TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol. 12, No. 8, August 2014, pp. 5784 ~ 5792
DOI: 10.11591/telkomnika.v12i8.6071

Simulink Based Multi Variable Solar Panel Modeling

Chandani Sharma*[1], Anamika Jain[2]
Electronics & Communication Engg., Graphic Era University, Dehradun, Uttrakhand, India
*Corresponding author, email: chandani19nov@gmail.com[1], anamikajain2829@gmail.com[2]

Abstract
Solar Energy, the most abundant and widely used Renewable Energy is not only reliable, scalable but serves solution to global warming around the world. This energy is used for electricity generation using Photovoltaics (PV) converting Solar Energy into electricity. Photovoltaics (PV) play significant role for future Distributed and Renewable Energy Generation Systems (DG). This study is an effort to visualize simulation tool for solar cell array under rapidly changing solar radiation and temperature by inserting a test signal in the control input. The main objective is to find the parameters of the nonlinear I-V and P-V equation by locating the curve at three points: short circuit current, open circuit voltage and maximum power. Future Smart Grids can be optimized if computerized and designed using mathematical modeling and simulation system at STC. Case study relative to factors including weather and seasonal variations is tested through SIMULINK model. Predicted changes are configured for determination of MPP. The proposed model is based on variations by changing absorption of light with physical inspections for data corresponding to low and high temperatures.

Keywords: *STC (Standard Test Conditions), distributed and renewable energy generation systems (DG), irradiance, MPP (Maximum Power Point), SIMULINK*

1. Introduction

India has high solar insolation with 1500-2000 sunshine hours per year generating about 600TW of power. At present solar photovoltaic is the prime contributor to the electricity infrastructure in developing countries. The study of Photovoltaic's describes physical process of solar cells by which sun light is converted into electrical current when it strikes a suitable semiconductor device. Photovoltaic being cost effective are used in many specific-purpose applications, including telecommunications, lighting, water-pumping and signaling. Applications in hospitals can be valuable in regions with unreliable conventional energy sources. A recent application, showing promising feature worldwide, is a Photovoltaic system that floats and purifies water in landlocked areas.

The fundamental limits of solar cell are relative to current, voltage, or resistance. They vary with change in irradiance and temperature contributing to losses and solar cell efficiency. As such determination of Maximum power point from IV and PV Characteristics is required to make full utilization of PV array output power [1, 2].

1.1. Basic Solar Cell

The most common solar cell is a large-area pn junction made from Silicon. For silicon solar cell, depletion region extends into the p-side because of more heavily doped n-region with built-in Electric Field (E) due to difference in Fermi Levels of p and n type. As the n-side is very narrow, most of the photons are absorbed within the depletion region and photo generate electron-hole pairs (EHPs). These are immediately separated by E which drifts them apart. An open circuit voltage develops between the terminals of the device with the p-side positive and n-side negative. If an external load is connected then the excess electron in the n-side can travel around the external circuit and reach the p-side to recombine with the excess holes there. If the terminals of the device are shorted, then the excess electrons in the n-side can flow through the external circuit to neutralize the excess holes in the p-side. This current due to the flow of photo generated carriers is called the photocurrent [5].

To understand the electronic behavior of a solar cell, it is necessary to create its equivalent electrical model. The model constructed is based on discrete electrical components

Received February 17, 2014; Revised April 8, 2014; Accepted April 26, 2014

whose behavior is well known. Experimentally behavior of solar cell is studied by designing its dc equivalent circuit as in Figure 1 [7]. We consider an ideal solar cell described using a current source in parallel with diode, series and shunt resistance added to it.

