The cost and emission saving potential of wind power

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ABSTRACT

This paper addresses the effect of the increasing wind penetration on the operating performance of a diversified electricity system comprising wind, thermal, hydro and other renewable power plants. A short term optimization model is used to run the exploration planning under different wind power scenarios. The seasonality of the hydro and wind regimes and the hourly variations of supply and demand are acknowledged in the model. Simulations for the Portuguese electricity system are presented in order to establish the use of the proposed model on supporting more informed decision making for future energy strategies. The cost savings and CO_2 abatement potential of wind power are estimated along with the effects on the operating performance and costs of thermal power plants.

KEYWORDS

Wind power; Cost impact; Emissions impact; Electricity scenarios; Planning model

INTRODUCTION

Using technologies of variable output such as wind energy to produce electricity differs from generating electricity by conventional power plants. The fluctuations on wind power output occur in a random pattern and have to be compensated for by the production of schedulable, conventional capacities in the power system [1]. Because of this, wind power does not work as a simple fuel saver, since it cannot easily be controlled and accurately predicted [2]. To properly assess the potential effects of wind power on the electricity system cost, on saved fuel and on avoided emissions, analysing how the existing generating system interacts with increasing amounts of wind power is crucial. Both the CO_2 abatement value and additional cost assigned to the system are highly dependent on the characteristics of the electricity system under analysis.

In general, it seems that wind power can make an important contribution to the reduction of fuel consumption and to complying with environmental international commitments. However, the interconnection capacity, the existing generation capacity mix and the characteristics of the wind power system itself have a significant effect on how the variable production is assimilated into the system and on the extent of this contribution. Avoided costs to the system result primarily from reduction of fuel consumption, as wind energy will reduce the amount of fuel burnt in gas and coal power stations. However, coal and gas units operate less efficiently when part loaded, increasing the operating costs per MWh of the thermal power plants. As for the impact that wind generation has on the overall emissions of the electricity system, it strongly depends on the structure of the conventional power generation capacities, the production of which is partly replaced. It seems obvious that systems based on highly polluting coal units are much more capable of achieving large emission reduction values than systems based on renewable, nuclear or gas technologies, when wind power is introduced.

The Portuguese electricity generating system is a mixed hydrothermal system. The total installed power reached in 2012 about 18 546 MW distributed between thermal power plants (coal, fuel oil, natural gas and gas oil), hydro power plants and Special Regime Producers (SRP- renewable plants and cogeneration) [3]. Portugal is strongly dependent on external energy sources, in particular oil. The only National resources come from the renewable energy sources, specially the hydro sector for electricity production. This way, the renewable energy sector has a fundamental role for the reduction of the external energy dependence, actively contributing to increase the security of supply.

This paper focuses on the impact of large scale wind scenarios on the power system operation for the particular case of the Portuguese electricity system. CO_2 abatement potential is estimated along with the effects on the operating costs of the electricity system. For this, simulations with increasing amounts of wind were conducted.

The paper is organized as follows. The next section reviews a few studies on the integration of wind power in power systems. After that, the case study is described and the results of the simulation are analysed. The main conclusions and future work are summarised at the end.

INTEGRATION OF WIND POWER ON THE POWER SYSTEM

The inclusion of power sources of variable output distributed through a large electricity grid has important effects on the control of the grid and delivery of stable power. As the load changes during the day, generators are brought online but larger prime movers may take a while to prepare for generation [4]. Capital-intensive plants with low operational costs such as nuclear or coal power plants are high merit or base load plants and will be in operation for as many hours as possible. Intermediate or mid merit plants are usually conventional plants brought on line but operating at part load operation. Low merit present low specific capital costs and quick-start capability but frequently high variable costs such as Single Cycle Gas Turbine Also the hydropower or pumped storage plants can be used during peak load periods.

To ensure the balance between supply and demand, the system operator needs to have a level of operational reserve power for unexpected variations, typically in a time range of less than an hour. The introduction of large amounts of wind power into the grid increases the short term variability of the supply, increasing the need for operational reserve [4]. The variable production pattern of wind power changes the scheduling of the other production plants and the use of the transmission capacity between regions [5]. Because of this, integrating wind energy into complex power systems is expected to incur system costs in excess of those incurred by equivalent amounts of energy delivered to the system on firm, fixed schedules [6].

