International Conference on Renewable Energies and Power Quality (ICREPQ'14)
Cordoba (Spain), 8th to 10th April, 2014
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, No.12, April 2014

Renewable energy production over the Iberian Peninsula: Optimizing power plants location and energy reservoirs.

J.P. Montávez[1], S. Jerez[1], R. Lorente-Plazas[1], J. Ruiz [1] and A. Sarsa[2]

[1] Department of Physics
Universidad de Murcia
Campus de Espinardo – Espinardo, 30100 Murcia (Spain)
Phone/Fax number:+0034 868 887005, e-mail: **montavez@um.es**

[2] Department of Physics
Universidad de Córdoba
Campus de Rabanales (Edificio C2), 14071 Córdoba (Spain)

Abstract. In this paper we present a methodology for obtaining a energy production system based on renewable energy able to generate the energy demand supported by hydro-electric pumped storage. This model is based on the minimization of the variance of the differences between energy demand and production. The minimization procedure uses the simulated annealing, and looks for the complementarity (spatial and temporal) of solar and wind resources. The minimized variance is controlled by the use of pumped-storage hydroelectricity. The renewable energy time series are obtained by using pseudo-real climatological series coming from a Regional Climate hindcast (10km spatial resolution, 1 hour temporal resolution) for the period 1959-2007 over the Iberian Peninsula. Once the optimal series are obtained, it is analysed the requirements that the hydro-electrical system must have. The exercise here presented gives an idea of the relationships between the renewable energy production, hydro-electrical power (pumping) and energy storage needed to guarantee the energy demand at long-term under the consideration of no loss of energy.

Key words

Solar Energy, Wind Energy, Climate, Regional Climate Models, Pumped-storage hydroelectricity.

1. Introduction

Renewable energy production is usually presented as the main solution to important environmental and economical problems. The use of renewable energy resources instead of the traditional fossil based (i.e. fuel, carbon) can serve to reduce the emissions of pollutants and carbon dioxide to the atmosphere, therefore contributing to increase air quality and decrease the greenhouse gases effect [1]. On the other hand, the renewable energy production reduces the dependence on imports of energy from abroad and promotes local employment [2,3]. These facts have important economical benefits based on the price fluctuations and the trade balance [4].

However some drawbacks are usually attributed to the use of some renewable energy resources. The high cost and their temporal variability due to their meteorological and climate dependence (specially wind and solar) difficult its implementation as main energy sources.

Nevertheless, during the last years, prices of installed MW of wind and solar power have strongly dropped, starting to be actually competitive. Regarding the meteorological dependence of these resources, the improvement of the energy production forecasts, specially at short time scales (from hours to 2 or 3 days), allows nowadays a reasonably good anticipation and planning, which does not prevent anyway the need of controllable background energy sources to which draw upon in case of blackout. This has negative effects over the final cost of the energy.

The aim of this paper is to propose a energy production system based on renewable energy that can be able to fit the energy production to the demand, minimizing the dependence on non-renewable energy.

2. Data and methods

A. Data

Hourly data of wind speed (at ~90 m height) and surface solar radiation were obtained from a regional climate simulation driven by reanalysis data that spans the period 1959-2070 and covers the Iberian Peninsula with a 10 km resolution regular grid. This data set, whose reliability has been previously demonstrated [5,6], will be use as input for the wind and solar energy estimations. These estimations were performed as in Jerez et al. [7].

