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ENVIRONMENTAL/CLIMATIC EFFECT ON STAND-ALONE SOLAR ENERGY SUPPLY PERFORMANCE FOR SUSTAINABLE ENERGY

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Abstract

This paper investigates the climatic effects and environmental variations on the performance of a stand-alone photovoltaic system. The effects of partial shading with different climate conditions and load resistance variations were examined. A survey of some of the work done in this field of environmental effect on solar panel was included. Also PV cell was modeled from which MATLAB simulations were carried out to investigate some of the climatic and environmental effects on PV system. A discussion of results obtained from simulations is also included in this paper. Simulated results are given and comparisons were made between simulated results and earlier works done. Simulation results obtained tries to justify the findings.

Keywords: solar radiation, maximum power point, Photovoltaic panel, environmental factors

1. Introduction

Global climatic change, world-wide increase in energy demand, uncertainty in price and availability of non-renewable energy and world energy policies on using environmental friendly source of energy have made PV systems suitable for energy generation in recent time. Similarly, with the cost of solar cells decreasing, the conversion of solar energy to electrical energy is increasingly becoming economically viable. This is particularly true in a Country like Nigeria where there is abundant solar energy available throughout the year with reserve estimate of 3.5 - 7.0 kW/m^2/day [1].

In order to maximize the energy generated from photovoltaic (PV) systems certain control mechanisms should be put in place. Such includes maximum power point tracker (MPPT) which will ensure that maximum power is being transferred to the load and dc- dc converter for effective operation. The battery bank may be used to maintain the desired output during the low insolation or at night time. High efficiency can be achieved by controlling the PV unit to operate at its maximum power extraction as mentioned earlier. There are two basic approaches in maximizing power extraction:

- using automatic sun tracker and,
- searching for the MPP conditions

In automatic sun tracker systems, the solar panels are made to track the movement of the sun [2]. Due to the high cost and the energy consumption of the sun tracker, this approach may not be suitable for energy conversions at a small to medium power range. Hence, the second option is rather preferred to sun tracker in both small and medium scale power supply.

In searching for the MPP condition popularly known as maximum power point tracking (MPPT), many techniques including perturb-and-observe method [3], voltage and current based MPPT method [4], fractional open-circuit

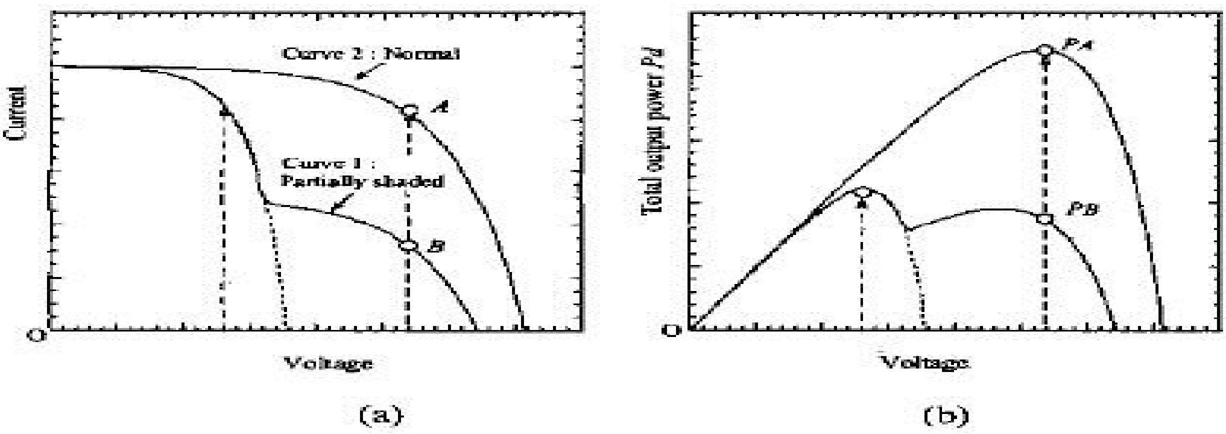


Figure 1: I-V and P-V curves of normal and partially shaded series arrays [10].

voltage [5], fuzzy logic method [6], Incremental Conductance (INC) [7] have been proffered. But in this paper the main objective was to model a PV cell from which simulations were carried out to investigate the effect of several climatic/environmental factors such as the solar radiation, the ambient temperature, the position of the sun with respect to the panel position and the state of the solar panels (ageing, cleanliness) on solar panel efficiency.

It is observed that recent PV technology which includes covering buildings rooftops and walls with PV arrays causes partial shading on the inter-connected arrays due to shades from clouds, tress and nearby building [8]. Since this shading causes the arrays temperatures and insolations to change, and due to the fact that the operation of PV arrays depends on the solar insolations and the temperatures, current research in the design and implementation of PV systems is focusing on MPPT techniques in order to deliver the maximum amount of power from solar panel to the load. Similarly, some techniques need to be extended to locate the maximum power point (MPP) when two or more arrays are connected in series or parallel under different shading, insolation and temperature conditions where local maxima could trap the MPPT algorithm at a false operating point [9]. So [10] carried out extensive work on the effect of partial shading on PV where local or false maxima occur as a result of partial shading.

