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Ensemble forecasting of solar irradiance by applying a mesoscale meteorological model

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ABSTRACT

The solar irradiance and its prediction interval are forecasted with the aid of a meteorological model for the prediction of the photovoltaic systems generation. The solar irradiances of the same target day are computed utilizing a model with different initial conditions, and the accuracy of the forecasting is discussed in this paper. Forecasting reliability is also estimated from the variance of the forecasted irradiances. The relationship between the forecasted reliability and the forecasting error is derived, and the prediction interval of the solar irradiance forecasting is evaluated from both its reliability and relationship. The performance of the probabilistic forecasting of the solar irradiance which consists of the prediction interval is discussed in the observation. The size of the prediction interval changes as the forecasting reliability varies. The observed data in the interval is almost the same rate as the coverage rate determined in advance.

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1. Introduction

In order to reduce greenhouse–gas emissions caused by conventional energy–production units, huge amounts of solar power systems have been installed and connected to the electric power grids in recent years. However, solar energy is predominantly affected by weather conditions. Besides, the fluctuation of photovoltaic (PV) power generation due to the weather is an uncertain factor in the electric grid management. Forecasting solar irradiance is the first and the most essential step in the prediction of PV–power generation, and it will be applied in electric grid managements, solar–energy project assessments (Kleissl, 2013), etc. Nevertheless, the forecasting error induces a relatively large influence on the prediction of the PV generation (Lorenz et al., 2009a).

Attempts in solar irradiance forecasting commenced more than thirty years ago (Jensenius and Cotton, 1981). Up to the present, different approaches to forecast solar irradiance in different time horizons have been proposed. Reikard (2009) applied statistical models and forecasts to the irradiance by analyzing historical data. Hammer et al. (2003) and Tyukhov et al. (2012) analyzed satellite images for irradiance forecasting. Perez et al. (2007) picked up sky cover from weather forecasting database and converted it to solar irradiance by applying a method developed with satellite image processing. Chow et al. (2011) monitored cloud conditions with a total sky imager to forecast solar irradiance. Zamora et al. (2005), Lorenz et al. (2009a,b), Lara-Fanego et al. (2012) and Perez et al. (2013) represented the physical atmospheric conditions by applying numerical weather prediction (NWP) models to forecast solar irradiance. Perez et al. (2010) compared the solar irradiance forecasts with some approaches, and showed that the satellite–image approach was better than others for a 5–h ahead forecasting; but after that, the NWP forecasting became better. The forecasting horizon of the present work is intra-day and several days ahead; therefore, an NWP model is employed here for solar irradiance forecasting.

Weather forecasting always comes with uncertainties. The weather condition is one of the factors affecting forecasting reliability; the reliability may be high under stable conditions, but there is a large risk in wrong forecasting under unstable weather conditions. A large error in weather forecasting or solar irradiance forecasting leads to the wrong prediction of PV generation, and therefore causes the instability of the electric power grid supply when a large number of PV systems are connected to the grid. To

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avoid the instability risk of the grid power supply, the electricity reserve should be considered in the grid management. The amount of reserve for the fluctuation of PV generation can be evaluated from the reliability of the solar irradiance forecasting or PV generation prediction. Fonseca Junior et al. (2015) forecasted the irradiance utilizing a meteorological model and evaluated its confidence interval with a statistical model. Monteiro et al. (2013) also evaluated the interval with weather forecasting and database of weather and PV generation. In meteorology, an ensemble method (Palmer et al., 2000; Richardson, 2000; Furukawa and Sakai, 2004; Wei et al., 2008) is used to evaluate the reliability of the weather forecasting for researches and also for commercial operations.

In this work, the ensemble method with a meteorological model is employed to evaluate the reliability and the prediction interval of the solar irradiance forecasting for the prediction of PV generations.

2. Solar irradiance forecasting with a meteorological model

2.1. Meteorological model

The Weather Research and Forecasting (WRF) model (Skamarock et al., 2008) is employed in this work for forecasting weather and solar irradiance several days ahead. This model is a fully compressible, non–hydrostatic mesoscale model developed by the National Centers for Atmospheric Research (NCAR) and the National Centers for Environmental Prediction (NCEP). This model is commonly used in the meteorological field throughout the world these days. This model is also used extensively for the estimation of renewable energy resources, because it can simulate realistic weather with high resolution. For example, Heinemann et al. (2006) investigated the resources of solar energy in recent years based on daily weather forecasting using this model.

2.2. Target area and observation data

Our target area for the solar irradiance forecasting is central Japan: namely, Nagano, Gifu, Aichi, Mie and Shizuoka Prefectures.

