SOLAR PHOTOVOLTAIC SYSTEM INTEGRATION WITH GRID USING NPC INVERTER

RAVI PATEL[1], APURVA TATU[2]
[1]PG Scholar, [2]Lecturer
[1]Electrical Department
LDRP-ITR, Gandhinagar, Gujarat, India

Abstract: In this paper modelling, simulation and control of grid tie PV system using multilevel inverter are described. A 20kW PV system is integrated to grid using 3 level neutral point clamped (NPC) voltage source inverter (VSI). An mppt control is implemented using incremental conductance (INC) method is employed to control boost converter. A closed loop control method is used to inject power into the grid using multilevel inverter. DC link voltage control and current control is implemented for controlling multilevel inverter. The resulting system can extract maximum power from the PV system under different operating conditions. The capacitor voltage balance across the inverter is achieved using SVPWM technique. Control of proposed system is based on synchronous reference frame control algorithm and hysteresis band current control. The effectiveness of proposed system is shown using MATLAB simulation results.

INRODUCTION

Due to increasing power demand many new alternatives of power generation are used effectively. Out of all these photovoltaic generation is effective and can easily be implemented. The power from the PV system have different outputs depending on the condition of temperature and irradiance. To extract maximum power from PV array different MPPT algorithms are available such as, perturb and observe (P&O), incremental conductance (INC) and many more. Out of all these INC have some advantages and commonly implemented in many PV applications. This mppt controller is used to extract maximum power under all the irradiance conditions using boost converter. The output of PV system serves as DC link for the inverter. A power controlling method is employed to synchronize the PV system with grid.

Generally, there are 2 main power stages in a grid tie PV system. First is DC link voltage control stage that maintains constant DC link voltage across inverter input and second stage consist of inverter current control that controls the current injected into the grid. Current control can be employed in many reference frames such as, stationary reference frame (α-β), synchronous reference frame (d-q) and natural reference frame (a-b-c). In the proposed system synchronous reference frame is employed using proportional integral (PI) controller.

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.

The PV Array is characterised based on the I-V and P-V characteristic. As we can see from Fig.2 and Fig. 3, the variation in irradiation result variation in 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 as shown in Fig. 4 and Fig. 5. So same observation we can made from the below graphs of I-V and P-V characteristics at different irradiation and temperature level.

