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Modelling the Single Diode PV Module MPP Characteristic Curves

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***Abstract*— The contribution of renewable energy in global energy demand and utilisation is now well established. In the solar energy sector, the photovoltaic appears to be the most promising because of its ability to easily convert solar energy into electricity. However, in operation, the characteristic curve of the photovoltaic is non linear and has the tendency to pitch power anywhere but the maximum power point. For an enhanced performance, the inclination of the PV system to operate below the maximum power point has to be resolved. Based on the single diode five parameters method, a photovoltaic module has been modelled and simulated in MATLAB/Simulink environment to obtain the characteristic curves. The model predicts higher power output with increasing insolation and lower power output with increasing temperatures. For validation, the predictions show fairly good agreement between the current model and a commercial multi-crystalline result. The maximum difference between the current study prediction and the commercial data is 1.679%.**

***Index Terms*— characteristic curvesinsolation), irradiance, Photovoltaic (PV) .**

I. Introduction

The environmental degradation resulting from the use of fossil fuels as the main source of energy coupled with the ever increasing energy demand and utilisation are some of the factors driving the repositioning of renewable energy as a major contributor in global energy mix. Currently, renewable energy resource such as solar, wind, etc., are being used in various places either as alternative or to complement to its conventional energy counterpart. This has been made possible as a result of improved understanding of the intricacies in renewableenergy technology exploitation particularly in the photovoltaic (PV) sector. It should be noted that solar energy is the most commonly deployed among all the other renewable energy resources, especially in regions with significant solar potential.

Although between the year 2010 and 2017, the manufacturing cost of the solar module has fallen by about 80% [1], there has not been a significant corresponding increase in system performance. As a result, maximising the performance of these technologies in different operating environments is still a challenge confronting PV producers and engineers [2]. In addition to the variability, intermittent functional nature and above all the non-linear characteristic of the PV system, the failure of some of the solar technology products to generate the designed wattage may explain the reluctance of many to buy into the photovoltaic sector. As result,many still doubt the potential benefits derivable from financial investments in solar energy technologies. It is therefore imperative to model and evaluate the performance and behaviour of these technologies with real meteorological data obtained from various districts not only for enhanced performance but also as confidence booster to all those who still doubt the solar PV technology. It is a common problem that the photovoltaic system rarely operates at the maximum power point. In operation there is a tendency for the system at best, to stabilise just below the maximum power point.

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Solar PV Module System

There is therefore the need to study the behaviour of the PV system for more knowledge on what to do in order to be able to extract the maximum power and obtain overall improved system performance. Several mathematical models of PV systems comprising one and two diodes have been developed for the evaluation of the parameters of the PV module atvarious operating points.The single diode model has been identified as the simplest but it can only be deployed where temperature variation is minimal and irradiance is considerably not too small. For improve model performance, additional diodes are usually required [3].Where temperature variation is considerable and there is a demand for operation near low irradiance, the onediode model provides a good compromise between the model accuracy and model simplicity as well as a balance between actual module design and ideal mathematical analysis [4, 5, 6, 7]. Different modelling and simulation software environment such as PV – Design, Solar Pro, PV – Spice, etc., have been utilised for the analysis of these models. Interest in this study is at Afaka, Kaduna State Nigeria where temperature variation is considered minimal and operation is from moderate to high irradiation level. Therefore, the purpose of this study is to usethe single diode model to evaluatethe effects of environmental and system parameters on the photovoltaic maximum power point.

II. MATERIALS AND EQUIPMENT

Figure 1 shows the graphical detail of the system to model. It is a single diode model, which consists of a photocurrent generator, single diode, series and parallel resistors. The modelling and simulation are carried out in

MATLAB/Simulink environment. For effective modelling and comparative analysis, a reference PV module: Kyocera KK280P – 3CD3CG multi-crystalline PV module [8], is selected For the purpose of validation, themanufacturing datasheet result in table 1 is to be compared with the PV module simulated result. Initial coefficients needed for the modelling work are also taken from the table.

