CONCLUSIONS FROM SMART GRID FIELD TESTS –DEPLOYMENT OF RESULTS, METHODS AND NEW TECHNOLOGIES

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ABSTRACT

Since about ten years, in Austria a chain of R & D projects related to efficient network integration has been performed by consortia constituted from research, Industry and DSOs. As in parallel to the development of decentralized generation the smart grid issue and Smart Metering arose, ICT based technology for voltage control has been deemed as a key for more efficient use of the grid. This paper discusses the main outcomes of these research projects from the DSO perspective and analyses important results and experiences from field tests as well as possible barriers for deployment of such solutions.

INTRODUCTION

The requirements to medium and low voltage distribution grids have been changing basically in the past decade. The voltage rise and drop caused by upcoming share of decentralized generation, slowly upcoming electric vehicle and power to heat applications like heat pumps lead into constraints requiring expensive network enforcement. Some findings from R & D projects related to this subject actually are implemented step by step to concepts and tools for planning. During the past decade a couple of projects around the DG DemoNet project-chain investigated the potential of the use of ICT based voltage control systems, starting at medium voltage level down to small customers connected to low voltage grids especially in rural areas. New approaches within network planning and operation supporting a more economic and efficient use of existing assets are discussed in respect to potential benefits, barriers and economic risks.

METHODS

In the past ten years R & D activities in the field of smart grid solutions for voltage control focused on more economic integration of decentralized generation units instead of constructing additional lines or lines with less impedance or splitting the load flow.

For voltage control at medium voltage level the following methods where applied as solutions under test within projects covering demonstration and evaluation in field tests.

- static and dynamic Voltage-Var Control
- On load tap changers at MV/LV- substations
- Autotransformers at MV & LV
- Remote control based on real time voltage measurements

Results from Analysis of the available hosting capacity demonstrate voltage levels close to the upper limits especially for regions in the mountains, with hydro generation units in the valleys. In case additional plants cannot be connected to the existing grid because of violation of this upper limit additional hosting capacity can be enabled compensating the voltage rise with reactive power consumption. To reduce losses and to avoid too much impact on the high voltage system the compensation of this reactive power (other plants or e.g. capacitors) should be located as close as technically possible.

A set point optimization at the bus bar of the primary substation or optimized characteristic of each plant can be based on real time voltage levels but requires a reliable, safe and performant communication system.

As medium voltage grids are designed typically to be operated in open meshes different topologies are given in case of maintenance or disturbance. Control systems have to detect such status and the control algorithms adopt their parameters and characteristics to the actual status.

A fully SCADA-based setup versus a standalone system setup for voltage control has been under test in two regions in Austria within the DG DemoNet Project.

The very small scale decentralized generation and voltage rise in low voltage systems typically occur from PV systems installed on roof tops of single family houses. Customer requests for connecting generation units require more or less detailed assessment, depending on the margin towards the upper voltage limit. For low voltage systems methods of assessment have been based on worst case assumptions resulting in an upcoming number of cases requiring enforcement of network or installation of voltage control systems.

- Planning: covering probabilistic estimations of loads, generation and asymmetric distribution. Similar to common practise of probabilistic load estimation gathered data from demo projects now is used to derive simple estimation methods for realistic hosting capacity. One of the targets to be met in mid run is setting up appropriate application of curtailment.

- Monitoring: Using additional monitoring devices or smart meters to get a realistic “footprint” of the grid to be used within a planning process.
- Control: starting from simple local control at the connector of the inverter or on load tap changer at the secondary substation and autotransformer at a peripheral node in the branch the pool of methods under test offers solutions for voltage control systems basing on real time measurements of voltage levels, providing optimized set points and control characteristics to inverters, active loads etc.

