Performance Analysis of Photovoltaic Cells at Varying Environmental Parameters and Solar Cell Precise Algorithm

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Abstract. Start your abstract here…olar irradiation and the temperature affects the output of photovoltaic modules in great extent. Environmental and electrical parameters affect the photovoltaic (PV) output power. Environmental parameters like solar radiance and temperatures has major contribution in PV output power. This research gives the precise algorithm for PV system simulation in Matlab. This research gives the simulation of current, voltage and power on different solar radiance level and temperature values. For allowing interaction with power converter, therefore this is mandatory to illustrate simulation that is based on circuit for PV cell. Simulation blocks are similar to PV module and they are compatible with various crystalline modules and different types of PV arrays. Concentrated photovoltaic systems are being operated at higher temperature than fixed PV setup, and system efficiencies and material properties has been affected with higher temperature. Hence, thorough understating of high temperature are very important. Misalignment and optics tolerances causes decrement in cell efficiency. As direct sunlight is used by PV system, therefore proper system design can reduce sensitivity to errors.

Keywords— Ideality Factor, Photovoltaic Cell, PV Panel, PV System, Solar Module, Solar Energy, Solar Irradiation Intensity, PV Operating Temperature.

1. Introduction
Misalignment and optics tolerances reasons decrease in cell efficiency. As direct solar intensity is used by photovoltaic system, hence proper system design can decrease errors. This research addresses the
issues of allowing interaction with power converter it is necessary to explain circuit based simulation for photovoltaic cell. Blocks of simulation are close to PV module and compatible with various types of PV modules. Working of Concentrated Photovoltaic (CPV) systems are at higher temperature than fixed PV setup, and system efficiencies and material properties has been affected with higher temperature. Solar radiation level and temperature values change from place to place. Twenty years back, there were less quantity of photovoltaic module based streetlights because in that time urbanization was not in rapid pace to grow higher and higher [1]. At the moment as people are shifting from rural vicinities to urban neighborhoods, so number of PV based streetlights with trackers seems to be increased so that people could enjoy their living and travelling along roads happily without any danger [2] [3].

Few regions are cold enough and others are very hot with high temperature value and more solar radiation level. PV cells with trackers follow the sun rays for conversion of solar energy to electrical energy. Photovoltaic modules are in integration with smart metropolitan streetlight mechanism based on trackers that is a need of an hour. Solar modules convert sunrays into solar energy depending on types of silicon cells [4]. Higher temperature that is more than 25 centigrade poses threats to output power of PV cells. Hybrid systems of water and air as coolant had been drafted and proposed in research of scholars [5]. Solar conversion is needed heavily for meeting needs [6]. Shift to new energies is necessary in future as well [7]. Solar energy is very cost effective [8].

2. Literature Review
Photovoltaic cells are really important to use for fulfilling demands of electricity shortage. This chapter contains some background data to assist the reader and comprehend the ideas and techniques behind the photovoltaic cell through Shockley PV cell equation. Solar radiation intensity and the temperature are given due consideration. The photovoltaic (PV) energy is the clean energy with extended lifetime and more reliability [9, 10, 11].

Therefore, it can be deliberated as one of the sustainable renewable energy source. These systems could be located where demand of electric energy increases, evading losses of transmission and donating reductions to CO2 emission in big urban areas. Photovoltaic (PV) module is result of joining chunk of PV cells in series and parallel with protection devices [12,13,14]. In Figure 1, Nsm denotes number of PV cells in series,while Npm represents the number of PV cells in parallel.

Figure 1. Photovoltaic Cell [3]
Basically, PV cell is composed of three layers, one is n-type doped with pentavalent element and second is substrate or dielectric and third is p-type which is doped by trivalent element, hence p-n junction is formed between p and n-type layers when photons hits the surface of n-type silicon material [3].

