A Unique Control Strategy for Grid Interactive Voltage Source Converter in a Solar Photovoltaic System Using MPPT

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***Abstract*—This paper deals with the study of different type of MPPT (Maximum Power Point Tracking) algorithms in a solar photovoltaic system (SPV) in order to extract maximum power from the solar modules. Here the solar array is integrated with the grid to provide power, as the traditional sources of power generation is depleting at a faster rate and also to provide power during peak hours in urban areas as well as supply power in the remote areas where grid set up is not possible. The solar photovoltaic array integration with grid can be made through power electronics interfacing i.e. by using the voltage source converter (VSC) and dc-dc converter (Boost Converter). A unique control strategy for the voltage source converter is applied in this paper for Solar Photovoltaic based grid interactive VSC system. A low pass LCL filter has been incorporated prior to the connectivity with the utility grid that can be expressed as Real or Active power (P) and Reactive power (Q). The overall performance of the system has been studied, modeled and simulated in MATLAB environment.**

Keywords-solar photovoltaic (PV) system; MPPT; voltage source converter; LCL filter

I. Introduction

In today's world there is about fourteen to fifteen TW energy is consumed at any instant of time and this amount of consumption will be going to rise about 1.5-2 times by 2040[1]. To cope up with this rising energy demand, all the existing forms of energy resources are needed to be upgraded at a faster rate in upcoming years. As it is not justifiable to use the conventional resources for power generation due to the pollution and greenhouse gas (GHG) emissions. But the vital drawback of using RES (renewable energy sources) is its nature of intermittency which faces the difficulty of power extraction in all the times of the day. As the RES are the one and only way left, hence it should be designed and modeled in such a way that the drawback of it could be overcome. By the increment in penetration level of RES, the reliability-cum-stability of the entire system is greatly affected. Hence in order to decline the negative impacts of RES, the RES based power plants should be regulated and thus the grid integration and control is very important which can be achieved by power electronics converters interfacing. Thence, the control of these inverters will be important to meet the requirements of grid integration.

Also PV panel price is found to be the primary contributor of the whole system; the price decrement leads the power generation companies to greatly focus on less expensive, pollution-free, maintenance free and innovative as well as extraordinary solution. Recently grid connected PV systems installation is increasing at a tremendous rate in many countries and it is expecting to increase in upcoming years [2,3].The main challenge of integrating renewable resources with grid is difference in output frequencies. For solving this issue, some sort of interfacing is needed to be implemented to make them capable of converting their output frequencies and injecting synchronized power into the grid. In the PV power conditioning system, the maximum power point tracking (MPPT) control technique is required to extract the maximum possible power from the PV array in order to achieve maximum operating efficiency; the current regulator is needed to control the active and reactive power. In addition the phase-locked loop (PLL) is also needed to receive the grid voltage and current information, such as the frequency, phase angle and amplitude, for controlling overall system. Moreover all the maximum power from PV array should be transferred to the grid. The system considered in this paper consists of a PV based DG system, synchronized with the grid and supplying power to local load as well to grid. The grid and local loads are at same voltage level. The PV cell is modeled with reasonable accuracy from [4]. The active and reactive power is controlled by controlling the d and q axis component with the PI controller. The d axis controlling the active power and the q axis component is controlling the reactive power. The control algorithms are established to control the dc link voltage to extract the maximum power from PV system and to control the power at different faulty conditions.

II. SYSTEM CONFIGURATION

A. Modelling of a PV Cell

The basic element of any PV system is the PV cell. Number of PV cells connected in series-parallel are generally treated as an array. The generated photocurrent is directly proportional to solar irradiation and also a dependent on temperature.