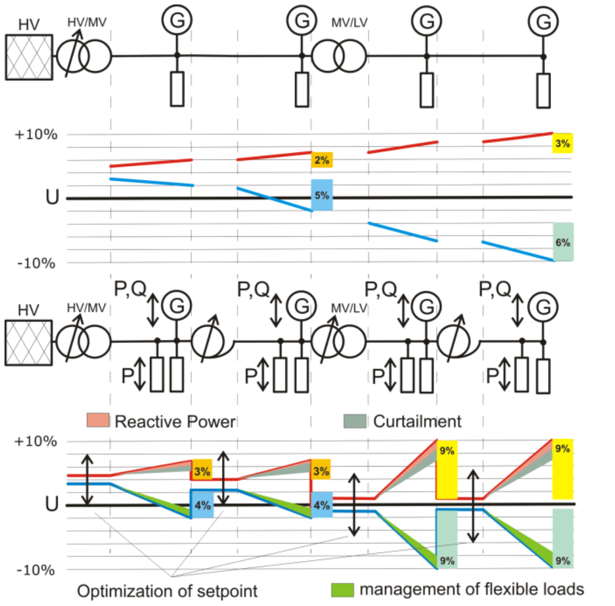

Figure1: Voltage control solutions enabling a wide range up towards the limits given by rated currents

Figure 1 demonstrates the various methods of voltage control combined in one system enabling in total a voltage band which might have inacceptable high losses depending on the annual total duration of extreme compensation or curtailment of generation. The only solution without increased losses by voltage rise and drop or curtailment is to manage to optimize local flexible demand for local supply.

RESULTS AND EXPERIENCES FROM FIELDTESTS IN LV GRIDS

Within the project DG DemoNet Smart LV Grid, in two different low voltage Grids of Netz OOe (farmers area and center of a village) field tests for voltage control were performed (see Figure 2). The necessary high share of PV-Systems, expected to be connected in many LV-grids within the next five years, was achieved by a funding from the regional government to the customers.

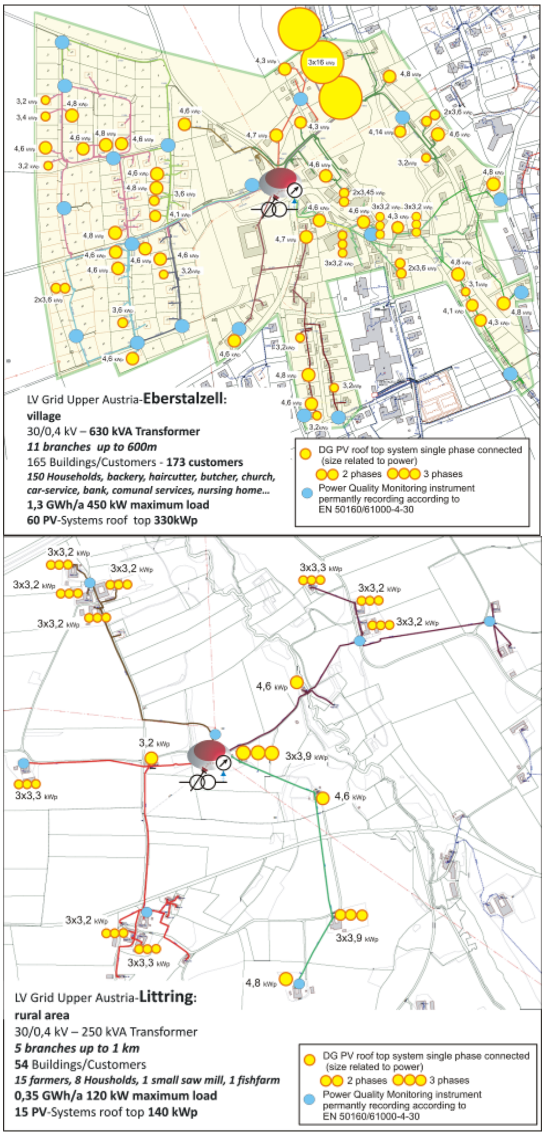

Figure 2: Low voltage grids with high share of PV Systems used for testing DG-DemoNet smart LV-Grid voltage control system.

For research purpose a PQ-Monitoring system according to EN 61000-4-30 is permanently recording synchronous 10-min-average voltage levels and for each interval 0,2-second-rms maximum and minimum levels (see Fig 2, blue dots) as well as Flicker, Harmonics, Dips and Swells.

