A Systematic Approach to Grid Connected PV System

Shazia Afroze
Dept of Electrical & Electronics Eng.
National Institute of Technology
Karnataka,India
e-mail:shazia.aid@gmail.com.

Udaykumar R.Y ,Member,IEEE
Dept of Electrical & Electronics Eng.
National Institute of Technology
Karnataka,India
e-mail:udaykumarry@yahoo.com

Anant Naik
Dept of Electrical & Electronics Eng.
National Institute of Technology
Karnataka,India
email:anantnaik05@gmail.com

Abstract— **This paper proposes a detailed mathematical model of Photovoltaic(PV) array and a three-level control scheme of a single-phase grid-connected system including maximum power point tracker, voltage source inverter and its controller based on the MATLAB/Simulink tool. The PV model is developed by using basic circuit equations of the photovoltaic (PV) solar cells including the effects of solar irradiation and temperature changes. The perturb-and-observe algorithm is used to extract maximum power from PV arrays and deliver it to the inverter and PI control algorithm is used to control the three-level voltage source inverter. The simulation result shows the power sharing between PV and the Grid for any given load. Here generation of PV depends on the insolation of PV array**

Keywords— Grid connected, photovoltaic (PV), proportional–integral (PI) current control, pulse width modulated (PWM) inverter.

I. INTRODUCTION

With the increasingly urgent energy issues, the world is great importance to begin the development of new energy and related technology. At present, large-scale photo voltaic power generation and scale of renewable energy has become important parts of development strategy, meanwhile it is the way to guide the development of photo voltaic industry. However, because of its own characteristics different from conventional power generation, grid-connected PV power station and its security, stability, reliable operation have become new challenges which power grid and PV power plant need to face [1]-[4].

The electrical system powered by solar arrays requires special design considerations due to varying nature of the solar power generated resulting from unpredictable and sudden changes in weather conditions, which change the solar Irradiation level as well as the cell operating temperature values [5][6].

In early days, PV systems were used as power supplies only for special applications like communication, satellite. With the development of power electronics device the role of PV source has been widened in all domestic and few commercial fields.

In many places renewable sources like PV system are being connected to the grid. The current that PV system inject into the grid should obey the regulations, such as the EN61000-3-2 and the IEEE 1547,which state the amount of injected harmonics and other parameters. The grid injected current contains lesser amount of harmonic contents if the ac output voltage from the interconnecting inverter has more levels. Multilevel inverters offer improved output waveform, smaller filter size, lower EMI and lower harmonic distortion [7]-[9].

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A complete model for engineering applications is established in MATLAB/Simulink tool. Combining the development trend of grid-connected photovoltaic system, a single-phase three-level grid-connected photovoltaic system is designed. The perturb-and-observe algorithm is used to achieve maximum power tracking function. PI control algorithm is used to control the grid-connected inverter. The simulation results show the load sharing by PV and grid based on the generation of PV.

II. BLOCK DIAGRAM OF COMPLETE MODEL

Fig. (1) shows the complete block diagram of proposed system where PV is connected to the grid with local load. PV is connected to the system through a DC/DC converter and an inverter. A DC/DC converter is used to achieve maximum power point tracking. A current control single phase three level voltage source inverter is used to interface PV with the grid. The load sharing between PV and grid is controlled by the controller block.

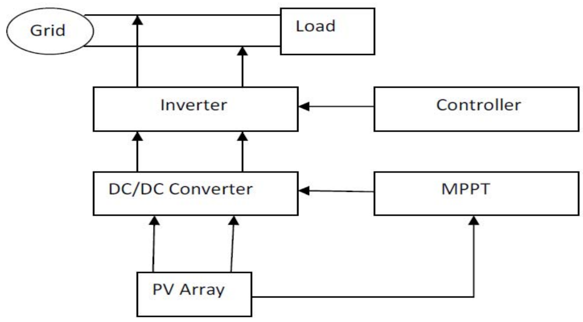


Fig. (1). Complete block diagram of grid connected PV system

III. Modeling Of The Photovoltaic Cell [6]

A solar PV array model is developed in Simulink tool. This array is used as a source for the maximum power point tracker system. The PV array makes use of the equations of a typical solar cell. The equivalent model of a solar cell is shown in Fig. (2). The current and voltage of the solar cell is given as follows:

$$I_{cell} = I_{ph} - I_D - \frac{V_{cell} + R_s I_{cell}}{R_p} \quad \text{.........(1)}$$

$$I_D = I_{sat}\left\{\exp\left[\frac{q}{KT}(V_{cell} + R_s I_{cell})\right] - 1\right\} \text{........(2)}$$

$$I_{pv} = N_p I_{ph} - N_p I_{sat}\left\{\exp\left[\frac{q}{KT}\left(\frac{V_{pv}}{N_s} + \frac{R_s I_{pv}}{N_p}\right)\right] - 1\right\} - \frac{N_p}{R_p}\left(\frac{V_{pv}}{N_s} + \frac{R_s I_{pv}}{N_p}\right) \text{........(3)}$$

where, I_{cell} = cell output current; V_{cell} = Cell output voltage; I_{pv}, V_{pv} = Solar cell current and voltage; I_D = Diode current; I_{ph} = Photo current; T = p-n Junction cell temperature; K = Boltzman contant; q = Electron charge; I_{sat} = Reverse saturation current; I_o = diode saturation current; R_s = Series resistance; R_p = parallel resistance; N_p = number of parallel cells; N_s = cells connected in series; $N_p I_{ph}$ = corresponds to the short circuit current of the solar array.

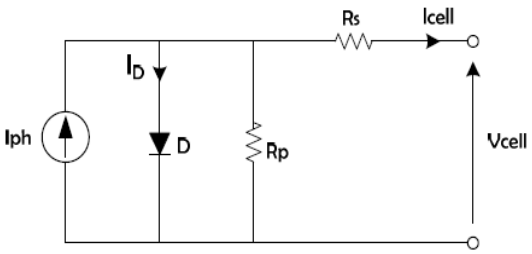


Fig. (2). Equivalent circuit of solar cell

IV. Control System Algorithm

The proposed inverter is used in a grid connected PV system. Therefore a PI controller is used to keep the output current sinusoidal and to have high dynamic performance under rapidly changing atmospheric condition. The amount of electric power generation by solar module is always changing with weather condition. To overcome this problem MPPT (Maximum Power Point Tracking) system is used. Therefore MPPT algorithm will ensure that maximum power is delivered from solar module. Here perturb & observation (P&O) algorithm is used to extract maximum power from PV module [10]. The feedback controller used in this application utilized the PI algorithm [11]. As shown in Fig. (4), the current injected into the grid I_g is sensed and fed back to a comparator which compares it with the reference current I_{ref}. I_{ref} is obtained by measuring the grid voltage and multiplying it with variable m. Here m is a modulation index obtained from MPPT to generate I_{ref}. Therefore, $I_{ref} = mV_g$

As variable m is dependent on the solar irradiation,
m α solar irradiation.

The PI algorithm can be expressed in the continuous time domain as,

$$u(t) = K_p e(t) + K_i \int_{\tau=0}^{t} e(\tau)d\tau \text{....................(4)}$$

where, error *e(t)*= set point-plant output.