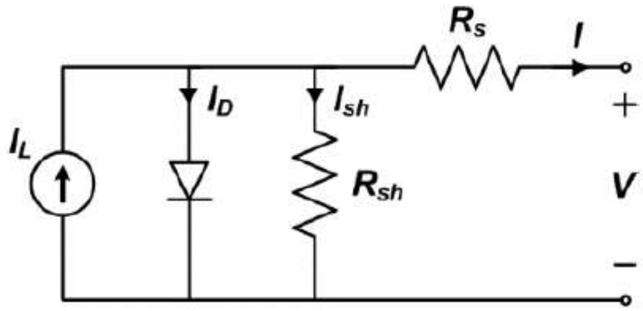

Figure 1: Equivalent circuit of PV cell

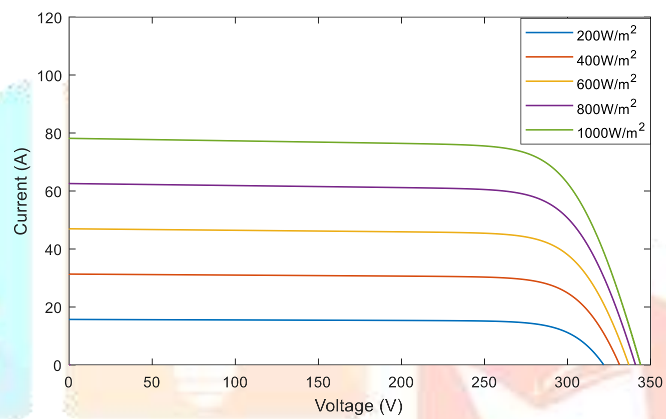

Figure 2: I-V characteristics of 20kW PV Array at different irradiation levels

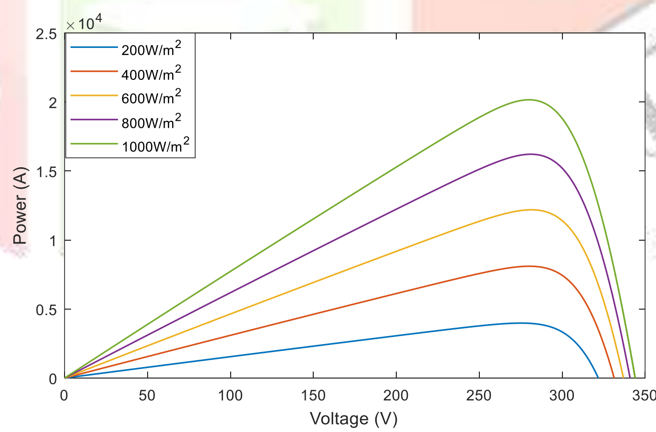

Figure 3: P-V characteristics of 20kW PV Array at different irradiation levels

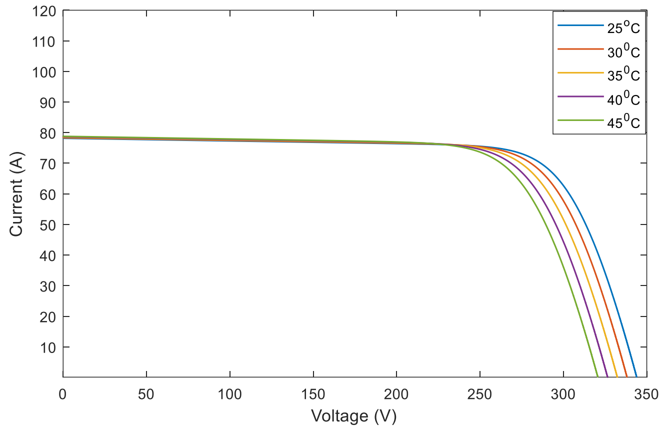

Figure 4: I-V characteristics of 20kW PV Array at different temperature levels

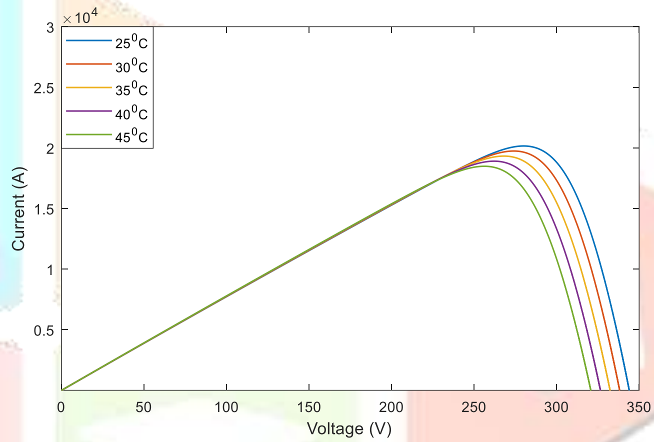

Figure 5: P-V characteristics of 20kW PV Array at different temperature levels

MAXIMUM POWER POINT TRACKING AND BOOST CONVERTER

INC MPPT is used along with boost converter to boost dc voltage to the required DC link voltage. An mppt control algorithm for INC is designed in MATLAB embedded function. The control of the switch used in boost converter is provided by the duty cycle generated using algorithm. Switching frequency of PWM generator is 20kHz. Fig. 7 shows the INC algorithm and Fig. 6 shows the design of boost converter.

