Modelling of Grid Connected Photovoltaic System through H-Bridge Inverter under Partial Shading Condition

T. Murali Mohan[1], V.S.Vakula[2]

[1]Assitant Professor, Department of Electrical and Electronics Engineering, UCEK, JNTUK, Kakinada

[2]Assitant Professor, Department of Electrical and Electronics Engineering, UCEV, JNTUK, Vizayanagaram

Abstract— ***Power generation from photovoltaic systems is a smart idea and is being adapted world wide as a sustainable solution for ever increasing electricity demand. This paper mainly focuses on modelling of PV array from the basic PV cell and its integration to the grid. A DC-DC boost converter is used to raise the voltage of the PV array suitable for conversion of DC quantities into ac quantities by the inverter. In order to have sufficient ac voltage at inverter terminals a multilevel inverter of cascaded h-bridge type is proposed. A pulse width modulation of phase disposition is used to generate the switching pulses to the inverter switches. At the point of common coupling the inverter and the grid share the connected load demand. For different shadings across the PV modules and different power factor loads, the exchange of power is analyzed. It is observed that the shading of modules significantly affect the power output of the PV system and power factor of the load also has the impact on the reactive power drawn from the sources.***

Keywords: — H-bridge Inverter, PV Array, Perturb and Observe MPPT, Pulse width modulation technique, Phase lock loop, Synchronous reference frame theory

I. INTRODUCTION

THE Solar photovoltaic (PV) energy utilization has grown consistently by 20%-25% per annum over the past 20 years. The growth is found mostly in grid-connected applications. However, there are certain technical issues in grid connection which are discussed in this paper. A PV module is formed by connecting the number of cells in series and parallel. By increasing the cells in series the voltage of a module can increase and by increasing the number of cells in parallel the current rating can increase. A Similar concept is used in the formation of PV array wherein the number of modules is connected in series to enhance the dc voltage. This voltage is suitable for inverter to produce proper ac voltage. Similarly number of strings is connected in parallel to enhance the PV array current capacity [1]-[3]. PV arrays are mostly interfaced with maximum power point tracking controllers in order to extract maximum power from the panels under all possible temperature and irradiance conditions. It is inevitable that the temperature and irradiance across the modules shall changes during the day time. However, there is no operation of the array during the night time. Therefore, MPPT is essential and the most commonly used MPPT is the perturb & observe MPPT which is used in this work and implemented in the simulation study [4]-[7]. When there are no shadows on the panels the temperature and irradiances are uniform but practically partial shadings are inevitable. This initiates the interest to analyze the effect of PV panels under different kinds of shadings [8]-[14].

Recently multi-level inverters are mostly used for integration of PV array into the grid. The main advantages of using these inverters include lower distortion in the voltage signal and voltage magnitude is increased as the number of levels increased. However, the disadvantages are increase in power loss due to fast switching and increased number of switches. A cascaded three level h-bridge inverter is used in this work to convert the dc voltage into a three level ac voltage. This voltage can have the frequency equal to the grid frequency and phase sequence as that of grid phase sequence [15]-[18].

Though there are different pulse width modulations techniques are available, a phase disposition type is used to generate the inverter switching pulses because of its simplicity. For an N-level inverter, (N-1) triangular carrier signals are used for generating the switching pulses to the inverter switches. The generated three phase ac power is integrated to the grid at the point of common coupling (PCC) where the grid and load shall meet at the same point [19]-[24]. This configuration is simulated in MATLAB/SIMULINK environment and the analysis has been carried out under different load types for various irradiances across the array.

II. PHOTOVOLTAIC SYSTEM MODELLING

A PV cell model is represented by a single diode model in which a constant current source is connected in parallel with a diode. The diode is used to carry the reverse leakage current. A series resistance is connected to represent the losses in the cell and a shunt resistance in parallel which comes in the path of leakage current and hence it is neglected. Anti parallel bypass diode is connected to a PV module to bypass the current in a string during partial shadings or module failure. The relevant diagram is shown in fig 1.

