Technical Solutions for Increasing PV Penetration in Distribution Grids in the Czech Republic in Terms of InterFlex Project

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***Abstract* — The paper describes proposed, implemented, tested and verified technical solutions supporting PV 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 PV 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 PV grid integration.**

I. 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 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.

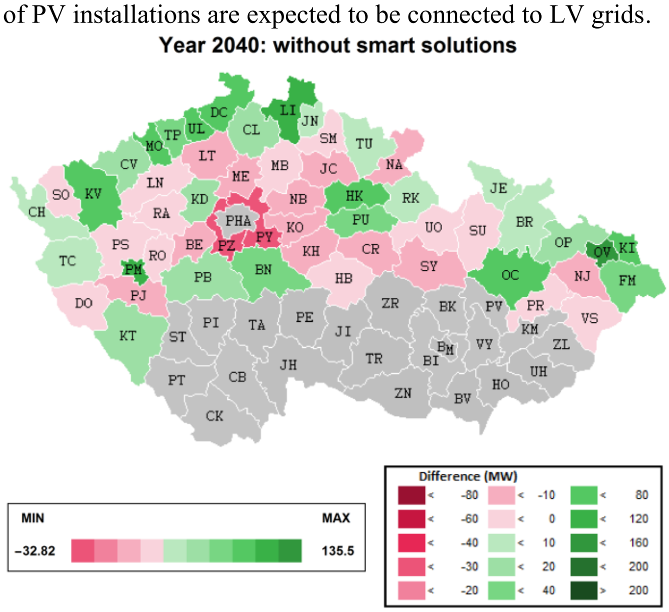

Fig. 1. Expected lack of DER hosting capacity in LV grids in 2040 in case that smart grid solutions are not implemented

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 (colored 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.

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 [2], [3].

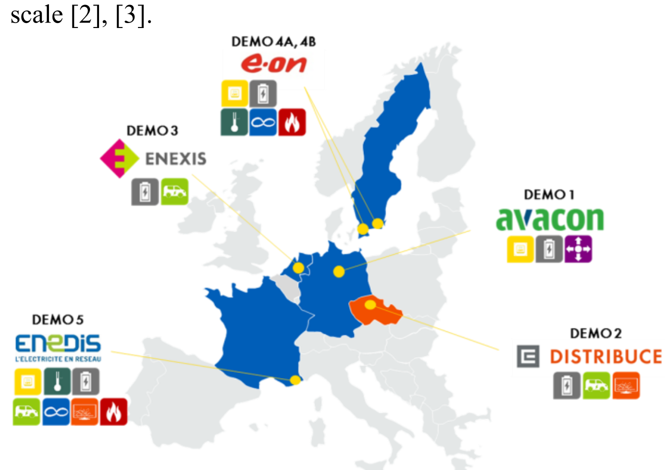

Fig. 2. European DSOs involved in InterFlex project

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

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. 3, in case the voltage rise even more, PV inverter starts to reduce 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.

