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Article

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Modeling the forecasted power of a photovoltaic generator using numerical weather prediction and radiative transfer models coupled with a behavioral electrical model

A. Razagui*, K. Abdeladim, S. Semaoui, A. Hadj Arab, S. Boulahchiche

Centre de Développement des Energies Renouvelables, CDER, BP 62, Route de l'Observatoire, Bouzaréah, 16340, Algies, Algeria

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Abstract

The intermittency of the solar radiation is the big challenger for the management of electrical SMART GRID network. So the forecasting of the solar radiation remains the crucial objective to anticipate the injection of the electrical power produced by a photovoltaic generator. In this study, we use the Numerical Weather Prediction model WRF coupled to a radiative transfer model libRadtran to forecast the global, direct and diffuse solar radiations. The NMM core of WRF model was used to predict the vertical profiles of the atmospheric meteorological parameters such as liquid and ice water concentration, cloud cover, relative humidity, temperature, etc. These data are used as input in libRadtran to calculate the hourly solar radiations components (Direct, Diffuse and Global) in real meteorological situations. The radiation values are obtained on regular geographical grid points. A behavioral electrical power model is used to compute the electrical power produced by a photovoltaic generator located at the Center of Development of Renewable Energy in the city of Algiers in Algeria. The comparative study shows well that the results are very encouraging.

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Keywords: WRF; libRadtran; Photovoltaic power; Solar radiation

1. Introduction

Incoming solar radiation is the most important meteorological factor that influences the electrical power production of the photovoltaic generator. In the other hand, electricity is not storable; demand must be met on a close to instantaneous basis. Now, the storages and management of energy electric remain the big challenge for every producers of the kind of energy [1]. So around the world, photovoltaic electrical central and even domestics are increasingly connected to the electric network. The availability of a predicted solar radiation data plays an important role in decision making for electrical manager and it is helpful for operational control and optimization of energy

* Corresponding author.
E-mail address: a.razagui@cder.dz (A. Razagui).

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system. So forecasting solar radiation, will lead to determinate the predicted production by solar system. In this work, we focus on the validation of the forecasted global solar radiation with the Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2). Two process are used to compute the global radiation. The first one is based on the use of the Numerical Weather prediction (NWP) model as the Weather Research and Forecasting (WRF) model to forecast the solar radiation components using its own implemented radiative model. Among these components, there is beam, diffuse and the global radiation. The second process compute indirectly the global radiation by the use of the Radiative Transfer Model libRadtran using as input the atmospheric profiles of the meteorological parameters forecasted by WRF. Lastly, to compute the forecasted photovoltaic electrical power as it is show in Section 3, we use a model, which takes into consideration the relationship with respect to the voltage, the global solar radiance and the ambient temperature forecasted by WRF. In recent years, several studies have focused on the forecasting of global radiation using NWP model [2–5].

2. Methodology

2.1. WRF model

WRF model was developed in the National Oceanic and Atmospheric Administration (NOAA), by the National Centers for Environment Prediction (NCEP). The version of WRF used in this work is the Non-hydrostatic Meso-scale Model (NMM). The physics active is Hong et al. [6], and GFDL shortwave scheme and Betts–Miller–Janjic cumulus parameterization scheme. The optical properties of water clouds are calculated either with the Hu and Stamnes [7]. The resolution of the NMM version used in this study is 10×10 km^2 as a horizontal resolution centered over Algeria and the range of the forecasting times is 48 h. The boundary and initial conditions are downloaded from the Global Forecast System (GFS) of the NCEP; under grib2 format.

2.2. libRadtran model

libRadran package has been described in Mayer and Kyling [8] and Gasteiger et al. [9]. In this study, we use the version 2.0.1 of libRadtran to compute the solar radiation components. The select solver of the latest is twostr and with the kato2 molecular absorption as parameterization. The mandatory fields forecasted by WRF and used as input by libRadtran are: the cloud liquid water (CLW), ice cloud water (IWC), cloud nebulosity and specific humidity given for each libRadtran levels. For the others gas profile (O_3, O_2, CO_2, NO_2) we use the climatology database given with libRadtran package.