According to [10], partial shading could be due to two main reasons; firstly, the existence of the PV arrays in urban areas where the shades of buildings cause the partial shading on the array; and secondly, the change of the insolation angle with daytime or season. This partial shading of the PV system would cause the voltage-current (V-I) and Power-voltage (P-V) curves of the series connected arrays to change as shown in fig: 1 (a & b). Taking a critical look at fig 1 above, one would be able to observe that partial shading of the PV causes local maxima as shown in curve 1.

Similarly, [11] proposed a two-stage MPPT technique that is expected to locate the global MPP of two PV arrays connected in series. The first stage is monitoring the irradiance (G) and temperature (T) of each PV array and finding the overall P-I curve of the arrays. Thus, when a certain change ΔG or ΔT of any array is detected, the corresponding P-I curve is generated and a search algorithm will be used to locate all local maxima, if found on the curve, and determine the global maximum in order to guide the controller to the general region of the real MPP. The sizes of the changes ΔG or ΔT are not constant during the day due to their different patterns of variation. It is worthy to note that the search algorithm proposed here serves as the starting point of the second stage.

From the above, it was observed that partial shading lowers the maximum power point at any instant in time. Secondly, since voltage is always affected, then the tendency of having local maxima is there as seen in Fig: 2, bearing in mind that power is $I * V$. Hence, when compared with the simulation results of this paper, it validates

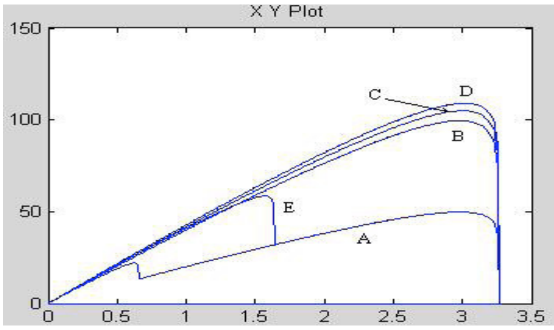


Figure 2: The P-I curves for different intervals [11].

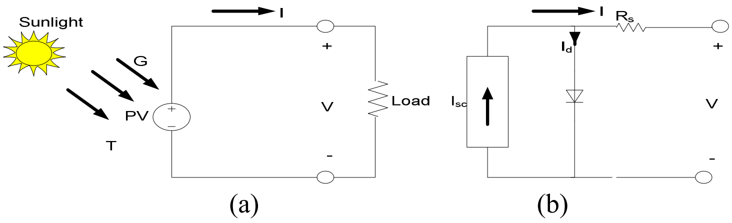


Figure 3: Equivalent PV circuit.

the literature since voltage is reduced when some numbers of the cells are partially or fully shaded. That leads to poor performance of the PV system (refer to Fig 9 below).

2. Modeling of Solar Module

To investigate I-V characteristics of PV array and maximum power point location for certain parameter variation, the BS-MS60_12V, a typical 60W PV module, was chosen for modeling. The module has $N_s = 36$ series connected polycrystalline cells. The circuit diagram for solar cell is shown in Fig: 4, with the output of the current source (which is directly proportional to the light falling on the cell), which is known as photocurrent. The equations generated in this section were used in MATLAB simulations under varying conditions to generate the results in section 6.

The current source represents the current generated by photons (often denoted as Isc or IL i.e. the photo-current IL is directly proportional to irradiance G, so when the cell is short-circuited, infinitesimal current flows in the diode), and its output is constant under constant temperature and constant incident radiation of light. The output current (I) from the PV cell is found by applying the Kirchoffs current law (KCL) on the equivalent circuit shown in Fig 3b

$$I = I_L - I_d \tag{1}$$

where: I_{sc} is the short-circuit current that is equal to the photon generated current, and I_d is the current shunted through the intrinsic diode.

The diode current I_d is given by the Shockley's diode equation, remember that when the cell is not illuminated the relationship between the cell's terminal voltage and current is given by Shockley's equation as below.

$$I_d = I_o(e^{q\frac{Vd}{kT}} - 1) \tag{2}$$

where V_d is the voltage across the diode in (V).

