Discrimination of Prosumers by Local Control of Photovoltaic Inverters

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Abstract

The capability of smart inverters to provide reactive power is used to control the voltage in low voltage grids with high PV share. But their impact on voltage strongly depends on the feeder parameters and the amount of absorbed reactive power. This work analyses for the first time the prosumer discrimination caused by the use of cosφ(P)- and Q(U)-control. Firstly, the theoretical background of the local X/R-ratio and the relative voltage drop compensation is described. Secondly, a deep analysis of the impact of different control strategies on prosumer discrimination is made. As a result, the Q(U)-control provokes a discrimination in principle, while that of cosφ(P)-control only does it, if individual control-characteristics are set for each prosumer.

Theoretical background

Local X/R-ratio:

The local X/R-ratio of prosumer i is a function of its distance l_i to the distribution transformer (DTR) and can be calculated as:

$$\frac{X_i}{R_i} = \frac{\mathrm{X_{DTR}} + \mathrm{X'_{line}} \cdot l_i}{\mathrm{R_{DTR}} + \mathrm{R'_{line}} \cdot l_i}$$

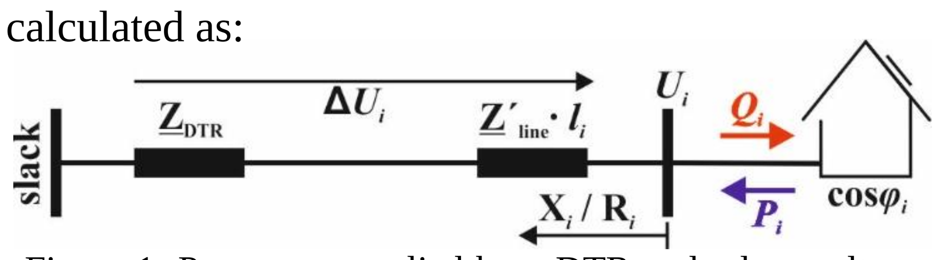

Figure 1: Prosumer supplied by a DTR and a low voltage feeder

The X/R-ratio starts at approximately 4 and decreases along the feeder, especially in case of a cable feeder.

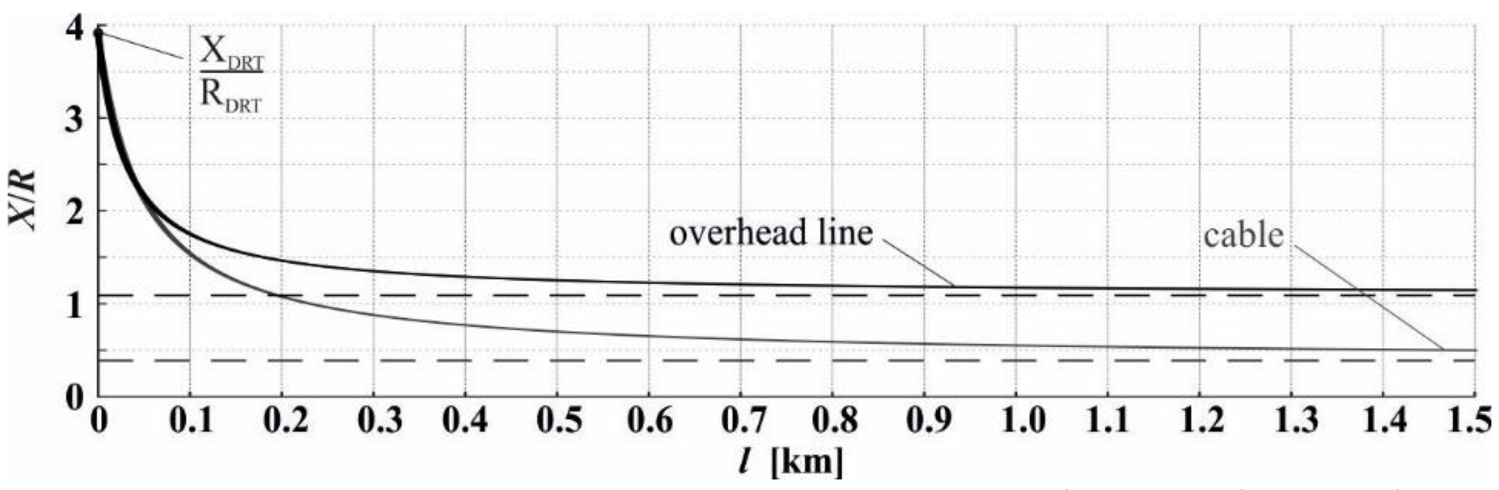

Figure 2: X/R-ratio along a cable and an overhead-line low voltage feeder as a function of line-length

