Modelling and Analysis of Grid Connected Renewable Energy Sources with Active Power Filter

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ABSTRACT
The control of renewable energy in electrical power system is investigated with the integration. The generation of electrical energy from renewable energy sources is fed to the grid after conversion by DC/AC converter. For compensation of current unbalance, load reactive power demand, load neutral current and load current harmonics etc, shunt active power filter are used. With the combination of grid interfacing, inverter and linear/nonlinear 3 phase 3 wire unbalanced load with the point of cpmmon coupling appears as balanced load to the grid. The proposed system is modeled and simulated in MATLAB Simulink environment. An extensive simulation study is carried out to validate the proposed control approach.

Keywords
Renewable Energy, Grid-interconnection, Active Power Filter, Power Quality. PLL, Hysteresis

1. INTRODUCTION
With high economic growth rates and over 17 percent of the world's population, India is a significant consumer of energy resources. Despite the global financial crisis, India's energy demand continues to rise. India consumes its maximum energy in Residential, commercial and agricultural purposes in comparison to China, Japan, and Russia. Due to advancement in renewable energy sources for generation of electrical power in power system such as photovoltaic solar cells connected to the power grid has enlargement in the last few years due to diminishing of the world's conventional sources of energy. Due to rapidly decreasing conventional sources of energy which are the primary source of energy causes the serious environmental pollution and problems. Another major factor working against fossil fuels is the pollution associated with their combustion. renewable energy sources are known to be much cleaner and produce energy without the harmful effects of pollution unlike their conventional counterparts therefore it appears to be one of the possible solutions to environmental problem.

Photovoltaic generation is becoming increasingly important as a renewable energy source since it exhibits a great merits such as less maintenance, noise free and pollution free. Also, the capability of the system to supply AC loads, relieving the grid demand and making possible to send energy from the panels to the grid.

The control of renewable energy in electrical power system is investigated with the integration. The generation of electrical energy from renewable energy sources is fed to the grid after conversion by DC/AC converter. For compensation of current unbalance, load reactive power demand, load neutral current and load current harmonics etc, shunt active power filter are used. With the combination of grid interfacing, inverter and linear/nonlinear 3 phase 3 wire unbalanced load with the point of common coupling appears as balanced load to the grid. The proposed system is modeled and simulated in MATLAB Simulink environment. An extensive simulation study is carried out to validate the proposed control approach.

2. PROPOSED TOPOLOGY
The proposed topology consists of control strategy of interconnection between photovoltaic panel and grid connected inverter as shown in figure (1).

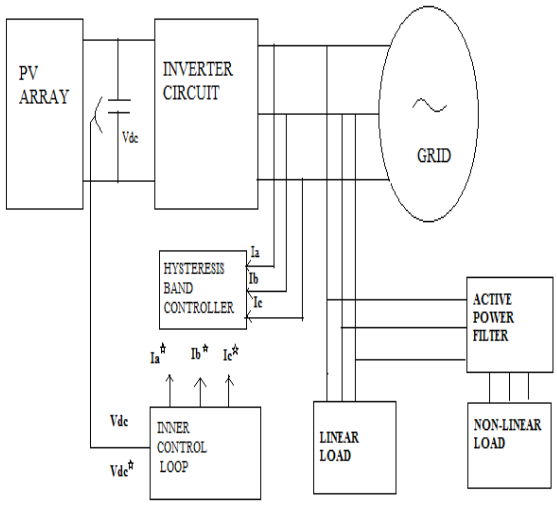

Fig.1: Grid Connected PV System

The power injected from the PV panel into grid through the dc/ac controller. The proposed system also operates as an active power filter which is capable of compensates harmonic components, generated by the non linear load connected to the system.

3. SYSTEM MODEL
3.1 Photovoltaic Array
Photovoltaic Array is formed by combinations of series and parallel connection of PV solar cells. A simple solar cell equivalent circuit model [4] is shown in figure (2). From the figure it is clear that I_{ph} is the photo-generated current or the amount of solar radiation (photon) that are received at the surface of solar cell, I_d is the diode current (i.e. The current between the p-n junction of the bulk material of cell which act as a diode).

