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Development Of An Agent-based Model For Assessing The Market And Grid Oriented Operation Of Distributed Energy Resources

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Abstract

The increasing share of renewable distributed energy resources (DERs) entails a rising number of congestions and consequently the need for grid expansion measures in distribution grids. Preventive congestion management measures using flexibility options are a frequently discussed alternative for grid expansion. The flexibility options in distribution grids comprise flexible generation and load management as well as storage systems. However, preventive congestion management is not yet established in distribution grids. Traffic light concepts and flexibility markets are among the congestion management concepts in discussion. In order to determine the optimal design option for the future, a model for the quantitative assessment and simulation of different congestion management measures (CMMs) is needed.

This publication presents a newly developed agent-based model for the evaluation of different congestion management concepts considering the perspectives of electricity market-oriented grid users and distribution system operators (DSOs). The market-oriented grid users can be divided into two major categories: Smart Homes (SHs) and Virtual Power Plants (VPPs). Both concepts combine synergies from distributed energy technologies. Four different congestion management concepts are analyzed with the model for an exemplary test case. The analysis of the test case shows that the necessary amount of curtailment in distribution grids can be reduced, when actively using SHs as part of a preventive congestion management. Depending on the considered CMM, the reduction of curtailment in the examined distribution grid ranges from 15% to 35%. The most promising strategy, a market-based flexibility deployment, reduces the curtailment costs for the DSO by 33% compared to the curtailment needed without the use of flexibilities.

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Keywords: Flexibility Options; Smart Homes; Virtual Power Plants; Operational Planning; Grid Congestion Management

1. Introduction

The decentralization process of the German generation structure implies an increasing feed-in at the distribution level by DER, causing new challenges for the planning and operation of distribution grids. For instance, the need to apply feed-in management to DER is increasing as a consequence of the high feed-in by DER [1]. The measure

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of feed-in management was originally considered to be an ultima ratio measure for solving grid congestions and is currently the only possibility for DSOs to intervene in DER operation. It allows a curtailment of renewable DER feed-in by the DSO in case of grid congestions and ensures that their owners receive financial compensations for the curtailed energy in return. Since the DSO transfers the resulting costs to the end consumers by the adjustment of grid usage fees, the question arises which preventative measures are suitable to keep the overall costs acceptable.

The use of flexibility options like energy storages or flexible generators and loads provides the option to complement conventional congestion management measures (CMMs), such as the feed-in management. However, many of these flexibilities are in private use (e.g. for maximizing the self-consumption) or could be used for a commercialization of the available capacity on the spot and control reserve markets. Since these flexibilities generate financial values for their owners, a grid oriented deployment implies a conflict of interests between the actors (DSO and the owners of flexibility). Hence, detailed investigations of the actor specific consequences are essential for deriving the optimal design of future congestion management concepts in distribution grids.

Two relevant groups of actors in the context of these flexibilities are owners of SHs and operators of VPPs. VPPs aggregate the capacities of DERs for market applications and maximize the profit of their clients, who nowadays are usually owners of renewable DER. SHs combine the generation capacities of solar power systems and combined heat and power (CHP) plants with flexible loads, storage systems and automated control systems. This combination enables owners of SHs to maximize their self-consumption. Alternatively, the use of these flexible applications is attractive to DSOs and VPPs.

Towards an organized coordination of flexibilities and DERs between a grid and a market oriented deployment, the German Federal Network Agency published the idea of a traffic light concept. This concept defines three network phases (green, yellow, red), without giving a precise design especially of the yellow phase [2]. Thus, several design proposals are discussed, ranging from local flexibility markets to improved feed-in management concepts (e.g. [3–5]). A common element is a network state forecast to predict congestions in the yellow phase. However, the choice of the mechanism to incentivize the provision of required flexibilities (flexibility procurement) and to solve the predicted congestion in the yellow phase remains unclear. Potential solutions are the application of network state depending load tariffs or a market for grid-oriented flexibility. Both satisfy the postulation of an interaction between market and grid without interventions by DSOs during the yellow phase. The red phase finally applies as a fallback option in case the procured flexibility does not prevent all congestions. The uncongested network state forecast is represented by the green phase (free market transactions) [3].

Generally, numerous research activities already address the use of flexible technologies in ensuring an uncongested distribution grid operation without taking into account their alternative market value (e.g. [6–8]]). Further recent publications incorporate a market and grid-driven flexibility deployment. However, their focus is on determining the theoretical best case of the flexibilities potential, since they assume the complete knowledge of one central actor on all relevant processes in the regarded distribution grid (e.g. [9,10]. Consequently, there is an evident need for approaches, which consider a separation of the roles and actor-specific available information in modeling the market- and grid-driven flexibility deployment. This publication presents such a modeling approach and contributes an assessment of the potential of different congestion management measures under consideration of SHs and VPPs.

2. Agent-based Framework

Agent-based modeling offers a modular realization of underlying simulation models and thus a clear separation of different actors (agents) as given by the regulatory framework in an unbundled power system. Accordingly, this approach is suitable to model the DER and grid operations separately and to address the different actors perspectives in case of coordinated flexibility procurement. This enables the analysis of actor specific implications against the background of a changing regulatory framework.

2.1. Input and Output

Figure 1 provides an overview on the model environment and its modules. Inputs of the model are on the one hand several time series (market prices, feed-in, load) in hourly or quarter-hourly resolution as well as technical asset specifications (DER), information about the grid topology and its electrical equipment. On the other hand the types