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Empirical Performance And Parametric Analysis Of Photovoltaic System In Uyo

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***Abstract*— The paper presented an empirical evaluation of polycrystalline and monocrystalline photovoltaic (PV) modules performance for roof-mounted and ground-mounted installations. The data used were obtained from experimental setup at the University of Uyo in Akwa Ibom State, Nigeria. Module temperature and power models were empirically developed as functions of solar irradiance and ambient temperature for each of the PV installations. The developed models performance was expressed in terms of root mean square error (RMSE) and R-squared indices. Thereafter, the models were used to predict the module temperature and power for the four PV installations considered in the study. Comparative analysis of the results obtained showed that the polycrystalline PV module performed better than the monocrystalline PV module even though both were exposed to the same environmental conditions. The ground-mounted module performed better than the roof-mounted for the two types of modules used in the study. Also, the power delivered by the two modules was less than the name plate rating. The power at standard test condition (STC) for the two modules was 80 W but the actual power produced is 55.5 W and 54 W for the polycrystalline and the monocrystalline modules respectively at solar irradiance of 1000 w/m2. Notably, the power produced by the two types of module in the study represents 68.7 % of the STC rated power for the polycrystalline module and 67.5.0 % of the STC rated power for the monocrystalline module. The results highlighted the importance of using the actual field performance of photovoltaic modules when designing any PV system so as to avoid low performance or failed system. Designers of PV system will find the models developed in this study useful in predicting module temperature and realistic PV module power output taking into consideration the effect of operating ambient and module temperatures.**

Keywords*— *Photovoltaic, PV Module Temperature, Roof-Mounted PV, Ground-Mounted PV, Monocrystalline Modules , Polycrystalline Modules, PVPerformance

I. INTRODUCTION

Nowadays, the use of solar energy is gaining popularity in different parts of the world[1,2,3,4,5].This is because solar energy is readily available in many part of the world. In order to harness the solar energy, it has to be converted to electricity. Among other methods, photovoltaic (PV) module is use to convert solar energy from sunlight to electricity by phenomenon called photovoltaic effect. The electricity generated by PV module depends on the environmental conditions and load profile as well as installation method [6,7,8,9].

Usually, PV module manufacturers specify the PV parameters and rating based on the standard test condition (STC) values. However, in practice, performance testing of the PV modules at outdoor operating conditions is required to have an accurate estimation of the power output under specific weather conditions. There are many models that can be used to estimate the PV system performance but the models sometimes give different results [10].

Furthermore, there is a marked difference between the operating conditions of a roof mounted PV and ground mounted PPV modules. Not many studies have been done in comparing performance of ground mounted and roof mounted modules. Among the factors affecting PV performance, operating temperature accounts for 50% [11]. The concept of PV performance investigation is to relate the input energy which is the sun to the output energy which is electricity.

In practice, installers of PV use NOCT as a suitable value of module temperature. However, the actual operating temperature need to be determined and is a key parameter for estimating the actual performance of PV panels considering the location, installation method and PV type.

PV installations in Uyo are mostly roof mounted. This study is to evaluate the effect of the rooftop materials on the module operating temperature and compare the performance for ground mounted and the roof mounted polycrystalline PV systems. Models for estimating PV module operating temperature and power output were developed for polycrystalline PV system. The models were developed empirically using data collected from the empirical field measurements.

II. METHODOLOGY

A two months data measurement of PV modules parameter was carried out for polycrystalline module installed at the

Faculty of Engineering University of Uyo. For comparative analysis, the module parameters were measured for ground and roof mounted PV modules. This allowed the effect of roof temperature to be investigated with respect to the module temperature and power output. The module temperature and power models were developed for the two PV installation methods–i.e. roof mounted and ground mounted. Models for predicting module operating temperature and power output were developed for the two installation methods by applying linear regression on the field measured data.

A. EXPERIMENTAL SET UP

The PV panel rated 80W/m^2 at STC was placed on a horizontally support but clear from any form of shading. Two test scenarios were considered. These are ground mounted and roof (zinc) mounted installations. Prior to carrying out the test, the module was cleaned and allowed to sit in the sun to reach thermal equilibrium. Figure 1 shows the block diagram of the experimental setup

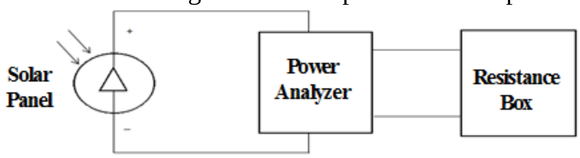

Figure 1: Block diagram of the experimental setup

Solar radiation was measured using a hand held solar power test meter with model number SM206 and resolution of 0.1W/m^2. The ambient temperature was measured and recorded using hand held thermometer. The module temperature was measured directly using a non-contact infrared thermometer. Power analyzer was used to measure the voltage, current and power from the PV. The variable resistor resistance was varied from 0 Ω to 100 Ω and data at maximum power point of the PV module were recorded. The maximum power point of the PV module occurs when the load impedance is equal to the optimal internal resistance value of the PV module [12].

