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Artificial neural network based daily local forecasting for global solar radiation

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HIGHLIGHTS

- A new method for local forecasting of daily global solar radiation is proposed.
- The model combines the artificial neural networks and the special modelling.
- The model exploits weather forecasts provided by specialized agency.
- The model's forecasts were compared to measured data for two locations.
- The developed model estimates daily solar radiation with satisfactory accuracy.

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ABSTRACT

When a part of the power is generated by grid connected photovoltaic installations, an effective global solar irradiation (GSI) forecasting tool becomes a must to ensure the quality and the security of the electrical grid. GSI forecasts allow the quantification of generated photovoltaic (PV) power and helps electrical grid operators anticipate problems related to the nature of PV power and the planning for adequate solutions and decisions. In this study, a new methodology for local forecasting of daily global horizontal irradiance (GHI) is proposed. This methodology is a combination of spatial modelling and artificial neural networks (ANNs) techniques. An ANN based model is developed to predict the local GHI based on daily weather forecasts provided by the US National Oceanic and Atmospheric Administration (NOAA) for four neighbouring locations. The methodology was tested for two locations; Le Bourget du Lac (45°38′44″N, 5°51′33″E), which is located in the French Alps and Cadarache (43°42′28″N, 05°46′31″E), which is located in the south of France. The model's forecasts were compared to measured data for the two locations and validation results indicate that the ANN-based method presented in this study can estimate daily GHI with satisfactory accuracy.

1. Introduction and problematic

The economic and environmental imperatives related to 1970s petroleum crisis such as fossil fuels' price fluctuations and resources limitation, greenhouse gas emissions, climate change, global warming and air pollution contributed greatly to the development of renewable energy sources and the importance of their role in the global power mix. The most abundant of all renewable energy sources is solar energy which can be harnessed for commercial uses through large solar array farms [1], and which is predicted by numerous analyses to become the mostly used energy resource by 2050 [2]. The solar energy conversion process into electric energy is carried out mainly through two mechanisms: thermal conversion and photovoltaic conversion. For the time period 2030–2050, The European Photovoltaic Industry Association (EPIA) together with the European Renewable Energy Council (EREC) has shown the high potential of PV within the RE-thinking 2050 scenario [3]. PV is expected to become a mainstream power source in Europe by 2020 and a major power source in 2050 with an approximation of 962 GW of installed capacity [4]. This is especially true due to the installation of grid connected PV systems [5,6]. As a result, new challenges have arisen in the PV industry over the past years such as: identifying and quantifying the impact of PV power on the electrical distribution grid; minimizing the influence of its fluctuations; managing uncertainties in order to guarantee a secure and reliable electrical power services; and the PV systems performance prediction.

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The performance of a photovoltaic (PV) installation is related to factors including the electrical parameters of its components such as PV panels and inverters, the characteristics of the installation (tilt angle, orientation, etc.) and the meteorological conditions. It is well known that the power produced by a photovoltaic (PV) field depends mainly on the absorbed solar irradiance. In fact, a linear correlation exists between the PV modules' maximum power and the solar irradiance [7]. Solar irradiance on a panel varies with geographic location, time, and the orientation of the panel relative to both the sun and the sky [8]. This explains the variable, chaotic and intermittent behaviour of generated solar power. To ensure an efficient exploitation and a large penetration for such a power source, it is important to predict the amount of energy that a PV installation can generate. Once fully exploited during the PV installations' design stage, PV production forecasting is, nowadays, a must to ensure an effective management system for the electrical distribution grid. Several studies were conducted to ensure this task [9–13]. Many of these studies consider global irradiance forecasts as a problem similar to that of solar power forecasts [13]. This could be achieved by reviewing the diagram of general principle illustrated in Fig. 1, where solar irradiance forecasts are used to predict the solar power that a given PV installation can generate by means of its mathematical model.

