VOLTAGE QUALITY PROVISION IN LOW VOLTAGE NETWORKS WITH HIGH PENETRATION OF RENEWABLE PRODUCTION

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ABSTRACT

Distribution system operators (DSO) are facing severe challenges of keeping the voltage levels within operational limits due to the rapid emergence of distributed energy resources (DER) on different distribution network voltage levels.

Low voltage (LV) networks were traditionally operated as autonomous entities with no much insight or control, but high penetration of renewables in most cases introduce serious voltage quality problems. DSOs have come under the high pressures of voltage quality provision, which grow even bigger with additional DER installations.

Article describes the Elektro Gorenjska, d.d. (EG) role in EU FP7 project titled "Increasing the penetration of renewable energy sources in the distribution grid by developing control strategies and using ancillary services" (INCREASE). During the project, different set of voltage control strategies were deployed and tested in order to be compared and evaluated for later day to day operations. Article summarises different demonstration cases outcomes and evaluates the benefits of each one.

INTRODUCTION

EG significantly contributed at demonstration of different low voltage network control strategies as being defined within the scope of the project.

LV network with a high penetration of photovoltaics (PV) was chosen as a demonstration polygon. LV network includes feeders with a large amount of PV installations on one hand and long feeders without PV generation on the other, and it is faced with significant over and under voltage situations simultaneously. The provision of adequate voltage profiles in the complete demonstration polygon was therefore the main project focus. To enable the demonstration of different voltage control strategies, a number of interesting network subsystems were implemented. Installation of 400 kVA distribution transformer equipped with on load tap changer (OLTC), real time monitoring system for enhanced network observability, local demo SCADA system for network control and up to date ICT system based on WiMAX broadband radio were some of them.

As the result of INCREASE project investigations, four different demonstration cases were implemented, thoroughly measured and later compared for further exploitation.

DEMONSTRATION POLYGON

Demonstration polygon is located in village Suha near Kranj (Slovenia). It is an example of a 0,4 kV rural cable network with a high penetration of PV. LV network is supplied by 400 kVA (20 kV/0,4 kV) distribution transformer with OLTC. LV network consists of three different types of feeders. Feeders build only for PV connection purposes, feeders which only supply loads and mixed ones with loads and PVs connected. Figure 1 represents the network topology with PV locations numbered from 1 to 7.

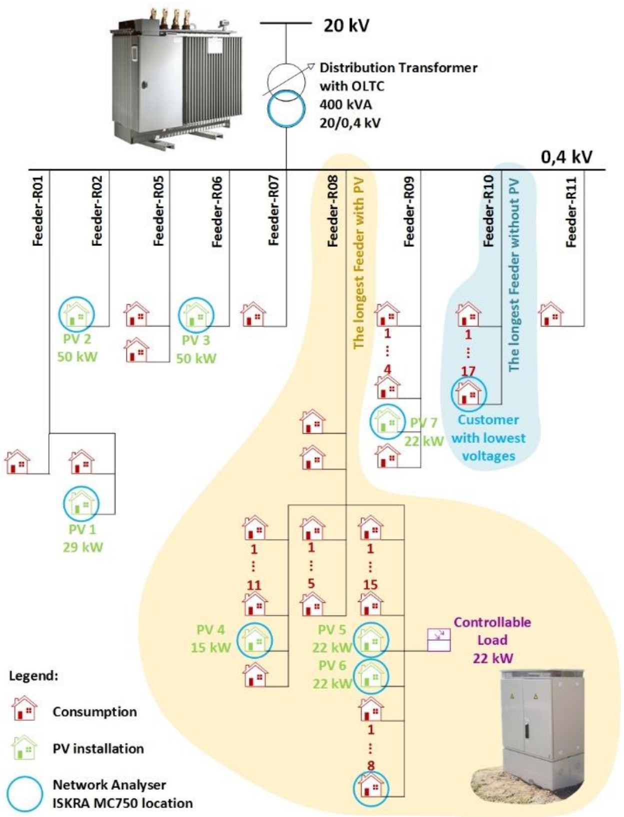

Figure 1: Network topology.