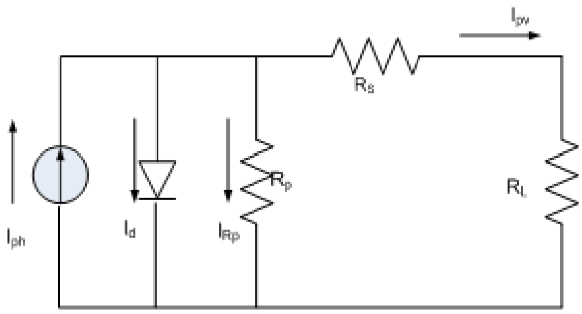

Fig 2: Equivalent circuit of photovoltaic cell

I_{Rp} is the shunted resistance (i.e. the resistance due to recombination of electron pair that are going to the load), R_s is the series resistance (i.e. the resistance between the bulk material within the contact of p-n junction) and R_L is the load resistance. Now, find out the photovoltaic current I_{ph} by applying the Kirchhoff's current law at particular node where I_{ph}, diode current I_d, R_p and R_s meet, we get the following equation:

$$I_{ph} = I_d + I_{Rp} + I_{pv} \quad (1)$$

We get the following expression for the photovoltaic current from the above equation:

$$I_{pv} = I_{ph} - I_d - I_{Rp} \quad (2)$$

$$I_{pv} = I_{ph} - I_o\left[\exp\left(\frac{V_{pv}+I_{pv}Rs}{VtA}\right) - \frac{V_{pv}+I_{pv}Rs}{Rp}\right] \quad (3)$$

where I_{ph} and I_o are the Photovoltaic (PV) and diode saturation current, respectively, and I_{pv} and V_{pv} is the photovoltaic current and photovoltaic voltage of the array and $V_t = NskT/q$ is the thermal voltage of the array. *N*s is the number of cells connected in series, q is the electron charge (1.60217646 × 10−19 C), k is the Boltzmann constant (1.3806503 × 10−23 J/K), T (in Kelvin) is the temperature of the p-n *junction*, and A is the diode ideality factor. The equation (3) gives the relationship between the output parameter of the solar cell i.e. I_{pv} and V_{pv}. The behaviour of these output parameter is non-linear as shown in figure (3), there are three important points: short circuit (0, Isc), MPP (V_{mp}, Imp) and open circuit (V_{oc}, 0) clearly shown in figure (3).

The expression of photo-generated current, I_{ph} is given in equation (4) where it linearly depends on solar Irradiance and also effected by temperature.

$$I_{ph} = \frac{S}{Sr}[I_{ph,r} + Ki(T - Tr)] \quad (4)$$

Where, $I_{ph,r}$ is the photo generated current at the reference condition(25°C and 1000W/m^2), S is the irradiance or insolation, T is the cell temperature, S_r and T_r is the irradiance and cell temperature at reference conditions, K_i is the short-circuit current/temperature coefficient.

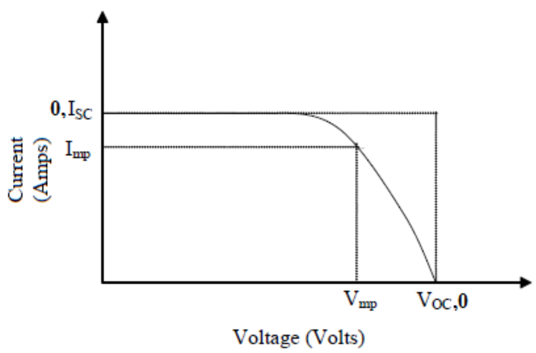

Fig3: V-I characteristics of PV cell

The expression of diode saturation current, Io is given in equation (5) which depends on temperature.

$$I_o = I_{o,r}\left(\frac{T}{Tr}\right)\exp\left[\frac{qEg}{Ak}\left(\frac{1}{Tr} - \frac{1}{T}\right)\right] \quad (5)$$

Where, $I_{o,r}$ is the reference diode saturation current, q =1.602 × 10-19 C is the electron charge, k =1.380×10-23 J/K is the Boltzmann constant, Eg =1.12 eV is the band gap energy. The expression of reference diode saturation current is given by the following equation:

$$I_{o,r} = \frac{Isc,r}{\left[\exp\left(\frac{Voc,r}{AVt,r}\right)\right] - 1} \quad (6)$$

Where, $V_{oc,r}$ is the reference open-circuit voltage, $V_{t,r}$ is the nominal thermal voltage of the cell $I_{sc,r}$ is the short-circuit current at the nominal condition (25°C and 1000W/m^2).

