Active and Reactive power Control of Grid-Connected PV System Using Cascaded H-bridge Multilevel Inverter

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Abstract - This paper proposes a framework that directs the genuine and responsive power for a serial H-bridge multiple level solar based (PV) inverters for Three-Phase Grid-Connected. A MPPT system is actualized to remove most maximum power from solar panel. The real and reactive power is consecutively compensated by consumer angle and by electrical converter output voltage extreme. The new real and reactive power management theme conferred depends on d-q transformation. The d-axis current id* control the active power and the q-axis current iq* control the reactive power within the rotating frame. Reactive power amount defines the angle phase between the grid current and also the grid voltage, the AC reference current generated at the output of complement dq conversion are used for the inverter output current compensation. By using the simulation results we can analyse the proposed method in MATLAB/Simulink.

Keywords: Grid Connected Three- Phase PV Inverter, Active and Reactive power control, PLL, MPPT, d-q transformation

I. INRODUCTION

These days, petroleum derivatives are winding up progressively costly because of their broad use in different fields. Therefore, renewable sources like sun, wind, hydro based power are picking up significance step by step[1]. Photovoltaic generation frameworks, have expanded in the most recent decades because of need of providing the world ascent interest for electric power since its preferences, for example, diminishment in the expenses of the PV boards, its operation does not pollute the environment and ability to supply AC loads and control of responsive power beginning from straight and non-direct loads, as per the lattice request (dispersed generation framework).The power available from PV is DC and voltage available as a fluctuating quantity which require AC converter to stabilize the fluctuations[3] . To extract more amount of power from solar panels there are individual MPPT methods such as perturb-and-observe (P&O) incremental and conductance, constant voltage.

Recently multilevel inverters are mainly used for integration of PV structure into grid. As they have advantage of lower distortion in voltage signal and voltage magnitude is increased[5]. A cascaded multiple level inverter is used in this paper to convert dc voltage into three level ac voltages through which we can maintain equal frequency and phase with grid. PWM modulation technique used for Cascaded–H –bridge inverter is phase opposition and disposition for implementing switching pulses in this work[6-7]. Control system for real and reactive is developed with the change of the reactive power command during the normal operation mode has no effect on the injection of the real power to grid to provide quality of power to the end user customer. The inverter should not be limited to inject the active power into the grid; quite it must have the capability to contribute in the voltage regulation and establishing the support of the grid through providing reactive power control as an ancillary service [8], injecting the reactive power if there is a lack, or absorbing the reactive power if there must surplus into the grid. Change in reactive power commend according grid demand will not affect the real power and the proposed system is based on synchronous reference frame (SRF-PLL)for grid synchronization .A current control technique is used to control the output current of inverter[10].The predictive current control techniques, is developed, as it is simple for implementation and very fast and accurate compared to other techniques. A three phase R load is attached between PV array and the grid with an inductor filter at the output side of the multiple level electrical converter to attenuate high frequency harmonics and stop them from moving into the power system grid[12].

II. PHOTOVOLTAIC PANEL MODELING

The modelling of PV panel is used to describe and predict its characteristics. Photo-voltaic cell are connected serial to produce larger output voltage and combined in parallel for larger output current .A module is combination of no of solar cells connected serial and parallel [2].

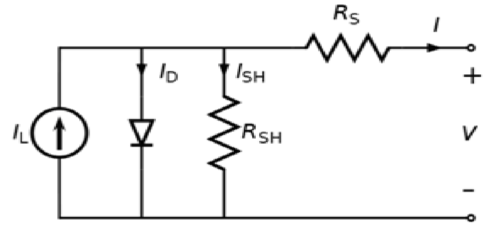

Fig.2.1 Equivalent Circuit of a Solar Cell

Therefore a specific PV array is combination of many PV module connected serial and parallel. Equivalent circuit includes a current supply (photocurrent), a diode parallel to that, a resistance serial describing an enclosed resistance to the flow of current and a shunt resistance that expresses aoutflow current as shown in fig2.1. Total current provided to the load is given as.

$$I = IL - Ioexp\left\{\left[\frac{q(V+IRs)}{a}\right] - 1\right\} - \frac{V+IRs}{Rsh} \qquad (2.1)$$

Solar Cell I-V graph curves are normally a graphical manner of the operation of a sun light intensity based PV array or structure. The current to voltage graphs of an electrical device is non-linear, light& temperature plays a vital role in predicting the I-V graphs and whereas designing the PV system. In fig 2.2,I-V and P-V characteristics are plotted for different irradiance with constant temperature (25 ℃) and different temperature at constant light (1000 W/m^2) in fig 2.3.