ISKRA MC750 network analyzers were installed on locations where the highest voltage deviations were expected (blue circles on Figure 1). Measurements are recorded with 1-minute time interval.

Figure 2 provides an insight into communication scheme. EG private WiMAX broad band network represents the basic communication platform. Network analyzers were connected to the WiMAX modems via ethernet port and measurements are transferred to EG power quality (PQ) server data base.

SCADA server, based on UniFusion platform represents the central control point providing:

- measurements collection from PQ server,
- measurement distribution to Algorithm server,
- algorithm set point collection from Algorithm server,
- remote control of transformer with OLTC.

Process algorithm is executed on separate server due to remote access safety reasons. It calculates adequate OLTC transformer tap position based on network measurements and provides the desired set point to SCADA server.

DNP 3.0 and OPC UA standard communication protocols were utilized throughout as depicted on Figure 2.

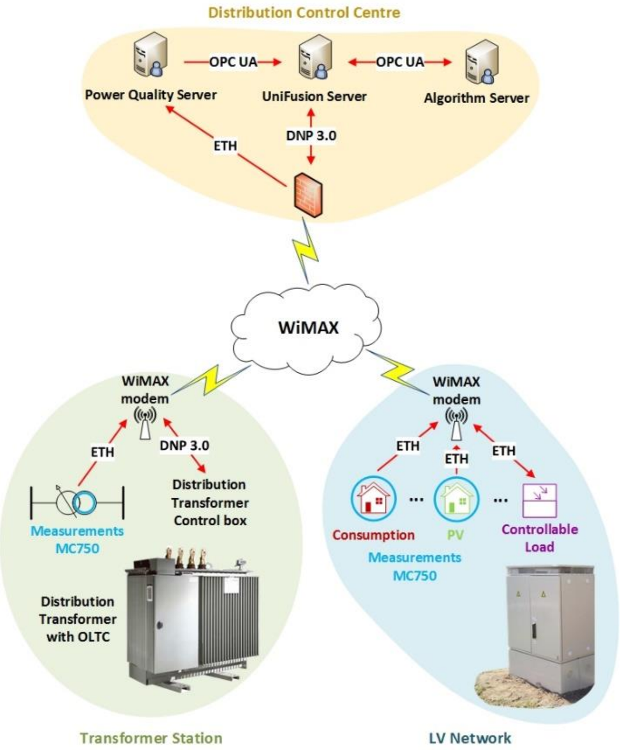

Figure 2: Communication scheme.

DEMONSTRATION CASES

Business as usual

Business as usual scenario represents network condition without any control measures applied. Since there are feeders with a large amount of PV installations on one hand and long feeders without PV generation on the other, the network was simultaneously faced with significant over and under voltages. Figure 3 demonstrates daily maximal voltage profiles at one of the PV installations and minimal voltages at the far end of the longest feeder without PV installations. Figure clearly shows a PV production point with dominating high midday voltages and consumer location with up to 15 V lower voltages due to load voltage drop.

Such voltage conditions are a challenge for voltage measures implemented in LV network. With overlaying OLTC control also such worst-case situations could be successfully tackled.

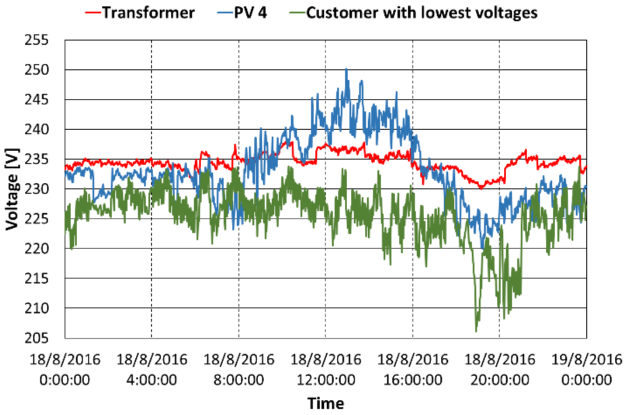

Figure 3: Daily voltage profiles of maximal and minimal voltages in demonstration polygon.

