Increasing of Renewables Hosting Capacity in the Czech Republic in terms of European Project InterFlex (Case Study)

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***Abstract*—The paper describes proposed, implemented, tested and verified technical solutions supporting distributed energy resources (DER) and electrical vehicles (EV) 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. Further an idea how to control EV charging power is introduced to integrate EVs smoothly.**

***Index Terms*--autonomous control functions, energy storage systems, smart EV charging, smart PV inverters, volt-var control**

I. Introduction

CEZ Distribuce as a European DSO has to be prepared for future expected development of DER and E-mobility 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 generators 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.

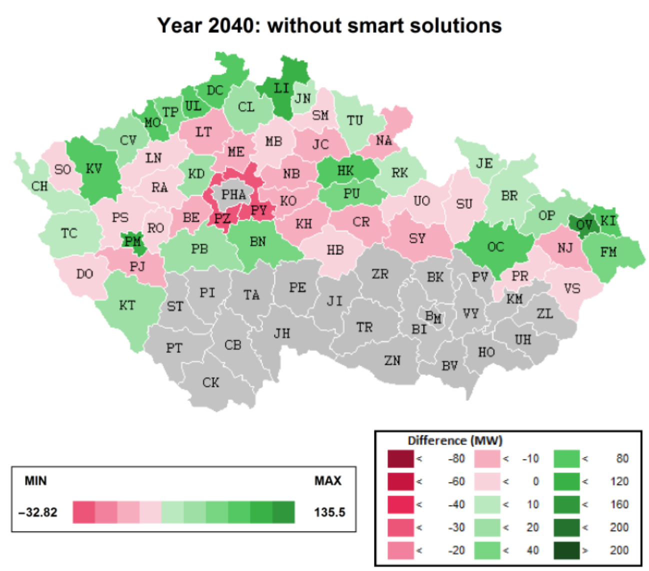

Figure 1. Expected lack of DER hosting capacity in LV grids in 2040 in case that smart grid solutions are not implemented

The National Action Plan for Clean Mobility [2] describes three scenarios of EV numbers in years 2020, 2030 and 2040 for the Czech Republic – see Fig. 2. Low scenario represents the situation with no incentives and the same trend of EV deployment as in years 2015 – 2017. Most probable medium scenario called “Reference” counts with national incentives for EV purchase and includes car manufactures goals published in last years. High scenario expects much higher demand for EVs particularly after 2025 when offer on the market is wide enough to secure EV for almost every driver.

The impact analysis of Reference scenario on low voltage grids of CEZ Distribuce has shown possible issues related mainly to exceeding nominal power of MV/LV transformers. Electricity peak demand in 2040 during afternoon hours without any control and limiting of EV charging would result in overloading of almost 12 000 (from 62 000 in total) distribution transformers. Those transformers should be replaced before planned 40 year lifetime by new transformers with higher nominal power, but this will result in huge costs for DSO.

Integration of such number of EVs which are charged almost simultaneously will need a reliable solution that could limit maximum power output of every charger in case of network constraints. This measure will secure cost effective integration of charging stations into distribution networks.

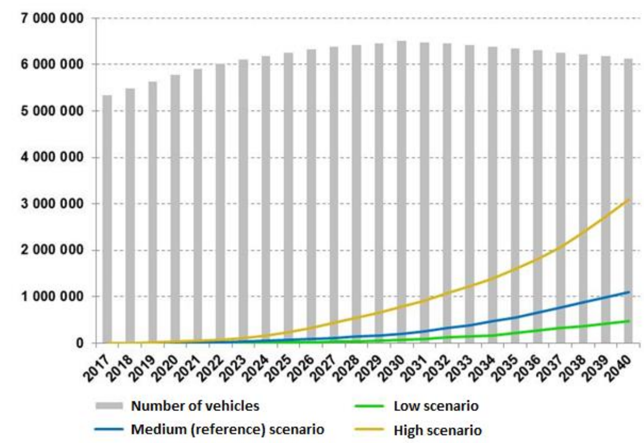

Figure 2. Three different electric vehicles scenarios for the Czech Republic

II. 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 project includes 20 partners who are exploring new ways to use various forms of flexibilities with the aim to optimize the electric power system on a local scale [3], [4].

