



Direct Current Control of Grid connected Photovoltaic Distributed Generation system

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Abstract: Grid connected Photo voltaic system is emerging as reliable and sustainable solution in future renewable energy segment. Conventional grid connected photovoltaic (PV) system consists of PV array, DC-DC boost converter with maximum power point tracking (MPPT) controller and a current controlled full bridge IGBT inverter with L-C-L filter. This paper proposes and demonstrates control architecture and technique for medium and large scale PV arrays connected to the power system grid. The array is interfaced to the grid through power conditioning unit to change output voltages and currents from DC to AC quantities. A DC-DC boost converter is used to step up the output voltage of the array and extract maximum power under a given temperature and solar irradiation via incremental conductance(IC) method. A voltage source inverter (VSI) under current control mode is connected to the DC converter through a DC link capacitor. The inverter is controlled in the rotating (dq) frame to inject AC power into the grid. A PI controller is used to regulate the DC link capacitor voltage and to keep it constant by balancing its input and output powers. MATLAB/SIMULINK software is used to simulate the proposed system and confirm the performance and effectiveness of the proposed technique.

Keywords: MPPT; Direct control; Photovoltaic (PV); Inverter; Hysteresis.

I. Introduction

Limited reserves of fossil fuels along with their environmental impact has encouraged gradual growth and drift towards green energy sources. Costly transmission infrastructure for suburban and rural market is another barrier for sustainability of conventional power system and shifted renewed focus on distributed generation. Among the available green energy sources, photovoltaic (PV) systems are becoming popular due to technological advancement, decreasing cost and acceptability of stakeholders. In past times, PV systems were used as power supplies only for special applications like communication and satellite fields. But with advancement of power electronic devices, application of photovoltaic source has entered into electricity market along with commercial fields. Intermittent nature of solar radiations is major concern and hence reliability, stability and quality of output power supply are areas where there is significant research scope for integration of PV systems with conventional power system. Grid connected Photo voltaic generation system involves two major issues. The first issue is to track and regulate output power at the Maximum Power point (MPP) with change in irradiation level. The second important issue to be considered is that inverter should inject sinusoidal current into utility grid with low total harmonic distortion (THD).

The paper contains design of a grid connected Photovoltaic generation system (PVGS) of 8 KW with direct current control strategy of inverter unit using two stages approach. The proposed control strategy is also validated under different environmental and load conditions. Owing to the fact that DC bus voltage of the boost converter will vary due to irradiation change, a DC bus voltage controller is designed to generate the injected current command. DC bus voltage controller is designed using PI controller. For direct current control of VSI, synchronous-reference-frame (SRF)-based control technique is used. In SRF, a synchronous frame regulator is required to transform a measured stationary frame ac current (or error) to rotating frame dc quantities, and transforming the resultant control action back to the stationary frame for execution. The simulation results show the load sharing between PV generation system and utility grid based on the generation of PV and load requirement of system.

II. PV Solar Array

This paper is based on solar cell model using a single diode, as given by equations (1-3) is used for simulation of PV module for datasheet KC200GT[1]. This model can be changed by user for any configuration of array by just multiplying required number of series and parallel cell given in equation (4).

$$I = I_{ph} - I_{s1} \left[e^{\frac{q(V+IR_{se})}{kT}} - 1 \right] - I_{s2} \left[e^{\frac{q(V+IR_{se})}{AkT}} - 1 \right] - \frac{(V + IR_{se})}{R_{sh}} \quad (1)$$

$$I = I_{ph} - I_s \left[e^{\frac{q(V+IR_{se})}{AkT}} - 1 \right] - \frac{(V + IR_{se})}{R_{sh}} \quad (2)$$

$$I_{ph} = I_{sc} \cdot \frac{I_{rr}}{1000} [1 + (T_{cell} - T_{ref}) \cdot K] \quad (3)$$

$$I = I_{pv} N_{par} - I_{0} N_{par} \left[e^{\left(\frac{V + R_s \left(\frac{N_{ser}}{N_{par}} \right) I}{V_t a N_{ser}} \right)} - 1 \right] - \frac{V + R_s \left(\frac{N_{ser}}{N_{par}} \right) I}{R_p \left(\frac{N_{ser}}{N_{par}} \right)} \quad (4)$$