2.3. Photovoltaic Model (PVM)

In this study, we use the model proposed by Eduardo Ivan in his thesis in 2006. The model take into consideration the relationship of the current respect to the voltage, effective radiation level. It can be described in terms of the values provided by manufacturer data. In the other hand, the advantage of the model is the fact that it can be easily resolved in any informatics language.

$$\mathrm{I(v)} = \frac{I_{scx}}{1 - e^{\frac{1}{b}}}\left(1 - e^{\left(\frac{v}{b.v_{ocx}} - \frac{1}{b}\right)}\right) \tag{1}$$

$$\mathrm{Voc_x} = s.\frac{E_i}{E_{in}}.TCv.\left(T_{cell} - T_n\right) + s.\left(v_{oc\_max}\right) - s.\left(v_{oc\_min}\right).e^{\left(\frac{E_i}{Ein}.ln\left(\frac{v_{oc\_max} - v_{oc\_ref}}{voc\_max}\right)\right)} \tag{2}$$

$$\mathrm{Isc_x} = \mathrm{p}.\frac{E_i}{E_{in}}\left[I_{sc\_ref} + TCi.\left(T_{cell} - T_n\right)\right] \tag{3}$$

$$P\left(V\right) = \frac{I_{scx}}{1 - e^{-\frac{1}{b}}}\left[1 - \mathrm{e}^{\left(\frac{v}{b.v_{ocx}} - \frac{1}{b}\right)}\right] \tag{4}$$

– P, I and V are the photovoltaic module output, respectively the power, current and voltage.
– I_{sc_ref} and v_{oc_ref} are the short-circuit current and the open-circuit voltage at 25 °C and 1000 W/m^2.
– v_{oc_max} is the open-circuit voltage at 25 °C and more than 1200 W/m^2 (usually closed to $1.03v_{oc\_ref}$).
– v_{oc_min} is the open-circuit voltage at 25 °C and less than 200 W/m^2 (usually closed to $0.85v_{oc\_ref}$)

- T_{cell} is the solar panel temperature in °C.
- $T_n = 25$ °C and $E_{in} = 1000$ W/m^2 are respectively, the nominal temperature and the nominal effective solar radiation, they represent the Standard Test Conditions.
- E_i is the real solar radiation in W/m^2.
- TCv is the temperature coefficient of v_{oc_ref} in V/°C.
- TCi is the temperature coefficient of I_{sc_ref} in A/°C. b is characterization constant
- s and p are respectively the number of panels in series and parallel configuration.

3. Discussion of results

WRF and libRadtran simulated charts of the global component of the solar radiation are generated in a temporal forecasting range of 60 min to 48 h during years of 2016 and 2017. MERRA-2 analysis data are used as validation data. Global radiation calculated by libRadtran and ambient temperature forecasted by WRF both are used to map the electrical photovoltaic described above power through the electrical model presented above. Processed charts are show in Fig. 1.

