Evaluation of the level of prediction errors and sub-hourly variability of PV and wind generation in a future with a large amount of renewables

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ABSTRACT

In this paper we propose a method for the simulation of errors in renewable energy sources generation forecasting (photovoltaic and wind) for use in power system planning studies. The proposed methodology relies on 5 elementary simulation steps. The first step is the simulation of photovoltaic plant and wind farm power production, with a sufficient spatial and temporal resolution (few km and hourly time step), the second is the simulation of the localisation of production sites, the third step is the generation of forecast errors using historic data of numerical weather predictions, and the last step is the simulation of intra-hourly variations of photovoltaic production. Finally, it is discussed how these simulation tools can assist the evaluation of the required tertiary reserves in a power system with a large share of renewable energies into the mix.

INTRODUCTION

In a future with a large amount of renewable energy sources (RES) integrated into the distribution system, there are many kinds of new constraints that cannot be neglected a priori in the power distribution system operation and planning. This includes short term (few hours in advance) forecast errors and sub-hourly variation of the RES production. However, the importance of these two quantities is subject to the so called aggregation effect and cannot be considered as a linear function of the installed capacity. Furthermore, this aggregation effect highly depends on the considered geographical perimeter of the area where the RES plants are located.

In this paper we present a methodology to estimate the level of short-term forecast error and sub-hourly production variations at any spatial scale. We apply the methodology in the case of France considering three scales: national, regional and down to the scale of the distribution network.

Before simulating forecast errors and sub-hourly variations, we describe in Section 2 the methodology used to simulate hourly wind power and solar power production at any location. In Section 3 our methodology for simulating forecast errors is exposed while Section 4 is devoted to the simulation of intra-hourly variations. The last Section gives conclusions.

SIMULATION OF THE RENEWABLE ENERGY PRODUCTION

We describe here the methodology used to simulate hourly wind power and solar power production at any given location. Wind power is simulated through the use of a statistically calibrated power curve and wind time series resulting from the use of a meteorological model in reanalysis mode. Solar power simulation is based on the use of data from the SODA database, and namely on estimations of the surface solar irradiation at an hourly resolution and at a spatial scale of 3km. The SODA data rely on the use of satellite images and physical modeling of radiative transfer in the atmosphere. Both models used to simulate production are validated on real data.

Simulation of wind power production

The simulation of wind power also relies on the combination of a model and meteorological data from MERRA refined spatially with a downscaling method, relying on meteorological data from ECMWF. The meteorological parameter used as input in the model here is the wind speed at 50 m height. The model is a statistical one that allows the conversion of wind speed into power production. It is a piecewise model combining a linear part, a locally polynomial part and a constant part for the plateau and finally a linear part to model the cut-off. A constraint is added to allow the reproduction of a realistic temporal variability. In the application, the parameters of the model are estimated for each region of France with a least square estimation procedure. In the end it is verified that the simulated production at the regional scale has a temporal variability and a capacity factor that is equal to that observed from the regional RTE (French TSO) production curves in 2013 (available at the RTE web site).

Simulation of solar power

Solar power production is simulated with a model of a solar photovoltaic system taking as input meteorological data: the irradiance corresponding to the inclination and orientation of the system, and the temperature. The model takes into account the effect of the temperature as well as the different losses up to that of the transformation station. Finally, the model is calibrated on several

different real production sites.
The temperature is obtained through meteorological reanalysis MERRA [1]. Meteorological reanalysis are the combination of earth measurements and the use of the physical equations of the atmosphere. They take the form of a spatio-temporal field of wind speed/direction and temperature for a temporal resolution of 1 h, and a spatial horizontal resolution of about 50 km. Concerning the irradiation data they are taken from the SODA database, which contains 10 years of earth irradiation estimated data obtained at 15 minute temporal resolution and about 3 km spatial horizontal resolution with satellite images combined with a radiative transfer model.

SIMULATION OF THE RES PLANTS SITE LOCATIONS

Any simulation of wind and solar power production at a regional scale requires a localisation of the installed RES power plants. We propose a method to generate localisations and installed capacity over all sites in France segmented with squares of 100m x 100m. This method contains 4 steps:

1. Computation of exclusion areas, i.e. areas where it is not possible to have PV or wind production sites due to a strong constraint (such as relief, protected areas, buildings for wind power, forest areas for PV…)
2. Application of an acceptability ratio: among the available areas (those remaining after step 1) only a fraction is selected and made available (10% for wind power and 5% for solar power)
3. Selection of the site with sufficient potential of energy production (the potential is computed with the energy simulated thanks to the simulation process described in the previous Section)
4. Selection among the remaining sites of those with the best score and attribution of a capacity according to the available surface. The score used is a combination of a random term and a term providing the energy potential of the site. The weight of the random term is a parameter of the procedure called Fp that allows measuring the proportion of the variability of the score due to the variability of the random term. In particular if Fp=1 the selection of the site is random and if Fp=0 the selection is done according to the energy potential.

An illustration of obtained results is shown in Figure 1 and in Figure 2 for PV production sites.