III. Integration of PV panel with DC-DC converter

The designed PV array is integrated with dc-dc Boost converter for system requirement. A controller based on IC algorithm is built to keep the output voltage of the PV panel at the maximum power point [2-3]. The function of the DC-DC converter is realized by using the energy storage devices such as inductor, capacitor and fast switching devices such as transistor and diodes. The values of inductor and capacitor are calculated using Equation (5,6) according to desired output levels of system [4].

$$L = \frac{(DV_{pv})}{(2f_{sh} \Delta i_1)} \quad (5)$$

$$C = \frac{(DI_d)}{(f_{sh} \Delta V)} \quad (6)$$

Where V_{pv} = Output voltage on PV side; D = Duty cycle of converter; i_1 = Input current (PV side) ripple; I_d = Output current on load side; V = Output voltage (load side) ripple; f_{sh} = Switching frequency.

Boost DC-DC converter steps-up a DC input voltage by a ratio which can be calculated as given by equation(7).

$$M = 1 / (1 - D) \quad (7)$$

From (7) it can be seen that boost converter is electronically adjustable by changing the switch duty ratio D . The output power flow is controlled by adjusting the ON/OFF duty cycle of the switch. The current and voltage is changed at the load side but the power remains constant at a required level even for the variation in load.

IV. Inverter Control

There are direct current control and indirect current control methods for grid side converter. The former need to detect the AC side current through the current regulator to keep the actual value of AC current followed the reference value in order to control the power factor. The latter control the reactive power and active power system by controlling the voltage amplitude and the phase deviation with the supply voltage at the AC side [5]. Possibility of compensating power without energy storage element is possible with the help of pq theory and this theory deals with all three phases simultaneously as a unity system. The SRF algorithm is also known as $d-q$ method, and it is based on $a-b-c$ to $d-q-0$ transformation (park transformation). In nonlinear power systems, the i_d and i_q components of the current include both oscillating components and average components, The reference current generated for d component of grid current is given as[6]:

$$i_d^* = I_{dc} + I_{loss} \quad (8)$$

The oscillating components of the current correspond to harmonic currents, and the average components of the current correspond to the active and reactive currents [7]. Here the objective is to provide independent control on feeding of active and reactive power. The transformation equation used for abc to dq0 conversion is:

$$\begin{bmatrix} i_{Lq} \\ i_{Ld} \\ i_{L0} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (9)$$

The reference for the ac mains grid in terms of abc components from the references in terms of dq0 component can be obtained using inverse Park's transformation given as:

$$\begin{bmatrix} i_a^* \\ i_b^* \\ i_c^* \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta - 2\pi/3) & \sin(\theta - 2\pi/3) & 1 \\ \cos(\theta + 2\pi/3) & \sin(\theta + 2\pi/3) & 1 \end{bmatrix} \begin{bmatrix} i_d^* \\ i_q^* \\ i_0^* \end{bmatrix} \quad (10)$$

Here, Phase Locked Loop (PLL) is used to generate angle theta which provides grid synchronization. PLL is a control system that generates an output signal whose phase is synchronized with the input 50 Hz signal. It is an electronic circuit consisting variable frequency oscillator and phase detector, to generate periodic signal and to compare the signal for the phase matching respectively.

In inverter control system, outer voltage loop generates error by comparing the reference DC link voltage and actual DC link voltage which is then given to the Proportional-Integral (PI) controller which generates reference current I_d and I_q kept zero. Values of these generated current references decide the amount of flow of active and reactive power in the system. Firing pulses are generated by hysteresis current controller (HCC). Control scheme block diagram is shown in figure 1.

