Effects of the DTRs' fixed tap positions on the behaviour of distribution grid with high PV penetration

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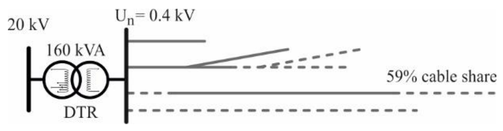
Abstract

PV-systems are often operated with local $Q(U)$-control to maintain voltages in low voltage grids (LVG) within the limits. Meanwhile, distribution transformers (DTR) usually have Off-Load Tap Changers. Their tap positions impact LVGs' voltages (direct effect), and thus the reactive power (Q) consumption of loads and $Q(U)$-controlled PV-systems. In further consequence, they impact Q-flows and voltage (indirect effect) in medium voltage grid (MVG). The indirect effect intensifies with the spread of $Q(U)$-controlled PV-systems.

Model

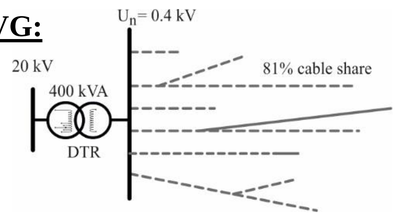
Two real LVGs are used for the simulations: rural and urban LVG.

Rural LVG:



- 61 (residential) prosumer plants are connected.
- Each prosumer plant includes a ZIP-load and a 5 kWp PV-system.

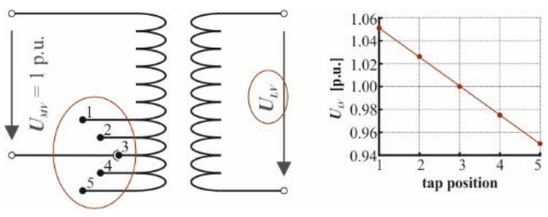
Urban LVG:



- 91 (residential) prosumer plants are connected.
- Each prosumer plant includes a ZIP-load and a 5 kWp PV-system.

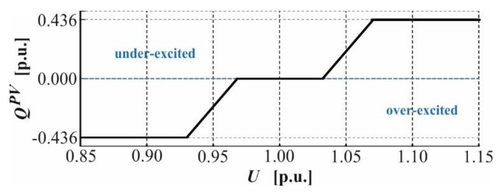
Tap changer of DTRs:

Each DTR has an Off-Load Tap Changer:



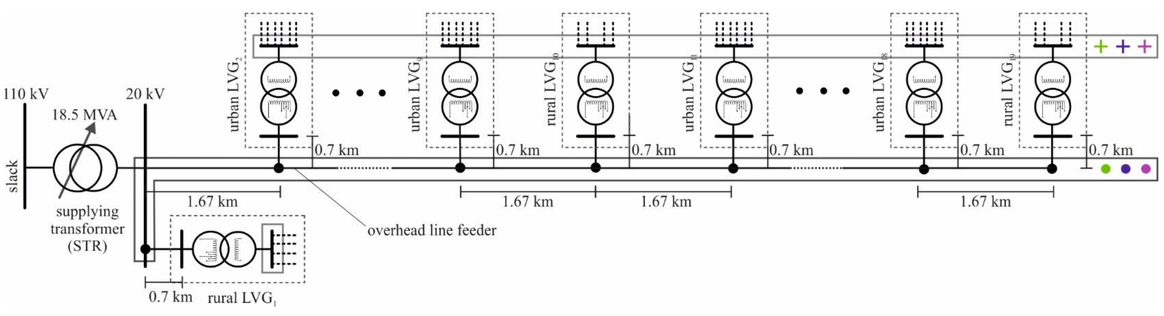
$Q(U)$-control of PV-inverters:

PV-systems are simulated without control, i.e. with $\cos\varphi = 1$, and with $Q(U)$-control:



Theoretical MVG:

One theoretical MVG is used for the simulations.



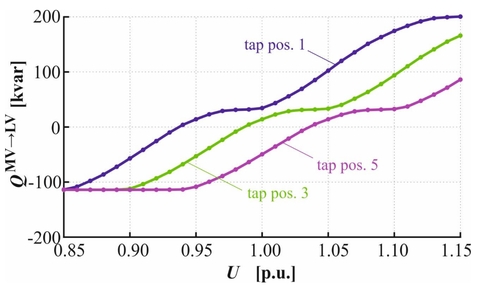
- On-Load Tap Changer keeps STR secondary voltage between 1.015 p.u. and 1.035 p.u.
- 3 rural and 16 urban LVGs are connected.

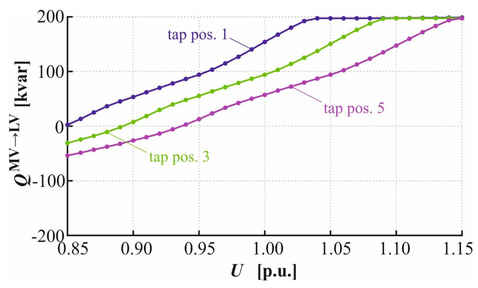
Impact of DTR tap position on LVGs' $Q(U)$-characteristics

The $Q(U)$-characteristics of both LVGs with $Q(U)$-controlled PV-systems are extracted from the results of load-flow simulations for different DTR tap settings and two critical scenarios: maximal load – no production, and minimal load – maximal production.

