Design of Grid integrated Solar Photovoltaic System to moderate the effect of partial shading

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Abstract: Partial shading are occurring on the Photovoltaic system due to moving clouds, building or nearby structures. Photovoltaic system loses huge amount of power due to partial shading on the PV Array. If such shading patterns are examined than it can help to improve the efficiency of a solar panels. Normally partial shade would shut down the inverter but adding a boost stage into the system before inverter to maintain the dc link operating voltage for the inverter can help the PV system to maintain the synchronization with the grid. A Boost input stage before inverter can double the operating range and also extract maximum power under irradiation and temperature variation. This paper presents design and control of grid connected photovoltaic system using DC-DC boost converter with Maximum power point tracking (MPPT) algorithm along with voltage source inverter (VSI). In this proposed system, injection of maximum real power using incremental conductance method as MPPT algorithm. Also, the control of this PV system is based on synchronous reference frame using PI controller. Simulation results have been achieved using MATLAB model.

***Index Terms* –Incremental Conductance, Solar Photovoltaic System, Maximum power point tracking (MPPT), Partial shading, DC-DC boost converter.**

I. INTRODUCTION

As electricity generation is gradually growing towards the renewable resources from fossil fuels. Renewable sources have a very large potential in power generation in many countries worldwide. Solar energy can be used in two ways as solar thermal power or as photovoltaic extraction using PV modules. Electricity generation is mainly now shifting toward renewable energy from fossil fuels worldwide. Also, there are many countries which are capable of generating electricity through renewable energy and filled with renewable resources in their territories. Solar energy can be utilized through two different ways. We can use solar energy through solar thermal energy extraction otherwise through photovoltaic extraction using solar PV modules. The main design objective of photovoltaic (PV) systems has been, for a long time, to extract the maximum power from the PV array and inject it into the ac grid. Therefore, the maximum power point tracking (MPPT) of a uniformly irradiated PV array and the maximization of the conversion efficiency have been the main design issues. However, when the PV plant is connected to the grid, special attention has to be paid to the reliability of the system, the power quality, and the implementation of protection and grid synchronization functions.

Now a days Solar PV technologies growth can be observed at much higher rate as the cost of solar panels and balance of system components is decreased. Modern power plants are required to maximize their energy production, requiring suitable control strategies to solve the problems related to the partial shading phenomena and different orientation of the PV modules toward the sun. Moreover, the new policy concerning the injection of reactive power into the grid makes the development of suitable topologies and control algorithms mandatory.

II. PARTIAL SHADING EFFECT IN PV SYSTEM

In Photovoltaic System installation, multiple PV modules made up of series connected solar cell are interconnected in different configurations. To maintain the solar cell efficiency and protect it from hotspot failure effect, bypass diode is connected in parallel with the PV module. Under uniform insolation, PV system exhibits a P-V characteristic such that it can operate at maximum power point. If one or more number of PV modules are shaded in PV array then PV array will show P-V Characteristic There are many causes of shading such as dust settlement in panels, passing cloud and shadows of neighboring structures or trees etc. The commonly used MPPT and charge controllers fails due to such conditions.

In large area covering photovoltaic plant, there is a common phenomenon of partial shading or complete shading of PV Panels due to moving clouds. Such a situation results in reduction of power generated by PV system which is an undesirable effect. Shading condition leads to varying irradiation on different proportion. Short circuit current of PV module is directly proportional to solar insolation level. That's why some part of electrical power generated by unshaded module is wasted in form of heat due to shaded modules. Hotspot effect is reduced by using bypass diode to protect the modules from local heating. It does not solve the problem of reduction in power generated by PV system under partial shading. But these diodes create multiple power peaks in P-V characteristics due to which maximum power point tracking using MPPT techniques is difficult.

In many literatures various classification of shading is done by dividing it into two major types such as 'objective' and 'subjective' shading. Objective shading is mainly due to cloudy weather or it can a simple day light with sparse irradiance availability. Therefore, objective shading cannot be avoided as the sun gets blocked in it and also the whole PV system is affected by such phenomena. The subjective shading is further classified into two groups as static and dynamic shading. The static shading is due to blocking of light on the PV modules due to some reason like dirt or bird dropping etc and also prefer as hard shading. Similarly, dynamic shading which is refer as soft shading is due to any building, trees or structure nearby the solar module installation. Hard shading can be removed by regular maintenance and cleaning. For removing the soft shading multiple technique are used to reduce its effect on output of the PV system.

