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ACTIVE POWER CONTROL IN GRID CONNECTED PV SYSTEMS

Himank Aggarwal, Himanshu Bharti, Manuraj Mina, R. L. Meena

[1-3]B. Tech Delhi Technological University, Shahbad Daulatpur, Delhi-110042
[4]Associate Professor R. L. Meena, Dept. of Electrical Engineering, Delhi technological Universty, Delhi, India

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Abstract - *A quick increase in the demand of energy with increasing population along with the adverse impact on the environment like global warming has forced us to explore other viable options of energy which is sustainable along with being economical and reliable. Out of many options already available and many more yet to be discovered one such option is solar energy. Nowadays, a production of green energy is in focus which includes solar PV system, Wind Generation etc. Recently Direct current micro-grids (DC) are considered for use because of their advantages. A DC micro-grid can supply power to both AC and DC load. The operating point of Solar PV is maximized by the use of Maximum power point tracking (MPPT) algorithm which use perturb and observe method(P&O). DC-DC boost converter is used to step up the voltage from the Solar PV system. Active power transfer is economical and reliable. The inverter is now controlled using PI controller to transfer the active power from PV array to the grid. The design and simulation of active power transfer is done. The compete study is done in MATLAB/SIMULINK environment*

***Key Words*: Active power control, DC micro-grid, Grid connected photovoltaic system, MPPT, PI control**

1. INTRODUCTION

Around the world the use of renewable energy use is on the rise and this alternative energy potentially are the key for tacking climate changes. Renewable energy is the form of energy that are produced from the sources that are naturally available to human beings and provided the nature. Most common sources are solar, hydro, wind, geothermal and many more yet to be discovered. Over 80% of the total energy consumed by the human beings is produced from the fossil fuels, however renewable is the fastest growing source of energy in the world. The advantages of using renewable energy are immense. First and most important is that it can combat climate change as it does not emit any greenhouse gases. The only disturbance it causes to the environment are indirect which includes in manufacturing, installation and repairing of these technologies but even these are minimal. Once produced the running cost is minimal as the fuel of operation is free. Solar energy has provided a solution for these problems. A photovoltaic system consists solar modules that are mounted on a structure. These PV system uses irradiation from the sun to produce the direct current. As the solar irradiation is not constant the DC current produced by the solar photovoltaic system varies with solar irradiance which is given by power versus solar irradiance level graph. Now, to work the solar PV system on its maximum power point we need a MPPT controller which would force the solar PV system to work on its maximum power point. A solar photovoltaic system can be operated without a photovoltaic system but then it will result in misapplication of the solar photovoltaic system and hence an MPPT is required. Almost all of the present time MPPT controllers have an excellent efficiency ranging from 94% to 98%. Other method to produce a constant DC bus voltage is to connect is to a grid with the help of an inverter. The dependence of the grid frequency on the active power is of the paramount importance and it needs to be regulated to maintain the frequency of the grid. Apart of this factor if a load is connected to the grid the active power can be supplied to the load with the aid of solar PV thus decreasing the operational cost of the power system and providing a clean energy. In this paper two cases are discussed. First case is the transfer of the active power as irradiation increases without any command given to the system. In the second case the active power is transferred based on a reference value given by the user. The system description is given in section (II). The proposed system is described in section (III) and the results are discussed in section (IV)

1.1 System Description

In the model various components are used they are briefly discussed below

A) The PV cell circuit module:

The phenomena by which the solar energy is converted to the electrical energy without any electromechanical energy conversion process is known as photovoltaic phenomena. The photovoltaic system is based on the electron theory of irradiation energy and the system based on this theory are said to be photovoltaic system. There are chiefly four components of the photovoltaic power system and these are solar PV module that that actually converts solar energy to the electrical energy. The second system is the power electronic systems that conditions the input available to it to the required energy also through the intelligent control of the firing angles of the power electronic devices it is possible to control the output voltage and waveforms of the input voltages. The third and the last one is the electrical load. Since, we are mainly focused on the DC bus the loads will be DC in nature. Apart from these three main components we also have a maximum power point tracking system whose main purpose is the make use of the solar panel in the most efficient way by constantly changing the output of the solar panels to its maximum voltage[1].

