

Modelling of Photovoltaic System with Converter Topology for Grid fed Operations.

K.UMADEVI

ASSOCIATE PROFESSOR,
EXCEL COLLEGE OF ENGINEERING AND TECHNOLOGY

P. NALANDHA

ASSISTANT PROFESSOR
AMET UNIVERSITY

C. CHENN KESAVAN

ASSISTANT PROFESSOR
AMET UNIVERSITY

Abstract— This paper presents the performance of a grid connected converter topology for PV array. The system containing solar cell, DC-DC boost converter, inverter and ac load (grid). This paper presents the simulation of a photovoltaic system using MATLAB, which can be representative of PV cell, module and array. The photovoltaic array is designed for 144 V. The proposed PV model was prepared on MATLAB scrip file and input parameters are solar irradiation and temperature. The output current and power characteristics of PV model are simulated for varying effects of temperature and solar irradiation. A DC-DC boost converter is used for boosting of DC voltage obtained from Photovoltaic system. A DC-DC converter is designed for 600 V and inverter is for 230 V (rms). The sinusoid ac output voltage is inverted from dc-link voltage via inverter using sinusoidal Pulse-Width Modulation (SPWM) technique. The proposed converter topology is built in PSIM software. The proposed converter concept is verified with simulations results.

Keywords— Photovoltaic module, DC/DC Boost Converter, PWM Inverter.

I. INTRODUCTION

Solar energy is the largest renewable carbon-free resource among the other renewable energy options. Conversion of solar energy to electrical energy depends on a device called the *photovoltaic cell*. A set of connected cells form a panel. Several panels electrically connected in series constitute an array and several arrays, electrically connected in parallel to generate the required power, constitute the generator or photovoltaic field. Photovoltaic systems have become increasingly popular and are ideally suited for distributed systems. Many governments have provided the much needed incentives to promote the utilization of renewable energies, encouraging a more decentralized approach to power delivery systems. Recent studies show an exponential increase in the worldwide installed photovoltaic power capacity. There is ongoing research aimed at reducing the cost and achieving higher efficiency.

Photovoltaic (PV) is a technology in which radiant energy from the sun is converted to direct current (DC) electricity. Unfortunately solar cells are still far to produce a significant fraction of the world's energy needs because of the initial investment cost. PV cells produce direct current (DC) energy. Because most residential and commercial electrical equipment is AC

(alternating current), this DC energy needs to be converted. An inverter is used to produce AC power from the DC generated PV cells. The AC power produced can also be provided to a utility. The voltage and current available at the terminals of a PV device may directly feed small loads such as lighting systems and DC motors. More sophisticated applications require electronic converters to process the electricity from the PV device. These converters may be used to regulate the voltage and current at the load, to control the power flow in grid-connected systems. The power from photovoltaic cell is given to the DC-DC boost converter where the input voltage is boosted up to the required DC voltage, then given to the DC-AC converter. [1]

The generated power in PV cells can be used in a standalone system or can be fed to the AC main grid. In standalone systems, the output power of the PV system can also be stored in batteries. However, the battery systems are expensive, bulky and require high maintenance. Where utility power is also available, another solution is to feed the power into the grid, which requires a grid connected inverter. The paper discusses the PV system topologies with MATLAB and the proposed converter topology using PSIM software. The classical

connection between photovoltaic array and AC grid is shown in figure 1. The main objective, from this interfacing, is to feed all the collected energy at the PV plant to the commercial AC grid. [6, 8]

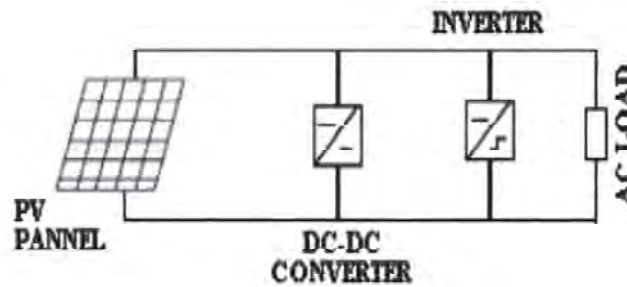


Fig. 1. Block diagram of fuzzy controller for a grid connected PV system.