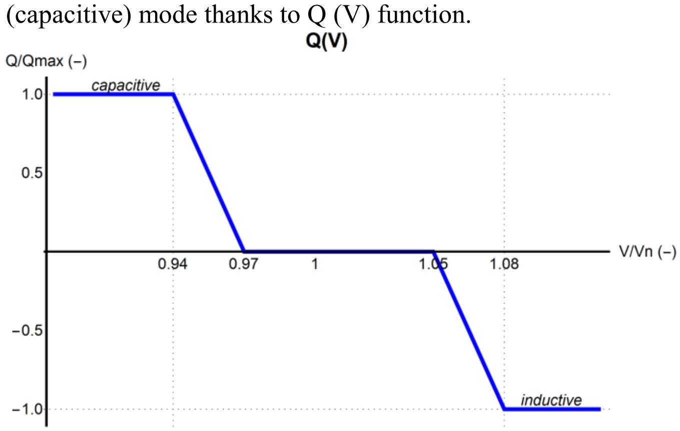

Fig. 3. Autonomous Q (V) function of smart PV inverter

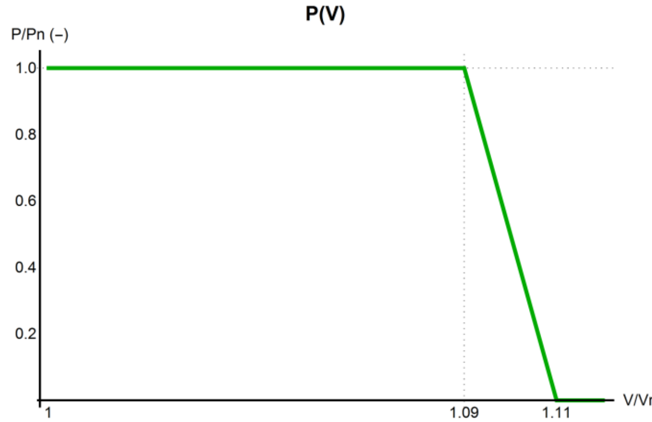

Fig. 4. Autonomous P (V) function of smart PV inverter

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 understood more or less 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.

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 behavior before field implementation. Both tests showed very good results with only minor deviations from expected characteristics. See Fig. 5, 6 and 7 for steady-state characteristics test results.

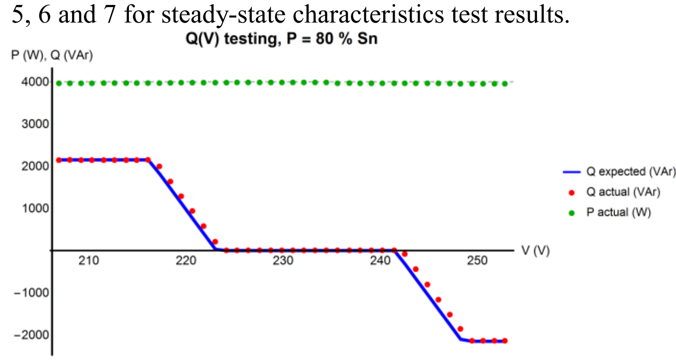

Fig. 5. Q (V) function test result for Fronius PV inverter

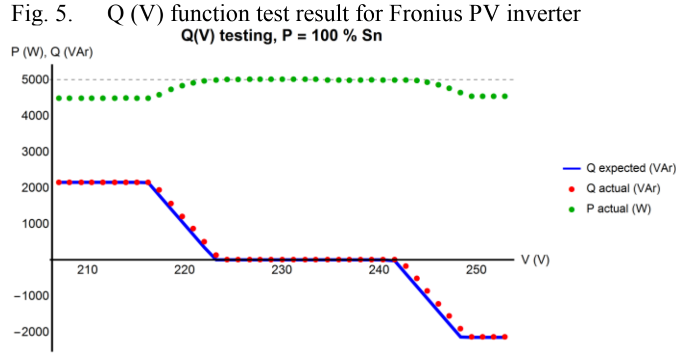

Fig. 6. Q (V) function test result for Fronius PV inverter

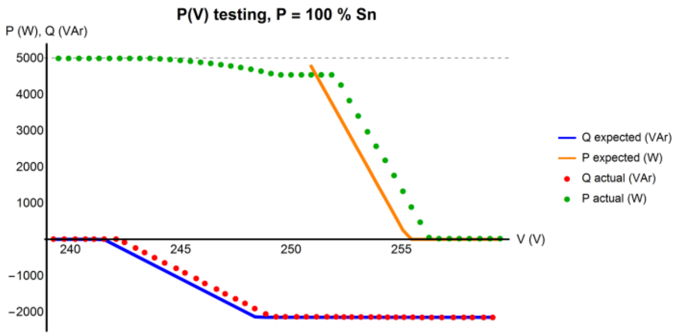

Fig. 7. P (V) function test results for Fronius PV inverter

If active power is 100 % Sn (inverter rated power), it must be reduced in case Q (V) function produces/absorbs any reactive power not to overload the inverter. The tested settings with minimal power factor equal to 0.9 results in P reduction to 90 % Sn. It must be mentioned that such a behavior results in a negligible annual energy production reduction from the PV system.