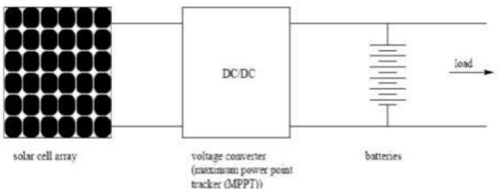

Fig 1: The photovoltaic power system

B) V-I and P-V characteristics of a PV cell:

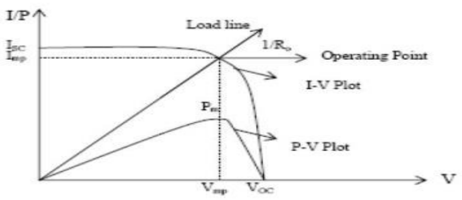

Fig 2: V-I and PV characteristics of a PV cell

The power across any element is calculated by multiplying the voltage across the element and the current flowing through the element. Similarly, power of a solar photovoltaic system is calculated by measuring the voltage across the PV module and the current through the solar cell. As seen from the graph that the power is maximum at a point in the graph and that point is known as maximum power point and if the load line is such that it intersects the maximum power point then the maximum power is available across the load[1].

C) DC-DC converters:

DC-DC converters are implemented where an average DC voltage is required from an input DC voltage. The output DC voltage can be higher or lower than the input DC voltage depending on whether a boost converter or a buck converter is used respectively. The converter topology that has been used in this study is the boost converter along with the MPPT algorithm which will caused a change in the duty cycle on the switch(IGBT) used in the boost converter[1].

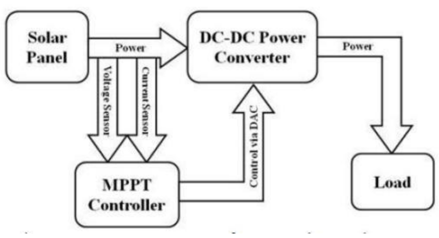

Fig 3: DC-DC converter used for operation of MPPT

D) Inverter:

If considered a black box inverter is a device that acts as a link between DC and AC sides. It converts DC applied to it to the AC based of the switching frequency of the switches in it. There are various topologies of the inverters that can be used. However, in this paper the 6 switches 3 phase PV grid tied inverter the meaning of this is on the DC side it is connected to the PV on the grid side producing output at 50Hz frequency while connected to the grid. The reason why this topology was selected is because it is easy to work being accurate at the same time.

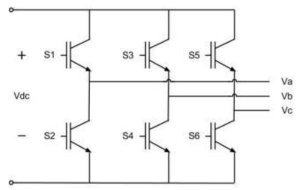

Figure 4: Three phase inverter topology

E) DC LINK CAPACITOR:

The capacitor at the DC link is of paramount importance. It helps to keep the voltage of the DC bus constant with respect to any fluctuations that might happen at the DC side so it can be well said that the DC link capacitor helps to reduce the voltage ripple, also the DC link capacitor act like a source of power during positive half cycle and sink of the power during negative half cycle thus maintaining a balance of the power at the DC side. In a cycle if the output power of inverter is greater than the power of solar PV the power at the DC bus is maintained by delivering the power and if the output power of inverter is less than the power produced by the solar PV then extra power is stored in the capacitor. If losses are ignored and if the inverter is operating as desired than it can be said that the time average of the power output from the inverter is equal to time average of the power generated by the solar photovoltaic system.

F) Final system description:

1)

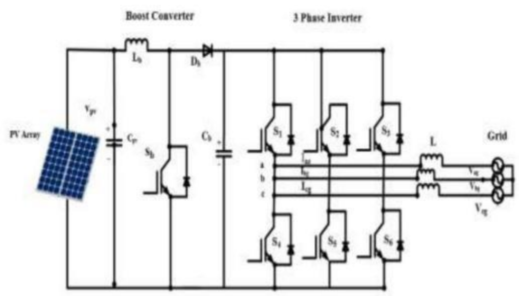

Figure 5: Configuration of Grid Connected solar photovoltaic system

The above figure shows the circuit topology that is being employed in the simulation model of the grid connected solar PV photovoltaic system. From the figure the various components that can be seen are Solar photovoltaic array, boost converter, DC link capacitor, 3 phase inverter and a grid. The irradiation of the solar PV array is not assumed to be fixed at a fixed value. In this simulation to simulate the solar irradiation the irradiation given to solar PV array is variable to see the effect of the active power transfer to the grid on a whole day basis. The maximum power output from the solar panel in this simulation is 50kW at an irradiation of 1000W/m² and 25°C at 406V and 127.9 Amperes. The specification and parameters of PV module are Module= 1 Soltech1STH-251-P, maximum power=213.15W, open circuit voltage Voc=36.3, Voltage at maximum power point Vmp=29V, Cells per module Ncell=60, Short circuit current Isc=7.84A, Current at maximum power point=7.35A The array has 14 series module and 17 parallel strings. The various parameters of the above configuration are: Cb=3200e-6 F, Cp=100e-6 F, Lb=5e-3H.

