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Simulink Software Tool Mathematical Modeling of Silicon Photovoltaic Cell and Its Dependency on Electrical Parameters

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Abstract

Matlab Simulink Software is a optimum tool to model the photovoltaic cell mathematically. Simulink software tool is up to the mark option to design parameters for solar cell. Choice of Matlab Simulink for modeling the silicon cell is valid and productive for future changes in design of crystalline cells. Resources of fossil fuel is decreasing day by day and they are very much costly. Due to consumption of fossil fuels, environment is getting damaged because of emissions of carbon in atmosphere. Electrical parameters of photovoltaic (PV) cells affect the output power. More solar radiation intensity is needed for more conversion of sun rays to electrical energy. Shunt resistance value in the electrical equivalent circuit of PV cell is having major role in the outcome of solar cell. Number of silicon made cells in PV module also matter in output power. Energy band gap in PN Junction of PV cell is having good character in producing solar energy. Shunt and series resistances poses challenges to optimal solar power. These values are chosen very carefully. 1000 watt/m2 is normally taken into account as standard radiation where maximum PV power is achieved. Temperature also affects the solar output, on standard test conditions 25°C of temperature is taken into account normally. As temperature increases then solar output gets decreased. Less temperature is preferred for higher solar power. This research has been striving to formulate accurate mathematical modeling in such a way that PV systems could be producing more energy with maximum conversion of sun rays by more solar radiance. Photovoltaic technology is greatly suitable to cater the needs of users who do not have supply from grid. Electrical parameters affect the photovoltaic output that is interesting for new researchers. Electrical parameters are judged in this research. Moreover, a detailed Matlab/Simulink modeling of PV cell is formulated which would be helpful to the beginners in order to boost up the interest of new learners and researchers in the field of energy systems, PV mathematical modeling is done carefully.

Keywords: Mathematical modeling of PV cell; Refractive index; Energy band gap; Number of cells; IV cell curve; PV cell curve; PV p-n junction; Poly crystalline cell; Mono crystalline cell; Amorphous silicon cell

Introduction

Matlab Simulink is the best choice for modeling monocrystalline and polycrystalline solar modules. Photovoltaic Matlab Simulink created system model is generic and can be used globally. Mostly every country access sun ray, therefore electricity can be produced everywhere, and this research work addresses the improvement of PV cells efficiency by examining PV cell's dependency upon electrical parameters, and standard test condition's values of solar irradiation intensity and environment temperature through PV mathematical modeling of PV cell in Matlab/Simulink are proposed. Therefore, it is vital to propose the suitable mathematical model with respect to certain region to get high level of solar radiation level [1]. In the countries of Asia continent, they receive solar radiation of 3000 hours per year and European countries receive around 2200 hours of solar radiations per year. Therefore, PV simulation model would be quite useful for advancing solar energy projects. As non-renewable sources are not much successful to fulfill the providence of electricity, therefore renewable sources must be researched out for fulfilling shortage in power generation, research in PV cells is more important. Photovoltaic (PV) cells are being used with different technologies in several applications. PV based streetlight system with LED lights are commonly being used now a day worldwide Figure 1.

MATLAB Software

Matlab is very productive Software for modeling the electrical and environmental parameters of photovoltaic cell in concise way [1-9]. For researches of Photovoltaic groups, the help of Matlab Simulink Software is needed to simulate the curves of Voltage versus Current and Voltage versus Power of PV modules [2,10,11]. In the Figure 1, with help of Simulink software tool, Power-Voltage output characteristics curve is given [2], in which on the solar intensity levels of 200 watts per square meter (w/m^2), 400 watts per square meter (w/m^2), 600 watts per square meter (w/m^2)m2, 800 watts per square meter (w/m^2) and 1000 watts per square meter (w/m^2) power is illustrated versus voltage of PV cell Figures 2 & 3. PV arrays are made up of solar modules which is named as basic conversion unit of PV generator system [3,9]. Power quantity is directly related (or proportional) to the solar intensity level. Many scientists and designers have conceived, designed and created omnipresent applications from the creation of integrated technology many centuries earlier to today to convert physical environments into intelligent rooms Figure 4.

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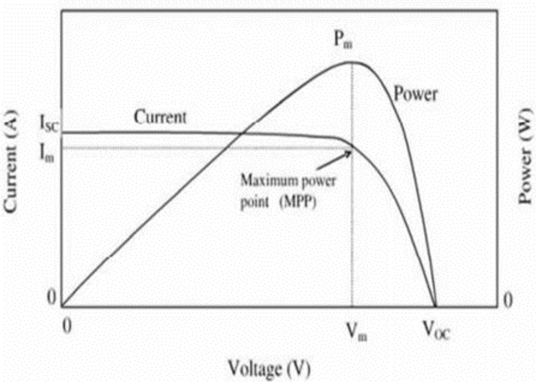

Figure 1: Constant Temperature' PV module Behaviour.