Inverter's control is key aspect in PV generation system. With the development of power electronics technology of pulse width modulation (PWM) has been widely applied in inverter. The sine PWM technology is applied into many aspects by its simplicity and easy implementation. In order to improve the efficiency and gains better quality of output power in PV power generation system, a novel standalone PV generation system based on SPWM control scheme for single-phase voltage source PWM inverter is proposed in this paper.

II. MODELING OF PV ARRAY

The elementary component of a PV generator is the photovoltaic cell where the conversion of the solar radiation into electric current is carried out. The cell is constituted by a thin layer of semiconductor material, generally silicon properly treated, with a thickness of about 0.3 mm and a surface from 100 to 225 cm². [1] The model inputs are the solar irradiation [W/m²], the ambient temperature [°C], the photovoltaic generator voltage [V], whereas the only output is the photovoltaic current which supplied by the panel [A].

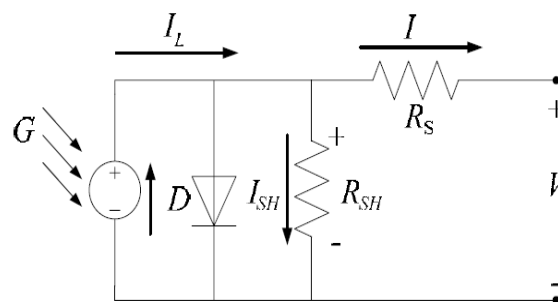


Fig. 2. Basic equivalent circuit of solar cell.

The cell structure and parameters involve photocurrent I_L , diode reverse saturation current, diode ideality factor, series resistance R_s and shunt resistance R_{sh} , which need to be identified for every operating condition for the accurate modeling of solar cell behavior [4]. A photovoltaic cell can be considered as a current generator in parallel with a diode and can be represented by the equivalent circuit as shown in Figure 2. When the cell is exposed to sun light, due to the photovoltaic effect some electron-hole couples arise both in the N region as well as in the P region. The output of the current source is directly proportional to the light falling on the cell. The solar cell works as a diode in absence of light. It produces neither a current nor a voltage [2].

In an ideal cell we would have $R_s=0$ and $R_{sh}=0$. Under short-circuit conditions the generated current is I_{sc} , whereas with the circuit open the voltage V_{oc} (open circuit voltage) [1].

A. Characteristic equations

The voltage-current characteristic equation of a solar cell is given as,

$$I = I_L - I_0 \left[\exp \left(\frac{q(V + IR_s)}{nkT_c} \right) - 1 \right] - (V + IR_s) / R_{sh} \quad (1.1)$$

where I_L is a light-generated current or photocurrent, I_0 is the cell saturation of dark current, q ($= 1.6 \times 10^{-19}C$) is an electron charge, k ($= 1.38 \times 10^{-23}J/K$) is a Boltzmann's constant, T_c is the cell's working temperature, n is an ideal factor. [3]

In general, the PV efficiency is insensitive to variation in R_{sh} and a small variation in R_s will significantly affect the PV output power. Equation (1.1) can be rewritten to be

$$I = I_L - I_0 \left[\exp \left(\frac{q(V + IR_s)}{nkT_c} \right) - 1 \right] \quad (1.2)$$