2)

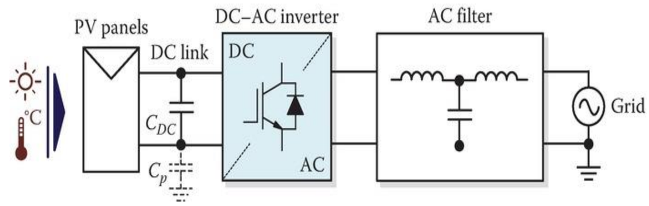

Figure 6: Configuration of grid connected inverter

For the simulation of active power transfer in part B of the simulation a grid tied inverter is employed without a DC-DC converter to reduce the overall cost of the power transfer system. This system will be operated at a constant irradiation and temperature while the user gives the reference power to be transferred to the grid. The MPPT is not employed here because the power demanded by the user is a variable. However, the system will fulfil the active power demand even if there is a change in irradiation or temperature. The inverter in this topology has to regulate the current while maintaining a constant voltage to fulfil the requested active power based on the gating pulses it obtain from the control system .The specification and parameters of PV module are Module= 1 Soltech1STH-251-P, maximum power=213.15W, open circuit voltage Voc=36.3, Voltage t maximum power point Vmp=29V, Cells per module Ncell=60, Short circuit current Isc=7.84A, Current at maximum power point=7.35A. Number of series connected module 27 and number of parallel strings is 7 giving maximum power of 2.3KW at 783V and 29.4 Amperes while operating at a irradiation of 1000W/m² and 25°C. Cdc=1000e-6 F.

1.2 Control Architecture

A) Perturb and observe maximum power point tracking system:

One of the simplest method to implement the maximum power point algorithm is perturb and observe method which is efficient, simple and effective as well. There are other methods of implementing perturb and observe method some of them are incremental conductance method, ripple correlation method etc. In the perturb and observe method, the operating voltage of the solar PV system is perturbed and its effect is observed on the power of the PV system. The power of the system before the voltage is perturbed is compared to the power after the voltage is perturbed and based on the difference of the power, the voltage of the solar PV is decided. If the difference of power is positive the new operating voltage will be greater than before and the duty cycle of the output pulses is increased and if the difference of the power is negative the solar panel will have to work at the reduced voltage so the duty cycle is reduced. Thus the operating voltage is constantly adjusted so that it remains at the maximum voltage. From the flowchart we can see that the MPPT require both voltage and current and according to the maximum operating voltage the current is automatically adjusted[2].

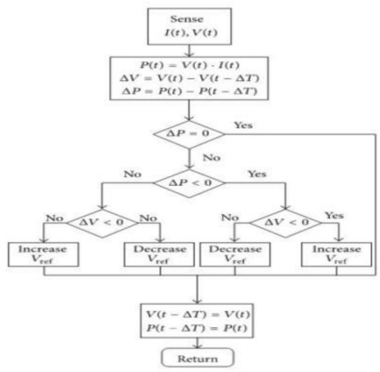

Fig 7: Flowchart for P&O MPPT algorithm

B) ACTIVE POWER TRANSFER CONTROL:

The active power transferred to the grid plays a vital role in maintaining the stability of the grid in which the power is being injected. One cannot be too careful while transferring active power to the grid so a suitable control in required to perform the desired task of transferring the active power to grid. The controller that is being used will have to ensure two things. In simulation (A) First, it has to ensure that the solar PV is operating at its maximum power point because utilizing the solar PV system below its rated capacities will result in underutilization of installed solar PV array. Second, since the whole system is connected to the AC grid the controller has to make sure that the current being injected in the grid has to be alternating in nature to make sure that it is operating satisfactorily. In this simulation the controller is employed with the help of the PI controllers to reduce the error if it occurs during any point of the operation by closed loop operation. In this control we utilize PLL block to obtain the frequency of the grid voltages and the closed loop controllers are utilized. PV array current and PV array voltages are used for the MPPT tracking to obtain the reference power for the inverter. The reference current to be injected in the grid now is obtained from the reference power, the grid voltage and the frequency[4]. With the help of the comparator the present current flowing in the grid and new reference current that is founded out are compared and an error in the current is founded out and are fed to a PI controller and by comparing carrier and modulating signal gating signals for the inverter will be obtained. This is now a current regulated system and the voltage output of the inverter will be decided by the grid voltage. The reference power that is used to calculate the reference current is obtained from the MPPT algorithm. Since the reference voltage is sinusoidal and the current that is injected to the grid is also alternating in nature abc to dq transform block is utilized to take advantage of the Parks transformation to convert the three rotating phases into three equivalent stationary dq0 phases. By using this transformation, the bandwidth and the speed of the controller is increased in simulation (B) the reference power will be directly given by the user and hence MPPT algorithm is not employed. In this case the power flowing previously (which can be easily computed by using three phase measurement) is now compared with the reference power to obtain the error in the power and that error is fed to a PI controller to generate a modulating signal based on the modulating signal the gating signal for the inverter is obtained[3].

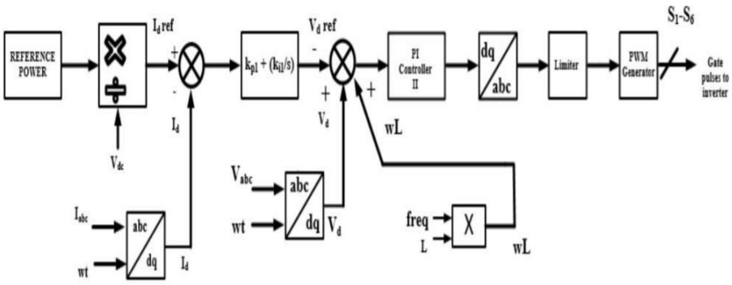

Figure 8: Block Diagram of PI Controller

Simulation Model (A)

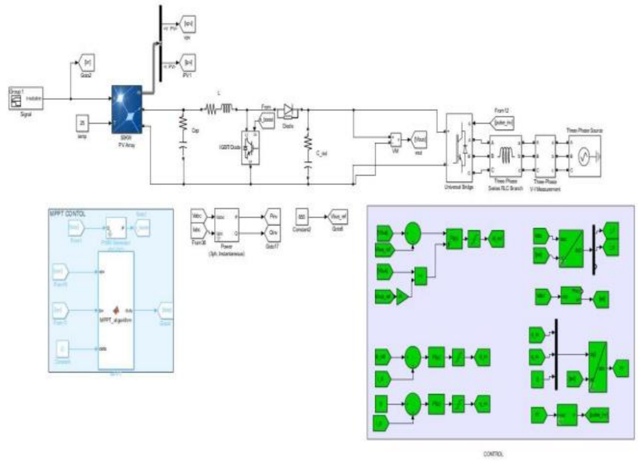

Figure 9: Simulation Model for part (A)

Simulation Model (B)

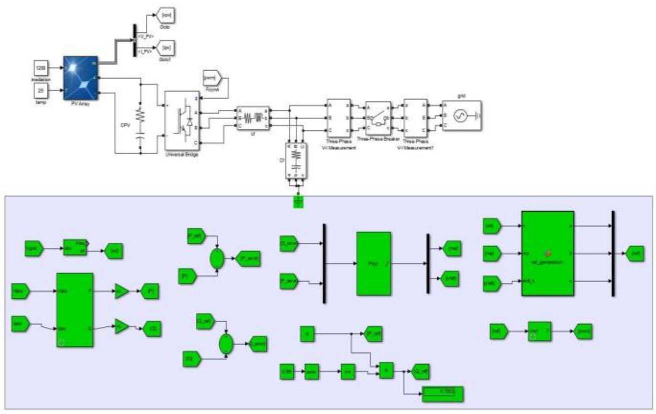

Figure 10: Simulation Model for Part (B)

2. RESULTS

PART(A)

After performing the simulation of the model we have obtained the following results:

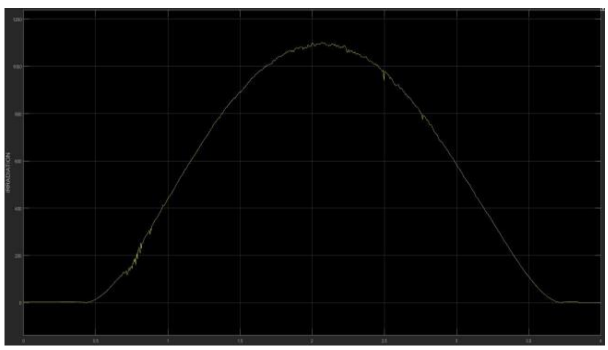

Figure 11: Irradiation

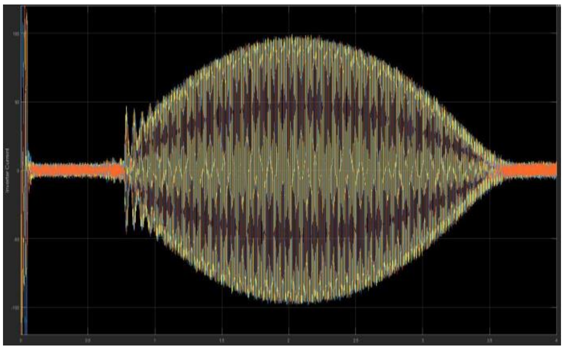

Figure 12: Inverter Current

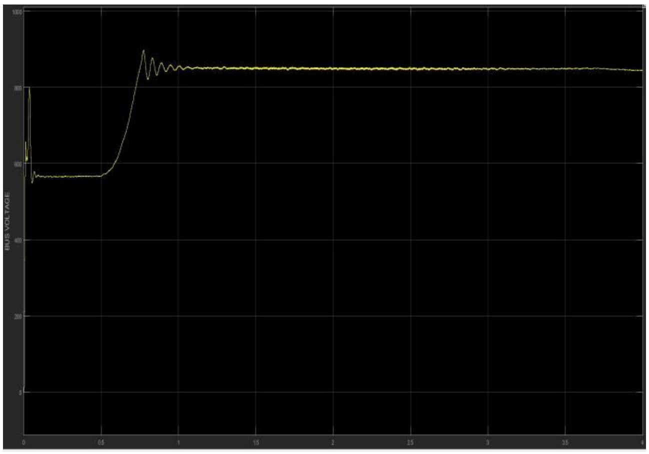

Figure 13: Bus Voltage

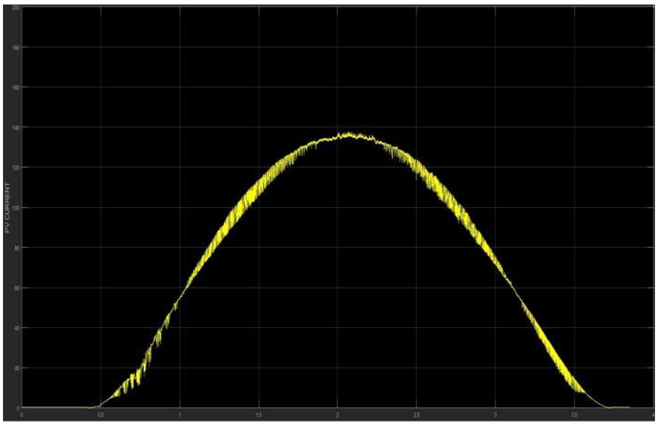

Figure 14: PV Current

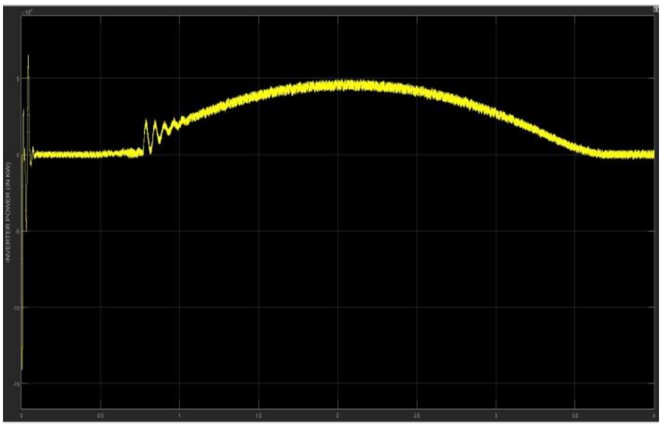

Figure 15: PV Power

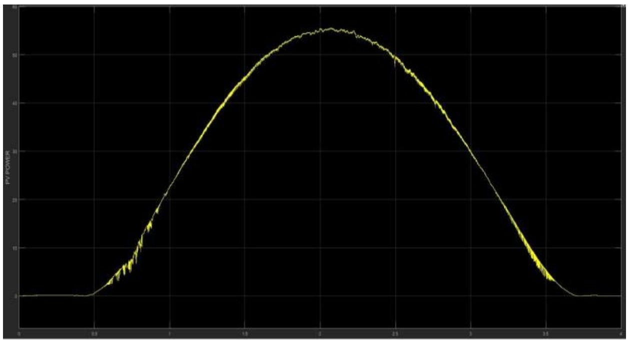

Figure 16: Inverter Power

Simulation was started at t=0. Initially the DC link capacitor was uncharged and we have set DC bus reference value at 850V so to maintain that voltage the inverter will supply the power as we see at t=0.00s the inverter power is found to be negative. Once the power has been sent to maintain the DC bus voltage there will be some overshoot in the DC bus voltage. Due to the overshoots the speed of the system increases and the DC bus voltage has been maintained at desired value at t=0.75s. which can be seen from figure (13) Also, the irradiation is continuously increasing from t=0 sec (can be seen from Figure (11)) and its effect can be seen on the power generated by the PV array which is increasing (As seen from Figure (15)). From t=0.50 sec, the power generated by the PV array becomes greater than the power at output of the inverter the active power will be send to the grid. At t=2.00sec the irradiation is maximum at 1097.26 W/m^2 the power generated by the solar PV array becomes max generating 55.49KW and the maximum active power send to the grid at this time is 46.03KW. It can also be seen that irrespective of the active power transferred from the PV array to the grid the voltage at the DC bus is maintained at constant value with an error lying in the range of 1%. From