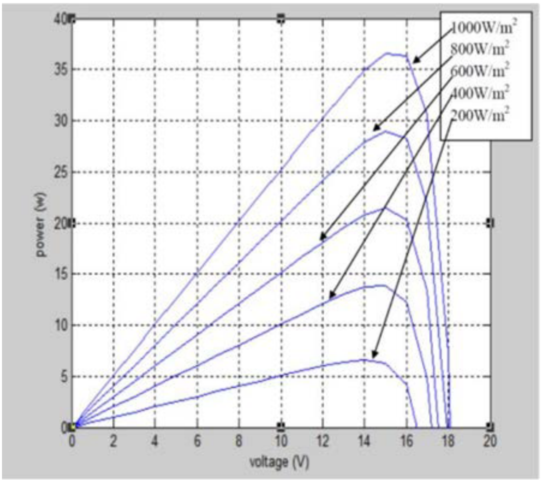

Figure 2: Maximum Power Point Illustration.

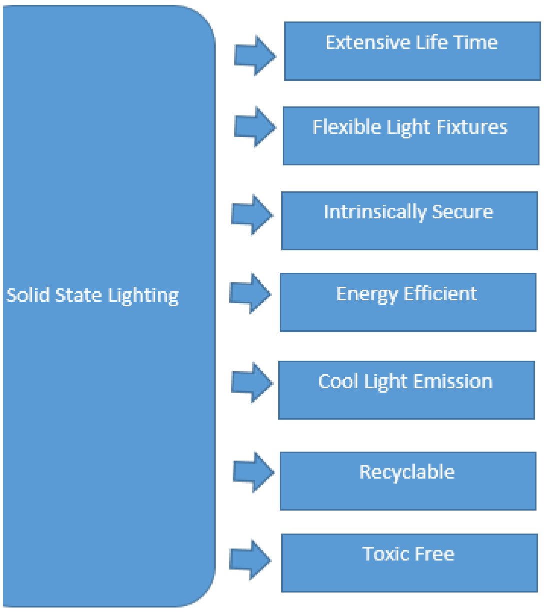

Figure 3: Solid State Lighting (SSL).

Literature Review

When energy hits PV cell's valence (in truly spirit) band, it releases bonded particles i.e electrons and transfers them to another layer (level) of energy called the band of conduction [4,12]. And at the band of conduction, those particles i.e electrons are able to have strength for conducting the electricity in the form of electrical load. Photovoltaic (PV cells) utilize energy of photons from sunlight (sun-rays) to breakdown their band gap energy in order to generating DC current Figure 5. Naturally, Photovoltaic (PV) cells generate low power such as 2 to 3 watts, therefore many cells are joined together to make modules and PV panels for developing higher power usage [2,13].

Germany, China, India and US by the year of 2040, they will have renewable energy penetration of around 74% 55% 49% and 38% respectively [3,11]. Curve for maximum power point (MPP) illustration [4,10] is given in Figure 2, for photovoltaic cell I-V output characteristic curve Figure 6.

The creation of digital depictions of the world remains an exposed inquiry question, with an overabundance of executing drivers permitting both hardware and software in recent years. Hardware drivers include RFID expertise, intelligent power outlets, integrated detectors, QR code and actuator systems, smart meters, and even Nano sensors. Hardware teamsters include Software drivers include interaction support middleware and frameworks with wider fields. Examining in depth different Figure 7.

Suggestions and applications of intelligent lighting schemes, different instruments and methodologies to evaluate and contrast such technologies is vital here Figure 8.

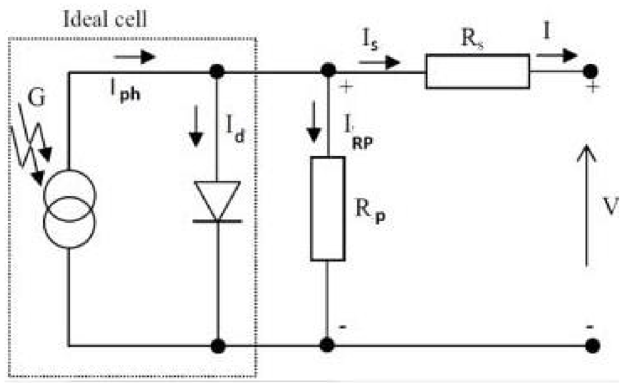

Figure 4: Electrical Equivalent Circuit of PV Cell.