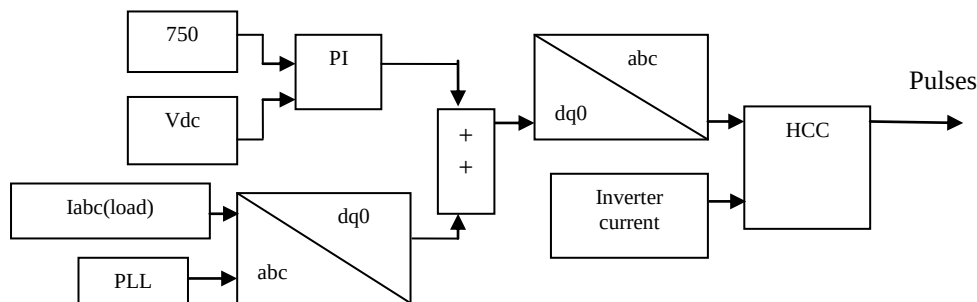


Figure1: Direct Current Control Scheme

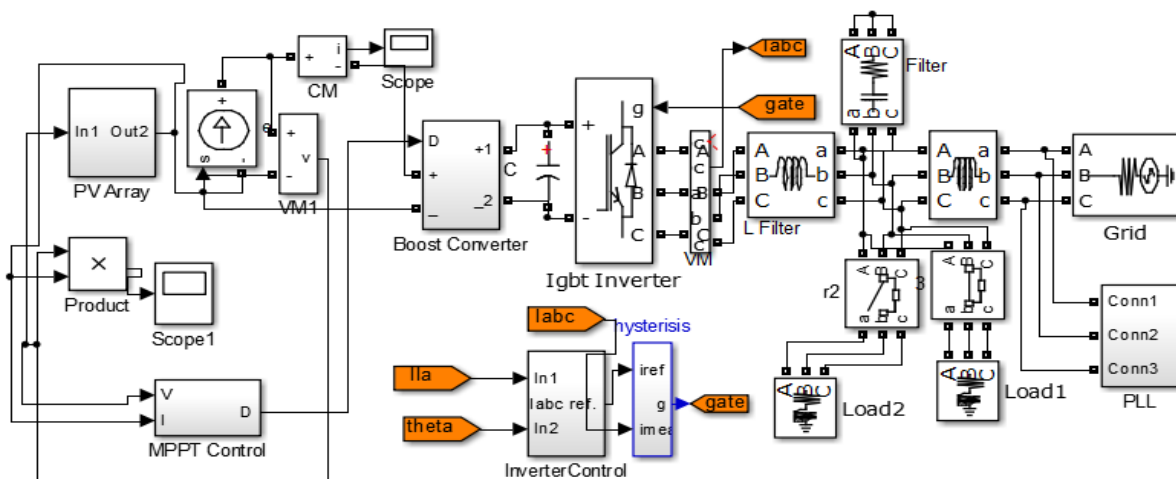


Figure2: MATLAB implementation of proposed PVGS

V. Result And Discussions

A simulation program is conducted by using MATLAB software to demonstrate the effectiveness of proposed control methodology for grid connected PVGS. Simulation has been carried for (i) Change in load. (ii) Change in irradiation level. Results for load voltage (V_{load}), load current (I_{load}), inverter voltage (V_i), inverter current (I_i), Active Reactive Power Provided by Grid (P_g) and PV source Power

(Ppv), DC link voltage(Vdc) and maximum power obtained from MPPT control (Pm) has been studied to verify the significance of Grid connected system behavior.

(i) Change in load

The simulation results as shown in figure 3 have been obtained under standard climatic conditions ($T=25^{\circ}\text{C}$ and $G=1000\text{W/m}^2$ and can be clearly conclude that, for standard condition the PV system provides maximum power i.e. 8kW. Simulation is run for 0.5 seconds initially a load of 24 kW, 9kVAR is connected up to 0.3 second, at 0.3 second 12kW,5kVAR is disconnected. It can be seen from the Figure 3b that PV is giving 8kW, power and grid is providing rest 16kW, 9kVAR for first 0.3 seconds, for further 0.2 second PV power is same as before and grid is now providing rest 4kW, 9kVAR with maintained THD level. Figure 3a shows the 8kW Maximum power provided by the PV array, regulated dc link voltage which is maintained at a constant level (750 V), inverter voltage, inverter current respectively and figure 3b shows load current, load voltage, source active reactive power, grid active reactive power respectively.