Cells combinations is used to enhance the performance or rating of the Cell, therefore cells connected in parallel increase the current and cells connected in series provide greater output voltages. Hence a practical PV array consists of several PV module(combination of solar cell) connected in series (N_s) and parallel (N_p). Therefore, the equation of PV array written as (7) which is the modified form of the equation (3).

$$I_{pv} = N_pI_{ph} - N_pI_o\left[\exp\left(\frac{V_{pv}+IRs\left(\frac{Ns}{Np}\right)}{V_{pv}tANs}\right) - 1\right] - \frac{V_{pv}+I_{pv}RS\left(\frac{Ns}{Np}\right)}{Rp\left(\frac{Ns}{Np}\right)} \quad (7)$$

For simplification $\frac{V_{pv}+I_{pv}RS\left(\frac{Ns}{Np}\right)}{Rp\left(\frac{Ns}{Np}\right)}$ term has been neglected and then further solve the equation (7), we get the following equations:

$$\frac{V_{pv}+I_{pv}Rs\frac{Ns}{Np}}{V_{pv}tANs} = \ln\left(\frac{NpI_{pv}-I}{NpIo} + 1\right) \quad (8)$$

$$V_{pv} = \frac{AktNs}{q}\ln\left(\frac{NpIph-I_{pv}}{NpIo} + 1\right) - RsI_{pv}\left(\frac{Ns}{Np}\right) \quad (9)$$

4. CONTROL STRATEGY

There are two control strategy namely hysteresis controller to generate appropriate pulses and inner control loop as shown in figure (1). These control topology are explained in this section as below:

Control Strategy of Grid Connected Inverter

This paper propose the current control approach based on hysteresis comparator [8] where reference current is the control variable. This reference current (Iabc*) is calculated by multiplication of in-phase component of reference current(Ic) to the unity grid voltage component (Uabc).

Where,

$$U_a = \sin\theta$$
$$U_b = \sin(\theta - 120^o)$$
$$U_c = \sin(\theta + 120^o)$$

Also, Ic current is calculated from the dc-voltage control loop as shown in figure (4) by comparing the Vdc to the Vdc*, and then respective error signal is given to the PI controller. This PI controller is responsible to maintain a constant dc – link voltage at the input of the grid interface inverter.

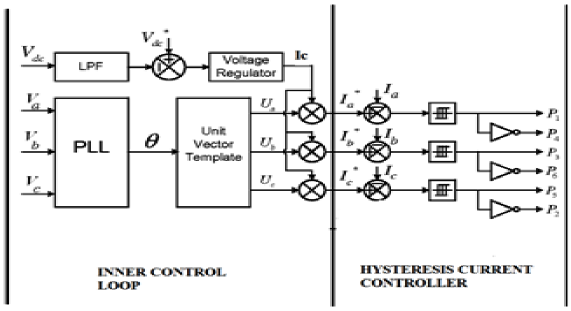

Fig.4: Control strategy of grid interface inverter

Now, the reference current(Iabc*) are compare with the actual grid current (Iabc) in the current control loop as shown in figure (4) and resulting error signal are given to the hysteresis current controller to generate the switching pulse for the grid interface inverter.

5. SYSTEM MODELLING IN MAT-LAB/SIMULINK

5.1 Validating the PV Array

Figure (5) shows the masked simulink structure of PV array based on equation (1 - 7)[8]. The model use the solar irradiation (G), temperature (T), number of cell connected in series (Ns) and parallel (Np) and PV Voltage as input and generate the PV current as output as shown in figure (5).