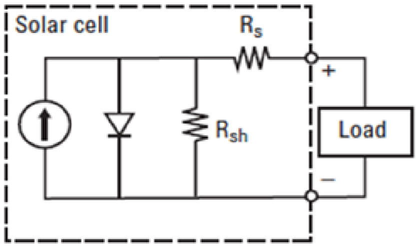

Figure 1. DC Equivalent Model of Solar Cell

Equations mentioned below prior to solar cell construction are modeled through electrical components graphically designed in SIMULINK. These include:

Thermal Voltage Equation

$$V_T = k_B T_{OPT}/q \tag{1}$$

Diode Current Equation

$$I_D = N_p\, I_S\, [e^{(V/Ns) + (IRs/Ns)/N\, V_T\, C} -1] \tag{2}$$

Load Current Equation

$$I_L = I_{Ph}\, N_p - I_D - I_{SH} \tag{3}$$

Photocurrent Equation

$$I_{ph} = [k_i\, (T_{OPT} - T_{REF}) + I_{SC}]\, I_{RR} \tag{4}$$

Shunt Current Equation

$$I_{SH} = (IR_S + V)/R_{SH} \tag{5}$$

Reverse Saturation Current

$$I_S = [I_{RS}\, (T_{OPT}/T_{REF})^{3} * q^2 Eg/N\, k_B * e^{(1/T_{OPT} - 1/T_{REF})} \tag{6}$$

Reverse Current Equation

$$I_{RS} = I_{SC}/\, [e^{(q\, V_{OC}/k\, C_i\, T_{OPT})} - 1] \tag{7}$$

Output Power

$$P = VI \tag{8}$$

Standard Test Conditions (STC) is followed for implementing above equations with values of parameters and constants equal to the ones mentioned in Table 1.

Table 1. STC and other Parameters Studied In Describing Solar Cell

SYMBOL	PARAMETER	
	NAME	***VALUE***
V_T	Thermal Voltage	Variable
V	Operating Voltage	Variable
V_{OC}	Open ckt voltage	21.1 V
I_{SC}	Short ckt current	3.8 A
I_S	Diode Reverse Saturation Current	2*10-4 A
I_{ph}	Photocurrent	Variable
I	Cell Output Current	Variable
T_{REF}	Reference Temperature of cell	25 °C
T_{OPT}	Operating Temperature	Variable
R_{SH}	Shunt Resistance of Cell	360.002 Ω
R_S	Series Resistance of Cell	0.18Ω
Eg	Energy Band Gap	1.12eV
N	Ideality Factor	1.36
k_B	Boltzmann constant	1.38 × 10-23 J/K
k_i	Current Proportionality constant	$2.2*10^{-3}$
q	Electron charge	1.602×10^{-19} C
G	Irradiance	$1000W/m^2$
N_s	No. of cells in series	Variable
N_p	No. of cells in parallel	Variable
C	No. of Cells in module	Variable

2. Simulink Modelling

Equation (1) to (8) mentioned for operating basic solar cell are modeled using Simulink. Modeling is done for STC using physical systems at component level instead equations.

Thus complete Subsystem formulation and representation of equations is achieved by SPS (Simulink to Physical Signal) and PSS (Physical to Simulink Signal) blocks given in Figure 2.