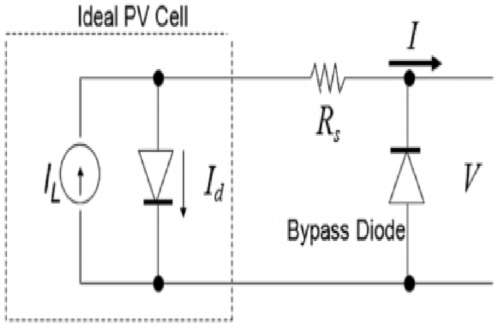

Fig.1 Equivalent circuit of PV cell with bypass diode

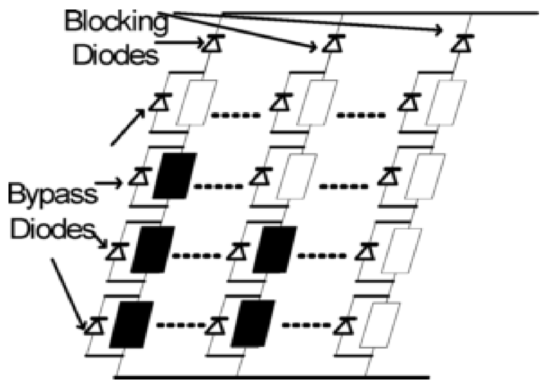

Fig. 2 PV array with bypass and blocking diodes

The dark modules imply shading

Sometimes there will be shadings on the modules due to movement of clouds or shadow due to nearby objects. Full shadow indicates the zero irradiance in the module and that yields no corresponding voltage or current. In order to bypass such modules bypass diodes would support. In case of string failure or under normal operation the reverse flow of currents or circulating currents are prevented by blocking diodes.

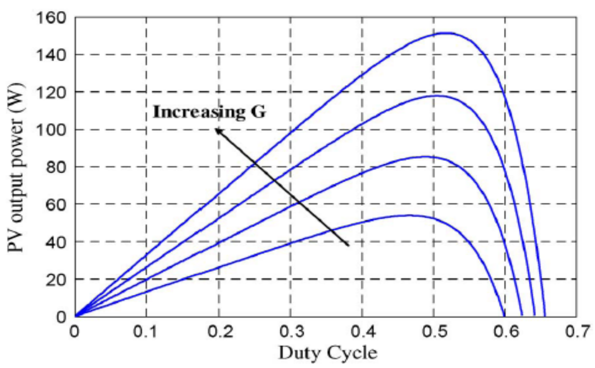

Fig .3 PV array output power for different irradiances

The net current comes out of an array is the sum of the individual string currents and net array voltage is the sum of the individual module voltages in a string. However these voltages and currents are affected by temperature and irradiance across the modules in an array. As the irradiance increases the power output of the array increases and as the temperature increase the power output decreases. The relevant waveforms are shown in fig.3 and fig .4 respectively

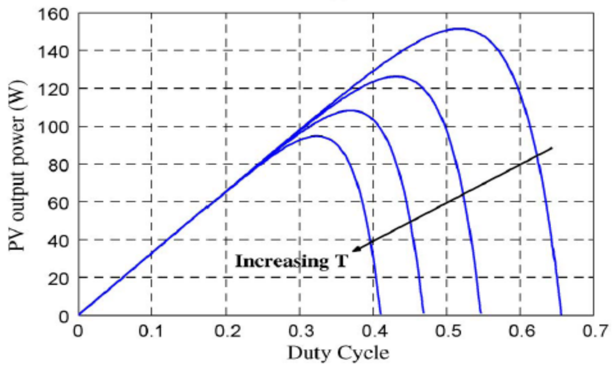

Fig.4 PV array output power for different temperatures

The characteristics which are shown in fig .3 and fig.4 are not the same under partial shadings but they have multiple peaks rather than a single peak in each curve. This poses a problem on array operating point at which the P&O MPPT operates. The search for peak power point by the P&O MPPT is implemented on a PV array which consists of six modules structure in which three modules are included in each string shown in fig.5