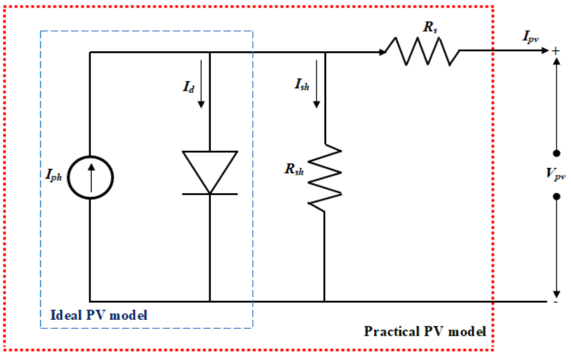

Figure 1: Equivalent PV model circuit

Table 1. Kyocera KK280P – 3CD3CG PV Module Datasheet Parameters at STC

Parameter	Value
Maximum Power (P_{max})	280 W
Maximum Power Voltage (V_{mp})	31.6 V
Maximum Power Current (I_{mp})	8.89 A
Open Circuit Voltage (V_{oc})	38.9 V
Short Circuit Current (I_{sc})	9.63 A
Number of Cell per Module (N)	60
Temperature Coefficient of V_{oc} (K_v)	-0.138 V/°C
Temperature Coefficient of I_{sc} (K_i)	0.00559 A/°C

III. MODELLINGPROCEDURE

The modelling process consists of first finding initial values of some for the unknown parameters defined by equations 1 to 6 using the Kyocera STC datasheet values in table 1. The unknown parameters include series resistance (R_s), shunt resistance (R_{sh}), , photo current (I_{ph}), diode current (I_d), and reverse saturated current (I_o). These values are then used as input in the simulation exercise.The accuracy of the PV cell modelling depends on proper estimation of model parameters which are functions of environmental conditions. Equation 1 relates to the ideal model illustrated in figure 1.

$$I_{pv} = I_{ph} - I_d = I_p - I_o\left[e^{\frac{q(V_d)}{N_s akT}} - 1\right] \quad (1)$$

Where; I_{pv} is the PV current ,I_{ph} is the photon current,I_d is the diode current, I_o is the reverse saturated current, V_d is the voltage across the diode, q is the electron charge (1.6x10^{-19}C), k is the Boltzmann's constant (1.381*10^{-23}J/K), T is the Junction temperature (K), a is the diode ideality factor and N_s represent the number of cells in series. This model may exhibit deficiencies under varying irradiance and temperature conditions.

However, for actual module design and ease of implementation, practical PV model which includes series resistance (R_s) and shunt resistance (R_{sh}) in addition to the ideal PV model is adopted as it provides a balance between ideal model and a more realistic model[4].. While the R_{sh}models the defective cells and leakage current of the p-n junction, the R_s models the resistance of contacts to the current flow in the cell p-n layers [9]. And the actual mathematical expression of the single diode, two resistances practical PV model is presented in the following equation:

$$I_{pv} = I_{ph} - I_d - I_{sh} \quad (2)$$

Where; I_{sh} is the shunt current, number of solar cells in series, N_s and $N_p$are number of cells in series and parallel respectively, the above equation is expressed as follows :

$$I_{pv} = N_p I_{ph} - N_p I_0\left[e^{\frac{q(V_{pv} + I_{pv} R_s)}{N_s akT}} - 1\right] - N_p\left[\frac{V_{pv} + I_{pv} R_s}{R_{sh}}\right] \quad (3)$$

Generally, some of the parameter values for PV model are usually not provided in the datasheet. However, for efficient and realistic, model simulation and prediction, all the model PV parameters are required. The unknown parameters in equation 3 are five ($I_{ph}, I_0, a, R_s, R_{sh}$) but through the application of a new simplified five-parameter estimation method developed by [15], with reference PV module data shown in Table 1, these parameters estimated values at standard test condition are I_{ph}= 9.647A, I_0 = 4.8575*10^{-09}A, a= 1.18,R_s = 0.2181Ω, and R_{sh} = 125.5583Ω respectively. However, solar cells are affected by varying environmental factors such as temperature and irradiance and as such the parameter computation of Photocurrent, Saturation current and reverse saturation current model as a function of temperature and irradiance are presented in equation 4, 5 and 6 respectively.