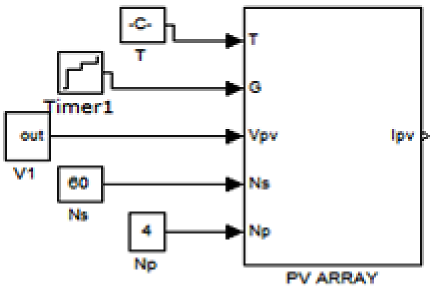

Fig.5: Masked simulink diagram of the solar PV panel

The M-file for diode current has been developed using the equation (5) and photovoltaic current subsystem block is developed using the equation (4). This diode current and photovoltaic current is connected according o equation (7) resulting to generate the PV current.

The waveforms obtained by varying the solar insolation but keeping temperatures constant which are fed into the PV array model have been plotted as shown in figure (6).

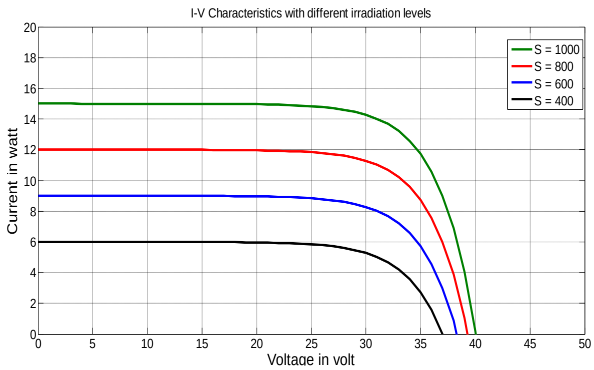

Fig.6: I-V Characteristics with different irradiation

From Figure(7), we observed that by increasing the solar radiation at constant temperature the voltage and current output from PV array also increases.Hence by increasing insolation we can get our required level voltage.

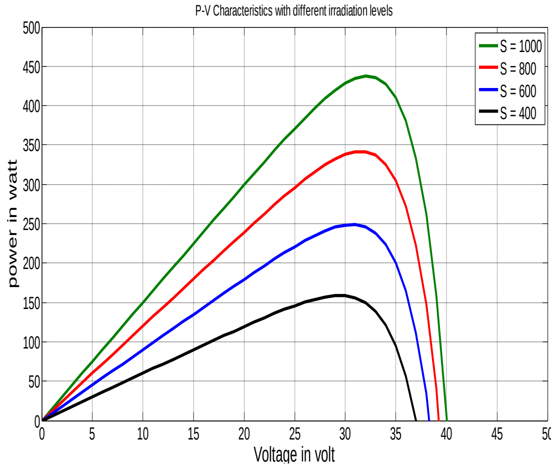

Fig.7: P-V Characteristics with different irradiation

5.2 Simulation Result Of Whole System

The PV array has been interface with the grid using a current controlled voltage source converter. This includes the PV module, inverter and control circuit [9]. In section B, control methodology has been explained, according to that the Vdc is calculated from the MPPT and Vdc* is given calculated value but in this paper Vdc* is set by itself according to phase to phase voltage given to grid. In this way controller generate the pulses for the inverter. The modeling and simulation of the whole system has been done in MATLAB/SIMULINK environment.

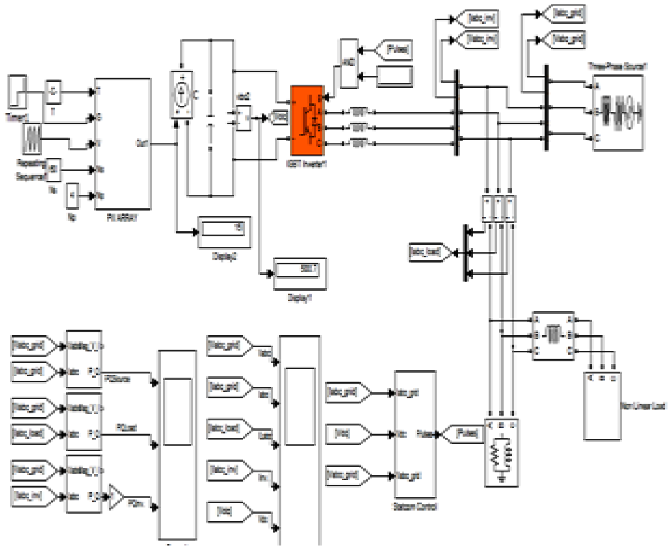

Fig.8: Grid Connected PV System

The proposed topology is validated with the help of figure(9) and figure(10) having system response for different solar insolation levels is given. The simulation is run for 1.5 sec and insolation is varied at each 0.5 sec such as insolation is set at 600w/m^2 initially from 0-0.5s after that insolation is set at 800w/m^2 from 0.5-1.0s and than insolation remains at 1000w/m^2 for remaining interval. The figure (11) shows the non-linear curve of phase ‘a’ and figure (10) shows that the harmonics generated by non linear load is compensated perfectly through active filter.