Open circuit voltage and short circuit current of PV string are affected directly by the hard shading. Also, the dust accumulation of 20 gm/m^2 on the PV panel can reduce the short circuit current, open circuit voltage and efficiency by 15-21, 2-6 and 15-35% respectively. In case of hard shading when the PV panel are fully blocked due to bird dropping or dust and irradiance is completely blocked, the bypass diode are active and panels are completely bypassed which overall reduce the voltage of whole PV string. While in case of soft shading, the maximum power point tracking (MPPT) algorithm of the inverter may reduce the current in the entire string to take the advantage of the maximum voltage through the string to maximize the output power. The main focus of project is only on 'soft shading losses' also referred as partial shading losses.

Partial shading is mostly observed in the residential sites of PV system installation as there are more structures building or trees around the plant with respect to the sun position having variable shapes of shades. When such shades reach the PV installation the output of the PV panels is decreased as it lowers the current generation of its cells which are connected in series. For this the solar panels have bypass diode which lower the losses by providing parallel path for the shaded PV panels and also it helps to prevent against hot-spots to protect it from permanent damage. But depending on the shapes of the shading, the losses can still be significant.

III. Solar Photovoltaic Array

The Solar Photovoltaic Array is formed by connecting several solar panels in series and parallel combination to generate the required power. The smallest component of the solar photovoltaic array is called photovoltaic(PV) cell. The ideal solar photovoltaic cell is represented by the equivalent circuit shown in Fig 1. These cells are connected in series of 36 or 72 cells to form one module. Similarly, several modules are assembled into a single structure to form array. Finally, assembly of these photovoltaic arrays are connected in parallel to obtain the required power. In PV module, series resistance (R_s) is comparatively more predominant and R_{sh} is considered equal to infinity ideally. The open circuit voltage(V_{oc}) of the PV cell is directly proportional to solar irradiation and V_{oc} is inversely proportional to the temperature.

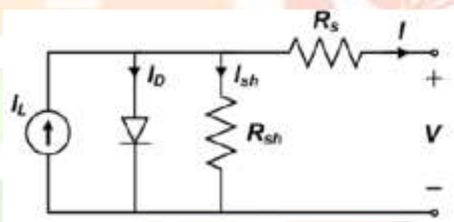

Fig. 1. Equivalent circuit of PV cell

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

$$I_{ph} \text{ (photo current)} = \left[I_{sc} + k_i\left(T_c - T_{ref}\right)\right]\lambda \quad (2)$$

$$I_s = I_{rs}\left(\frac{Tc}{Tref}\right)^3 e^{\left[q\frac{Eg\left(\frac{1}{Tref}-\frac{1}{Tc}\right)}{ka}\right]} \quad (3)$$

Where,

I_{ph} = photo current

I_s = reverse saturation current.

V = voltage across solar panel terminal.

I = current across solar panel terminal.

ka = Boltzman constant.

a = ideality factor

Tc = cell working temperature

T_{ref} = Ideal working temperature

k_i = short circuit current temperature coefficient

R_{sh}=shunt resistance

R_s =series resistance

The PV Array is characterized based on the I-V and P-V characteristic. As we can see the irradiation result direct vary the current and the curves of I-V characteristic vary largely for different level of irradiation. The irradiation directly affects the PV Array current while the change of temperature directly affects the voltage generated by the PV Array. So same observation we can made from the below graph of I-V characteristics at different irradiation level.