K_p = Proportional gain

K_i = Integral gain

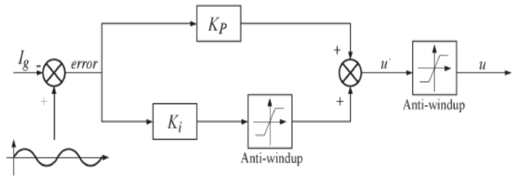


Fig. (3). PI control algorithm

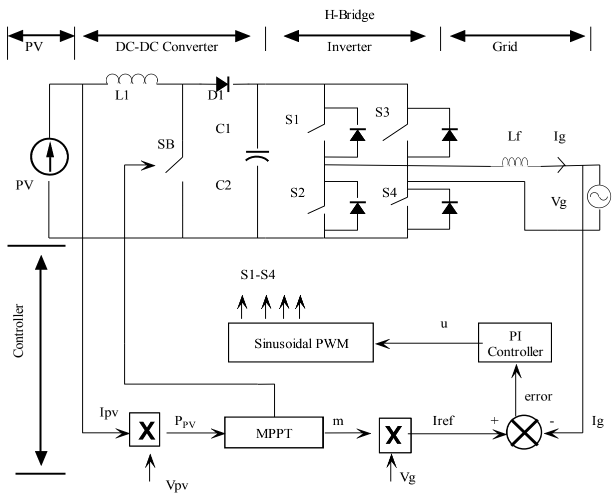


Fig. (4). Three level inverter with Control Algorithm

V. Result And Discussion

A. PV Cell Characteristics

The PV cell operates at different solar irradiation and temperature. The change in V-I and P-V characteristics is shown in Fig. (5) to Fig. (8) for different temperature and irradiation.