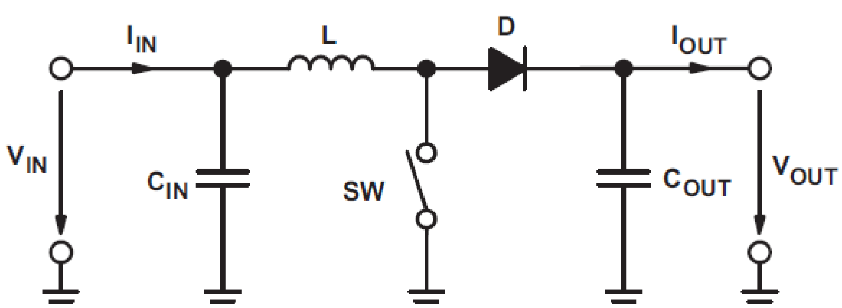

Figure 6: Boost Converter

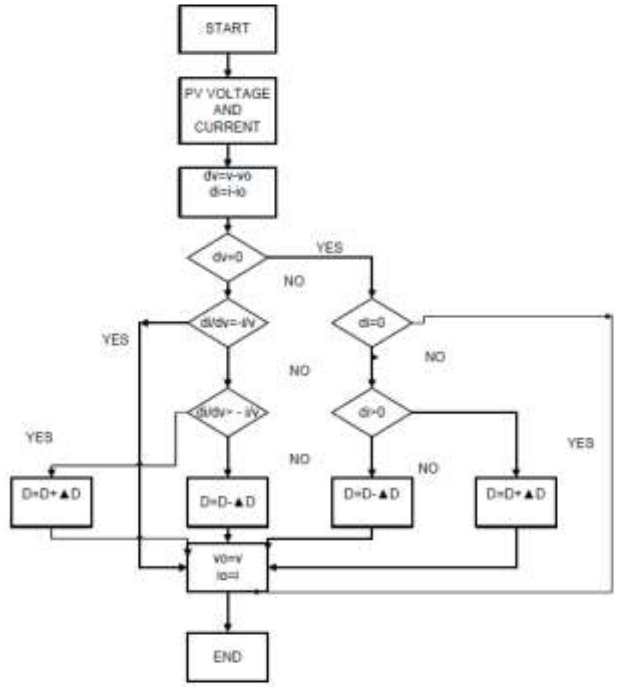

Figure 7: Incremental Conductance Algorithm

NEUTRAL POINT CLAMPED INVERTER

Fig. 8 shows the circuit configuration of the NPC inverter. Each leg has four IGBTs connected in series. The applied voltage on the IGBT is one-half that of the conventional two-level inverter. The bus voltage is split in two by the connection of equal series connected bus capacitors. Each leg is completed by the addition of two clamp diodes. This topology traditionally has been used for medium voltage drives both in industrial and other applications. In addition to the capability of handling higher voltages, the NPC inverter has several favourable features including lower line-to-line and common-mode voltage steps and lower output current ripple for the same switching frequency as that used in a two-level inverter.

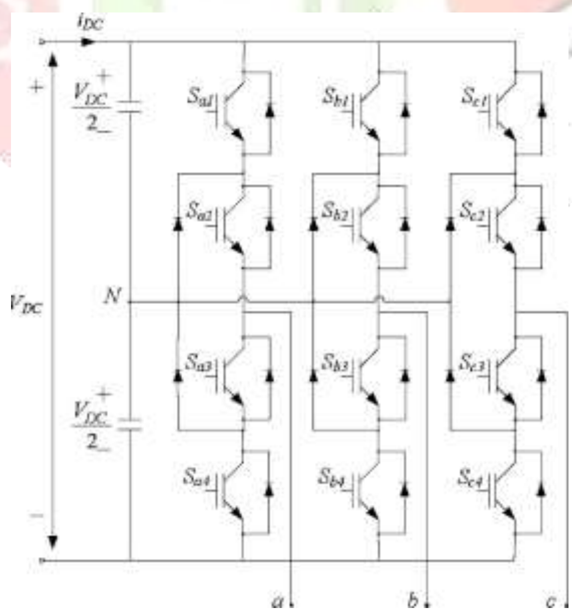

Figure 8: Three phase Three level NPC VSI [3]