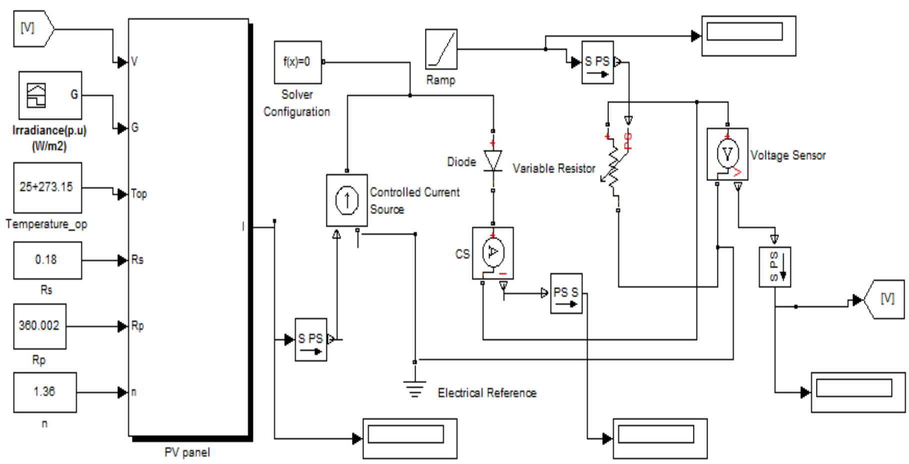

Figure 2.Complete Subsystem Model

2.1 STC (Standard Test Conditions)

The electrical output of solar panels is measured in watts. There are several scenarios during which solar panels reach their maximum output. High noon is peak time as it is the hottest part of the day. When it is not raining or snowing and skies are clear, solar panels produce maximum efficiency. The STC for solar cell modeling is temperature of 25°C (298.15K) and an irradiance of 1000W/m^2. Other conditions include altitude angle with perpendicular sun and optimum tilt of panel. The location of site selected is also considered.

Single cell output is maximum with 20% efficiency covering 100cm^2 (0.01m^2) surface area producing 2.0 watts of power. Single solar cell output modeled at STC is plotted by IV and PV Characteristics graphs given below in Figure 3 and 4.

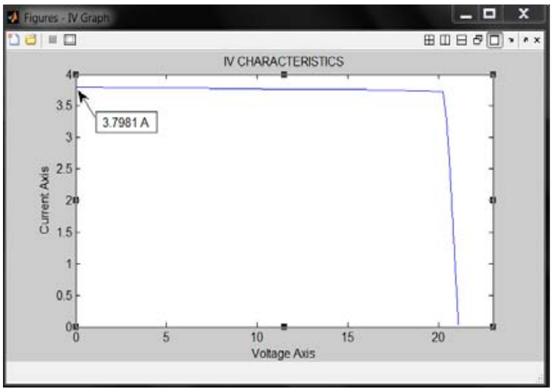

Figure 3. IV Graph Characteristics of Solar Cell

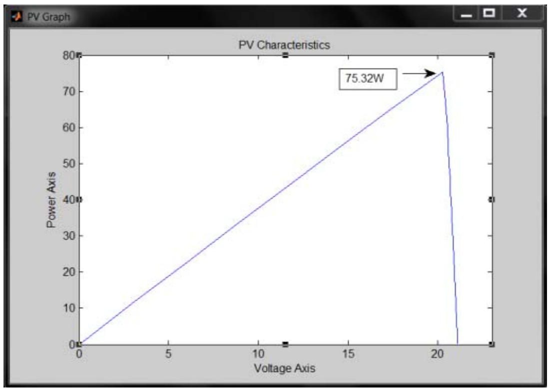

Figure 4. PV Graph Characteristics of Solar Cell

An intersection of IV and PV Characteristics are used for determination of Maximum Power Point (MPP). MPP refers to PV unique operating point delivering maximum power giving highest efficiency of solar cell or an array. It varies with solar irradiance and temperature.

The values for various parameters at MPP for single solar cell are V_{OC}=21.096V, I_{SC}=3.7981A and P_{MAX} =75.32W.

Experimentally when single solar cell is modeled above parameters is indicated through intersection of IV and PV graphs as in Figure 5.

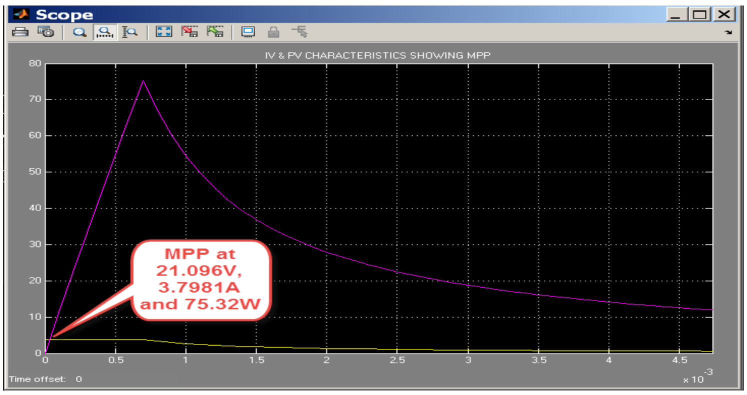

Figure 5. SIMOUT Scope Characteristics of Solar Cell

Irradiance and temperature largely affect IV and PV graphs for single solar cell. Thus for proper monitoring, array of solar cells is used. Solar panels consist of solar cells. As one single solar cell does not produce sufficient energy for most purposes, solar cells are put together in solar panels so that they produce more electricity jointly.

