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# Integration of Renewable Generation into the Portuguese Power System: The Impact of Different Hydrological Regimes

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**Abstract.** The Portuguese power system has experienced an increasing integration of renewable energy sources during the last years and is still making considerable efforts to increase its share of renewable generation. Wind power is the renewable source of energy that has experienced the highest increase. According to the national power system operator predictions, by the year 2011, wind power will account for 27.5% of the Portuguese installed capacity and for 37.1% of the generated energy.

Such integration of wind power induces particular challenges in balancing the power demand and generation, emerging as the cause of some power system instability. That potential to the power unbalances occurrence tends to increase during the years of higher rainfall, especially in systems like the Portuguese, with considerable hydro generation.

The main objective of the present paper is to understand the sensitivity of the Portuguese power system capacity to integrate the renewable generation under different hydrological regimes. Along the paper, the authors forecast the potential of occurring power unbalances between demand and generation, analyse the contribution of the installed pumping-hydro power-plants to mitigate those power unbalances and quantify the needs of renewable generation curtailment.

## Key words

Renewable energy, power balancing, energy storage, pumping-hydro, unit commitment.

## 1. Introduction

The Portuguese power system has experienced an increasing integration of renewable energy sources during the last years and is still applying a considerable effort in increasing its share of renewable energy. The geographical characteristics of the country allow the exploitation of several renewable energy sources, like wind, hydro, photovoltaics, waves and biomass.

The main challenges associated to the integration of renewable energy into the power systems derives from their availability, uncertainty and variability. The non-dispatchable nature of some renewable energy sources, like wind power, induces particular difficulties in balancing the power demand and generation, emerging as a possible cause of some power system instability [1],[2].

Unbalances between power demand and generation are likely to occur, particularly during the off-peak periods, when the demand is lower [3]. That potential to the power unbalances occurrence tends to increase during the years of higher rainfall, especially in power systems with considerable installed hydro power.

Power systems, like the Portuguese one, equipped with significant pumping-hydro installed capacity should be able to deal with the power balancing issue induced by the integration of larger amounts of wind power. The ability of those hydro power-plants to operate as an energy storage system allows the absorption of the potential power unbalances, enabling a time shift of the power generation [4].

Pumping-hydro plants installed in Portugal are integrated in river courses and are operated in a perspective of being hydro power-plants with pumping capacity, in opposition to the perspective of pure pumping-hydro power-plants. This particularity introduces some restrictions to their operation, especially related to the compromise of simultaneously generate power, using the upper reservoir river inflows, and contributing to avoid the power unbalances that results from the variability of the wind power generation. Those operation constraints tend to increase as the rainfall tends to be higher.

Regarding the restrictions of the pumping-hydro when subjected to different rainfall conditions, the present paper intends to study the consequences of different hydrological regimes in the ability of the Portuguese power system to integrate the renewable generation.

## 2. Objectives and Methodology

The main objective of this paper is to assess the Portuguese power system capacity to integrate the renewable generation, under different hydrological regimes. Along the paper, the authors intend to forecast the potential of occurring power unbalances between demand and generation and to quantify the needs of renewable generation curtailment, in order to avoid those power unbalances.

The methodology developed along the paper, as presented in fig. 1, can be divided in three steps. The first step corresponds to the forecasts of generation, demand and net import, the second step corresponds to a unit commitment algorithm and the third step corresponds to the results analysis.

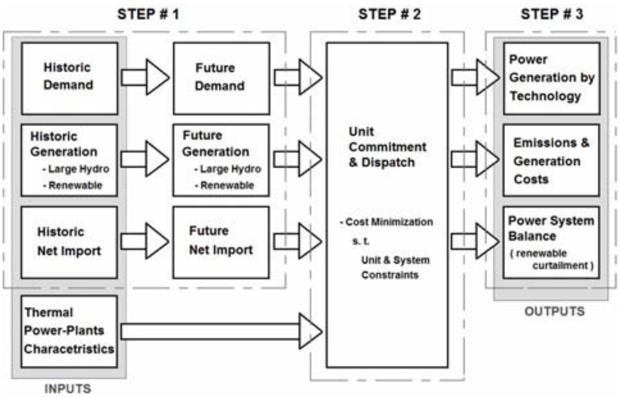



Fig. 1. Diagram of the proposed methodology

The forecast procedure consists of determining the future renewable energy and large hydro generation, demand and net import. The procedure is based on historic time-series, predictions for the future installed capacity and predictions for the demand increasing rates.