Relative voltage drop compensation:

The contribution of prosumer i, ΔU_i, on the total voltage drop is a function of its active and reactive power injection or absorption:

$$\Delta U_i \approx \frac{R_i \cdot P_i - X_i \cdot Q_i}{U_i} = \Delta U_{P,i} - \Delta U_{Q,i}$$

The relative voltage drop compensation ξ_i of prosumer i is calculated as:

$$\xi_i = \frac{\Delta U_{Q,i}}{\Delta U_{P,i}} = \frac{X_i}{R_i} \cdot \frac{Q_i}{P_i} = \frac{X_i}{R_i} \cdot \tan(\varphi_i)$$

The power factor which is required to achieve a certain relative voltage drop compensation decreases along the feeder, especially in case of a cable feeder.

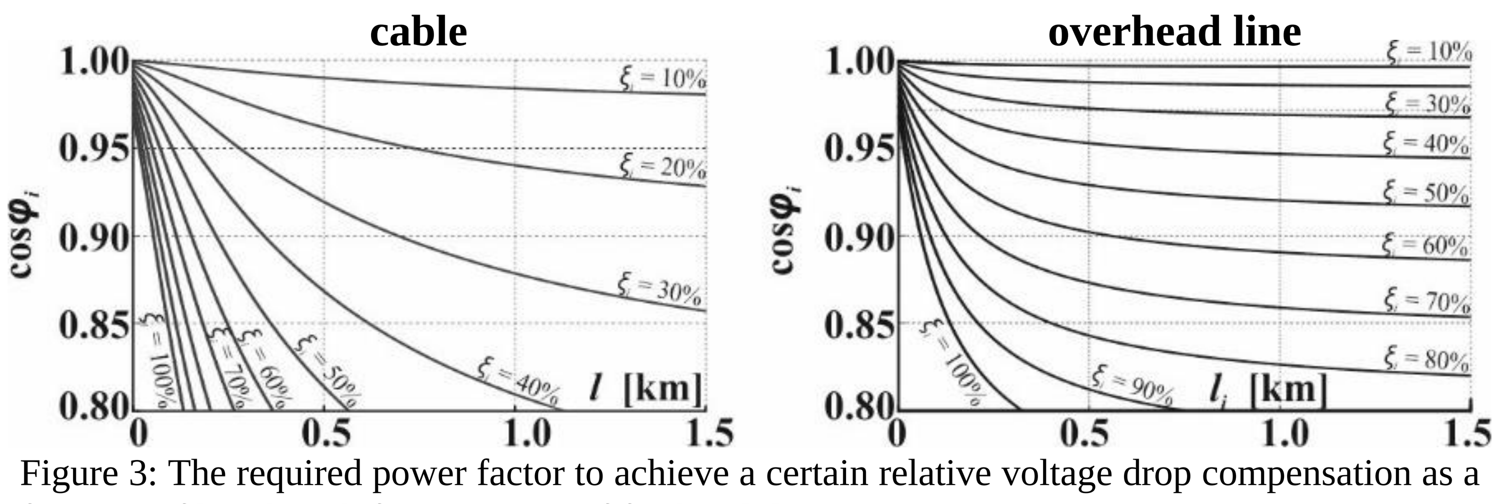

Figure 3: The required power factor to achieve a certain relative voltage drop compensation as a function of line-length for two types of feeders [1]

Discrimination:

The procurement of non-frequency ancillary services by DSOs should be transparent, non-discriminatory and market based [2]. In a non-discriminatory market, the applied voltage control strategy should enable all prosumers an equal and fair prospect to offer ancillary services to the DSOs.

Prosumer discrimination by cosφ(P)- and Q(U)-control

Load flow simulations are performed on a cable feeder for **no-**, **cosφ(P)-** and **Q(U)**-control. The **PV**-system of each prosumer injects **5 kW** and their **loads are set to zero** for simplicity. Slack voltage is set to 1.00 p.u..

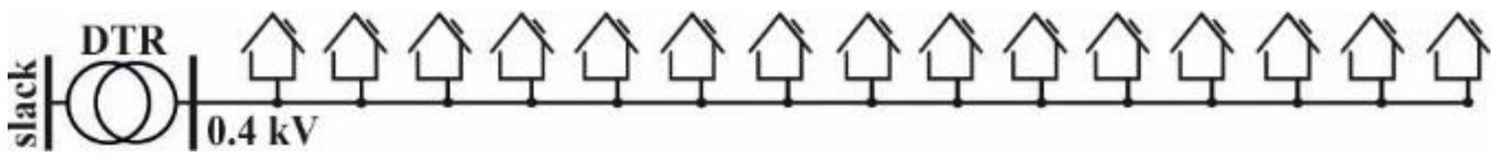

Figure 4: Test cable feeder with prosumers and DTR

Q(U)- and especially cosφ(P)-control partly compensate the PV-induced voltage rise.

