Energy Policy 112 (2018) 427–436

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

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

Hans Schermeyer[a,*], Claudio Vergara[b], Wolf Fichtner[a]

[a] Chair of Energy Economics, Karlsruhe Institute of Technology (KIT), Hertzstrasse 16, 76187 Karlsruhe, Germany
[b] MIT Energy Initiative, Massachusetts Institute of Technology (MIT), 77 Massachusetts Avenue E19-307, Cambridge, MA, USA

ARTICLE INFO

Keywords:
Curtailment
Optimization
Renewable energy
Congestion management
Optimal power flow

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.

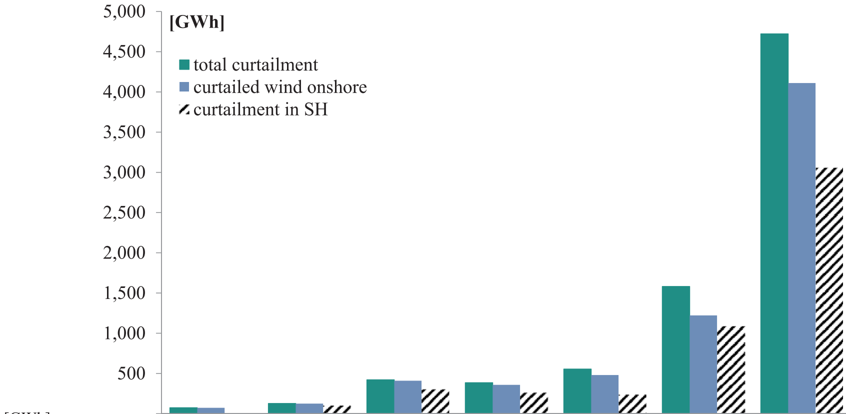
In 2015, about 4.7 TWh of potential DG were curtailed within the feed-in management scheme in Germany, causing an estimated 478 million euros of compensation payments (BNetzA, 2016). Furthermore, the amount of curtailed energy strongly increased over the recent years and tripled in 2014 and 2015 (Fig. 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; ENTSOE-E, 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

* Corresponding author.
E-mail addresses: hans.schermeyer@kit.edu (H. Schermeyer), cvergara@mit.edu (C. Vergara), wolf.fichtner@kit.edu (W. Fichtner).

http://dx.doi.org/10.1016/j.enpol.2017.10.037
Received 13 March 2017; Received in revised form 16 October 2017; Accepted 19 October 2017
0301-4215/



[GWh]	2009	2010	2011	2012	2013	2014	2015
total curtailment	74	127	421	385	555	1,581	4,722
curtailed wind onshore	73	125	410	358	480	1,221	4,110
curtailment in SH		100	308	262	239	1,092	3,055

Fig. 1. Curtailment of power generation from renewable energy sources in Germany over time. For each year the share of curtailed wind power and curtailment within the distribution grid of the grid operator Schleswig-Holstein Netz AG are shown as well. (BNetzA, 2012, 2013, 2014, 2015b; MELUR, 2016a).

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 with 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: "Redispatching" regulated via the German Energy Act (Deutscher Bundestag, 2017b), "feed-in management" regulated via both the German Energy Act and the German Renewable Energy Act (Deutscher Bundestag, 2017a), and "adjustment measures" regulated via the German Energy Act. Adjustment measures allow the grid operator to adjust any feed-in, feed-out or the transit of power in order to guarantee the safety and reliability of the power system. They may only be applied if redispatch measures do not suffice. The amount of energy affected by adjustment measures is two orders of magnitude smaller than that affected by both other instruments and is therefore ignored in the following. The impact of redispatch measured in energy and estimated cost was 16 TWh and 412 million euros in 2015 (BNetzA, 2016). Redispatching largely affects conventional power plants and is exclusively driven by transmission grid constraints. It is also omitted for this work.

Our analysis will focus on the DG curtailment resulting from feed-in management. To the present, the German Renewable Energy Act allows for curtailment only in the course of a congestion management approach that minimizes the amount of curtailment (Deutscher Bundestag, 2017a, p. 16). Even though the legislator recently passed a very concrete scheme to support the installation of power-to-heat units if they "efficiently" alleviate congestion (Deutscher Bundestag, 2017b), it remains unclear how such flexible and additional demand becomes part of the congestion management algorithm.

2.2. Literature review

The existing literature on power systems analysis with grid constraints is abundant. To point out where we intend our contribution, we narrow our review down to literature dealing with congestion management challenges arising from an increasing renewables penetration in a power market like Germany. We choose to cluster the relevant literature we identified into qualitative and quantitative work on how to improve congestion management, starting with the latter:

Kunz (2013) reproduces re-dispatching of transmission grid operators (TSO) in Germany and predicts a significant increase in congestion and associated cost for the future. He argues for a strong need to improve the congestion management approach currently in place. Trepper et al. (2015) similarly argue for the importance of an improved congestion management. They analyze whether and how much splitting the German price zone on transmission grid level can contribute to reducing the need for re-dispatching and increasing welfare. Egerer et al. (2016) focus on a scenario with two and four price zones to analyze the effect on congestion within the German transmission grid and conclude for a need of different approaches to regional pricing to deal with network constraints. The mentioned studies provide excellent examples for the increasing occurrence of congestion and the need to improve congestion management addressed in this work. However, the existing studies focus on transmission grid constraints and investigate the corresponding tools: Splitting the uniform price zone, changing the

[1] There are exceptions, for example for combined heat and power plants serving a heat demand. More details on how curtailment is to be executed are given in the latest curtailment guidelines by BNetzA (2017) that are currently being discussed.