The time-series data used to feed the forecasting algorithm refers to the year 2007 and have been acquired for intervals of 30 minutes in all the transmission network interfaces with the power demand, the power generation and the interconnections.

The data acquired correspond to 35 transmission network interfaces with the ordinary producers (conventional technologies), 53 interfaces with the special regime producers (renewable energy), 70 interfaces with the so-called power demand, including the supply of the distribution networks (regional aggregated demand) and some industrial power consumers and, finally, 6 interconnections between the Portuguese and the Spanish power systems.

The predictions for the future installed capacity, used in the forecast procedure (step #1), are based on the national power system operator projections, while the predictions for the demand increasing rate and the net import follow the trend of the historic data.

In the second step of the developed methodology, a unit commitment algorithm, based on GAMS software, is supplied by the forecast results from the first step to compute the optimal operation of the thermal and pumping-hydro power-plants in order to minimize the variable costs and to maximize the integration of the renewable energy generation [5].

The thermal units' variable costs include the fuel costs, the $CO_2$ emission costs and start-up costs. The restrictions imposed by the thermal power-plants into the optimization process consider the maximum power, the minimum technical power and the respective ramp-rates [6]-[8].

The pumping-hydro units considered in the unit commitment are operated with the objective of avoiding, whenever possible, the potential power unbalances induced by the renewable energy generation, namely the wind power. This action allows the minimization of the renewable generation curtailment, reducing the needs for thermal power generation.

The restrictions introduced by the pumping-hydro units in the unit commitment algorithm are associated to the maximum limits of stored energy imposed by the upper and lower reservoirs and to the need to maintain a specific level of power generation imposed by the river inflows of the upper reservoir.

The third step corresponds to quantifying the resulting costs of the thermal power generation, the power unbalance and the needs for renewable generation curtailment.

## 3. Evolution of the Renewable Energy Sources in the Portuguese Power System

The Portuguese authorities have established ambitious targets for the incorporation of renewable energy sources in the power system. As presented in fig. 2, from the year 2007 to 2011, the renewable energy installed capacity (excluding large hydro) is expected to be multiplied by a factor of 2.2, corresponding, by 2011, to 44 % of the overall Portuguese installed capacity. Besides the so-called renewable technologies, the Portuguese power system is also equipped with a significant quantity of conventional hydro power-plants, totalizing around 4500 MW, accounting for 31 % of total installed capacity (year 2007) [9], [10].

The renewable technologies implemented in the Portuguese power system are: wind, small-hydro, biomass, photovoltaics and cogeneration. Cogeneration is included in the renewable technologies because of its contribution for the energy efficiency improvement.

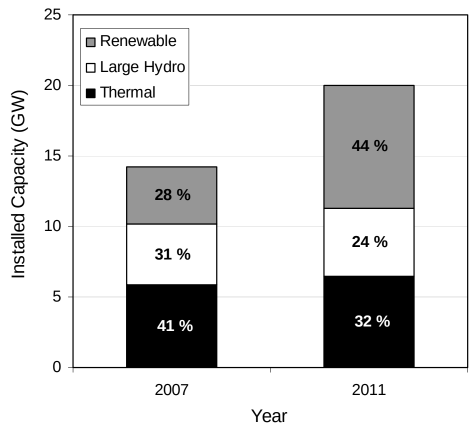



Fig. 2. Prediction for the evolution of the Portuguese installed capacity [10]

Wind power is the renewable energy source that has experienced the highest increase in the Portuguese power system. At the end of the year 2007, the wind power installed capacity was about 2200 MW, 8.5 times higher than in 2003. Figures of the end of 2009 report almost 3400 MW of wind installed capacity. According to the national power system operator predictions, by the year 2011, wind power will correspond to 27.5% of the installed capacity (fig. 3).