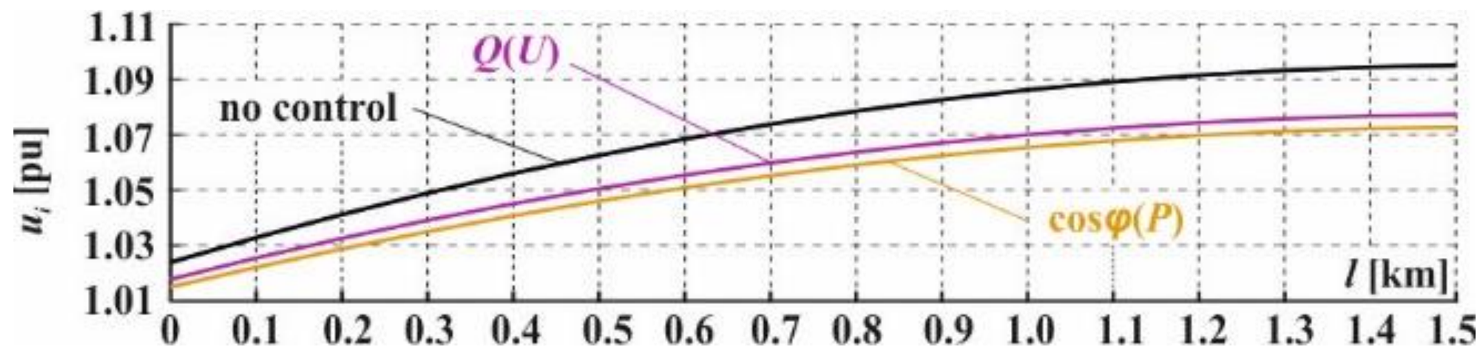

Figure 5: Voltage profile of test cable feeder for no-, cosφ(P)- and Q(U)-control

For no-control, PV-systems inject with cosφ=1, and for cosφ(P)-control, they do with cosφ=0.9. In case of Q(U), those close to the DTR have higher power factor than those at the end of the feeder.

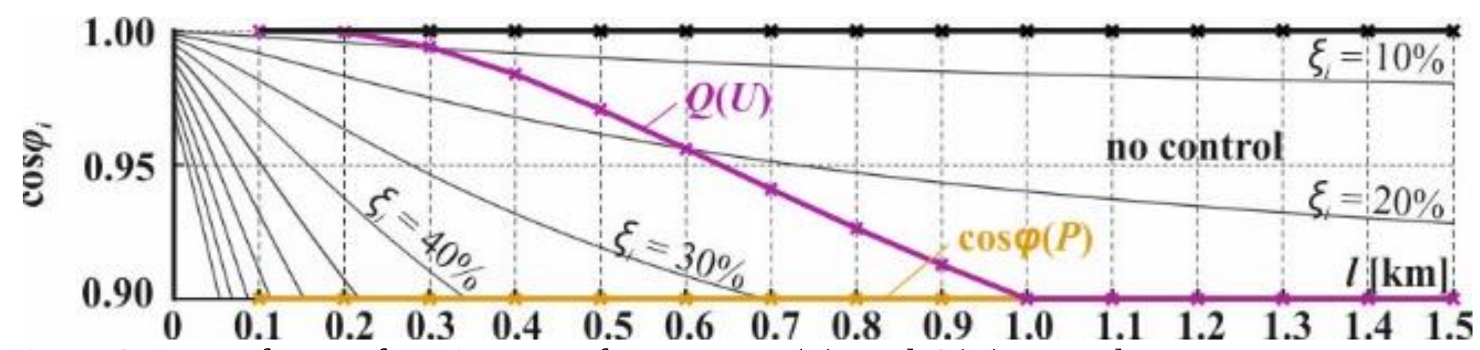

Figure 6: Power factor of PV-inverters for no-, cosφ(P)- and Q(U)-control

For cosφ(P)-control, the inverters absorb the maximum reactive power. For Q(U)-control, those close to the DTR absorb less reactive power than those at the end of the feeder.