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) [5]:

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
4) Smart energy storage

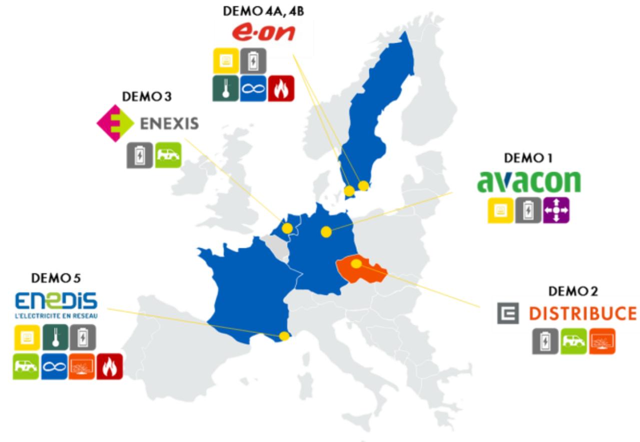

Figure 3. European DSOs involved in InterFlex project

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

In WP6, CEZ Distribuce co-operates with other InterFlex partners – Austrian Institute of Technology, CEZ Solarni, Fronius, Schneider Electric and Siemens.

III. Use Case 1: Increase DER Hosting Capacity of LV Distribution Networks by Smart PV Inverters

UC1 is focused on testing and implementation of new generation 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 towards 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. 4, in case the voltage rise even more, PV inverter starts to curtail active power generation thanks to P (V) function – see Fig. 5. In case voltage is lower than a threshold, PV inverter switches to the over-excited (capacitive) mode thanks to Q (V) function.

Standard inverters are usually able to be operated with symmetrical active and reactive powers in all three phases today. Therefore Q (V) function works with the voltage average from all three phases to support the overall grid voltage. The P (V) function is used as the last measure to keep voltage quality level, therefore it works with maximal value of the three phase-to-ground voltages. The inverter voltage measurement input for both functions is based on several seconds moving average.

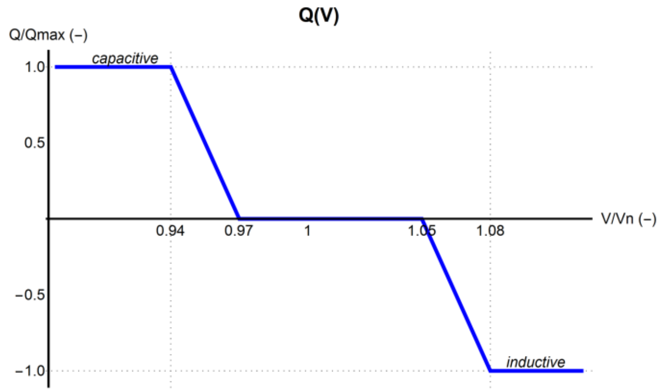

Figure 4. Autonomous Q (V) function of smart PV inverter

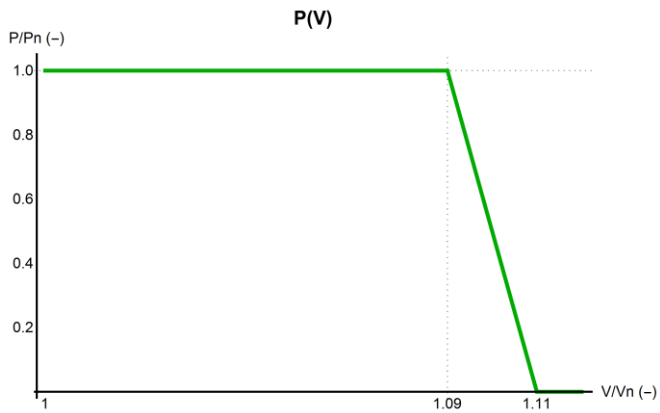

Figure 5. Autonomous P (V) function of smart PV inverter

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. 6, 7 and 8 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 a behaviour results in a negligible annual energy production losses of the PV system.