the data it can be seen that at 1000W/m^2 the maximum power that can be generated by the PV array is 50KW, so from the simulation it can also be said that the efficiency of MPPT is 98% which is excellent. After t=2seconds the irradiation starts to decrease from 1097.26 W/m^2 so the power produced by the PV array also reduces and the net active power transferred to the also reduces but the DC bus voltage is maintained at a constant value. Finally, the simulation ends at t=4 sec. Results are shown in Table 1 below,

TABLE 1: Comparison of PV Power, Inverter Power, Irradiation, Bus Voltage

Time (seconds)	Irradiation (W/m^2)	Inverter Power (KW)	PV Power (KW)	DC Bus Voltage (V)
0	2.71	-0.261	6.62e-06	0.0007
0.25	2.718	0.198	0.13	565.67
0.50	16.43	0.347	0.59	568.26
0.75	152.56	2.218	6.78	849.48
1.00	447.59	21.59	23.74	854.79
1.25	686.6	31.74	36.2	851.8
1.50	890	40.30	45.64	850.78
1.75	1034.15	43.83	52.21	849.42
2.00	1097.26	46.03	55.49	848.82
2.25	1069.92	44.68	54.52	848.02
2.50	978.02	43.65	49.85	849.96
2.75	808.81	36.8	41.66	846.48
3.00	587.96	28.23	29.98	848.78
3.25	348.69	16.54	17.48	848.98
3.50	107.97	5.54	4.37	849.28
3.75	2.59	0.33	0.03	848.68
4.00	0	0	0	843.99

PART(B)

In this simulation the Grid voltage is maintained at 300 V and the reference active power to be transferred is varied from t=0sec. Since the power is being transmitted to AC grid the voltage will remain constant. The inverter is being operated nearly at unity power factor so the change in the reference power will be reflected upon the current supplied to the grid. For an increased power the current that is being fed in the grid will be high compared to situation when the demanded power is less.

