ELECTRICITY STORAGE AND GRID – MODELLING INTERDEPENDENCIES, INCENTIVES AND EFFICIENT REGULATION

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Overview

With declining cost for renewable generation technologies and chemical storage there is an increasing number of integrated systems that allow for a co-optimization of power production and consumption using storage (prosumage). In addition to temporal arbitrage and portfolio optimization, electricity storage has great potential to be used for network services in both the distribution and the transmission grid (Schill et al. 2017). However, these usages depend on storage properties like its location and size as well as its operation (dispatch) and the different objectives might counteract with each other. Moreover, storage owners are likely to neglect system effects and potential services that their storage can provide, but rather focus on other purposes like maximization of arbitrage, reduction of wind power curtailment or the increase of self-consumption.

This paper focuses on the interaction of prosumage with the distribution and transmission grid and investigates how efficient regulation can be used to overcome countervailing objectives of different entities.We evaluate different incentive schemes and regulations introduced by the distribution system operator (DSO) with respect to their efficiency and distributional effects.These policies allow the DSO to influence storage dispatch and hence decrease required grid expansion. However, the resulting storage operation and distribution grid capacities are not cost efficient from a systems perspective and lead to non-optimal deployment of transmission lines and use of dispatchable generation.

Methods

Drawing from different literature streams in multi-objective and multi-level power system modelling (e.g. Zou et al., 2016; Huppmann and Egerer, 2015), we develop a three stage numerical model, which consists of a schematic representation of a transmission grid with separate distribution grids adjacent to each of the transmission system nodes. We consider generation capacities (conventional and renewable) as well as demand and storage capacity to be exogenous and renewable feed-in to be fluctuating. Every distribution grid is operated by a DSO, who must construct a grid that suffices for contingencies like peaking renewable feed-in or peaking loads with lack of renewables. The transmission system operator TSO benevolently decides on the cost efficient transmission grid capacities.

Formally, this approach resembles an equilibrium program under equilibrium constraints (EPEC), set up as a three stage strategic game (cf. Figure 1): The lowest level (iii) corresponds to the nodal balance, where conventional power generators and prosumage are price takers and Stackelberg followers in an equilibrium electricity market. We assume an incomplete market, where the network constraints at the distribution level are not anticipated by power producers and consumers. Therefore, efficient nodal pricing informations are only available at the transmission level. Acting as Stackelberg leaders (ii), strategic regional DSOs anticipate these decisions. They minimize necessary distribution grid extensions by the use of incentive payments or legislation towards prosumage, which allow them to influence the storage operation and thereby the maximum prosumage load and feed-in. Finally, on the first level (i) the TSO minimizes system costs given the lower level constraints. By expanding the transmission grid, the TSO can influence resulting market prices and thereby alter the equilibrium in the lower stages. The game is solved using a variation of a disjunctive constraints reformulation following Ruiz et al. (2012), Huppmann and Egerer (2015), and Zerrahn and Huppmann (2017).(Zerrahn and Huppmann 2017)

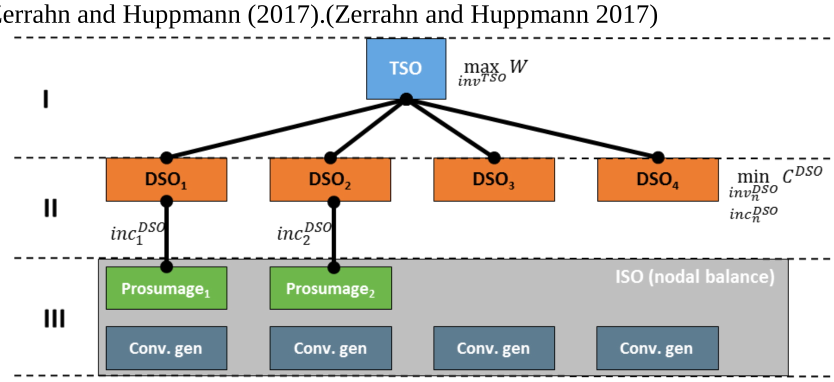

Figure 1: Three stage game structure.

We calibrate the set-up to projections for Germany in 2035. These include generation, demand as well as renewables and coupled PV-storage system capacities. For our analysis, we distinguish four scenarios:

i) a first best Base Case (BC), where the total costs for power provision are minimized;

ii) a No Coordination (NC) case, where DSOs cannot influence storage operation and are bound to supply sufficient grid capacity to support market-oriented deployment of prosumage;

iii) a Self-Consumption (SC) case, where the DSOs can set an upper limit to the feed-in of the prosumage; and

iv) a DSO-deployed Storage Case (DS), where DSOs have full control over the dispatch of the storages.

Results

We find that DSOs set wrong incentives for storage from the systems perspective, which can only partly be mitigated by the TSO. They overuse storage to reduce the necessity for distribution grid deployment. It follows that the costs for power generation rise overproportionally compared to the BC case. However, allowing intervention by the DSO performs better than the uncoordinated case (NC), i.e. lower costs can be achieved.

While the uncoordinated (NC) and hence purely price-driven dispatch of storage leads to the lowest generation costs among the cases, it also leads to high investment requirements, in both the distribution and the transmission grid. Generation costs are higher in the BC, as it incorporates the trade-off between generation and investment costs, which is unconsidered in the NC case. In the SC case generation cost are higher than in the NC case, as less storage capacity is available to the market to mitigate price peaks. Investment in the DSO grid is smallest in the DS case, where storage is used to reduced investment requirements. In the SC case DSO investment are also lower than in the NC case but cannot achieve the levels of the DS case, due to the imperfection of the regulatory instruments.

The benevolent TSO can partly mitigate inefficiencies by additional transmission grid expansion. In fact, the efficient size of the transmission capacities is inversely proportional to the DSO's ability to influence storage operation. By choosing higher capacities, the TSO increases integration and reduces price peaks, which leads to more system-friendly storage generation.

Conclusions

To our knowledge, there is so far no other approach considering the comprehensive dynamics and coordination challenges between transmission and distribution system operators as well as storage. The results are highly relevant for the recent debates about market integration of and regulatory design for storage. Furthermore, they shed light on the limitations of network beneficial storage use.

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