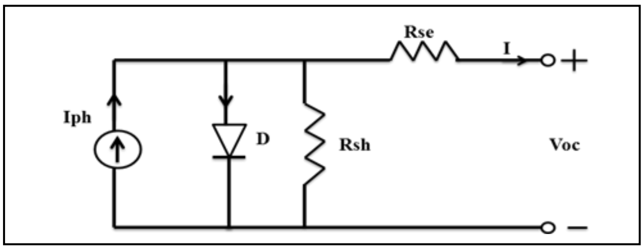


Figure 1. Equivalent circuit of a PV cell

The solar cell can be interpreted as a current source and a diode, which is connected in parallel with the current source. Two resistances, series resistance i.e. R_{se} and a shunt resistance i.e. R_{sh} are connected to represent solar cell as implicitly no solar cell is ideal. The value of R_{se} is considered to be very small and R_{sh} is very high.
The output current of the solar PV module i.e. I_{pv}

$$Ipv = Np * Iph - Np * Io\left[\exp\left\{\frac{q*(Vpv + IpvRs)}{NsAkt}\right\} - 1\right] \quad (1)$$

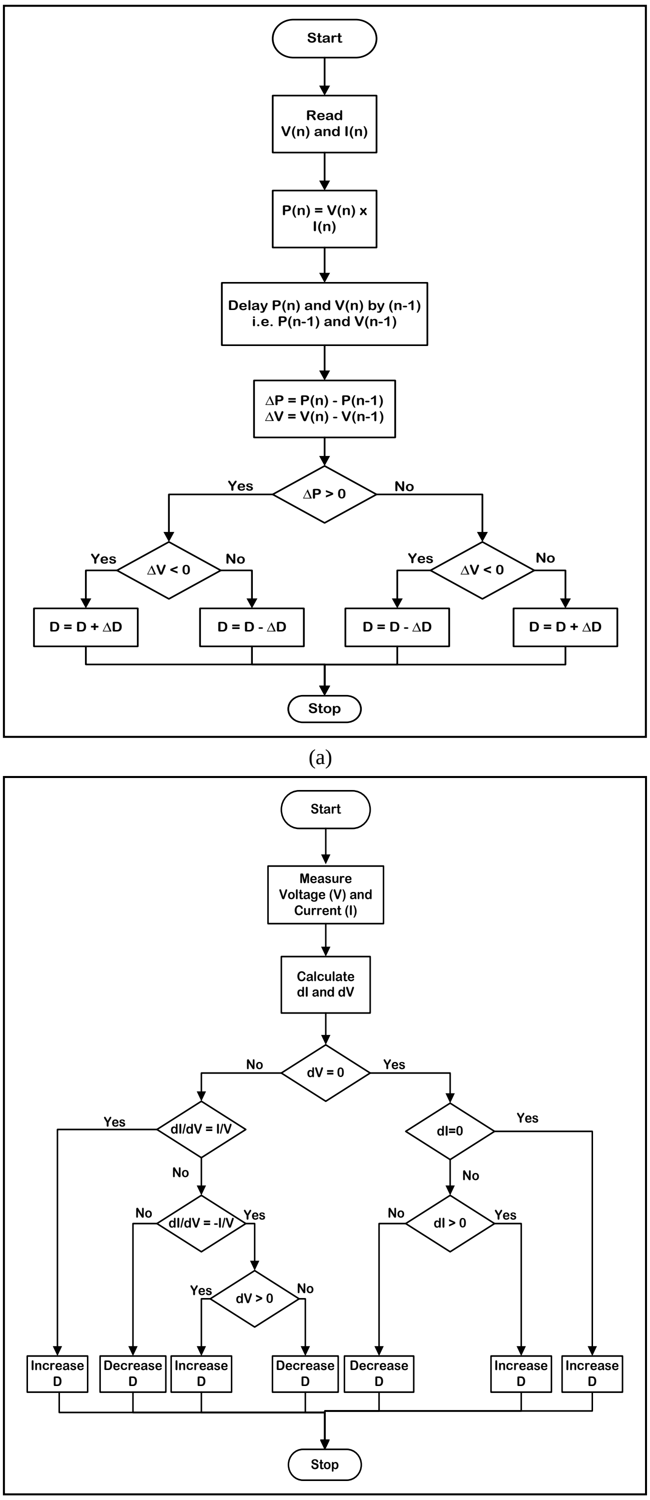
Where, T_c is working temperature of the cell, V_{pv} is the output voltage and I_{pv} is the output current of PV array.

B. Maximum Power Point Tracking Algorithm Implementation

There is only one unique operating voltage, at which the power generated is maximum. In order to attain maximum efficiency the PV must operate at that voltage. Hence, a suitable mechanism which can detect the changes in the operating conditions and can give the information about operating voltage to get maximum efficiency is necessary. This objective is carried out by maximum power point tracking (MPPT) system.
Here two types of MPPT are taken into account.