Generally an array of 36 or 72 cells is constructed. Commercially these panels prove best for practical applications of street lighting and water heating systems. The various parameters for array outputs when model is varied for different cells result in Table 2 observations:

Table 2. Array Output

CELLS IN ARRAY	SIMOUT READINGS		
	VOLTAGE V_{OC}	*CURRENT I_{SC}*	*POWER P_{MAX}*
36	21.073	3.798	60W
72	21.049	3.797	50W

It is clear that on increasing no. of cells in array, output decreases.

3. Factors Affecting Simulink Model Results

Many factors affect the energy output of solar energy system. Some vary like irradiance and temperature whereas some are fixed like series and shunt resistance and diode ideality factor. A proper monitoring of all these factors is essential.

In this proposed work 36 solar cell array is tested for varying values of temperature and Irradiance mainly.

3.1. Weather Conditions causing Variable Irradiance (G)

The power of solar energy system to be generated is greatly reduced due to various atmospheric distractions. These include clouding and shading effects due to fog, haze and smog in domestic or industrial areas. Rain and snow also affects solar panel efficiency.

For describing these deviations, Irradiance model is constructed using Constant, Step and Trapezoidal signals. Variations related to different signals result change in characteristics of solar cell as described in Figure 6, 7 and 8.

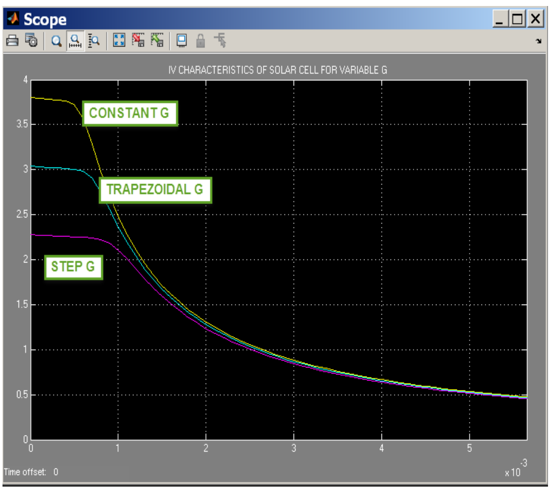

Figure 6. Variable G Output for Array IV Scope

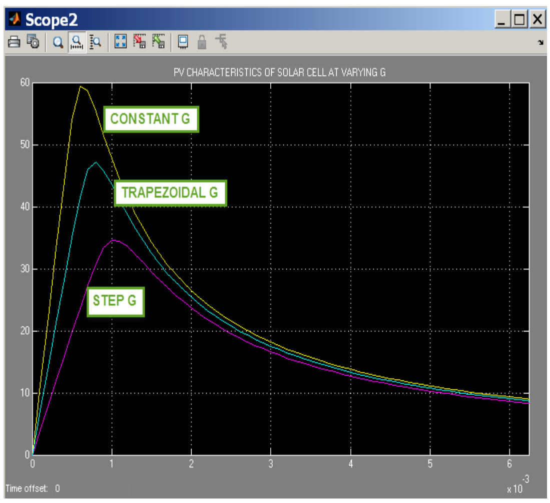

Figure 7. Variable G Output for Array PV Scope

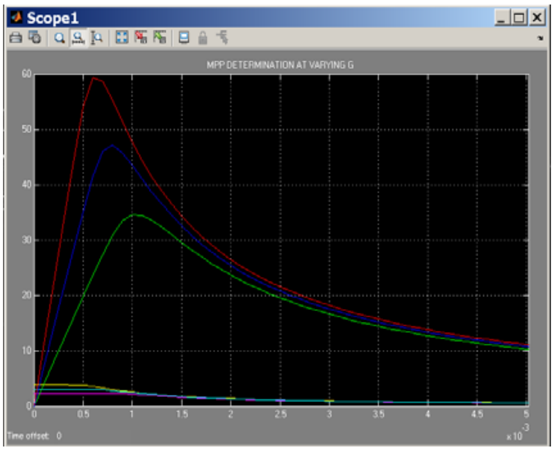

Figure 8. Variable G MPP Scope Output

It is clear that highest output is evident for Constant irradiance. But in practical irradiance is never constant, and varies. However graphically variation is not very large and is appreciably good for trapezoidal signal when compared to step signal.