For Sharps NUS0E3E PV module, maximum power is 180 watts, short circuit current is 8.37 ampere, current at maximum power is 7.6 ampere, open circuit voltage is 30 volts, voltage at maximum power is 23.7 volts, temperature coefficient for short circuit current 0.053 % per ◦C, these facts with the P-V curve are shown in Figure 1 with various solar radiation intensity values in part a, ranging from 200 watts per square meter (w/m²) to 1000 watts per square meter (w/m²), this is one or the output characteristic curve of PV model. In this same Figure, in part b, I-V Characteristic curve is shown from 200 w/m2 to 1000 w/m2 values of solar irradiance. In part c, d on different temperature values, P-V and I-V output characteristic curves are drawn.

Sun is the main source of energy. Solar radiation intensity changes with respect to the time of the day, hence the temperature also varies resulting transient response of solar panel efficiency. Current-Voltage and Power-Voltage curves are the output characteristics curves of PV module. Maximum power is achieved at maximum current and maximum voltage. Maximum voltage is less than short circuit current of PV cell. Maximum Voltage is less than open circuit voltage. On Standard Test Condition (STC) temperature is 25 ◦C and solar radiation intensity is
1000 watts per square meter (w/m²), and sometimes mismatch occurs in these curves. Algorithm looks for knee point or maximum power point (MPP) (Marcelo Gradella Villalva & Filho, 2009). Solar radiation values are changing, and beside this temperature values do not remain same at all time (Shukla, Khare, & Shukla, 2015).

Photovoltaic (PV) modules are being used with sun tracker in order to get more solar radiation intensity. With PV arrays, mostly two types of trackers are used, one is single axis and other is dual axis solar tracker. Single axis solar tracker is less expensive than dual axis and it tracks from east to west only. Usage of fossil fuels that is leading to high alarms of environmental pollutions and thus forcing society to discover new technologies for creating electrical energy from renewable sources, the usage of energy is uninterruptedly increasing and it is announcing that an excessive amount of pressure on the current sources of nonrenewable sources of generation is high, so use of renewable sources must be done, for instance, to utilize geothermal energy, solar energy, wind energy and hydro-energy.

Photovoltaic Crystalline Family: In past very less investment was made in the domain of advancing PV cells, even they have strength to cater the needs of shortage of electricity, but now a days investment and researchers are very much focused to get benefit from PV modules because they are easy to implement, reliable, flexible, and they need low maintenance cost and no repair regularly. These PV cells are used in streetlights also. Design of LED highway lights encounters several consideration with respect to multiple factors, like efficiency of solar panels, either to use PV crystalline family cells, which are PV mono crystalline and PV polycrystalline, or to make use of PV amorphous silicon cells, and other factors those are cost and reliability duration to name a few. Mono-crystalline gives more efficiency than both polycrystalline and amorphous, but its cost is more also. And amorphous silicon is less efficient than both crystalline cells. However, cost effectiveness and efficiency of PV (Photovoltaic) cells are the two major concerns in PV system design. Dust on solar panel decrease the solar output from PV cells. In winter tilt angle must be ten plus latitude of station.

3. Methodology

The general Shockley equation of diode is given by (Physics, n.d.), research work builds a reproduction prototypical of solar cell according to the solar cell equation of Shockley for examining the solar cell efficiency. The specific curves of the solar cells are equated by varying the sun radiation level and the exterior temperature. The representative feature curves of solar cells are achieved by the help of Simulink and MATLAB. The circuit shown in Figure 3 is electrical equivalent of photovoltaic cell, in which G is solar radiation intensity, Iph is photon current that is divided into parallel current across Rp, diode current and PV cell current, Id diode current, and I is cell current, V is voltage across PV cell.
Rs does not affect the output greatly but Rp, that is parallel resistance, it affects output with great extent. Equation of Shockley 3.1 is shown and I the diode current equation from electrical equivalent circuit of PV cell.

$$I = I_s \left( \frac{V}{q n V_t} - 1 \right)$$  \hspace{1cm} (1)

Where $I$ denotes diode current, $I_s$ denotes reverse leakage current, $V$ denotes diode voltage, $n$ denotes ideality factor and it is one for silicon, $V_t$ denotes thermal voltage. Basically here environmental and electrical parameters are to be varied and efficiency of solar cells is being measured.