The photocurrent I_L ,

$$I_L = I_L(T_1) + K_0(T - T_1) \quad (1.3)$$

$$I_L(T_1) = I_{sc}(T_{1,nom})(G/G_{nom}) \quad (1.4)$$

$$K_0 = (I_{sc}(T_2) - I_{sc}(T_1))/(T_2 - T_1) \quad (1.5)$$

The saturation current of the diode I_0 ,

$$I_0 = I_0(T_1)(T - T_1)^{(3/n)} \exp \left(\frac{qV(T_1)}{nk \left(\frac{1}{T} - \frac{1}{T_1} \right)} \right) \quad (1.6)$$

$$I_0(T_1) = I_{sc}(T_1) / \{ \exp(qV_{oc}(T_1)/nkT_1) - 1 \} \quad (1.7)$$

A series resistance R_s ,

$$R_s = -(dV/dI_{Voc}) - (1/X_V) \quad (1.8)$$

$$X_V = I_0(T_1)(q/nkT_1) \exp(qV_{oc}(T_1)/nkT_1) - (1/X_V) \quad (1.9)$$

B. I-V curve of PV cell

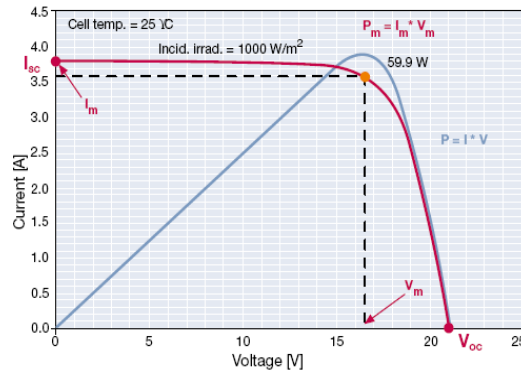


Fig. 3. A voltage-current characteristic curve of a PV cell.

The voltage-current characteristic curve and power-voltage characteristic curve of a PV cell is shown in Figure 3 [1]. This figure is quoted for standard conditions: and irradiance of 1 kW/m^2 and a cell temperature of 25°C .

C. Simulation of PV Module

The Solarex MSX60 PV module was chosen for modelling, due is well-suited to traditional applications of photovoltaic system. The key specifications are shown in Table 1 [2,4]. The model of the PV module was implemented using a Matlab program. The program, calculate the current I , using typical electrical parameter of the module (I_{sc} , V_{oc}), and the variables Voltage, Irradiation (G), and Temperature (T).

TABLE I
TYPICAL ELECTRICAL CHARACTERISTIC OF MSX-60 PV MODULE.

Symb ol	Parameter	Value
Pm	Maximum Power	60W
Vm	Voltage@Pm	17.1V
Im	Current@Pm	3.5A
Isc	Short circuit current	3.8A
Voc	Opencircuit voltage	21.1V
B	Temperature coefficient of open-circuit Voltage	$-(80 \pm 10)\text{mV}/^\circ\text{C}$
A	temperature coefficient of shortcircuit current	$(0.0065 \pm 0.015)\%/^\circ\text{C}$

A MATLAB script file was implemented using the parameters of MSX-60 module as shown in fig. 4 [2].

% input variables are suns, Tac, Rs

k= 1.38.*10.^-23;

q= 1.60.*10.^-19;

n=1.75;

Vg= 1.12;

```

T1 = 273 + 25;
Voc_T1 = 21.06./Ns;
Isc_T1 = 3.80;
T2 = 273 + 75;
Voc_T2 = 17.05./Ns;
Isc_T2 = 3.92;
Tak = 273 + Tac;
K0 = (Isc_T2 - Isc_T1)./(T2 - T1);
IL_T1 = Isc_T1.* Suns;
IL = IL_T1 + K0.*(Tak - T1);
Vc = Va./Ns;
Ia=zeros(size(Vc));
I0_T1=Isc_T1./(2.71.^((q.*Voc_T1)./(n.*k.*T1))-1);
for j=1:5;
Ia=Np*(IL-I0*((2.71^(q*(Vc+Ia*Rs)/(n.*k.*Tak))-1)));
end

```

Fig. 4. A MATLAB script file for the PV module model.

