GHI AND DNI FORECASTING USING GFS, NEURAL NETWORS AND SOLAR RADIATION ESTIMATED FROM SATELLITE IMAGES

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1. Introduction

Solar energy is gaining a huge significance due to the unsustainable current energetic model. In the certain case of solar energy technology to produce electricity, the integration of all these power to the electricity grid challenges new horizons, such as the estimation of short range electricity generation to optimize its management, avoid situations of load reduction and anticipate supplying problems.

This paper presents a methodology to forecast hourly global horizontal solar irradiance (GHI) and direct normal irradiance (DNI) using global forecast system (GFS) model from NOAA and neural networks models. Forecasting horizon of the predictions is 72 hours. Predictions are done operationally with a model which runs 24 hours a day. The predictions are generated 4 times a day at 05:10 UTC, 10:10 UTC, 17:10 UTC, 23:10 UTC, after availability of the predictions from GFS model which begin its run at 00:00UTC, 06:00UTC, 12:00UTC and 18:00UTC.

2. Experimental Solar Radiation Dataset

The dataset used in this study is based on hourly global solar irradiance ground measurements from stations of Meteorological and Climatological Service of Navarra (http://meteo.navarra.es) Weather Underground (http://www.wunderground.com), which is an amateur meteorological network and solar radiation estimated from Meteosat Satellite images. Table 1 summarizes the main geographic characteristics of the stations as well as the initial date of availability of the ground measurements. The temporal acquisition of the measurements and the quality of radiometric data available are two crucial factors related to adjustment of the models proposed. Manufacturer of the pyranometer used in the stations of the Meteorological and Climatological Service of Navarra (Cadreita and Sartaguda stations) is the Dutch firm Kipp&Zonen and belong to CM11 series. In the rest of the meteorological stations, which belong to Weather Underground network, the instrument used to measure solar radiation is a photocell incorporated in a meteorological station which manufacturer are mainly Davis Vantage Pro2 and Oregon Scientific.

The measurements are registered with a temporal resolution of 10 minutes. A historic database of hourly ground measurements has been created to train the neural networks models. Every day at 01:00 AM, the system connects to the web page of each station and interprets the HTML code to store the measured data in the data base.

1. Methodology

The first model developed makes use of the 3-hourly predictions from GFS model to obtain hourly values using an interpolation and a clear sky model. The other models implemented are based on neural networks and make use of the predictions from GFS and solar irradiance measurements to make non-linear correlations between synoptic/global and local radiometric conditions for the locations where we want to obtain the predictions.

Tab. 1: **Geographic coordinates and measurement data time period of the ground station.**

Station	Latitude	Longitude	Altitude	Initial Date
Cadreita	42.20º	-1.69º	267m	04/1999
Sartaguda	42.36º	-2.00º	307m	04/1999
Calpe	38.65º	0.04º	91m	05/2008
Elche	38.25º	-0.70º	82m	01/2008
Albox	37.40º	-2.15º	480m	12/2009
Frigiliana	36.78º	-3.89º	194m	01/2008
Mijas	36.50º	-4.72º	185m	10/2008
Badajoz	38.80º	-6.95º	185m	01/2008
Cabrera	41.51º	2.40º	11m	01/2008
Castellar	41.62º	2.09º	342m	05/2008
Fals	41.74º	1.71º	400m	01/2008
Fernando	36.47º	-6.19º	8m	02/2009
Santander	43.47º	-3.78º	9m	10/2008
Benavente	42.01º	-5.67º	750m	01/2008
León	42.59º	-5.53º	944m	08/2008
Murcia	38.00º	-1.08º	37m	01/2008
Yecla	38.63º	-1.15º	610m	10/2008
Gijón	43.54º	-5.625º	27m	01/2009

3.1 Global Forecast System (GFS)

The Global Forecast System (GFS) is a global numerical weather prediction model run by NOAA. This mathematical model is run four times a day and produces forecasts up to 16 days in advance. The model is run in two parts: the first part has a higher resolution and goes out to 180 hours (7 days) in the future; the second part runs from 180 to 384 hours (16 days) at a lower resolution. The resolution of the model is 0.5ºx0.5º horizontally. The predictions are made using directly the output variable DSWRF at surface level from GFS model. The nearest grid output point of GFS model to each station is used as the basic predictions. Afterwards, 3-hourly values are interpolated to one hourly value using an interpolation and a correction with a clear sky model is applied. The bias for the last 30 days of the GFS model is done independently for each forecasting temporal horizon.