$$I = I_{ph} - I_d$$  \hspace{1cm} (2)

Equation 2 is taken from electrical equivalent circuit of solar cell. Where $I$ denotes the cell current, $I_{ph}$ denotes photo current, $I_d$ denotes Diode current. Through applying Kirchhoff’s current law on the node at Figure 3, as current entering is equal to the current leaving on a node. Here diode current, current in the path of shunt resistance $R_p$, and current in the way of series resistance $R_s$ are leaving currents, while photocurrent or insulation current acts as current entering. This explanation can be illustrated mathematically in equation 2, it is taken from node where $R_p$, $R_s$, diode and $I_{ph}$ meet. This equation is to be used by algorithm design of PV cell.

$$I = I_{ph} - I_d - I$$  \hspace{1cm} (3)

$I_{rp}$ is current in path of parallel resistance. Here $I$ is current in the branch of PV cell in given circuit. The photovoltaic (PV) current, i.e $I$, can be determined from Equation as follows;

$$I = I_{ph} - I_d - I_{rp}$$  \hspace{1cm} (4)

Where $I_{ph}$ is photocurrent or insulation current. By putting $I_{rp}$ and $I_d$ in equation, above equation can be written as;

$$I = I_{ph} - I_o \left( \frac{e^{\frac{V_{ph}}{V_t}}}{1} - 1 \right) - \left( \frac{V_{ph} + I_{ph} R_s}{R_p} \right)$$  \hspace{1cm} (5)

Where $I_o$ is current at reverse saturation, $I$ is Cell current, $V_t$ is thermal voltage, $V$ is Cell voltage, $q$ is charge of electron, $T$ is Temperature in kelvin, $R_p$ is parallel resistance, $V_t$ is series resistance, $I_{ph}$ is insulation current or photocurrent and $K$ is Boltzman Constant. Where $I_{ph}$ is given by
Tr represents cell ref. temperature, T represents cell temperature, S represents solar intensity, Iscr represents short-circuit current of cell w.r.t reference temperature and solar radiation intensity. ki represents short circuit current temperature coefficient.

The photovoltaic model that is being used to clarify above photovoltaic array is given by the Equation 7.

\[ I = n_p I_{ph} - n_p I_{rs} \left( e^{\frac{qU}{n_p k T}} - 1 \right) \]  

(7)

Where I denotes PV array o/p current, ns denotes number of cells in series, V denotes PV array o/p voltage, np denotes cells in parallel, q denotes charge of an electron, A denotes (p-n) junction ideality factor, Irs denotes current of cell reverse saturation, k denotes constant of Boltzmann, T denotes cell temperature in kelvin(K). The cell reverse saturation current that is denoted by Irs changes with temperature according to the following equation (7).

\[ I_{rs} = I_{rs} \left( \frac{T_r^3}{T} \right) e^{\frac{qE_g}{k A} \left[ \frac{1}{T_r} - \frac{1}{T} \right]} \]  

(8)

Where, Tr represents cell ref. Temperature, Eg represents band gap of semiconductor used in PV cell lrr represents temperature of cell reverse saturation at Tr. Photovoltaic power can be calculated by;

\[ P = n_p I_{ph} V_{rs} \left( \frac{qU}{KTA_n s} \right) \]  

(9)

4. Experimental Data and Results

The PV algorithm addresses the issues of environmental parameters and their variations. For this electrical parameters are kept constant as ideality factor of 2.15 is considered in designing suitable algorithm for photovoltaic cell. Energy band gap value of 1.16 is given for maximum power output. The Current Temperature Coefficient of 0.473 is finalized for optimum PV output curves. The Voltage Temperature Coefficient of 636 is given for illustrating I-V and P-V curves. This section assess the environmental parameters. In the Figures 4, 5, 6, result of current versus voltage on different solar radiation level is drawn, here at 1000 watts per square meter, PV current is 13.65 amperes, 13.68 amperes, and 13.61 amperes on 0 C, 25 C, and 45 C respectively. In this research simulation, five different values of solar radiation values were given as 200 watts per square meter, 400 watts per square meter, 600 watts per square meter, 800 watts per square meter, and 1000 watts per square meter. The MATLAB code is present in appendix 1. Equations of methodology were followed to come up with MATLAB simulation in order to draw I-V curve.
Figure 4: IV Cells Curve at Temperature of Zero Centigrade