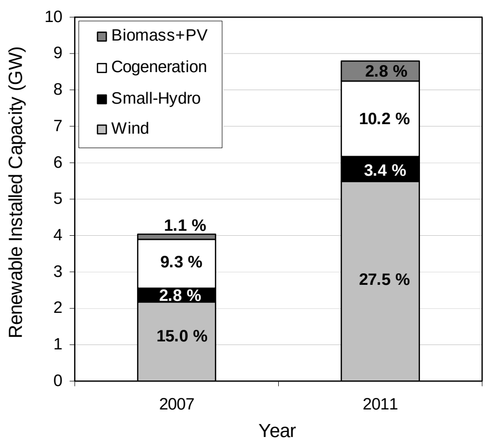



Fig. 3. Prediction for the evolution of the renewable energy installed capacity in the Portuguese power system [10]

## 4. Pumping-Hydro Installed Capacity

The increasing integration of non-dispatchable renewable energy sources, like wind power, induces particular difficulties in balancing the power demand and generation.

Pumping-hydro power-plants, with their energy storage capacity emerge as a solution for the power generation and demand unbalance issue, enabling a time shift of the power generation. Therefore, power systems equipped with significant pumping-hydro installed capacity, like the Portuguese, can mitigate potential power unbalances and integrate larger amounts of wind power.

The characterization of the pumping-hydro power-plants installed in the Portuguese power system is presented in table I.

Table I. – Characterization of the pumping-hydro power-plants

| Power-plant | Power | Energy | |
|---|---|---|---|
| | ( MW ) | ( MWh ) | ( h ) |
| Aguieira | 336 | 2352 | 7 |
| Alqueva I | 240 | 5760 | 24 |
| Alto Rabagão | 68 | 8160 | 120 |
| Frades | 196 | 23520 | 120 |
| Torrão | 140 | 980 | 7 |

## 5. Scenario Assumptions

Three scenarios have been considered, corresponding to different hydrological regimes. Next, one presents the assumptions of each scenario.

*A. Base Case*

The base case scenario is defined for the average evolution values of the Portuguese power system in what concerns power demand, net cross border power exchanges and hydrological regime.

The power demand evolution analysis (fig. 4) show a trend to reduce the demand increasing rate, as a result of the Portuguese economy contraction of the last years. For the period of observation, the average power demand increasing rate corresponded to a 1.7 % / year value. This value was retained for simulation purposes.

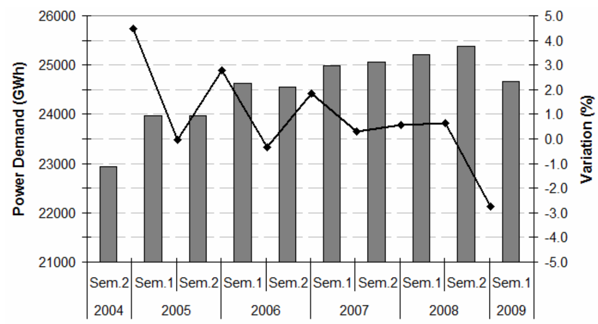



Fig. 4. Evolution of the Portuguese power demand and respective variation [11]

The analysis of the historic power flows between the Portuguese and Spanish power systems shows that Portugal is typically power importer. From the last 10 semesters data, presented in fig 5, outcomes an average net import value corresponding to 14 % of the annual power demand. This was the value considered in this study.