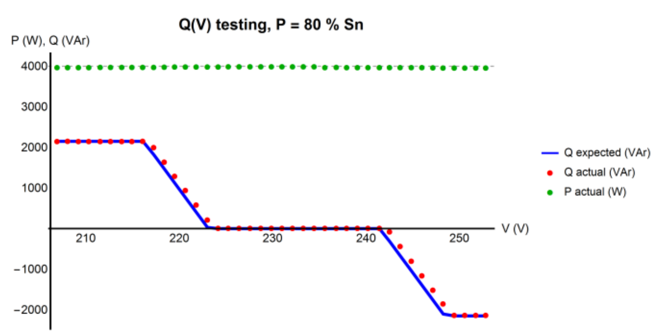

Figure 6. Q (V) function lab test results for Fronius PV inverter

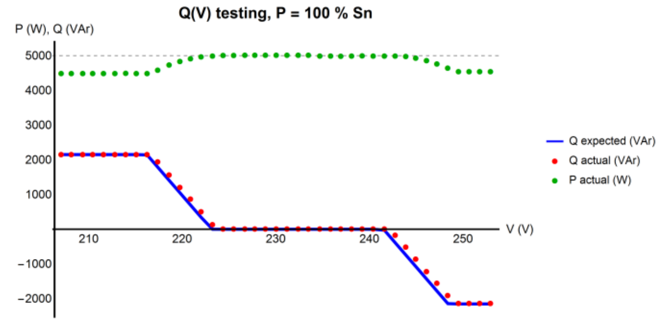

Figure 7. Q (V) function lab test results for Fronius PV inverter

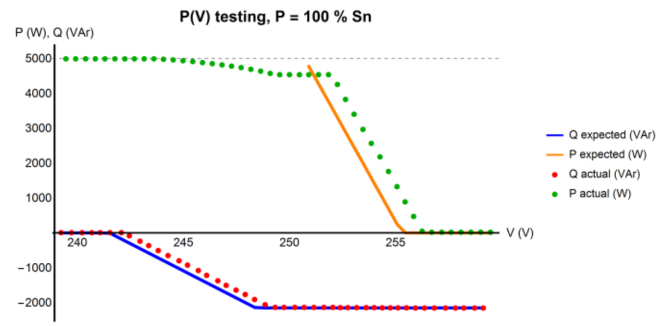

Figure 8. P (V) function lab test results for Fronius PV inverter

The inverter functions dynamic behaviour should follow technical standard EN 50438:2013 [6] 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. 9 for the settings with the time constant 5 s for both Q (V) and P (V) function.

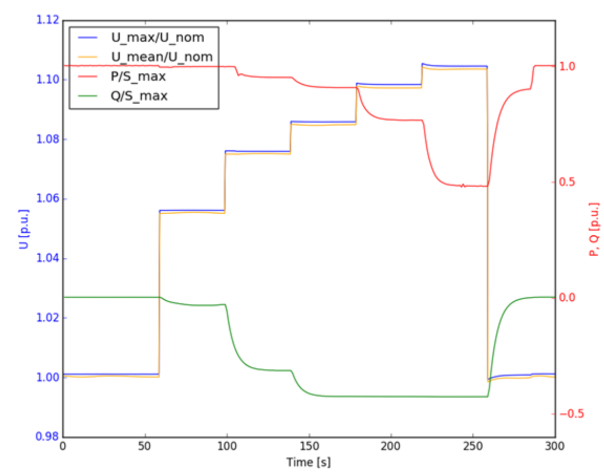

Figure 9. Control dynamic behavior for Fronius PV inverter

Several rooftop PV installations with smart inverters were commissioned during winter season 2017/2018. The most interesting results from the demonstration will be obtained in summer 2018, however the first data are already available. Fig. 10 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. 10 shows only few minor curtailments of active power around the noon time.

