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Correlations of Light Intensity and Humidity Factor on Power Performance for Fixed Flat PV generator. A short term field Evaluation in the Tropics

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Abstract. This paper shares some field observations for two environmental factors of humidity (% RH) and light intensity (Lumens) towards the field performance of 1 kW Fixed Flat (FF) PV generator system installed in tropical ground condition. The reliability, energy efficiency and durability of PV generators largely depends on environmental factors due to its locality nature to be installed outside and withstanding extreme weather conditions up to 20 years of thermal cycles. Results from the multiple linear regression (MLR) technique and analysis of variance (ANOVA) shows that light intensity and humidity projects a fairly strong correlation factor of 0.89 within the specified confidence intervals.

Keywords: Fixed PV, ANOVA, Tropics, Light Intensity, Humidity

1. Introduction

Adaptation of Solar PV technology and application in tropical-based country like Malaysia requires in-depth research work in various aspects especially environmental conditions [1]-[3]. Although Malaysia enjoys a uniform temperature throughout the year, it is however, extremely rare to have a full day with completely clear sky in various seasons even in periods of severe drought. On the average, Malaysia receives about 6 hours of direct sunshine per day where it's seasonal and spatial variations are thus very much the same [4]. The Government of Malaysia has approved and officially started the Fit-In-Tariff (FiT) Enactment of the Renewable Energy Law by third quarter of 2011 to show full commitment in pursuing solar PV potentials for Malaysia which is estimated to be 1,370 MW by the year 2030 [5]-[8]. Solar PV received the highest FiT rate compare to the other RE resources with the rates of RM1.25 to RM1.75 for the duration of 21 years with 8% degradation [7], [8].

Generally, a photovoltaic solar cell consists of two layer semiconductor material which in non radiated condition. The concept of electricity generation via PV Cell comes from the sun radiation or Photonic Effect towards the surface of PV cells. Piazza et al. in [9] explains that through doping process, the solar Grade silicon cell treated with negative and positive charged semi-conductor excites electrons which flow within the cells. The electron flow process from Negative Junction (Phosphorous) to Positive Junction (Boron) creates the electron-hole pair that yields current also known as PV Effect.Around the globe, research in Photovoltaic cell and processing technologies are focusing on new approach to reduce cost via reducing the number of processing steps with high consideration of overall performance and efficiency [10], [11]. This

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trend is further continued for the durability and reliability testing procedures under the Standard Testing Conditions of IEC 61215 before it can be certified for public usage [12], [13].

The reliability, energy efficiency and durability of PV generators largely depends on environmental factors due to its locality nature to be installed outside and withstanding extreme weather conditions up to 20 years of thermal cycles. The PV modules deployed in tropical regions are exposed to a different set of environmental conditions where it poses several unique challenges for PV modules where high year-round humidity is the greatest threat to PV module durability, while high ambient temperatures and highly diffuse light conditions can negatively affect PV module output power [1]-[15]

The light intensity factor obviously correlates directly with the sun radiation as the main energy source for PV system but for humidity factor, it is inversely correlated. Recent study by [16], [17] have shown that power output efficiency from PV modules degrades with the increase in moisture content due to high percentage of surrounding humidity ingress with very high value of efficiency drop of 63 % for mono-Si PV modules which suffers from biased damp heat tests at 85 % relative humidity condition.

Koehl et al. in [18] highlights that water element is considered as an important degradation factor for PV-modules by causing hydrolysis of polymeric components, corrosion of glass and of metallic components like grids and interconnectors where from this condition, the type approval testing of Damp-Heat test and Frost-Thaw test under IEC standards is conducted to estimate the service life of a module. Humidity by means of moisture weakens the reliability of PV modules and this is largely related to the packaging process which could reflect delamination of encapsulant and warpage of PV cells [19]. This study projects some field observations for two environmental factors of humidity (% RH) and light intensity (Lumens) towards the field performance of 1 kW Fixed Flat PV generator system installed in tropical ground condition.