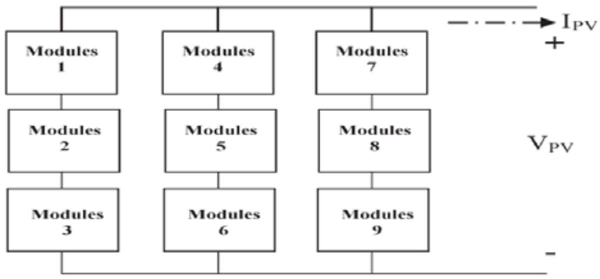

Fig. 5 PV array system with nine modules

III. PERTURB AND OBSERVE MPPT

Maximum power point tracking (MPPT) is essential for a PV system to extract the power corresponds to the peak point. The most commonly used MPPT algorithm is Perturb & Observe method. This is very simple method to implement. In this method both voltage and current are measured at PV array terminals and used to calculate the power. When the power difference between any two subsequent samples is zero, then perturbation of reference voltage Vref is not required. When the power difference is greater than zero or positive, then increase the reference voltage if the voltage difference is positive and decreases when the difference is negative. Suppose if the power difference is negative, then, increase the reference voltage if the voltage difference is negative otherwise decrease the reference voltage. This approach shall drive the tracking system towards the peak power point. The corresponding flow chart and power curve shown in fig.6 and fig.7 respectively.

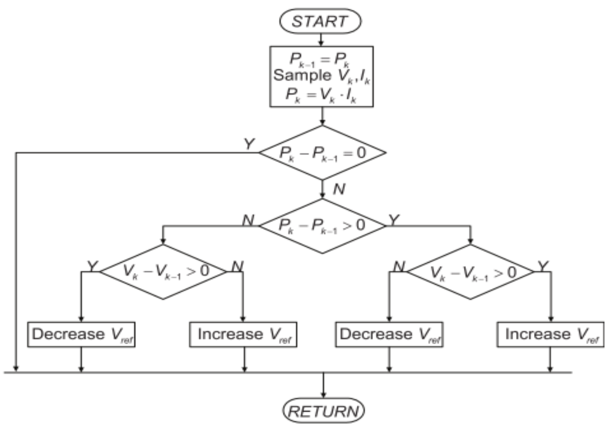

Fig. 6 P&O Algorithm

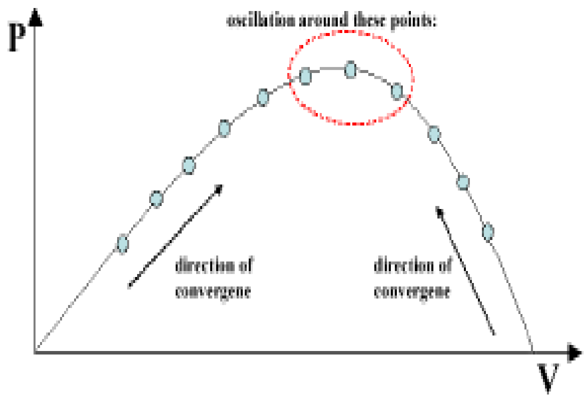

Fig. 7 Graph Power versus Voltage

IV. THREE LEVEL H-BRIDGE INVERTER

A Cascaded H-bridge inverter is a multi-level inverter mostly used to reduce the distortion and to enhance the voltage magnitude. Figure 8 shows a three level h-bridge inverter configuration for a three phase system. A pulse width modulation (PWM) technique of phase disposition is used. In this PWM technique for N-level inverter the number of triangular carrier waves used are (N-1) and they are vertically disposed shown in figure 9. In a three level inverter, two carrier waves are used in which upper triangle ranging from +1 to 0 and lower triangle ranging from 0 to -1. The output ac voltages in three phases has three levels which are $+V_{DC}$ /2, 0, $-V_{DC}$ / 2.

The converter is switched on to $+V_{DC}$ / 2 when reference is greater than the two carrier waveforms. It is switched to zero when the reference is less than the lower carrier waveform but greater than the upper carrier waveform. It is switched to – V_{DC} /2 when the reference is less than the both carrier waveforms. However in carrier based PWM technique at every moment the modulation signals are compared with carrier signal and depending on which is greater the switching pulses are generated.

