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Impact of wind power production in a European Optimal Power Flow

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ABSTRACT

This paper presents a study of a large part of the European synchronous electrical network, spanning latitudinally from Denmark to Italy and longitudinally from France to Poland. The aim of the developed methodology is to select wind power production scenarios among a large range of scenarios considering their impact on the economical dispatch of power plants. For this study the transmission network, loads and production are aggregated at the Extra High Voltage (EHV) level. The calculations are carried out using Optimal Power Flow simulations and allow to obtain different kind of results: local results like power transits on lines or borders, congestion indicators for lines, and overall results like the cost of a given dispatch, in each zone, or re-dispatching indexes.

The study is carried out on a near future winter peak hour (2018), the load being estimated at 310 GW, and wind power installed capacity at 94 GW for the part of Europe considered, whereas photovoltaic is neglected as the peak hour occurs at 7 p.m.

Wind power production is very important and, due to its variability, it seems clear that a single wind production scenario is not sufficient to characterize correctly the net demand. For this reason, we develop in this paper a technique that, starting from historical time series aggregated at the country level, leads to the selection of a shortlist of wind production scenarios statistically relevant. We show how to use Principal Component Analysis and clustering techniques to obtain the shortlist of scenarios to be simulated. Different techniques are compared, analysing the statistical impact on relevant results (transits, cost). The results follow a discrete distribution dependent on the wind scenarios selected, and thus allow to capture the correlations with wind production in different countries.

1. Introduction

To analyse the European synchronous transmission network and the impact which lines and interconnections have on the economical dispatching of power plants, one possible approach is to carry out Optimal Power Flow simulations. Different methods have been developed for this type of calculations [1] and applied also to the European transmission network [2].

For these purposes, the transmission network is often represented only at the Extra High Voltage (EHV) level, loads and production are aggregated at this level. This abstraction allows to evaluate global and local indicators, and thus analyse trends or compare different situations.

The network we consider in our studies (shown in Figs. 1 and 2) spans latitudinally from Denmark to Italy, and longitudinally from France to Poland; it includes explicitly 12 countries and details are given on the grid considered in Section 2.1.

Due to the many countries considered, the simulations presented here allow to obtain various interesting results, like for instance: power transits on specific lines or borders, congestion indicators for lines, cost of a given dispatch in each country and re-dispatching indexes. It has already been shown in some cases, for instance the Belgian case [3], that high renewable energy penetration could congestion lines and imply re-dispatching.

A reference point used in transmission network studies is the winter peak hour (identified as the third Wednesday in January at 7 p.m.) when the electrical demand is at its highest.

In order to study correctly the winter peak in a near future (3–5 years horizon) it is of great importance to be able to estimate the net demand, defined as the load demand minus the non dispatchable production. As the peak occurs at 7 p.m., in this study no photovoltaic (PV) production is considered.

Wind production is variable, and can have a very high impact on results since for the part of Europe we consider and for a 2018 horizon, the estimated installed capacity is 94 GW; there is a further

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Fig. 1. Countries in the network considered (in pink). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

47 GW of non dispatchable generation consisting of small hydroelectric productions and cogeneration considered to be always active during the winter peak. Details on generation are given in Section 2.2.

Peak load demand amounts to 310 GW. The hypothesis on repartition keys of loads and wind production are discussed in Section 2.3.

To study correctly the statistical impact of wind production on generation dispatch, we develop in this paper a technique to select a shortlist of wind production scenarios.

To do this, we start with wind production time series, aggregated at the country level (and described in Section 2.5). Since these are three-hourly and based on 52 years of historical data, they present a challenge in term of simulation time due to the large number of lines and generators of the network considered.

We therefore develop a method to select a shortlist of meaningful wind scenarios to be simulated. To this aim, we show how to first pre-filter these time series in Section 3.1, and how to use Principal Component Analysis (PCA) (described in Section 3.2) and implement clustering techniques (Section 3.3) to obtain the shortlist of scenarios to be simulated.

We sum up in Fig. 3 the flowchart how to obtain a shortlist of wind load scenarios starting from wind speed time series, and these steps are detailed in the following sections.

The different results obtained are discussed in Section 4, analysing transits and costs, and discussing the statistical impact of wind production, and the correlation of some of these results, namely costs, to wind production.

2. Network data and calculation methodology

2.1. Grid data

The network we consider, shown in Fig. 2, has 2882 nodes, each with an associated load, 4282 branches of which 3831 are lines and 451 transformers; each of the branch has a loading limit that is used as a constraint for the Optimal Power Flow (OPF) calculation.

The data used for the network was taken from ENTSO-E (European Network transmission Operators for Electricity) [4] and updated with public data from ENTSO-E and different Transmission System Operators (TSO) [5], to account for the expected network in 2018.

The lines represented have voltage levels of 400 kV or 225 kV; in Denmark, Netherlands and Austria the 150 kV transmission levels are also represented.

The connections to some neighbouring country through HVDC links, when considered relevant for the simulations, have been simulated using one node for a country and a line connected to it.

2.2. Generation data

The network includes 2941 generators [6], connected either to the 400 kV or 225 kV levels.

Thermal, and a part of hydro production units, are represented as dispatchable generators, with a variable cost, and minimum (Pmin normally set to 0), and maximum (Pmax) generation limits, these characteristics intervene in the OPF calculation.

140 GW of non-dispatchable generators are present,consisting of cogeneration units (CHP) amounting to 36 GW, non dispatchable hydroelectric generators amounting to 11 GW, and a large part of the wind power generators amounting to 94 GW installed capacity. These generators are all considered to be always on, but a spillage cost allows the algorithm to curtail them, when they cause congestions not solvable in other ways. The wind power is also modulated by a wind load factor fixed for each country (cf. Section 2.5), i.e. the ratio between the produced wind power, and the installed wind capacity. The cost of dispatchable generators is evaluated following the technique used in Ref. [7]. The types of dispatchable generators, sorted by ascending cost are summed up in Table 1, the important aspect is to respect the order of merit between the different technologies. The water value is considered to have a range between that of Hard Coal and that of Gas; this was decided analysing their historical activation in respect to other technologies [8].

The value of wind power installed, detailed in Table 2, as well as the position of generation throughout the network, has been obtained from the website "thewindpower.net" [9]. More detail on the wind power time series used is given in Section 2.5.

Due to the high volume of wind power capacity installed, it stands out that it is really important to consider the impact of the variability of wind power production in a precise way, and some countries, f.i. Germany, may have a high influence also on neighbouring countries.

2.3. Load data

We study the winter peak, as it can represent a critical situation for the grid. Because the peak occurs at 7 p.m., during the winter, no PV generation is considered in this study, but the methodology we develop for wind could also be used to study PV impact on a summer peak hour.

The total network load is around 310 GW, and is taken from the 2015 Scenario Outlook & Adequacy Forecast B (SOAF B) scenario [10]. Its distribution by country is detailed in Table 2.

Some outer countries interconnected and considered to be always importing or exporting are represented by one equivalent load or generator. Other countries with important HVDC links are explicitly represented by one node, with a load plus a generator with an equivalent price: this is detailed in "other neighbour countries" in Table 2. The idea is that if an HVDC link has a maximum power of P, the load is taken as P, and the equivalent generator as 2*P, so that the transit in the cable can go both ways up to the maximum power P.

2.4. Optimal Power Flow calculation procedure

The network contains a large number of parameters to take into account for medium term studies (cf. Sections 2.1–2.3) with some contingencies to be assessed. Each OPF calculation can take a long