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Data-driven short-term forecasting of solar irradiance profile

Poh Soon Loh[a,*], Jialing Vivien Chua[b], Aik Chong Tan[b], Cheng Im Khaw[b]

[a]*Energy Market Authority, 991G Alexandra Rd, 119975, Singapore*
[b]*Institute of System Science, National University of Singapore, 25 Heng Mui Keng Terrace, 119615, Singapore*

Abstract

Autoregressive and non-linear models are frequently used for solar irradiance forecasting, and their results are found to vary depending on the forecast horizon, time resolution and location. Given that higher accuracies are often reported at lower time resolutions and areas with less cloud cover, it was found necessary to separately assess the applicability of models for tropical Singapore where high solar irradiance variabilities are experienced.
This paper presents a short-range forecasting system of 30-min irradiance averages for 0.5 to 6 hours ahead based on per-min data of solar irradiance and ambient temperature. In addition, it explores the possibility of predicting volatility by looking at the distribution of solar irradiance in the next 30-min period with a novel approach that estimates the proportion of points within each of 21 bands defined to cover the range of irradiance. With it, upper and lower bound predictions for the period are obtained to calculate upside and downside risks posed by photovoltaic (PV) generation. Using persistence models for comparison and assessing accuracy across 8 locations, all models showed marked improvement, especially at longer forecast horizons. On average, MAE of point forecast models decreased by 9% (98 to 89 W/m^2) and 58% (299 to 125 W/m^2) for the 0.5 and 6-hour horizons respectively. For volatility models, MAE decreased from 4.8 to 3.7% in proportion predictions while errors of making upper and lower bound predictions outside the actual range of per-min fluctuations decreased from 43.0 to 10.4% and 30.6 to 3.4% respectively.

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Keywords: short-term forecasting; solar irradiance; volatility prediction;

* Corresponding author. Tel.: 68727338; fax: 68727300.
E-mail address: LOH_Poh_Soon@ema.gov.sg

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1. Introduction

Solar energy has been identified as the most viable renewable source for electricity generation in Singapore. However, due to its intermittent and non-dispatchable nature, a high penetration of photovoltaic (PV) in the power grid may lead to reduced load predictability and increased variability in voltage and frequency, resulting in grid instability [1]. In anticipation of continued and large-scale adoption of PV, it is hence crucial to obtain accurate solar irradiance predictions to maximize the value of solar energy while minimizing the impacts associated with its variability.

2. Related Works

The forecasting of global horizontal irradiance (GHI) has been investigated by many. Among all methods studied, classical time series models such as autoregressive integrated moving average (ARIMA) models have been used most widely. However, as the amount of solar irradiance received depends on multiple meteorological elements like temperature, water vapor, suspended solids and cloud cover, these methods have been proven inadequate for the prediction of GHI [2].

To represent these characteristics, nonlinear models such as artificial neural networks (ANN) have been explored for GHI estimation. Although these models had the advantage of not requiring knowledge of internal system parameters, they presented large forecasting errors [2]. Understanding that no single model consistently provided better forecasts in all solar irradiance contexts, ensemble learning techniques which combined different models were hence used to improve forecast performance [2-4].

In modeling, GHI is commonly converted to a transmissivity measure called the clearness index, in order to obtain a stationary series. The clearness index k is defined as the ratio of irradiance observed at ground level (GHI) to irradiance at the top of the atmosphere (GHI_{TOA}) [5]

$$k = GHI / GHI_{TOA}$$

For comparison of models, clearness index persistence is often used as a baseline, where the last available observation of k is used as the next forecast. Through multiplying the forecasted k by the expected GHI at the top of atmosphere for the following period, the final forecasted GHI can be obtained with corrections made to account for changes in solar elevation in time [6].

3. Motivation

Examining results published, it was found that model accuracies varied widely depending on forecast horizons (ranging from 15 minute to 72 hours ahead), time resolutions (of 15, 30 or 60-minute averages), and geographical location. Moreover, errors were found to be largely reported as a singular aggregated figure across the day even though errors tended to be greater during midday. As a result, a separate study was found necessary to determine possible forecast model capabilities and assess applicability in tropical Singapore where intermittent rains and cloud cover are common occurrences, and high solar irradiance variabilities are experienced.

Defined by the schedules of transactions in the local wholesale electricity market as well as limitations in generator start-up, it was established that GHI forecasts are required for each 30-minute period over the next 6 hours. In addition, it was found that an average forecast per period was insufficient as it could not account for intra-period variability which impacts grid operations.

4. Data

4.1. Collection and preprocessing

For this study, per-minute GHI and ambient temperature sensor data recorded at 8 different locations in Singapore were used. To avoid using erroneous data, the following rules were applied:

- If a negative GHI reading is detected, it is zeroed