Figure 10. Daily behavior of smart PV inverter with Q (V) and P (V) functions

An overall assessment of PV inverter smart functions behavior is shown in Fig. 11. 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 also due to the contribution of P (V) function.

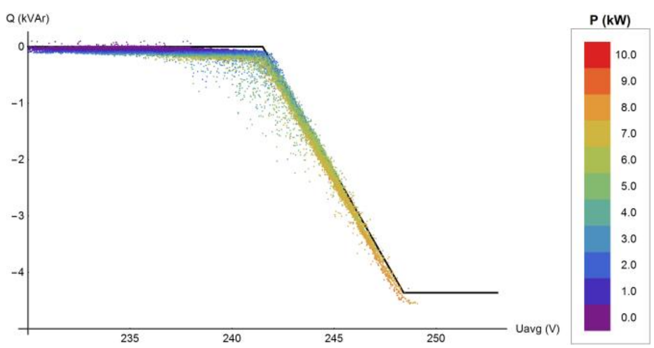

Figure 11. Smart PV inverter operation points in April 2018

Further results will be available before the end of 2018. Results will evaluate and confirm possibility for increasing PV hosting capacity. They will focus mainly on overall statistics, voltage quality and P production curtailment in context with PV integration increase.

IV. 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 points from DSO Distribution Management System (DMS) and controls its reactive power in order to stabilize the voltage.

Field tests proved reliable and adequate reactive power response of volt-var control system which helps to stabilize the voltage in MV grid. Fig. 12 and 13 show daily field test results for 1.1 MWp PV Zamberk, Fig. 14 shows long-term operation statistics.

Daily courses show the correct changes between the under-excited (inductive) and over-excited (capacitive) mode within a voltage tolerance band for two different voltage and active power behaviors. 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).

Figure 12. Demonstration of volt-var control system on 1.1 MWp PV

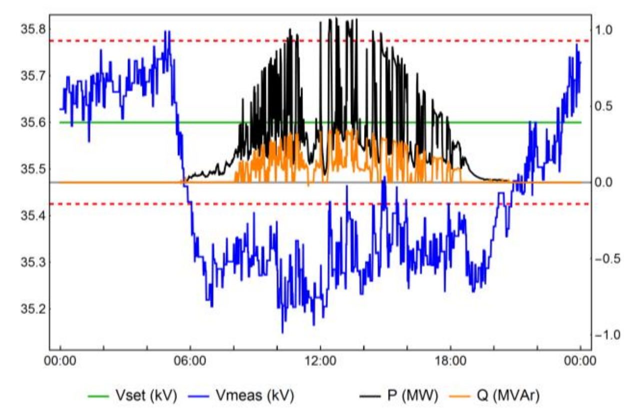

Figure 13. Demonstration of volt-var control system on 1.1 MWp PV

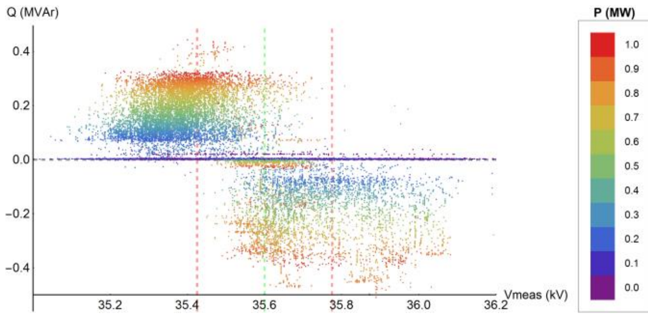

Figure 14. Long-term statistical assessment of volt-var control system behavior on PV Zamberk (installed capacity 1.1 MWp)

V. USE CASE 3: SMART EV CHARGING

Objective of UC3 is to reduce maximum charging power of smart charging station in case of underfrequency, undervoltage or in case of receiving signal from DSO in case of emergency through narrow band simple one way PLC communication (also known as ripple control system) and power quality measurement during EV charging process (evaluated according to EN 50160).

