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Performance Analysis of a Grid Tie Voltage Source Inverter based Photovoltaic System

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Abstract— **Grid connected photovoltaic (PV) systems are most encouraging renewable energy solutions available today, as they give tremendous benefits to the end users and the utility network. Distributed PV generation in which sections of PV strings are connected to a common inverter is picking up speed on commercial front as it increases use of available floor space but still faces some technical hinderances like maintaining the DC voltage at common bus bar and design MPPT based of DC-DC converter during uncertainties of weather conditions. In this paper the load pattern and solar irradiations of an academic institute is considered. The main contribution of this paper is to analyze performance of the current control method used for grid connected inverter. Moreover, two separate configurations of a single 110kW PV system and 65-45kW distributed PV system studied and simulated in MATLAB/SIMULINK environment. It was observed that distributed PV systems give better output than a single PV system.**

Index Terms— **Current controller, Maximum power point tracker(MPPT), Photovoltaic Cell, Voltage source inverter**

I. INTRODUCTION

The continuously increasing energy requirement causes overloading of Electric Grid. Grid overloading arise problems such as outage, grid instability, power security, deterioration of power quality etc. To balance energy demand and generation, the renewable energy sources like photovoltaic (PV), wind and biogas which are readily available should be considered instead of conventional energy sources as these sources are environmentally friendly. Out of all these renewable sources solar is considered as one of the most useful source because it is relatively cheaper, abundant in nature and pollution free. As the generated voltage from the PV is dc we need to convert it into ac by using inverter before connecting it to grid. During grid connection voltage and frequency of inverter and grid should be equal to avoid instability.

Mathematical modeling of PV module is discussed in [1]-[4]. PV based power generation system have traditionally been used in two modes as standalone and grid tied mode is presented in [5]. Different controlling strategies for standalone photovoltaic and grid tied system have which are reported in [6]. In standalone PV system the frequency and voltage should be controlled and in grid tied mode PV system current is controlled as discussed in [7]. The current control strategy used in grid connected mode is presented in [8]. The standalone generation of energy is required for the places such as deserts, remote villages and all such places where direct access to the grid is not available. The standalone PV system power generation can be locally made to meet their load demand and if excess power is available it can be transferred to meet other loads through possible grid connection. Huge work has been done in standalone PV system and grid tied operation of PV system to meet requirements of residential loads and water pumping systems [9]. The grid tie inverter is controlled in grid connected mode as presented in [10]. In this paper an analysis of performance of grid tied PV system to meet distributed varying load conditions is presented. To extract maximum power from PV incremental conductance MPPT algorithm has been implemented [11]. The presented paper studies two (110kW & 65-45kW) photovoltaic grid connected systems. In grid connected mode PV system supplies the generated power to the distributed load and excess power to grid. The inverter is controlled by current controlled mode to deliver the predefined power to the grid. The case study is carried out on P. V. G's. C.O. E. T institute, in Pune city.

The paper has been organized as follows: Section II describes Modeling of PV module. Section III describes MPPT algorithm. Section IV describes Transformation from abc to dq0. Section V describes Inverter control. Section VI describes dynamic modeling and simulation results.

II. MODELLING OF PV SYSTEM

The building block of PV arrays is the solar cell, which is basically a p-n semiconductor junction, that directly converts light energy into electricity. Cells are grouped to form PV modules which are further interconnected in series and parallel configuration to form PV arrays. The equivalent circuit of the solar cell is shown in Fig. 1. It consists of a current source generating photo current which depends on the irradiation. Diode represents to the p-n transition area of the solar cell; series resistance represents the voltage losses and parallel resistance indicates the leakage current. The output current and voltage relationship for PV module can be expressed as follows: [1]-[3]