Figure 4 represents transformer power flow and summarized PV power production on a typical sunny day. Reverse power flow can be observed during periods of high PV production. There is a peak load in the morning and evening hours, which cannot be reduced with a local PV production.

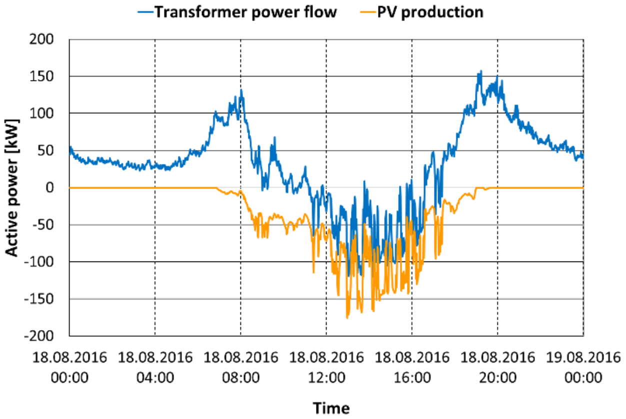

Figure 4: Transformer power flow and PV power production on a typical sunny day.

Local OLTC control

To enable adequate network voltage control a new 400 kVA (20 kV/0,4 kV) distribution transformer with OLTC (9 taps of 1,5%) was installed. To evaluate the performance of integrated OLTC busbar voltage control, standard voltage regulation with U_{set}=235 V, dead band ± 1% and 1 minute time delay was tested.

Results clearly show, that integrated standard algorithm successfully keeps the transformer busbar voltage within specified voltage dead band and additionally improves overall satisfactory transformer voltages. On the other hand, utilization of standard transformer algorithm generally does not improve above discussed network voltage derogation problems.

Overlaying OLTC control

Overlaying OLTC network control is based on algorithm installed on special server in distribution control centre. The algorithm constantly monitor single phase voltages of 10 measuring points in LV network where critical voltages are expected (blue circles on figure 1). Measured voltages are compared to algorithm set points U_{min} and U_{max} and after predefined time delay the algorithm defines the optimal transformer tap position in order to remain network voltages always within predefined voltage band. New OLTC tap position settings are provided remotely from control centre to the substation on the field via WiMAX network. U_{min}=226 V, U_{max}=238 V and 1 minute time delay were basic algorithm set points during tests.

Unlike the local OLTC control algorithms, this algorithm operates based on voltage measurements from multiple (critical) points of the LV network, since the aim of the algorithm is improvement of the voltage in the whole corresponding LV network.

Local PV droop control

PV operation results in local voltage rise and grid protection normally disconnects the PV in case of breaching predefined upper voltage level.

PV droop control should linearly reduce the inverter power output according to the network voltage rise as depicted on the curve on Figure 5. The PV curtailment starts at U_{cpb} point and linearly reduces the PV output to zero until U_{max} is reached. With this functionality disconnection of the PV installation in case of overvoltages is avoided.

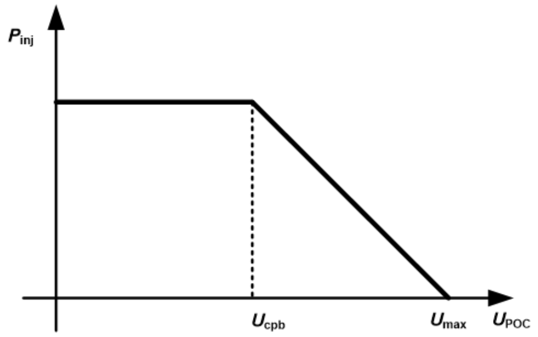

Figure 5: Voltage-based droop control.

The voltage-based droop control settings were U_{cpb}=236 V and U_{max}=246 V.

Original plan to demonstrate local PV droop control was the installation of new inverter with integrated droop control. This plan included significant interactions with private owned PV installation, therefore alternative approach was used. Simple solution with controllable load was applied. 22 kW three-phase controllable load was deployed and connected after the inverter PCC in the DSO part of network. This controllable load was used to achieve the same effect as the controllable inverter with integrated droop control.