$$I_{ph} = [I_{sc} + K_I(T - T_{STC})]\frac{G}{G_{STC}} \quad (4)$$

$$I_o = I_{o,STC}\left(\frac{T}{T_{STC}}\right)^3 e^{\left[\frac{qE_g}{ak}\left(\frac{1}{T} - \frac{1}{T_{STC}}\right)\right]} \quad (5)$$

$$I_{0,STC} = \frac{I_{sc}}{\left[e^{\frac{qV_{oc}}{akTN_s}} - 1\right]} \quad (6)$$

Where; T is the current cell temperature, T_{STC} is the temperature at STC, G and G_{STC} are the irradiance on the device surface measured in W/m^2 at normal and at STC (1000W/m^2) respectively. $I_{o,STC}$ equals the reverse saturated current at STC and E_g is the bandgap energy of the cell (typically 1.12eV for silicon cells). However, in this paper, the estimated values of $a, R_s$and R_{sh} at STC are assumed constant for all other environmental condition and these values are used in the simulation.

Simulation model in MATLAB/SIMULINK

Although the Kyocera KK280P – 3CD3CG system is used for initial parameter values, .in a study [6] it has been indicatedthat one is free to consider the use any other models.

In this study the MATLAB/Simulink implementations of equations (3 – 6) are given as block diagrams and a representative sample for shunt and photocurrent are given by figures 2 and 3respectively.

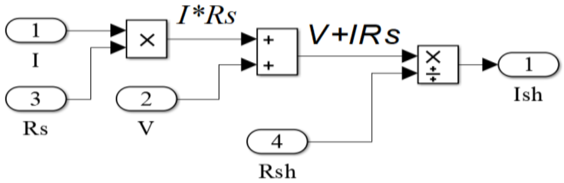

Figure 2: Shunt Current Implementation

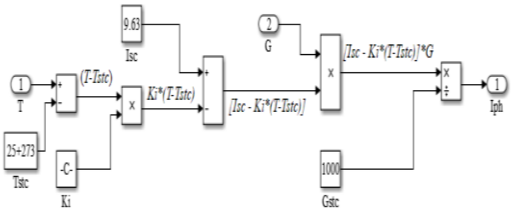
Figure 3: Photocurrent Implementation

Each of these equations is modelled and combined with others to form a subsystem, these subsystems combine to formthe PV module, with its ideality factor, shunt and series resistors indicated as shown in figure 5.

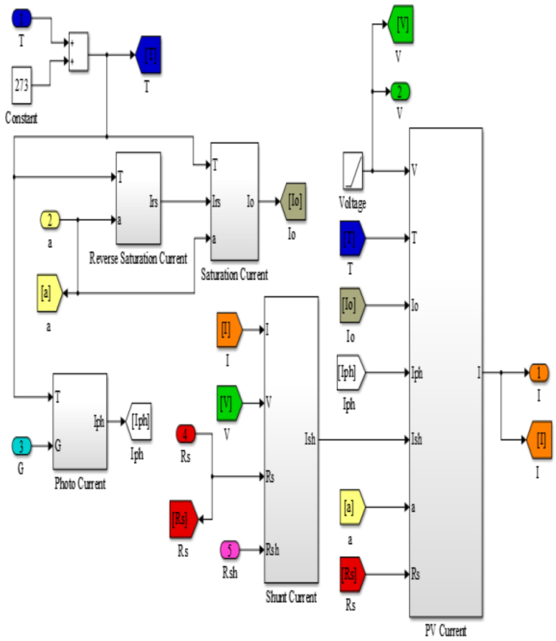
Figure 4: PV subsystem model link Implementation

The PV module as implemented and simulated in MATLAB/Simulink to study the influence of relevant parameters is presented in figure 6. The analysis of the module I –V and P –V characteristic are presented in the following section.