- Perturb & Observe(P&O)
- Incremental Conductance(INC)

Perturb-and-Observe method is changing of DC link operating voltage between PV array and power converter. In the method of next perturbation can be determined by the sign of immediate previous perturbation and sign of last increment in power. On the left side of the MPP voltage incrementation increases power while in the right side of MPP voltage decrementation power is increased. If there will be increment in the power, the perturbation will be keep on changing in same direction and if there will be decrement in the power, the perturbation will be shifted in opposite direction. By applying these techniques, the P&O algorithm is implemented and the algorithm loop continues till the maximum power point is reached. This method of MPPT is found to be very much effective.



(b)

Figure 2. MPPT algorithm using (a) P&O (b) INC method

The disadvantage of the perturb-and-observe method to track the peak power under fast varying atmospheric condition is overcome by IC method. The IC can determine that the MPPT has reached the MPP and stop perturbing the operating point. If this condition is not met, the direction in which the MPPT operating point must be perturbed can be calculated using the relationship between dl/dV and –I/V This relationship is derived from the fact that dP/dV is negative when the MPPT is to the right of the MPP and positive when it is to the left of the MPP.

C. MPPT Modelling and Working as SCC

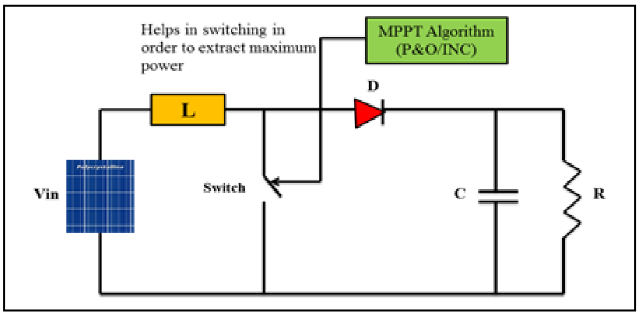


Figure 3. Working of MPPT

The MPPT algorithm helps in switching of boost converter. The values of L and C of the boost converter are set in order to get boost up voltage at the output terminals than its input voltage. This mechanism is known as MPPT and the system is combinely known as Solar Charge Controller (SCC).

D. Modelling of Voltage Source Converter(VSC)

The converter proposed in this work is a three phase bi-directional DC-AC converter with PWM modulation using six power switches. The simplified electrical diagram of converter is shown in Figure 4.

The bi-directional characteristic of the converter is very important in the proposed photovoltaic system, because it allows the processing of active and reactive power from the generator to load and vice versa, depending on the application. Thus with an appropriate control of the power switches it is possible to control the active and reactive power flow.

