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Hybrid pricing in a coupled European power market with more wind power[☆]

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ABSTRACT

In the European electricity market, the promotion of wind power leads to more network congestion. Zonal pricing (market coupling), which does not take the physical characteristics of transmission into account, is the most commonly used method to relieve network congestion in Europe. However, zonal pricing fails to provide adequate locational price signals regarding scarcity of energy and thus creates a large amount of unscheduled cross-border flows originating from wind-generated power. In this paper, we investigate the effects of applying a hybrid congestion management model, i.e., a nodal pricing model for one country embedded in a zonal pricing system for the rest of the market. We find that, compared to full nodal pricing, hybrid pricing fails to fully utilize all the resources in the network and some wrong price signals might be given. However, hybrid pricing still outperforms zonal pricing. The results from the study cases show that, within the area applying nodal pricing, better price signals are given; the need for re-dispatching is reduced; more congestion rent is collected domestically and the unit cost of power is reduced.

1. Introduction

Power markets constitute an interesting and important application area where concepts from economic theory, like welfare optimization, is implemented by explicit optimization of market outcomes based on bids for generation and demand and a representation of available network resources. Even if the general principles are similar across regions, different power markets have implemented different procedures and algorithms in order to take account of various technical and economic characteristics like hydro scheduling, thermal start-ups, renewable resources, ramping constraints and network flows, giving rise to different optimization problems to be solved in practice, including linear, quadratic, integer and stochastic programs. Even in Europe, under EU rules, there are differences between countries, although market integration, with a joint day-ahead market covering a large fraction of Europe, has progressed rapidly over the last 8–10 years.

One of the main differences between market clearing algorithms is the way they deal with network flows and network constraints. Most power systems are alternating current (AC) and the problem that we ideally would like to solve is an alternating current optimal power flow (ACOPF) problem. This is a difficult problem to solve, due to non-linearities and non-convexities. Thus, in practical applications a direct current (DC) approximation is used to solve DCOPFs, like in the nodal pricing systems in the US, or even simpler network flow approximations, without considering Kirchhoff's loop rules, like in the European zonal pricing models. Network constraints in the presence of new renewable capacity in European power markets is the main topic of this paper.

Efforts to meet the renewable energy target of the Renewable Energy Directive 2009/28/EC have led to a large number of wind capacity installations in EU countries. Promotion of renewable energy sources has challenged the current power system. As wind power requires high upfront capital investment and its operation costs are low, it is placed in the beginning of the merit order curve and has priority access under the current European power network which relies on zonal pricing to handle congestion. Due to the uncertainty of wind generation, excess wind power might lead to grid congestion. Furthermore, the installed wind power plants are usually located in places without sufficient consumption. Therefore, the utilization of wind energy often requires long distance transportation, which creates an extra burden for the network and may exacerbate congestion. The impact of wind energy on network congestion has been observed in the German electricity network, in which huge amounts of power are transported from the northern part, where the main installations of wind turbines are located,

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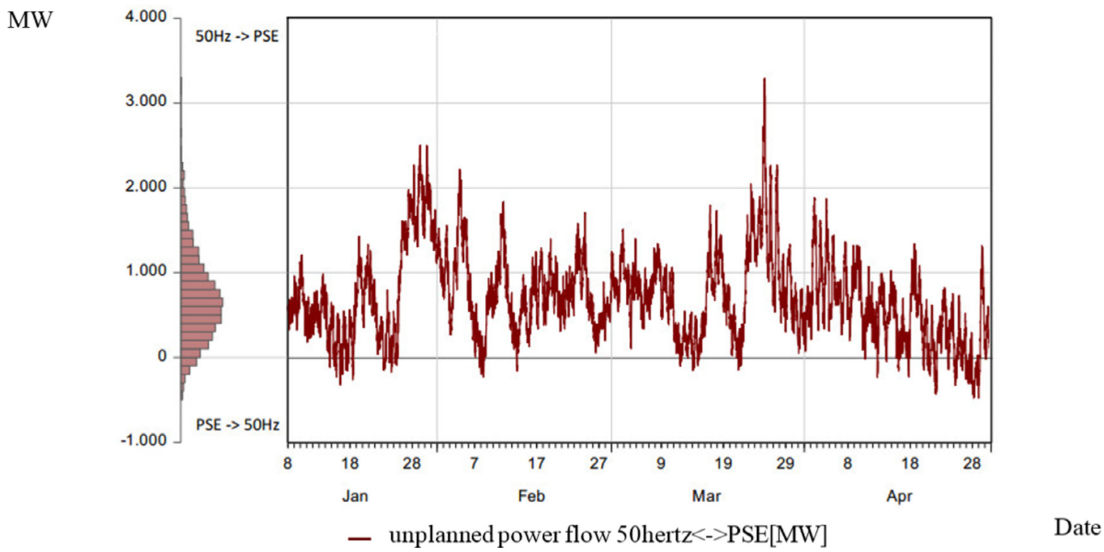

Fig. 1. Unplanned power flows between the 50Hertz area (Germany) and the PSE area (Poland).
Source: 50Hertz (2014).

to the southern and mid-western parts where the demand is high (Bundestag, 2010).