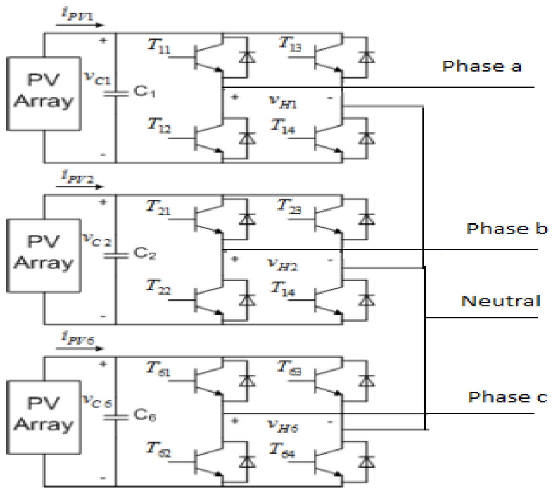

Fig. 8 Three level H-bridge inverter

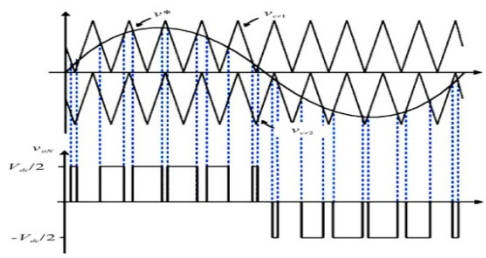

Fig. 9 Phase disposition PWM technique

V. GRID CONNECTED PV SYSTEM

Solar Energy Corporation of India (SECI) and Ministry for New and Renewable Energy Sources (MNRE) have been promoting roof top PV systems in the recent days. Most of the parts in India referred the national central electricity authority (CEA) of India regulations for grid integration of PV systems.

While interconnection there are certain issues with regard to the limits on the system size and allowed interconnection voltages. The inverter plays a vital role in the PV grid integration scenario since it decides the power quality of the system. According to CEA in grid integration, harmonics, flicker and DC injection are the important power quality parameters. The CEA follow global best standards as shown below.

- Harmonics- IEEE 519, wherein THD < 5%
- Flicker- IEC 61000
- DC injection - IEEE 1547 standard, wherein the maximum permissible level is 0.5% of the full rated output at the interconnection point.

In addition to the standards mentioned above the system is allowed to function within a certain range of voltage and frequency limits. The CEA currently permits the system to function within a range of 80-110% of voltage and 47.5-51.5 Hz of frequency band. When there is a violation of the said limit, the inverter automatically stalls the injection of the power to the grid by setting itself off mode. However, the advanced controllers make the inverter to function continuously even after the excursion of these limits without creating the nuisance tripping. The standards allow the inverter to function even after the violation of the standards during temporary fault conditions.

Modern inverters are capable of injecting the power to the grid besides the control of local grid frequency and voltage excursions. Inverters provide frequency support and reactive power support to maintain the grid parameters within the limits. Since the output of the inverter is a three phase it is integrated to the three phase grid. The simulation of the circuit is developed in MATLAB/SIMULINK and results are validated.