CEZ Distribuce together with partners aims at testing the influence of smart EV charging stations functions to show their potential for increasing the network flexibility. This will be done through optimization of the future EV charging stations operation in order to prevent from power quality issues and to contribute to the system stability and flexibility without reduction of customer comfort.

VI. 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 function is the 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 or in case of receiving ripple control signal (through one way simple PLC) from CEZ Distribuce DMS. The Fronius equipment used for solution implemented in the InterFlex project is shown in Fig. 15. The first two systems were commissioned in March 2018 and other installations will follow.

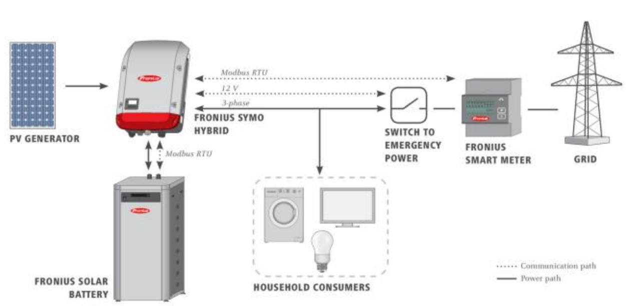

Figure 15. Fronius solution with smart energy storage

An example of active power daily course (1-minute values) measured at the customer point of common coupling is shown in Fig. 16. The 5.2 kWp PV has a limitation for feed in power to the grid set to 2.6 kW and this limit has never been 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.

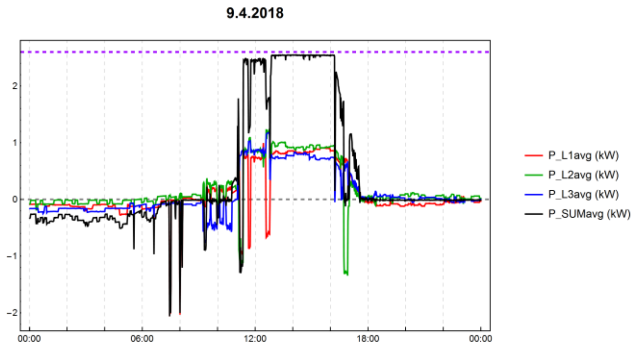

Figure 16. Daily behavior of customer with PV and energy storage – PV 5.2 kWp, feed in power limited to 50 % (2.6 kW)

If we take out the net PV production, i.e. separating 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. 17. 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 (which is calculated as a sum of all three phases) 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. 18. 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.

Since the autonomous Q (V) and P (V) functions are also active in case of smart hybrid inverters, it's also appropriate to evaluate the voltage quality. Fig. 19 shows that the limit 1.1 Vn – 253 V (green) was never exceed also due to the activation of both autonomous functions.

As in UC1 the most significant results should be available after summer season 2018.

