Large Scale Integration of Wind Power Generation

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ABSTRACT

In a scenario of large scale penetration of renewable production from wind and other intermittent resources, it is fundamental that the Portuguese electric system have appropriate means to compensate the effects of the variability and randomness of the wind power availability. This concern was addressed in the recent studies of the electric grid operator, by the promotion of the wind resource studies and in the identification of solutions based on reversible hydropower dams. However, in the electric system planning, other options deserve to be evaluated. This paper evaluates the complementarity between renewable sources and analyses possible demand-side technologies to influence the load diagram, to minimize the impact of the intermittent production.

Keywords: wind power, grid integration, intermittent renewable resources, sources complementarity, demand-side management, energy storage.

1 INTRODUCTION

The 2001/77/CE European Commission Directive sets the target of 22% and 39% of gross electricity generation from renewables for the Europe and Portugal, by 2010. To satisfy this target, it is planned the installation of additional generation capacity from renewable sources, in which the biggest part of the increase it is in wind power, with an installed power in 2010 of 5300 MW.

If the contribution of this production vector in energy terms is not a cause of concern, the power balance, and therefore the impact in the supply security needs attention due to the intermittent and random character of this production option. It is possible to forecast if in a concrete zone, the average wind power density for the whole year; however it is impossible to precisely forecast the days or the hours with wind [1]. Supply of power from wind turbines is stochastic in nature and the actual power is more or less proportional to the third power of the wind velocity. The wind output varies seasonally between summer and winter [2] by a factor of two to three and the variations are also present on shorter time scales, namely on hourly basis [3]. Previous results also reveal a diminishing benefit as wind power penetration increases [4].

The connection of wind turbines to the electricity grid can potentially affect supply reliability and power quality, due to the unpredictable fluctuations in wind power output [5]. In a scenario of large scale penetration of renewable production from wind and other intermittent resources, it is fundamental that the Portuguese electric system have appropriate means to compensate the effects of the variability and randomness of the wind power availability. This concern was addressed in the recent studies of the electric grid operator, by the promotion of the wind resource studies and by the identification of solutions based on reversible hydropower dams [6]. However, in the electric system planning, other options deserve to be evaluated.

Portugal has a relatively large hydro capacity 4580 MW and only about 50% of the potential is used. Large solar photovoltaic plants have been installed and are planned. The sharply decreasing costs will allow a large increase of the solar capacity in the next 10-15 years. To ensure an optimal mix in the medium term, three main renewable sources (hydro, wind and solar) deserve to be considered.

2 SOURCES COMPLEMENTARITY

2.1 Climate Model

To evaluate the intermittence and complementarity from renewable energy production, climate data was collected. The collected information includes the global solar radiation (monthly average), the wind velocity (monthly average) and the monthly water inflow in dams. The locations for data collection were selected based on the approximation between the collected data and the annual variation of the wind power, solar photovoltaic and hydropower in all the country. In each variable a 50 years time series was collected.

The three collected variables have different units of measurement, and thus to enable a comparison between them, a conversion to an undimensional unit was made, the load factor. With the collected data, a mathematical model was developed, to generate random years, enabling the study of the sources complementarity for a large number of years.

The variable with lesser intermittence is the solar radiation and thus was tacked has the base model. As it can be observed in the Figure 1, the collected data has a distribution close to a normal distribution, and thus the solar radiation was generated randomly with the Box-Müller transformation.

The wind velocity is more uncertain than the solar radiation, but lesser than the water inflow and thus was then considered as secondary variable in the model. However wind speed cannot be determined purely by a random

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distribution, because the two variables are not independent. But because a perfect correlation does not exist, it is incorrect to determine the wind velocity only with the correlation with the solar radiation.

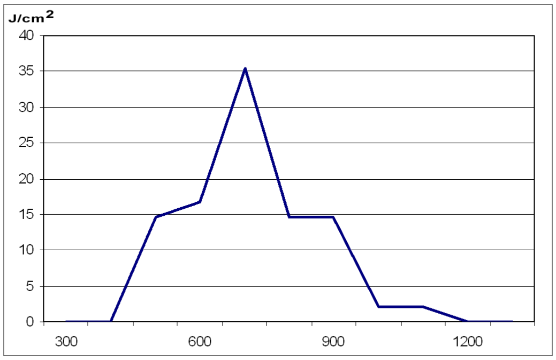

Figure 1: Distribution of the solar radiation from January.