Hoogwijk et al. [7] specify the high load following capability of the generation mix (generation that can ramp at a relatively high rate) and the degree of interconnection with other grids, as very important factors for dealing with variable supply of wind power. The authors pointed out the benefits of combining wind power with hydro power or biomass, to smooth out the variability of wind. This work and Holttinen and Hirvonen's [5] emphasise also the importance of forecast tools for wind power production. Accuracy of wind forecasts contributes to risk reduction and to the reduction of the required additional reserves. An accurate forecast allows the system operator to rely on wind capacity, improves the utilisation of wind sources and lowers operational costs without jeopardizing the system reliability.

These studies demonstrate that the growth of the wind power share will have a strong impact on all the electricity generating system. In case of Portugal, the large penetration of wind power will influence significantly the energy system cost but the hydropower can have an important role on reducing the impact of the wind variability on the operating performance of thermal power plants.

CASE STUDY ASSUMPTIONS

For the simulation process a short term optimization model designed for the Portuguese electricity system from [8] was used. The cost objective function corresponds to the total variable cost of system, including operation and maintenance costs, operating fuel costs, the emissions allowance cost and the startup and shutdown costs. A set of constrains is included, describing the demand requirements, the thermal power startup and shutdown ramp constraints, minimum up and down time of thermal power groups and hydro capacity functions.

The model was applied to the Portuguese case and the power system was described according to the thermal power groups (natural gas and coal), large hydro groups (dams and run of river) and SRP groups forecasted to 2020. The simulation was conducted assuming different scenarios, each one representing different levels of wind capacity going from the base scenario with 4080 MW until 6120 MW, and demand forecasts for the year 2020. The results were described by the hourly power output of each group for a typical winter, summer, spring and autumn week. This allowed to take into consideration the daily pattern of the renewable resources and of the demand and also the yearly seasonality. For the sake of simplicity, the simulation assumed a close system with no interconnection capacity.

The simulation was conducted assuming four different wind power scenarios in 2020:

- Reference (W1): installed wind power equal to 4080 MW.
- Low growth (W2): installed wind power equal to 4900 MW.
- Moderate growth scenario (W3): installed wind power equal to 5300 MW.
- High growth (W4): installed wind power equal to 6120 MW.

The chosen wind scenarios represent an average penetration between 17% and 25% of the total installed power in Portugal in 2020.

ANALYSIS OF THE RESULTS

The simulation scheduling was based on the variable cost of the system. Figure 1 presents the simulation results for the for the four wind power scenarios, corresponding to the four typical days in 2020. The results indicate that wind power will have a very reduced impact on the hydro power, since the hydro production remains almost unchanged for every wind power scenarios. This way, a clean energy form will not replace another renewable and emissions free electricity production.

Wind production added to the system will decrease mostly thermal power production. Although being expected a reduction of the coal power electricity generation, these plants will still be base load. Coal groups be operating near full load but a reduction of the operating hours is noticed specially for large wind power scenarios. Natural gas power plants will be strongly affected by the increase of wind power, both with a reduction of their operating hours and of their load factor. Between W1 and W4, the reduction of coal power output is close to 10% but the reduction of gas power output reaches 29%.