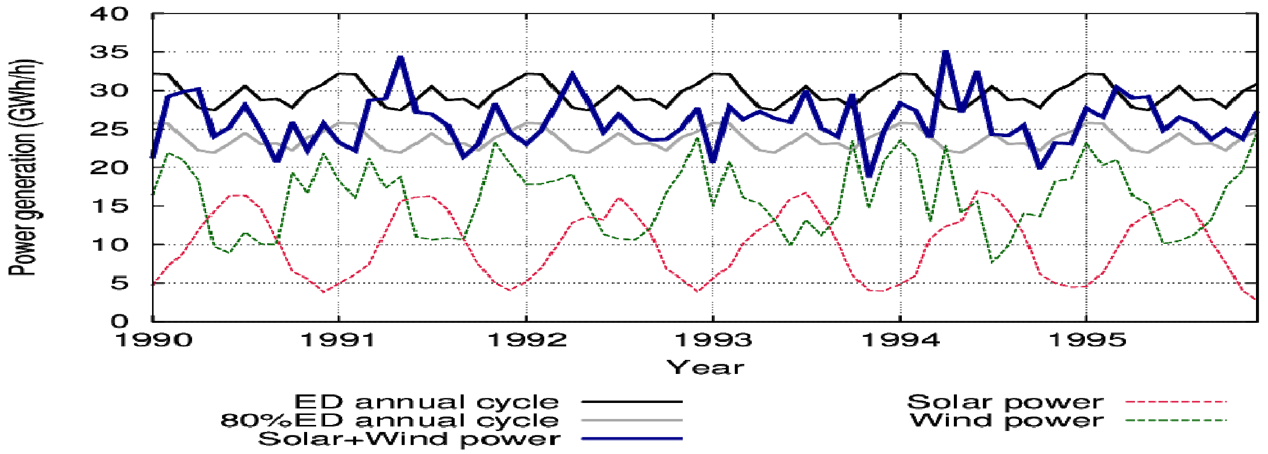

Fig. 1: Time slice of the monthly time series (1999-1996) of energy production of solar (red) and wind power (green) and total (blue). The black line denotes the annual cycle demand and the gray line the imposed condition (see text for details).

Data of energy demand were retrieved from the Spanish REE institution (www.ree.es). For this study only the monthly mean annual cycle of the energy demand, calculated over the period 2007-2011, has been used.

B. Methods

The main idea of this work is to find a distribution of renewable power plants along a given area that approximately covers the energy demand with minimum temporal fluctuations. This means to minimise both the magnitude and the variance of the differences between production and demand. This optimisation problem can be applied to different time scales. The exercise presented here was performed using monthly time series.

The spatial distribution of the renewable power plants (given roughly the number of them to be installed) that meets the former optimisation criteria was identified using a simulated annealing algorithm as in [7]. This methodology estimates the spatial distribution for solar and winds power plants over an area so that (1) the monthly mean values of the resulting solar-plus-wind energy production series are above certain thresholds and (2) the temporal variability of such production series is minimum.

Using these series as inputs, the next step is to include a pumped-storage hydroelectricity system that permits to absorb the variance of the remaining differences between energy production and demand. The objective is to have an energy system that provides as much energy as demanded at each time. Hence, when the input renewable energy production is larger than the energy demand, the surplus energy (E_s) is stored (pumping); when the input renewable energy production is lower than the energy demand, the stored energy is retrieved to fully satisfy the energy demand (hydropower). Note that these two processes imply a energy loss linked to the pumping efficiency (μ_p) and hydroelectric production (μ_h). The total energy loss will be given by $E_l=(1-\mu_p\mu_h)\,E_s$.

The system should be designed in order to avoid lost or fault of energy at long term. This constrain will fix the relation between mean energy demand and production and therefore the energy lost for a given total efficiency ($\mu_p\mu_h$).

The design of this system should also consider its capability for storing (pumping) and releasing (hydropower production) water. Given a initial energy storage, this varies as a function of the available wind and solar production at each time step. The energy reservoir necessary to guarantee the energy demand with no energy loss can be calculated as the difference between the maximum and the minimum energy to be stored in a period, and will depend on the particular sequence of wind-plus-solar energy production series along such a period.

3. Results

A. *Wind and solar power plants distribution*

The first step is to look for the optimal distribution of solar and wind energy plants. The total number of grid cells to be occupied with solar and/or wind energy farms should be specified. It is allowed to have both wind and solar plants in the same grid cell. Each grid cell selected for having renewable plants of any kind will be considered to have ¼ of its area occupied by either solar panels or wind turbines in each case. Given that the size of the grid cells is 100 km^2, and following the specifications provided by [8], this assumption implies having 1250 (135) MW of solar (wind) installed capacity in each selected grid cell This will define a single solar (wind) plant in the following. The eligible grid points were restricted to only those with energy production over the median, calculated using all grid points (see gray squares and empty black circles in Figure 2).