Replacing I_d of the (1) by the (2) gives the current-voltage relationship of the PV cell.

$$I = I_L - I_o\left[e^{q\left(\frac{V+I.Rs}{nk}\right)} - 1\right] \tag{3}$$

But the photon-current is affected by temperature and irradiance, (4) & (5)

$$I_L = I_L(T_{ref})[1 + K_o(T - T_{ref})] \tag{4}$$

$$I_L(T_{ref}) = \frac{G}{G_{nom}} \cdot I_{sc(Tref)} \tag{5}$$

$$K_o = \left(\frac{I_{sc(Tref)-I_{SC}(Tref)}}{T\_T_{ref}}\right) \tag{6}$$

$$I_o = I_o(T_{ref})\left(\frac{T}{T_{ref}}\right)^{\frac{3}{n}} \cdot e^{\left[\frac{-q\cdot V_g}{nk}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right.} \tag{7}$$

Where K_o is the cell's short-circuit current temperature coefficient (3mA/°C) and V_g is the band-gap energy of the semiconductor used in the cell with its value as 1.12V. The diode ideality factor (n) takes a value between one and two;

$$I_o(T_{ref}) = \frac{I_{SC}(T_{ref})}{e\left\{\frac{qV_{OC}(T_{ref})}{nKT_{ref}} - 1\right\}} \tag{8}$$

Where the suffix 'nom' refers to rated lights at standard test condition given by: $G = 1\text{kW/m}^2$, $T_{ref} = 25°\text{C}$ and A.M 1.5 while I_{sc} is short circuit current (3.8A) and V_{oc} is open-circuit voltage (21.06/Ns)V; k is Boltzmann constant

($1.38*10^{-23}$J/K); G is solar irradiance W/m^2; n is ideality factor of the PV module(1.5), q is magnitude of the electron charge ($1.6*10^{-19}$ C); R_s is series resistance of the PV module (Ω), T is PV module temperature (K); I_o is diode saturation current (A). All the constants in these equations obtained from the manufacturers rating of the PV system that one is using.

3. Influence of Climate on PV

Influence of climate on PV was verified under the sub-headings below.

3.1. Influence of the temperature variation on PV

As we all know that meteorological parameters, especially the temperature do not remain constant all day long, but change considerably. It is then worth investigating the influence of the daily average temperature variation on the performances of the optimized system.

With increasing temperature, the short circuit current of the cell increases, whereas the open-circuit voltage decreases (fig: 6). The effect of temperature on the power is quantitatively evaluated by examining the effects on the current and the voltage separately. Assume I_L and V_{oc} are the short-circuit current and the open-circuit voltage at the reference temperature T, while α and β are their respective temperature coefficients. If the operating temperature is increased by, then the new current and voltage are given by the following.

$$I_{SC} = I_L(1 + \alpha\Delta T), \text{ and } V_{oc}(1 - \beta \cdot \Delta T) \quad (9)$$

Since the operating current and the voltage change approximately in the same proportion as short-circuit current and open-circuit voltage, respectively, the new power is as shown below.

$$P = V \cdot I = I_L(1+\alpha \cdot \Delta T) \times V_{oc}(1-\beta \cdot \Delta T) \quad (10)$$

By ignoring a small term,

$$P = P_o[1 + (\alpha - \beta) \cdot \Delta T] \quad (11)$$

For typical single crystal silicon cells $\alpha = 500\mu u$ per °C and $\beta = 5mu$ per °C The power is therefore:

$$P = P_o[1(500\mu u - 5mu) \cdot \Delta T] \text{ or } P_o[1 - 0.0045\Delta T] \quad (12)$$

This expression indicates that for every °C rise in the operating temperature above the reference temperature (T = 25°C), the silicon cell power decreases by 0.45 per cent. Since the increase in the current is much less than the decrease in the voltage, the net effect is the decrease in power at high operating temperature (fig: 6a & b) .

Simulations were done on temperature variation between 0°C and 75°C at constant solar radiation of 1kW/m^2. Figs: 6 show that at constant irradiance of 1kW/m^2, it was observed that with increase in working temperature, the short-circuit current of the PV cell increases, whereas the maximum power output decreases. In as much as the increase in the output current is much less than the decrease in the voltage, the net power decreases at high temperatures.

3.2. Influence of the solar radiation (insolation) variation on PV

Insolation is a measure of solar radiation energy received on a given surface area (such as solar panel surface) in a given time. Factors that affect the amount of solar radiation include:

- The area's latitude: - At high- intensity solar regions near the equator, solar radiation is especially affected by cloudy periods
- Cloudy periods: - Long cloudy periods significantly reduce the amount solar energy available.
- Humidity: - High humidity absorbs and hence reduces radiation.
- Atmospheric clarity: - Atmospheric clarity, reduced by smoke, smog and dust, also effects incoming solar radiation.

The total amount of solar energy received at a location may vary from season to season, but is quite constant from year to year. Hence, a variation of insolation from 250W/m^2 to 1000W/m^2 at constant temperature of 25°C was equally investigated. The absorbed rays in form of light energy shrink the band-gap and thereby allowing the charged carriers to jump from the valence band to conduction band in contribution to the flow of current from the module. As the irradiation of the sun increases on the PV module, the current proportionally increase on the same thread.