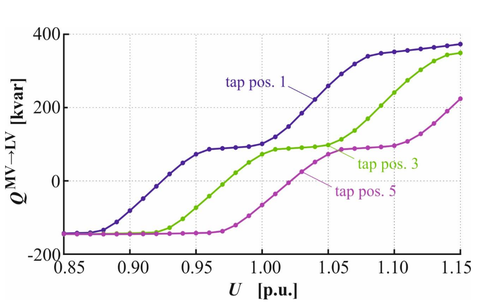
max. load – no production: | **min. load – max. production:**

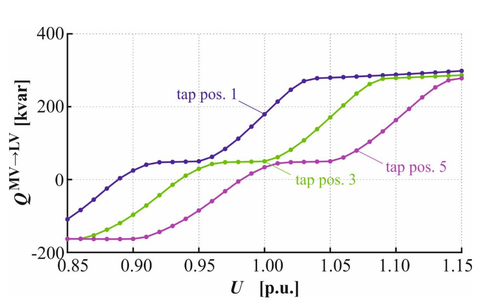
Rural LVG:





Urban LVG:





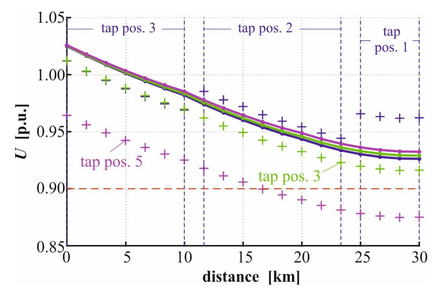
Results show that the DTRs' tap positions have a strong impact on the LVGs' $Q(U)$-characteristics, if PV-systems are $Q(U)$-controlled. Increasing the DTRs' tap positions shifts the characteristic to the right.

Impact of DTR tap position on MVG voltage profile

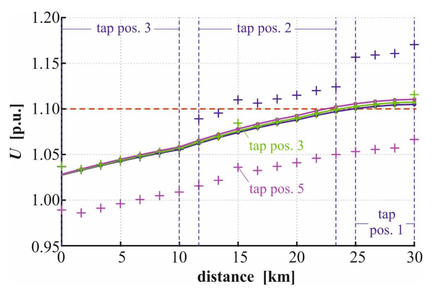
The MVG voltage profiles and the Q-consumption of connected LVGs with uncontrolled PV-systems are identified for different DTR tap settings and both LVG scenarios.

Without $Q(U)$-control:

max. load – no production:



min. load – max. production:

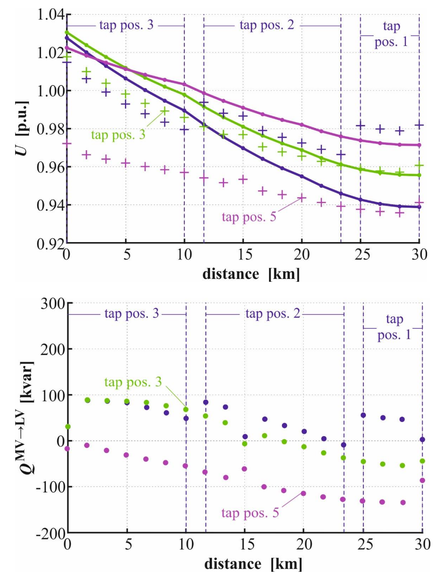


Results show that in the case of uncontrolled PV-systems the DTRs' tap positions have a slight impact on MVG's voltage profile and on the Q-consumption of LVGs. Increasing the DTRs' tap positions decreases LVG voltages and thus the Q-consumption of ZIP-loads. This slightly increases MVG voltages.

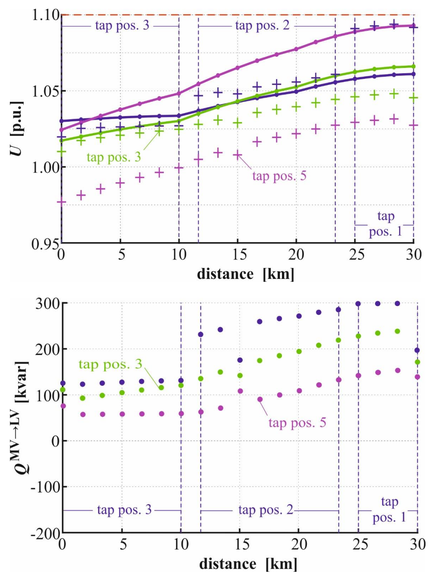
In the following are shown the MVG voltage profiles and the Q-consumption of connected LVGs with $Q(U)$-controlled PV-systems identified for different DTR tap settings and both scenarios.

With $Q(U)$-control:

max. load – no production:



min. load – max. production:



Results show that in the case of $Q(U)$-controlled PV-systems, the DTRs' tap positions have a strong impact on MVG's voltage profile and on the Q-consumption of LVGs. Increasing the DTRs' tap positions decreases LVG voltages and thus the Q-consumption of ZIP-loads and PV-systems. In return, this significantly increases the voltages in MVG.

Conclusion

The fixed DTR tap position has a strong impact on the behaviour of the distribution grid with high share on $Q(U)$-controlled PV-systems. Increasing the fixed DTR tap position …

- … shifts the $Q(U)$-characteristic of the corresponding LVG to the right.
- … decreases the voltage within the corresponding LVG. → direct effect
- … increases the voltage within the corresponding MVG. → indirect effect

The indirect effect intensifies with the spread of $Q(U)$-controlled PV-systems.

Acknowledgement

The authors acknowledge Lukas Kloibhofer who did all calculations in the framework of his Master Thesis [1].

[1] L. Kloibhofer, „Einfluss der fixen Stufenstellung auf das Netzverhalten bei einem großen dezentralen Erzeugungsanteil in Niederspannungsnetzen“, M.Sc. Thesis, Institute of Energy Systems and Electrical Drives, TU Wien, Vienna, Sept. 2018.