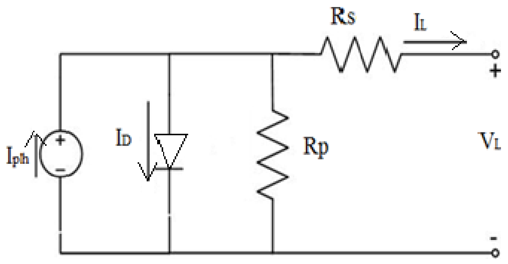

Fig.1. Equivalent circuit of solar cell

By using Kirchhoff's laws,

$$I_{ph} - I_D - I_P - I_L = 0$$

$$\text{i.e.} I_L = I_{ph} - I_D - I_P \quad (1)$$

$$\text{And } (V_D = V_P) = V_S + V_L$$

$$V_D = R_S I_L + V \quad (2)$$

Where, $I_P = \frac{V_P}{R_P} = \frac{V_D}{I_P}$

Put V_D from (2)

$$I_P = \frac{I_L R_S + V_L}{R_P} \quad (3)$$

The diode current can be expressed as, [3, 4]

$$I_D = I_{sat} \left(e^{(V_D/mN_S V_T)} - 1\right) \quad (4)$$

Where, $V_T = \frac{KT}{q}$, put V_T in (4)

$$I_D = I_D = I_{sat} \left(e^{(qV_D/mN_S KT)} - 1\right) \quad (5)$$

By substituting (3) and (5) in (1) then the load current can be written as,

$$I_L = I_{ph} - I_{sat} \left(e^{(qV_D/mN_S KT)} - 1\right) - \frac{I_L R_S + V_L}{R_P} \quad (6)$$

Where, I_{ph} is the photo current, I_D is the diode current of the PV cell, I_P is the shunt current and I_{sat} is the reverse saturation current. Ns is the number of cells connected in series, V_T is the thermal voltage and equals to 25.7V at 25 ºC (298K) and m is the ideal factor of the diode (1-5(V_T)). K is the Boltzmann constant (1.381×10-23 J/K) and q is the charge of the electron (1.6021×10-19C). R_S and R_P are the equivalent series and parallel resistance of the solar module, respectively.

Sun irradiance and temperature affect the value of I_{ph}. So the effect of these two factors can be shown as follows [2].

$$I_{ph} = [I_{sc} + \alpha_i (T-25)]\frac{G}{G_{ref}} \quad (7)$$

Where, I_{ph} is the photo current at standard tests condition (STC) (temperature= 25 ºC and irradiations= 1000 W/m^2). I_{sc} indicates nominal short circuit current of the module. G and G_{ref} denote the amount of actual and nominal irradiation, respectively. T is the temperature in Kelvin (K) and α_i is the current temperature coefficient. I_{sat} and I_{sc} can be obtained according to the following equations [1].

$$I_{SC} = I_{SC,\,ref}\left(\frac{R_P + R_S}{R_P}\right) \quad (8)$$

$$I_{sat} = \frac{I_{sc,ref} + \alpha_i (T-25)}{e^{q(V_{oc,ref} + \alpha_v (T-25))/N_S mKT}} \quad (9)$$

The $I_{sc,ref}$ is the short circuit current and $V_{oc,ref}$ is open circuit voltage of the module at STC, whereas, α_v is the open circuit voltage temperature coefficient. Normally these values are calculated by the manufacturer.

The output current of the module will be as follow:

$$I_L = [I_{sc} + \alpha_i (T-25)\frac{G}{G_{ref}} - I_{sat}\left(e^{(qV_D/mN_S KT)} - 1\right) - \frac{I_L R_S + V_L}{R_P} \quad (10)$$

III. MPPT ALGORITHUM

MPPT (Maximum power point tracking) is a technique used to obtain the maximum possible power from a varying source. In this proposed work incremental conductance method is used to track the maximum power point. At slope of power vs. voltage curve will be zero at the maximum power point, on this principle the algorithm works to track the maximum power point. dP/dV = 0 indicates the maximum power point (MPP) is reached. dP/dV>0 indicates that the slope of the power vs. voltage is positive so the MPP point is to the right of the current operating point. dP/dV< 0 indicates that the slope of the curve is negative and MPP point is to the left of the current operating point.