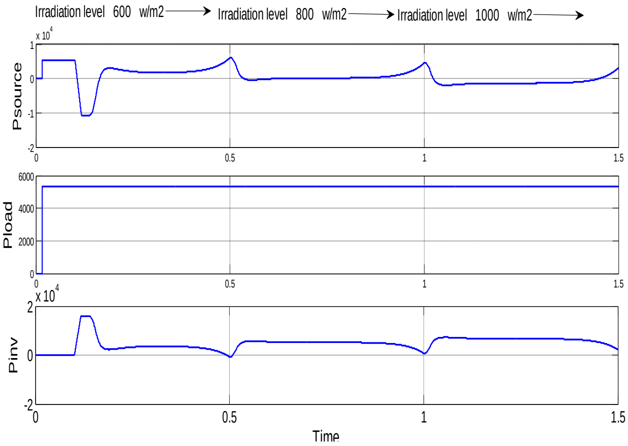

Fig.9: Distribution of power

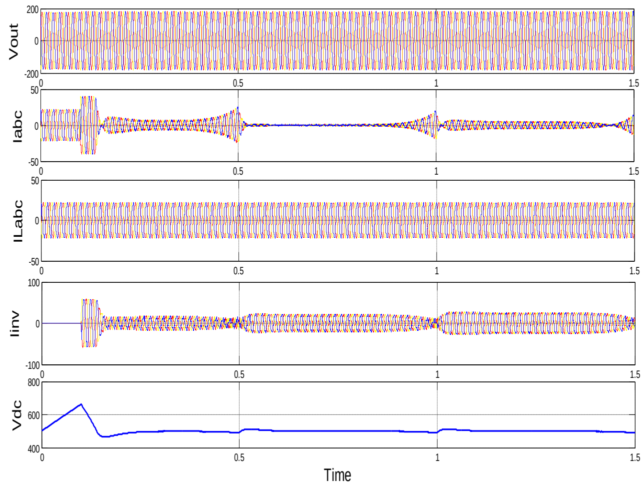

Fig.10:Simulation Results

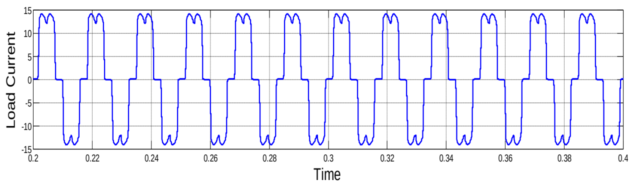

Fig.11: Non-Linear curve of phase 'a'

i. First mode of operation – Grid and PV feeds the load demand

ii. Figure (12) shows the experimental results when load demand is shared by both grid and photovoltaic system. The simulation time for this mode is 0-0.5sec and after feeding the power from PV, the remaining demand is fulfilled by power grid. the phase opposition of voltage and current waveform of phase 'a' shows that the grid is feeding the load.