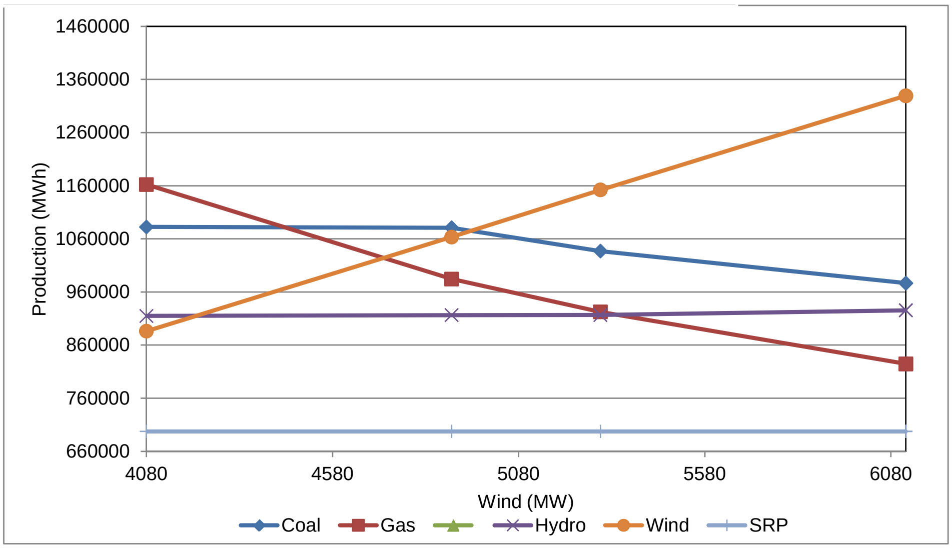

Figure 1. Simulation results for the electricity production, when adding wind power to the system.

The results of the simulation did not demonstrate a relevant effect on of different wind scenarios on the number of start-ups thermal powered units in Portugal. Works like ESB National Grid [9] for Ireland or Holttinen and Pederson [10] for Denmark indicate that increasing the penetration of wind in the system, would result on increasing the starts and stops of the thermal power plants. In Portugal, the hydro power sector will certainly have an important role on the system management with high shares of wind power. The proper combination of wind power and hydro storage capacity may reduce significantly the impact in what concerns the starts and stops of the thermal plants. Figure 2 demonstrates the behaviour of the wind, thermal and dams power groups in a typical winter week for the reference scenario. The results demonstrate the importance of hydro power able to quickly respond to wind power shortages and reducing impacts on the thermal power plants operation.

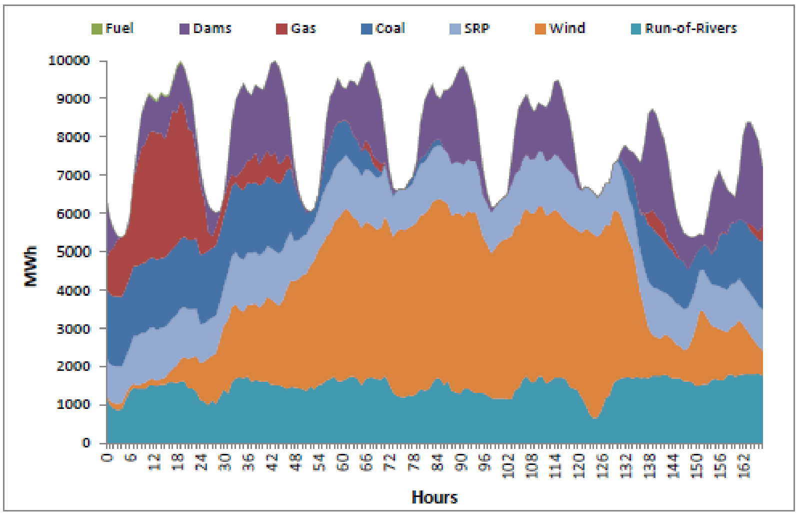

Figure 2. Simulation results for the wind, thermal and dams power output for W4 winter week (Source: [8])

The CO_2 abatement of wind power may be computed from the reduction of CO_2 emissions per unit of electricity produced from wind. The CO_2 savings result from the reduction of fuel that would be consumed in thermal power plants under reduced wind power alternatives. Table 1 presents the average CO_2 emissions of the system per unit of electricity produced, the CO2 reduction over the low growth wind scenario and the CO_2 abatement of wind power for each wind scenario against the low growth wind scenario.

Table 1. CO_2 abatement of wind power over the low growth wind scenario for 2020.