III. CONVERTER TOPOLOGY

The boost converter, also known as the step-up converter, is another switching converter that has the same components as the buck converter, but this converter produces an output voltage greater than the source. The ideal boost converter has the basic components, namely a power semiconductor switch, a diode, an inductor, a capacitor and a PWM controller.

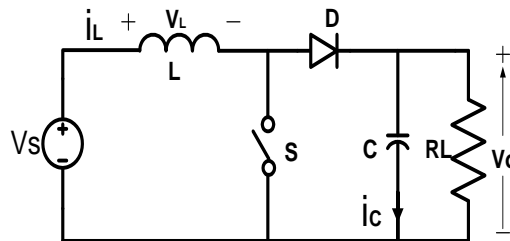


Fig. 5. Basic Circuit of Step-Up Converter

The basic circuit of the boost converter is shown in Fig. 5. The basic Equations to calculate the Inductor and Capacitor are as follows,

$$V_o \div V_s = 1 \div (1 - D) \quad (2.1)$$

$$T_{on} = DT \quad (2.2)$$

$$V_s I_s = V_o I_o \quad (2.3)$$

Inductor calculation:

$$L = (V_s * D) \div (f * \Delta I) \quad (2.4)$$

Capacitor calculation:

If we take the variation at the output side is 5% of output voltage,

$$C = (I_o * D) \div (f * \Delta V_o) \quad (2.5)$$

where, V_o and V_s are output voltage and source voltage and D is duty cycle, switching frequency f and I_o is Output current.

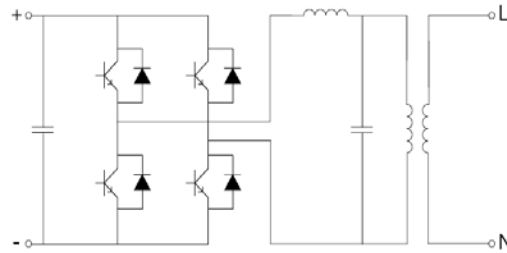


Fig. 6. Principle scheme of a single-phase inverter.

Figure 6 shows the principle scheme of an inverter. The transistors, used as static switches, are controlled by an opening-closing signal which, in the simplest mode, would result in an output square waveform. To obtain a waveform as sinusoidal as possible, a more sophisticated technique – Pulse Width Modulation (PWM) – is used; PWM technique allows a regulation to be achieved on the frequency as well as on the r.m.s. value of the output waveform.[1]

A. Simulation of Converter

The DC-DC converter and inverter is simulated using PSIM® (a simulation tool designed for power electronics and dynamic systems). Figure 7 shows the basic components of the simulation model, including the PV cell that is represented by the VDC1 (Figure 2). [6]

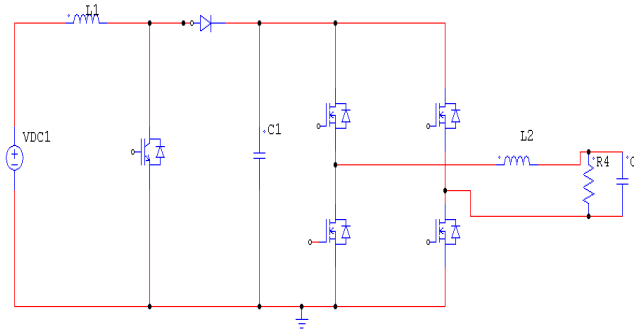


Fig. 7. PSIM schematic of the converter topology.

The model consists components such as one static switch, Diode D, two inductors L1, L2 and capacitors C1, and C2. In boost converter, it can be seen that there are capacitor C1, inductor L1 and diode D1 added into the circuit. Capacitor C1 performs the characteristics to lift the capacitor voltage VC1 by a source voltage VDC1. In self-lift the switch S is IGBT device. The basic principle of voltage lift circuit in boosting up the output voltage. In DC-AC inverter there are four switches of MOSFET power device. In order to generate sinusoidal current with low harmonic distortion, a sinusoidal PWM is used since it is one of the most effective methods. Sinusoidal PWM is obtained by comparing a high-frequency carrier with a low-frequency sinusoid, which is the modulating signal or reference signal. The carrier has a constant period; therefore, the switches have constant switching frequency. The switching instant is determined from the crossing of the carrier and the modulating signal. Capacitor is connected in parallel with the load to filter output ripple and maintain a constant output voltage. The simulation parameters are shown in Table II and III. [7, 8]