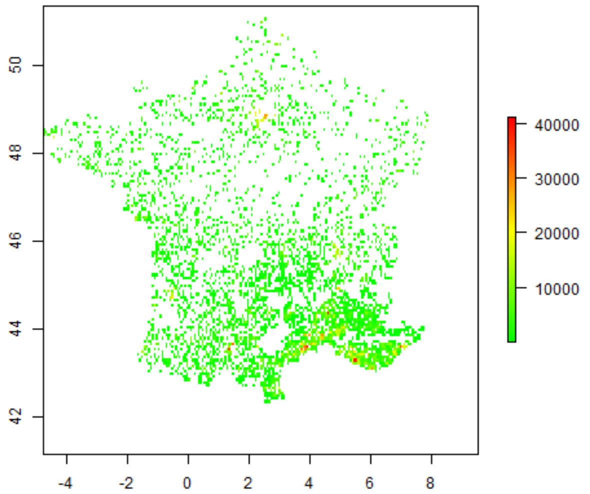

Figure 1: Spatial distribution of solar panels for Fp=0.8 (almost uniform)

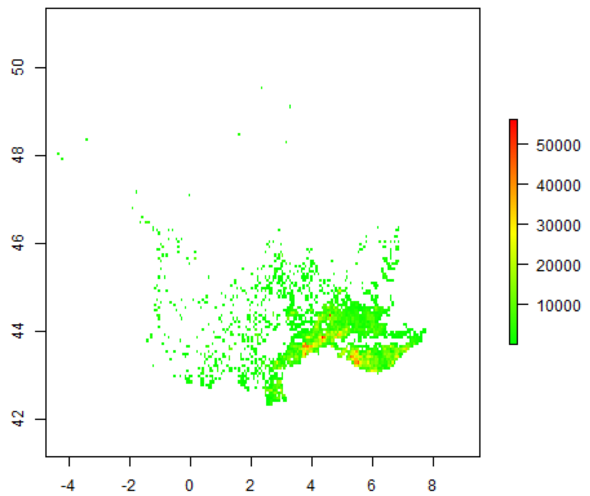

Figure 2: Spatial distribution of solar panels for Fp=0.3 (more concentrated on locations endowed with the highest energy potentials)

SIMULATION OF FORECAST ERRORS

Our methodology for simulating forecast errors mimics real forecasting, performed on the simulated production data. The real forecasting model is simplified in order to allow a large number of computation repetitions. In the case of PV forecasting as well as Wind Power forecasting, it is used as input two explanatory variables: meteorological forecast of ECMWF (wind speed for wind power and surface solar irradiation for PV) and recent past production measurements. The simulation is performed along several years and thousands of different implantation configurations. The distribution of errors is obtained as a function of the spatial scale and the chosen time horizon. An example of results for photovoltaic production is shown on Figure 3, according to the 1st quantile, allowing to measure the level of the worst errors. In Figure 4, the average error of wind power production forecasted 12 hours in advance is represented spatially. In Figure 5, we show the time series of the sum of hourly forecast errors for three different temporal horizons: 6 hours, 3 hours and 1 hour ahead. The corresponding errors are the sum of PV and wind power forecast errors at the scale of France, in a 100% of RES scenario, including 63 GW of PV systems and 33 GW of wind power.

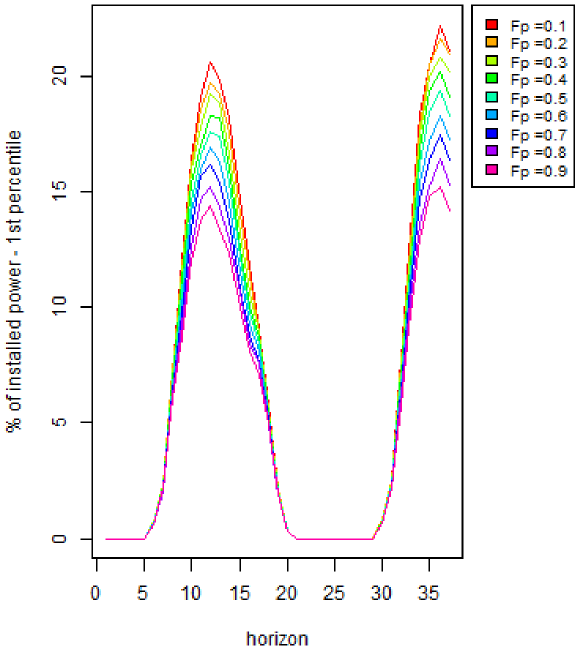

Figure 3: level of the worst errors of PV production along years 2007 up to 2012, as a function of the forecasting time horizon, and the spatial dispersion of PV systems (Fp=0.1 represents a concentration of solar panels only on the best sites and Fp=1 represents a uniform distribution over France). Only the forecasts issued at 00:00 are used in this Figure.