Wind scenario (MW)	**Average CO_2 emissions (Mton/MWh)**	**CO_2 reduction (%)**	**CO_2 abatement of wind power (ton/MWh_w)[1]**
4080	0.284		
4900	0.270	4.9%	0.367
5300	0.260	3.4%	0.409
6120	0.239	8.4%	0.473

[1] MWh_w- electricity produced from wind

The CO_2 savings result from the reduction of fuel that would be consumed in thermal power plants under less wind power alternatives. For the Portuguese simulation, additional wind power will mostly replace gas power output. Only for large wind power scenarios there would be a reduction of coal power production, increasing the CO_2 abatement. It seems, that in Portuguese system the environmental gains of the increasing wind power overcome the possible loss of efficiency of thermal power plants even for large wind power scenarios. However no linear relationship can be assumed, as the emissions reduce at a lesser rate than reduction of electricity production from thermal power plants, but the increasing wind power production (with null operating costs) seems to compensate most of efficiency loss of the system. In fact, the emission reduction of W4 against W1 is 15.6% but thermal power production is reduced by almost 20%.

The economic value of wind power may be computed from the cost reduction per unit of electricity produced from wind. The avoided costs result from the reduction of fuel that would be consumed by thermal power plant, the consequent reduction of emission costs, and also from the reduction of the variable O&M costs. Table 2 presents the average operating cost per unit of electricity produced, the operating cost reduction and the value of wind power over the low growth wind scenario.

Table 2. Value of wind power over the low growth wind scenario for 2020.

Wind scenario (MW)	**Average operating cost (€/MWh)**	**Operating cost reduction (%)**	**Value of wind power (€/MWh_w)[1]**
4080	22.52		
4900	20.57	8.6%	51.78
5300	19.98	2.9%	45.04
6120	18.07	9.6%	46.99

[1] MWh_w- electricity produced from wind

According to the results, the electricity production cost reduces with the increasing wind power capacity. Once more, the economic gains obtained with the reduction of fossil fuel consumption still compensate the possible loss of efficiency of thermal power plants, even for large wind power scenarios. However, the value of wind power for W2 is quite higher than for the W3 and W4 scenarios, which can be explained by the reduction of coal power output with higher environmental gains to the system but with less reduced economic gains dues to its lower fuel costs.

CONCLUSIONS

The impact of large wind power scenarios on the operation of electricity system as whole has been debated for long in particular for systems strongly dependent on thermal and even nuclear power plants. The increasing need for backup, storage and/or interconnection capacity is frequently seen as an important drawback of renewable electricity systems. In fact, the efficiency and consequently the emissions from fossil fuel fired generators can be strongly affected by the operation regime of the plants. The quantification of the emission saving from an increasing share of wind power, must take into consideration that large variations in wind power output can result in operating conventional power plants less efficiently. However, the role of hydro power can in fact be very relevant, contributing to achieving the renewable energy sources targets, reducing greenhouse gas emissions and allowing compensating wind power variability on the grid.

From the simulation results, it was possible to conclude that an increase of the installed wind power would mostly affect thermal power plants load hours. it was possible to conclude that an increase of the installed wind power would mostly affect gas groups operation. Coal power plants would remain working in a stable regime near full load for moderate wind growth scenarios but for increasing wind power levels there would be a reduction on the number of operating hours of coal groups. The results indicate that the economic value of wind power may slightly reduce for high wind power scenarios, but there is still a remarkable potential for wind power gains in the system.

Portugal presents a particular configuration of the electrical system, with a large share of hydro power, thermal power and no nuclear power plants. The simulation assumes a fixed non wind capacity in the system, meaning that increasing wind power will increase the total installed power. This results in increased capacity of production in Portugal and can lead to a large increase in net exports not dealt in the model. In a previous work from the authors the importance of these exportations for the balance of a high renewable electricity system was already demonstrated [11] . This previous work already indicated that the increasing penetration of wind power in the system would have significant effects on the natural gas power plant operation and to a less extent on the coal power groups.

Future work will now address the possibility of interconnection with Spain in order to analyse if large wind power scenarios would be feasible and their potential impacts. Although the hydro power sector can have an important role on avoiding high fluctuations requirement from thermal power plants, the average load factor of gas power plants is expected to be strongly affected by the increasing of wind power in the system. As such, the possible loss of efficiency must be included in the model, checking if and how this will affect the wind power value for these hydro-thermal power systems. Finally, it must be underlined that the results are quite sensitive to underlying fuel price assumptions demonstrating the need to proceed with a sensitivity analysis to check the robustness of the results as the economic value of wind largely depends on the high fossil fuel costs.

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