MEASUREMENTS

For easiest presentation of results statistical analysis of measurements for different demonstration cases has been made. As specified in the previous chapter, four different demonstration cases were analysed:

- Demo 1 – business as usual (no control),
- Demo 2 – local OLTC control (U_{set}=235 V ± 1%),
- Demo 3 – overlaying OLTC control (U_{min}=226 V, U_{max}=238 V),
- Demo 4 – coordinated overlaying OLTC control (U_{min}=226 V, U_{max}=238 V) and local PV droop control (U_{cpb}=236 V, U_{max}=246 V).

Three most prominent network locations were analysed for presentation of the results:

- transformer station,
- PV 5 (location with the highest voltages) and controllable load installation,
- Customer location with lowest voltages.

Statistical analysis in form of percentile box diagrams suits the representation of results.

Transformer station

Statistical distribution and mean voltage values at LV transformer busbar are represented in figure 6.

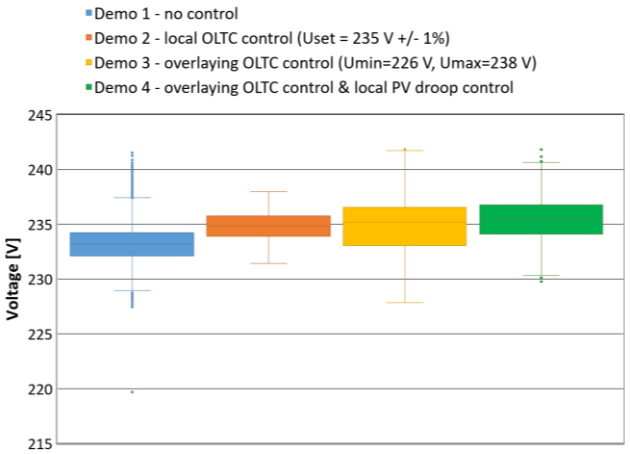

Figure 6: Transformer busbar voltages.

The most significant voltage quality improvement was obtained in case of factory-build local OLTC control (Demo 2). The transformer maintain his LV busbar voltage between 235 V ± 1%. Demo 3 and 4 are focused on improvement of the voltage in the entire network (not only transformer), hence more significant transformer voltage variations are evident.

Figure 7 demonstrates single day operation of distribution transformer with OLTC in Demo 3. Overlaying OLTC control algorithm requested 24 tap changes between tap 4 and 7 position in order to keep network voltages in predefined limits.

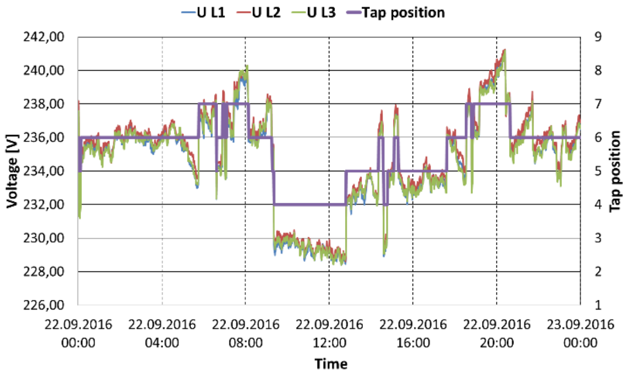

Figure 7: Transformer LV busbar voltages and tap position changes.

PV 5 (location with the highest voltages) and controllable load installation

Figure 8 depicts the outcomes of individual demo case. High voltages were most significantly reduced in Demo 3 (overlaying OLTC control) and Demo 4 (coordinated overlaying OLTC control and local PV droop control). It was further confirmed that basic local OLTC control as in Demo 2 is not the best option to address high voltage issues at PV locations far from the transformer.