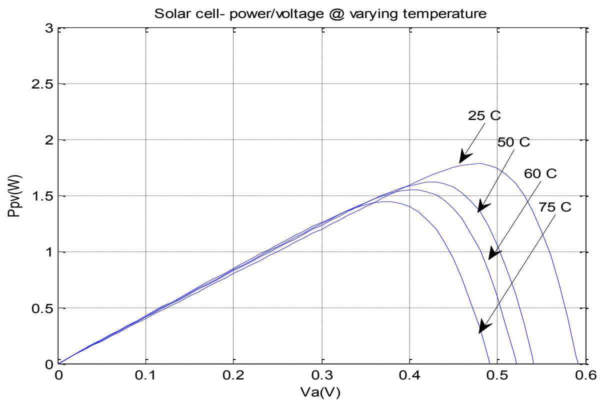


Fig. (5). V-P curve @ varying temperature

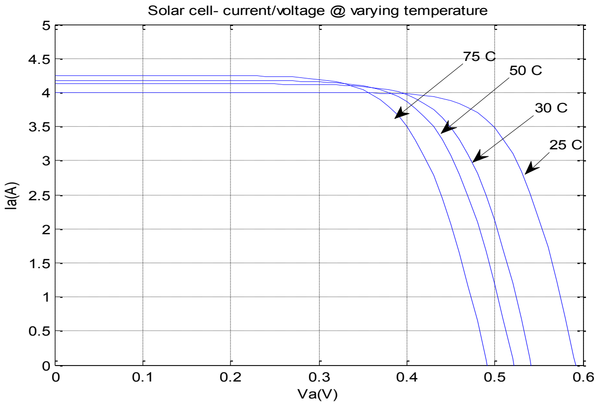


Fig. (6). V-I curve @ varying temperature

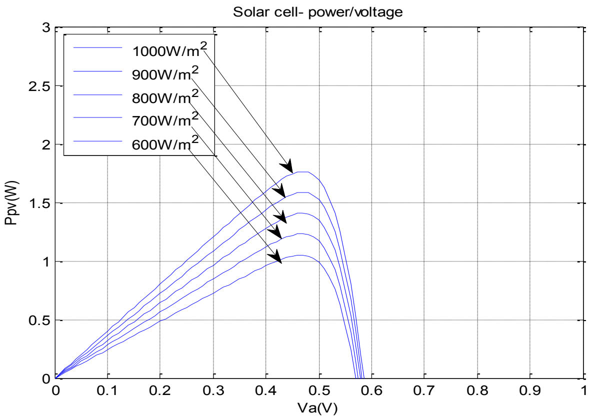


Fig. (7). V-P curve @ varying solar insolation

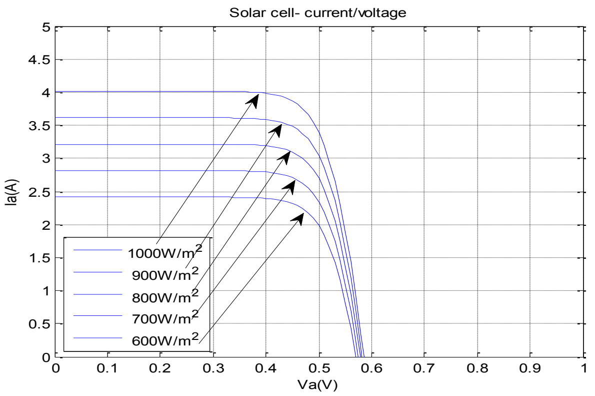


Fig. (8). V-I curve @varying solar insolation

B. Operation Of MPPT

PV array is designed for the voltage of 290 volts at the insolation point 20W/m^2. The output voltage of PV module is shown in Fig. (9).

However to fetch the maximum power at all operating condition MPPT is used. MPPT Circuit consists of Buck/Boost Converter. The corresponding output nature at given operating condition is shown in Fig. (10).

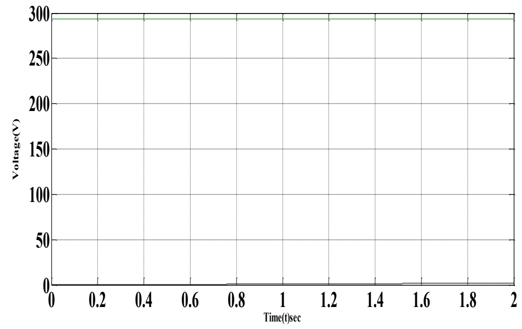


Fig. (9). Output voltage of PV module

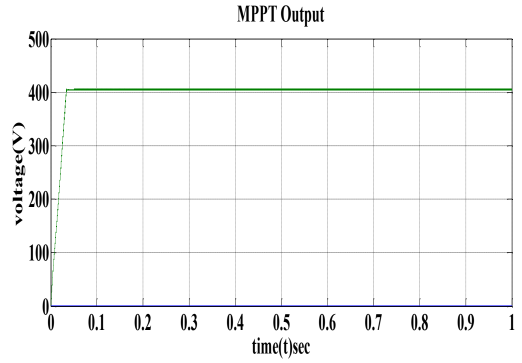


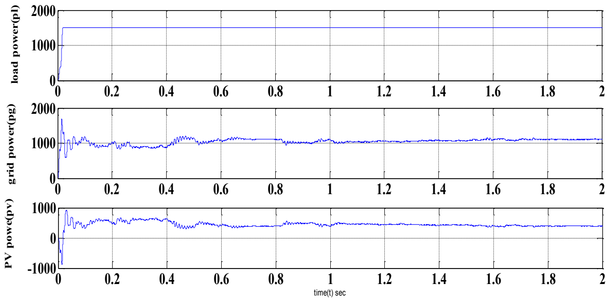
Fig. (10). Output of MPPT

C. Operation Of Complete Model.

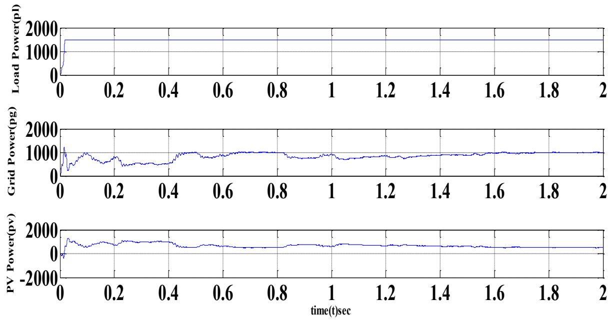
TABLE 1

Load	Insolation (W/m^2)	Grid power(Pg) (W)	PV Power(Pv) (W)
1500W	1000	-9500	11000
	500	-1000	2500
	200	1200	300
	100	1000	500
	20	1100	400
2500W	1000	-8000	11000
	500	-400	2900
	200	1600	900
	100	2000	500
	20	2100	400
5000W	1000	-5900	12000
	500	2600	2400
	200	4200	800
	100	4500	500
	20	4600	400

