National Technical
University of Athens

Connecting European
Smart Grid Infrastructures

# VOLTAGE CONTROL OF DISTRIBUTION NETWORKS - INTEGRATION OF DG

The students are already familiar with the theory of conventional voltage control approaches, such as the use of capacitors and OLTC and the effect of the active and reactive power of the load on the voltage, as shown in equation (2).

$$\Delta V \approx \frac{P \cdot R_{line} + Q \cdot X_{line}}{V_{load}} \tag{2}$$

Fig. 1 shows the overall setup for the second experiment. A hardware PV inverter and a load bank (Load 2) are connected to a weak distribution network fed by a transformer equipped with an OLTC. As a transformer with OLTC is not available in the lab it is simulated in the DRTS via PHIL simulation. An additional load (Load 1) is inserted in the real-time simulation.

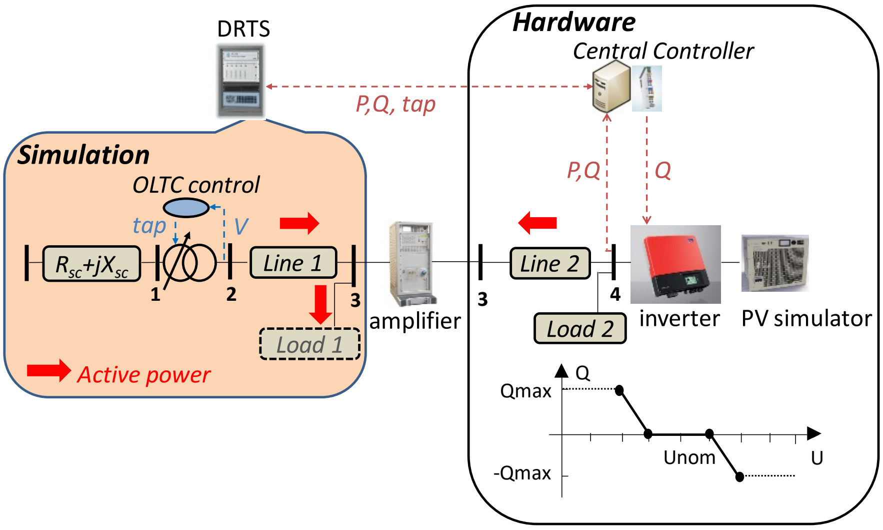

*Figure 1. Voltage control by DG, OLTC and centralized coordinated control (PHIL and CHIL simulation).*

Conventional voltage control is applied first without the presence of the PV inverter and the simulated load (Load 1). The OLTC controller employs line-drop compensation, i.e. it estimates the voltage at the end of the feeder based on the measured voltage and current on the secondary side of the transformer. The hardware load (Load 2) is gradually increased, leading to a voltage drop below the lower threshold of the OLTC. The OLTC changes the tap position in order to bring the voltage within the desired range.

Next, the physical PV inverter is connected at the end of the long feeder and the OLTC gets deactivated. The students control the active power of the PV simulator by changing the irradiation for a given I-V curve via its software environment. While keeping Load 2 low, they steadily increase the active power of the PVs from zero to nominal and observe the voltage rise occurring at the inverter’s terminal (concrete experience). The students try to solve this overvoltage problem, which is one of the main challenges faced by the integration of DG in rural distribution networks (reflective observation).

Extending equation (2) to include also generation the students understand the effect of reactive power absorption by the PV inverter on the voltage rise (abstract conceptualization). The students send reactive power absorption set-points to the PV inverter (until minimum cos φ = 0.8) via its software interface, monitor the voltage and validate its effect (active experimentation). Then a reactive power vs. voltage droop curve is implemented (i.e. Q(U) shown in Fig. 1) locally in the inverter's control, as required by recent standards [1], and the experiment is repeated with similar results. The need for DG to support the grid by providing ancillary services is highlighted. Additional solutions are discussed, which can also be derived from equation (2) (i.e. grid reinforcement, DG active power curtailment).