The literature presents numerous models for PV modules which can be used to quantify the anticipated produced electric power [14–18]. Also a significant number of studies on solar irradiation modelling and forecasting have been undertaken, offering a wide range of possibilities [19–30] gleaned from diverse areas of knowledge such as atmospheric physics, solar instrumentation, machine learning, forecasting theory and remote sensing in its quest for better predictive skills [31]. However, while the choice of the model to be used for PV installations is based solely or mainly on its efficiency and complexity for the purpose of accuracy and software programming constraints respectively, the choice of the solar irradiation's forecasting methodology should take into account additional considerations such as the kind of the desired solar irradiation: diffuse [32–35] or global [36–42], horizontal or inclined [43], hourly [44,45], daily [33,46–51] or monthly forecasts [52], the scale time of the forecasts (short, medium or long term) including the need of a long term measured database and its availability which can take much time and generate additional costs.

This paper presents a part of the research in progress that seeks to estimate and forecast PV installations' production one day ahead. This part concerns how to forecast the daily GHI for a given site without the availability of a local measured database. For this a novel methodology that combines spatial modelling and the artificial neural networks (ANNs) modelling techniques has been developed. An ANN is used to model the GHI profile for a given site by means of a daily forecast provided by a specialist provider for four neighbouring locations.

The remainder of the paper is organized as follow: Section 2 describes the measurements and the database. Section 3 presents and explains the developed methodology while the results and the analysis are presented in Section 4. Finally, the conclusions are given in Section 5.

2. Sites, measurements and database

Two types of data are used in this study. The first group is taken from measurements performed continuously every 5 min during one year from June 2008 to May 2009 at two locations: Le Bourget du Lac (45°38′44″N, 5°51′33″E), located in the French Alps and Cadarache (43°42′28″N, 05°46′31″E), located in the south of France. The second group of data comes from the US National Oceanic and Atmospheric Administration (NOAA), which provides daily weather forecasts in the United States and even internationally for many locations represented by points of a meshgrid. The NOAA's forecasts have a time resolution of 3 h and a nominal ground resolution of one by one degree (i.e., ~80 × 100 km). For this study, only forecasts provided by the NOAA for the nearest neighbouring locations surrounding Le Bourget du lac (Fig. 2) and Cadarache and belonging to the meshgrid are considered as explained in the next Section.

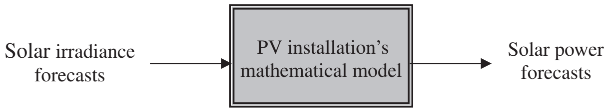

Fig. 1. GHI forecasts for predicting the generated PV power.

Fig. 3 illustrates part of the GHI values as measured at INES while Fig. 4 illustrates the GHI data for the whole year after a pre-processing step. The purpose of this pre-processing is to replace the daily measurements that contain varying numbers according to the respective day–time–duration data, with average values in order to get the same time resolution as NOAA's data. These average values will later be used to quantify energy generated by a photovoltaic installation. These final data are illustrated in Fig. 4, in which it is possible to discern the seasonal variability of the GHI while Fig. 5 shows the measured data at INES versus the NOAA forecasts.

3. The methodology

To understand the basic idea of the herein developed methodology for GHI forecasting, it should be appropriate to begin by presenting the context of its use which justify choices that were made. First, the purpose of the survey is to enhance the GHI forecasting method developed by the R&D team of Laboratory for Solar Systems (L2S) at the French National Institute of Solar Energy (INES) [53] and used for the one-day ahead prediction of the solar energy that a PV grid connected installation can generate. The particular feature of this method is that it may be used even at locations which do not have a previously measured database, generally indispensable for that kind of task. To overcome this lack of measured data, daily weather forecasts for the nearest four NOAA meshgrid's points surrounding the target location has been used as input information as shown by Fig. 6. To model the existing relationship between the NOAA forecasts and the real values of the GHI at the target location, an ANNs based model is used. The training of the ANN can be programmed in a few days after the recording of the initial measurements and redone periodically during the installation's life-time as explained in the next section.

4. Results and analysis

The ANNs modelling can be divided into three stages: (1) the topology design stage which includes the choice of the ANN type, the number of its layers, the number of neurons in each layer, its inputs and outputs, the choice of training and validation samples; (2) the training stage during which samples are presented to the ANN and the weights are adjusted accordingly till a predetermined condition is satisfied; and finally (3) the validation stage, during which the obtained ANN model is tested using samples not treated during the training stage. If the validation test is successful, the model could perform its designed function otherwise one or more changes should be made during the previous stages as described by Fig. 7.

4.1. ANN topology design

Multi-layer perceptron neural networks with different topologies were considered in order to obtain the best mapping between