Capacity tariffs and DSO-side down-regulation as grid-relieving measures in future low-voltage distribution systems

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Overview

A transformation of energy systems is undergoing also at the distribution level. In order to meet the future decarbonization goals, electrification of heating and mobility is often proposed as an efficient pathway. For instance, transmission system operators of Germany currently base their grid development plans on the possible adoption of up to 14 million heat pumps and 31 million battery electric vehicles (BEVs) by 2037. With such widespread electrification in the low-voltage distribution systems (LVDSs), however, grid capacity loadings will reach unforeseen levels, possibly necessitating the reinforcement of these in the long term. Motivated from the long lead times and the high costs associated with these infrastructure projects, additional instruments have been proposed to maintain the grid loading at allowable levels, such as 1) new pricing schemes for residential consumers such as capacity tariffs and time-variable grid surcharges, and 2) remote modulation of heat pump and BEV charging stations by the distribution system operator (DSO) at peak hours ("*14a regulation*"[1] as recently proposed by the Federal Network Agency in Germany). Intelligent operation of the household components under these instruments might lead to alleviation of the grid loading in the medium term and thereby reduce the need for urgent expansion of the distribution grid capacities.

Methods

To address these aspects, we implement an MILP-based approach based on [1] to investigate the techno-economic potentials of the mentioned grid-alleviating instruments in representative LVDSs. Thanks to the bi-level approach and aggregation of model time series, the presented optimization framework is highly scalable, allowing a largenumber of household components and reliably conducting a linear power flow optimization for up to ~100 distinct load buses (buildings).

In our case study, we investigate a status-quo LVDS with suburban characteristics which would undergo high levels of electrification. We formulate the

1) optimal dimensioning and the flexible operation of new household components (such as PV, batteries, heat pumps, thermal storages and charging stations) under the various price mechanisms and
2) the grid-side reinforcement measures (such as parallel cabling and on-load tap changing transformers) alongside with operational measures such as curtailment and DSO-side downregulation

as sequential MILP-based optimization problems. We define various planning paradigms, including:

3) a status-quo where no grid-relieving instruments are present,
4) with various levels of capacity tariffs, time-variable grid surcharges and/or the possibility of DSO-side modulation measures, and
5) a best-case scenario, where a coordinated, holistic planning of the whole distribution system takes place.

A direct comparison of these paradigms allow for the techno-economic assessment of the individual measures.

Results

Figure 1 show illustrates the optimized power exchange of one building within the distribution system with various capacity tariffs. With capacity pricing, the households are charged not only on a volumetric (per kWh) basis, but

[1] https://www.bundesnetzagentur.de/DE/Beschlusskammern/BK06/BK6_83_Zug_Mess/841_SteuVE/BK6_SteuVE_node.html

also depending on their peak demand throughout the year. Under this scheme, the flexibilities within the buildings such as storages and intelligent BEV charging are utilized to smoothen the feed-in and import profiles. This way, peak reductions of up to 50% are achieved even under a modest value of 10€/kW, while higher prices reducing the peak moderately further.