TABLE 1 shows that for a fixed value of load as the solar insolation decreases, grid power (Pg) and PV power (Pv) also changes according to the load. If solar insolation increases then PV power also increases and according to the load grid power decreases. If PV power is more than the load requirement then the extra power is fed to the grid. On the other hand if PV power is less than the load requirement then extra power is fed from the grid. Corresponding to TABLE 1, Fig. (11)(a) to Fig. (11)(e) shows the change in grid power and PV power for different solar insolation for a fixed value of load of 1500W.



(a)



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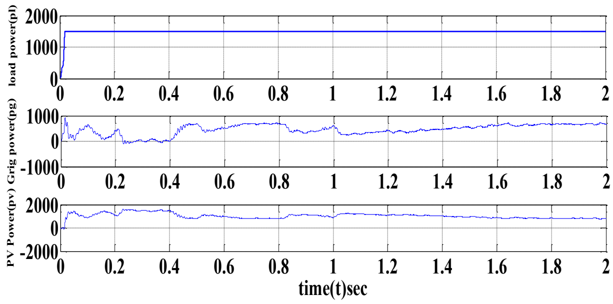
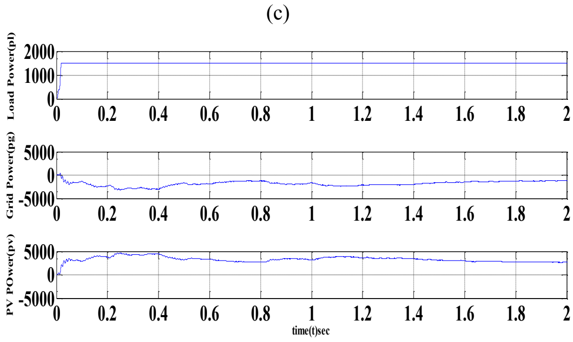
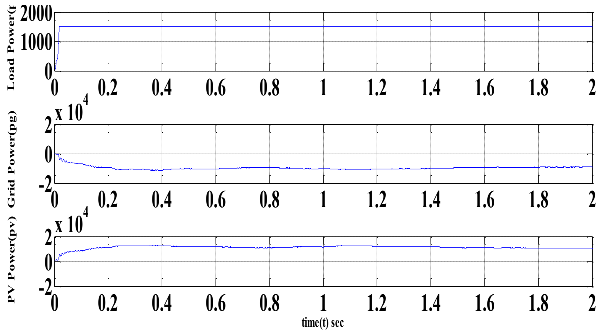


(c)



(d)



(e)

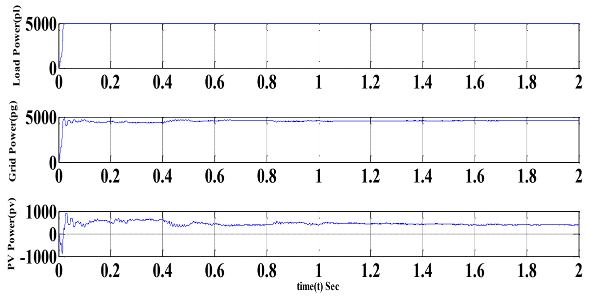
Fig. (11). grid power and PV power for different solar insolation for a fixed value of load P_L=1500W

(a) Insolation=20W/m^2 (b)Insolation=100W/m^2(c)Insolation=200W/m^2 (d)Insolation=500W/m^2 (e)Insolation=1000W/m^2