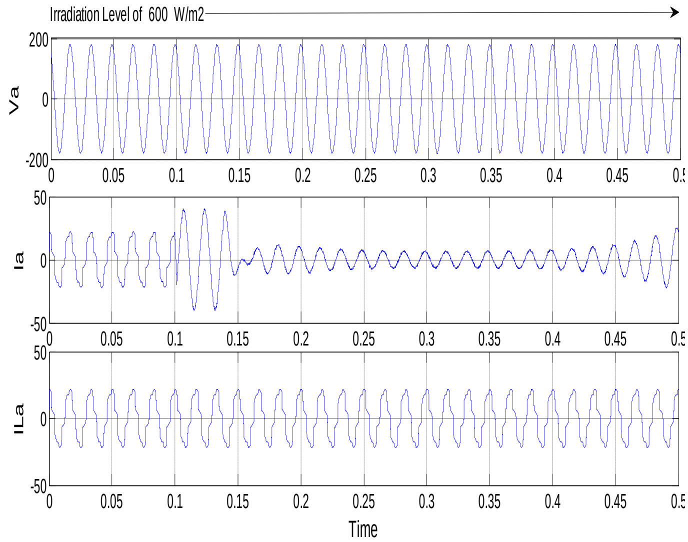

Fig.12:Power injected from the grid

iii. *Second mode of operation – no need to grid power*Figure (13) shows the experimental results when load demand is fulfilled by the photovoltaic system and there is no need to grid power. The simulation time for this mode is 0.5-1.0sec.

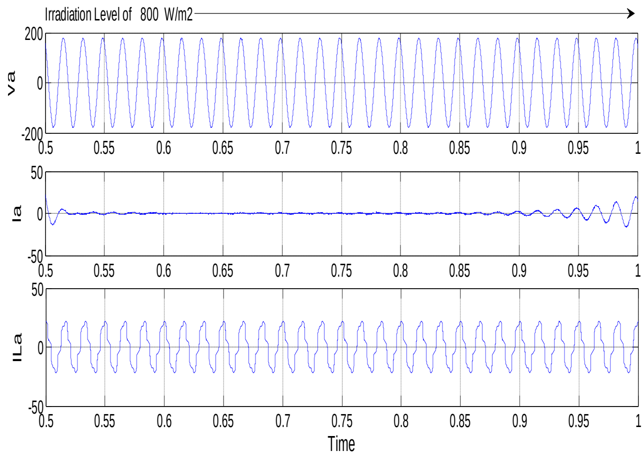

Fig.13: No need to grid power

iv. *Third mode of operation – PV feed power to load as well as grid*

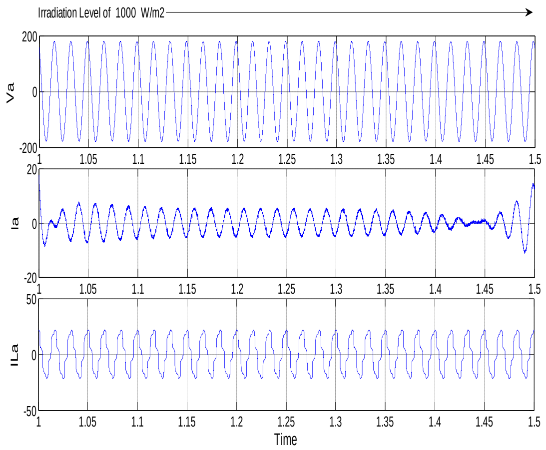

Fig.14 :Power absorbed by the grid

Figure (14) shows the experimental results when load demand is fulfilled by the photovoltaic system and remaining power is injected to grid. The simulation time for this mode is 1-1.5sec. The same phase of voltage and current waveform of phase 'a' shows that the power is absorbed by the grid.

6. CONCLUSION

In this paper, the model of grid connected photovoltaic system is implemented. The system contains a simple model of photovoltaic array, and grid connected inverter, and active power filter. DC voltage control loop with current control loop method of DC-AC inverter control is used in this paper. The various values of the voltage and current obtained have been plotted in the I-V curves of the PV array at different insolation levels and simulation results of filtering and grid connected inverter verify the correctness of the proposed model.

7. FUTURE SCOPE

There's always room for improvement, hence all the suggestion given here to help the other interested researchers to continue this journey in future. The first suggestion is that in the modelling part, instead of just modelling two parameters which is solar radiation and cell temperature, perhaps beam radiance, diffuse radiance, the zenith angle of the sun, the incidence angle of beam irradiance on the array and the ratio of beam radiation on the PV array to that on the horizontal should taken into account while modelling to have better accuracy simulation results which will help in estimating energy output while designing the PV system. Another research suggestion is on the analysis part where the efficiency of the PV system also can be studied. On the other hand, the smart PV panel is another interesting part to work on as the maximum power point changes according to cell temperature and solar radiation. The maximum power point tracking system can be studied using the artificial intelligence to have better yield of energy output. As grid connected project concerns the power electronics, the inverters also can be studied too in achieving a better and quality energy output.

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