The wind velocity was determined with two components. The first was obtained with the correlation with the randomly generated solar energy and the second component was randomly generated by the same process that was used to the solar radiation, because the wind energy also has a normal distribution. The final value is the addition of the correlated value weighed by the correlation and the random value weighed by one minus the correlation value.

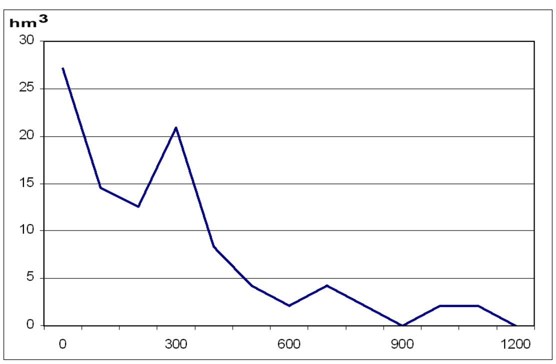

Figure 2: Distribution of the water inflow from January.

The water inflow is the most uncertain variable and has a different distribution (Figure 2). Because of its shape a normal distribution generation cannot be used. For each month the data was divided in intervals and for each interval a number of random values proportional to the probability distribution were generated. Due to the larger uncertainty, both the correlations with the solar radiation and wind velocity were used. The final value is the addition of the correlated values weighed by the correlations and the random value weighed by two minus the sum of the correlations.

2.2 Renewable Energy Complementarity

Using the climate model, a series of 500 years was generated for the three variables. As it can be observed in Figure 3, the solar radiation has small fluctuations relatively to the average year and additionally the yearly variation curve does not change in shape.

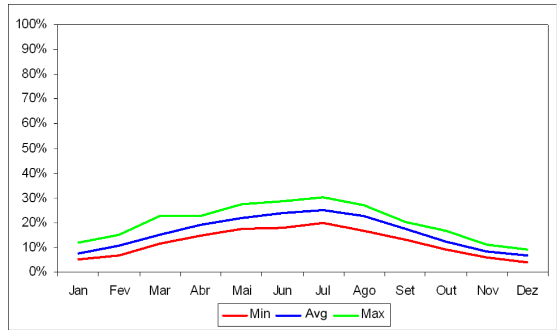

Figure 3: Monthly variation of the solar load factor.

The daily variation of the solar radiation also presents a constant shape, with the advantage of the concentration of the availability in the hours of higher energy consumption (Figure 4).

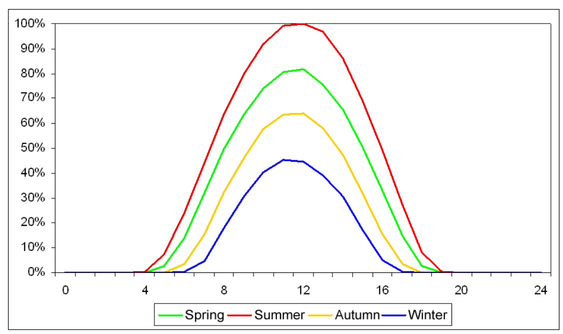

Figure 4: Average hourly values of the solar load factor.

The wind velocity presents high variations relatively to the average year, with impact in the yearly variation curve shape (Figure 5).

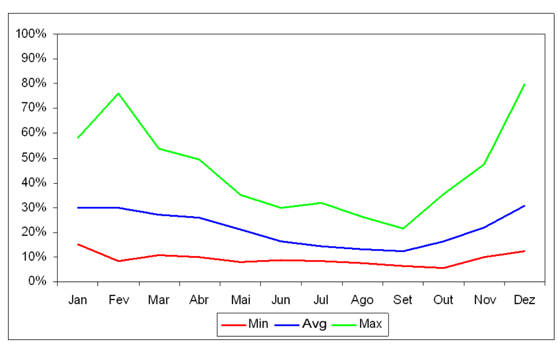

Figure 5: Monthly variation of the wind load factor.