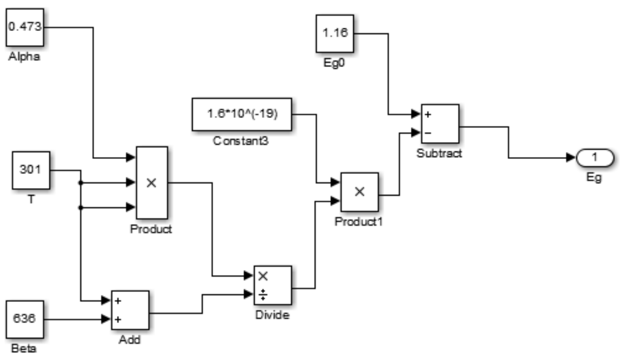

Figure 5: Energy Band Gap Subsystem in Matlab/Simulink of PV Cell.

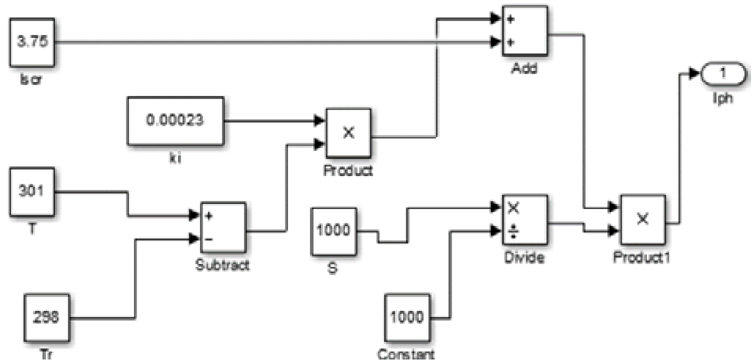

Figure 6: Photon Current Subsystem in Matlab/Simulink.

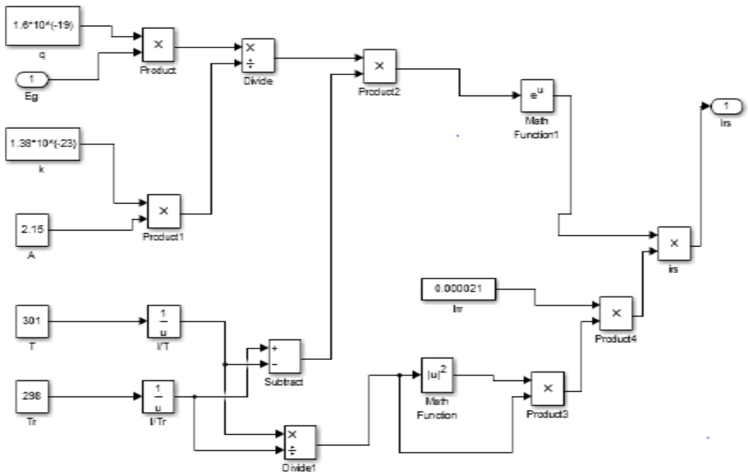

Figure 7: Reverse Saturation Current Subsystem in Matlab/Simulink.

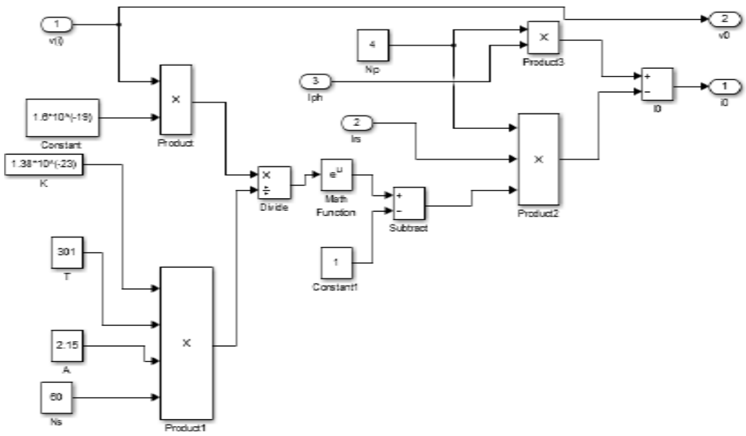

Figure 8: PV Cell Saturation Current I0 Subsystem in Matlab/Simulink.