3.2 Statistical Downscaling using Neural Networks (NN)

Neural network models are an abstract simulation of neural biological systems which tries to synthetic its abilities (Haykin, 1998). Due to non-stationary behavior of hourly global solar irradiance time series, a transformation to measured and predicted global solar irradiance time series has been done to obtain a new variable, clearness index (Kt), which will be used as input to the NN models. Clearness index is defined as the ratio between ground measured global solar irradiance and extraterrestrial solar irradiance. Input to the neural network models consist of the 72 hours Kt predicted values from GFS and previous 24 hourly values of Kt measured. The output of each neural network configuration is the next 72 hours values of Kt which are transformed to predictions of hourly global solar irradiance. The different neural network configurations used to forecast hourly solar irradiance are presented in Table 2.

Tab. 2: Statistical Downscaling based on neural network models tested.

NN Model	Number of Layers	Neurons in each Layer
Model NN1	1	1
Model NN2	2	3-1
Model NN3	3	5-3-1
Model NN4	4	7-5-3-1
Model NN5	5	9-7-5-3-1
Model NN_pred	3	5-3-1

3.2 DNI prediction using kb-kt models

Once GHI predictions are obtained, DNI predictions are estimated using the model of Louche. This model is based on a simple correlation between beam transmittance and clearness index (Louche et al., 1991):

$$k_b = 0.002 - 0.059k_t + 0.994k_t^2 - 5.205k_t^3 + 15.307k_t^4 - 10.627k_t^5 \qquad \text{(eq. 1)}$$

Fig 1. shows the schema of the methodology used to obtain hourly predictions of DNI from predictions GHI using the model (GFS or NN) for each station. Also, an algorithm to detect clear sky days has been implemented (Polo et al., 2008), in such a case the prediction for the next day for GHI and DNI components is done using the ESRA clear sky model (Beyer et al., 1996).

2. Main Results

The indexes to measure the errors of the models are the relative mean bias deviation (rMBD) and the relative root mean squared deviation (rRMSD) which are measured using the following expressions:

$$\text{rMBD} = \frac{1}{N}\sum_{i=1}^{N}\left(\hat{x}_i - x_i\right) \qquad \text{(eq. 2)}$$

$$\text{rRMSD} = \frac{\sqrt{\sum_{i=1}^{n}(x_i - \hat{x}_i)^2 / n}}{\overline{x}} \qquad \text{(eq. 3)}$$

where N is the population size, x is the observed value, $\overline{x}$ is the mean of observed values and $\hat{x}$ is the predicted value.

The dataset of each station is divided sequentially into two independent groups: the training and validation datasets. For each radiometric station, the assessment of the models proposed is performed with data from the period 1th of June 2010 until 10th of March 2011. The rest of the previous data is used to train neural networks models. In the validation, only values of measured or predicted global solar radiation higher than 100W/m^2 are considered.

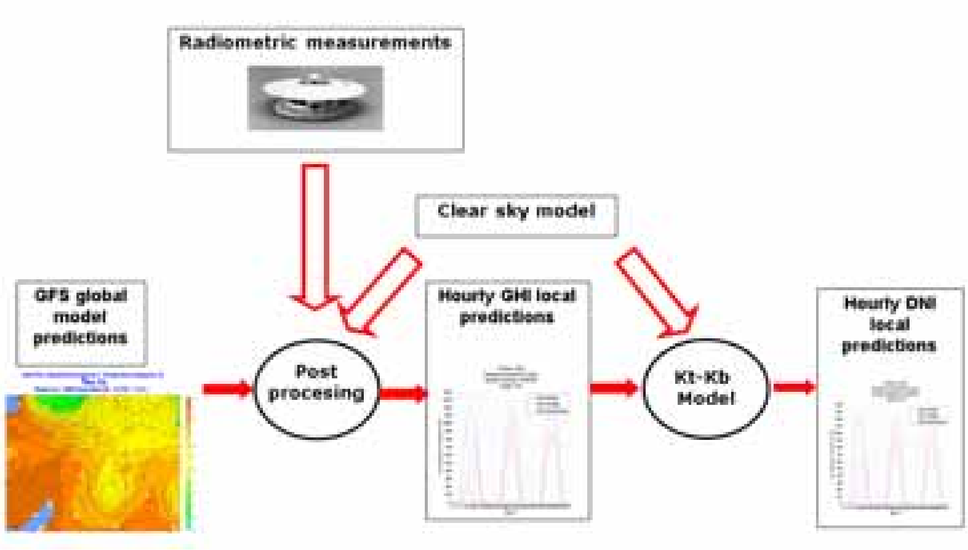

Fig. 1. Schema of the methodology used to obtain hourly predictions of DNI.

The errors in term of RMSD vary between 18% and 35% for hourly predictions of solar radiation.

3. Conclusion

The results show that GFS model have lower uncertainty in terms of rRMSD for most of the stations. For some stations like Benavente and Leon and a certain NN configuration, a huge improvement has been achieved compared to GFS model. The results are consistent with other preliminary works (Perez et al., 2007).

4. References

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