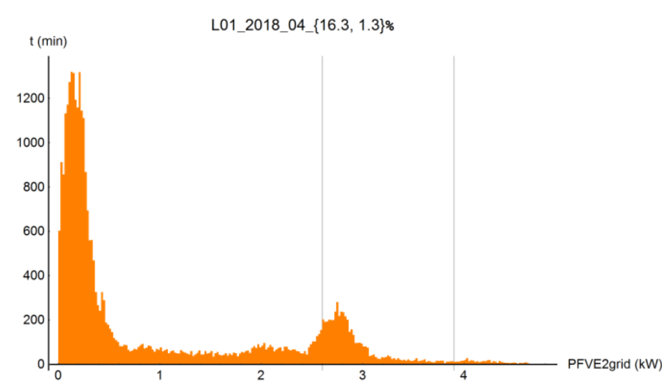

Figure 17. Net PV production with smart energy storage – PV 5.2 kWp

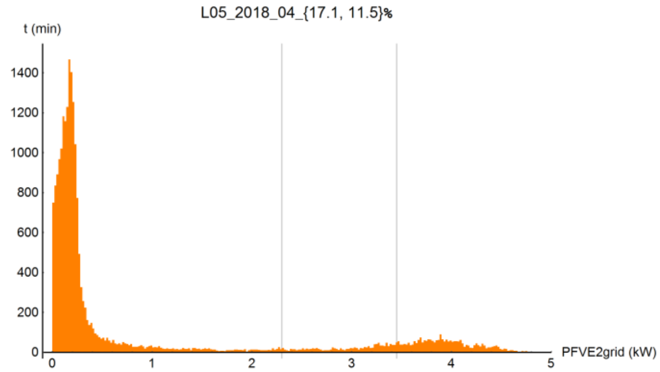

Figure 18. Net PV production without any energy storage – PV 4.6 kWp

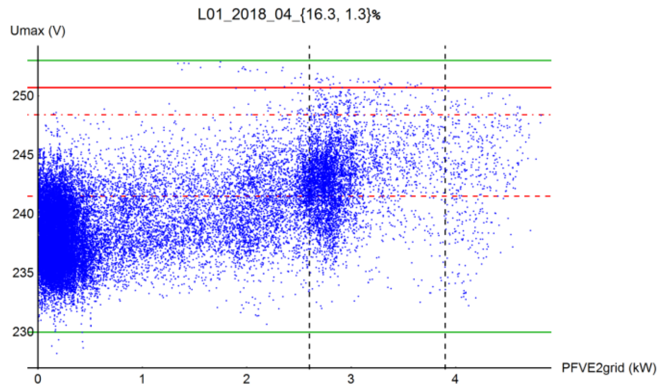

Figure 19. Net PV production with smart energy storage – PV 5.2 kWp

VII. 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. 20. 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 %.

It's expected that smart EV charging concept (if rolled out) could significantly contribute to increasing the flexibility of distribution network in case of congestion or undervoltage and to increasing the flexibility of transmission network in case of emergency.

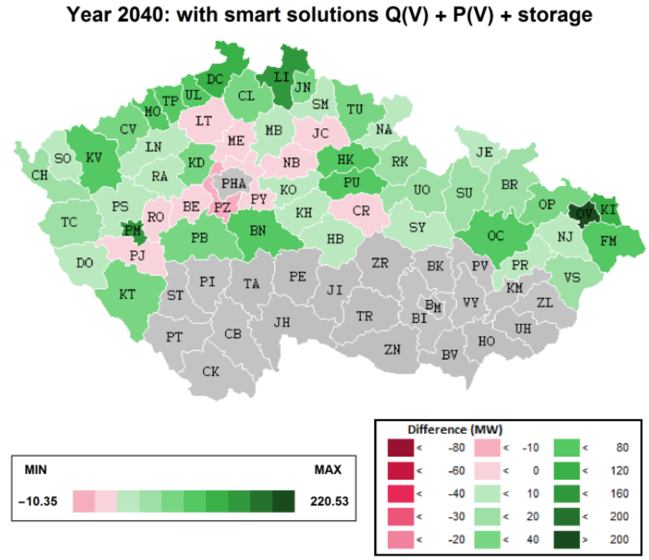

Figure 20. Expected lack of DER hosting capacity in LV grids in 2040 in case that smart grid solutions are implemented

VIII. Conclusion

Final results of field demonstrations are expected in 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.

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