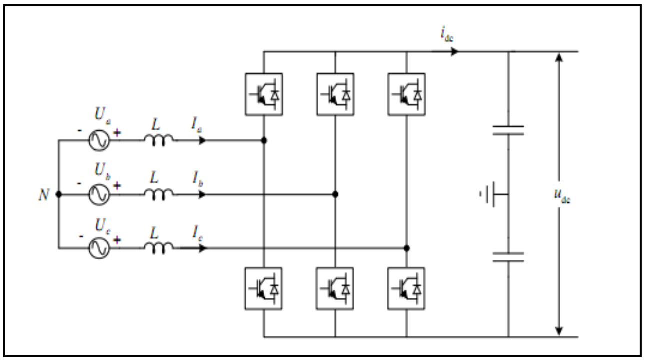


Figure 4. Two level voltage source converter

E. Control Strategy of the Voltage Souce Converter(VSC)

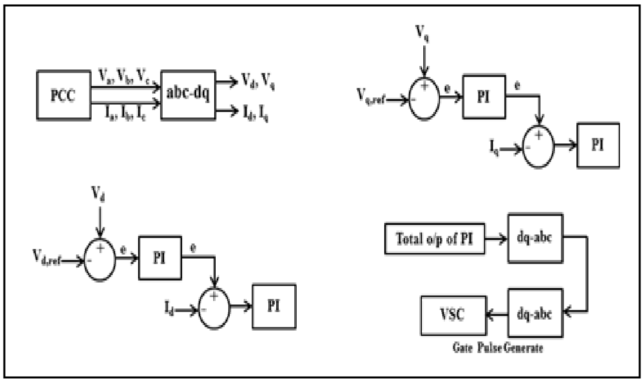


Figure 5. Control Strategy of VSC

To control the commanded active and reactive power first the voltage and current is taken from the PCC, Three phase power is measured using voltage and current. A phase locked loop is used to determine the frequency and angle reference of the Point of Common Coupling (PCC) voltage. The a-b-c currents are transformed using Park Transformation to their d-q components. The Id current component controls the active power supplied by the DG, while Iq controls the reactive power output of the DG.

$$e_{dc} = V_{dc} - V_{ref} \tag{2}$$

$$u_d = e_{dc}\left(K_{pd} + \frac{K_{id}}{s}\right) \tag{3}$$

$$e_Q = Q_{ref} - Q \tag{4}$$

$$u_d = e_Q\left(K_{pd} + \frac{K_{id}}{s}\right) \tag{5}$$

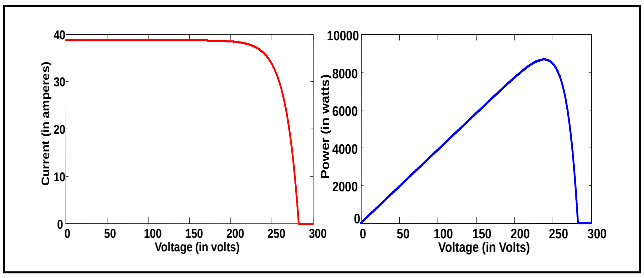
F. LCL Filter

L-filter is a 1st order filter with 20dB/decade attenuation over the entire frequency range. These filters are applicable where converter used with high switching frequency. Similarly, LC-filter is known as a 2nd order filter with damping characteristics better than that of L-filter. And LCL-filter is a 3rd order filter having an attenuation 60dB/decade above resonant frequency, hence low switching frequency based converters use this filter. With lower value of inductance, harmonics distortion level can be reduced. Thus this LCL filters is found to be very suitable for RES (renewable energy resources) integration with utility grid.

III. RESULTS AND DISCUSSIONS

The PV generator system supplying the local load, integrated with the grid is modeled and developed in MATLAB/SIMULINK environment to validate the proposed methodology for grid-connected PV generation system. The solar insolation is set at 800W/m^2, the temperature is taken at 320k and the maximum power of the system is set at 8660 Watt.

Per unit calculation are done by taking the base power as 10000 Watt and Base RMS voltage as 115v line to line and grid frequency is at 50 Hz. Only resistive load of 6000Watt is taken. Then the PCC voltage, PCC current, active power and reactive power at healthy condition are studied.



(a) (b)

Figure 6. Maximum Power delivered by PV system (b) Current in PV system

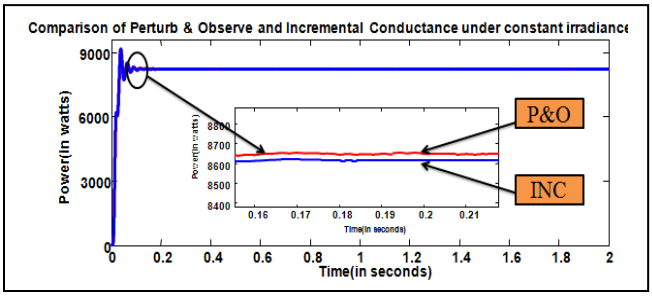


Figure 7. Comparison of P&O and INC under constant irradiance

As the irradiance isn't available constantly during all times of a day, so MPPT charge controller is needed in order to extract maximum power from the solar PV array. Here two types of MPPT methods i.e. Perturb-and-Observe (P&O) and Incremental Conductance (INC) are considered. While the P&O method is used for obtaining maximum power from the solar PV array (8660W=8.66KW), hence there is about 650W rise of power in case of P&O as compared to INC at constant irradiance of 800W/m^2 which can be seen from above Figure . It can also be seen that when the P&O method operates, the system takes some time to obtain maximum power and gives more power than that of INC method though it takes lesser time than that of P&O.