The results of the simulation are given below:

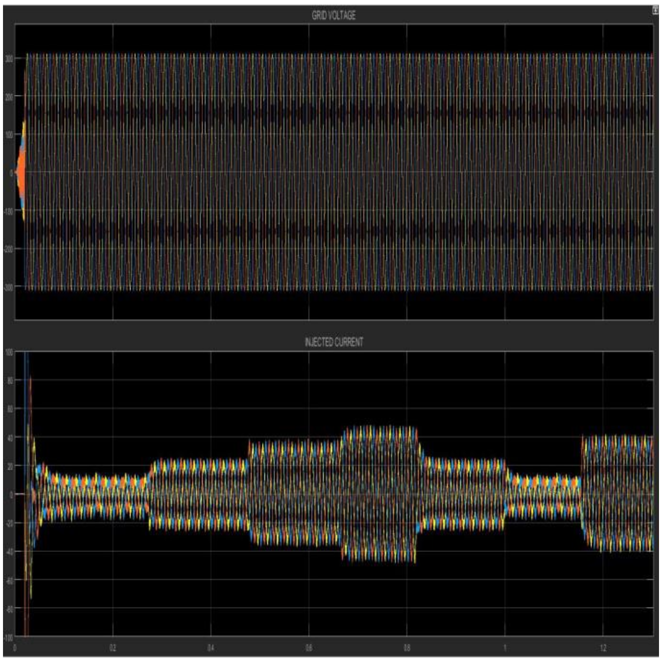

Figure 17: Variation of line voltage and line current with reference power

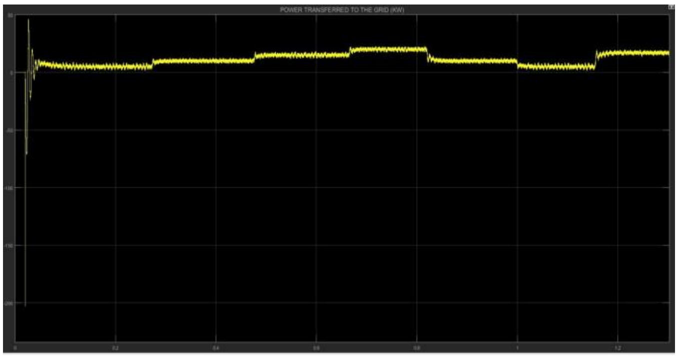

Figure 18: Reference Active power variation

The PV array is operating at $1200W/m^2$ at 25 degree Celsius. From t=0sec to t=2.8sec the reference power is 5KW as seen from the figure 18 for that the injected current in the grid is 10.2A while the line voltage is around 300 V. At t=2.8 second the reference power was increased to 10KW to deliver this power the current supplied to the grid is regulated to 20A which can be seen from the figure 17. At t=0.68 second the reference power was increased to 20KW, still the voltage is maintained at 300V while the current that is fed in the grid increased to a value 49A. From the model a fast and accurate control has been obtained. However, if the reference power is increased beyond the maximum power that the PV array can supply (in this case 23.02KW) the system becomes unstable.

3. CONCLUSIONS

Solar PV connected systems are continuously improving providing better efficiency with excellent transient response of the system. New pulse modulations techniques are being introduced which will improve the quality of power that is being injected into the grid. In the simulation (A) the maximum capacity of the PV array was 58KW at irradiation of 1097.26 W/m^2 and the output obtained was 55.49 KW with an efficiency of 0.95 per-unit. The power being delivered to the grid was 46.03 KW with an efficiency of 87%. The efficiency of the overall system can be improved by using other controls. In simulation (B) the response of the system was fast while maintaining the grid voltage constant and supplying the active power in an efficient way. The system was designed for 24.03 KW and it was supplying 23.9 KW. If the demanded power increased beyond the capacity the system will become unstable. The above modelling technique can be further extend to various types of controllers for achieving a better efficiency.

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[2] International Journal of Pure and Applied Mathematics Volume 119 No. 16 2018, 4547-4555 ISSN: 1314-3395 (on-line version) url: http://www.acadpubl.eu/hub/ Special Issue DC MICRO GRID USING BOOST CONVERTER WITH MAXIMUM POWER POINT TRACKING(MPPT) OF PERTURB AND OBSERVE METHIOD

[3] IJSTE - International Journal of Science Technology & Engineering | Volume 2 | Issue 10 | April 2016 ISSN (online): 2349-784X All rights reserved by www.ijste.org 824 Active Power Control in Grid Connected Photovoltaic System

[4] MODELING AND ANALYSIS OF A PV GRID-TIED SMART INVERTER'S SUPPORT FUNCTIONS A thesis presented to The Faculty of California State University