CONTROL SYSTEM

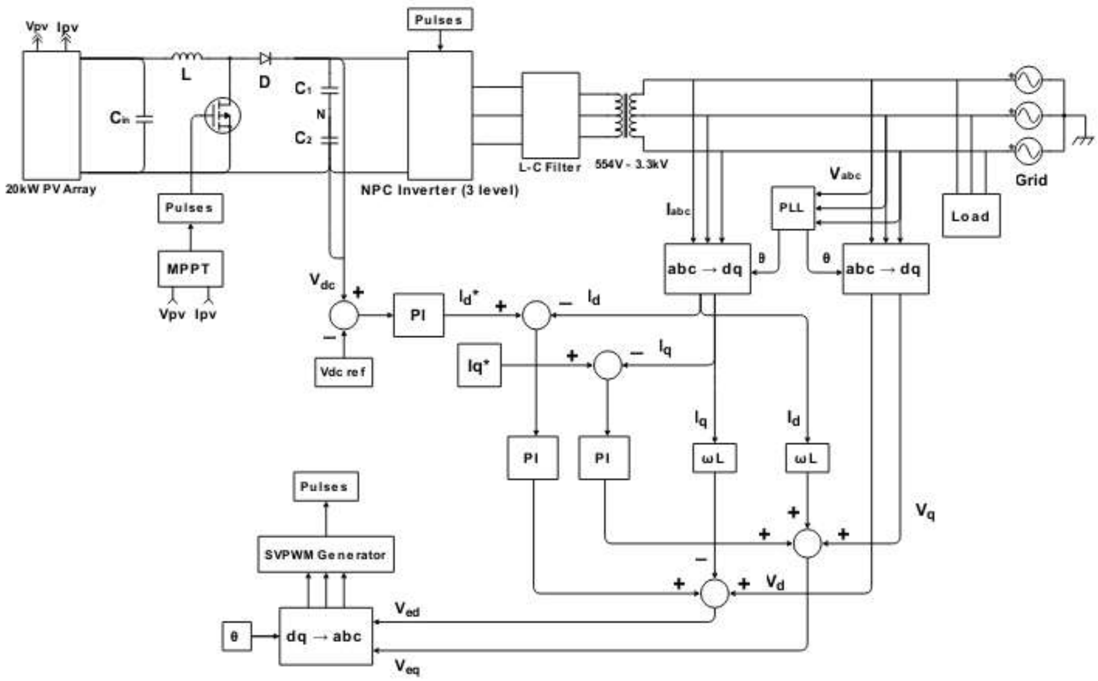

Figure 8: Control Block diagram of Grid tie PV System

Fig. 8 shows the complete block diagram of grid tie PV system using multilevel inverter. The boost converter is used to boost the DC voltage supplied by the PV system to the DC link voltage required at the input of the multilevel inverter. PWM strategy is used to control the pulses required for the switching purpose. The inverter control consists of two loops: (a) voltage control loop and (b) current control loop. The voltage control loop is used to control the DC link voltage at the input side of inverter. These control loop is used maintain the constant DC voltage. The current control loop is used to control the current injected into the grid. PLL is used to get the frequency and phase angle synchronization. Synchronous reference frame is used to convert the three phase AC parameters into (d-q) parameters. Synchronous reference frame parameters are controlled using PI controller.

As shown in Fig. 8 voltage and current from the grid are converted into d-q reference frame using PLL. Further these d-q components are compared with the reference values obtain by comparing the DC voltage and error signal is generated. In the proposed system active power is controlled where as reactive power control is not implemented. The error signal generated is then forwarded to feed forward control loop, which controls the current more precisely. Finally, the output of the feed forward loop is converted back to abc reference frame. SVPWM generator is used to provide the required pulses for the three-level NPC VSI. Any changes in the system parameters will produce equivalent results.

The differential equation for the system described at PCC in Fig. 8 is given as,

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = R \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} V_{ga} \\ V_{gb} \\ V_{gc} \end{bmatrix} + L\frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (1)$$

On further differentiating and rearranging the final equations for feed forward loop is given as,