Figure 3 shows real measurement data for voltage levels, generated power and consumption of reactive power for a period of four consecutive days:

- *1st day:* full generation compensation of voltage rise by on load tap changer
- *2nd day:* full generation compensation of voltage rise by reactive power consumption
- *3rd day:* full generation without compensation - reference day
- *4th day:* no generation due to very cloudy weather

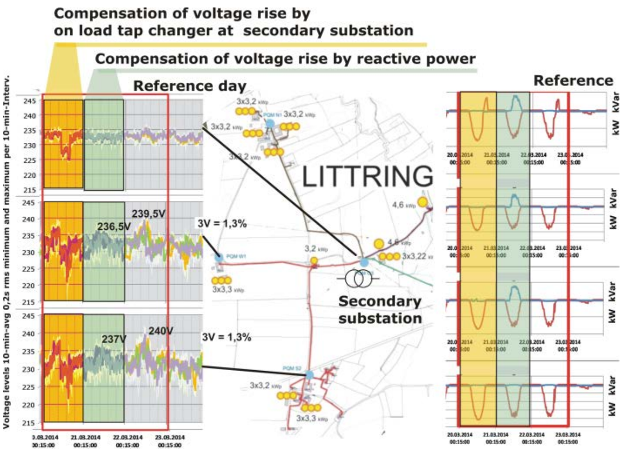

Figure 3: Voltage control solutions under test in the field

The impact of the reactive power can be seen very clearly in the branches as well as even at the bus bar of the secondary substation. Due to the dominant inductive part of the network impedance at the secondary busbar the impact of reactive power is much stronger than from active power.

During a longer validation period of the voltage control system every day system was set to one of four different operational modes for three different low voltage grids.

Furthermore in the LV-Voltage Grid supplying the center of the village of Eberstalzell a autotransformer (LVRSys^{TM}: Low Voltage Regulation System, a-eberle) has been under test succesfully. The System compensates voltage rise and drop with small transformers in series to the line for each phase independently up to +/-6% of input voltage.
Unbalance of load can cause a significant use of voltage band which can be completely compensated by such solutions. Nevertheless the unbalance of the interphase voltages increases but typically within the tolerance according to EN 50160. The system compensates 10-min-average voltage levels perfectly but cannot reduce rapid voltage changes. Therefrom the 0,2-second-rms minimum voltage levels at the output are almost identical to those at the input side (see Figure 4). There is no impact on flicker and harmonics. The total losses observed are about 0,25kW (about 2000 kWh/a) almost independent from control status.

Within the Demo-Project the autotransformer operates independently from the central controling system at the secondary substation. The autotransformer is not interconnected to the communication system of the metering system. A malfunction could be detected by reading the real time measurement values from selected meters or analysing the voltage level statistics performed by the meters (s. Figure 5).

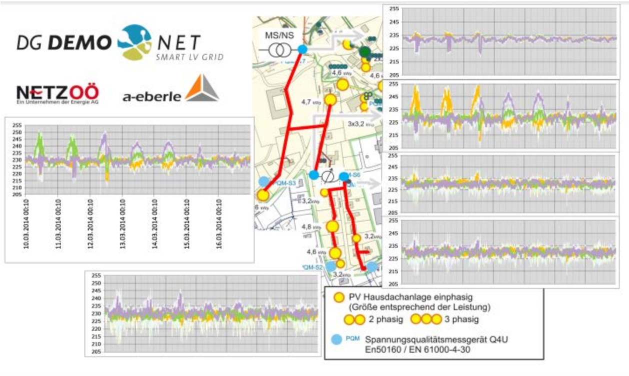

Figure 4: Application of the autotransformer within the Field Test in Eberstalzell.