We fix the number of power plants (as defined above) to 400, and impose a minimum mean energy production of the 80% of the mean energy demand for each month (see black and grey curves in Figures 1 and 3). In the case presented here, 51 grid cells for having solar and 349 for

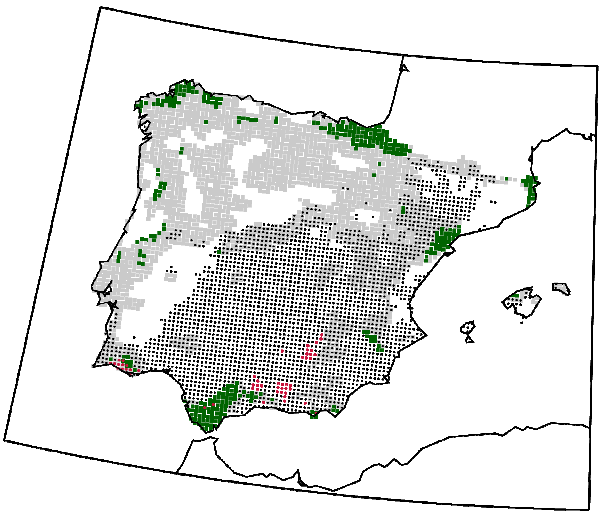

Fig 2. Spatial distribution of wind (green) and solar (red) power grid cells. Gray shaded (points) represent the grid cells elegible for wind power (solar) instalations.

having wind power plants were selected (red and green symbols in Figure 2), which gives a total of 63 and 47 GW installed of each technology respectively. With this distribution, the capacity factor obtained was of 35% and 15% for wind and solar power plants respectively. The low capacity factor for solar energy should be due to the fact that photovoltaic panels are not oriented but just horizontal.

Figure 1 shows the temporal evolution during the period 1990-1995 (although the optimisation was done considering the whole period 1959-2007) of the renewable energy production (solar plus wind) production series from the fictitious plants at the selected locations. It can be clearly observed the temporal complementarity of the solar and wind power generation. The total renewable energy production is most of the time over the 80% of the energy demand imposed (gray line) and some times over the total energy demand (black line). Figure 3 shows the annual cycles of both energy demand and production, highlighting the still remaining inter-annual variability of

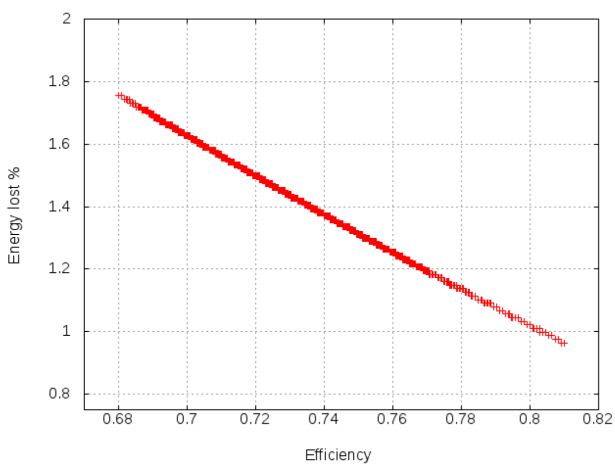

Fig 2: Energy lost (percentage respect renewable energy production (%)

