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Combining solar irradiance measurements, satellite-derived data and a numerical weather prediction model to improve intra-day solar forecasting

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ABSTRACT

Isolated power systems need to generate all the electricity demand with their own renewable resources. Among the latter, solar energy may account for a large share. However, solar energy is a fluctuating source and the island power grid could present an unstable behavior with a high solar penetration. Global Horizontal Solar Irradiance (GHI) forecasting is an important issue to increase solar energy production into electric power system. This study is focused in hourly GHI forecasting from 1 to 6 h ahead. Several statistical models have been successfully tested in GHI forecasting, such us autoregressive (AR), autoregressive moving average (ARMA) and Artificial Neural Networks (ANN). In this paper, ANN models are designed to produce intra-day solar forecasts using ground and exogenous data. Ground data were obtained from two measurement stations in Gran Canaria Island. In order to improve the results obtained with ground data, satellite GHI data (from Helioclim-3) as well as solar radiation and Total Cloud Cover forecasts provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) are used as additional inputs of the ANN model. It is shown that combining exogenous data (satellite and ECMWF forecasts) with ground data further improves the accuracy of the intra-day forecasts.

1. Introduction

According to the trend shown for renewable energy generation, the proportion of these kinds of energies in the power system will increase in the next years. Renewable energies show a fluctuating generation profile because of their dependence on meteorological conditions. Since grid operators need to keep under control these variations, in order to accommodate the input/output balance of the system, forecasting methods are necessary to improve the coupling of renewable sources. This becomes an important issue when facing the fact that photovoltaic and solar thermo electrical plants are widely spread in most of the present power systems.

The output power of a PV plant is mainly correlated with the global solar irradiance received on the plan of the modules. The calculation of this received irradiance requires the knowledge of the direct and diffuse components of the solar irradiance. But in many cases as in our study, no measurement of these two components exists. Thus, these two components are commonly derived from the global horizontal irradiance (GHI) with decomposition models [1–3]. When no assumption is done on the inclination of the PV modules, the key factor becomes the GHI. So, in this work, we will only focus on the forecasting of the GHI. Indeed, a reliable Global Horizontal Irradiance (GHI) forecasting model is considered as an important tool to avoid unstable behavior in the electrical grid, maintaining the balance between demand and supply [4,5].

Isolated power systems, such as the one in Gran Canaria Island, need to generate all the electricity demand solely with their own resources. The island power grid could present an unstable behavior if there is a large-scale solar energy introduction. This is aggravated when a great variability in solar radiation conditions are shown in the Canary Islands, caused by the diversity of the climatic areas that emerge as a by-product of the differences in its orography [6,7].

GHI forecasting has been developed in the last years using a

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wide range of methods. The most common forecasting models used in this field are:

- Statistical models, models based on GHI time series prediction: most common statistical models used in GHI forecasting are linear models, such us autoregressive (AR) and autoregressive moving average (ARMA), and machine learning techniques, such as Artificial Neural Networks (ANNs) [8].
- Forecasting using Ground-based sky images: models based on sky images obtained with 180° vision angle cameras. Sky images lead to know cloud cover conditions for a few minutes ahead.
- Satellite images models. Geostationary satellites get atmosphere images all around the Earth with temporal resolution less than an hour. The high development occurred in the recent years in satellite data retrieving makes this technique a very useful tool to improve GHI forecasting [9,10].
- Numerical Weather Prediction models (NWP) based on physical models for estimating atmosphere conditions, including clouds formation and dissolution. Physical models are described with differential equations solved with numerical methods. NWPs models offer time horizons forecasting from few hours to 15 days ahead [4,11].

Depending on the forecasting time horizon and granularity, forecasting results are used for different purposes and are based on different input parameters [12,13]. Ground-based sky images models show high precision information about cloud cover conditions and movement for intra-hourly forecasting horizons [14]. On the other hand, forecasting models based on cloud motion vectors derived from geostationary satellite images offer accurate results for hourly prediction range up to 6 h ahead [9,10]. NWPs forecasting precision varies depending on the selected time scale and the geographic zone of the study. Heinemann [4] showed that acquiring the radiation values for clear skies without deviation is possible. NWPs models associated with a post-processing method using hourly ground measurements showed accurate results for predictions from 6 h onwards [15].