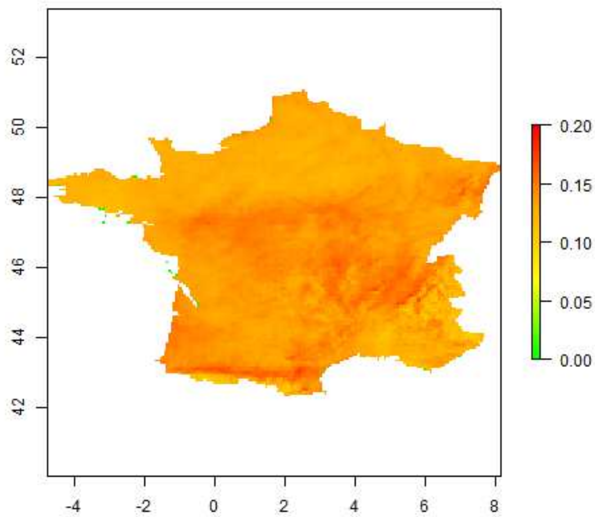

Figure 4: Average forecast errors of wind power made 12 hours in advance expressed in root mean square error per unit of installed capacity.

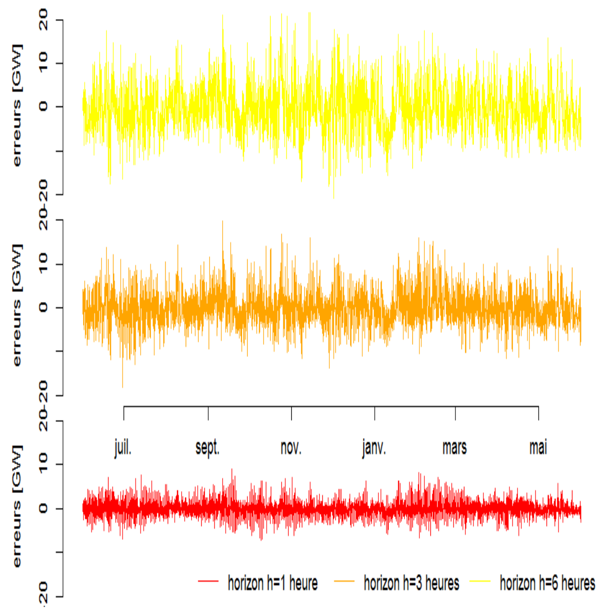

Figure 5: Forecast errors at the level of France, given according to three different forecasting time horizons: 1 hour (red), 3 hour (in orange), and 6 hours ahead (in yellow), in a scenario including 33 GW of wind power and 63 GW of PV (the errors represented here are the sum of PV and wind).

SUB-HOURLY VARIATIONS SIMULATION

Concerning the simulation of sub-hourly variations, we propose a machine learning procedure, based on a data set of several years of sub-hourly generation measurements, on more than 30 different systems located in different places in the south of France. The simulation method contains 3 steps, applied for each day, and each site for which a simulation is performed:

1. An hourly simulation is produced with the method proposed in Section 2.
2. Using the simulation of the first step, detection of the K=20 nearest days in all the learning set composed of the 30 different sites. (i.e. those minimizing the Euclidian distance between the simulation and the observation).
3. Random selection of a day in the set of K days obtained at the step 2. The difference between the hourly values and the 5 minutes resolution values in the selected day is added to the hourly value of the simulated day.

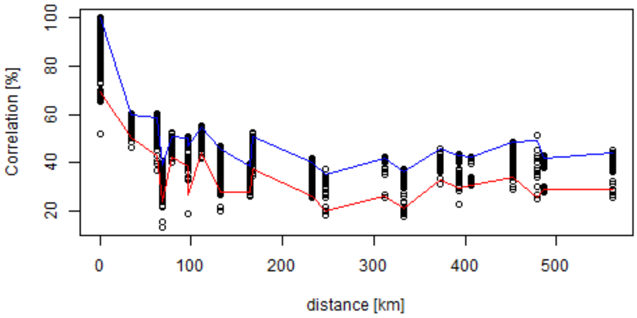

Figure 6: Evolution of correlations between the difference of mean hourly production values, and 5 minutes resolution production values, as a function of the distance between sites.

CONCLUSION

In this paper we have presented the methodology that was elaborated in the French project SmartReserve (founded by ADEME) in order to evaluate the required volume of tertiary reserve, in a future with a large share of renewable energy in France. The methodology allows the simulation of wind and solar power forecast errors as well as the intra-hourly variation of PV production at any geographical scale. For the case of France with a very high penetration of renewable energy (i.e. more than 30 GW of wind power and 60GW of PV) the results presented in Figure 5 show that the worst event won't exceed a few GW for the total forecast error calculated an hour in advance. This output is however not sufficient for the evaluation of tertiary reserve. Indeed in a future with a large share of renewable energy, it is likely that the installed capacity of flexibility such as hydro storage or power 2 gaz (to handle variability of production) will largely exceed the few GW required for the tertiary reserve and that most of the time this capacity will be available to handle the forecast errors and the intra-hourly variations.

MISCELLANEOUS

Acknowledgments

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