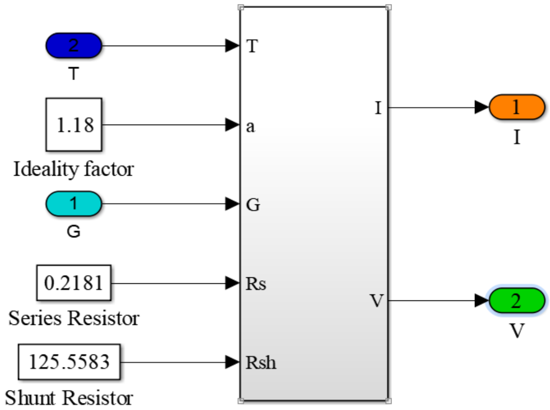

Figure 5: PV Module

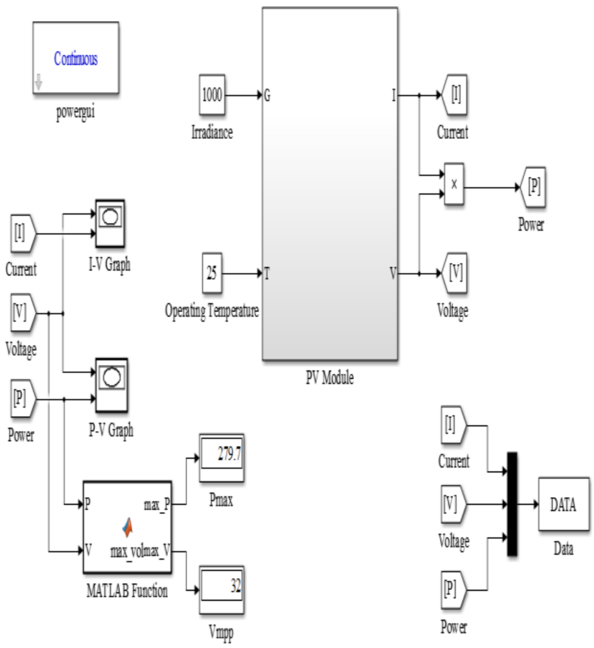
Figure 6: PV Module model

IV. RESULT AND DISCUSSION

Simulated results for various parameters are given in figures 7to 10. Table 2 is a comparison of the simulated results and the given Kyocera datasheet values.

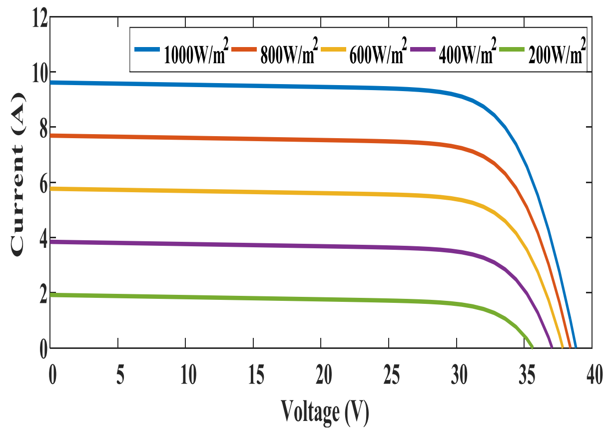

Figure 7: I – V characteristics at constant temperature (25°C) and varying irradiance

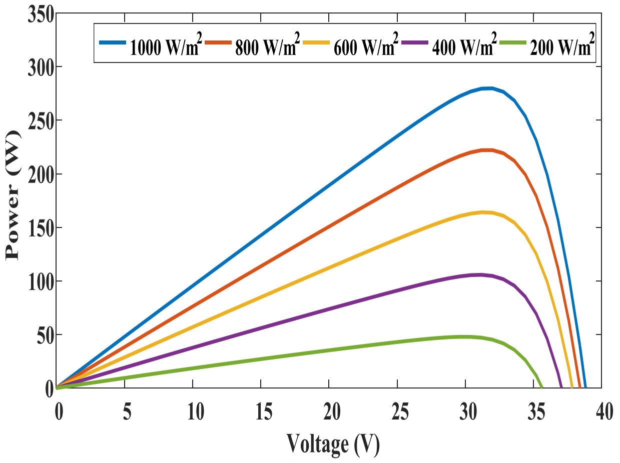

Figure 8: P – V characteristics at constant temperature (25°C) and varying irradiance