Starting with research of energy usage and light performance for LEDs and standard heating technologies. Introduction of a number of suggested and applied intelligent outdoor lighting alternatives in literature along with its results. Various power technologies are suggested for the analysis and comparison of intelligent lighting technologies, is given Figure 9.

There is such a huge chance for ecologically comfortable technology to ornament with solid state lighting (Short form: SSL), which is specifically designed for energy efficiency, UV free, compressed, cheaper, and with extensive diversity of characteristics, and finally a deep eradication and replacement for lamps of incandescent and flaming [5]. For giving good light and lower consumption of energy,

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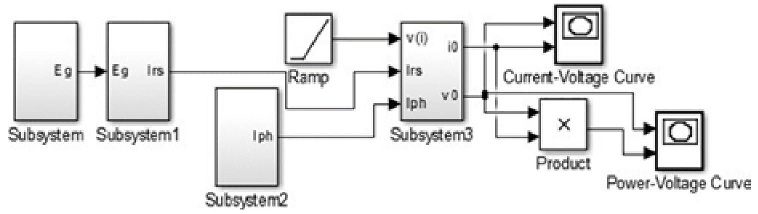

Figure 9: Integration of Subsystems.

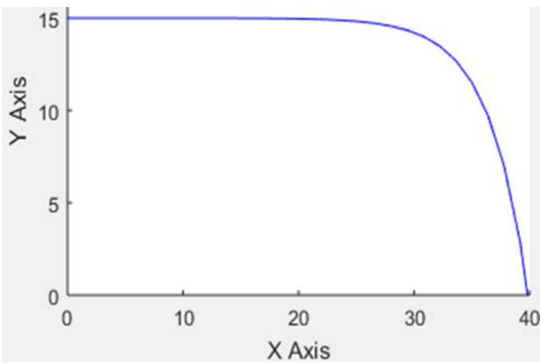

Figure 10: I-V Output Curve of Solar Cell.

SSL can be used with PV plant for saving energy. These LEDs are used with PV systems to consume less energy while proving good quality of light to the environment Figure 10.

Methodology

Matlab/Simulink tool has been used to model solar cell. First of all, subsystems have been created with following equations in Simulink. Shockley equation is base and has helped to design mathematical modeling of PV cell, electrical equivalent form of circuit of solar (PV) cell has been used to deduce equations.

Here I am current in the branch of PV cell in given circuit. The photovoltaic (PV) current, i.e I, can be determined from Equation as follows:

$$I = I_s\left(e^{\frac{V_s}{nV_t}} - 1\right) \text{ (1)}$$

Where

I is diode current

Is is reverse leakage current Vs is diode voltage

n is ideality factor and it is one for silicon

Vt is thermal voltage.

Basically, here electrical parameters are to be varied and efficiency of solar cells is being measured

$$I = I_{ph} - I_d \text{ (2)}$$

en from electrical equivalent circuit of solar cell.

Where

I am the cell current

Iph is photo current

Id is Diode current

Through applying Kirchoff'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 wayof series resistance R_s is 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 Iph meet. This equation is to be used by mathematical modeling in Matlab/Simulink of PV cell.

$$I = I_{ph} - I_d - I \text{ (3)}$$

Where

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;

$$I = I_{ph} - I_d - I_{rp} \text{ (4)}$$

where

I_ph is photocurrent or insulation current

By putting I_rp and I_d in equation, above equation can be written as;

$$I = I_{ph} - I_o\left(e^{\frac{V+IR_s}{V_t}} - 1\right) - \left(\frac{V+IR_s}{R_p}\right) \text{ (5)}$$

Where

Io is current at reverse saturation I is Cell current

Vt is thermal voltage V is Cell voltage

q is charge of electron

T is Temperature in kelvin Rp is parallel resistance Vt is series resistance

Iph is insulation current or photocurrent and K is Boltzman Constant

The photovoltaic model that is being used to clarify above photovoltaic array is given by the Equation 6.

$$I = n_p I_{ph} - n_p I_{rs}\left(e^{\frac{qV}{KTAn_s}} - 1\right) \text{ (6)}$$

where

I is PV array o/p current

n_s denotes number of cells in series V represents PV array o/p voltage

n_p denotes cells in parallel

q represents charge of an electron

A is (p-n) junction factor i.e ideality factor

I_rs is current in PV cell of cell reverse saturation k is denoting Boltzmann's constant

T is cell (K) temperature in kelvin(K)

The cell reverse current i.e saturation current that is denoted by Irs changes with temperature according to the following equation (7).

$$I_{rs} = I_{rs}\left(\frac{T^3}{T_r}\right)e^{\frac{qEg}{KA}}\left[\frac{1}{T_r} - \frac{1}{T}\right] (7)$$

Where

Tr is cell ref. temperature

Eg is band gap of semiconductor used in PV cell Irr is temperature of cell reverse saturation at Tr

Now the most important factor that is the efficiency of a PV cell, it can be defined as "ratio of peak power (Vmax *Imax) to the input solar power".