B. DATA COLLECTION AND MEASUREMENT

In this study, two sets of data were measured: these are electrical and environmental data. The electrical data measured included voltage, circuit current and power output. Environmental data measured include solar irradiance, ambient temperature, and module temperature. These data were gotten for both the roof mounted and ground mounted panels. The recorded data was the average of five data sample taken within a period of two minutes.

C. EMPIRICAL MODELLING OF THE PV MODULE TEMPERATURE

The operating temperature plays an important role in the photovoltaic conversion efficiency, hence, the power output of a PV module. Many models correlating module temperature and weather variables such as ambient temperature and irradiance exist. One of such models that relate the PV module temperature, ambient temperature and solar irradiance is given by [13];

$$T_{MOD} = T_{AMB} + KG_{MOD} \quad (1)$$

Here, T_{MOD} is the module temperature, T_{AMB} is the ambient temperature, G_{MOD} is the irradiance on the plane-of-array of the PV system and K is the Ross coefficient. This Ross coefficient K depends on installation method, location and module type. The main difficulty in application of this model is accurate determination of K for a particular installation method, location and type of module. The Ross Coefficient K, for each installation method is determined using linear regression method as given as;

$$K = \frac{n\,(\Sigma G_{MOD} \times \Delta T) - (\Sigma G_{MOD} \times \Delta T)}{n(\Sigma G_{MOD}{}^2) - (\Sigma G_{MOD})^2} \quad (2)$$

Where n is the number of dataset, ΔT is change in temperature ($T_{MOD} - T_{AMB}$) and G_{MOD} is the solar radiation.

D. THE TEMPERATURE MODEL FOR THE GROUND-MOUNTED POLYCRYSTALLINE PV MODULE

In order to determine the Ross coefficient,Kfor ground-mounted polycrystalline PV installation, Equation 2 is applied to the measured data using MATLAB code.The value of the Ross coefficient K, gotten is R = 0.0382. then, substituting K = 0.0382 into Equation 1, the temperature model for ground-mounted polycrystalline PV installation is given as:

$$T_{MOD} = T_{AMB} + 0.0382G_{MOD} \quad (3)$$

E. THETEMPERATURE MODEL FOR THE ROOF-MOUNTED POLYCRYSTALLINE PV MODULE

Similarly, to determine the Ross coefficient K, for roof-mounted polycrystalline PV installation, Equation 2 is applied to the measured data using MATLAB code. The value of the Ross coefficient K, gotten is R = 0.0397. Substituting K = 0.0397 into Equation 1gives the temperature model for roof-mounted polycrystalline PV installation as:

$$T_{MOD} = T_{AMB} + 0.0397G_{MOD} \quad (4)$$

F. THE TEMPERATURE MODEL FOR THE GROUND-MOUNTED MONOCRYSTALLINE PV MODULE

The value of Ross coefficient, K obtained for the ground-mounted monocrystalline PV installation is K = 0.0399. Hence, substituting K = 0.0399 into Equation 1 gives the temperature model for ground-mounted monocrystalline PV installation as:

$$T_{MOD} = T_{AMB} + 0.0399G_{MOD} \quad (5)$$

G. THETEMPERATURE MODEL FOR THE ROOF-MOUNTED MONOCRYSTALLINE PV MODULE

The value of Ross coefficient, K obtained for roof-mounted monocrystalline PV module is K = 0.042. The, substituting K = 0.0426 into Equation 1 gives the temperature model for roof-mounted monocrystalline PV installation as:

$$T_{MOD} = T_{AMB} + 0.0426G_{MOD} \quad (6)$$

H. EMPIRICAL MODELLING OF THE PV MODULE POWER

The instantaneous output of the PV system depends directly on the operating temperature of the PV module. The operating temperature is one of the most influential parameter in terms of predicting the PV system output. The PV power can be calculated using the power temperature coefficient model given by [14] as;

$$P = P_{STC}[1 + \alpha_p\,(T_{MOD} - T_{STC})] \quad (7)$$

Here, P_{STC} is the power at standard test condition, $\alpha_p$is the power coefficient, T_{MOD} is the module temperature and T_{STC} is the temperature at standard test conditions. Unfortunately, Equation 7 do not take into consideration losses associated with PV system installations, such as mismatch, diode and connection, DC wiring, Sun tracking and PV efficiency. In order to accommodate these losses, de-rating factor is introduced into Equation 7 which resulted in Equation 8.