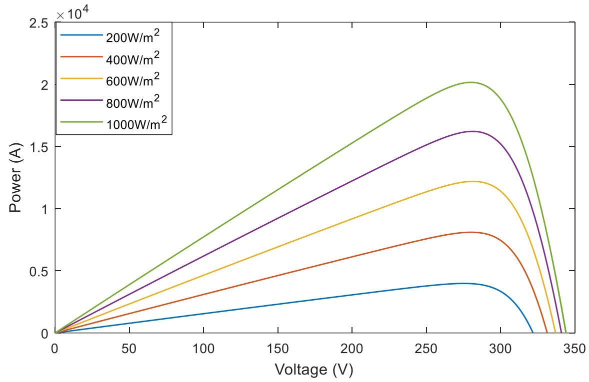

Fig. 3. P-V Characteristics of PV Array at different irradiation levels

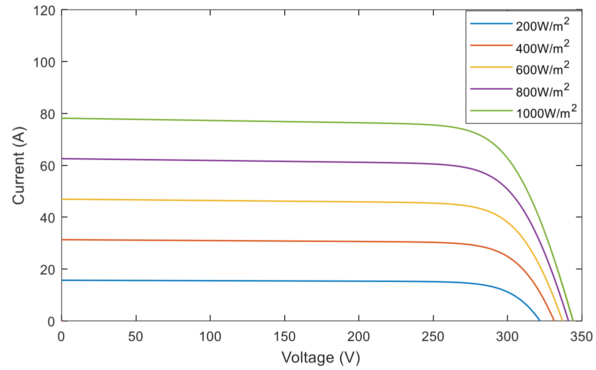

Fig. 2. I-V characteristics of PV Array at different irradiation levels

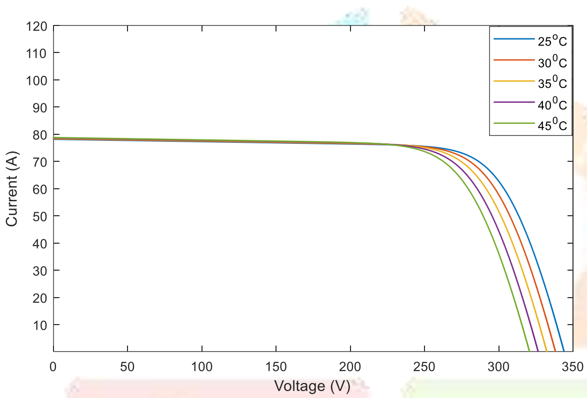

Fig. 4. I-V Characteristics of PV Array at different temperature levels

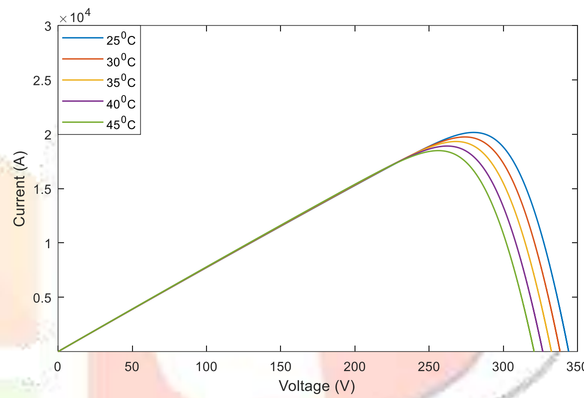

Fig. 5. P-V Characteristics of PV Array at different temperature levels

IV. Incremental Conductance Algorithm

Practically the solar efficiency is 30% to 40% with respect to incidence of solar insolation. To extract maximum power from solar photovoltaic system we use MPPT (maximum power point tracking). As per rule of maximum power transfer whenever load impedance matches source impedance. MPPT help to improve the efficiency of PV Panel.

So MPPT charge controller is used alone with boost converter to control the duty cycle and get the voltage correspond to maximum power. So, we can get maximum power transfer from PV to LOAD just by varying the duty cycle of the boost converter. The Incremental Conductance method is used to reach the maximum power in P-V characteristic slope of PV Array. It works on the principle that MPP is achieved when the derivative of Photovoltaic array power with respect to its Voltage is equal to zero. The Incremental Conductance algorithm works on the following condition:

$$\frac{dP}{dV} = 0, \text{ at MPP}$$
$$\frac{dP}{dV} > 0, \text{ left of MPP}$$
$$\frac{dP}{dV} < 0, \text{ right of MPP}$$

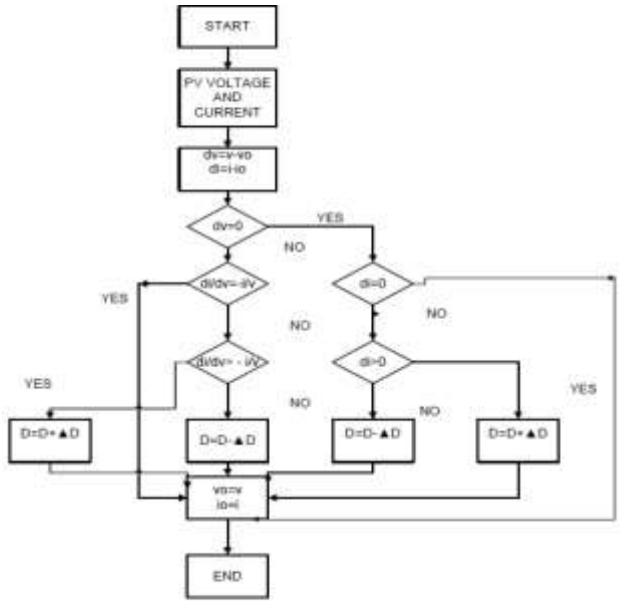

Fig. 6. Algorithm for Incremental Conductance

The main idea of incremental conductance is to be equated the incremental conductance and instantaneous conductance, so accordingly the duty cycle can be varied to get the operating voltage corresponding to maximum power.