2. PV Generator Setup

The Fixed Flat PV generator system shown in Figure 1 configures 12 units of CEEG 95W PV Modules with the characteristic of 95 W maximum power (P_{max}), open circuit voltage (V_{oc}) of 22.32 V, short circuit current (I_{sc}) of 5.52 A and cell efficiency of 17.5 %. The PV modules are customized in serial connections to produce the desired DC output power for grid-tied applications.

Fig. 1: Field setup of 1 kW Fixed Flat (FF) PV Generator system. Courtesy of Sichuan Zhonghan Solar Power Co. Ltd.

A unique platform interface for PV monitoring system is developed using Compact Reconfigurable Input Output Device (cRIO) embedded with LabVIEW programming to capture measurement from multiple sources and analyze visually in real-time and synchronize mode which is the crucial aspect for rapid fluctuating data flow. The specifications of the FF PV array, pre-calibrated Light Intensity and RH sensor are described in Table 1.

The correlation coefficient in the ANOVA test are used to measure the strength of the relationship between DC power (in kW), Humidity (in % RH) and light intensity (Lumen) with range between -1 to 1 as the degree of correlation. This approach shows how well trends in the predicted values follow trends in past actual values [20], [21]. It also measures the predicted values from a forecast model to "fit" with the real-life data and this can be written as correlation coefficient as in equation (1).

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2}\sqrt{\sum (y_i - \bar{y})^2}} \quad (1)$$

Table 1: Technical specifications of sensor unit and PV generator

MSO Temperature and Humidity	Photasgard (AHKF) Outdoor Light Intensity sensor	Fixed Flat PV array
		- Common Flat PV array - Series connecting 12 units of CEEG 95W Monocrystalline module - Built up Area: 3.6m × 2.4m - Rated Power : 1 kW - V_{oc} : 22.5 V x 12 = 270 V_{dc} - I_{sc} : 5.56 A_{dc} - P_{dc} : 1.5 kW (rated at STC) - Slanting angle : 7.6 degree tilt angle facing 160^0 South - Open Rack system with Z-strack / PV mounting structure.
- Temperature Range: -40 ℃ to +60 ℃ (may be set to Fahrenheit) - Temperature Resolution: 0.1 ℃ (may be set to Fahrenheit) - Temperature Accuracy: ±0.5 ℃ (may be set to Fahrenheit) - Relative Humidity Range: 0 - 100% - Relative Humidity Resolution: 1% - Relative Humidity Accuracy: ± 4%	- Power supply : 24V AC/DC (current consumption max. 10mA) - Sensor : Photodiode with glass case - Measuring ranges : 0 – 100 kLux - Output : 4 – 20 mA (active) or 0 – 10 V (linearised) - Measuring error : 10 % of final value - Enclosure : Plastic, material polyamide, 30% glass-globe-reinforced - Dimensions: 72 x 64 x 39.4 mm - Protection Type : IP 65 - Standards : CE conformity, electromagnetic compatibility (EN 61326, EMC directive 2004/108/EC	

The Multiple Linear Regression (MLR) projects a linearly correlated mathematical model *n* given observations can be denoted as equation (2) for general multiple linear function

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \beta_3 x_{i3} + \varepsilon_i \quad \text{for } i = 1,2,\ldots.n \quad (2)$$

The MLR technique observes the varying value of y by expressing the overall correlation as Data = Fit + Residual, where the β represents the Fit terminology and the ε for the residual or deviations of the observed and mean values of y. Daily samples of trend analysis for Humidity and Light Intensity for KLIA, Sepang, Malaysia weather station is shown in Figure 2. The sample duration is taken as daily mean from January 2012 until July 2013.