Against this background, performance is largely affected causing huge differences in Fill Factor and Efficiency of panel.

Fill Factor is defined as maximum square fitting intersection of IV and PV curves. It describes ratio of maximum power generated by a solar cell to the product of V_{OC} and I_{SC}. It is given by expression $FF = P_{MAX}/V_{OC}I_{SC}$. This in turn deteriorates Efficiency (η) defined as output of power delivered from solar panel to incident power. It is related to FF through expression $\eta = V_{OC}I_{SC}FF/P_{IN}$.

Description of observations for MPP is given in Table 3:

Table 3. Irradiance Effect on Array Output

COLOUR PV/IV	PARAMETER	SIMOUT READINGS		
	IRRADIANCE	***VOLTAGE V_{OC}***	***CURRENT I_{SC}***	***POWER P_{MAX}***
	Constant	21.073	3.798	59.393
	Trapezoidal	20.786	3.038	47.120
	Step	20.415	2.278	34.615

Fill Factor and Efficiency of panel are calculated in Table 4:

Table 4. Irradiance Effect on Array Output

PARAMETER	ESTIMATED OUTPUTS	
IRRADIANCE	***FILL FACTOR $FF = P_{MAX}/V_{OC}I_{SC}$***	***EFFICIENCY $\eta = V_{OC}I_{SC}FF/P_{IN}$***
Constant	0.742085	98.9883%
Trapezoidal	0.746185	78.5333%
Step	0.744323	57.6917%

As FF is a measure of the "squareness" of the IV curve, a solar cell with a higher voltage has a larger possible FF as compared to lower voltage that takes up less area. The maximum theoretical FF from a solar cell can be determined by differentiating the power from a solar cell with respect to voltage and finding where this is equal to zero. Thus methods to maintain constant irradiance using Controllers or Battery Banks are desired.

3.2. Effect of Varying Temperature (T)

Although the temperature doesn't affect the amount of solar energy received by solar panel, it does affect how much power is obtained. Panels produce less power from the same amount of sunlight as they start getting hotter. On increasing temperature, band gap reduces resulting increase in release of energy by exited electrons due to sun energy. Since the difference in rest state and exited state of electrons determine voltage output. The parameters most affected by increase in temperature are the open-circuit voltage that decreases and short-circuit current that increases and vice versa. Since the voltage decreases faster than increase in the current, the result is that the overall efficiency goes down as $\eta = V_{OC}I_{SC}FF/_{/}P_{IN.}$ But overall the effect is not very strong so solar panels can still function properly even in the summer when it is hot outside.

However, this difference of varying temperature is insignificant and can be controlled upto 55°C therefore model in results show changes from 5°C to 55°C. After 105°C, sharp decrease in output occurs. As practically such huge temperature is not feasible to obtain these are not considered.

The Seasonal variation of temperature on IV and PV characteristics is depicted in Figure 9 and 10.