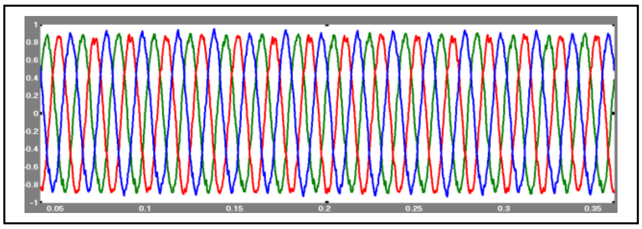


Figure 8. Voltage at PCC

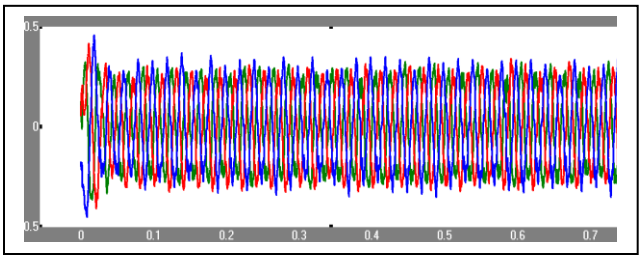


Figure 9. Current at PCC

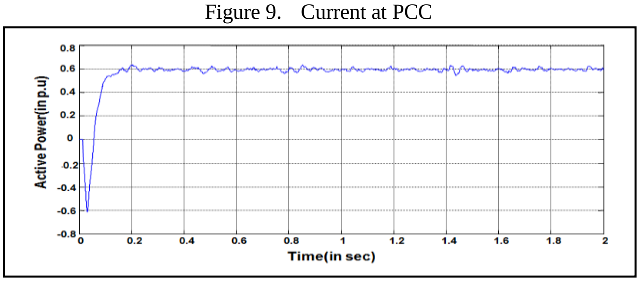


Figure 10. Active power supplied by DG system

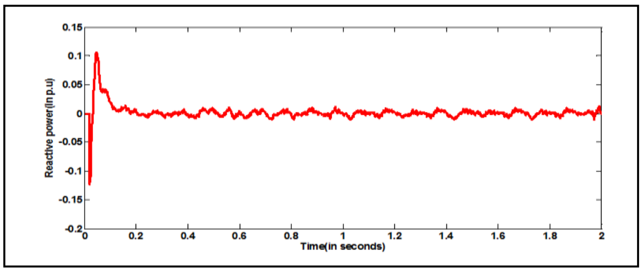


Figure 11. Reactive power supplied by the PV system

The PCC voltage, PCC current, active power supplied by PV system and reactive power by PV system is shown from Figure.8-11.The system is delivering near about 0.6 p.u(6000W) active power and about zero reactive power. The robustness of the proposed algorithm in different cases is shown below. The sole purpose of the study of the modeling of grid connected PV system is to study the performance i.e. how the PV module is responding to the different conditions. Like fault conditions (most common fault-Line-to-ground and three-phase to ground) and how the system is responding to it.

Case A: Three phase to ground fault

In the 1st case, the system is tested under three phase to ground fault.