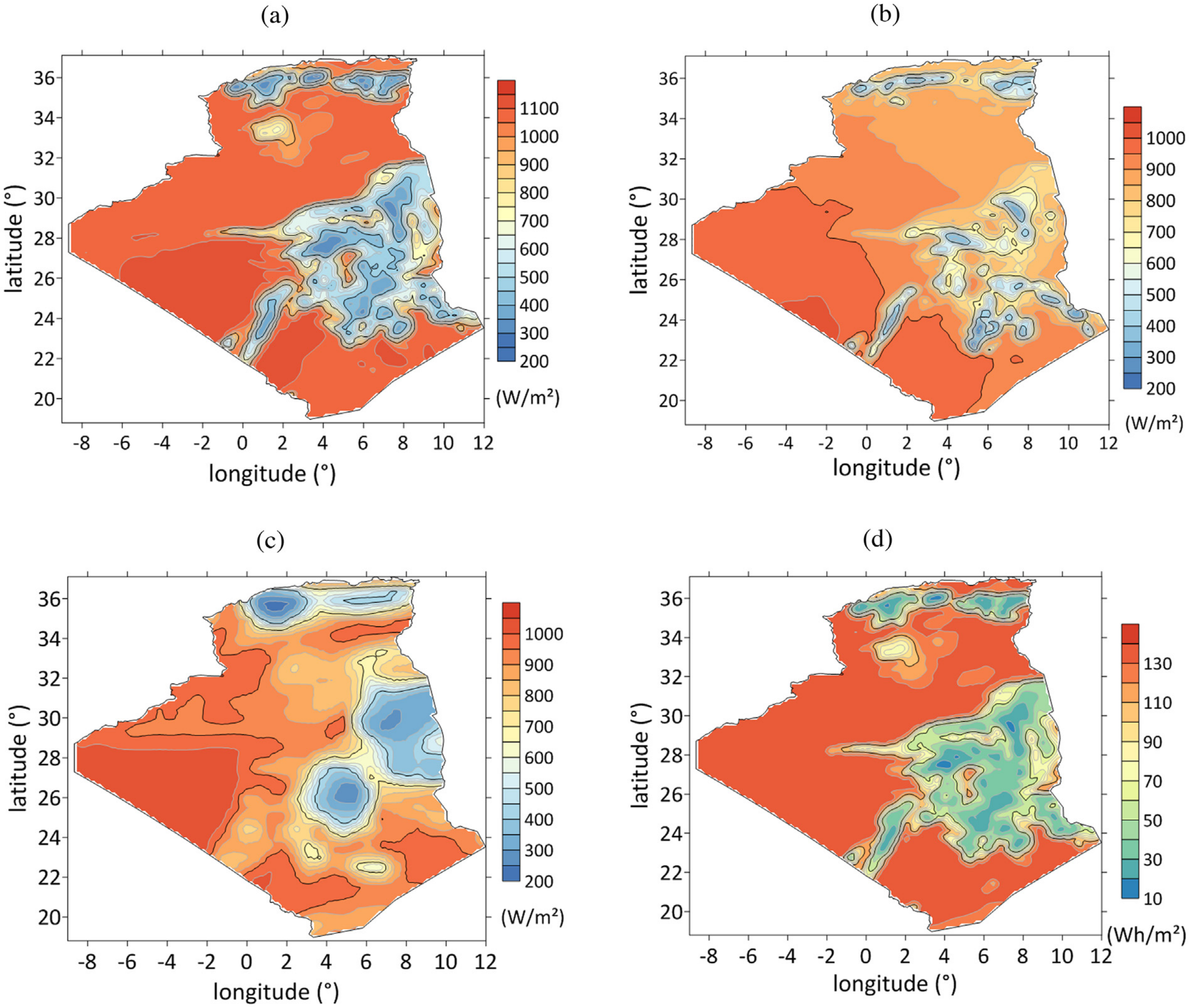

Fig. 1. Global radiation in (W m^{-2}) Calculated by libRadtran (a) forecasted by WRF (b), MERRA2 analysis data (c) and the electrical Power for 1 m^2 of photovoltaic monocrystalline solar panels type (d) with a tilt angle equal to the latitude of location, situation of the 01 June 2017 at 12h00 UTC.

The visual analysis of Fig. 1, shows well a good similarity between predicted and observed charts for both models, Nonetheless, WRF simulated values are slightly lower than those of libRadtran. On the other hand, both models reproduce well the spatial configuration of the global radiation in clear sky cases compared to the MERRA-2 analysis data. For the local scale, WRF has tendency to omit the lows radiations affected by clouds, while libRadtran reproduces them well. Through this analyze, we note that for many cases as it is show on Fig. 1, libRdatran model tends to generate locally, some lows radiations, which are not registered in the reference image. Fig. 1(d) represent the forecasted electrical power mapped by using the model described above. The latest uses as input, the global solar radiation calculated by libRadtran and the temperature at 2 meters forecasted by WRF. In this study, we take the tilt angle of the photovoltaic panels equal to the latitude of location for all the grille points (Fig. 1(d)).

