INTERACTION OF DYNAMIC PRICING AND LOCAL MARKET CONSIDERING DISTRIBUTION NETWORKS WITH HIGH PV PENETRATION

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Overview

In recent years the number of prosumers and distributed energy resources has risen substantially because of continuous cost reductions and technological advancements in renewable energy technologies, especially in solar PV and batteries [1]. Although an increasing number of prosumers can improve energy efficiency and sustainability to some extent, it might also be detrimental to the stability of our energy system. It consequently becomes increasingly important for procumers to schedule their offtake and injection as to (i) maximize the electricity market value of their recourses whilst (ii) not excessively burdening the local grid. Both items are discussed in turn next.

From a system point of view, prosumers should operate their solar PV installations and especially their batteries based on wholesale market signals. Indeed, if exposed to granular electricity prices, prosumers are able to leverage their batteries by performing price arbitrage (storing electricity when the price is low, and selling or consuming stored energy when prices are high). The revenues obtained via such a strategy can be linked to savings in the wholesale electricity market (e.g. by avoided high variable cost power production during periods of high demand). In principle, this can be achieved through real-time pricing where prosumers are directly connected through the wholesale market. On the other hand, prosumers might not want to be exposed to such levels of price variability and hence, other forms of dynamic pricing (e.g. three-hourly retail prices) are worth investigating as well.

Despite its merits, dynamic contracts may also cause some problems, for example, as prosumers are always to maximize their own profits, sometimes they might coincidently withdraw or inject significant amount of powers from or to the grid, which can excessively burden the local network. One way to mitigate the negative impacts of dynamic contracts and alleviate the burden of network while still keeping the prosumers' incentives is to introduce some form of a local market, e.g. through tradable grid capacity[3], with which the stability of system can be guaranteed and at the same time DERs can be better distributed. As such, one might speculate that the desirability of such local markets may increase as prosumers move towards more granular retail price signals.

Both dynamic price granularity and the local market design will have influences on the long-run equilibrium state of the electricity market, as both of them will have significant impacts on retail price, thus affecting investment behavior of the prosumers. This paper mainly focuses on the interactions between a local market in the form of tradable grid capacity and dynamic retail pricing in distribution networks with significant PV and battery penetration, as well as their collective effects on the whole energy system in the long run. To be more specific, this research investigates how the size of averaging period (granularity) of the wholesale market price and tradable grid capacity in local market affect total system cost and investment behaviors of all agents in the energy system.

Methods

We model a long-run wholesale market equilibrium model where decisions are made about installed capacitities of each technology (prosumer PV and battery capacity, and the wholesale generation mix). In the market, there are four types of agents: conventional generators, renewable generators, passive consumers, and active prosumers with solar PV and battery storage system. For generators, their objectives are to maximize their profits while for prosumers and consumers, they are to minimize their yearly electricity bills. The objective of all agents are coupled by the market clearing constraint which also determines the wholesale market price. The local market for tradable grid capacity is embedded into the same equilibrium model. We apply an adjusted alternation direction method of multipliers (ADMM) to model the non-cooperative game and solve the problem.

We model multiple cases which vary based on several variants of retail price variability (ranging from hourly to yearly-averaged) and crosswise compare these with different implementations of the grid capacity market (i.a. full trading, no trading). As such, the set-up allows to separately examine the desirability of a higher price granularity and local grid capacity market, as well as the interaction between.

Results

The results are expected to show that for the both two grid capacity market designs (i.a. full trading and no trading), high granularity in retail price will lead to a lower total system cost (total technology investments by all agents) compared to the case of yearly price signal. Moreover, it is also expected to see that with more dynamic retail prices, more battery installation also triggers significant increase in investment in solar PV. On the other hand, with excessive injection capacity of prosumers, though total system cost is lower because of large penetration of PV, it will distort the market to a great extent reflected by the negative or zero electricity price in the wholesale market. However, with the implementatiuon of local grid capacity market, this problem can be abated. With tradable grid capacity, investment incentives for batteries and solar PV will drop a bit but with an increase in the total social welfare because of the more efficient distributions of DERs. Thus, when high price granularity stimulates excessive investments in PV and batteries, the local market of tradable injection capacity is expected to maintain the balance between system stability and high penetration of renewables.

Conclusions

This paper investigates varying retail price granularity while utilizing novel local market designs where imposed grid capacity are limiting the penetration of DER's in order to guarantee grid stability. It can be concluded that with the implementation of dynamic pricing and local market of injection capacity, a balance between system stability and high penetration of DERs can be achieved. In the light of the further deployment of PV and energy storage systems (ESS), this research could be used by regulators or governments who would like to have an insight in the interations between dynamic retail pricing and tradable grid injection limit (in local market) and how they might influence the whole energy system and investment behavior of prosumers.

References

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