$$V_{ed} = V_{cd} + Ri_d + L\frac{di_d}{dt} - wLi_q \quad (2)$$

$$V_{eq} = V_{cq} + Ri_q + L\frac{di_q}{dt} + wLi_d \quad (3)$$

SIMULATION RESULTS

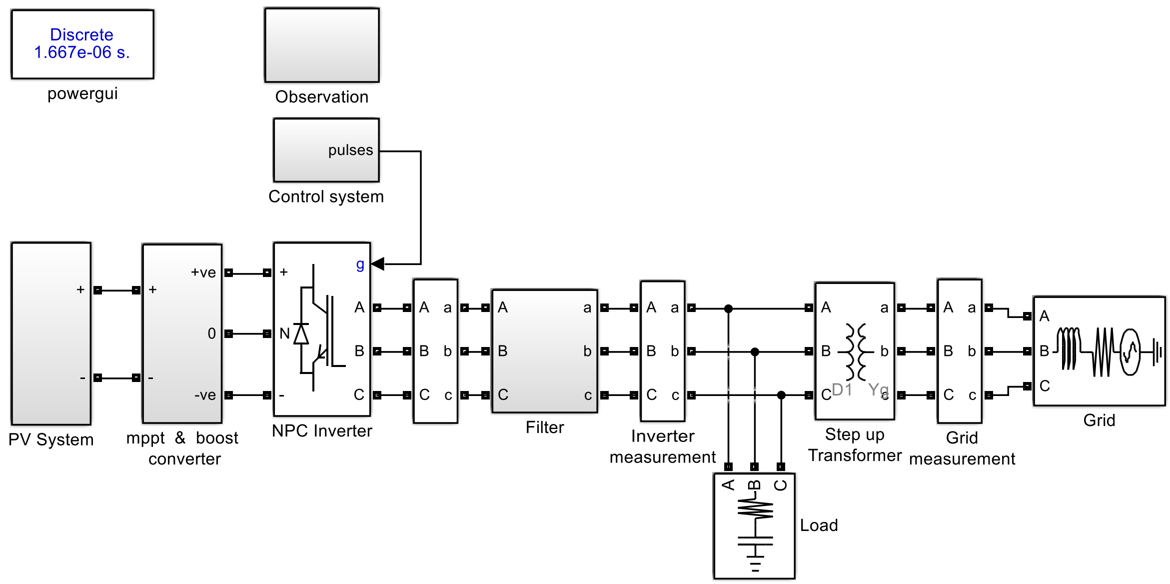

Figure 9: Grid tie PV array using Multilevel Inverter

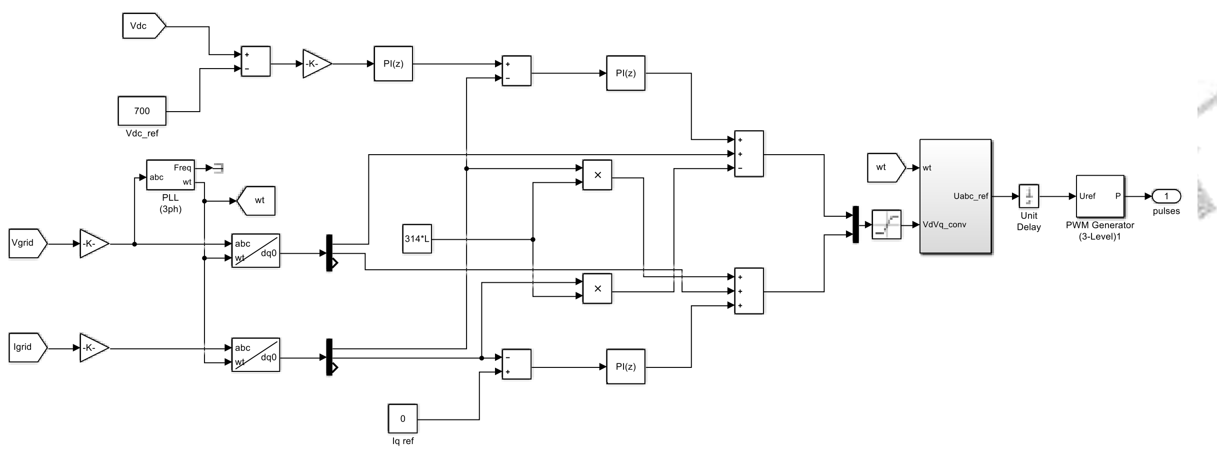

Figure 10: Feed forward control loop

Fig. 9 shows the MATLAB based schematic diagram of grid tie PV array using multilevel inverter. It also shows the transformer modelling for the grid tie PV system. Fig. 10 shows the inner current control loop using feed forward method. The output pulses of the feed forward loop is processed by SVPWM block which further provides signal to the PWM generator block. 2kHz switching frequency is used for generating pulses for inverter control. A 3.3kV (rms) grid is synchronized with 20kW PV array using a step-up transformer. Fig. 11 shows the three level voltage pulses of the inverter compared with the grid voltage which shows perfect synchronization of the system. Fig. 12 shows the inverter three phase voltage and current waveform before filter. Fig. 13 shows the three phase voltage and current waveforms after the L-C filter. Fig. 13 shows the THD analysis of the inverter current having THD less than 5% as per standard norms.