$$P = P_{STC} \times F_{PV}[1 + \alpha_p(Tmod - Tstc)] \quad (8)$$

Where F_{PV} is the overall de-rating factor of the experimental setup and is determined by the product of individual de-rating factors of all the PV system components that give rise to power losses in the system. The overall de-rating factor used in this study is F_{PV} = 0.95×0.98×0.99×0.98×0.95 = 0.858. Also, in this study, the power coefficient α_p of - 0.5%/°C and T_{STC} of 25℃ were used. Substituting the values of F_{PV}, α_p and T_{STC} into Equation 8 and simplifying the expression gives the power model as;

$$P = P_{STC}(0.858)[1 + (-0.5\%)(T_{MOD} - 25)] =$$
$$P_{STC}(0.858)[1 - 0.005(T_{MOD} - 25)] \quad (9)$$

Hence,

$$P = P_{STC}[0.96525 - 0.00429T_{MOD}] \quad (10)$$

In order to account for the effect of irradiance on PV performance, the power output was normalized with their output power at STC. Hence the derived power model is given as;

$$P = P_{STC} \times \frac{G_{MOD}}{G_{STC}}[0.96525 - 0.00429T_{MOD}] \quad (11)$$

Here, G_{MOD} is the irradiance falling on the module, G_{STC} is irradiance at standard test condition, T_{MOD} is the PV module operating temperature and P_{STC} is the PV module Power at STC (Rated maximum power)

III. RESULTSAND DISCUSSION

Using the developed models for rooftop-mounted PV installation and ground-mounted PV installation, the polycrystalline and the monocrystalline module temperatures were predicted for the given measured values of solar irradiance and ambient temperature. The predicted values of the module temperature and power were compared with the measured values using root mean square error (RMSE) and R-Squared indices and the results are presented in Table 1and Table 2.

Table 1: RMSE and R – squared values for ground mounted and roof mounted polycrystalline PV

	RMSE		R-squared	
	Ground Mounted Polycrystalline PV	**Roof Mounted Polycrystalline PV Module**	**Ground Mounted Polycrystalline PV**	**Roof Mounted Polycrystalline PV Module**
Module Temperature	**1.373**	**1.229**	**0.9908**	**0.9896**
Module Power	**1.123**	**0.777**	**0.9917**	**0.9934**

Table 1: RMSE and R- squared values for ground mounted and roof mounted Monocrystalline PV modules

	RMSE		R-squared	
	Ground Mounted Monocrystalline PV	**Roof Mounted Monocrystalline PV Module**	**Ground Mounted Monocrystalline PV**	**Roof Mounted Monocrystalline PV Module**
Module Temperature	1.234	1.063	0.992	0.9977
Module Power	0.738	1.175	0.994	0.984

The performance of the modules was evaluated and compared for the different installation methods. MATLAB code was used to plot the performance analysis for the module temperature and power shown in Figures 2 and Figures 3.

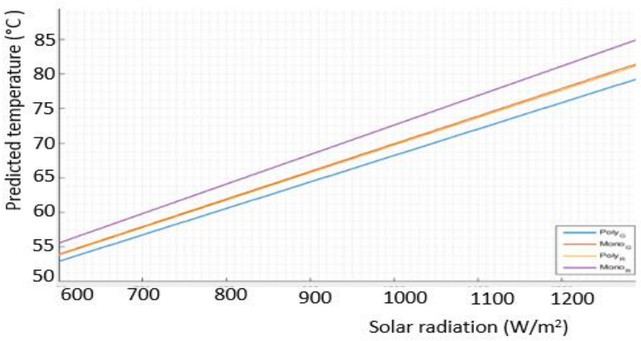

Figure 2: Linear regression for the ground mounted and the roof mounted monocrystalline and Polycrystalline Temperature

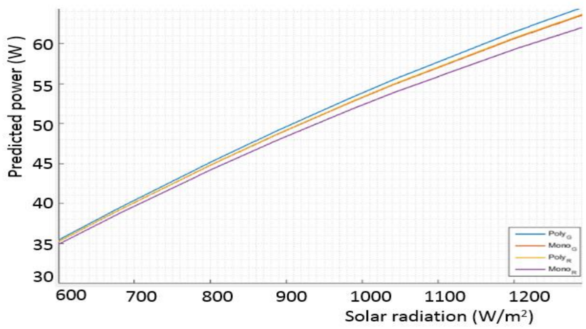

Figure 3: Linear regression the ground mounted and the roof mounted monocrystalline and Polycrystalline Power

In order to design a PV system with a realistic power output, the operating temperature must be estimated correctly in view of its effect on the PV performance [15]. In this work, models that are based on empirical data obtained from field experimental set up was developed for predicting the PV module temperature for the ground mounted and the roof mounted polycrystalline modules. The root means square error was between 1.229 and 1.373 for measured and predicted temperature which is in agreement with 1.35 obtained by [16].

The lowest R squared value for the two installation methods for the polycrystalline module was 0.9896 which shows a good correlation between measured and predicted values. It can be seen that the rise in module temperature in the ground mounted module is lower than in the roof mounted case, as shown in Figure 2.

IV. CONCLUSION

Linear regression models for estimating polycrystalline module temperature for ground mounted and roof mounted PV system are presented. The linear model can be used to determine the module temperature using the solar irradiance and the ambient temperature as input. The developed models can be used in designing PV systems for optimal performance in Uyo. Designers of PV system will find the models developed in this study useful in predicting module temperature taking into consideration the effect of environment factors and the installation methods.

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