TABLE II.
SIMULATION PARAMETERS OF DC/DC CONVERTER

Parameter	Description
P = 30 kW	Converter Power
Vi= 144 V	Input Voltage (DC)
Vout= 600 V	Output voltage (DC)
Fs = 20 kHz	Commutation Frequency
L =1260 uH	Converter inductance
C= 253.5 uF	Converter capacitor

TABLE III.
SIMULATION PARAMETERS OF AC/DC INVERTER

Parameter	Description
$V_i = 600\text{ V}$	DC Source voltage
$V_{out} = 320\text{ V(rms)}$	Rated output voltage
$F = 50\text{ Hz}$	Rated output frequency

IV. SIMULATION RESULTS

A. PV Module Simulation results

The output VI characteristic for 1000 W/m^2 , 400 W/m^2 solar irradiation and various temperatures are shown in fig. 8 & 9. The output PV characteristic for 1000 W/m^2 , 600 W/m^2 solar irradiation and various temperatures is shown in fig. 10 & 11. The simulated characteristic shows the change in power as variation in irradiation and temperature.

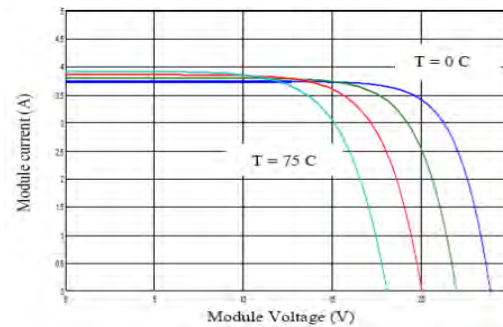


Fig. 8. V-I output characteristics with $\lambda = 1000\text{ W/m}^2$ and $T = 0, 25, 50, 75^\circ\text{C}$.

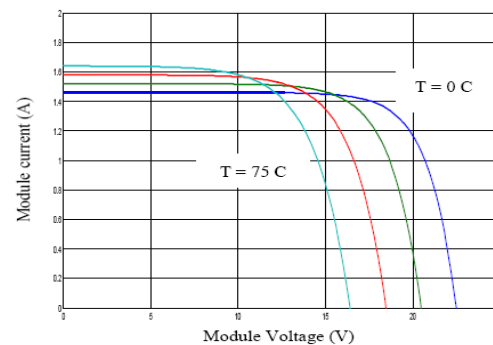


Fig. 9. V-I output characteristics with $\lambda = 400\text{ W/m}^2$ and $T = 0, 25, 50, 75^\circ\text{C}$.

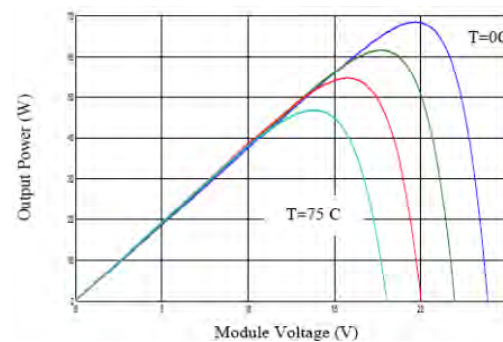


Fig. 10. P-V output characteristics with $\lambda = 1000\text{ W/m}^2$ and $T = 0, 25, 50, 75^\circ\text{C}$.

