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Quantifying variability for grid-connected photovoltaics in the tropics for microgrid application

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Abstract

This paper quantifies the variability of solar resource for PV systems located in the tropical climate. Global horizontal irradiance data is obtained from a site in Melaka, Malaysia with one-minute-average values for a full year. Clearness index and variability index are used together with a clear sky model for tropical location to classify the days according to its fluctuation profile. The results show that significant amount of variability occur throughout the year for this site while days with clear skies are almost negligible. PV can potentially supply part of the loads during the day but precise planning on storage and backup generators is crucial for independent microgrid operation.

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Keywords: *grid-connected photovoltaics; solar variability; microgrid; tropical climate.*

1. Introduction

Countries located in the equatorial region with tropical climate enjoy high amounts of daily sunshine throughout the year as it experiences almost no seasonal variation. This pose an advantage in continually harvesting and utilizing solar energy. Another advantage is that the peak power produced from PV

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systems generally correlate with the industrial and commercial peak demand. Effective and economical measure to tap this resource can greatly enhance the proliferation of grid-connected PV systems.

However, variability of solar resource is a crucial element that needs to be considered. Solar resource variability is mainly caused by two factors, the sun's daily movement and cloud cover. The former factor is deterministic in the sense that it can be calculated with very high precision. However, the latter is stochastic and is known to cause significant ramps in solar irradiance and PV power output [1] .

Variability profiles are location dependent. This is because each location is subjected to different climates and local weather conditions. Even places situated within a few kilometres of each other can have different weathers at the same time due to different microclimates. Therefore it is vital that studies on the variability characteristics are conducted based on the location where PV systems will be utilised [2].

The objective of this paper is to quantify the solar variability of a single-site PV system in a tropical climate. This information is useful, particularly for microgrid operation where power output smoothing through geographical dispersion of PV systems is not possible. The quantification involves determining the categories of variability happening throughout a year, its severity and respective timeline.

2. Methodology

2.1. Data

The measured Global Horizontal Irradiance (GHI) values used in this paper are obtained from a weather station located on the rooftop of the Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka (2.32ºN, 102.3ºE). The weather station is equipped with two pairs of Kipp and Zonen's CMP 11 pyranometers located approximately 40 meters apart that measure horizontal and plane of array (POA) irradiance (15º tilt, facing South). Data from one of the GHI pyranometer is selected. GHI is chosen over POA irradiance since the former is more generic. To convert to equivalent POA values, transposition models can be applied with sufficient accuracy. The data is taken every second and stored in a main and backup server. For this paper, the data are averaged every minute and the duration is from 1 January 2015 to 31 December 2015, a full year to account for seasonal variation. Only three days are omitted from this dataset (11, 14 and 17 June) due to missing and incomplete data.

2.2. Solar resource evaluation

In order to quantify the solar resource, two indices are used to classify the type of days that occur--the daily Clearness Index, *CI* [3] and daily Variability Index, *VI* from Stein, Hansen and Reno [4]. *CI* is defined as the ratio of the measured irradiance at the earth surface with the horizontal extraterrestrial radiation reaching the outer surface of the atmosphere and can be written as:

$$CI = \frac{G_{meas}}{I_o E_0(t) \cos\theta_i(t)} \tag{1}$$

with I_0 = 1367 W/m^2 ,the solar constant, E_0 the earth eccentricity factor and θ is the incidence angle which is latitude dependent. In essence, it is a ratio of irradiance with losses and ideal irradiance. Typical values range from 0.2 during overcast condition to 0.7 during clear skies.

VI is a relatively new index that is introduced as a simple measure of irradiance variability over a time period and can be written mathematically as