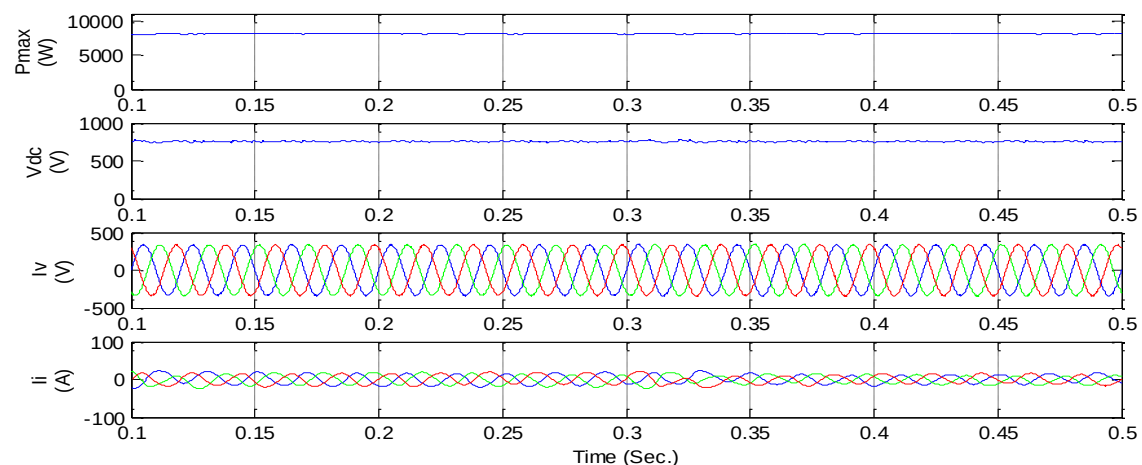


Figure: 3(a) Performance of the system for change of load

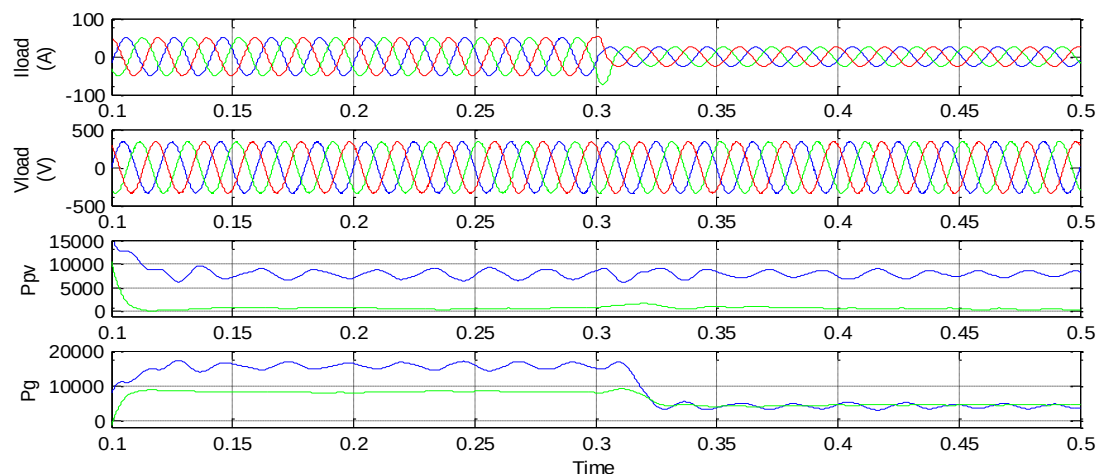


Figure: 3(b) Performance of the system for change of load

Change of climatic conditions

Figure 4 presents the evolution of the grid-connected PV system during a variation in solar radiation. It can be seen that the system is tracking the new operating point quickly. The maximum power point is tracked when the radiance changes between $t=0.2\text{s}$ to $t=0.4\text{s}$ for $G=300\text{W/m}^2$. Figure 4a represents Maximum power tracking with the change in irradiation, dc link voltage i.e. maintained at a constant level $V_{\text{ref}}=750\text{V}$, grid side converter voltage, grid side converter current respectively. Figure 4b depicts load current, load voltage active & reactive power provided by the inverter, active reactive power provided by the grid respectively.