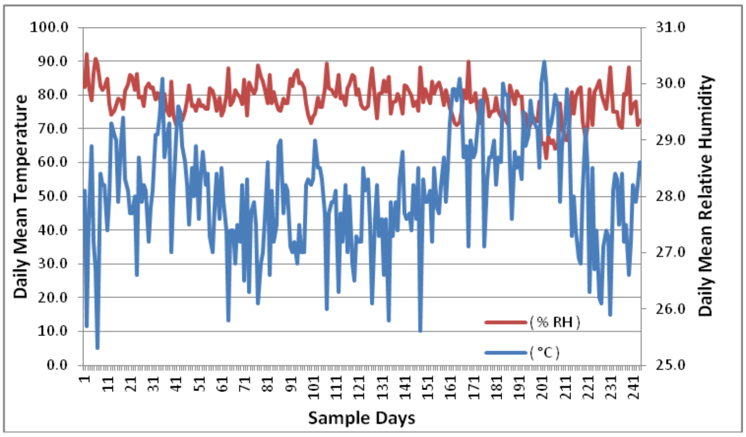

Fig. 2: Daily trend for mean ambient temperature and relative humidity. Source purchased from Meteorological Department of Malaysia.

3. Results and Discussion

The data at site is observed based on 151 samples of 15 minute intervals in synchronize mode as shown in Figure 3 for light intensity and humidity. It is taken for approximately 10 hours each day from sun rise till sun set.

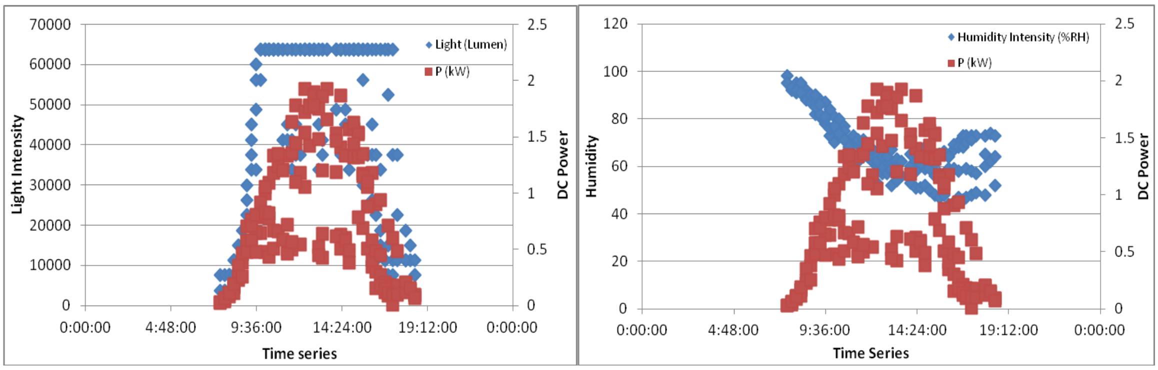

Fig. 3: Data of Light Intensity and Humidity vs DC power

The results from MLR and ANOVA test shows that strong correlation of R^2 = 0.89 between the each factor of DC Power and variables of humidity and light intensity with fairly good regression fit within acceptable confidence interval range.

Table 2: Correlation coefficients between dependant and independant factors

	Humidity Intensity (%RH)	*Light (Lumen)*	*P (kW)*
Humidity Intensity (%RH)	1		
Light (Lumen)	-0.520224338	1	
P (kW)	-0.371401293	0.628305271	1

An increase of 10 % RH results in reduction of 5.2 lumens of light intensity and it flows the same with DC power with reduction of 3.7 kW for every increment of the RH as shown in Table 2. For a tropical base ground condition, more than 90 % of RH reflects the condition of heavy rain and thick cloudy sky with very high moisture content. From the linear correlation approach a unique mathematical model for DC Power (P_{dc}) can be denoted as

$$P_{dc} \text{ (kW)} = 0.63 * \text{Light Intensity (Lumen)} - 0.37 * \text{Humidity (\% RH)} \qquad (3)$$

4. Conclusions

The study confirms the fact that the power generated from PV modules correlates directly with the increase of light intensity by the factor of 0.63 and inversely correlated with humidity ingress by the factor of 0.37. This finding is especially important for PV manufacturer and installer as to forecast the energy generation and load consumption for PV generators installed in the tropics.

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