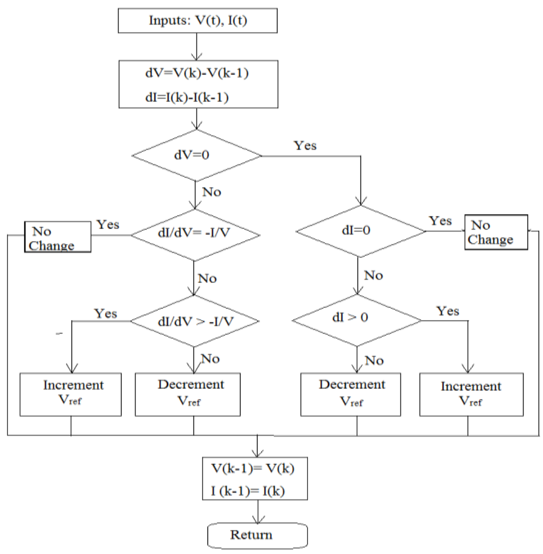

Fig.2. Incremental Conductance algorithm

The instantaneous values of conductance (-I/V) are compared with incremental conductance (dI/dV) in this method. The position of the operating point of solar panel is decided by the algorithm based on comparison.

IV. INVERTER CONTROL

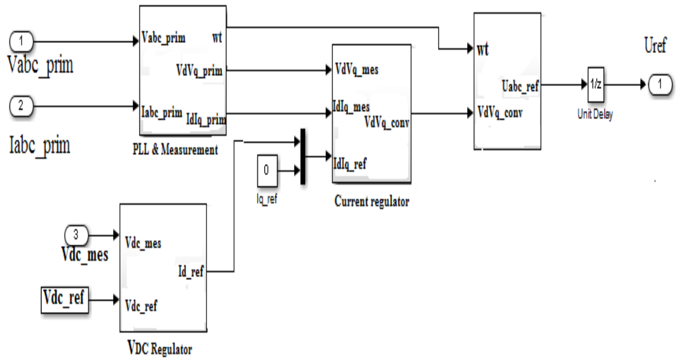

Fig.3. Current control scheme

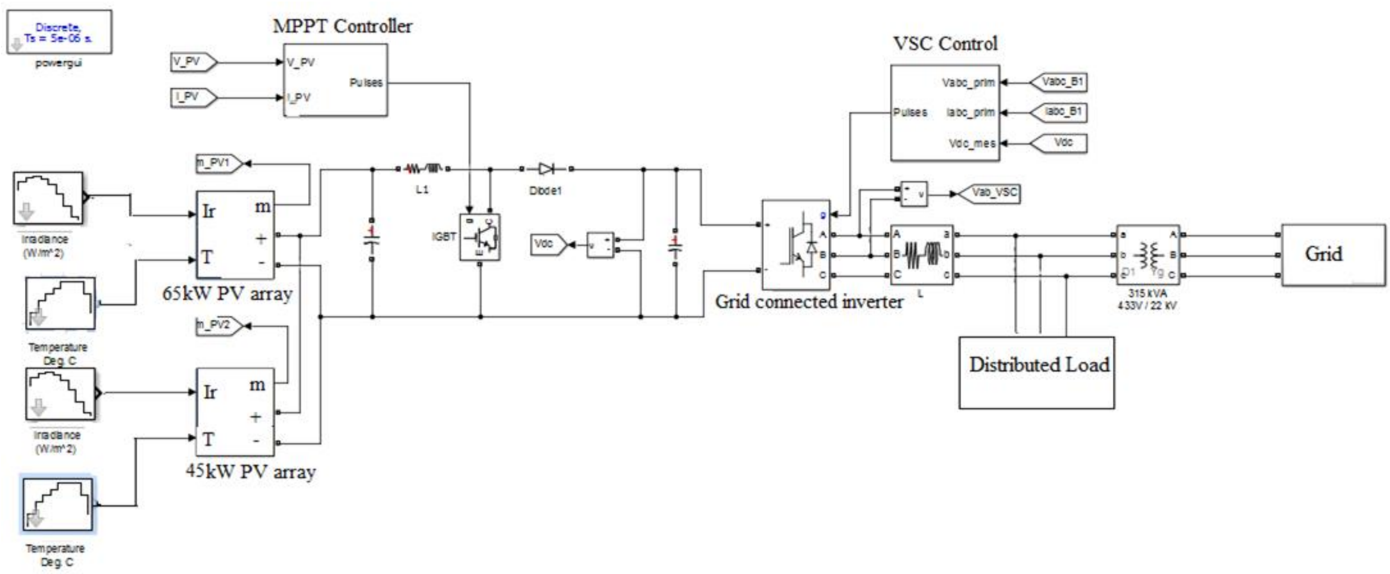

Fig.4. 110kW grid connected PV system

The current control scheme is used to supply constant current output [8]. The switching action of the inverter is monitored by the controlling action of controller. The inputs to controller are the instantaneous value of dc-link voltage, three phase grid-voltage and grid-current. The dc link voltage is given to the voltage regulator to generate the reference current signal. A PLL is used to gain the reference angle and frequency of the point of common coupling PCC. [10] The system is designed to synchronous rotating frame to reduce the complications in design and its operation. The output currents from the filter are transformed into synchronous frame by park's transformation and are regulated in dc quantities. The regulated dc quantity is compared with the reference current to generate a current error which is passed to the PI controller to generate the voltage references for the inverter. The voltage references in dc quantities are transformed into stationary frame by using the inverse park's transformation. Further these stationary frame voltages are utilized to calculate pulse width of each bridge arm of the inverter [12].

V. DYNAMIC MODELLING AND SIMULATION

A. Simulation Model

The PV array is used as a direct current source and connected to the grid via DC/DC boost converter, a three-phase inverter, filter and a three-phase transformer. The distributed load of total 200kW is considered and is controlled with the help of circuit breaker. The inputs as irradiation and temperature to PV array are also varied. The two systems are considered in study, first is 110kW grid tie PV system is shown in Fig. 4 and second is distributed 65 kW and 45kW grid tie PV system as shown in Fig. 5. Both the PV system arrays are provided with the same irradiation and temperature variation.

B. Simulation Result and discussion

Simulation results are modeled and simulated in MATLAB/SIMULINK^R platform. Practically on site measured irradiation and temperature readings are provided as input to the PV arrays and its output varies according to variation in irradiation and temperature. The load pattern considered in the simulation is the actual load of an educational institute under study.

System I: 110kW Grid connected PV Array system.

The simulation considered from 9am to 6pm time slot is shown in Fig 6. The dynamic distributed load of 200kW is considered. Three different time instants cases are considered in study are as follows;