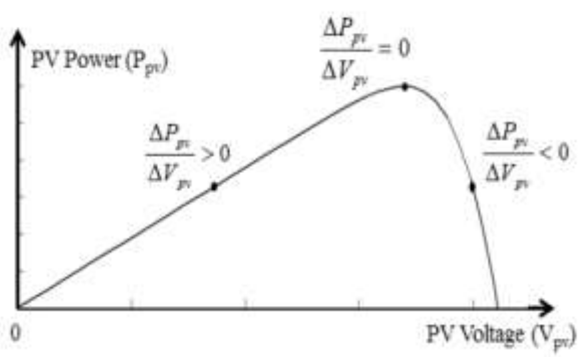

Fig. 7. Working Principle of Incremental Conductance method

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I\frac{dV}{dV} + V\frac{dI}{dV} = I + V\frac{dI}{dV} \tag{4}$$

$$I + V\frac{dI}{dV} \cong I + V\frac{\triangle I}{\triangle V} \tag{5}$$

Therefore,

$\frac{\triangle I}{\triangle V} = -\frac{I}{V}$, at MPP

$\frac{\triangle I}{\triangle V} \geq -\frac{I}{V}$, left of MPP

$\frac{\triangle I}{\triangle V} \leq -\frac{I}{V}$, right of MPP

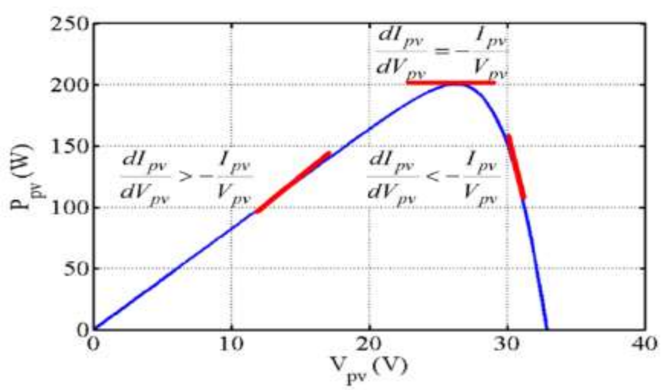

Fig. 8. Incremental Conductance Algorithm graph

V. Control System

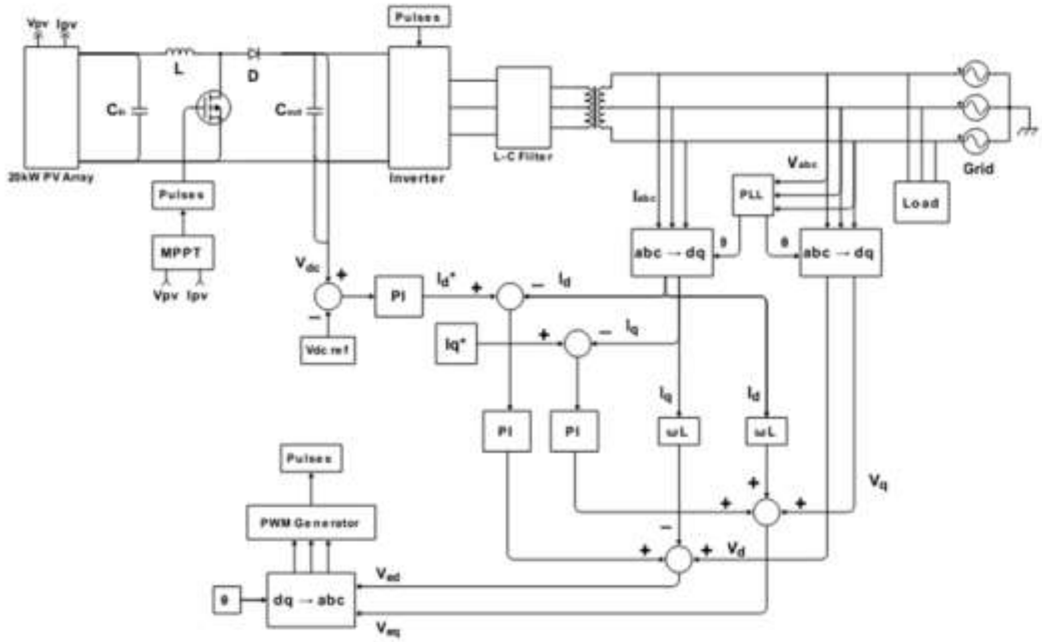

Fig. 9. General Diagram of Control System

Grid synchronization includes techniques such as zero crossing, atan function and phase locked looped (PLL) are used in α-β and d-q frame. The simplest way for grid synchronisation is zero-crossing technique. The zero crossing points of grid voltages are detected every half cycle of the time and grid frequency is obtained but the disadvantage of this technique is that it is not having fast dynamic response for frequency variation.