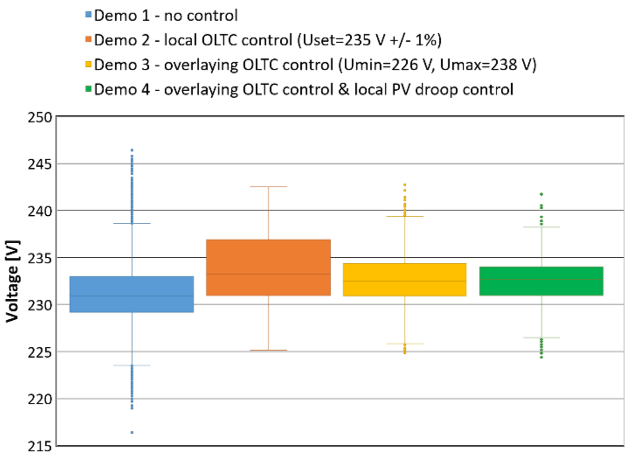

Figure 8: PV 5 – location with the highest voltages.

Customer location with lowest voltages

Figure 9 represents a statistical distribution and mean voltage values at costumer location with lowest voltages. Slight voltage improvement can be observed in Demo 2 (local OLTC control), which could confirm that local OLTC control has a positive impact on feeders without DER installations. The most significant improvement at the lowest voltage location was achieved in Demo 3 and 4, since they both utilize overlaying OLTC control.

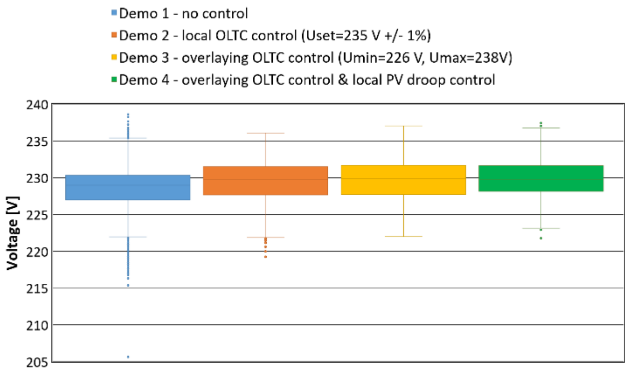

Figure 9: Customer location with lowest voltages.

FIELD EXPERIENCES

During the project and establishing of the system also some problems occurred.

Distribution transformer with OLTC

Hardware failure of OLTC control box was experienced. During the normal transformer operation, a short circuit within OLTC control box resulted in number of damaged contactors. After the fault, the OLTC tap changer positioned itself in the middle tap position allowing the operation as a normal non regulated distribution transformer. The fault was cleared by factory experts.

Power quality system

Failures in data transmission from individual network analysers were experienced occasionally, what caused the abortion of the overlaying OLTC control and automatic activation of the local OLTC control. During the project, a number of measuring locations with normal voltage quality was excluded from algorithm evaluation in order to additionally minimize algorithm failures. The reduction of evaluated points (only those with no voltage issues expected) proved to be a good decision as a number of coordinated control algorithms was additionally reduced.

Demo SCADA system

Demo SCADA was implemented separately and exclusively for demo purposes and as such some fine tuning was required during the whole project. At the end, a stable operation was achieved.

CONCLUSION

It had turned out, that voltage quality provision in low voltage networks, experiencing the diversity of voltage profiles requires much more than a simple and straightforward solution.

The demonstration has clearly proved a great value of integrated OLTC busbar voltage control to maintain transformer voltage within required bandwidth. The same regulation does not improve the network local voltage situation in case of the high differences between minimal and maximal network voltages. As the utilization of

standard OLTC transformer regulation will not be able to solve entire voltage network problems by itself, the additional mitigation principles will often be required.
Overlaying network control proved to be an upgrade in a line of demonstrated concepts. Implementation generally improves voltages on all network locations, having mainly the highest voltage deviation locations in mind.
Introducing PV droop control additionally improves local voltage conditions, but the utilization of this method is highly questionable due to undesired production curtailment principle.

Based on positive experience and results achieved, the demonstrated overlaying OLTC voltage control have already been implemented in Elektro Gorenjska daily operations.

Based on the lesson learned, the overlaying network voltage control principle will be further upgraded towards higher reliability standards of operations. For that matter, the implementation of the complete control system locally at transformer station location will be our next and very interesting challenge.

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