enough. Fig. 9 shows only few minor curtailments of active power around the noon time.

Fig. 8: Daily behaviour of smart PV inverter with Q (V) and P (V) functions

An overall assessment of PV inverter smart functions behaviour is shown in Fig. 9. The figure aggregates all 1-minute voltage samples during April 2018. Very good Q (V) function precision in comparison with the ideal characteristic line was proved. Higher demand for reactive power control in case of higher active power production is obvious, as well as voltage quality level (1.1 Vn – 253 V) fulfilment.

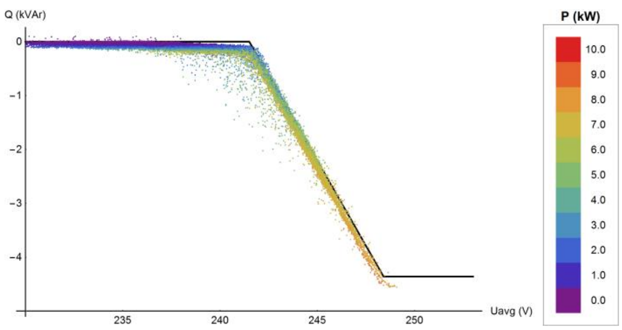

Fig. 9: Smart PV inverter operation points in April 2018

USE CASE 2: INCREASE DER HOSTING CAPACITY IN MV NETWORKS BY VOLT-VAR CONTROL

UC2 is focused on implementation of volt-var control system on existing DERs connected to MV grids for increasing DER hosting capacity by voltage stabilization. CEZ Distribuce is testing this solution on 4 different DER technologies (1.1 MW PV, 4.6 MW Wind, 1.25 MW Biogas, 6.4 MW Hydro).

DER receives voltage set point from DSO Distribution Management System (DMS). The required voltage results from grid operation optimization process and it can be changed several times a day (however it is usually fixed over a long period – days, weeks). Comparing the required and measured voltage in the point of DER connection, DER controls its reactive power in order to stabilize the voltage. A great advantage of this approach is that the control can work more or less correctly even in case of loss of communication with DMS because grid operation conditions don't change required voltage set point significantly. The volt-var control for MV generation units above 100 kVA is obligatory according to the Czech Distribution grid code. The control method depends on each DSO, CEZ Distribuce requires the mentioned voltage set point method.

Field tests proved reliable and adequate reactive power response of volt-var control system which helps to stabilize the voltage in MV grid. Fig. 10 shows a daily field test result for 1.1 MWp PV Zamberk, Fig. 11 shows long-term operation statistics.

The daily course shows the correct changes between the under-excited (inductive) and over-excited (capacitive) mode within a voltage tolerance band if the HV/MV transformer tap was changed. Long-term statistical assessment for 3 months period shows the correct operational modes for all 1-minute values (i.e. no capacitive (over–excited) mode for higher voltage levels and no inductive (under–excited) mode for lower voltage levels).

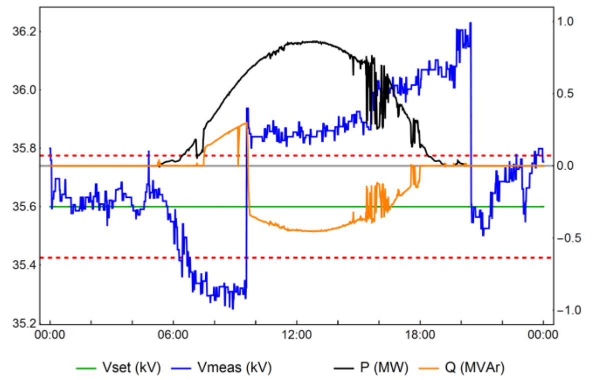

Fig. 10: Demonstration of volt-var control system on 1.1 MWp PV

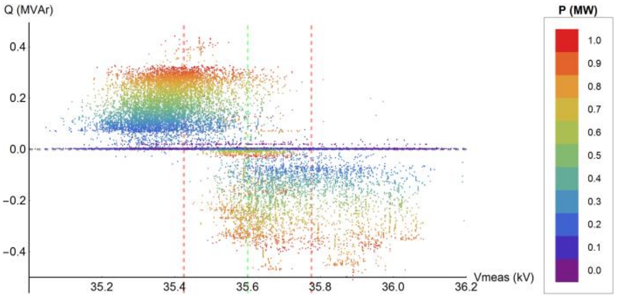

Fig. 11: Long-term statistical assessment of volt-var control system behaviour on PV Zamberk (installed capacity 1.1 MWp)

USE CASE 4: SMART ENERGY STORAGE

UC4 is focused on increasing DER hosting capacity in LV grids and supporting the grid in case of under-voltage, under-frequency or emergency state by implementation of smart hybrid PV inverters in combination with home energy storage (batteries). In addition to Q (V) and P (V) autonomous functions as in UC1, the basic tested function is the permanent feed-in limitation of active power into the grid which is set to 50 % of the PV installed capacity. Another function is discharging of the battery in case of under-voltage, under-frequency (autonomous control) or in case of receiving ripple control signal (through one way simple PLC) from CEZ Distribuce DMS. The ripple control signal is supposed to be used only in case of grid emergency states requiring overall loading reduction.

An example of active power daily course measured at the customer point of common coupling is shown in Fig. 12. The 5.2 kWp PV has a limitation for feed in power to the grid set to 2.6 kW and this limit was never exceeded. As this limit is summation for all three phases and the inverter operation is balanced, individual phases can differ because of household self-consumption.