The inverter functions dynamic behavior should follow technical standard EN 50438:2013 [5] 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. Very good lab tests results are presented in Fig. 8 for the standard settings with the time constant 5 s for both Q (V) and P (V) function.

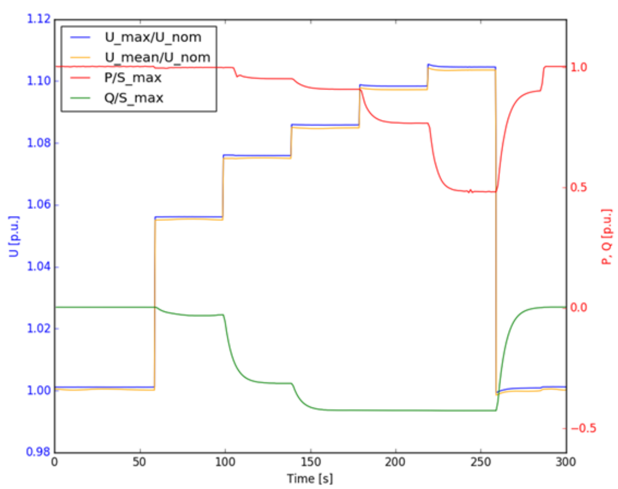

Fig. 8. Control dynamic behavior for Fronius PV inverter

Several rooftop PV installations with smart inverters have been commissioned during winter season 2017/2018. We expect the most significant results in spring and summer months 2018, however the first results are already available. Fig. 9 shows an example of daily course of 10 kWp PV on 7th May 2018. The measurement is carried out directly at the inverter AC output, all quantities are 1 minute average values. Since all installations are in rather weaker grids (more PVs in one feeder), the PV active power production increases grid voltage significantly. Q (V) function goes to the inductive mode if the average voltage (blue) exceeds 1.05 Vn (red dashed) and is fully activated if the average voltage exceeds 1.08 Vn (red dot-dashed). The active power reduction is activated only if maximal phase voltage exceeds 1.09 Vn and P is high enough. We can only two minor reductions after the noon time.

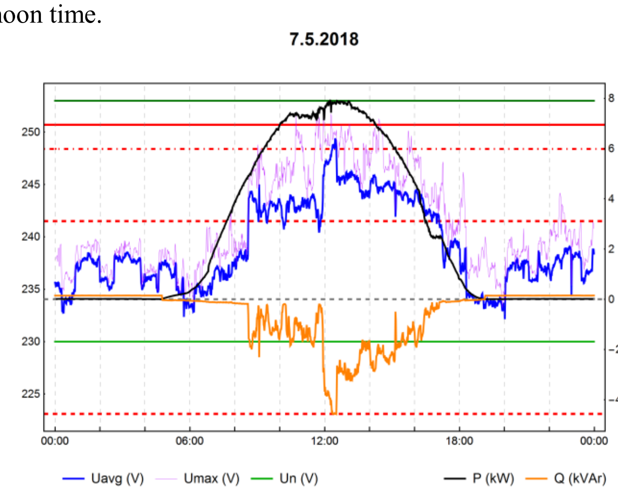

Fig. 9. Daily behavior of smart PV inverter with Q (V) and P (V) functions

An overall view at PV inverter smart functions is shown in Fig. 10. It aggregates all minute values during April 2018. We can see a very good Q (V) function precision in comparison with the ideal characteristic line, higher demand for reactive power control in cases of higher P production, as well as voltage quality level (1.1 Vn – 253 V) fulfilment also due to P (V) function.