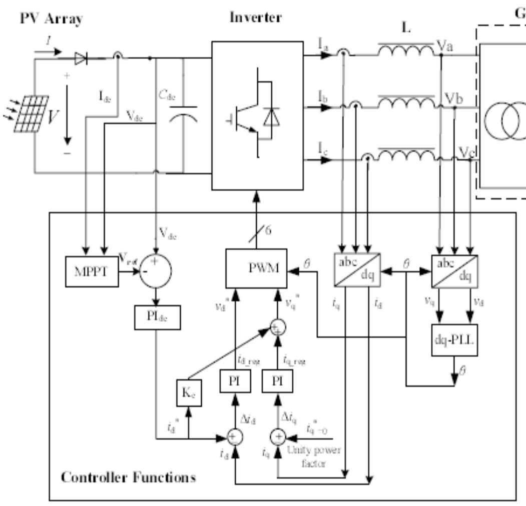

Fig. 10 Configuration of grid connected PV system

TABLE -1 PV ARRAY SPECIFICATIONS

Parameter	Value
Maximum power (P_{max})	1372.14 W
Voltage at Pmax (Vmp)	108 V
Current at Pmax (Imp)	Current at Pmax (Imp)
Open-circuit voltage (Voc)	130.2 V
Short-circuit current (Isc)	13.2 A
Temperature coefficient of Isc	0.0032±0.015) % / °C
Temperaturecoefficientof Voc	– (80±10) mV / °C

Fig.10 shows the PV system integrated to the grid with associated MPPT and inverter control circuit. PV array and devices chosen for simulation from fig.10 have certain specifications shown in Table I and Table 2. The inverter provides the three phase ac output of grid frequency and phase sequence.

TABLE -2 GRID AND FILTER SPECIFICATIONS

Parameter	Value
Grid line voltage (V_{L-L})	415 V
Grid phase voltage (Vph)	240 V
DC source voltage (V_{dc})	100V
DC current (I_{dc})	10A
Output power fed to grid (P_n)	1000W
Grid frequency (f)	50 Hz
Switching frequency(f_s)	1KHz
Filter inductor	70 mH
Filter Capacitor	60 µF
Parameters PI	K_p =10, K_I = 0.02

Case 1: Under no shadings

When there are no shadings, the irradiance upon all the modules are assumed as 1000 W/m^2, while the temperature remains same at 25^{0}C. The obtained DC voltage, current and power is shown in Fig. 11, 12, and 13 respectively. A load of 10KW is connected at the PCC where grid and inverter meet together. Fig. 14, and Fig. 15 shows the active and reactive power of inverter, grid and load respectively.

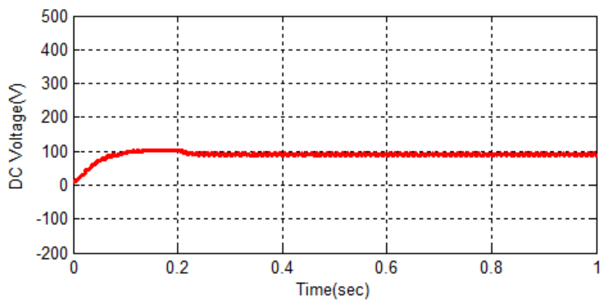

Fig.11 DC voltage of PV array

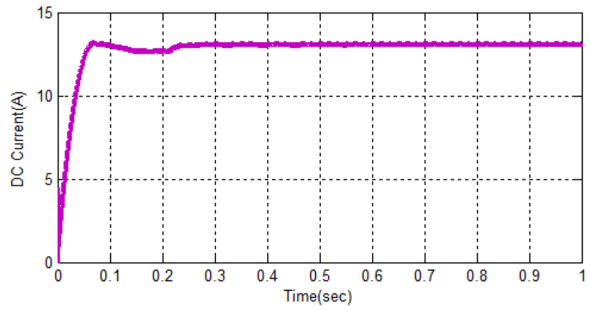

Fig. 12 DC current of PV array

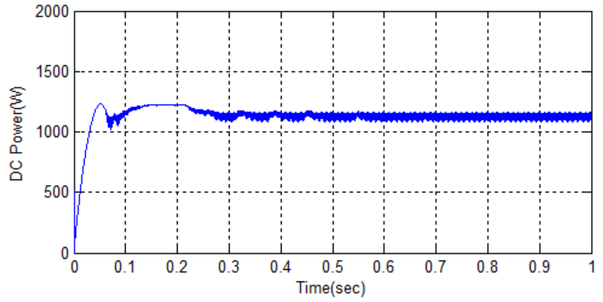

Fig. 13 DC Power of PV array

From fig. 11 to 13 illustrates that under normal operating conditions the voltage of PV array voltage, current and power are constant with respect to the time. The power output is equal to the product of PV voltage and current.