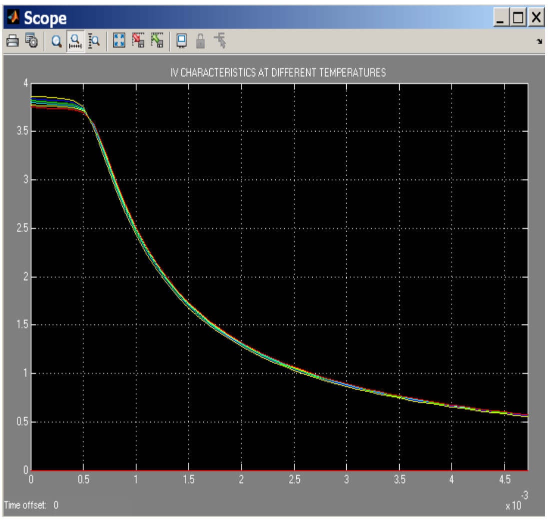

Figure 9. Temperature Effect on Array IV Scope Output

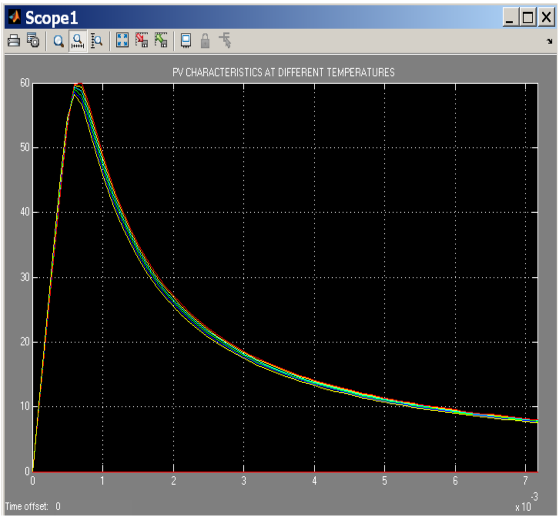

Figure 10. Temperature Effect on Array PV Scope Output

Table 5. Temperature Effect on Cell Output

COLOR IV/PV	PARAMETER	SIMOUT READINGS		
	TEMPERATURE	*VOLTAGE V_{OC}*	*CURRENT I_{SC}*	*POWER P_{MAX}*
/	5°C	21.305	3.754	59.829
/	15°C	21.191	3.776	59.651
/	25°C	21.073	3.798	59.393
/	35°C	20.951	3.820	59.064
/	45°C	20.826	3.842	58.670
/	55°C	20.697	3.864	58.218

Table 6. Temperature Effect on Cell Output

PARAMETER	ESTIMATED OUTPUTS	
TEMPERATURE	*FILL FACTOR* $FF = P_{MAX}/V_{OC}I_{SC}$	*EFFICIENCY* $\eta = V_{OC}I_{SC}FF/P_{IN}$
5°C	0.748059	99.715%
15°C	0.745477	99.41833%
25°C	0.742085	98.98833%
35°C	0.737997	98.44%
45°C	0.733251	97.78333%
55°C	0.727969	97.03%

As observed, huge variations in outputs are observed for higher temperatures as compared to lower ones. This variation causes output to vary decreasing efficiency and fill factor calculation. This is well defined through Table 5 and 6.

Hence significant operating temperature needs to be selected when used in mounting of fixed panel structure. Sometimes to make array less temperature dependent with seasonal changes, Controller is attached with system. This delivers continuous non distorted output for off-noon time when temperature decreases.

4. Other Factors Affecting Output of Solar Cells

Many other factors affect the energy output of solar energy system. These are described below.

4.1. Shading

The solar energy system needs to be installed in an open area not influenced by shade. The energy output reduces, if even a small section of the solar panels is shaded. This is due to variation causing change in resistance of solar cell. Both the magnitude of series and shunt resistance for solar cell depend on the geometry of cell. These changes result shift in operating point of the solar cell. Ideally standard values have been used in experimental analysis for solar cell model using fixed R_S and $R_{SH.}$

4.2. Diode Ideality

The ideality factor N, of a diode is a measure of how closely the diode follows the ideal diode equation. Recombination is limited by minority carriers in Band to band low level injection that occurs for N<=1. Recombination is limited by majority carriers for band to band high level injection with N<=2. For N=2/3 there are more majority carriers than minority required for recombination. Hence value of N is chosen 1.32 such that appropriate values are obtained.

4.3. Proximity to the Equator

Site selections nearby equator generate more electricity power output than others. This is due to fact that the rate of rotation of earth spin is fastest and sun is vertically above at midday. Generally a fixed mount solar panel located on equator with adjusted 15^0 angles to clean in the rain without manual rotation.

