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Daily clearness index profiles and weather conditions studies for photovoltaic systems

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Abstract

The increasing number of distributed photovoltaic (PV) systems connected to the power grid has made system planning and performance evaluation a challenging task. This is mainly due to the computational complexity, such as load flow analysis with large irradiance datasets collected from various locations of the installed PV farms. Solar irradiance data are known to possess the characteristic of high uncertainty, due to the random nature of cloud cover and atmospheric conditions. This paper presents the studies on the relationships of clustered clearness index profiles and the weather conditions obtained from the weather forecasting stations. Four years of solar irradiance and weather conditions data from two locations (Johannesburg and Kenya) were obtained and are used for the analysis. The preliminary study shows that the weather condition is related to the daily clearness index profiles. This work will form the basis for estimating the daily clearness index profile with weather conditions.

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Keywords: photovoltaic system; clustering; clearness index

1. Introduction

Photovoltaic (PV) systems are being connected to the grid via the distribution systems at an exponential rate [1]. This is the result from reduced cost and increased in economy of scales of PV systems [2]. The transition in the way power is generated is welcomed by the government and environmentalist. Green energy, i.e. solar PV can reduce the

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carbon emission and environmental pollutions. However, this also poses a serious problem for system operators. Power and voltage fluctuations on the grid are the main concerns, as a direct result from the non dispatchable PV generation. The problem is worsened with the fact that PV systems in general are of small scale and situated in various locations. Feed-in-tariffs from various countries promote the installation of small scale PV farms, typically of kilowatts. The solar irradiance can be of significant difference at different locations due to the climate and cloud cover. Large scale irradiance datasets are required for detail analysis of the PV farms to the grid in order to prevent brownouts and blackouts.

Currently, irradiance fluctuations are mostly studied with statistical techniques [3-9]. The advantage of these methods is that few parameters can be used to characterize the massive quantity of data. Clearness index (CI) can be useful in studying the fluctuations for solar energy applications [6, 10-12]. The diminish impact of the atmosphere on solar irradiance with respect to the amount of extraterrestrial solar irradiance that reaches the surface of the earth can be presented by CI.

The recent work in [13] presents a study in cluster analysis of daily CI profiles. This work aims to study how well the proposed clustering method correlates with the weather forecasting information, i.e. weather conditions. This will confirm the dependency of the CI and the weather conditions and in addition, the accuracy of the clustering results. The results will also suggest that the clustering procedure can be applied to other locations for PV system evaluations, such as sizing and distribution system load flow analysis. This will be useful in estimating the CI profiles with limited weather conditions data. Also, it provides a validation method for the cluster analysis results and to confirm the generality of the clustering approach.

One of the major issues that needs to be addressed is the question of “How is a ‘Clear day’ defined?”. As an example, can a day with strong cloud cover in the noon for two hours and with no cloud for the rest of the day be classified as a ‘Clear day’? This question will be explored and addressed in the paper. Section 2 presents the formal definition of CI. The cluster analysis results of Kenya with Fuzzy C-Means Dynamic time warping (FCM DTW) will be given in Section 3. Section 4 will present the study of weather conditions and clearness index. An algorithm is proposed to determine the percentage of clear days from a set of daily weather conditions. Conclusion and future work are given in Section 5.

2. Clearness Index

The solar irradiance received on the ground will be equal to the value of the solar constant subtract the amount of atmospheric absorption under the ideal atmospheric condition. In general, the global solar irradiance consists of two main components, these are known as diffuse sky irradiance and the direct beam component. Typically, the real-life solar irradiance collected for solar application studies is from a pyranometer device. It measures the solar irradiance on a flat surface and measures the solar radiation flux density in W/m^2. The CI is calculated from the data obtained from the pyranometer data and clear sky model. The CI has a value between 0 and 1. The value 0 signifies that a total cloud cover occurs and no irradiance is to be received on the ground. Conversely, a value of 1 signifies that the maximum theoretical amount will be received on the ground. Exceptional cases need to be made when using CI, such as the definition of CI before sunrise and after sunset where the irradiance will be zero. As these conditions are not useful in this study, they will be neglected during the analysis. The equation for CI calculation is given in Equation (1) below:

$$CI(t) = \frac{I_{pyranometer}(t)}{I_{model}(t)} \tag{1}$$

I_{model} is the clear-sky solar irradiance from the solar model and $I_{pyranomter}$ is the real-life solar irradiance at time t. The clearness index obtained in this work are calculated from the clear-sky solar irradiance model in [13]. Various variables are incorporated in the solar model to compute the clear-sky solar irradiance. These include correction factor to mean solar distance, optical air mass corrected for station height, solar altitude angle and Rayleigh optical depth.