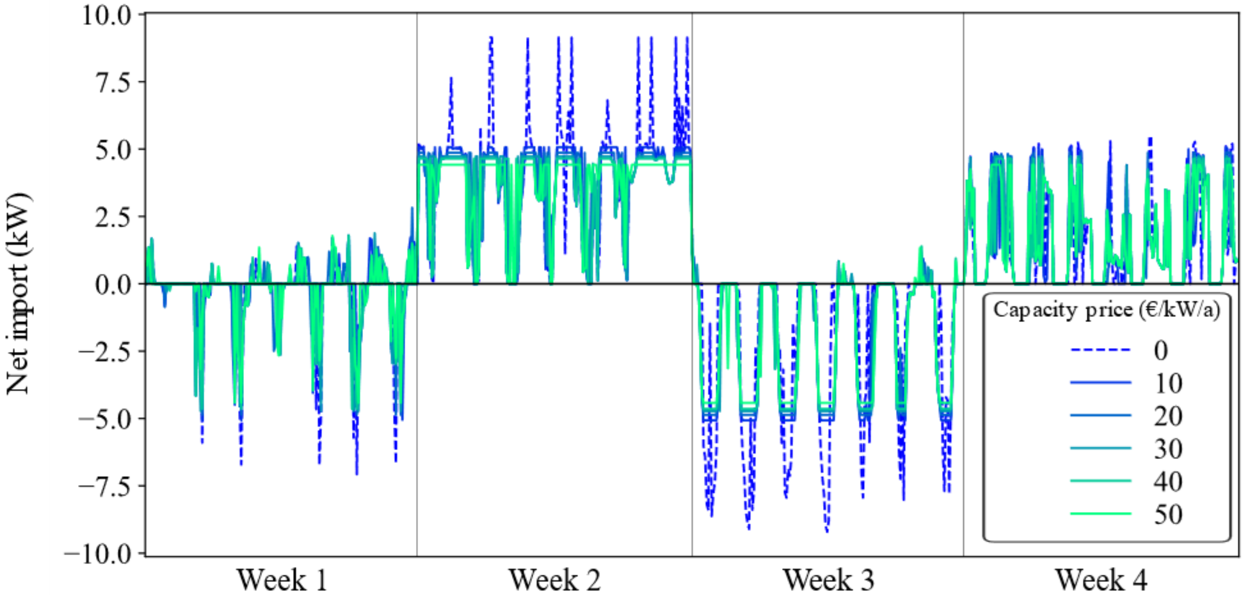

Figure 1. Flexible operation of one building under various capacity price levels.

The influence of capacity pricing on the overall distribution system can be seen in Figure 2, where the hourly course of the power flow through the distribution grid transformer is depicted. From a price of 30€/kW/a on, the replacement of the existing 400kVA transformer to the next size class (630 kVA) could be avoided.

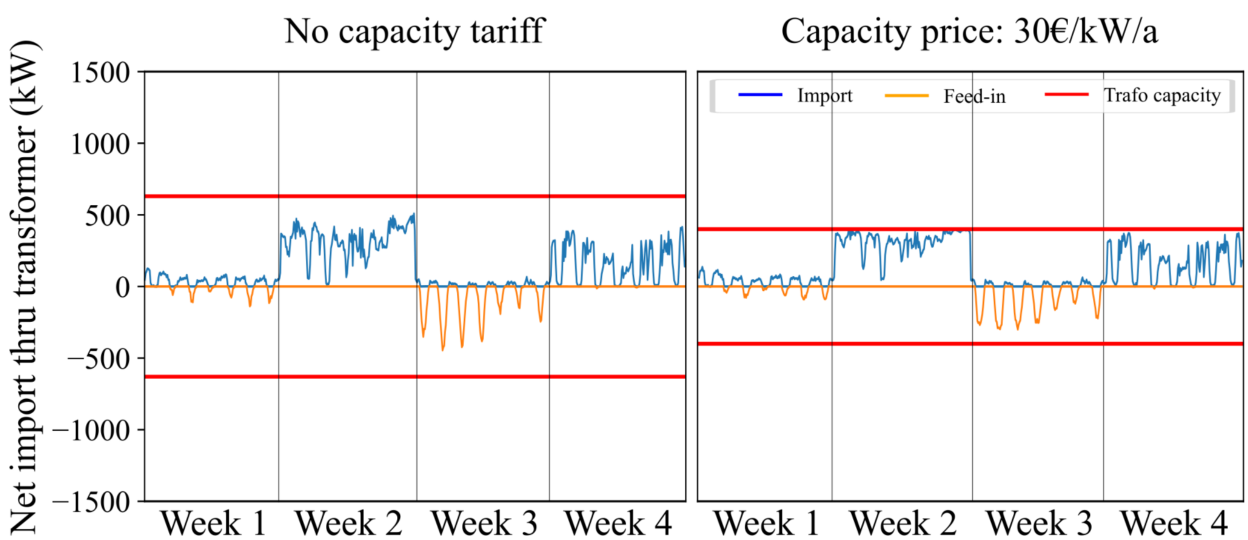

Figure 2. Influence of capacity pricing to the transofmer size requirements.

Conclusions

Presented tentative results demonstrate the considerable utility of the capacity pricing scheme for distribution grid relief. As mentioned in the overview and methods, further aspects such as DSO downregulation or time-variable grid surcharges will be presented in the full work.

With the presented analysis framework, various stakeholders such as regulators, grid planners, households and utilities can derive policy and strategy implications regarding the future transformation of the distribution system landscape.

References

Candas, Soner, et al. "Optimization-based framework for low-voltage grid reinforcement assessment under various levels of flexibility and coordination." *arXiv preprint arXiv:2209.03715* (2022).