The magnitude of the photocurrent is maximum under full bright sun (G =1000W/m^2). On a partially sunny day the photocurrent diminishes in direct proportion to the sun intensity. On a cloudy day, the short circuit current decreases significantly, whereas, the reduction in the open-circuit voltage is small Figs: 5 show the effect of radiation at constant temperature. With the increase of solar radiation, the short-circuit current of the PV generator module increases, and the maximum power output increases as well. The reason is that the open-circuit voltage is logarithmically dependent on the solar irradiance, yet the short-circuit current is directly proportional to the radiant intensity. As a result, the global PV system efficiency increases.

3.3. Sun angle and house orientation

During the course of a day, the angle of sunlight striking the solar module will change due to earths rotation and this will affect the power output of a PV system. Being able to calculate the path the sun will take over a solar panel is useful in order to approximate the amount of sunlight that will be reaching the panel. It is also useful in determining the tilt angle of the panel. This can be crucial if a solar panel is essentially stationary. And in this paper MPPT is used hence stationary solar panel. Determining the angle is a function of the sun's path and also the consumer's energy needs. The earth revolves around the sun in an elliptical orbit with the sun at one of the foci. However, there is only about a 2% difference between the maximum and minimum distances so the mean distance of 1.5* l011 m is often used in calculations [12].

In order to calculate the sun's approximate path, one must first find the declination,. For purposes of this paper, the point of reference will be University of Nigeria. Nsukka which is in Nigeria with Latitude 10°N. The declination is the angle of deviation of the sun from directly above the equator. A value for δ is generated by (13), where d is the day of the year which properly starting from January 1st.

$$\delta(d) = 23.45\,\text{deg}\sin\left[\left(\frac{360}{365}\right)(d-81)\,\text{deg}\right] \quad (13)$$

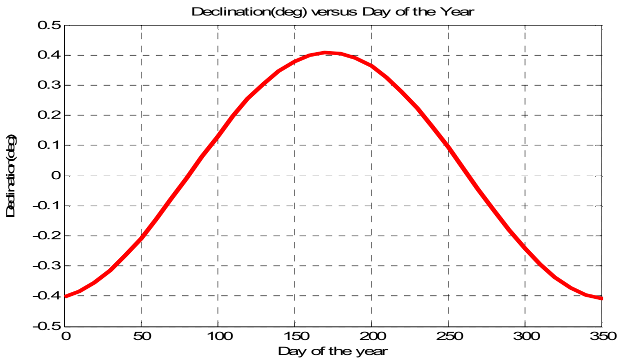


Figure 4: Declination (deg) verses Day of the year.

Positive angles from Fig: 4 are considered north of the equator and negative angles are considered south of the equator. These results are only approximate, however, since the year is not exactly 365 days long. The general performance of PV will gradually rise from zero at early morning hours to the peak at midday and then decrease gradually to zero at night hours, While this variation is due in part to the changing intensity of the sun, the changing sun angle (relative to the modules) also has an effect to the output performance of any panel.

4. Environmental Effect

4.1. Effect of dirt and dust on solar PV

Dirt and dust can accumulate on the solar module surface. They block some of the sunlight from striking the cells and thereby reducing output performance of the panel.

Although typical dirt and dust is cleaned off during every rainy season, it is more realistic to estimate system output taking into account the reduction due to dust buildup in the dry season. A typical annual dust reduction factor to use is 93% or 0.93 [13]. So the 100W module, operating with some accumulated dust may operate on average at about 79 W (85 W x 0.93 = 79 W). It has been observed that heavy accumulation of dirt and/or dusts have also the same effect as partial shading discussed below.

4.2. Shading of solar cells

In addition to what was said in section (1) concerning partial shading, one can see in Fig:

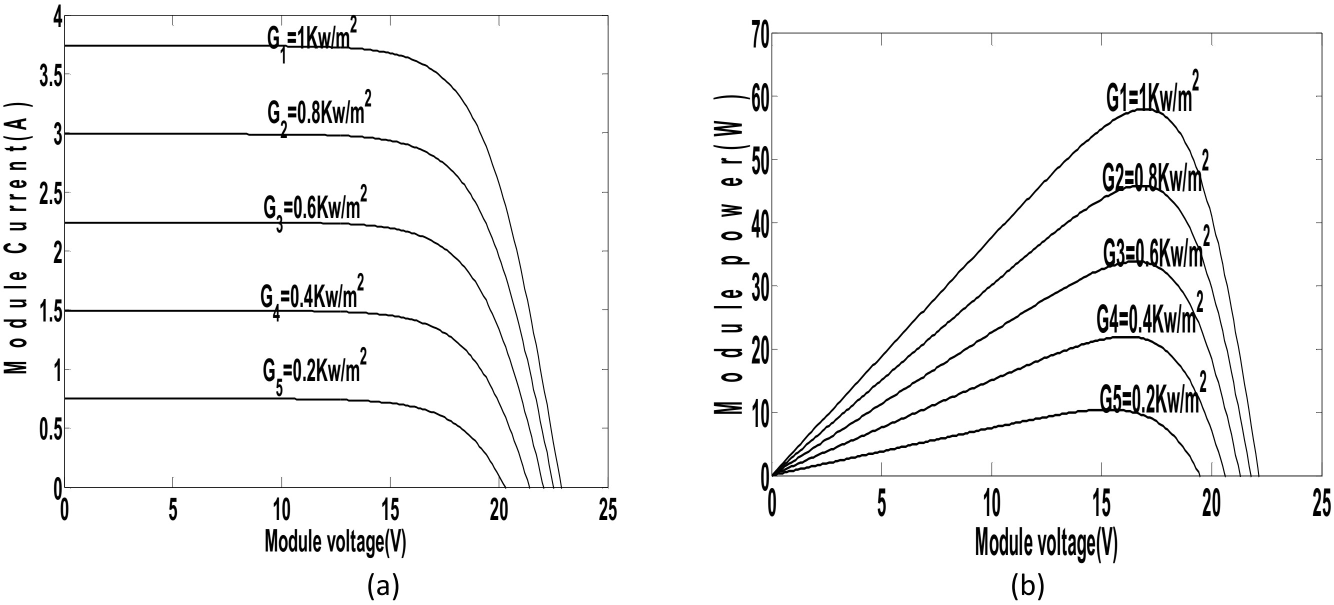


Figure 5: (a) I-V and (b) P-V characteristics at constant temp; of 25°C.

9 below that, as the number of cells (Ns) continue to decrease due to shading or dirt/dusts, the amount of voltage produce will equally decrease even though the current produced remains the same. Hence, shading a single cell can considerably lower a output of PV crystalline module and possibly damage it. The damage occurs since cells were connected in series and therefore carry the same current. So blockage in one or even more cells eventually prevent them from generating current rather they consumes current by converting it to heat energy. That is to say, if a cell in a long-series string gets completely shadowed, it will lose the photo voltage, but still must carry the string current by virtue of its being with the other fully operating cells. Without internally generated voltage, it cannot produce power. Instead, it acts as a load, producing local I^2R loss and heat. Therefore, the remaining cells in the string must work at higher voltage to make up the loss of the shadowed cells voltage. Higher voltage in healthy cells means lower string current as per the I-V characteristic of the string. The current loss is not proportional to the shadowed area, and may go unnoticed for mild shadow on a small area. However, if more cells are shadowed beyond the critical limit, the $I - V$ curve gets below operating voltage of the string, making the string current fall to zero, losing all power of the string.

Even a single tree branch, a weed or a bird's nest could shade one cell and cause electrical production to fall drastically, although, the above explanation is peculiar to certain type. Amorphous and multi-junction-type modules are less affected by small shadows than crystalline type modules.

4.3. State of the PV (aging)

Anything under the sun has life span and solar PV cannot be exempted from it. Hence, the state of solar PV will determine its output performance. Another factor that causes reduction in the performance of solar PV is ageing. Though naturally as year goes by ageing naturally sets in but there are environmental factors that facilitates ageing such as acid rain.

Acid rain occurs from precipitation that contains sulfuric and nitride oxides. These oxides react with water to form acid. As the acid rain falls on the PV module the module will deteriorate which will speed up the ageing process. But the effect of aging cannot be determined using the simulations done.

4.4. Inherit factor

Inherit factors considered were the diode duality factor (n) and the internal series resistances (Rs). Ideality factor (n) is a parameter added to the diodes to compensate for or offset their nonideal behaviours. As the ideality factor increases, the non-linearity behaviours of the diode decrease changing the gradient of its $I-V$ plot. The fig.10 shows that in-between 0-23V, on varying the ideality factor; the $I-V$ curve shows un-deviated horizontal line. Beyond this region, the increase in ideality factors softens the knees of the curve. As the knees of the curve softens the generated current of the PV and the voltage decreases then, the resultant effect is the reduction in power output and drops in the efficiency of the solar cell.

The effect of Rs becomes very conspicuous in a PV module that consists of many series-connected cells, and the number of cells multiplies the value of resistance. As series resistance increases, the voltage drop between the junction voltage and the terminal voltage becomes greater for the same flow of current i.e. increase in PV power loss. The result is that the current-controlled portion of the $I-V$ curve begins to sag toward the origin, producing a significant decrease in the terminal voltage V and a slight reduction in I_{sc}, the short-circuit current. Very high values of Rs will also produce a significant reduction in I_{sc}; in these regimes, series resistance dominates and the behavior of the solar cell resembles that of a resistor. Losses caused by series resistance are in a first approximation given by $P_{loss} = I^2 R_S$ and increase quadratically with (photo-) current. From fig:8, when the series resistance is zero, the $I-V$ has its maximum curve, but when Rs increases, the curve falls towards the origin thereby reducing the efficiency of PV output.