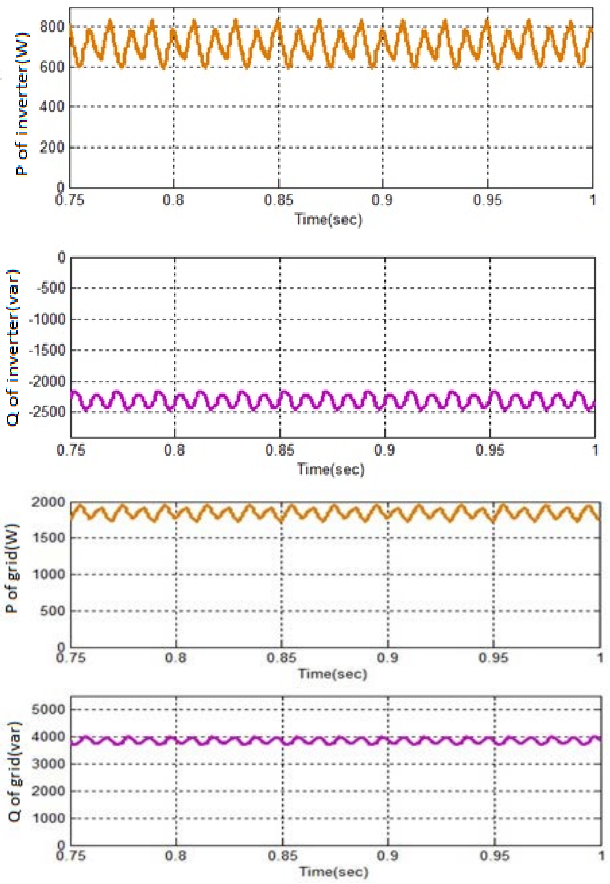

Fig. 14 Active and reactive power of Inverter and Grid

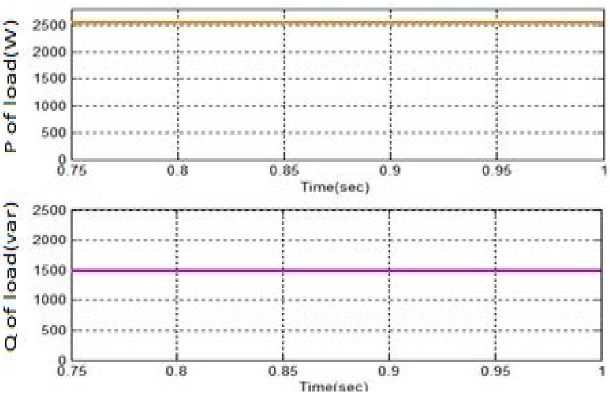

Fig. 15 Output active and reactive power of Load

Case 2: A string has 50% shading

A string in a photovoltaic Array has been given 50% shade with an irradiance of 500 W/m^2 and at constant temperature of 25^{0}C. However, the load on the system remains same as in case 1. Fig.16 and Fig.17 shows the power drawn from the inverter, grid and load respectively