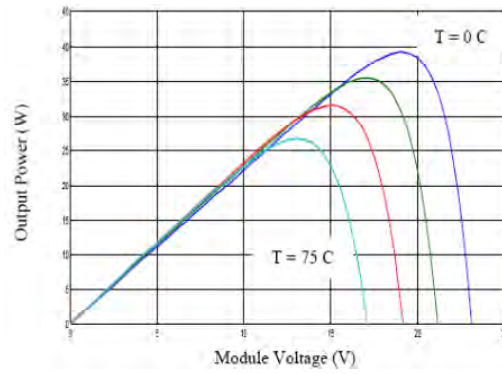


Fig. 11. P-V output characteristics with $\lambda=600 \text{ W/m}^2$ and $T=0, 25, 50, 75^\circ\text{C}$.

B. Input-Output Waveforms Using Simulation

The PV generation system is designed to electrify ac loads (or grid connected) with specifications of 230 V (RMS) and 50 Hz. To supply ac loads, a boost dc-dc converter is utilized to increase the voltage from 144 V to the required dc bus level of 600 V, which is necessary for generating the ac output voltage of 230 V from an inverter. The simulation results of the dynamic performance, which validates the PV generation system. The PV voltage, current are shown in Fig. 12 and Fig. 13. Fig. 14 shows the output voltages of boost converter. The voltage and current of the load (inverter) have been shown in Fig. 16 and Fig. 17.

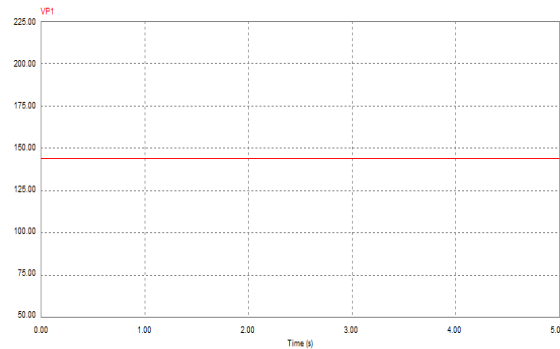


Fig. 12. Simulated result of output voltage from PV module.

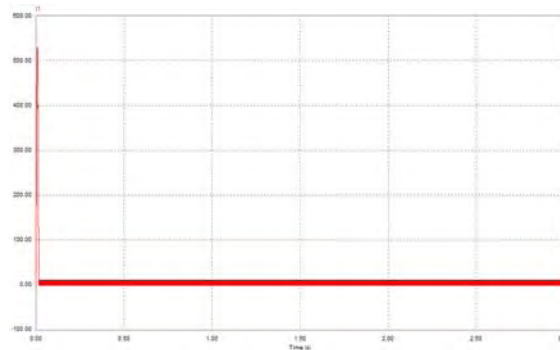


Fig. 13. Simulated result of output current from PV module.

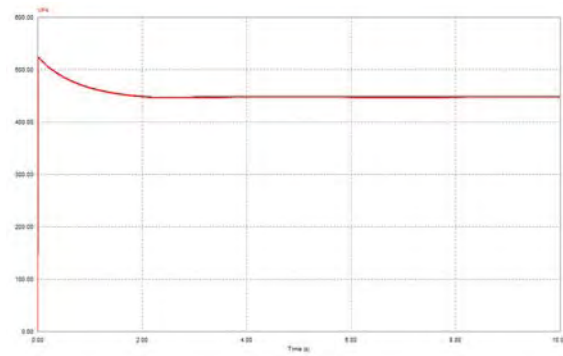


Fig. 14. Simulated result of the output voltage of DC-DC converter.

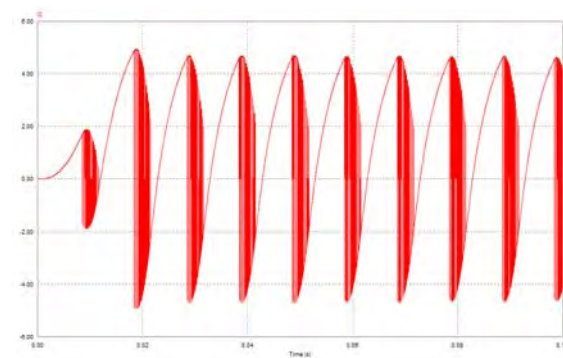


Fig. 15. Simulated result of the output current of DC-DC converter.