5. Influence of External Resistive Load

The current and voltage are influence by the circuit connections (insolation or solar irradiations, solar reference spectrum, cell temperature, suns incidence angle) and external resistances. The effect of external resistance was verified as thus; a solar cell may operate over a wide range of voltages (V) and currents (I). By increasing the resistive load on an irradiated cell continuously from zero (a short circuit) to a very high value (an open circuit) one can determine the maximum-power point, the point that maximizes $V * I$, that is, the load for which the cell can deliver maximum electrical power at that level of irradiation.(refer to fig 11).

6. Simulation Results

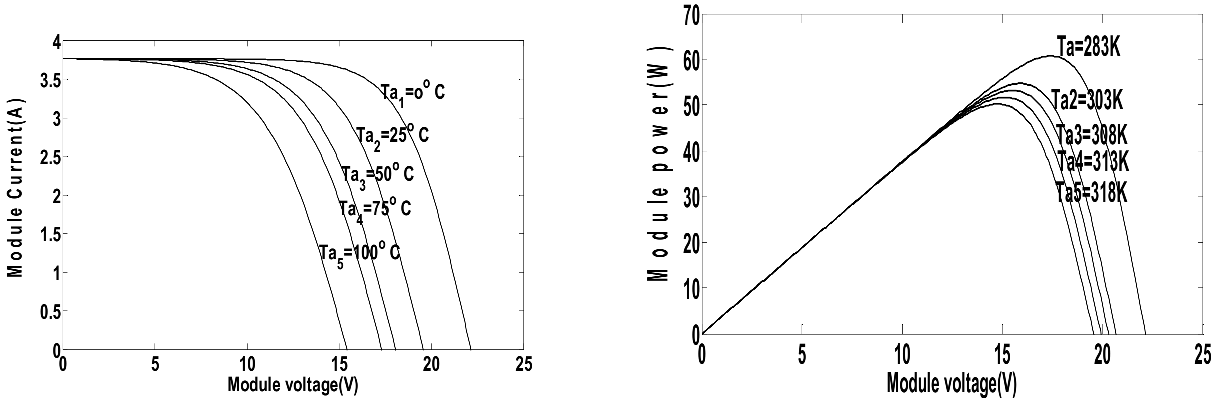
7. Analysis Of Simulation Results

Figures 5 show $I-V$ behaviour parameterized by illumination level. The short-circuit current is approximately a linear function of illumination intensity. From Figs, 5 above, one can deduce that the PV generator current increases with rise in irradiance at constant temperature of 25°C, hence power at the same temperature condition increases as the solar radiation increases. As a result, the global PV system efficiency increases.

Voltage-Current behavior parameterized by temperature was presented in figs.6. Temperature alters the cell voltage at about -0.45%/°C (12). This reduces output voltage very significantly in operation; a good quality cell is about 15% efficient at converting light to electricity. So 85% of incident light heats the solar cell rather than contributing to electrical output. Hence, an effective MPPT is needed for closed-loop control to correct changes in both illumination and temperature. Static settings such as constant voltage, constant current or even constant impedance will not be effective under both types of variation. Figures 6 show that at constant irradiance of 1KW/m^2 power decreases as temperature increases. Also PV current remains constant as voltage decrease with increase in temperature.

From $I-V$ temperature variation curve of Fig 7, it is observed that as temperature increases the voltage decreases while the current is constant showing that a good percentage of incident light heats the solar cell rather than contributing to electrical output performance of the PV system.

In a practical PV cell, there is a series of resistance in a current path through the semiconductor material, the metal grid, contacts, and current collecting bus. These resistive losses are lumped together as a series resistor (Rs). Its effect becomes very conspicuous in a PV module that consists of many series-connected cells, and the number of cells multiplies the value of resistance. The series resistance of the panel has a large impact on the slope of the $I-V$ curve at $V = V_{oc}$ as seen in fig 8. From Fig (8), one can observe that when internal series resistance Rs is changing the performance of the PV panel changes. In this case the performance is maxima at the calculated total value of the panel series resistance.



(a) (b)

Figure 6: (a) I-V and (b) P-V characteristics at constant G-1KW/m^2.

When the PV cells are wired together in series, the current output is the same as the single cell, but the voltage output is the sum of each cell voltage, as shown in Figure 9. Which indicate that as number of cells in series increases the output voltage increases also. Similarly, if some of the cells are shaded either by trees or dusts, the voltage output reduces drastically.