Also the daily variation of the wind velocity presents big variation and unpredictability, however has a higher availability in the hours of higher energy consumption (Figure 6).

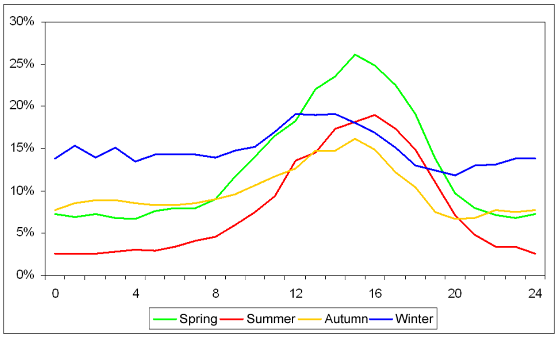

Figure 6: Average hourly values of the wind load factor.

The hydro inflow presents huge variations relatively to the average year and unpredictability (Figure 7) impeding a reliable estimation on a daily basis.

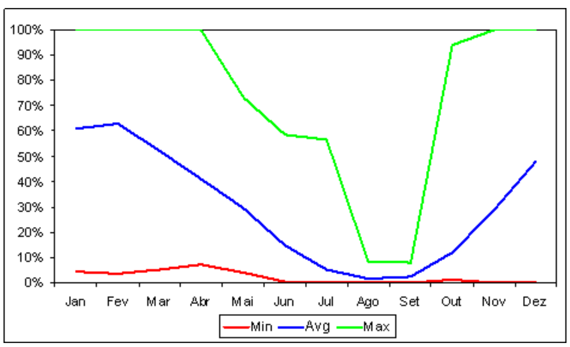

Figure 7: Monthly variation of the hydro load factor.

Figure 8 shows the average monthly load factor for each variable (wind velocity, solar radiation and water inflow). As it can be observed the solar radiation is higher between May and September, occurring the opposite with the wind velocity and water inflow. Thus, the solar radiation has the maximum value in July and the minimum in December. Both the wind velocity and water inflow has the maximum value in February, registering the minimum in September and August, respectively.

The wind velocity and the water inflow have average variations along the year with a very similar course, having the two curves a high correlation (0.98). The solar radiation varies almost inversely relatively to the wind velocity and the water flow (correlation of -0.7 and -0.66, respectively). That observation indicates that the complementarity between solar energy and the pair wind power/hydropower is high. Solar energy can then be used to face the seasonal variations of wind power. The hydropower is not complementary to wind power but due to its similar variations is the ideal means to store the excess wind energy to cope with the intermittence, using the storage, dispatchable power and dynamic response capacities. Also other dispatchable energy technologies, such as biomass, can have a positive contribution, reducing the intermittent power requirements

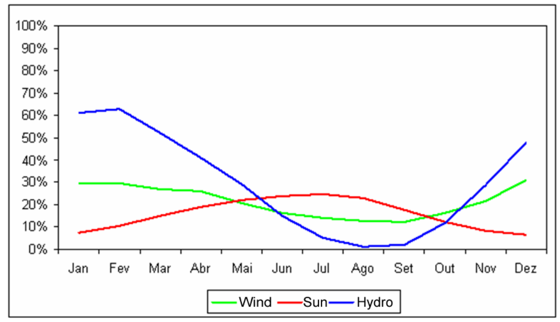

Figure 8: Yearly variation of the wind, solar and hydro load factor.

3 DEMAND-SIDE MANAGEMENT

Rather than attempting to match power generation to consumer demand, the philosophy of load management takes action to vary the load to match the power available. Through the proper application of demand-side management (DSM) technologies [7] it is possible to reduce the need of new installed intermittent power to achieve the renewable targets.

As example the impact of the European Union Energy Services Directive that has the target of achieve a consumption reduction of 9%, between 2008 and 2016, was analyzed. Several demand-side management technologies were considered to accomplish such objective, trying to achieve a larger impact with a minimal cost. Finally, the application impact in the load diagrams of the selected technologies in the residential, services and industrial sectors was determined. In the Figure 9 the impact in the Portuguese load diagram in 2016, can be observed.