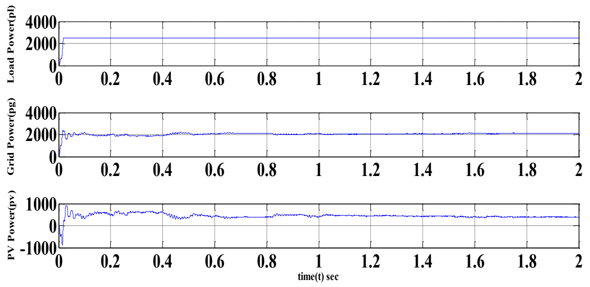
TABLE 2 shows that for a particular value of solar insolation PV power generated is constant but grid power changes according to the load. As the load increases grid power also increases because PV power is constant for given operating point. As solar insolation is increased, PV power is increased and if it is more than the load requirement the extra power is fed to the grid. Corresponding to TABLE 2, Fig. (12)(a) to Fig. (12)(c) shows the change in grid power for different load condition where solar insolation is fixed at 20W/m^2.

TABLE 2

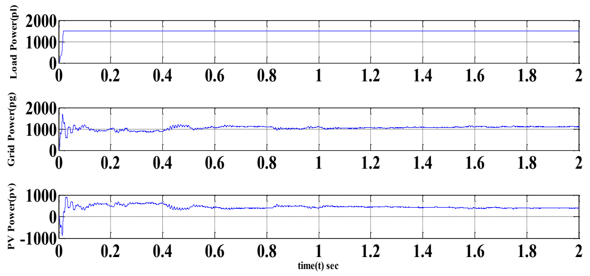
Solar Insolation (W/m$^{2)}$	**Load Power(Pl) (W)**	**GridPower(Pg) (W)**	**PV Power(Pv) (W)**
20	5000	4600	400
	2500	2100	400
	1500	1100	400
100	5000	4500	500
	2500	2000	500
	1500	1000	500
200	5000	4200	800
	2500	1600	900
	1500	700	800
500	5000	2600	2400
	2500	-400	2900
	1500	-1000	2500
1000	5000	-5900	12000
	2500	-8000	11000
	1500	-9500	11000



(a)



(b)



(c)

Fig. (12). Grid power and PV power for different load condition for a fixed value of insolation 20W/m^2

(a)P_{L1}=5000W (b)P_{L2}=2500W(c)P_{L3}==1500W

Fig. (13) shows grid power for different solar insolation at some load condition.

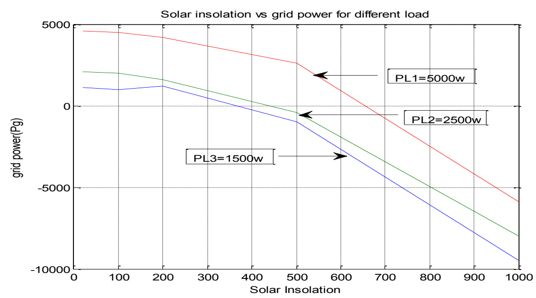


Fig. (13). Insolation vs Grid Power at varying load

Fig. (14) shows PV power for different solar insolation at some load condition. From Fig. (13) and Fig. (14), it is clear that for P_{L1}=5000W and insolation of 1000W/m^2 , P_{pv} = 12000w and Pg=-5900W. So, extra power is supplied to the grid.

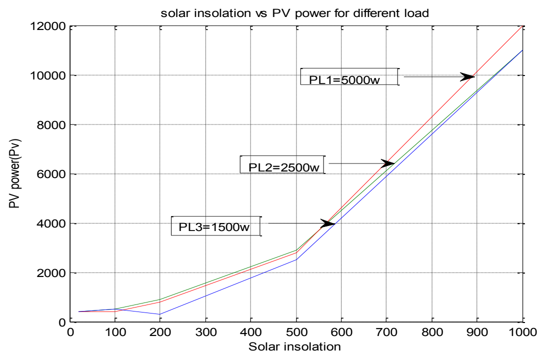


Fig. (14). Insolation vs PV power at varying load

VI. Conclusion

This paper presented grid connected single phase three level inverter with its controller for PV application. PV array, MPPT, inverter and the controller part is developed in MATLAB/Simulink tool. The Load sharing between the PV and grid is also presented for different combinations of solar insolation and load level.

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