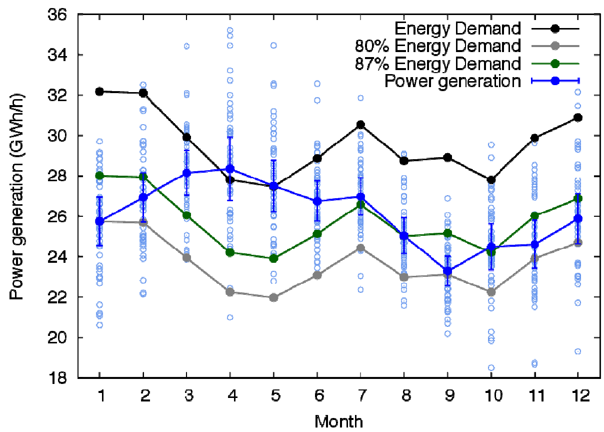

Fig. 3: Annual cycle of energy demmand and production. Black line denotes the total annual cycle energy demand, The gray line the imposed condition and the green line the guarantized energy cycle. Blue open circles accounts for the energy production each time step. Mean and standard deviation of production is denoted by filled blue dots and bars.

this latter despite the optimisation effort carried out by combining solar and wind powers.

B. *Pumping and storage considerations*

Given the former series of solar-plus-wind energy production, the second step is to design a pumping/releasing hydropower system aimed at reducing the still remaining differences between energy production and demand and their variance.

The first question to address is the percentage of the total demand that the whole system (wind plus solar plus hydropower) would be able to guarantee, including all the temporal variations of the demand. The results indicate that around the 87% of the total demand can be ensured without long-term net loss of stored energy. This factor would depend on the total efficiency of the hydro-electrical-pumping system. Figure 3 shows this curve (in green).

The energy loss would depend on μp and μh, explained above. Figure 4 shows the relationship between energy loss and efficiency. This relationship, in the usual range of efficiency values, is lineal. Such a range is taken in this study between 0.68 and 0.82, i.e. between the 32% and 18% of the surplus energy is lost. But this percentage over the total energy ranges between 1.8% and 1%.

The above results presuppose that there are not losses due to a limitation in the storage of energy. Let's now to fix μ_p=0.85 and μ_h=0.85. The energy storage capacity necessary for the real temporal evolution of the input energy production series considered is two times the mean monthly energy demand. However, we can have different temporal evolutions under a same climate (i.e. a fixed probability distribution function of wind and solar radiation). To face up this problem, the necessary energy storage capacity is calculated for several cases. These are

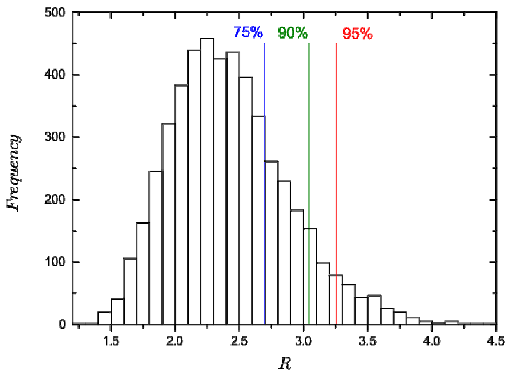

Fig. 5: Histogram of the maximun storage required contructed for 5000 ramdomly time evolutions. Vertical color lines depicts some probabilities of occurence. Values are normalized to the mean monthly energy production.

obtained by permuting randomly the order of the monthly renewable energy series by 5000 times. Figure 5 shows the histogram of the energy storage size obtained for the 5000 energy time evolutions. The maximum difference between minimum and maximum storage energy (i.e. storage capacity) ranges from 1.5 to 4 times the mean monthly energy production, being 2.25 the most likely case.

In order to store the surplus energy and to recover it when necessary, it is required to install a given pumping and hydroelectric power. This amount of installed power can be extracted by analysing the histograms of the stored and released energy provided in Figure 6. The inputs and outputs present similar distributions. The maximum value is 0.35 times the monthly mean renewable energy production, although in more than a 95% of the cases this values is under 0.2.

4. Conclusions and discussion

In this theoretical study we demonstrate that it is possible to design a sustainable energy production system based on wind and solar power supported by a pumping-hydroelectric background system.