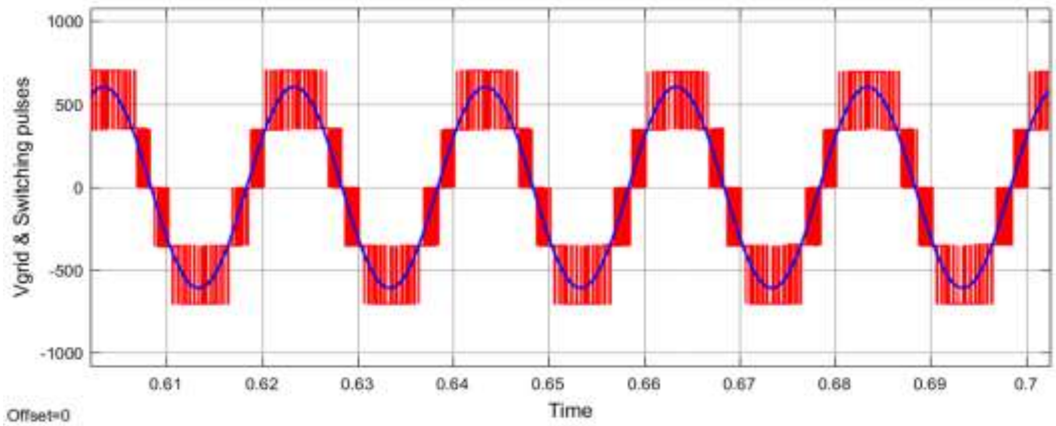

Figure 10: Feed forward control loop

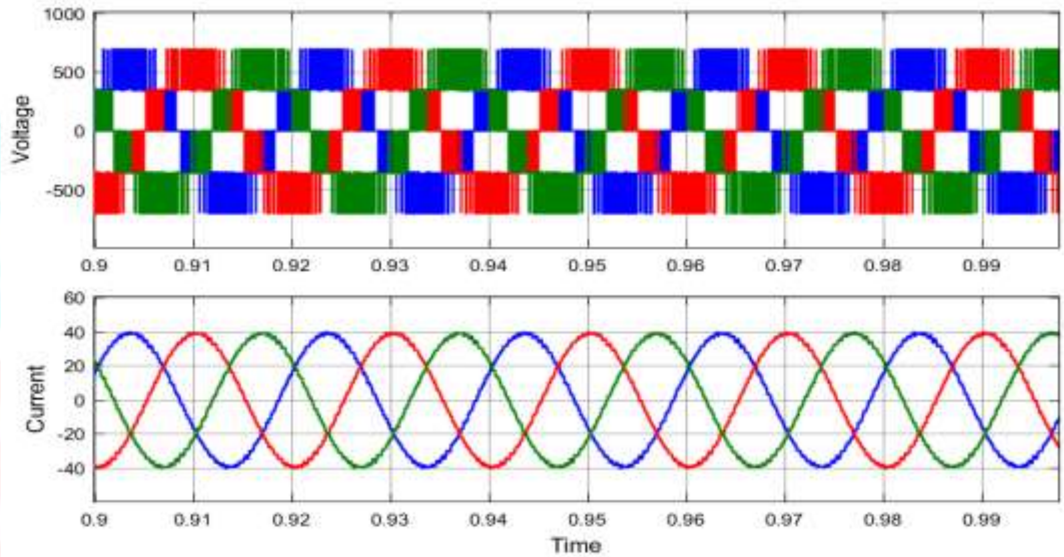

Figure 11: Three phase inverter voltage and current waveforms (before filter)