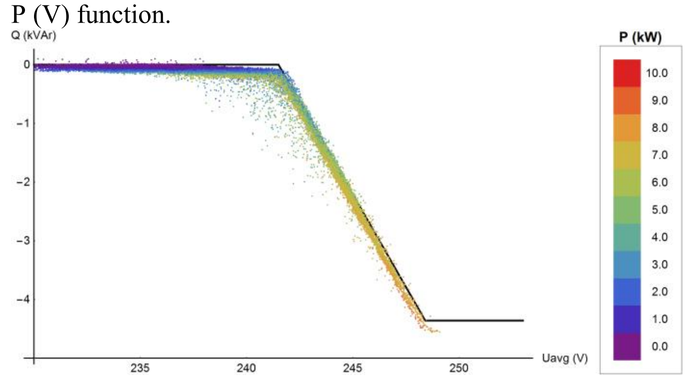

Fig. 10. Smart PV inverter operation points in April 2018

Further results will come during 2018. They will focus mainly on overall statistics, voltage quality and P production reduction 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. 11 and 12 show daily field test results for 1.1 MWp PV Zamberk, Fig. 13 then long-term operation statistics.

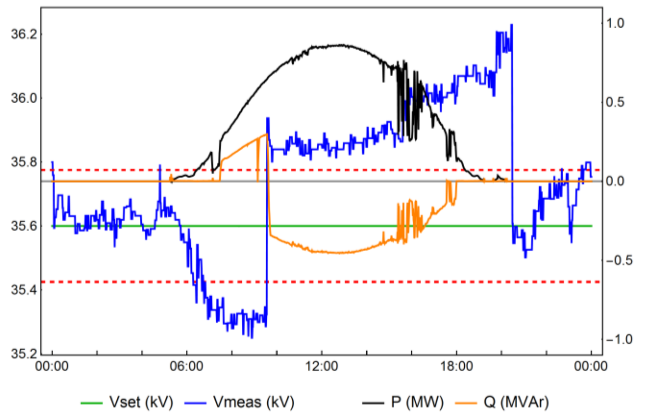

Fig. 11. Demonstration of volt-var control system on 1.1 MWp PV

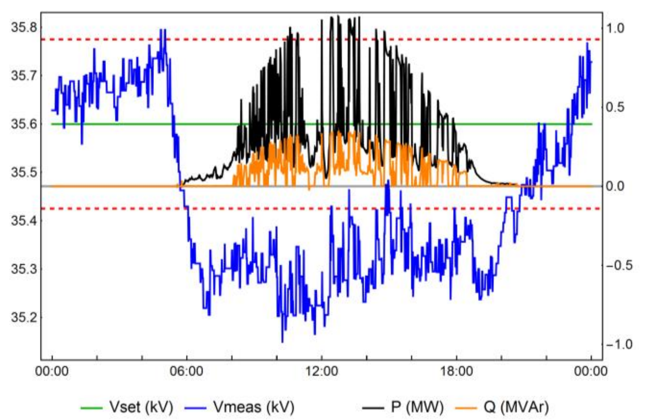

Fig. 12. Demonstration of volt-var control system on 1.1 MWp PV

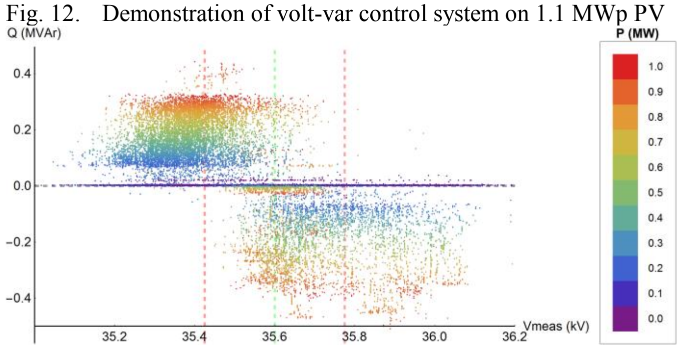

Fig. 13. Long-term statistical assessment of volt-var control system behavior on PV Zamberk (installed capacity 1.1 MWp)

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 mode for higher voltage and no inductive mode for lower voltage).

V. 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 solution used for InterFlex project is shown in Fig. 14. Such systems have been commissioned in one location in winter 2018 and some other will follow.