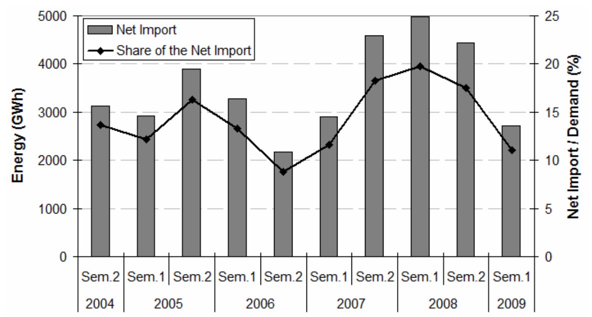



Fig. 5. Evolution of the Portuguese net import [11]

In what concerns the hydro power generation, a hydrological regime corresponding to a unitary hydro power generation index (fig. 6) was assumed, in the base case scenario. This is equivalent to an average hydrological year.

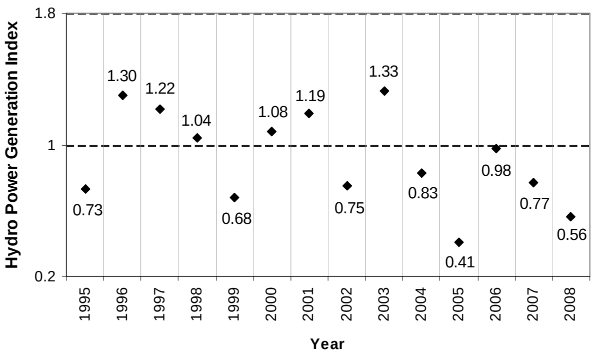



Fig. 6. Annual evolution of the Portuguese hydro power generation index [11]

*B. Dry Year*

The second scenario corresponds to a dry year. In this case, the hydro power generation is 41 % of the average hydrological regime. As presented in fig. 6, this scenario corresponds to the hydrological regime of the year 2005, when it was observed the lowest rainfall of the last 12 years.

*C. Wet Year*

The third scenario considers a wet year, i.e., a hydrological regime with considerable rainfall. In this scenario, the hydro power generation of the base case is multiplied by a factor of 1.33, corresponding to the hydro power generation index of the year 2003, the wettest regime of the last 12 years (fig. 6).

## 6. Results – 2011 forecasts

Some results from the application of the developed methodology to the Portuguese power system, by 2011, are presented below.

The results from the unit commitment demonstrate that the installed pumping-hydro power-plants contribute to partially avoid the power unbalance issue that results from the renewable generation.

Fig. 7 presents the mismatch between power demand and generation along one arbitrary week of the base case scenario. In this figure, it is also possible to observe the operation of the pumping-hydro, storing energy during the periods when the demand is lower and returning that energy during the peak-hours, avoiding the use of the most expensive thermal power-plants.

In spite of the pumping-hydro contribution for the power system balance, during some periods it is not possible to integrate all renewable generation. Therefore, it is necessary to partially cut that generation to keep the power system stability.

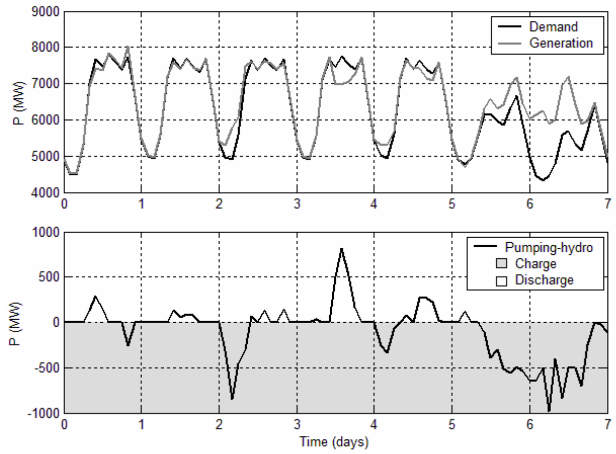



Fig. 7. Contribution of the pumping-hydro operation to the power system balance along one week of the base case scenario

Quantifying the renewable generation curtailment helps to understand the power system ability to incorporate increasing amounts of renewable sources.

According to the simulation results, in the year 2011, for the base case scenario, power unbalances induced by the renewable generation are expected to occur for more than 12.5 % of the year (1100 hours), reaching the peak value of 3700 MW. Furthermore, an annual renewable generation curtailment equivalent to 1334 GWh has been forecasted.