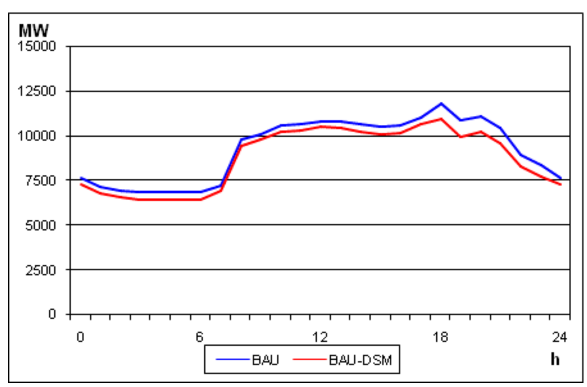

Figure 9: Impact of the DSM in the load diagram (January 2016).

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The application of DSM measures will reduce the investment needs to integrate intermittent power and will lead to a large reduction on the peak power, which can prevent the most dangerous situations of unbalanced power.

Other kinds of technologies that can perform a major role in the integration of renewable intermittent power are the Demand Response (DR) technologies [8]. With these technologies it is possible to direct or indirectly force a consumption reduction in critical situations. In the past the Demand Response technologies were typically used to attend to economical concerns. However nowadays they can be used to improve the system reliability, reducing instantaneously the energy consumption to prevent the most unbalanced situations, like the problems that result from the large space conditioning consumption on days with reduced wind velocity.

Considering the portuguese load diagram with the impact of DSM measures to 2016, the DR impact was determined. With a control of 5% of the peak load (Figure 10) it is possible to reduce it and make an identical control on unbalanced situations, when abrupt reductions of wind velocity occurs.

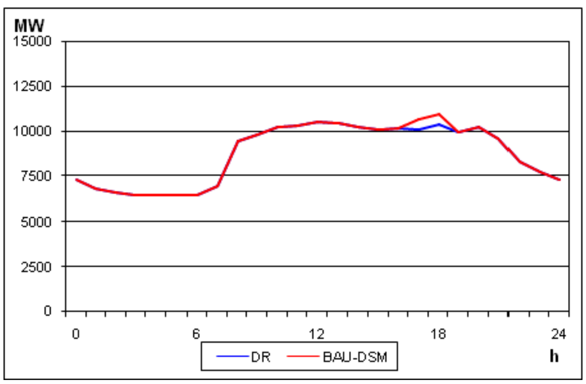

Figure 10: Impact of the DR in the load diagram (January 2016).

4 ENERGY STORAGE

The energy storage in electric energy generation systems enables the adjustment between the energy production and demand [9]. The produced energy by intermittent renewable sources can be transferred in time to be released in low production or high consumption times

This is an aspect of crucial importance in the electric sector, because the energy demand has high horary, diary and seasonal variations. Additionally, the energy generation from renewable energy sources has significant variations, either in short term (few seconds) as in long term (horary, diary and seasonal). The energy storage is an appropriated option to make possible the large-scale integration of intermittent renewable sources. For this kind of energy storage, high power and a very long autonomy are needed (from hours to several days) and the hydropower is the traditional mean to respond to the problem. However new emerging technologies promise to make possible the energy storage in these applications.

For short term applications several technologies can be applied, such as: supercapacitors, batteries, flywheels or hydrogen storage. However are long term applications that can have an important role in the integration of intermittent sources, due to the large impact that the long variations can have. The technologies that can storage energy in large scale include: compressed air (in caverns), electrochemical batteries, flow cells and high temperature thermal storage.

5 CONCLUSIONS

To face the intermittence of renewable sources several options must be considered. The option to join complementary energy sources like wind power and solar power will reduce the problems, instead of the bet in only one source of renewable energy. More important is the utilization of dispatchable technologies of renewable generation that can compensate the fluctuations of the other sources. As complement, new energy storage technologies can be used.

Also the demand-side technology can have a major role, either reducing the needs of new intermittent power or adjusting the consumption in real time, to face production variations.

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