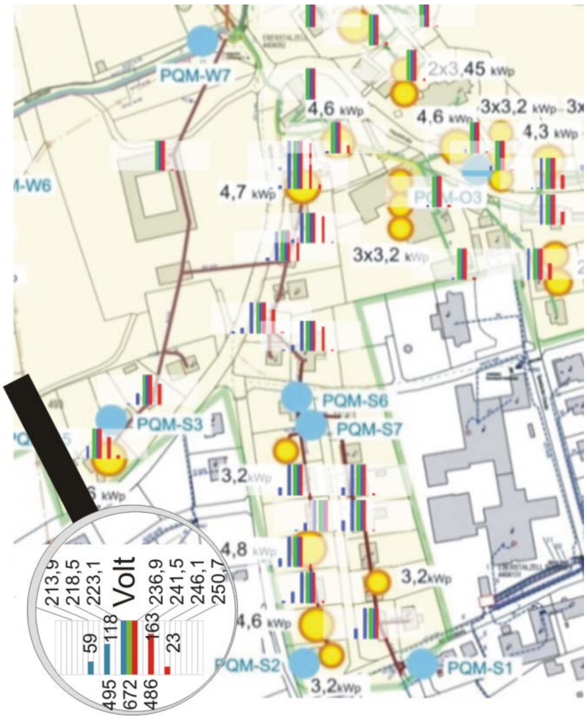

Figure 5: Histograms for voltage level from smart meters (green bar: Number of 15-min-avg-voltage levels, red bar: number of maximal 1-sec-rms and blue bar: number of minimal 1-sec-rms level – all bars cut off at 200)

The weekly voltage level statistics (Voltage Guard Function [2]) as an example shown in Figure 5 for the branch where the autotransformer is installed demonstrate the cummulative voltage rise and drop with increasing distance from the secondary substation till the node where the autotransformer is installed. As the red and blue bars represent 1-second-rms voltage levels and the autotronsformer does not compensate rapid voltage changes 1-second-minimum values still can be detected at the output side.

Reactive power potentially reduces voltage levels around 43% of voltage rise (1,3% in case of 3% voltage rise from dezentralized generation). Remote control of tap changer enabled within the demoproject depending on availabel taps and given different voltage profiles in the branches another 30% of voltage rise. Finally a coordinated control optimizing reactive power characteristics for inverters enables another 20% of voltage rise. At a voltage rise limited to 3% the voltage control systems which have been under test enabled almost +100% of hosting capacity.

CONCLUSIONS

After ten years of R&D projects on voltage control and monitoring solutions with smart meters some knowledge and experience can be transferred to planning and operation of distribution grid.

Medium voltage grids

- The rated apparent power of existing generators typically is almost identical to the rated active power. Thus in case of high production the owner of the plant does not agree to miss some generation for providing the consumption of reactive power.
- The local voltage control is not supported by all systems. Customers do not accept to be charged by investments for required upgrade.
- Well performing systems require interconnection of all relevant plants to the control system, the transmitting of status data and real time voltage level measurement data. Due to a typically poor demand of telecommunication services in mountain regions fibre or performant radio communication are not available and in case very expensive.
- The economic performance strongly depends on the development of decentralized generation in detail. Parameters like order, location and timescale of increase as well as the age and status of given assets are relevant.
- The integration of complex control systems to SCADA System is the preferred solution as the maintenance effort for a standalone system is very expensive.

Low voltage grids

- At most sites the real voltage levels show higher margins to the tolerance limits than estimated values from conventional planning methods do – thus some additional DG can be integrated without any investment to the grids.
- Monitoring of voltage levels opens access to existing reserves of the grid for integration of loads and generation units. Voltage band available from superior levels can be used temporarily and if a need occurs compensated by on load tap changers at secondary substation.
- High and low voltage levels occurring at the same time and sometimes even at the same node are typically blocking the use of many voltage control solutions. Unbalanced loads and generation are wasting a certain part of the available voltage range.
- Based on Power-Snap-Shots or other measurement results an optimization of LV grids can be performed in certain cases successfully to save 3% up to 6% of voltage band.
- Voltage control methods are enabling additional voltage range. Each stage should be implemented on demand in case of real voltages (including the given voltage band required for medium voltage) are exceeding limits. For voltage control technologies simply applicable tools for planning, economic assessment and installation are required.
- Economic performance of smart grid technologies versus reinforcement of lines depends mainly on operational expenses but also on age and state of existing assets and mainly on the price for related software and firmware - maintenance included.

OUTLOOK

The complexity of solutions tested within the DG DemoNet Smart LV Grid project would in case of deployment challenge manufacturers and DSOs because of exploding operational expenses. Development and maintenance of performant and stable operating components at a stage of only view early users will result in high cost stressing manufactures. High prices for components and high operational costs but also bad performing systems are significant barriers for deployment of such technologies in competition with enforcement of network. In case well performing and economic efficient solutions are available voltage control systems might become an important solution for adopting existing grids until the given assets require reinvestment.

Acknowledgments

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