In the case of the dry year scenario, the integration of the renewable generation increases. The lower hydro power generation results in a reduction of the maximum unbalance to a value of 2300 MW, as like as a reduction of the renewable generation curtailment needs to 118 GWh.

In opposition, the wet year scenario results in higher power unbalances, reaching a maximum of 4600 MW. To avoid power unbalances implies an annual renewable generation curtailment of 2995 GWh.

The forecasted impact of different hydrological regimes in the renewable energy curtailment needs, by the year 2011, is presented in fig.8. The curtailment is evaluated as a percentage of the wind generation, as it is the renewable energy source that mainly contributes to the generation surplus.

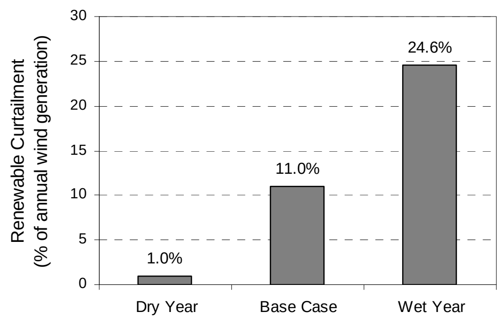
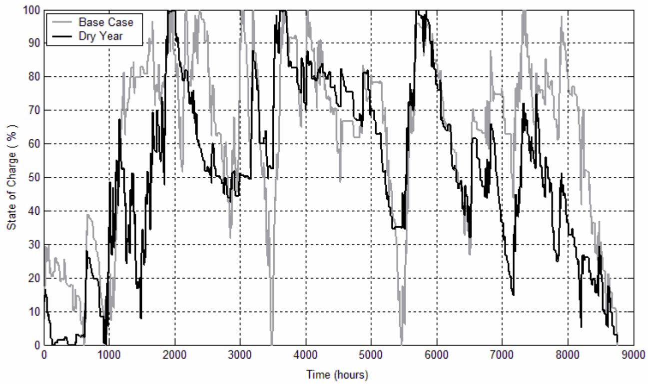
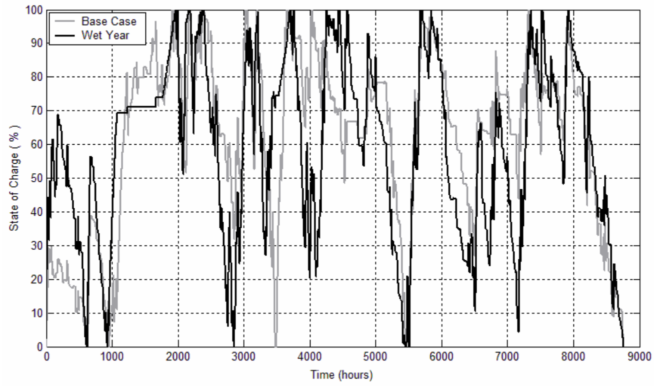



Fig. 8. Impact of different hydrological regimes in the needs for renewable generation curtailment




a) Dry hydrological regime




b) Wet hydrological regime

Fig. 9. Evolution of the aggregated pumping-hydro state of charge

As previously mentioned, wet hydrological regimes increase the difficulties to reach the power balance without curtailment of renewable generation. This fact results from two different causes.

The first one, and prominent, is the fact that higher hydro power availability reduce the need for additional generation of the other technologies, especially during the off-peak periods, when the demand is lower, disabling the integration of the total wind power generation.

The second cause results from the need of the pumping-hydro power-plants for using the available water inflows to generate power, reducing their availability to operate as an energy storage system.

The impact of the different hydrological regimes on the operation of the pumping-hydro power-plants is presented in fig. 9. Results show that wet years intensify the use of the pumping-hydro storage capacity, forcing more charge/discharge cycles with the state of charge often alternating from the 0 to 100%.