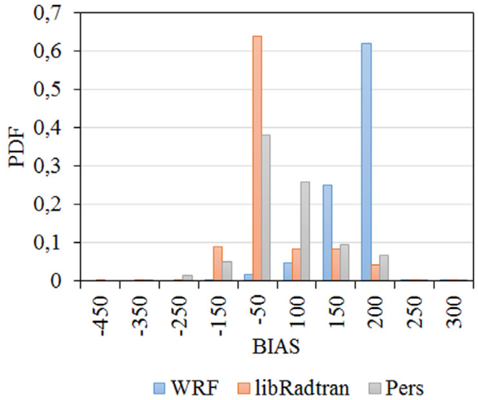

Fig. 2. Probability Density Function (PDF) for the all grille points of the domain, situation of the 02 September 2017 at 12GMT forecasting hour.

The highest values of PDF (see Fig. 2) corresponding to the low values of bias between forecasted and observed global radiation are those of libRadtran and the persistence. For WRF the maximum of PDF is moved around values of bias of 150 W/m^2. The results show well that solar radiations processed by libRadtran model using WRF forecasted outputs, are clearly best compared to those predicted directly, by WRF model when it uses its own transfer radiative model. For the month of September 2017, the correlation for all grille points is about 0.59 for both models. The bias is clearly better for libRadtran (−40 W/m^2) when it is about (−79 W/m^2) for WRF. The RMSE is in order of 125 and 110 W/m^2 respectively for WRF and libRadtran according to a monthly mean value of 560 W/m^2 for MERRA-2 analysis data.

A comparative study between electrical power forecasted by libRadtran model and this produced by the experimental photovoltaic central located at the CDER is discussed in the following. This central has three generator each with 90 monocrystalline silicium panels and 3 kWh as a nominal electric power.

Fig. 3 shows that measured and forecasted power are well correlated however forecasted values over estimates the measured ones. The analyze of Fig. 3, (situation of 01 January 2017) show a fall of measured electrical power at 14h GMT due to a passage of clouds at this time. However, this fall of power is not observed on the curve of the forecasted power. This can be explain by the fact that forecasted cloud event by the model may be false or moved locally or well forecasted but not where event is observed. Another explanation is difference of the representativeness of the spatial resolution between measured and forecasted values. In effect for every grille points of NWP model, the forecasted power represent an area corresponding to its spatial resolution, while it represent a measured value for a specific location. For situations of clear sky and synoptically meteorological situations especially in winter, the forecasting quality may be very correct. However for the very isolated and small-fractionated clouds, the forecasted global radiation may be randomize which has a direct impact on the forecasted electrical power.

4. Conclusion

In this study, we have first investigate two ways to forecast the solar radiations. The first is based on the use of the Meteorological NWP Model namely WRF. The latter uses its own transfer radiative model to compute solar radiations components. The second method uses the meteorological parameters forecasted by WRF such as the liquid and ice cloud water, specific humidity and other gas on vertical profiles as input for libRadtran. MERRA-2