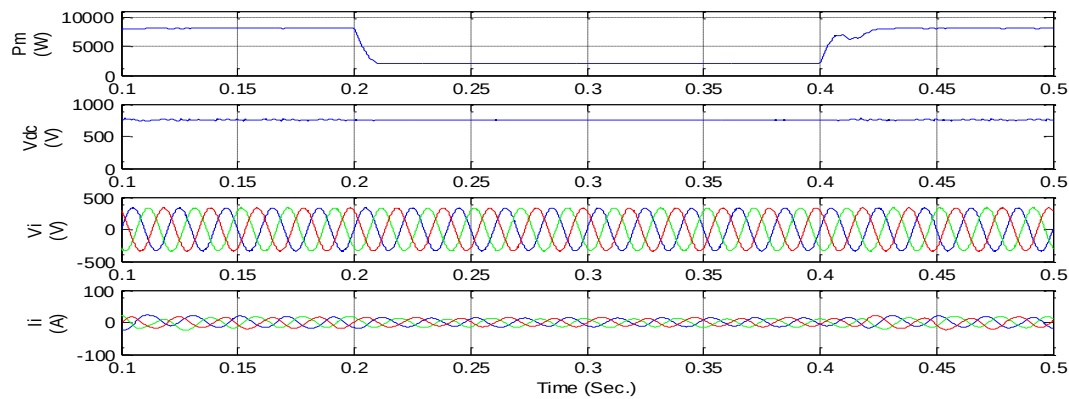


Figure:4(a) Performance of the system for change of irradiation level

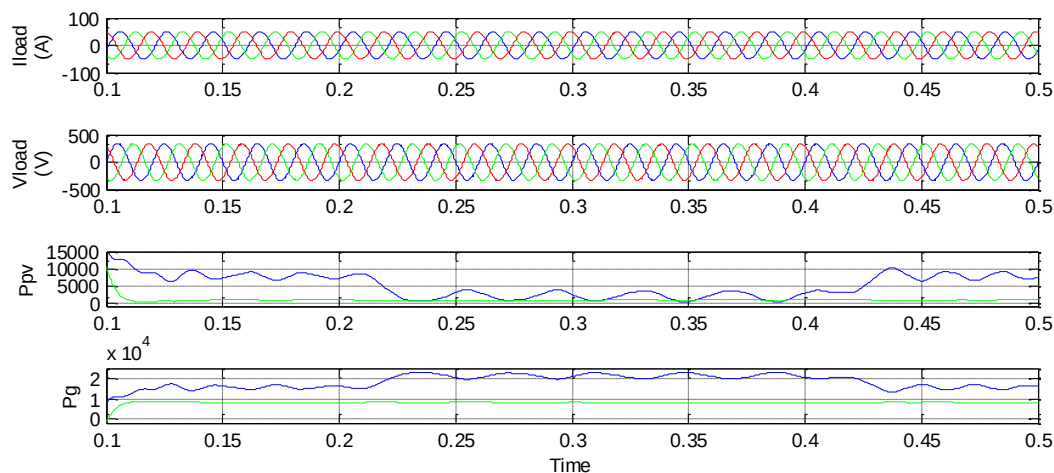


Figure:4(b) Performance of the system for change of irradiation level

VI. CONCLUSION

The grid interconnected PVGS performance is investigated and analyzed under different environmental conditions and load variation. The DC bus voltage and PCC voltage maintained at desired level for different conditions with maintained THD level under 5%. Results verify the satisfactory performance of proposed system.

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