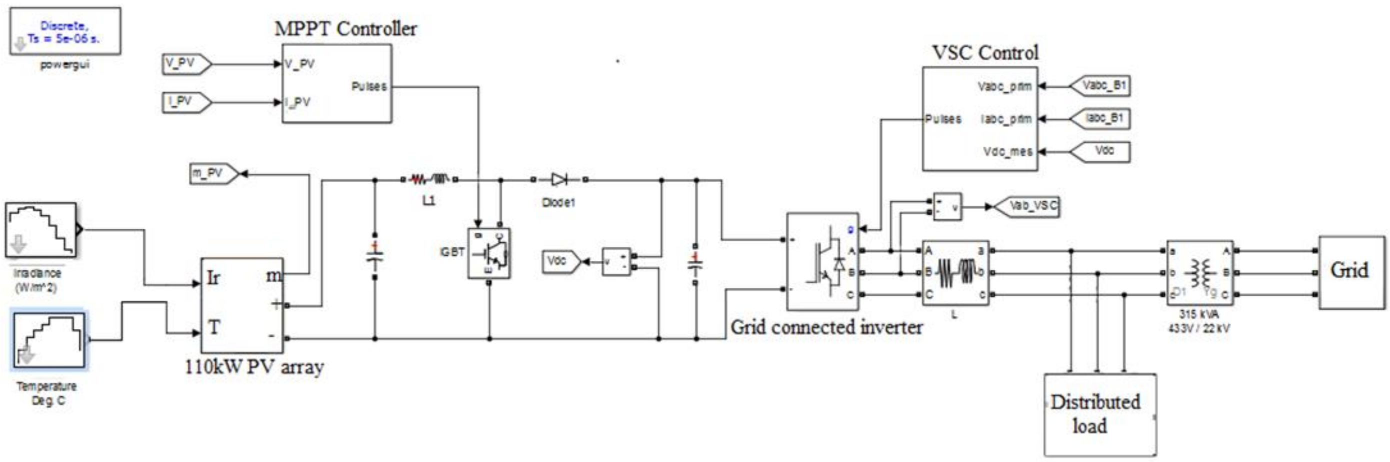

Fig.5. 65-45kW Grid connected PV system

Case 1: Initially PV is not contributing due to less irradiation and entire power is supplied by the grid as per load requirement. As irradiation and temperature varies accordingly the solar output also varies. From 9a.m to 12p.m the load is 50kW and PV starts contributing gradually and its generation increases to 62kW. The irradiation from 9am to 10am is 655W/m^2, and the output of PV at this irradiation is 62kW. Hence the power generated by the solar is greater than the load demand. The surplus 10kW generation by PV is given to grid out of 12kW and remaining 2kW loss takes place in the inverter and filter.

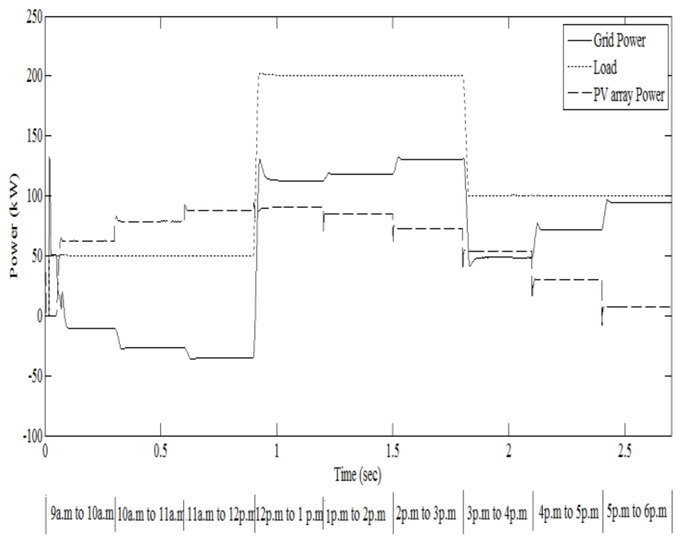

Fig.6. Power flow scenario for Grid connected 110kW PV array.

From 10am to 11am the irradiation is 825W/ m^2, for which the PV output is 78kW, where 28kW is the surplus. The 26kW is given to grid and remaining 2kW is loss. From 11am to 12pm the irradiation is 920W/m^2, for which the PV output is 87kW, the surplus generation is 37kW out of which 35kW is given to grid and remaining 2kW is loss.

