Energy 119 (2017) 288–298

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Hourly forecasting of global solar radiation based on multiscale decomposition methods: A hybrid approach

Stéphanie Monjoly, Maïna André, Rudy Calif *, Ted Soubdhan

EA 4935 - Laboratoire de Recherche en Géosciences et Énergies, Université des Antilles, 97170 P-á-P, France

ARTICLE INFO

Article history:
Received 6 August 2016
Received in revised form
17 October 2016
Accepted 8 November 2016

Keywords:
Global solar radiation prediction
Multiscale decomposition
Hybrid model
Autoregressive model
Neural network model

ABSTRACT

This paper introduces a new approach for the forecasting of solar radiation series at 1 h ahead. We investigated on several techniques of multiscale decomposition of clear sky index K_c data such as Empirical Mode Decomposition (EMD), Ensemble Empirical Mode Decomposition (EEMD) and Wavelet Decomposition. From these differents methods, we built 11 decomposition components and 1 residu signal presenting different time scales. We performed classic forecasting models based on linear method (Autoregressive process AR) and a non linear method (Neural Network model). The choice of forecasting method is adaptative on the characteristic of each component. Hence, we proposed a modeling process which is built from a hybrid structure according to the defined flowchart. An analysis of predictive performances for solar forecasting from the different multiscale decompositions and forecast models is presented. From multiscale decomposition, the solar forecast accuracy is significantly improved, particularly using the wavelet decomposition method. Moreover, multistep forecasting with the proposed hybrid method resulted in additional improvement. For example, in terms of RMSE error, the obtained forecasting with the classical NN model is about 25.86%, this error decrease to 16.91% with the EMD-Hybrid Model, 14.06% with the EEMD-Hybid model and to 7.86% with the WD-Hybrid Model.

1. Introduction

Solar energy is available in abundance in tropical zone. However this resource is highly variable over multiple time scales due mainly to cloudy passages. Consequently, in the insular context, such as Guadeloupe island, the electricity grid is not connected and the output of PV power generation is highly random, with a fluctuating and intermittent nature. The increasing of PV plants to meet demand will increase the variability and uncertainty that must be managed by system operators and planners of (photovoltaics) PV system [41]. Hence, the development and utilization of this intermittent energy suffer from limitations. In order to increase the integration of solar energy into electricity grid, a good knowledge of global solar radiation variations and more accurate solar forecasts are needed. Forecasting of global horizontal irradiance can be categorized according to the input data used which also determine the forecast horizon [18].

- Numerical Weather predictions (NWP) models has been sucefuly applied for solar radiation forecasting such as Heinemann et al. [28], Lorenz et al. [38] and Perez et al. [43]. Nevertheless these modeling process has robustness for time scale higher than 6 h forecast horizon.
- Short-term irradiance forecasting models (forecast horizon from few minutes to hours) based on clouds information using sky cameras and satellite images [9,39,42].
- Statistical models based on solar irradiance measurements are applied for forecast horizon from 5 min up to 6 h. The statistical models are based on techniques such as:
  - Linear method: Autoregressive process (AR, ARMA, ARIMA, STRAMA) [22,29,46,50,51].
  - Non linear methods based on artificial intelligence techniques [40]. The most popular is Artificial Neural Network (ANN) [7,25,36,48].

As mentioned in Ref. [19] another class of predict models concerns probabilistic forecast models. They are based on uncertainly estimates in using quantile, interval or density forecast, which is crucial for end-users [8,23,24,54].

A good knowledge of global solar radiation variations is also needed in order to increase the integration of solar energy into electricity grid and improve solar forecast, as previously mentioned. Solar radiation is an environmental data and exhibits

* Corresponding author.
E-mail address: rcalif@univ-ag.fr (R. Calif).

