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Effect of increased renewables generation on operation of thermal power plants

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HIGHLIGHTS

- Impacts of increased renewables in central European transmission system are assessed.
- Individual transmission lines and power plants of transmission system are modelled.
- Starts and ramps of thermal power plants significantly increase with increased renewables.
- Impact of renewables on thermal power plants is highly dependent on location.

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ABSTRACT

High spatial and temporal resolution optimal power flow simulations of the 2013 and 2020 interconnected grid in Central Western and Eastern Europe regions are undertaken to assess the impact of an increased penetration of renewables on thermal power plants. In contrast to prior studies, the present work models each individual transmission line and power plant within the two regions. Furthermore, for conventional plants, electricity costs are determined with respect to fuel type, nameplate capacity, operating condition and geographic location; cycling costs are modeled as function of the recent operational history. For renewable power plants, costs and available power are determined using mesoscale weather simulations and hydrology models. Countrywide validation of the simulations shows that all renewable and most conventional power production is predicted with less than 10% error. It is shown that the increased penetration of renewables in 2020 will induce a 4–23% increase in the number of starts of conventional plants. The number of load ramps significantly increases by 63–181%, which underlines the necessity for equipment manufacturers and utilities to adapt to scenarios of high penetration of renewables. The increased cycling operation of coal plants is shown to depend strongly on the power plant's location and is mainly observed in Germany and the Czech Republic. Austrian coal plants are cycled less because they supply more base load power to southern Germany, where several nuclear power plants will be phased out by 2020. Thus there is a need for more transmission capacity along Germany's north–south corridor to transport renewable power from the windy regions of northern Germany to the demand centers in southern Germany.

1. Introduction

In 2009, the European Commission released the Renewables Directive 2009/28/EC, which targets an EU-wide 20% share of energy production from renewables in 2020 [1]. This requires approximately 35% of electricity generated in the EU to be renewable by 2020 – a two-fold increase compared to 2008 [2]. This large increase in renewables has major impacts on the power system. For example, as generation centers are shifted away from demand centers, there is an increased need for high voltage power transmission. Moreover, the availability of electricity on windy and/or sunny days causes the electricity prices to drop. As a consequence, original equipment manufacturers (OEMs) and utilities potentially face financial setbacks as the electricity sector continues to evolve to reach the EU targets. The predicted adverse effects of renewables penetration on the financials of thermal power plants has led the largest German utility to disaggregate into separate thermal and renewables power companies by 2016 [3]. Additional challenges and opportunities arise from the fact that renewable generators do not necessarily have maximum production during hours of highest demand. Conventional power plants will therefore

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Nomenclature

f	fuel and O&M cost ($)
$f_{g,t}^{total}$	total cost being minimized ($)
$p_{g,t}$	power output (MW)
Δp_{g}^{ramp}	per hour ramping capability (MW)
$r_{g,t}$	ramping costs ($/MW)
$s_{g,t}$	start costs ($)

Subscripts

g	generator
t	time step (one hour)

face increased cycling operation in order to balance the electricity grids. Several studies have shown significant increases in variability of loads due to increasing penetration of renewables [4,5]. To avoid excessive curtailment of renewable power in systems with high penetration of renewables, conventional power plants will have to provide more ramping capabilities and have a larger range of operation [6].

An increase in load cycling has a detrimental effect on a conventional power plant's life, results in poor financial performance, and leads to increased emissions from the power plant [7–9]. Given the new market challenges, it becomes crucial for both OEMs and utilities to quantify the effects of increased renewable penetration on conventional power plants. While OEMs seek to quantify the value of plant flexibility to customers, utilities are optimizing the geographic locations and specifications of new plants so that they can achieve beneficial financials and plant lifetimes.

Several studies have assessed the impact of increased renewables penetration on the overall power systems. A common limitation of these prior studies is the aggregation of the European power system on the scale of a country [10] or in lumped control regions [11]. This is problematic, because the geographic system size heavily affects the impact of increased renewables penetration on flexibility demand for conventional power plants. Studies on isolated subsystems tend to overestimate the flexibility requirements [12]. It is necessary to analyze the central European power grid as an interconnected system since in the upcoming decades the EU targets an integrated, transnational energy system [13]. The detailed representation of the transmission system, which has not been done in previous works, is a key aspect of the present work as it allows an accurate assessment of the flexibility requirements in the interconnected central European transmission system. A previous study focusing on the cycling aspect of conventional power plants [14] has applied the open source modeling tool WILMAR [15]; however this tool does not model the transmission system. Another comprehensive simulation tool for the planning of large-scale energy systems is EnergyPLAN [5,16]; however this also uses aggregated elements to model national power systems. To enable both long-term system planning and short-term flexibility assessments, several studies have coupled energy system modeling tools with power system models [17,18]; however, these studies also do not consider the individual transmission lines and individual power plants within the power system.

While the aforementioned approaches enable general assessments of large-scale power flows across the continent, it is not possible to analyze the effects of renewables penetration on individual thermal power plants nor on individual transmission lines within the geographically widespread transmission system. Analysis with such level of detail is desirable, since renewable generators are not being installed uniformly across Europe. There are large concentrations of wind parks around the windy North Sea, primarily in Germany and Denmark. Poland also plans a substantial development of wind energy [19], whereas the Czech Republic has focused on photovoltaics [20]. Austria and Switzerland see opportunities to use their hydro storage capacities to balance Europe's renewable electricity generation [21,22]. Therefore, a conventional power plant in northern Germany will experience different changes in flexibility requirements due to renewable power installations compared to a power plant in Austria. Furthermore high spatial resolution, on the order of meters, is required, because renewable generation technologies differ fundamentally from conventional power generation in characteristics such as production costs, availability and predictability of power deliveries. The goal of this paper is to assess the impact of renewables on operation of thermal power plants. The approach in this work is conducted with high spatial (30 m × 30 m) and temporal (hourly) resolution.

The paper is organized as follows. In the methodology section, the framework for the optimal power flow simulations of central Europe is detailed. Several simulated scenarios are then presented. In the results section, the simulation outcomes are analyzed with regard to changes in the operation of thermal power plants and loadings on transmission lines. Conclusions are derived in the subsequent section.

2. Methodologies

In this study, the interconnected grid in Central and Western Europe (CWE) and Central and Eastern Europe (CEE), that spans across Switzerland, Germany, Poland, Austria and the Czech Republic is investigated, as shown in Fig. 1. A Geographical Information System (GIS) database of the power systems infrastructure, which comprises 1000 substations, 70,000 km of high-voltage transmission lines, 160 transformers and 3000 power generators across the region, was developed from publicly available sources [23,24].

To model the physical and economic aspects of power generation, transmission and demand across large areas, EnerPol [25–28], our in-house developed integrated simulation tool is used. Simulations of AC and DC power systems infrastructure are conducted by integrating MATPOWER, an open-source MATLAB based AC Optimal Power Flow (ACOPF) tool [29], into EnerPol. To enable assessments of the cycling of conventional power plants, the OPF simulations are carried out at hourly resolution for a year-long period, and the MATPOWER simulation structure is augmented to incorporate costs and constraints of power plant cycling (see Section 2.1.2). For the simulations, a power system representation is created in a geo-localized manner by using the relevant data from the GIS database. The characteristics of the power system that differ from hour-to-hour are the electricity demand, the fuel costs for conventional generators and the weather-dependent renewable generation. The hourly simulations are conducted in chronological order using the ACOPF tool, such that the recent operational history of all conventional power plants is tracked to enable dispatch decisions for the subsequent hours. Highly resolved dispatch curves are determined by modeling the costs of electricity production for individual conventional and renewable generators.