Another series of experiments involves the use of the OLTC. The OLTC gets activated and regulates the voltage at the end of the feeder, while the PV inverter operates at unity power factor. A large load (Load 1 in Fig. 1) is now connected to the network and the resulting active power flow is shown in Fig. 1 (the reactive power is not shown for simplicity as it weakly affects this experiment). Obviously, the previous simple line drop compensation estimation is not valid due to the presence of Load 1, therefore the voltage at the end of the feeder is measured and sent to the OLTC controller. Fig. 2 shows that the OLTC manages to reduce the overvoltage at the PV inverter's bus, however it generates a higher under-voltage at the bus of Load 1. The necessity of a coordinated operation of existing voltage control appliances (e.g. OLTC) and modern devices (e.g. PV and storage inverters) is noted. More complex interactions of OLTC and DG [2] can be used.

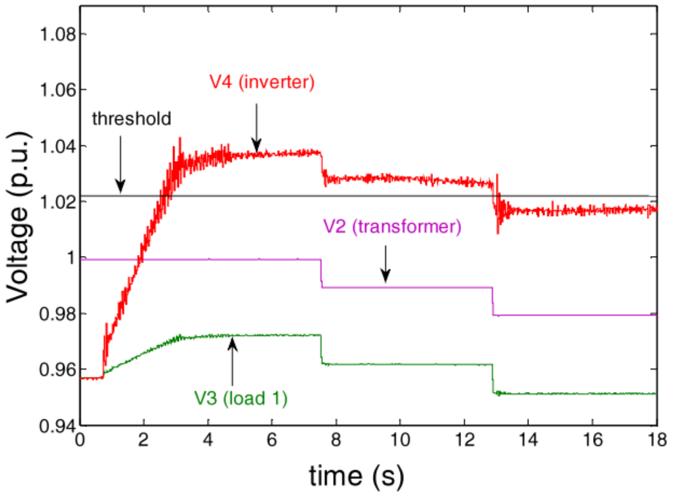

*Figure 2. The PV production raises the inverter's voltage (V4) which is then decreased by the OLTC, however reducing further the voltage of Load 1 (V3).*

An optimal coordinated voltage control scheme is applied next, where a central controller measures the active and reactive power at all nodes and sends reactive power set-points to the PV inverter and tap changing commands to the OLTC. The objectives of the optimization problem are the minimization of the voltage deviations, number of tap changes and line losses. A hardware controller, executing the optimization algorithm, exchanges signals with the DRTS (i.e. CHIL) and the hardware PV inverter. The setup used is shown in Fig. 1 and the full implementation is presented in [3].

During the experiments the students measure the active-reactive power, voltage-current (rms), vector diagram and waveforms of voltage and current (to see the phase shift and changes in the amplitude of the current) on the hardware PV inverter and the transformer voltage, the number of tap changes, voltage step and time-delay of the OLTC in the DRTS. The students report the influence of active and reactive power on the voltage at different R/X ratios of the lines (i.e. low voltage, medium voltage, high voltage lines) among other topics. In this way, the coupling of active power with voltage in networks with high R/X ratios (e.g. underground low voltage cables) is highlighted, contrary to networks with low

R/X ratio (e.g. overhead high voltage lines) where the voltage is predominantly influenced by reactive power.

*References:*

[1] P. Kotsampopoulos, N. Hatziargyriou, B. Bletterie, and G. Lauss, “Review, analysis and recommendations on recent guidelines for the provision of ancillary services by distributed generation,” in Proc. IEEE Int. Workshop Intell. Energy Syst., Vienna, Austria, Nov. 2013, pp. 185–190.

[2] P. Kotsampopoulos, F. Lehfuss, G. Lauss, B. Bletterie, and N. Hatziargyriou, “The limitations of digital simulation and the advantages of PHIL testing in studying distributed generation provision of ancillary services,” IEEE Trans. Ind. Electron., vol. 62, no. 9, pp. 5502–5515, Sep. 2015.

[3] M. Maniatopoulos, D. Lagos, P. Kotsampopoulos, N. Hatziargyriou, “Combined Control and Power Hardware-in-the-Loop simulation for testing Smart grid control algorithms”, IET Generation, Transmission & Distribution, Vol. 11, Issue 12, August 2017

*source:*

*P. Kotsampopoulos, V. Kleftakis, N. Hatziargyriou, “Laboratory Education of Modern Power Systems using PHIL Simulation”, IEEE Transactions on Power Systems, Vol. 32, Issue: 5, September 2017*