http://dx.doi.org/10.1016/j.energy.2016.11.061
0360-5442/

simultaneous coexistence of nonlinear and non-stationary properties at different time scales. The fluctuations present a process at all intensities and all level scales, taking account extreme events. In literature, a variety of tools have been used to study the properties of solar radiation at different temporal scales. The analysis of fluctuations at all scales and intensities can be carried out by multifractal tools, wavelet methods [32,33], multifractal detrend fluctuations analysis(MFDFA) [34], arbitrary order Hilbert spectral analysis included Empirical Mode Decomposition(EMD) [30,31]. These different techniques was applied to global solar radiation data by Calif et al. [11]. The results revealed that EMD was an efficient tool to analyze the nonlinear and non stationary characteristics of solar radiation time sequences. We can quote also Barnhart et al., 2011 [6]) who applied the EMD techniques to solar radiation. Recently, wavelet analysis methods have gained increasing interest as local representation of signals in the time and frequency domains in solar energy area [1,45]. In this paper, we are interested in using EMD and wavelet methods for multiscale decomposition of clear sky index time series for a yearly period. We used also an extension of EMD method named Ensemble Empirical Mode Decomposition (EEMD). The goal of this paper is to bring an improvement of solar forecast at 1 h ahead in building an hybrid model combining linear model and non linear model, based on multi scale decomposition of clear sky index time series. Zhang [55] confirms that a hybrid model with both linear modeling and nonlinear modeling could be a robustness alternative for predicting time series data. Other hybrid models are presented in Refs. [12,40,50,51]. The literature showed ANN model has self-adaptiveness, robustness and has been successfully applied for solar radiation forecasting. Often, this model is combined to another to build an hybrid process. In this work, we employ an hybrid AR and ANN model combined with a multiscale approach to predict solar irradiance in the tropical climate conditions of Guadeloupe. The fact that Guadeloupe is an island not electrically interconnected with high variability of solar resource, entails that the manager of electrical network must be very quickly able to react to a large variation of the production. The forecasting horizon of 1 h chosen corresponds to the time required for the manager of electrical network to optimize at best the stoppage or the starting up of a means of production. The goal of this paper is to show the relevance of the combination of multiscale decomposition with AR and NN models. From the multiscale decomposition methods (Wavelet, EMD and EEMD), we built 11 decomposition components signals and 1 residu signal presenting different dynamic and time scale properties. This paper is organized as follows: In Section 2, we present the experimental measurements and data pre-processing method. In Section 3, we present a brief description of the theoretical methodology of three multiscale decomposition techniques (wavelet, EMD and EEMD). In Section 4, the hybrid forecasting model used for solar forecasting at 1 h ahead is described. In Section 5, the analysis results of fluctuations and non-stationary characteristics of solar radiation from the different multiscale decompositions is provided. The choice of forecasting method is adaptative on the characteristic of each decomposition component. Then, we demonstrate the effectiveness of the proposed technique. The hybrid model developed is compared with AR and ANN models whithout multiscale decomposition.

2. Data pre-processing

2.1. Global solar radiation measurements

The Global Solar Radiation measurements were recorded at the meteorological station of Le Raizet (Météo France situated at 16° 26'N latitude and 61° 51'W longitude), located at Guadeloupe island. The data are sampled at 1 h during two years in continu January 2012 to December 2013. This represents 7818 samples. The GHI was measured by a pyranometer CM22 from Kipp & Zonen. Pyranometer accuracy given by the manufacturer is 3%. The Raizet station is subject to a continental insular regime. In this area, the cloud formation is mainly due to the convection of air masses. This meteorological phenomenon makes that global solar radiation signals exhibit high variability.

We performed a filetring criterion in order to remove values of solar radiation in night hours. Indeed, values of global solar radiation in night hours are low and no significant to generate electricity. The filtering method is based on the filtering process described in Lauret et al. (2015): the SZA (Solar Zenith Angle) filtering process. This technique consists in removing solar radiation data for which the solar zenith angle is greater than 80° [36].

2.2. Detrended time series

2.2.1. Method for stationary hourly solar series

To perform the modeling process used in this paper, detrended time series must be used. The original solar radiation series is not stationary. We note that there are different methods to achieve stationarity such as local polynomial regression fitting to detrend the solar irradiance time series by first determining an additive diurnal cycle [53], the differencing technique, used frequently in ARIMA forecasting or the clear sky index often used as a strategy to detrend solar global radiation. We choose to remove temporal trend via the clear sky index. This method does not make the series perfectly stationary but in practice, it is usually admitted [16,36]. Consequently, detrended time series are obtained by clear sky index described by the following equation:

$$K_c = \frac{GHI_m}{GHI_{clear}} \tag{1}$$

where *GHI* is the Global Horizontal Iradiance, index *m* refers to the measured GHI index and *clear* refers to theoretical irradiance computed by Kasten clear sky model.

2.2.2. Clear sky model

The calculation of the deterministic component is based on Kasten model [35] to account for the clear sky index. This model calculates ground irradiance components by considering the absorption and scattering. The inputs of this model are air mass, Linke Turbidity, and elevation [35]. Solar radiation is diffused by the permanent air molecules and scattered by the suspended solid and liquid particles. Information on the quantity and the properties of these particles are needed to accurately estimate the clear sky radiation. The Linke turbidity coefficient TL quantifies this information. It describes the optical thickness of the atmosphere due to water vapor and the aerosol particles relative to a dry and clean atmosphere. With larger Linke turbidity, there is more attenuation of the radiation by the clear sky atmosphere. Fig. 1.a illustrates GHI measured over 30 consecutive days (solid line blue) superimposed to the GHI_{clear} (dotted line red) computed by Kasten model. Fig. 1b represents the corresponding clear sky index.

3. Multiscale decomposition

Physical process in nature, like Global solar Radiation, are nonlinear and non-stationary, exhibiting simultaneous coexistence of different time scales. Decomposition Multiscale are efficient tools to analyze the nonlinear and nonstationnary characteristics of these time sequences [11].