Modelling Flexible Market Participants in Distribution Grids by Coupling an Agent Based Simulation with a Fundamental Model

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Overview

The ongoing integration of variable renewable energy sources (vRES) as well as the projected rising number of ICT-based grid participants pose new challenges to distribution grid expansion planning (cf. [1][2]). Notably, a significantly increased complexity of the system and a remarkable uncertainty regarding the penetration of new, possibly ICT-based and sector-coupling technologies like heatpumps, mini- and micro-CHPs or E-Mobility arises. The smart integration of these new grid-participants as flexible market-participants, possibly contributing to local markets too, is one major alternative to traditional network expansion. However, the presence of these flexible electricity based technologies (FEBT) combined with a significant number of vRES makes the calculation of interactions between these technologies and with the market extraordinarily complicated. Thus, alternative models are necessary in order to depict the operational behaviour of distribution grid participants and their impact on network operation. As a result, a set of hourly "grid utilization cases" is derived which serves as input to a future distribution grid network extension planning.

In this paper we present a model which combines a high resolution, time-series based and voltage level overarching agent-based simulation of a distribution grid with a fundamental market model in order to investigate possible future grid utilitzation cases under endogenous consideration of market feedbacks. Additionally, we consider incentives for increased self consumption for selected consumers or prosumers as induced notably by regulatory imposed price components (e.g. grid charges or renewable levies) and incentives provided by local price mechanisms reflecting network congestions.

Methods

To depict the interactions between all distribution grid participants, namely vRES (photovoltaic and wind energy), loads, heatpumps, storages and the grid itself, an agent-based simulation environment designed in JAVA JADE[1] is used (based on [2] and extended within the ongoing research project Agent.GridPlan[2]). Hence, it is possible to investigate different penetrations of relevant technologies in various combinations and individual parameterizations easily. However, if an increasing number of ICT-based grid participants is assumed to participate at the energy markets and provide flexibility through storages, time-flexible infeed or consumption choices, curtailment or any combination of these, six major challenges emerge which were not taken into account in the existing model so far.

First, the impact of vRES and FEBT on the market and vice versa the impact from the market on the operational behaviour from vRES and FEBT must be considered. By introducing an agent-based implementation of a peacewise linearized merit-order fundamental model (cf. [3][4]) into the existing simulation environment, the overarching electricity market including price forecasts may be depicted. Second, owners of vRES and FEBT will optimize their operations, if at all, mostly for their own use; e.g. owners of a PV system and a storage will optimize both in view of increased self-consumption. Hence, the flexible combination of several devices (agents) and their joint optimization in a portfolio is implemented. Third, these optimizations require realistic parametrizations reflecting the regulatory context. In Germany (as a rather extreme case), 79 % of the household electricity price consists of grid fees, levies and taxes ([5]). Thus, we extend the model and introduce consumer-specific price components driven by the regulatory framework. This allows to depict the impact of the regulatory framework on the bid structure and operation of vRES and FEBTs. Fourth, both optimization driven by self-consumption and market signals as well as grid-oriented operation require ex ante informations, i.e. forecasts. The weather data based calculation of vRES infeeds allows an easy consideration of vRES infeed forecasts by using weather data forecasts. Moreover, endogenously calculated price forecasts are introduced and thus the role of expectations in operation strategies can be reflected. Fifth, the specific combination and penetration of FEBT and vRES is not predictable but developments are expected to be at least nationwide (on a global market level). This implies that ICT-based FEBT and vRES are

[1] http://jade.tilab.com/
[2] http://www.agent-gridplan.net/

likely to have market impacts which must be taken into account endogeneously. Consequently, the existing agent-based simulation environment is extended through regional aggregation agents which depict the impact of other parts of the wholesale market area where the distribution grid is not modelled. Sixth, in future energy systems the coordination of all flexibility options becomes a major challenge and distribution grid flexibilities are expected to play a major role. Therefore, through a consecutive market based coordination of vRES and FEBT and resulting grid congestion (forecasts), it is possible to illustrate the effects of spatio-temporarally differentiated price-signals – i.e. local markets.

Results

Since distribution network extension must consider the operational behaviour of FEBTs and vRES which will be influenced by and influencing future energy markets, this paper shows a unique modelling approach which takes these effects into account. More in detail, the impact of vRES and FEBT on resulting energy price forecasts and prices is analysed by integrating a piece-wise linearized merit-order model accounting for the global (nationwide) energy market and extending it to consider agents infeed forecasts and energy bids. The market impacts are highlighted through the investigation of the overall price level as well as on the price variance while the impacts on the vRES and FEBTs are analysed through the operational changes of their behaviour and its consequences. Notably, changes in their profitability are illustrated. Moreover, the impacts of the regulatory framework on different consumers and prosumers, their (portfolio) optimization and their market bid structures are revealed.

Besides this economic indicators, this paper emphasizes the consequences of flexible market particpants within the distribution grid on the resulting grid utilization cases. Additionally, the model enables the introduction of local markets through sending network-congestion specific price signals to subgroups of agents which again, could have an impact on their behaviour. Thus, this paper analyses local network congestion management possibilities through local markets by applying a specifically designed local market concept.

Conclusions

Future energy systems aiming to reduce emissions will face a significant increase of vRES and sector coupling technologies. Since these technologies offer new flexibility potentials and will mainly be within the distribution grid, an increasing number of ICT-based market participants is expected to have a significant impact on both, distribution grid utilization cases and the global market, too. Additionally, local markets are expected to contribute to diminish network extension requirements by intelligently using the flexibility potential of these new market participants. However, the parallel simulation of network calculations and possibly millions of small-size market participants induces computational challenges for network extension planning which must systematically simulate distribution grid operations in a world as described above.

The presented modelling approach enables the investigation of future distribution grid utilization cases by depicting the market feedbacks of future FEBTs and vRES and the impact from the market on their behaviour under consideration of a given regulatory framework. Through the consideration of other regions outside the detailed analysed distribution grid, impacts on a global market level are modelled approximatively. Additionally, the impact of a local market is analysed in a simplified manner.

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