These are results from the unit commitment algorithm, where, at the starting hour, it is considered that the pumping-hydro power-plants present their maximum capacity to store energy (0 % state of charge) and the same conditions are assumed for the end of the year.

The state of charge is one of the state variables of the unit commitment and for each pumping-hydro power-plant the maximum storage capacity (100 % state of charge) is based on the data presented in table I.

The occurrence of different hydrological regimes, besides influencing the ability of a power system to integrate the renewable energy generation, also impacts on other levels of the power system operation, as it is the case of the equivalent hours of the thermal technology or the thermal generation costs. Some of those impacts are presented in fig. 10, in which the base case scenario results correspond to the 0 % variation.

One can observe that low rainfall hydrological regimes are usually responsible for higher thermal generation due to the power demand satisfaction. This is what happens in the dry year scenario, wherein the equivalent hours of the thermal generation increase, resulting in higher $CO_2$ emissions and higher annual thermal generation costs.

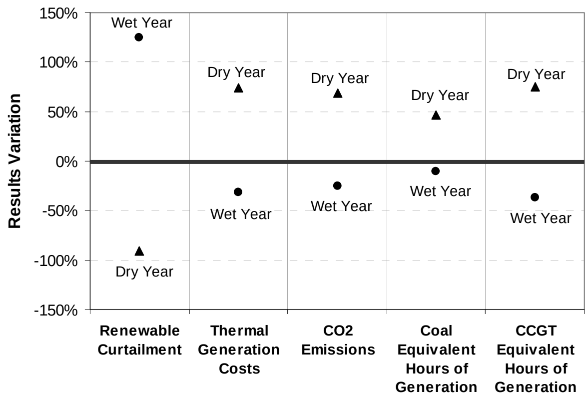



Fig. 10. Impact of different hydrological regimes in the power system operation parameters, in the year 2011

In opposition, in the wet year scenario, despite the renewable generation curtailment increases, the thermal generation decreases, reducing the $CO_2$ emissions and the annual thermal generation costs.

## 7. Conclusions

The paper here proposed evaluates the impacts of different hydrological regimes on the ability of the Portuguese power system to integrate the renewable energy generation.

The significant influence of different hydrological regimes in the integration of renewable energy generation comes from the share of hydro power existing in the Portuguese generation mix. The occurrence of years or periods of the year with higher rainfall, results on a higher hydro power generation, therefore reducing the ability to integrate other renewable energy sources, like wind power. This fact is expected to occur especially during the off-peak hours, when the demand is lower.

On the other hand, as the pumping-hydro installed capacity is planned to cooperate in the integration of the wind power generation, acting as an energy storage system, the occurrence of different hydrological regimes also influences the operation of those power-plants, modulating their capacity to store energy.

The methodology developed along the present paper has the objective of quantifying the influence of different hydrological regimes on the ability of a power system to integrate the renewable generation. The methodology was divided in three different steps corresponding to the non-dispatchable generation, demand and net import forecasts, the unit commitment algorithm and the results analysis.

The developed methodology was applied to the forecasted Portuguese power system operation in 2011. From the results obtained, we conclude that for wet years, because of the higher hydro power generation and lower pumping-hydro power-plant storage capacity, the integration of renewable energy generation is lower, resulting in a higher need for renewable generation curtailment, namely wind power. In the wet year scenario, that renewable generation curtailment may be equivalent to 25 % of the annual wind generation.

In opposition, the reduced hydro generation that occurs in the dry year scenario almost allows the integration of all renewable generation. The higher availability of the pumping-hydro installed capacity to operate as an energy storage system during the years of lower rainfall, also contributes to increase the integration of the renewable generation.

The results of the methodology application also demonstrate that for power systems with important share of hydro power, like the Portuguese one, in spite of a lower rainfall regime enabling a better integration of the renewable generation, the need for satisfying the demand induces additional thermal power generation and consequently, additional thermal generation costs.

Future developments of the present work, currently under way perspective the study of the implementation of other kinds of energy storage systems in the Portuguese power system, in order to mitigate the potential of power unbalance occurrences.

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