The effect of varying the diode ideality factor (n) can be seen in fig 10. As the knees of the curve softens, the generated current of the PV and the voltage decreases then, the resultant effect is the reduction in power output and drops in the efficiency of the solar cell.

Figure 11 shows how external resistance variations contribute to the location of maximum power point of a panel.

8. Conclusion

PV system was modeled in matlab, from where the performances of PV system were investigated using both inherit, environmental and climatic factors on PV to ascertain its performance level. From the simulations done, it was observed that installation of PV away from obstruction increases its performance. Also the paper suggests that PV array performance will be enhanced by the use of MPP controller, converter as an interface between PV array and load for effective and efficient utilization of naturally available sun power.

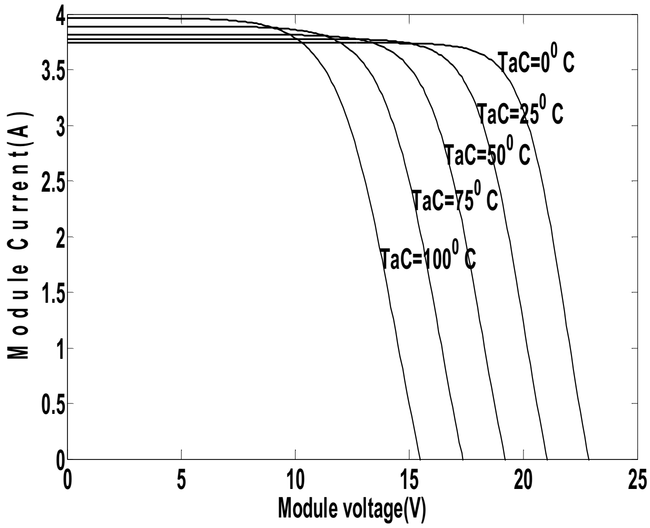


Figure 7: I-V temperature variation curve.

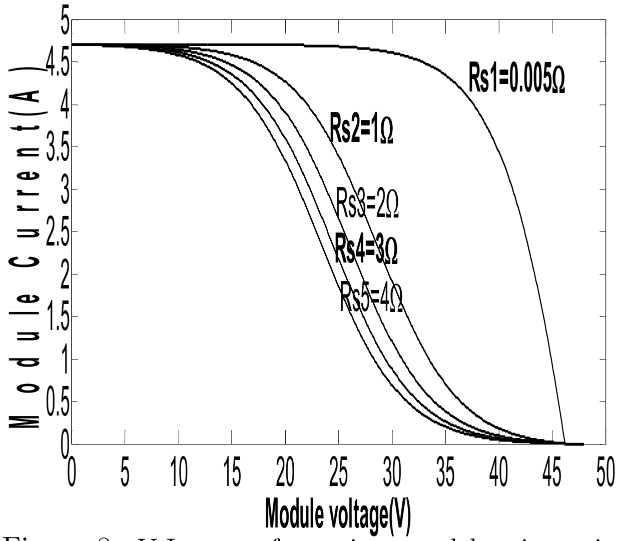


Figure 8: V-I curves for various model series resistances Rs.

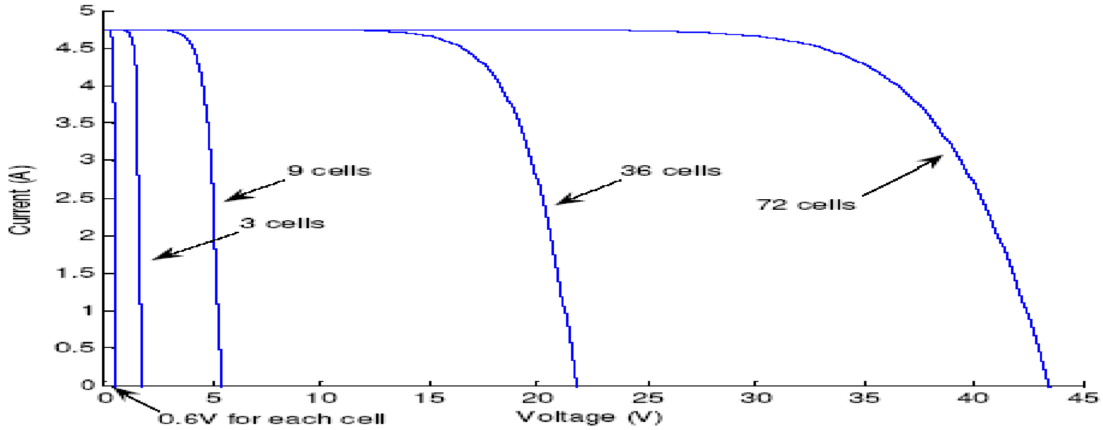


Figure 9: I-V for various wafers of cells of PV in series (N_s) due to shadow.