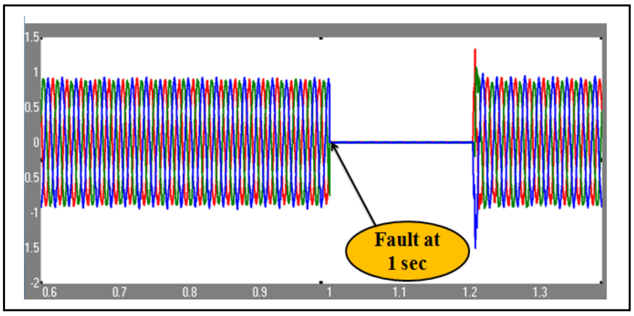


Figure 12. Voltage at PCC during three phase to ground fault

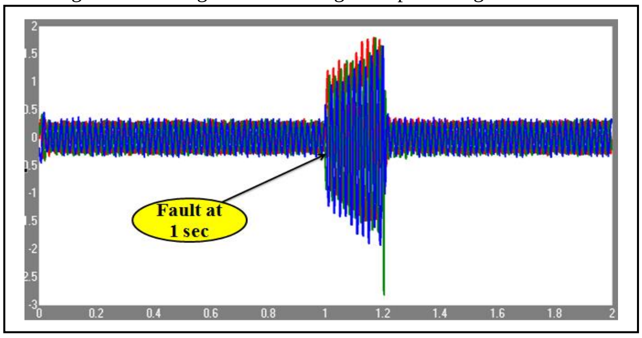


Figure 13. Current at PCC during three phase to ground fault

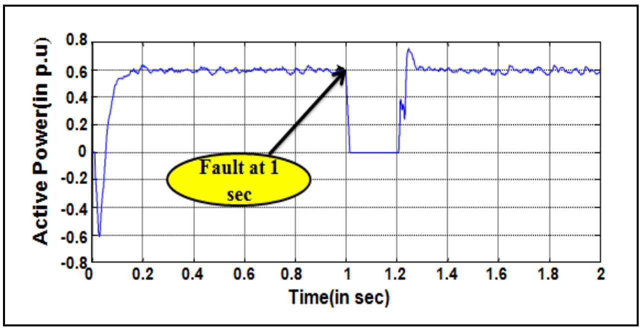


Figure 14. Active power during fault at 1-1.2second

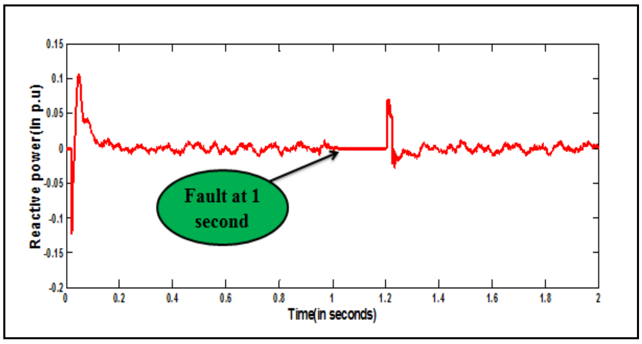


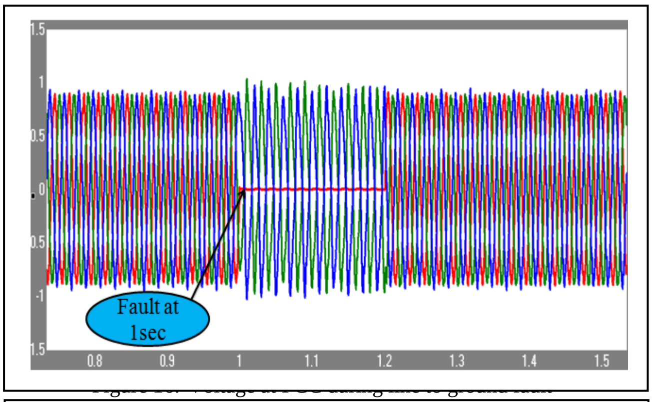
Figure 15. Reactive power during fault at 1-1.2second

The PCC voltage, PCC current, active power and reactive power are shown in Figure.12-15.

The main aim of the proposed control algorithm is to examine that how fast the system comes to previous steady state position after the fault occurrence. The swiftness of the control strategy can be studied after fault clearance. Here the fault is occurred at 1-1.2seconds. As we can see that in every case i.e. the PCC voltage, PCC current, active power and reactive power the fault is occurred for 0.2sec and soon after the fault is cleared the control strategy starts its action in order to bring the system to previous position.

Case B: Line to Ground Fault

Here line to ground fault (L-G) fault is considered, where the fault occurs for 0.2seconds i.e. 1sec to 1.2sec. Line to Ground fault means one of the phase of transmission line is shorted to ground. This may happen due to various reasons. But we use some protection devices in real life scenario to clear out the fault as soon as possible. This time frame is enough to study the change in nature of the parameters.