There are 61 observation sites for solar irradiance in the area. Fig. 1 shows the location of the sites. Each site measures solar irradiance on horizontal ground plane (Global Horizontal Irradiance, GHI) with a 10–s frequency. The observed data are used for the verification of the forecasting with WRF and also for the evaluation of its prediction interval.

The computational domains with WRF are set as shown in Fig. 2. The resolution of the domains D01, D02 and D03 are 18 km, 6 km and 2 km, respectively, and they are nested in two–way; therefore the meteorological data computed in course and fine grids are exchanged interactively through the side boundaries. All of the 61 observation sites lie in the domain D03.

The GHI is measured with 10-second interval on the sites. The high resolution data contain short–term fluctuations, but the averaged irradiance is considered for the applications (Lorenz et al., 2009a). The observation data are, therefore, smoothed as 30–min averages and then averaged over all sites, because they operate in the area under one commercial electric power grid. The WRF outputs are also averaged in the same way as the observation data. Fig. 3 depicts the time series of the observed GHI from 10–s interval, 30–min average at a single site (136.9°E, 35.1°N) and 30–min average from all 61 observation sites during daytime on July 1st, 2013. The fluctuation of GHI at a single site is reduced and the trend of the time variation of the irradiance is emphasized by calculating the mean value in time and space as shown in this figure.

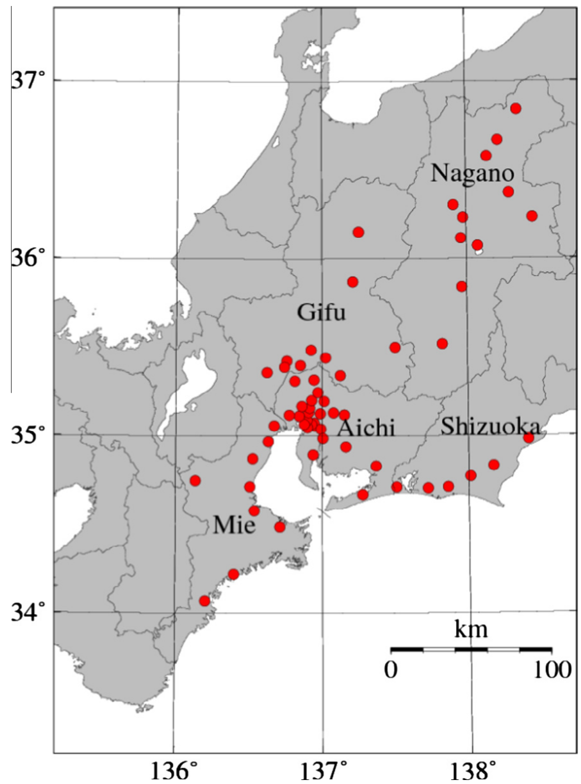

Fig. 1. Target area of the solar irradiance forecasting and observation sites (red dots). This area corresponds to the Domain D03 in Fig. 2 and Table 1. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

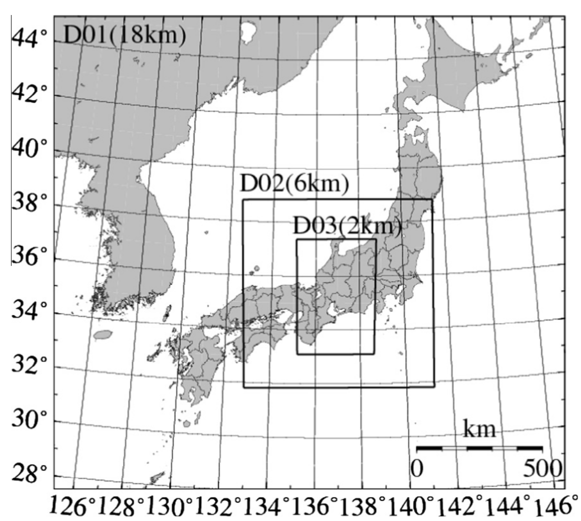

Fig. 2. Computational domains of the WRF.

2.3. Computational conditions

The computational settings for the weather forecasting with WRF are summarized in Table 1. The Japan Meteorological Agency (JMA) Global Analysis data for the Global Spectral Model for Japan Area (GSM–JP, Japan Meteorological Business Support Center, 2015) ($0.2° \times 0.25°$and 3–h time interval, 72–h ahead), the analysis data of Global Forecast System (GFS) ($0.5° \times 0.5°$and 3–h time interval, 72–h ahead) from the National Center for Environmental Prediction (NCEP, 2015), and the Operational Sea Surface

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