Power grids are connected between European countries, therefore, the effect of wind power is not limited by national borders. The use of zonal pricing (uniform pricing) for congestion management in most of the European countries has made this problem difficult to solve. Within the domestic market, zonal prices are calculated regardless of the constraints imposed by physical laws and the network capacity. International commercial power exchange between two countries is limited by a pre-planned Net Transfer Capacity (NTC) value. Therefore, the scheduled commercial power exchange is not necessarily equal to the real (physical) power exchange. In windy days, due to the effect of loop flow, countries that are close to wind farms might greatly suffer from unscheduled power exchange. For example, the Polish and Czech network operators claim that unscheduled cross-border flows from wind generation in Germany overload their transmission networks more frequently, making their grids less stable and secure (Kunz, 2013). Moreover, Aravena and Papavasiliou (2017) show that a zonal market clearing can undermine system performance by leading to suboptimal commitment of slow generators and creating significant unscheduled flows in day-ahead markets.

In practice, in order to limit the large amount of loop flow caused by wind/solar generation from Germany, Poland uses a very low Net Transfer Capacity (NTC) to reduce the power exchange with Germany. However, a low NTC can only restrict physical power exchange by restricting commercial trading between two connected countries. It cannot prevent the wind-generated power in northern Germany from entering the network because information about the location of power generation within Germany and the detailed network constraints is not used in the day-ahead market. Fig. 1 shows the unplanned power flows, measured by the differences between the day-ahead scheduled commercial flows and the physical power flows between the 50Hertz area (Germany) and the PSE area (Poland) for the period between January and April 2014.[1]

The values of the unplanned power flows mostly range between −300 megawatts and 1600 megawatts, with a maximum of 3286 megawatts (end of March) and a minimum of −484 megawatts (mid-April). In comparison, the two interconnectors between Germany and Poland consist of a northern line with capacity 914 megawatts and a southern line with capacity 2771 megawatts (Siewierski, 2011). Compared to the capacity of the interconnectors, the unplanned power flows are substantial, and may lead to serious overloads. The unplanned power flows are expected to increase when wind power capacity increases in northern Germany. This is because demand is located in the south of Germany and Germany is represented by a single price area in the day-ahead market clearing model. This means that there are no constraints on commercial flows within Germany in the day-ahead market. When power is transported from north to south in the real grid, however, due to loop flow, power will also be transmitted along parallel paths in neighboring countries, including Poland. This is part of the unplanned power flows, which may overload the interconnectors between Germany and Poland, but also overload internal transmission lines within Poland. The large magnitudes of unplanned flows shown in Fig. 1 may indicate that a lower NTC did not help Poland to eliminate the loop flow caused by the wind-generated power from Germany during this period.

In contrast to zonal pricing, nodal pricing gives the value of power for each location by including all the physical and technical constraints (Schweppe, Caramanis, Tabors, & Bohn, 2013). Nodal pricing limits the need for re-dispatching and reduces the corresponding cost. Furthermore, it gives the correct incentives for future investments by reflecting the value of scarce transmission capacity (Hogan, 1992).

Leuthold, Weigt, and von Hirschhausen (2008) have shown that the nodal pricing scheme is economically superior to the zonal pricing scheme for the integration of wind and solar power into the German grid. However, Leuthold et al. (2008) do not examine how intercountry power exchange affects the application of

[1] With this measure, unplanned power flows may arise both due to the simplified network model in the day-ahead market and because uncertain wind generation and demand have changed from day ahead, causing re-dispatch in real time. Ideally, we would like to distinguish between the two effects, since in this paper, we are more interested in the first. A better measure of unplanned power flows due to the lack of congestion management could be to compare commercial flows including the effects from trades in the intraday markets. Intraday markets are open until close to real time, thus a considerable part of the uncertainty is revealed before they close, and typically intraday markets use the same network model as the day-ahead markets for cross-border and inter-area trades. Unfortunately, however, we have not been able to find data to make this comparison. Although intraday markets increase in importance, so far, volumes traded and the commercial use of interconnectors by intraday markets have been low compared to day-ahead markets (<10 %), see for instance ACER/CEER (2016).