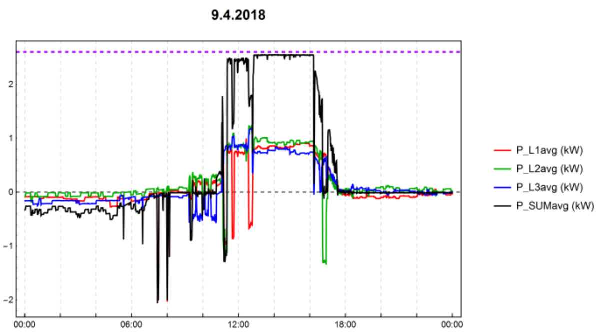

Fig. 12: Daily behaviour of customer with PV and energy storage – PV 5.2 kWp, feed in power limited to 50 % (2.6 kW)

If we take out the net PV production, i.e. separate household self-consumption and the effect of energy storage, the active power samples which are input for the evaluation of possible DER integration to the grid could be depicted. The overall statistical view for April 2018 is shown in Fig. 13. The histogram shows that 16.3 %

active power samples exceed the limit 50 % Pn (mostly slightly) because there are situations with unbalanced loads which result in higher PV production (which is balanced for tested PV inverters) even if the total feed-in limit to the grid is not exceeded. On the other hand the statistical distribution is much different for the PV installation 4.6 kWp without any energy storage in the same location – see Fig. 14. Here lots of values occur in the range from 70 to 90 % Pn. This phenomenon illustrates another possibility how to increase DER integration to distribution grids.

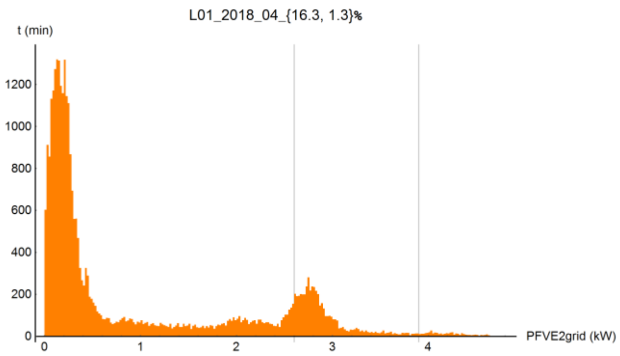

Fig. 13: Net PV production with smart energy storage – PV 5.2 kWp

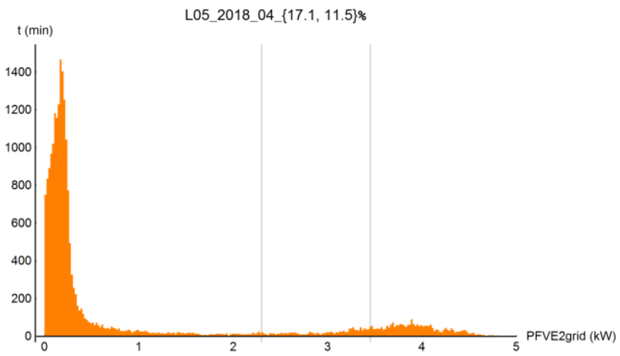

Fig. 14: Net PV production without any energy storage – PV 4.6 kWp

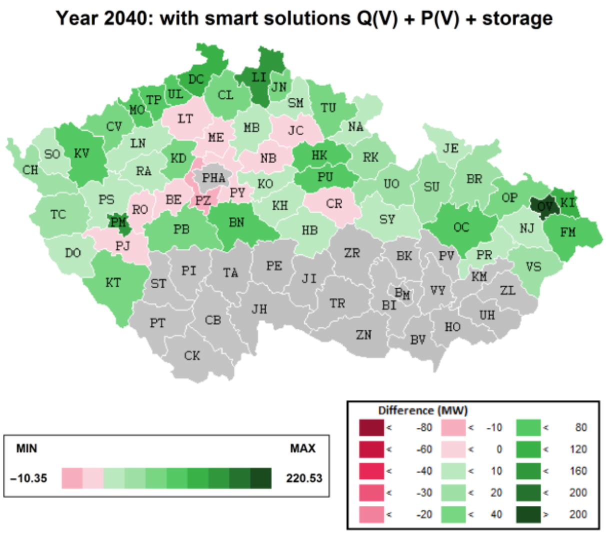

Fig. 15: Expected lack of DER hosting capacity in LV grids in 2040 in case that smart grid solutions are implemented

BENEFITS AND EXPECTATIONS

Autonomous Q (V) and P (V) functions together with smart energy storage concept should significantly reduce number of regions with insufficient DER hosting capacity in LV grids and thus reduce costs for DER integration (costs for grid reinforcement) – see Fig. 15. Increase of DER hosting capacity is foreseen between 30 and 50 %. Volt-var control system on DER connected to MV level could significantly increase DER hosting capacity, the expected impact depends heavily on grid topology and is foreseen between 20 and 100 %.

CONCLUSION

Final results of field demonstrations are expected during 2019. After evaluation, CEZ Distribuce is going to propose grid code update (calculation for DER hosting capacity in distribution grids) in order to allow more connections of DER equipped with Q (V) and P (V) functions on LV level and DER equipped with volt-var control system on MV level. This approach based on InterFlex results is going to contribute to significant cost reduction of future DER integration in CEZ Distribuce areas in the Czech Republic. The smart solutions described in this paper could be scaled and replicated worldwide.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n° 731289

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