Case 2: From 12p.m to 3p.m the load requirement is 200kW, i.e. all distributed loads are considered. The solar irradiation during 12p.m to 1pm increases to 945W/m^2 and PV generation is 90kW. Here the PV generation is less than the load demand, so the remaining power required by the load of 112kW (including losses) is feed by the grid. From 1pm to 2pm the irradiation varies to 890W/m^2, for which the PV output is 84kW.The load requirement of 118kW is fulfilled by grid. From 2pm to 3pm the irradiation is 765W/m^2, for which the PV output is 72kW and remaining load requirement of 130kW including losses is feed by grid.

Case 3: From 3p.m to 6p.m the load requirement is 100kW i.e. one of the distributed load is cut off using circuit breaker. The irradiation during 3p.m to 4p.m decreases to 572W/m^2. The PV system output during this period is 53kW, which is not sufficient as the total load is 100kW. So remaining power of 48kW (including losses) is supplied by the grid. From 4pm to 5pm the irradiation is 335W/m^2, and PV output is 30kW and remaining power requirement of 71kW (including losses) is feed by grid. From 5pm to 6pm the irradiation is 100W/m^2, for which the PV output is 7kW and remaining load requirement of 94kW (including losses) is feed by grid.

System II: 65KW and 45kW Grid-Connected PV Array

The time instants are same as discussed in system-I. The simulation result is shown in Fig. 7, starts from t = 0s to 2.7s. The load of 50 kW is considered up to 0.9s then 200kW up to 1.8s and finally 100kW up to 2.7s. Three different time instants cases are considered in study are as follows;

Case1. Initially PV is not contributing, from 9a.m to 12p.m the load is 50kW and PV starts contributing gradually and its generation increases to 64kW. The irradiation from 9am to 10am is 655W/m^2, and the output of PV at this irradiation is 64kW. Hence the power generated by the solar is greater than the load demand. The surplus 12kW generation by PV is given to grid out of 14kW and remaining 2kW loss takes place in the inverter and filter. From 10am to 11am the irradiation is 825W/ m^2, for which the PV output is 81kW, where 31kW is the surplus. The 29kW is given to grid and remaining 2kW is loss. From 11am to 12pm the irradiation is 920W/m^2, for which the PV output is 91kW, the surplus generation is 41kW out of which 39kW is given to grid and remaining 2kW is loss.

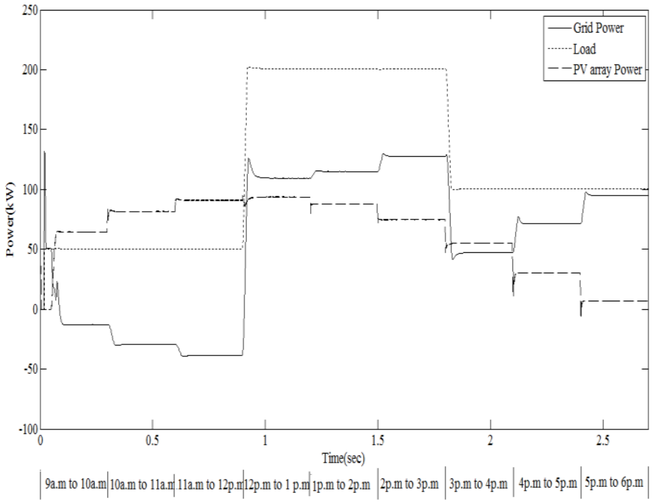

Fig.7. Power flow scenario for Grid connected 65-45kW PV array

Case 2: From 12p.m to 3p.m the load requirement is 200kW. The solar irradiation during 12p.m to 1pm increases to 945W/m^2 and PV generation is 93kW. Here the PV generation is less than the load demand, so the remaining power required by the load of 109kW (including losses) is feed by the grid. From 1pm to 2pm the irradiation varies to 890W/m^2, for which the PV output is 87kW.The load requirement of 115kW is fulfilled by grid. From 2pm to 3pm the irradiation is 765W/m^2, for which the PV output is 74kW and remaining load requirement of 127kW including losses is feed by grid.