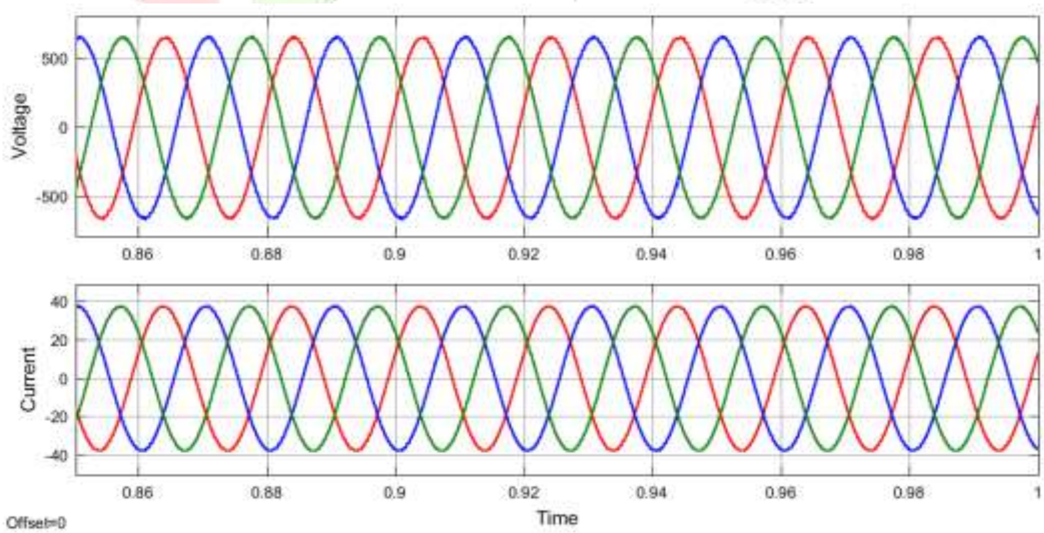

Figure 12: Three phase inverter voltage and current waveforms (after filter)

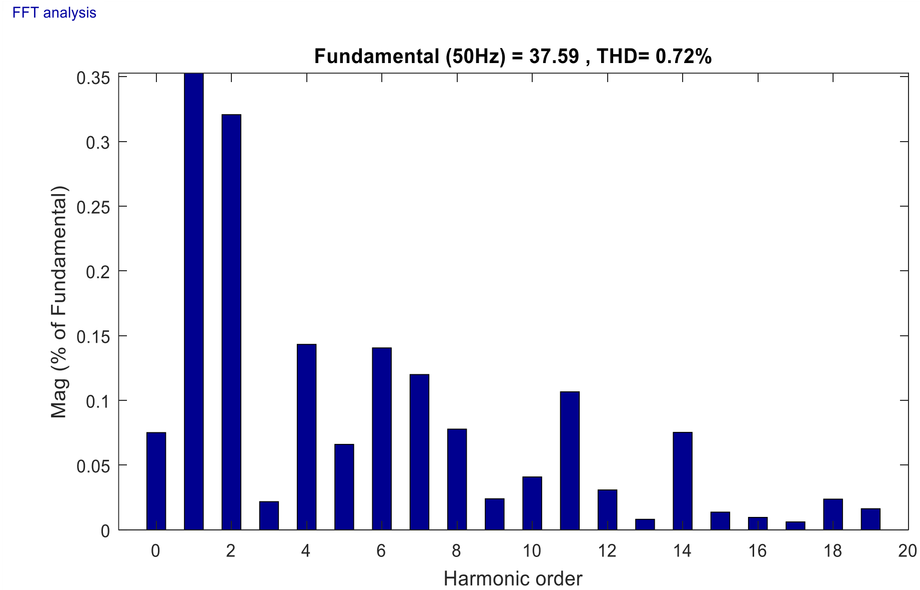

Figure 13: THD analysis of the current waveform at 2kHz switching frequency

CONCLUSION

As shown in the graph 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. To achieve maximum power point, we can control the current or regulate the voltage to maintain the power. In the proposed system, MPPT regulates the duty cycle to maintain voltage and achieve maximum power. Grid connected inverter control strategy is successfully implemented using the hybrid strategy of VSI. As shown in the proposed strategy voltage control using feed forward control is implemented to control the triggering pulses of the inverter. The Inverter is controlled in order to feed active power to the grid, using synchronous d-q transformation. PLL is used to lock grid frequency and phase. The phase detection part of PLL is properly done by using *dq* transformation in the three-phase system. The FFT analysis of the inverter output current shows that the THD is within limits and the controlled injected current generates three phase balance current which controls power at the output of the transformer. Grid connected PV array design is carried out using multilevel inverter and a step-up transformer. PV array is designed to provide 20kW power, so inverter is designed accordingly. The proposed control strategy can be used with any topology and converters to get the satisfactory results.

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