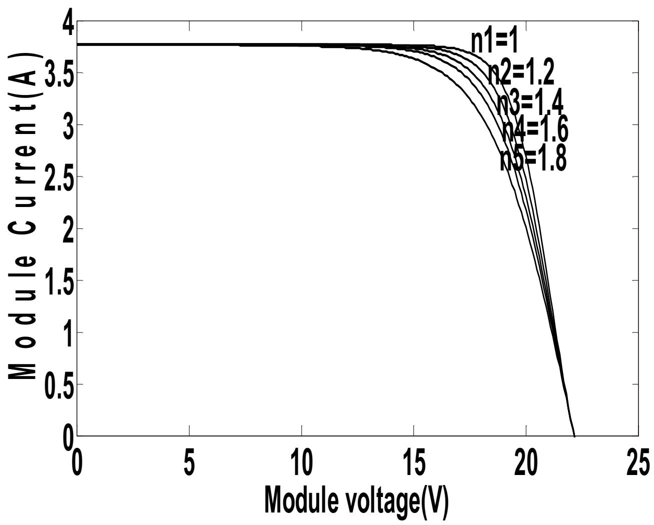


Figure 10: Effect of diode ideality factors (n).

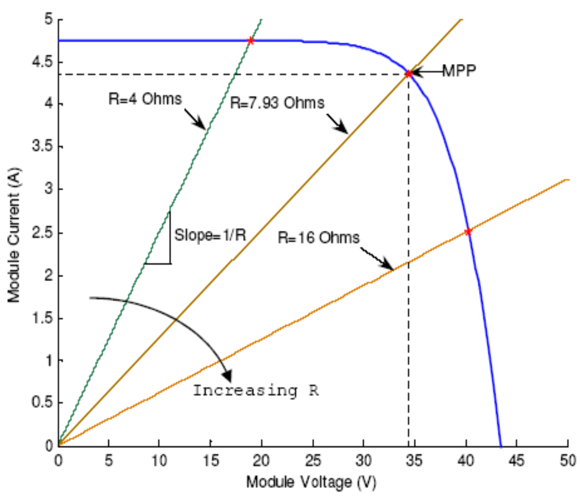


Figure 11: I-V curves of PV module and various resistive loads.

References

1. A.S. Sambo, *Strategic Developments in Renewable of Nigeria*, International Association for Energy Economics, 2009, pg. 15-19

2. A. Konar and A.K. Mandal, Microprocessor base automatic Sun tracker, *IEE Proceedings A.*, Vol:138, Iss:4, 237-41, July 1991.

3. Dezso Sera, Remus Teodorescu and Temas Kerekes, *Teaching Maximum Power Point Tranckers Using a Photovoltaic Array Model with GUI*,

4. Mohmmad A.S Masoum, Hooman Dehbnei, and Ewald f, Fuchs, Theoretical and Experimental Analyses of Photovoltaic Systems with Voltage- and Current-Based Maximum Power Point Tracking *IEEE Trans.on Energy conv.* Vol.17, no 4. Dec. 2002.

5. J. J. Schoeman and J. D. van Wyk, A simplified maximal power controller for terrestrial photovoltaic panel arrays, In *13th Annual IEEE Power Electron. Specialists Conf.*, 1982, pp. 361- 367.

6. M. Veerachary, T. Senjyu, and K.Uezato, Neural-network-based Maximum-Power point tracking of coupled-inductor interleaved-boost converter-supplied PV system using fuzzy controller, *IEE Trans. Ind. Electron.*, vol. 50, pp. 749-758, Aug. 2003.

7. Hussein, K. H., I. Muta, T. Hoshino, M. Osakada. Maximum Photovoltaic Power Tracking: an Algorithm for Rapidly Changing Atmospheric Conditions, *IEEE Proceedings-Generation, Transmission and Distribution* vol. 142 January 1995, page 59-64

8. D. Casadei, G. Grandi, C. Rossi, Single-Phase Single-Stage Photovoltaic Generation System Based on a Ripple Correlation Control Maximum Power point Tracking, *IEEE Transactions on Energy Conversion*, Vol. 21, No. 2, June 2006.
9. T. Esram, and P. Chapman, Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques, *IEE Transactions on Energy Conversion*, in 9, Urbana.
10. T. Mishima, T. Ohnishi, A Power Compensation and Control System For a Partially Shaded PV Array, *Electrical Engineering in Japan*, Vol. 146, No. 3, 2004.
11. Ali M. Bazzi, Maximum Power Point tracking of Mulitple PV Array, *Technical Session XII on Control and Power Systems*, pg. 336-342.
12. Aliceson Nicole Dusang, *Smart Utility Interface for Photovoltaic Converters*, A Thesis in Electrical Engineering Submitted to the Graduate Faculty of Texas Tech University for Master degree, August, 2003.
13. M. Buresch, *Photovoltaic Energy Systems*, New York, McGraw-Hill, 1983