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Influence of renewable energy sources on transmission networks in Central Europe☆

Karel Janda[a,b], Jan Málek[c], Lukáš Rečka[a,*]

[a] Charles University, Prague, Czech Republic
[b] University of Economics, Prague, Czech Republic
[c] Universiteit van Amsterdam, Amsterdam, Netherlands

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ABSTRACT

This article focuses on the influence of increased wind and solar power production on the transmission networks in Central Europe. The German Energiewende policy together with insufficient transmission capacity between northern and southern Germany as well as the existence of the German-Austrian bidding zone heavily contribute to congestion in the Central European transmission system. To assess the exact impact on the transmission grid, the direct current load flow model ELMOD is employed. Two development scenarios for the year 2025 are evaluated on the basis of four representative weeks. The first scenario focuses on the effect of Energiewende on the transmission networks, the second one drops out nuclear phase-out and thus assesses isolated effect of increased feed-in. The results indicate that higher feed-in of solar and wind power increases the exchange balance and total transport of electricity between transmission system operator areas as well as the average load of lines and volatility of flows. Solar power is identified as a key contributor to the volatility increase, wind power is identified as a key loop-flow contributor. Eventually, it is concluded that German nuclear phase-out does not significantly exacerbate mentioned problems.

1. Introduction

This paper investigates a contradiction between two important energy policy directions of EU: on one side creating a unified energy market, on the other side promoting renewable energy, where the problems with accommodation of renewable electricity in electricity transmission networks provide strong policy incentives to close the national networks and to refuse the transfer of electricity from other countries during high-production events (Huppmann and Egerer, 2015). In order to address this problem we use the non-linear optimization model ELMOD, which maximizes social welfare under a number of constraints. We analyse the impacts of increased renewable energy feed-in and nuclear phase-out on cross-border grid congestion in Central Europe (CE) and on volatility growth in transmission networks in CE. The important contribution of this paper is that, unlike many others, it focuses on the whole region of CE in the same detail as Germany and particularly elaborates on the influence of individual components of German Energiewende policy (i.e. renewable energy promotion and nuclear phase-out) on the whole area. Also, this paper stresses the importance of the German - Austrian bidding zone which was mostly neglected in the previous research. This paper uses a "critical scenario approach". This means that the results must be interpreted in the context of what would be the impact of electricity flows on the grid if nothing was changed in the grid development.

On the renewable energy side of the policy conflict there are EU 20-20-20 targets (European Commission, 2009) and even more ambitious targets of 2030 climate energy framework (at least 40% cuts in greenhouse gas emissions (from 1990 levels), at least 27% share for renewable energy and at least 27% improvement in energy efficiency) (European Commission, 2014). On the market integration side of the controversy there is the effort to create a European Energy Union, officially launched in 2015 (European Commission, 2015).

The development of variable renewable energy sources (VRES) in Germany caused severe problems with transmission network in CE

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* Corresponding author.
E-mail addresses: Karel-Janda@seznam.cz (K. Janda), janmalek.jm@gmail.com (J. Málek), lukasrecka@gmail.com (L. Rečka).

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Nomenclature

Sets and indices

L	set of all lines
N	set of all nodes
C	set of all controllable plants
T	set of all time periods
$l \in L$	line within the network
$n, nn \in N$	nodes within the network
$n' \in N$	slack node(s) within the network
$c \in C$	controllable power plant unit
$t \in T$	time periods

Parameters

G_{nt}^{wind}	wind input at node n in time t
G_{nt}^{solar}	solar input at node n in time t
PSP_{nt}^{out}	pump storage plant release at node n in time t
PSP_{nt}^{in}	pump storage loading at node n in time t
G_{ct}^{max}	maximal generation of generation unit c in time t
$\overline{P}_{lt}$	maximal available capacity limit of line l in time t
H_{ln}	network transfer matrix
$B_{n,nn}$	network susceptance matrix
A_{nt}	intercept coefficient at node n in time t
D_{nt}	slope coefficient at node n in time t
M_{nc}	marginal cost coefficient of power plant unit c at node n

Variables

w	welfare function
$\pi_{nt}(q_{nt})$	inverse demand function at node n in time t
g_{nct}	generation of generation unit c at node n in time t
q_{nt}	demand at node n in time t
v_{nt}	net input to node n in time t
p_{lt}	power flow over line l in time t
$\theta_{nt}, \theta_{nn,t}, \theta_{n't}$	flow angle at node n in time t

region, defined as Germany, Czech Republic, Slovak Republic, Poland and Austria in this paper. Excess production in the north has to be transported to the consumption centres in the south of Germany, to Austria and other energy deficient countries in southern Europe. The existing German grid is not able to accommodate such a big feed-in of intermittent renewable energy and, therefore, exhibits congestion. As a result, electricity flows through the systems of adjacent countries, Poland and the Czech Republic, and this causes congestion in their grids as well. These problems are exacerbated by the market integration, in particular by the existence of German-Austrian bidding zone which enables these two countries to trade electricity disregarding the physical grid constraints as illustrated in Fig. 1. While this single bidding zone also includes Luxembourg, we refer to it as German-Austrian zone because of the Central European focus of this paper.

Czech and Polish transmission system operators (TSOs) react to this by the requirement of splitting up the German-Austrian bidding zone (CEPS, 2012), which was also supported by the Agency for the Cooperation of Energy Regulators (ACER) (ACER, 2015), or even for splitting up Germany in more zones. TSOs also attempt to solve this problem by installing phase-shifting transformers that should be able to stop the physical electricity flows in case of emergency. Nevertheless, in January 2016, the Director of DG Energy declared that European Commission is against the split of the biding zone as it considers this step to be “meaningless” (Kamparth, 2016).

While many academicians conducted research on the topic of the influence of renewables on spot and forward market prices of electricity (Cludius et al., 2014; Ketterer, 2014), public budgets and consumer prices (Janda et al., 2014; Průša et al., 2013) or power system in general (Blesl et al., 2007; Havlíčková et al., 2011; Rečka and Ščasný, 2016, 2013; Ščasný et al., 2009), less attention has been drawn to equally important transmission networks issues. The majority of the literature assesses the transmission network issues only in the context of Germany (Kunz, 2013; Kunz and Zerrahn, 2015; Schroeder et al., 2013; Egerer et al., 2014; Dietrich et al., 2010).

For the transmission network analysis in this paper we use the most

Fig. 1. Stylized map of situation in CE.
Source: ENTSOE (2016).