4.4. Dirty Panels

Solar panels can become dirty due to Pollution, traffic dust and bird droppings leading to soiling on panel. To combat this, panels need to be cleaned regularly. A solar panel consists of solar cells covered by a protective glass coating. Physical inspection on periodic basis is done. Sometimes, monitoring device is attached for automated cleaning and system troubleshooting if less output is detected.

4.5. Control Flow System

Solar Energy System can be more efficient by making sure it includes a control system. The control system ensures that constant MPP is maintained throughout the panel operation irrespective of changes in irradiance and temperature. Using controller, quantity of lights to be lit or volume of water that needs to be heated in applications can be reduced. This increases solar energy system efficiency. Solar shingles covering entire roof can also be used but problems as the tilt angle can be removed using appropriate control system.

5. Conclusion

This article provides a classification of solar cell panel construction technique based on fixed number of control variables. The model is developed using basic circuit equations of the solar cells including the effects of solar irradiation and temperature changes. These are followed by identification of MPP for a particular application. The results of the analysis are related to variable irradiance model in first part of paper. The results show that the performances are approximately identical under both static (constant) and dynamic (trapezoidal and step) conditions. This portion serves as a tutorial on PV device and helps in understanding the parameters that compose the single-diode PV model.

In the second part, temperature variations are measured during a year widely spread from range 5°C to 55°C. The outputs are very sensitive to changes in temperature when used for determining efficiency. Simulation and experimental results show the high stability and high efficiency of 36 cells PV arrays. It is interesting to point out that slight differences in performances contribute huge change in fill factor and efficiency. To obtain STC, implementation through digital controllers can be applied to minimize error functions for changeable irradiance and temperatures.

6. Future Work

Currently total energy produced through solar is less than 1% of total demand hence there is a large scope in this area. Solar power generation is merely concentrated in three states Gujarat, Rajasthan and Maharashtra. There are immense opportunities in Uttrakhand where PV systems are being distributed and installed by UREDA on subsidy basis to meet the lighting requirements. LED Based Solar Home Lighting Systems (SHLs), Solar Street Lights and Solar Lanterns, are amongst few stand-alone techniques.

Multiple modules may be used and operated through Government-funded solar power projects for Grid generation. This could prove beneficial when used in research and technology validation projects at various levels.

Test and validation studies for 36 cells array with proper circuits was simulated and results were presented here. However, the objective to obtain fixed maximum power point for Distributed Energy Generation Systems still needs to be worked upon.

References

[1] Tarak Salmi, Mounir Bouzguenda, Adel Gastli, Ahmed Masmoudi. MATLAB/Simulink Based Modelling Of Solar Photovoltaic Cell. *International Journal of Renewable Energy Research Tarak Salmi Et Al*. 2012; 2(2).

[2] Dr P Sangameswar Raju, Mr G Venkateswarlu. Simscape Model of Photovoltaic cell. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering.* 2013; 2(5).

[3] URL http://pveducation.org/pvcdrom/solar-cell-operation.

[4] URL http://photovoltaic model in MATLAB/simulink.

[5] Savita Nema, RK Nema, Gayatri Agnihotri. Matlab/simulink based study of photovoltaic cells/modules/array and their experimental verification. *International Journal of Energy and Environment*. 2010; 1(3): 487-500.

[6] Pavels Suskis, Ilya Galkin. Enhanced Photovoltaic Panel Model for MATLAB-Simulink Environment Considering Solar Cell Junction Capacitance. *Industrial Electronics Society*. IECON - 39th Annual Conference of the IEEE. 2013.

[7] Islam MA, Mohammad N Khan PKS. *Modeling and performance analysis of a generalized photovoltaic array in Matlab. Joint International Conference IN 2010 on* Power Electronics, Drives and Energy Systems by IEEE. 2010.

[8] Shekoofa O, Taherbaneh M. *Modelling of silicon solar panel by Matlab/simulink and evaluating the importance of its parameters in a space application*. 3rd International Conference on Recent Advances in Space Technologies. RAST '07 by IEEE. 2007.