First, a smart distribution of non-controllable energy plants (solar and wind power) providing energy production series that follow a given curve of energy demand with minimum variance, was identified. These series were then used to define the probability functions of non-satisfied demand, and were used as inputs for the design of a hydro-electrical-pumping system aimed at reducing the differences between energy production and demand at each time step.

The results obtained in this exercise revealed that the needed energy storage for guaranteeing the energy demand varies from 1.5 to 4.5 times the mean monthly renewable energy demand, depending on the actual energy production temporal evolution. However, the maximum size can be strongly reduced if it is assumed a certain probability of non-capability of energy storage/release.

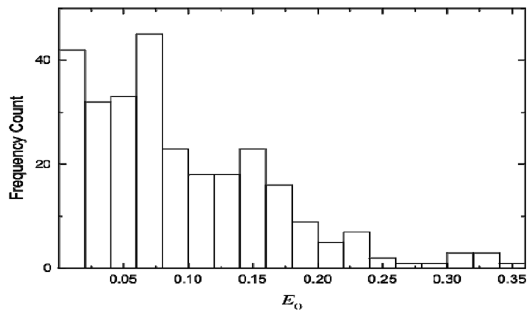

Fig. 6: Histogram of normalized pumped energy frequency. Values are normalized to the mean monthly energy production.

A similar behaviour was found when analysing the necessary pumped hydro-electrical power installed. Our results indicate that it would be necessary to install around a 7% of the total renewable power installed to guarantee the storage of the surplus energy and its later conversion into hydropower. Permitting some loss of energy can considerably reduce this percentage.

Therefore the system can be strongly improved from the an economical point of view, by allowing loss of energy or just by introducing some controllable energy resources. It can be estimated the necessary power (controllable) to be installed in order to guarantee (with a certain probability of assurance) the energy demand.

In this work we have imposed the actual climate, although it was allowed to have different time evolutions. An interesting exercise would be to assess the impact of climate change on the capability of the system to maintain its stability.

Another remarkable issue is that the results presented here are obtained using monthly energy values. Therefore the energy system presented here only analyses low frequency energy variations. It would be necessary to address the same problem at shorter times scales, daily or even hourly.

References

[[1] IPCC (2011). IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1075 pp.

[2] Moreno, B. and López, A.J. (2008). The effect of renewable energy on employment. The case of Asturias (Spain). *Renewable and Sustainable Energy Reviews*, 12(3):732-751.

[3] Bhattacharyya, S.C. (2009). Fossil-fuel dependence and vulnerability of electricity generation: Case of

selected European countries. *Energy Policy*, 37(6):2411-2420.

[4] Apergis, N., and Payne, J.E. (2010). Renewable energy consumption and economic growth: Evidence from a panel of OECD countries. *Energy Policy*, 38(1):656-660.

[5] Lorente-Plazas, R., Montávez, J.P., Jerez, S., Gómez-Navarro, J.J., Jimenez, P.A., and Jimenez-Guerrero, P. (2014). Evaluation of regional simulations of surface wind over the Iberian Peninsula. Submitted to *International Journal of Climatology*.

[6] Jerez, S., Trigo, R.M., Vicente-Serrano, S.M., Pozo-Vázquez, D., Lorente-Plazas, R., Lorenzo-Lacruz, J., Santos-Alamillos, F., and Montávez, J.P. (2013a). The Impact of the North Atlantic Oscillation on Renewable Energy Resources in Southwestern Europe. *Journal of Applied Meteorology & Climatology*, 52, 2204–2225.

[7] Jerez, S., Trigo, R.M., Sarsa, A., Lorente-Plazas, R., Pozo-Vázquez, D., and Montávez, J.P. (2013). Spatio-temporal Complementarity between Solar and Wind Power in the Iberian Peninsula. *Energy Procedia*, 40, 48–57.

[8] Ruiz-Arias, J.A., Terrados, J., Pérez-Higueras, P., Pozo-Vázquez, D., and Almonacid, G. (2012). Assessment of the renewable energies potential for intensive electricity production in the province of Jaén, southern Spain. *Renewable and Sustainable Energy Reviews*, 16(5), 2994-3001.