The Iph (Photo Current) depends on the solar radiance intensity and temperature by relation 8.

$$I_{ph} = \frac{[I_{scr} + K_i(T - T_r)]\,S}{100} (8)$$

1 scris short-circuit current of cell w.r.t reference temperature and solar radiation intensity.

k_i is short circuit current temperature coefficient.

S is the solar radiation intensity.

The photovoltaic power could be calculated using Equation 9.

$$P = n_p I_{ph} Vrs\left(\frac{qv}{KTAn_s}\right) (9)$$

Experimental Data and Results

In Simulink, subsystems of energy band gap (Figure 5), photon current (Figure 6), reverse saturation current (Figure 7), and PV cell saturation current (Io) (Figure 8) are created, then these subsystems are integrated to reach at output characteristic curves of PV cell. From Figure 9, I-V and P-V curves are drawn. Electrical parameters are being varied to reach at optimal solar output. Shunt resistance is high, series resistance is low for better results. PV silicon technology is cost effective and reliable and it needs low repair, hence this research proposed how to get optimum solar output power. Rural areas have much scope for trapping solar energy and world is having more rural vicinities and this research can be used in many projects worldwide. Here shunt resistance is 636 ohms, and series resistance is 0.473 ohms. Here in simulation energy band gap is 1.16 for silicon solar cell Figure 11.

Energy band gap is 1.16 for optimal result. Series and Shunt resistances are 0.473 and 636 respectively for maximum result. Standard temperature of 25°C at STC was considered, and operating temperature of 0°C is giving good results, but here in atmosphere in Karachi, Pakistan 28°C is considered as operating temperature. Current-Voltage and Power-Voltage output characteristic curves are given in Figures 10 and 11 respectively.

AT 28°C, maximum output is achieved. Current, Voltage and Power are 13.68, 32, and 437.9 respectively at 1000 watts/m2 of solar intensity.

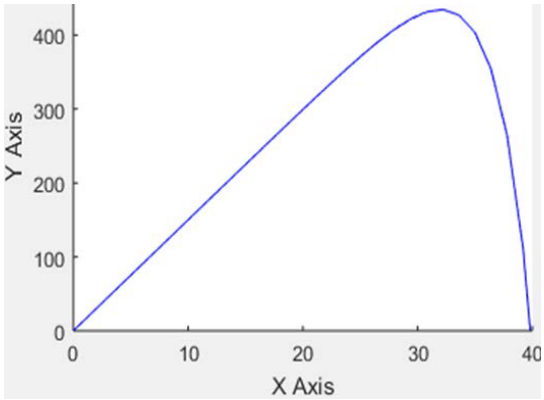

Figure 11: P-V Output Curve of Solar Cell.

Conclusions

Lower solar irradiation and higher temperature reduces the solar power. More shunt resistance and less series resistance are preferred for maximum output. More number of cells are producing more output power. Energy band gap of 1.16 is for silicon cell. Power of 437.9 is achieved at 28°C. This research work gave the method of simulating behavior of PV cell with optimum values to the electrical parameters for getting maximum output. In mathematical modeling, number of PV cells here were 240.

The government of the Unites States of America estimates that every year planet Earth receives more than 173000 terawatts of energy and it is ten thousand times higher than humanity needs. This research strived to explore this sector to get benefit of catering those humanity needs. The scholars and researchers in the United Kingdom estimates that costs of PV modules will fall in high speed to allow PV cells to contribute twenty percent of world consumption needs by the year of 2027. New businesses are being run with adoption of solar energy for world consumption.

The future direction for this research work includes smart connection of solar based streetlight system with wind energy plants. And this system may be made smarter by connecting with smart homes. Solar trackers might be connected as a combination of complex system, where both single as well as dual axis solar trackers with smart technology mechanism may be used along with fixed system scheme of PV modules for enhancing efficiency of overall renewable energy plant.

PV array losses are occurring; they can be reduced by working in right direction. Full battery loss can be avoided if any suitable scheme is researched in near future. In coming research from young scholars and researchers, with optimum PV system design performance ratio can be increased to 0.88 (88%) and onwards. This research benefits the manufacturer what to consider in the manufacturing solar panels. New learners should be going to green power production that is required as climate changes globally.

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