The statistical method proposed in this paper is based on Artificial Neural Network (ANN) for GHI hourly forecasting from 1 to 6 h ahead. ANNs are considered a very attractive method for GHI forecasting because of their capacity to establish relationships between an input and output datasets [8]. ANNs have been used for solar radiation prediction using past ground measurements. Many papers have described ANN accurate results for GHI predictions with time horizons from few hours ahead, such as explained in Ref. [16–19], to 24 h ahead daily irradiation forecasting [20,21]. Statistical models based on ANN offer the possibility to combine historical GHI ground data with other meteorological data. Rehman [20] used air temperature and ground relative humidity for daily irradiation forecasting. Kemmoku [22] designed an ANN to forecast daily irradiation using atmospheric pressure and several meteorological parameters. Sfetsos & Coonick [23] used GHI ground data, air temperature, wind velocity and pressure for solar irradiance hourly forecasting. Moreover, several papers studied the influence of sunshine duration, air temperature, relative humidity, latitude and longitude to obtain GHI hourly and daily forecasting [18,24,25].

ANNs may even lead to more accurate GHI forecasts by combining ground measurement time series analysis with exogenous data, such as ground irradiance derived from satellite images and different NWPs data. In the last years, several studies used different techniques such as autoregressive models (AR) [26–28], artificial neural networks [29,30] and genetic algorithms for choosing the relevant information from satellite-derived data [28].

In this paper satellite-derived and ground data are combined with solar radiation and total cloud cover predicted by the European Centre for Medium-Range Weather Forecasts (ECMWF). The satellite-derived data is selected as in Ref. [30], using correlation analysis results. In this work, we used the Bayesian framework [31] which improves ANNs learning process. In addition, the Bayesian approach provides techniques to optimize the ANN architecture and to select the most relevant inputs [32,33].

The organization of this paper is as follows. In section 2, we present the ground data, satellite-derived data and ECMWF data used in the present paper. The clear sky model is described in Section 3 and we analized Ground data distribution in Section 4. In Section 5, we detail the forecasting methods theory, in Section 6 we explain the ANN architecture optimization and Section 7 is devoted to the selection of the most relevant satellite inputs. In Section s8, we show the error metrics used in this paper and in Section 9 we detail the results of the different models and discuss the influence of the different exogenous data to improve GHI forecasting. Finally, Section 10 gives main remarks and conclusions.

2. Available data

The datasets used in the present study to build the forecasting model include ground, satellite and numerical predicted data. All the data will be converted into an hourly basis in order to compare and contrast all the information in a coherent manner. The temporal availability for all type of data was restricted to the year 2005 because this is the only year in which ground and satellite data overlaps: ground data have been processed up to the year 2005, meanwhile the satellite data recollection started on the same year.

The application of the ANN models requires the division in training and testing datasets. Therefore, due to the restriction of only one year, we took the decision to select three weeks of a month for training and one week for testing purposes since this study only possess one year available. In this manner we can assure that training and testing datasets share similarities regarding meteorological behaviors, while keeping a ratio of 75% training and 25% testing [28].

2.1. Ground data set

Ground data are obtained from two measurement stations located in Gran Canaria Island (Spain) and managed by the Canary Islands Technology Institute (Instituto Tecnológico de Canarias). These stations are part of a network of 23 stations in the Canary Islands, validated by the elaboration of a solar map of the zone [6,34]. The selected stations are representative for the climatic division present on this island [6,35]. This climatic contrast between the northern region, with higher cloudiness, and the southern one, with clearer days and less variability, is well known and produced by the strong influence of the trade winds of the area.

The equipment used to acquire global solar horizontal irradiance (GHI) is a secondary standard pyranometer, the CMP-11 of Kipp & Zonen, with 3% accuracy for daily sum of GHI. Data are recorded for every 5 s, 1 min average and later assembled into an hourly basis. In order to maintain enough quality of the data, all the measurement data were treated with the SERI-QC control software [36,37]. This treatment consists on filtering values of radiation that are negative or higher than the top of the atmosphere.

Furthermore, in global solar radiation forecasting, it is usual to remove night data and anomalous readings from the equipment at dawn and sunset, or other shadowing effects. Therefore, a filter based on the solar zenith angle (SZA) was introduced to establish a frontier of 80° for all data. This threshold is validated in the bibliography [38], and also concurs with the careful observations of the shadow effect for each station.