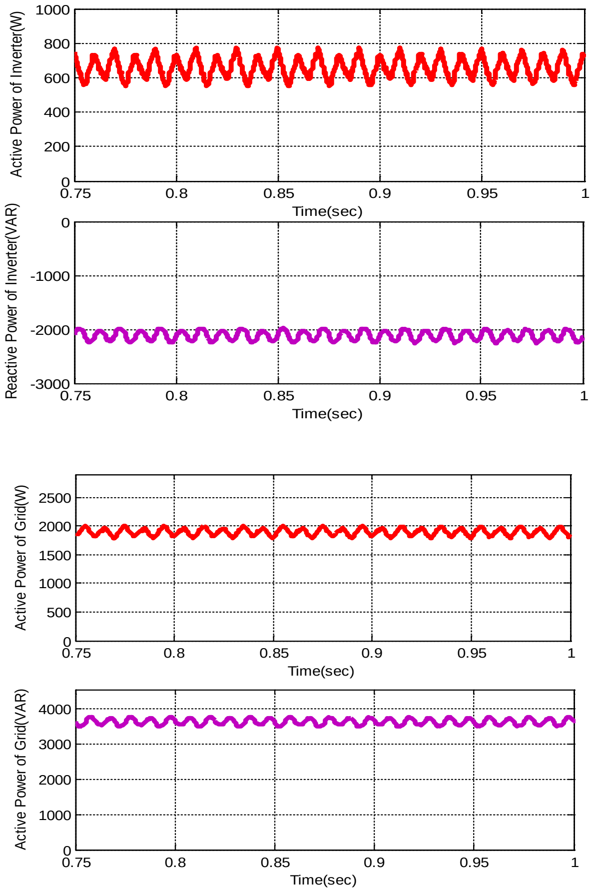

Fig. 16 Active and reactive power of Inverter and Grid

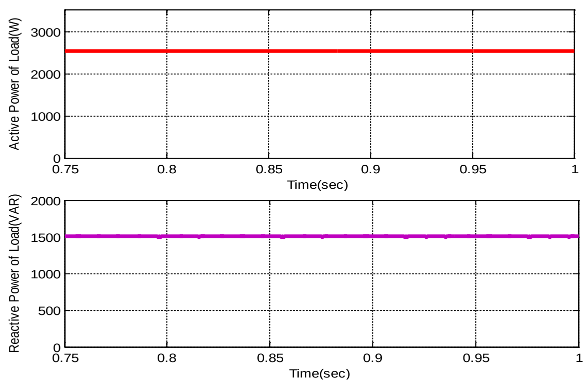

Fig. 17 Output active and reactive power of Load

Case 3: One string has 100% shading

In this case a string in a photovoltaic array has been completely shaded which has an irradiance of 0 W/m^2. However, the connected load has active power 10 KW and inductive reactive power 8.81 KVAR. The obtained results are Fig. 18 and Fig. 19 which shows the active and reactive power of inverter, grid and load respectively. It is understood that the power flows through the load is the sum of the powers supplied by the inverter and the grid. This is true in both real and reactive power cases.