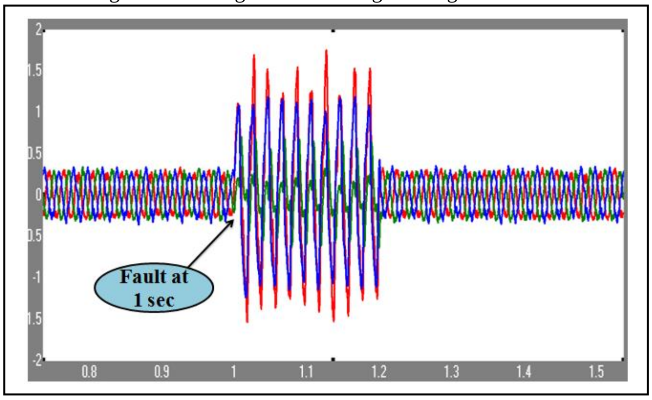


Figure 17. Current at PCC during line to ground fault

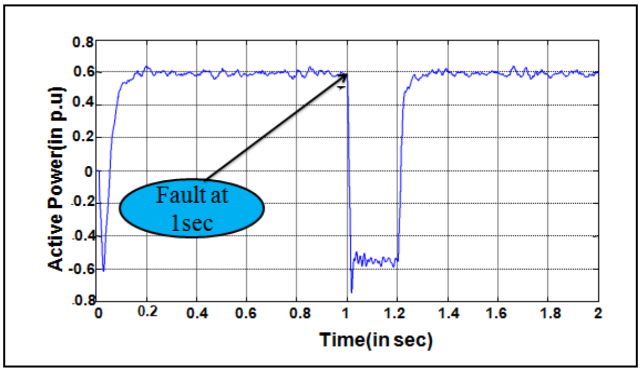


Figure 18. Active power during fault at 1-1.2seconds

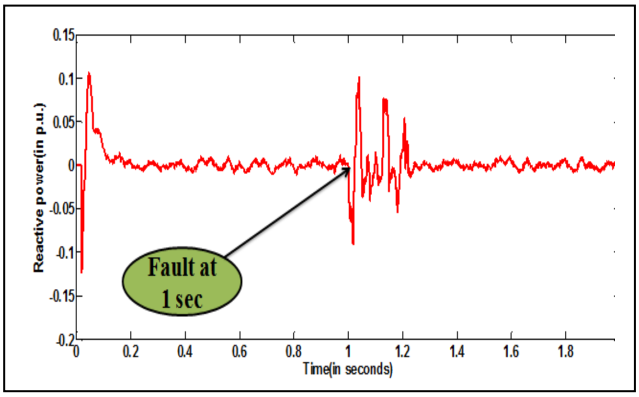


Figure 19. Reactive power during fault at 1-1.2second

The PCC voltage, PCC current, active power and reactive power are shown in Figure.16-19.

Likewise the previous Case A, in this case also the fault is for 0.2 seconds. The robustness of the controller is studied after the fault clearance. It has been seen that as soon as the fault is cleared the controller takes proper action in order to bring back the system to the previous state.

IV. CONCLUSION

The PI controller has been proposed to control the active and reactive power of the grid connected PV system, The intention of the control system is to achieve peak power point tracking to extract the maximum amount of power from the PV array and control the output current and voltage of the inverter.

It has been seen that MPPT algorithm used, tracking the maximum power point correctly and from the result it is observed that controller tracking the active and reactive power perfectly.

Two types of MPPT i.e. P&O and INC are compared over here and among of those two MPPTs, P&O gives more power i.e. about 8660W and hence it is implemented in the grid connected PV system.

The robustness of the controller has been checked by taking different condition such as three-phase to ground fault and L-G fault, it is observed that during the fault time there is a change in active and reactive power and oscillation is there during that period.

As the fault gets rectified, the controller helps in retrieving the system from unstable to stable condition i.e. back to its steady state value. It has also been observed that the proposed controller maintaining the PV system to supply its maximum power to the local load.

TABLE I. P&O AND INC COMPARISON AT CONSTANT IRRADIANCE

MPPT	P&O	INC
Power obtained	8660W(8.66kW)	8600W(8.6kW)
Time of tracking (when the run time is 2 sec)	0.163sec	0.154sec

TABLE II. BOOST CONVERTER PARAMETERS

Inductance (L)	1mH
Capacitance (C)	100e-6F
Dc link capacitance	22e-6F

TABLE III. SOLAR PV SYSTEM PARAMETERS

Number of series connected PV modules	300
Number of parallel connected PV modules	7
System Maximum Current (I_M)	8.01A
System Maximum Voltage (V_M)	268 V
System Maximum Power (P_M)	10 KW

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