Renewable energy curtailment: A case study on today's and tomorrow's congestion management

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ABSTRACT

This work aims at contributing to the development of congestion management in power systems facing a strong expansion of renewable electricity generation. We address a comparatively new but increasingly important challenge to electricity markets with a uniform price zone: Renewable curtailment due to grid constraints. Our goal is to provide a model framework suitable to investigate the impact of expanding the grid operator's flexibility under varying congestion management regimes. We aim to expose the limitations of the current regime and to present a favorable alternative. For our analysis, we develop an optimal power flow program to replicate the current congestion management regime for distribution grids with high penetration of distributed generation in Germany. Furthermore, we introduce district heating as additional flexibility option and investigate the impact under different approaches to congestion management. Our results suggest that introducing additional flexibility, while keeping the current congestion management regime, bears significant risk to increase the cost of congestion management. Adjusting the regime to take into account economic criteria, as outlined in this work, eliminates this risk and grants direct control on the trade-off between curtailment and cost.

1. Introduction

Numerous countries in Europe and around the world are in the process of transforming their power systems to generate more electricity from renewable energy sources. The large-scale employment of distributed electricity generation from renewable energy sources (DG) is associated with increasing grid congestion and, hence, DG curtailment in many of the affected power systems. In the context of this work, curtailment refers to the reduction of renewable generation due to grid constraints in contrast to a market-driven reduction due to, for instance, negative prices. Geographically, we concentrate our analysis on Germany.

In 2015, about 4.7 TWh of potential DG were curtailed within the feed-in management scheme in Germany, causing an estimated 478 million euros of compensation payments (BNetzA, 2016). Furthermore, the amount of curtailed energy strongly increased over the recent years and tripled in 2014 and 2015 (Fig. 1). This suggests that the amount of future curtailment and compensation might further increase.

With regard to grid reinforcement, there has been significant activity for several years aiming to alleviate congestion and the associated cost in the medium and long terms (BNetzA, 2015a). Despite these efforts, curtailment amounts rose to their historic peak in 2015. Less activity could be observed with regard to improving the congestion management algorithm. Regulators and policy makers are called upon to increase the efficiency of existing congestion management approaches and the coordination between grid operators (50Hertz GmbH et al., 2017; BDEW, 2015; Ecofys and Fraunhofer IWES, 2017; ENTSOEE, 2016; Gerard et al., 2016; VDE, 2014).

To contribute to the development of future congestion management and to shed light on the causation of renewable curtailment in Germany, we develop a model of the real-world 110 kV distribution grid system in Schleswig-Holstein, including all interconnectors to the transmission grid. We select this case study because the vast majority, roughly 70%, of Germany's total curtailment occurs within this distribution grid (Fig. 1). According to the relevant German regulations, grid operators facing congestion caused by DG are to apply a congestion management algorithm that minimizes the amount of curtailed energy (Deutscher Bundestag, 2017a). However, since there are no exact details provided on how congestion management is carried out, there is a high uncertainty among market participants and scientists with regard to the resulting curtailment. Nevertheless, very concrete plans are on the way to expand the flexibility options available to grid operators when managing congestion: For example, the installation of up to 2000 MW power-to-heat capacity at district heating systems to grant...
combined heat and power (CHP) plants more flexibility, incentivized by the revised Energy Act 2017. Our contribution consists of a model framework suitable to investigate the impact of expanding the range of flexibilities to the grid operator and to compare the performance of different congestion management scenarios. Besides modeling the current congestion management regime, we develop two concrete future scenarios: Whereas the first is inspired by the current state of regulation and still minimizes renewable curtailment, the second breaks with precedence and takes economic factors into account.

The sections below are structured as follows: In Section 2, we provide an overview of the background of our study and the relevant literature. Section 3 presents the model implementation consisting of the full representation of the three optimization programs, the input data of our real-world case study in Northern Germany and the interface to the wholesale market. Section 4 summarizes the results of applying the different model derivatives and closes with a critical review of our modeling approach. In Section 5, we outline the implications of our results and derive concrete policy recommendations.

2. Background

The approaches to design power markets around the world are diverse and the resulting regulation complex. Therefore, we focus our summary of the regulatory background of congestion management and the resulting DG curtailment on Germany. Subsequently, we present a brief overview of existing work from literature investigating a similar angle.

2.1. Congestion management and renewable curtailment in Germany

In Germany, DG, in accordance with the German Renewable Energy Act (Deutscher Bundestag, 2017a), enjoys priority access to the grid infrastructure. This generally means that congestion has to be relieved by means of conventional power plants, and DG remains only as a last resort.¹ As electricity in Germany is traded within a single price zone, congestion is unlikely to be prevented by the price signals of the market. Therefore, grid operators often have to intervene to alleviate congestion. Aside from transmission switching and network topology optimization, intervention is based on three legal instruments: congestion. Aside from transmission switching and network topology congestion is unlikely to be prevented by the price signals of the grid operator, and DG remains only as a last resort.¹ As electricity in Germany is traded within a single price zone, congestion is unlikely to be prevented by the price signals of the market. Therefore, grid operators often have to intervene to alleviate congestion. Aside from transmission switching and network topology optimization, intervention is based on three legal instruments: congestion. Aside from transmission switching and network topology optimization, intervention is based on three legal instruments: congestion. Aside from transmission switching and network topology optimization, intervention is based on three legal instruments: congestion. Aside from transmission switching and network topology optimization, intervention is based on three legal instruments: congestion. Aside from transmission switching and network topology optimization, intervention is based on three legal instruments: congestion. Aside from transmission switching and network topology optimization, intervention is based on three legal instruments: congestion. Aside from transmission switching and network topology optimization, intervention is based on three legal instruments: congestion. Aside from transmission switching and network topology optimization, intervention is based on three legal instruments: congestion. Aside from transmission switching and network topology optimization, intervention is based on three legal instruments: congestion. Aside from transmission switching and network topology optimization, intervention is based on three legal instruments: congestion. Aside from transmission switching and network topology optimization, intervention is based on three legal instruments: congestion. Aside from transmission switching and network topology optimization, intervention is based on three legal instruments: congestion. Aside from transmission switching and network topology optimization, intervention is based on three legal instruments: congestion. Aside from transmission switching and network topology optimization, intervention is based on three legal instruments: congestion. Aside from transmission switching and network topology optimization, intervention is based on three legal instruments: congestion. Adjus...
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