Figure 5: IV Cells Curve at Temperature of 25 Centigrade
Figure 6: IV Cells Curve at Temperature of 45 Centigrade

Figure 7: PV Cells Curve at Temperature of Zero Centigrade
Figure 8: PV Cells Curve at Temperature of 25 Centigrade

Figure 9: PV Cells Curve at Temperature of 45 Centigrade
Figure 10: PI Cells Curve at Temperature of Zero Centigrade

PI curve is given below on temperature of 25 Centigrade.

Figure 11: PI Cells Curve at Temperature of 25 Centigrade
Performance of PV cells is readily depends on conditions of operation and output parameters such as output current, voltage, power, and fill factor (FF) differ with changes in solar radiation intensity and temperature. Outcomes shows that decrease occurs in the open-circuit voltage for cells of silicon is about per ◦C. Other factor, that is to say as short-circuit current (Isc) it increases slightly with increment in temperature. Moreover, Short circuit current i.e Isc is having direct relation to solar radiation intensity, and open circuit voltage follows logarithmically variation with solar radiance.

When temperature of panel is from 0 ◦C to 25 ◦C, it is observed, as panel temperature gets increased, there is bit increase in short circuit current and beside this, maximum current values are very close. Oppositely, when temperature of panel gets increased, open circuit voltage and maximum voltage get decreased. Hence panel power decreases. In the Figures 7, 8, 9, result of power versus voltage on different radiation level is drawn. PV power is 491.5 watts, 437.9 watts, and 390.8 watts with PV voltages of 36 volts, 32 volts, and 28 volts respectively at the solar radiation intensity value of 1000 watts per square meter. Power is decreasing with decrement in the level of solar radiation. Here maximum power is the product of maximum current and maximum voltage and that is 491.5 watts.
Table 1: PV Current, Voltage and Power at 0 °C

| Solar Radiation $w/m^2$ | PV Current(Amp) | PV Voltage(Volts) | PV Power(Watts) |
|--------------------------|-----------------|------------------|-----------------|
| 1000                     | 13.65           | 36               | 491.5           |
| 800                      | 11.03           | 35               | 386.0           |
| 600                      | 8.30            | 34               | 282.2           |
| 400                      | 5.49            | 33               | 181.4           |
| 200                      | 2.74            | 31               | 84.95           |

Table 2: PV Current, Voltage and Power at 25 °C

| Solar Radiation $w/m^2$ | PV Current(Amp) | PV Voltage(Volts) | PV Power(Watts) |
|--------------------------|-----------------|------------------|-----------------|
| 1000                     | 13.68           | 32               | 437.9           |
| 800                      | 10.68           | 32               | 341.9           |
| 600                      | 8.02            | 31               | 248.8           |
| 400                      | 5.46            | 29               | 158.6           |
| 200                      | 2.70            | 27               | 73.14           |

Table 3: PV Current, Voltage and Power at 45 °C

| Solar Radiation $w/m^2$ | PV Current(Amp) | PV Voltage(Volts) | PV Power(Watts) |
|--------------------------|-----------------|------------------|-----------------|
| 1000                     | 13.61           | 29               | 394.7           |
| 800                      | 10.61           | 29               | 307.6           |
| 600                      | 7.95            | 28               | 222.6           |
| 400                      | 5.20            | 27               | 140.6           |
| 200                      | 2.66            | 24               | 63.88           |

In the Figures 10, 11, 12, result of power versus current on different radiation level is drawn. The significant matter to be discussed here is that the most vital points majorly used for relating the PV crystalline (mono, poly etc) modules electrical factors’ performance are, first, that is the short circuit (sh point) point on this point, current is at the level of maximum and it is normally called as Short circuit current $I_{sc}$, on this point voltage over the module is 0. The second point is the open circuit point on this point, the current is 0 besides voltage is at the maximum, this voltages is called...
Open circuit voltage Voc. Third point of noticing is the maximum (Max pp) power point, on this place, the product of PV crystalline current (I) and PV crystalline voltage (V) has their maximum. And the PV crystalline cells power (P) that is being delivered by a PV crystalline module gains a maximum value at Imp and Vmp points (Imp, Vmp).