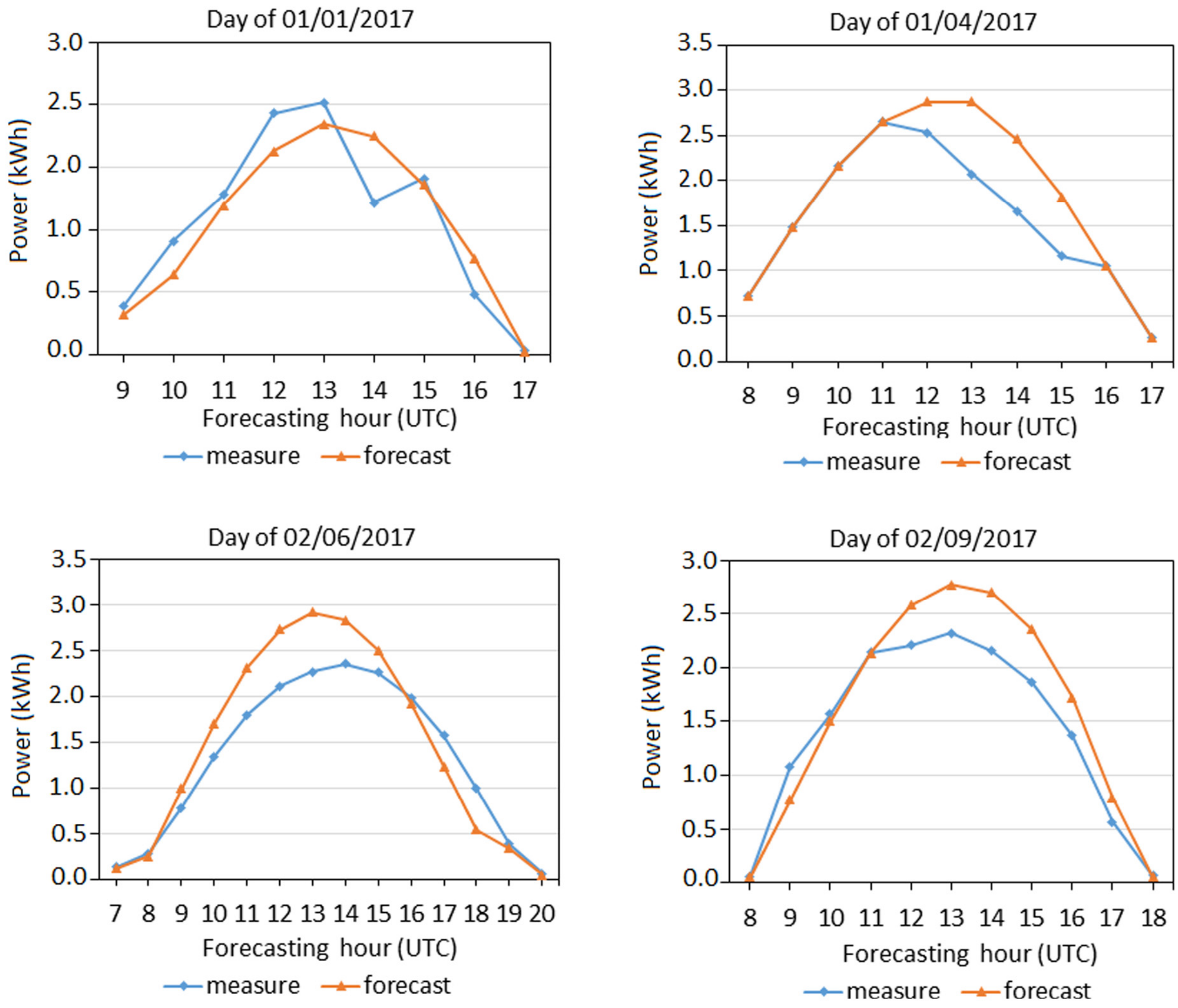

Fig. 3. Measured and forecasted electrical power for a photovoltaic generator with a peak power of 3 kW with surface about 21.6 m^2 of photovoltaic panels.

data are used to do statistical validation covering the period of the year of 2016 and 2017. Results shows clearly that the second method gives a best result particularly for meteorological situation with small and isolated clouds. Through the statistical study, we can say that for the clear sky situations, forecasted radiations values by WRF underestimates the MERRA-2 data however for libRadtran there is an overestimation. As a last step, we modeled the electrical power produced by a photovoltaic generator using a behavioral electrical model, which uses as input the global radiation on tilt plane and temperature at 2 m. The results of the case of study are enough fairly and satisfactory. In this study, we have focus on the forecasting of the global radiation, which has a direct impact on the prediction of electrical power generated by the photovoltaic generator.

Despite the short period of validation, the result of the comparative study are very encouraging. It show globally a good correlation between measured and forecasted power values. We think that a validation on very long period can allow objective criticism.

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