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Model output statistics cascade to improve day ahead solar irradiance forecast

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Abstract

In this paper a new hybrid Model Output Statistics (MOS), named MOS cascade, is developed to refine the day-ahead forecast of the global horizontal irradiance provided by the Weather Research and Forecast (WRF) model. The proposed approach is based on a sequence of two different MOS. The first, called MOSRH, is a new physically based algorithm, built to correct the treatment of humidity in the WRF radiation schemes. The second, called MOSNN, is based on artificial intelligence techniques and aims to correct the main systematic and learnable errors of the Numerical Weather Prediction output. The 1-day and 2-day forecast accuracies are analyzed via direct comparison with irradiance data measured in two sites, Rome and Lugano. The paper shows that a considerable reduction in error was achieved using MOSRH model and MOS cascade. The differences between the two sites are discussed in details. Finally, the results obtained are compared with the benchmark accuracy reached for the data available for the average climate in Southern Spain and Switzerland.

Keywords: Forecast; Solar irradiance; Photovoltaic; Model output statistics

1. Introduction

Intermittent renewable energy presents a big challenge specifically in the reliability of the electric power grid operation. The development and optimization of smart grids has come to the attention of many research centres and recently the European Commission, together with other national and international entities, has boosted its funding towards research in this field. Solar photovoltaic (PV) energy, along with other renewable energies, requires a precise daily or even hourly weather forecast to prevent both power failures and overloads and to manage the power share between the utilities.

At the same time, power produced from PV systems continues to increase, grabbing a bigger slice of the energy

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market day by day. For these reasons vendors need the forecast of Global Horizontal Irradiance (GHI) to be as accurate as possible in order to calculate the energy production of the plants and for critical decision making in energy trading.

The most commonly used methods for the day ahead solar irradiance forecast (24/72 h horizon) are based on Numerical Weather Prediction models (NWP). These models are simulation software able to provide the numerical integration of the coupled differential equations describing the dynamics of the atmosphere and radiation transport mechanisms. The NWP models can be classified in two main categories: the global models, such as IFS (European Centre for Medium-range Weather Forecast), GFS (Environmental Modeling Centre) and GEM (Environment Canada Center), that simulate the whole earth atmosphere and the mesoscale models, like MM5 and WRF, which cover a smaller geographical area and have a higher resolution using initial boundary conditions extracted from the global models.

A comparison of main Numerical Weather Prediction models (global and mesoscale) for solar irradiance forecast in different locations can be found in Perez et al. (2010, 2013) and Muller and Remund (2010).

Even if the NWP models take all the main physical processes that govern the atmosphere into account, these processes are only an approximation. Moreover the non-linearity of the governing equations leads to a strong dependence on the initial conditions used for the numerical integration. This chaotic behaviour of the system is amplified even more because the initial conditions come from a heterogeneous and irregularly distributed observational network that can be too sparse in some regions of the world therefore providing insufficient data. In addition, the spatial resolution of the integration grid is too coarse with respect to the PV plant size and the temporal output interval may be greater than one hour. Furthermore, NWP models are not finely tuned for radiation forecast even considering the most recent sophisticated radiation schemes, which are implemented in current meteorological models. Indeed, the radiation schemes usually run independently from the governing equations of a NWP model making rigid assumptions for sub-grid cloud variability and showing little ability to translate quick changes in meteorological conditions, especially for cloud cover and humidity. As a result the NWP outputs still do not reach the desired accuracy and they are often affected by systematic errors.

For these reasons, outperforming forecasts could be achieved by post processing techniques called Model Output Statistics (MOS) that use ground measurements to remove bias and learnable errors from the NWP data.

Several MOS that use statistical analysis or stochastic learning techniques have been developed by various authors. A pure statistical post-processing correction of the bias errors of the NWP data of ECMWF was proposed by Lorenz et al. (2009a). This seems to be the best performing MOS model for global horizontal irradiance forecast (Lorenz et al., 2009b). Perez et al. (2007) developed a semi empirical model that correlates the NWP sky cover (provided by the National Digital Forecast Database, USA) with the global horizontal irradiance.

Other authors set up MOS models based on stochastic learning approaches. In Marquez and Coimbra (2011), Huang et al. (2010) and Yona et al. (2008) the Multi Layer Perceptron Neural Networks (MLPNN) were used, and in Wang et al. (2011) this Artificial Neural Network (ANN) architecture was coupled with the Gray Model. The Radial Basis Function Neural Network is developed in Chen et al. (2011) and Yona et al. (2008) while the non-linear autoregressive network with exogenous inputs in Cai et al. (2010). Recurrent Neural Networks and Diagonal Recurrent Wavelet Neural Networks were implemented in Cao and Lin (2008) and Yona et al. (2008).

An overview on solar irradiance and PV power forecast techniques can be found in Paulescu et al. (2013), Kleissl (2013) and "Photovoltaic and Solar Forecasting: State of the Art", IEA PVPS Task 14 (2013), while a complete study on solar radiation benchmarks is reported in Lorenz et al. (2009b), Beyer et al. (2009) and Traunmuller and Steinmaurer (2010).

One of the most used Mesoscale models is Weather Research and Forecast (WRF) – Advanced Research WRF (ARW) developed by the National Center of Atmospheric Research (NCAR), USA.

The aim of this work was to refine the irradiance forecast coming from WRF using a sequence of two different MOS.

The first post processing technique (MOSRH) is a new physical based algorithm that improves the forecast of the concentration of water vapour in the atmosphere. It uses regression coefficients that can be calculated from ground measurements, with the intent of reproducing more realistic absorption curves that take into account the entire vertical column of the atmosphere.

The second post processing approach (MOSNN) is based on stochastic learning algorithms that use Artificial Neural Networks ensemble to correct the NWP bias error. It was effectively used in a previous study (Cornaro et al., 2014) to refine the irradiance prediction of ECMWF reaching a considerable level of improvement in forecast accuracy. Thus the MOSNN has been used to refine the MOSRH output generating a hybrid MOS called "MOS cascade".

There are two main reasons for using this MOS cascade. Firstly, the MOSNN, when applied to the MOSRH output, can remove all the learnable errors not directly related to the forecast of humidity. Secondly, the MOSNN can directly provide the PV energy forecast, without the need of any further calculations, if trained with the power data produced by a PV plant. Indeed one of the advantages of the MOS based on stochastic learning techniques is that the variable predicted by the MOS (as PV energy) can be different from the input data provided by the NWP forecast (as GHI).