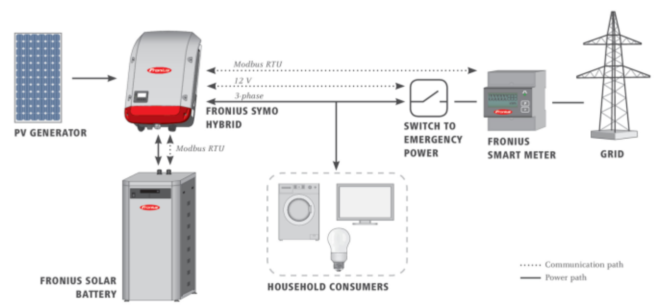

Fig. 14. Fronius solution with smart energy storage

An example of active power daily course (1-minute values) measured at the customer point of common coupling is shown in Fig. 15. The 5.2 kWp PV results in 2.6 kW limit for power supply to the grid which is never exceeded. As this limit is summation for all three phases together and the inverter operation is balanced, individual phases can differ because of standard home consumptions.

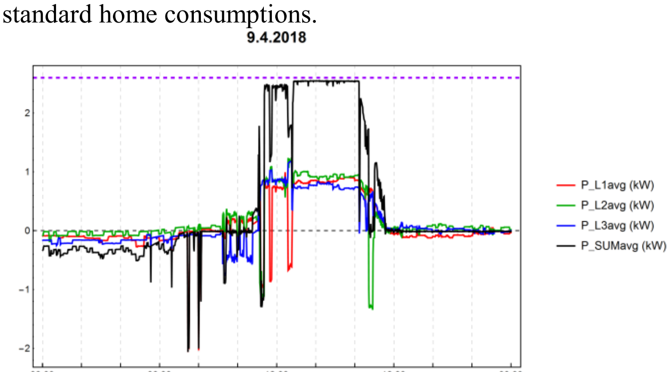

Fig. 15. Daily behavior of customer with PV and energy storage

If we take out the pure PV production, i.e. separating home consumption and energy storage, we can show the active power which is the criterion for evaluation of possible DER integration to the grid. The overall statistical view for April 2018 is shown in Fig. 16. The histogram shows that 16.3 % values exceed the limit 50 % Pn (mostly slightly) because there are states with unbalanced load which result in higher balanced PV production even if the total feed-in limit to the grid is not exceeded. On the other hand the statistical distribution is much different from the one for standard PV installation without any energy storage in the same location – see Fig. 17. Here lots of values occur in the range 70 to 90 % Pn. This issue introduces another possibility how to increase DER integration to distribution grids.

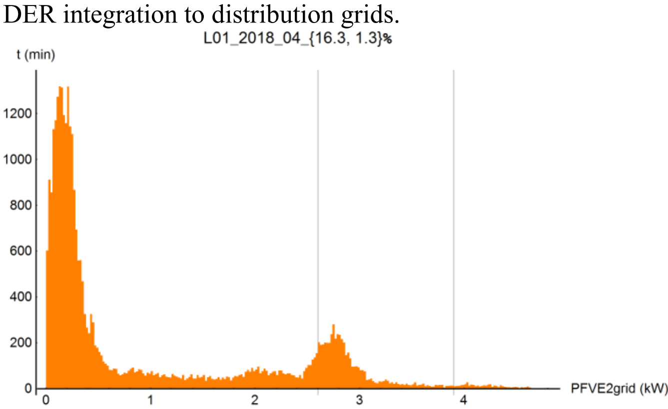

Fig. 16. Pure PV production with smart energy storage

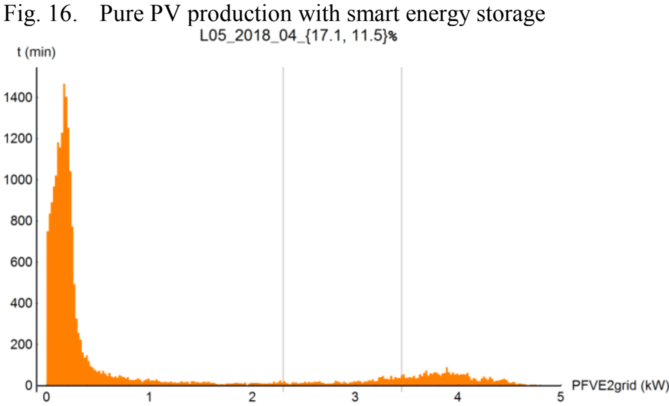

Fig. 17. Pure PV production without any energy storage

Since the autonomous Q (V) and P (V) functions are also active in case of smart hybrid inverters, it is also suitable to look at the voltage quality. Fig. 18 shows that the limit 1.1 Vn – 253 V (green) was never exceed also due to both functions activation and correct function.