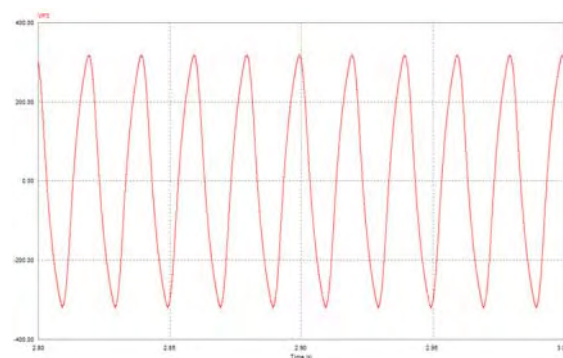


Fig. 16. Simulated result of the output voltage of DC-AC inverter.

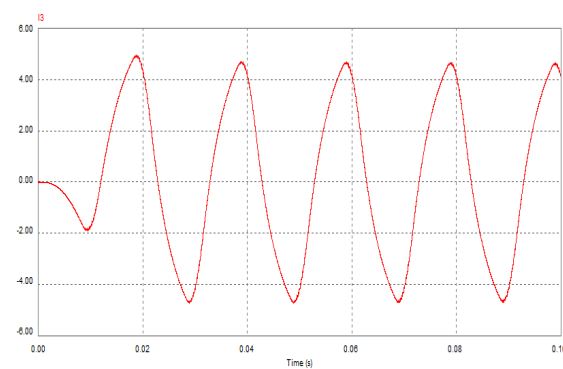


Fig. 17. Simulated result of the output current of DC-AC inverter.

V. CONCLUSION

The PV generation system has been considered for grid fed operations. The modeling of the system including PV array, Boost converter and SPWM controlled inverter was provided. The PV module characteristics complied with the theoretical characteristics, the boost converter stepped-up the input voltage and sinusoidal output voltage and current can be obtained using inverter. The simulation was conducted to confirm the PV system performances for irradiance and temperature changes using MATLAB software. The inductor and capacitor sized such that the minimum ripples in waveforms of voltage and current for converter which prove from its simulation results using PSIM software. The single-phase PWM inverter to be employed in a grid connected photovoltaic generation system.

VI. REFERENCES

- [1] ABB ,Book on Technical Application Papers No.10 on Photovoltaic plants, pp 1-25.
- [2] Francisco M. González-Longatt, 'Model of Photovoltaic Module in Matlab™', II CIBELEC 2005.
- [3] Huan-Liang Tsai, Ci-Siang Tu, and Yi-Jie Su, Member, IAENG, 'Development of Generalized Photovoltaic Model Using MATLAB/SIMULINK', Proceedings of the World Congress on Engineering and Computer Science, October 2008.
- [4] P. S. Revankar, W. Z. Gandhare and A. G. Thosar, 'Maximum Power Point Tracking for PV Systems Using MATLAB/SIMULINK', Second International Conference on Machine Learning and Computing, 2010.
- [5] Mukund R. Patel, Wind and Solar Power Systems, pp 33-158, CRC Press (New York), 2005.
- [6] G. Ertasgin, D.M. Whaley, N. Ertugrul and W.L. Soong, 'A Current-Source Grid-Connected Converter Topology for Photovoltaic Systems'.
- [7] Mateus F. Schonardie and Denizar C. Martins, 'Application of the dq0 Transformation in the Three- Phase Grid-Connected PV Systems With Active And Reactive Power Control', ICSET, 2008.
- [8] Y.Thiagarajan, T.S.Sivakumaran and P.Sanjeevikumar, 'Design and Simulation of FUZZY Controller for a Grid connected Stand Alone PV System', ICCCN, 2008.