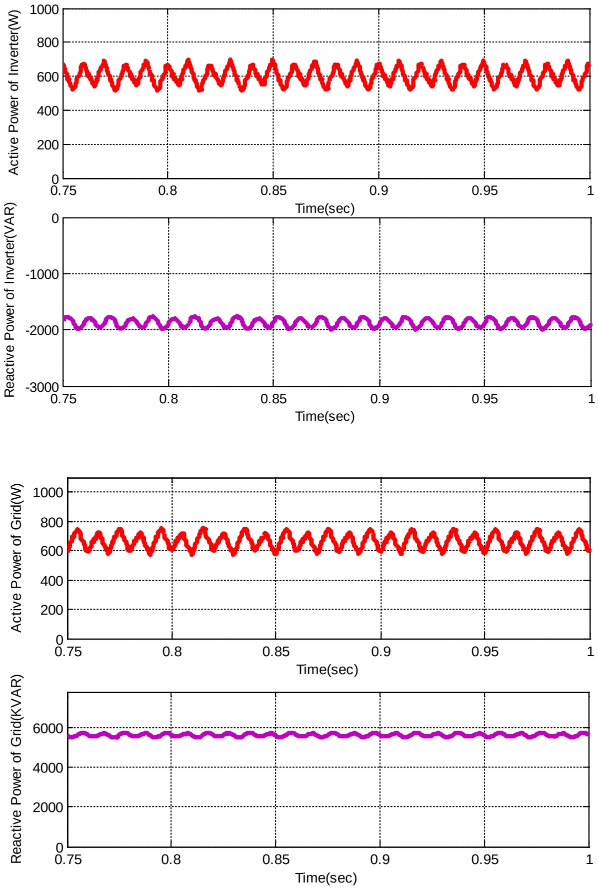

Fig. 18 Active and reactive power of Inverter and Grid

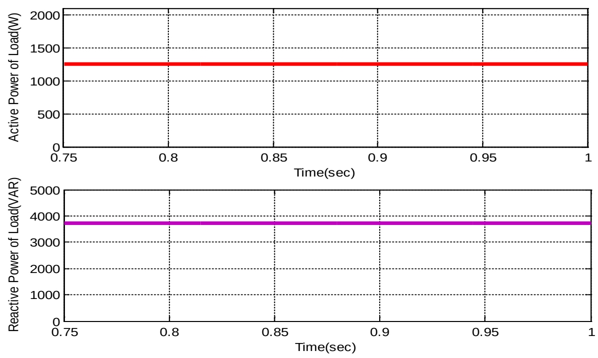

Fig. 19 Output active and reactive power of Load

Case 4: Two strings are completely shaded

In an array of three strings, two strings are completely shaded. A load of active power 10 KW and inductive reactive power 8.81 KVAR is connected and observed the results. Fig. 20 and fig.21 show the active and reactive power of inverter, grid and load respectively.

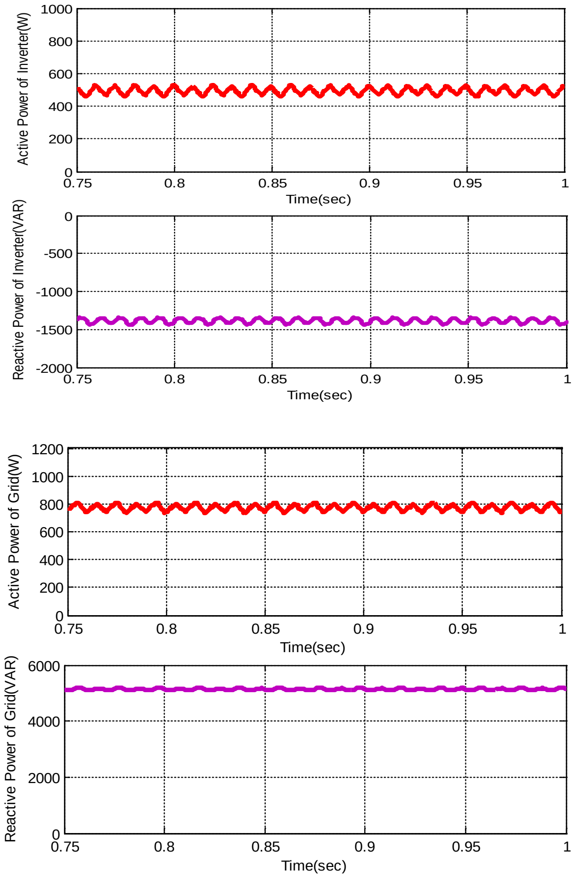

Fig. 20 Active and reactive power of Inverter and Grid

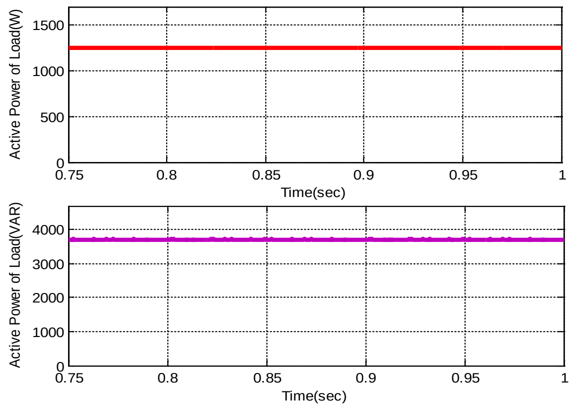

Fig. 21 Output active and reactive power of Load

VI. CONCLUSION

A Photovoltaic array has been developed which is suitable for simulating the partial shadings. The popular perturb and observe MPPT is Simulated and interfaced with the PV array by means of DC-DC boost converter. A PV array has been integrated to the grid through H-bridge inverter. A three phase transformer is used next to the inverter and tested the system performance. The analysis is done at different loads with different power factors under various partial shadings. It is observed that partial shadings produce less power from PV array as a result the power drawn from the grid increases in order to meet the load demand.

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