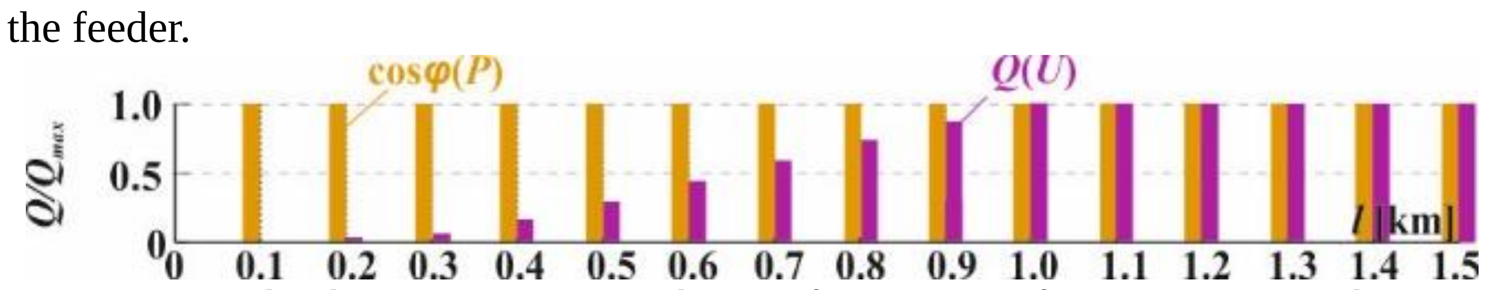

Figure 7: Normalized reactive power contribution of PV-inverters for no-, cosφ(P)- and Q(U)-control

For cosφ(P)-control, the relative voltage drop compensation is high at the DTR and decreases along the feeder. For Q(U)-control, it is small at the DTR and increases along the feeder, up to 1 km distance, and decreases again afterwards.

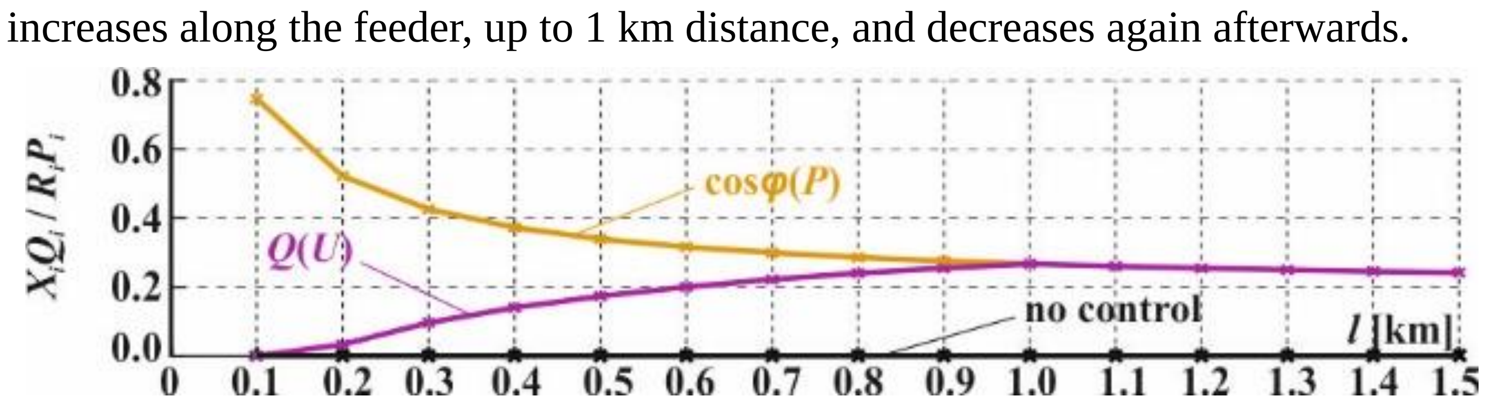

Figure 8: Relative voltage drop compensation of PV-inverters for no-, cosφ(P)- and Q(U)-control

Conclusion

- cosφ(P)-local control does not provoke a discrimination of prosumers if one common control-characteristic is used; inverters inject with the same power factor. In this case, their relative voltage drop compensation is unequal. In contrast, the use of individual control-characteristics does provoke a prosumer discrimination.
- Q(U)-local control does provoke a discrimination of prosumers even if one common control-characteristic is used; each inverter injects an individual amount of (normalized) reactive power. Also in this case, their relative voltage drop compensation is unequal.

[1] D.-L. Schultis, "Volt/var behavior of low voltage Grid-Link in European grid type", M.S. thesis, Institute of Energy Systems and Electrical Drives, TU Wien, Vienna, 2017.

[2] Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on common rules for the internal market in electricity (recast), COM/2016/0864 final - 2016/0380 (COD).