As in UC1 the most significant results should come in spring and summer season. Then annual statistics reflecting also different characters of home consumption during the year should be available.

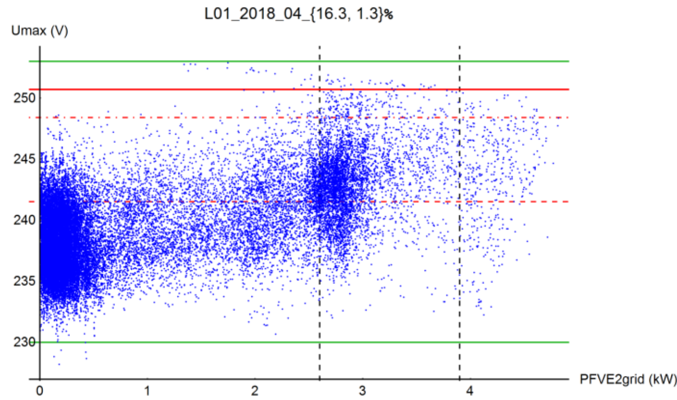

Fig. 17. Pure PV production without any energy storage

VI. 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. 9. Increase of DER hosting capacity is foreseen between 30 and 50 %.

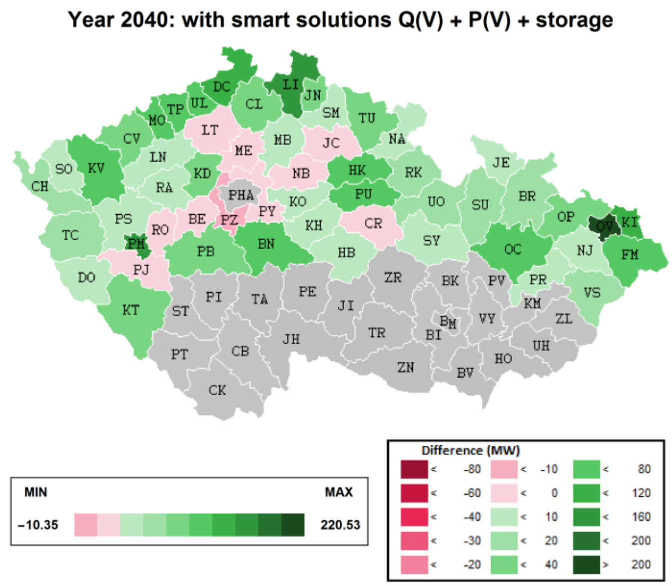

Fig. 9. Expected lack of DER hosting capacity in LV grids in 2040 in case that smart grid solutions are implemented

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 %.

VI. 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.

References

[1] *National Action Plan for Smart Grids (NAP SG)*. [Online]. Available: https://www.mpo.cz/dokument158711.html. [Accessed: 19-Jan-2018].

[2] "InterFlex project," *InterFlex - European Commission*, 01-Jan-2017. [Online]. Available: https://ec.europa.eu/inea/en/horizon-2020/projects/h2020-energy/grids/interflex. [Accessed: 19-Jan-2018].

[3] *InterFlex project*. [Online]. Available: http://interflex-h2020.com/. [Accessed: 19-Jan-2018].

[4] S. Hes, "InterFlex Deliverable 6.1: Design of solution," Prague, rep., 2017.

[5] CSN EN 50438 ed. 2: Requirements for the connection of micro-generators in parallel with public low-voltage distribution networks. CENELEC, 2013.