PLL is the most popular and widely used synchronization technique. PLL is generally implemented in the d-q reference frame. The q-component of grid voltage is controlled by PLL to provide synchronization. Here the inverter is controlled by the SPWM and the synchronization will be provided by the PLL method. The grid voltages are measured and the grid angle is determined by the PLL method.

The Grid angle is used to get the grid currents and grid voltages from the a-b-c reference frame to d-q reference frame by park transformation. And the reference and measured d-q currents are used for the calculating the error and this error is given to the PI regulator. The maximum value of grid current is defined by the reference d-component. Similarly, the control of the reactive power is done by the q-component.

VI. Simulations and Results

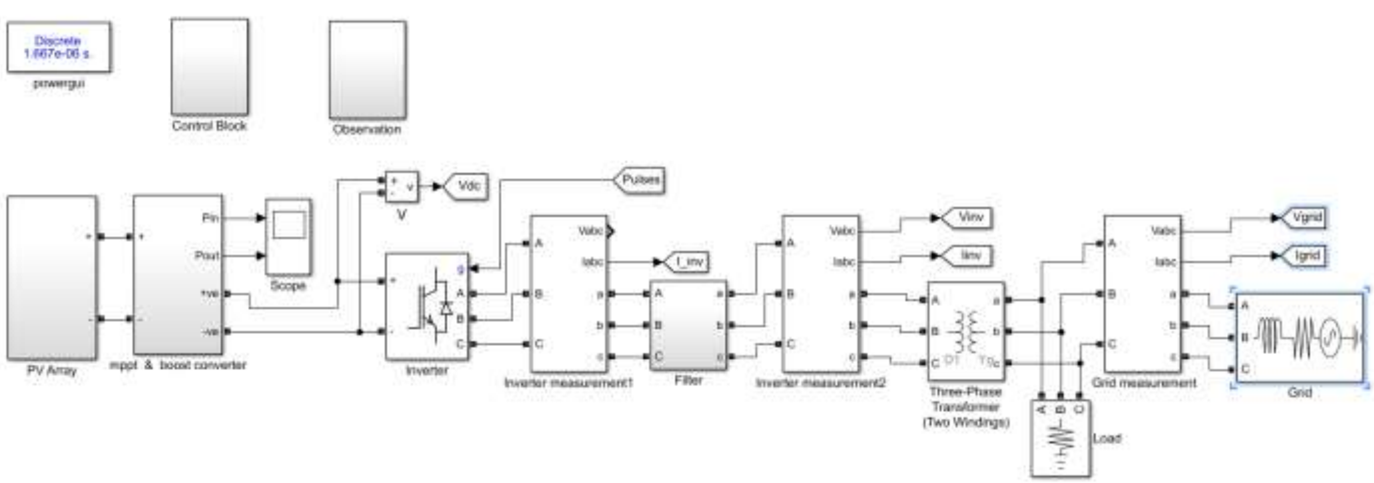

Fig. 10. Simulation of Grid integrated 20 kW Solar Photovoltaic System

PV Array of 20 kW is shown in the figure along boost converter and mppt controller. To generate 20 kW power the required number module will be 64. After connecting these 64 modules of Waaree Energie WSM-315 in series parallel combination we can generate power of 20 kW. Here, In the simulation work of module of Waaree Energie WSM-315 and string of 8 series connected such modules and 8 parallel strings are formed to generate 20 kW power. Simulation parameter for 20 kW PV system is shown in the below table:

TABLE 1. PV array Specification

Quantity	Value
Pmp	315 x 64 = 20.16 kW
Vmp	280 V
Imp	72 A
Voc	344 V
Isc	78.16 A
Ns	72

Total number of 64 module are arranged in series and parallel combination. Such 8 modules are connected in series and these series connected PV array are again connected in parallel. 8 such parallel combination is arranged. Under the effect of partial shading, these parallel connected arrays are shaded due various natural or made reasons. So, under such circumstances, the output I-V characteristics and P-V characteristic of solar PV Array will be as shown in below figure:

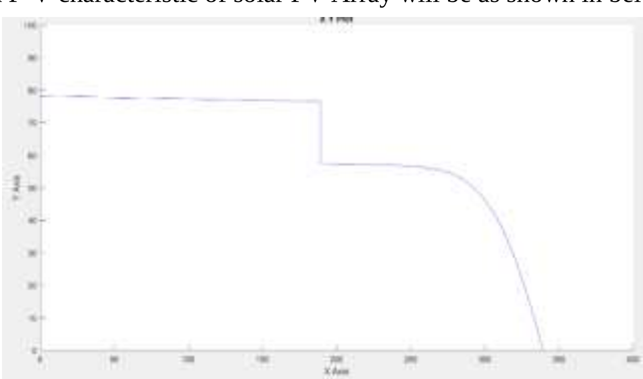

Fig. 11. I-V Characteristics of PV Arrays under partial shading condition

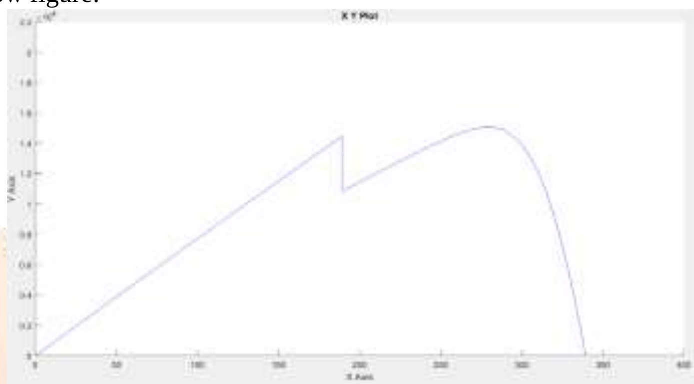

Fig. 12. P-V characteristics of PV Array under partial shading condition

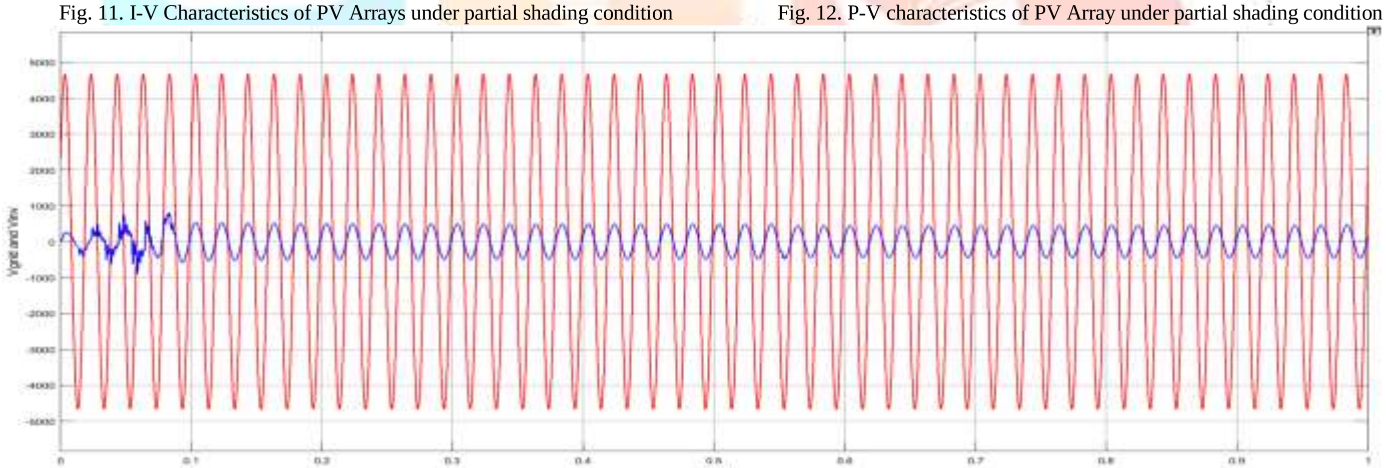

Fig. 13. Synchronised voltage waveform of inverter and grid

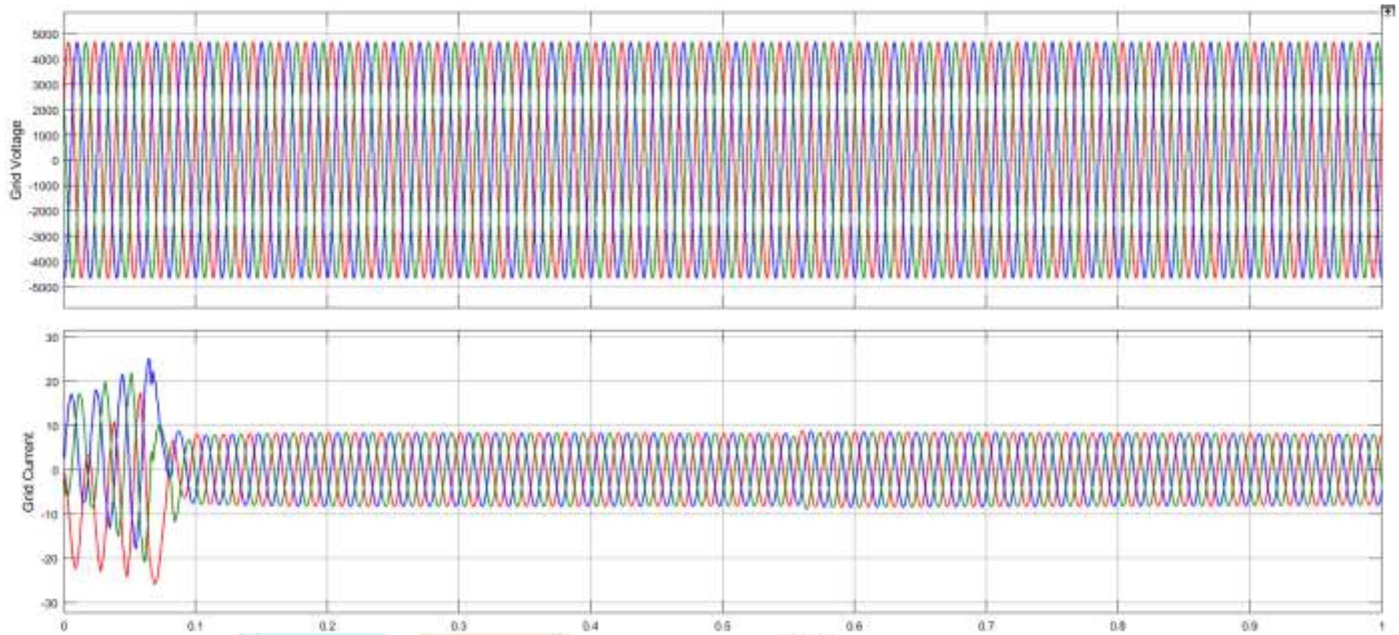

Fig. 14 Grid Voltage and Current waveform under the effect of partial shading condition

VII. CONCLUSIONS

As we have observed the graph showing the P-V and I-V characteristics of PV system changes as per the change in temperature as well as irradiation. So, the PV Generation is very sensitive to any change in the value of temperature as well as irradiation. So accordingly, the output values of all the components connected will be directly affected to this variation. So, we can conclude that without MPPT boost converter combination it is very difficult to obtain a smooth output and maximum power. To achieve maximum power point, we can control the current or regulate the voltage to maintain the power. Here, MPPT regulates the duty cycle to maintain voltage and achieve maximum power. A two-stage control is implemented in this system. DC side voltage is controlled using boost converter, which is controlled using Incremental Conductance (INC) algorithm. The control algorithm of INC is implemented in Embedded MATLAB function. The inverter control is implemented using two control loops i.e, voltage control loop and current control loop. Voltage control loop maintains DC link voltage constant and current control loop controls the current injected in the grid. The control strategy proposed in this paper is verified for different operating conditions through simulations. This shows that system is responsive to any variation in the input parameters. The proposed control strategy can be used with any topology and converters to get the satisfactory results. Different types of renewable energy sources can also be integrated with the proposed system to form micro grid.

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