Case 3: From 3p.m to 6p.m the load requirement is 100kW. The irradiation during 3p.m to 4p.m decreases to 572W/m^2. The PV system output during this period is 55kW, which is not sufficient as the total load is 100kW. So remaining power of 47kW (including losses) is supplied by the grid. From 4pm to 5pm the irradiation is 335W/m^2, and PV output is 30kW and remaining power requirement of 71kW (including losses) is feed by grid. From 5pm to 6pm the irradiation is 100W/m^2, for which the PV output is 6kW and remaining load requirement of 95kW (including losses) is feed by grid.

C. Comparison between the output of 110kW PV array and output of combined 65kW and 45kW PV array.

It is observed that for the simulation time 0 to 1sec the output power as shown in Fig. 8, the combined 65kW and 45kW PV system is greater than a single 110kW PV system if compared for same irradiation and temperature values.

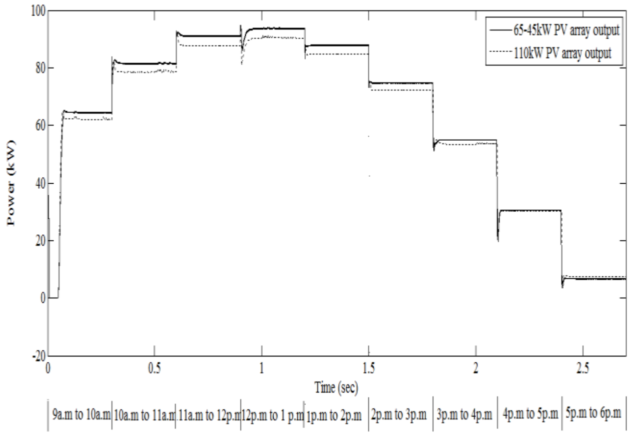

Fig.8. Output power of 110kW PV system and 65kW & 45kW PV system

The FFT analysis of the grid current as a frequency spectrum is shown in Fig. 9.

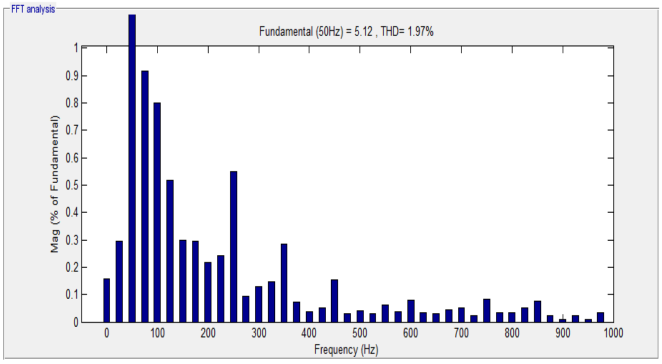

Fig.9. FFT Analysis of Current at PCC

The THD of grid current is calculated for the starting time of 1.5sec of the waveform. It is calculated for the two cycles from the starting time. As the frequency of the waveform is 50Hz so the fundamental frequency selected is 50Hz. The FFT analysis of output current of inverter shows that THD is within limit and obtained simulation results is 1.97%.

VI. Conclusion

The presented model simulates 110kW and 65kW-45kW photovoltaic system in grid tie operation. Incremental conductance MPPT algorithm is used to extract maximum power from PV array for varying irradiation and temperature. This algorithm is considered as it tracks maximum power from PV array for varying irradiation and temperature faster than perturb and observe method. Inverter used operates in current control mode to feed active power to grid using synchronous d-q transformation. The practical varying irradiation and temperature are provided to PV array so that its output in the simulation is nearby to the practical output. Practical load reading on working day of educational institute under study is considered in the simulation. When load demand is less than the PV generation then surplus power is given to grid and when load demand is greater than the PV array generation then remaining power required by load is fulfilled by grid. The comparison study of 110kW and 65kW-45kW PV array system output shows that the output of 65kW-45kW PV system output is greater than 110kW PV system for same irradiation and temperature.

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