5. Conclusion

From tables 1, 2 and 3, effects of environmental parameters on PV output power have been observed in detail. More solar irradiation intensity produce more output power in photovoltaic cells. Higher temperature decreases solar output power. Therefore, less temperature and higher irradiation are preferred for optimum output from PV modules. The designed algorithm provided the outcomes that at 0 °C PV output power is increasing proportional to solar radiation intensity. With increasing solar radiation intensity, PV output power increases and slight increment in PV current. These environmental parameter has major contribution in the PV output power.

PV Model Simulations results show when temperature of panel is 0 °C, then maximum current of the panel increases as proportional to irradiance of Sun, and there is a minute increment in the value of maximum voltage of the panel. When the solar irradiance intensity level is increased from 200 w/m² to 1000 w/m², there is increment in panel power. When the solar radiation level is amplified gradually under 25 °C and 45 °C panel temperature then maximum current of the panel and the short circuit current get increased proportionally. Bit increment in maximum voltage is observed.

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References

[1] Muhammad Samiul Alam, (Year 2019) “MATLAB Simscape Simulation of Solar Photovoltaic array fed BLDC Motor using Maximum Power Point Tracker”, January 2019, Conference: International Conference on Robotics, Electrical and Signal Processing Techniques (ICREST) At: Dhaka, Bangladesh.

[2] Chew I, Karunatikala D, Tan C P, and V K (Year 2017), Smart lighting: The way forward? reviewing the past to shape the future, (p. 180-191) Energy and Buildings.

[3] H. Natsheh E M, A A (Year 2011), Photovoltaic model with mpp tracker for standalone/grid connected applications, IET, Manchester Metropolitan University, School of Engineering, UK.

[4] S. Gonçalves and Armando C.Oliveira (Year 2019) “Educational solar energy tool in Matlab environment”, 6th International Conference on Energy and Environment Research (ICEER 2019), SCIEI, 2019, 22–25 July, Aveiro, Portugal.

[5] Dev A, and Jeyaprabha S B (Year 2013), Modeling and simulation of photovoltaic module in matlab.

[6] AbdelHady R. (Year 2017), “Modeling and simulation of a micro grid-connected solar PV system” Water Sci., 31 (1) (2017), pp. 1-10, 10.1016/j.wsj.2017.04.001.

[7] S. Dubey and G. N. Tiwari, Solar Energy 82, 602-612 (Year 2008).

[8] Abdullahi N., Saha C., and Jinks R. (Year 2017) “Modeling and performance analysis of a silicon PV module” J. Renew. Sustain. Energy, 9 (3) (2017), pp. 1-11, 10.1063/1.4982744.
[9] A. Tiwari, P. Barnwal, G. S. Sandhu, and M. S. Sodha, Applied Energy 86, 2615-2625 (Year 2009).
[10] Vinod, S K. Singh (Year 2018) “Solar photovoltaic modeling and simulation: As a renewable energy solution” Science Direct Volume 4, November 2018, Pages 701-712.
[11] M. Wolf, Energy Conversion & Management 16, 79-90 (1976).
[12] J. K. Tonui and Y. Tripanagnostopoulos, Solar Energy 82, 1-12 (2008).
[13] Divine Atsu, Alok Dhaundiyal, (Year 2019) “Modeling of Photovoltaic Module Using Matlab”, Journal of Natural Resources and Development, Volume 9, pages 59-69, DOI:10.5027/jnrd.v9i0.06 Published 01/12/2019.
[14] T. T. Chow, Applied Energy 87, 365-379 (2010).