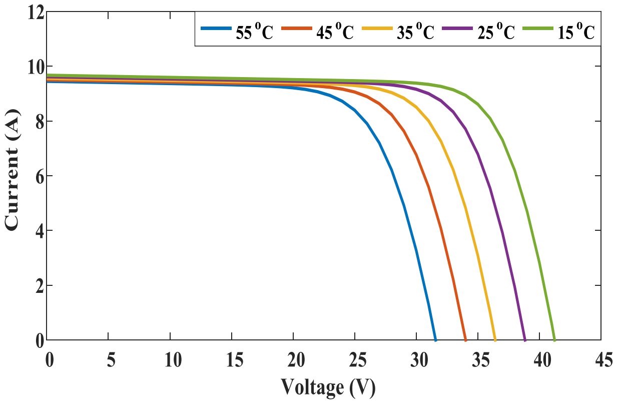

Figure 9: I – V characteristics at constant irradiance (1000W/m^2) and varying temperature

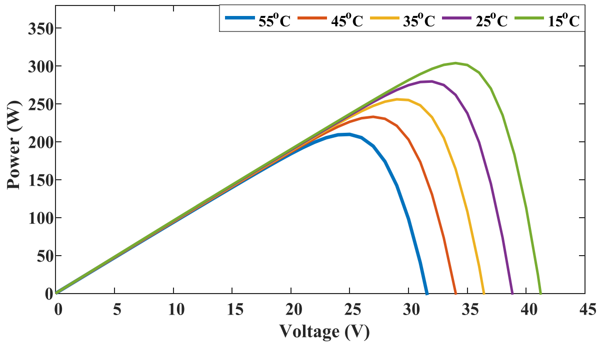

Figure 10: P – V characteristics at constant irradiance (1000W/m^2) and varying temperature

Figures 7 and 8 show the effect of varying the insolation on the on both the current voltage and the power voltage curves. In figure 7, for a given voltage the current rises with increasing insolation. The slopes of the curves are hardly distinguishable within the lower voltage range. As the voltage increases, there is a drastic drop in current values for each of the insolation. The current values converge as they approach zero. For the power voltage plot in figure 8, each curve rises linearly until it approaches the peakwhere after the peak they converge as power approaches zero. Figures 9 and 10 show the effect of temperature on both the current voltage and power voltage curves. In figure 9, there is virtually no discernibledifference between the curves at lower range of the voltagehowever, as the voltage increases, the effect of temperature on the current voltage curve could clearly seen. Within this range, the curves show that for a given voltage, the current increases as the temperature is reduced. In figure 10, the curves at the lower range of voltages, can hardly be distinguished and the power rises linearly within this range. After the maximum, the effect of temperature on the power predicted is clearly discernible, lower temperatures predict higher power output while the reverse is the case with increasing temperatures. In table 2 the simulated result at standard test condition (STC) of 1000W/m^2 of irradiance and 25°C of temperature is compared with the manufacturer's data, the referenced model to show fairly good agreement between the two. The maximum relative error between the two model is found to be 1.6794%

Table 2: Comparison of PV model parameter value at STC

Parameter	Reference model (Kyocera KK280P – 3CD3CG) parameters	Simulated model parameters	Relative error (%)
P_{max} (W)	280	279.7032	0.1060
V_{mpp} (V)	31.6	32	1.2658
I_{mpp} (A)	8.89	8.7407	1.6794
V_{oc} (V)	38.9	38.8308	0.1778
I_{oc} (A)	9.63	9.6133	0.1734

V. CONCLUSION

The single diode five parameters PV modulehas been modelled and simulated. The influence of important environmental parameters has been predicted to show that the power curve rises with rising insolation and falls with rising temperatures. For validation, the predicted results have been compared with manufacturer's datasheet to obtain fairly good agreement between the two and with a maximum error of 1.679%

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