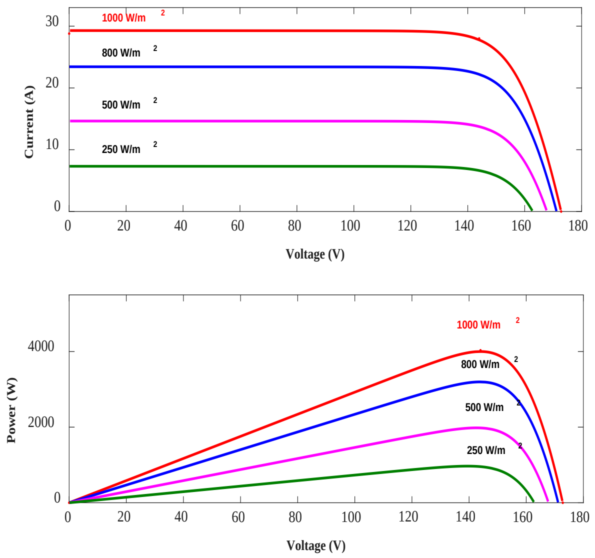

Fig.2.2PV array I-V and P-V characteristics with constant temperatureand with different irradiance

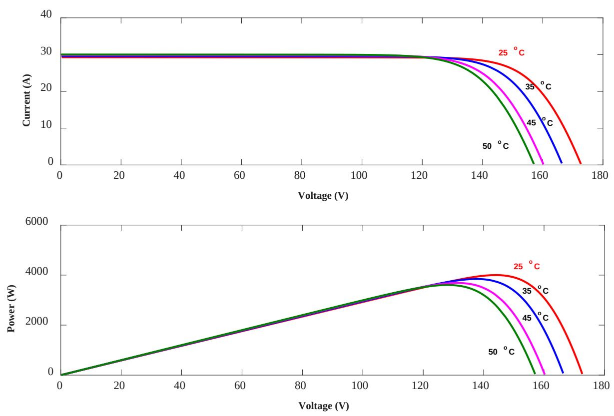

Fig.2.3 PV array I-V and P-V characteristics withdifferent temperature and constant light intensity (1000 W/m^2)

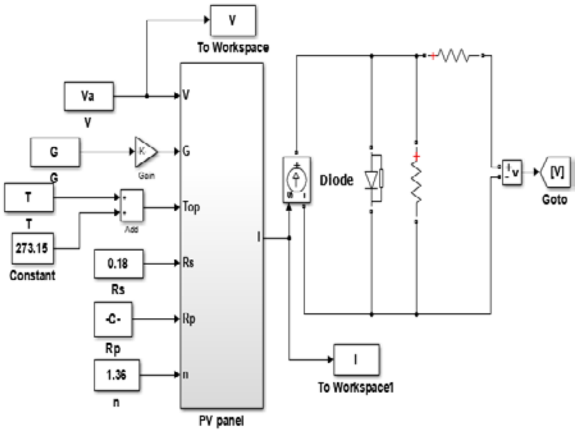

Fig.2.4 Simulink model of PV array in MATLAB/Simulink

PV array is designed in MATLAB/Simulation with eight modules in series and parallel as presented in fig 2.4 and the parameters utilising in implementing the MATLAB/Simulink for the Photovoltaic array is tabled below.

TABLE.2 parameters for PV array

Parameters of PV array	**Values**
No of module inparallel	8
No of module in series	8
Maximum voltage V_{max}	176V
Maximum power P_{max}	4KW
Maximum current I_{max}	30A
Electron charge(q)	1.6 × 10-19 C
Boltzmann constant (K)	1.3805×10^{-23} J/K
Ideality factor (n)	1.12

III. MAXIMUM POWER POINT TRACKING

Perturb and observe (P&O) technique uses current and voltage sensors to measure the output of a solar array and it is easy for implementation cost and operation. In this algorithm in fig 3.1after one perturbs operation the current power is measured and related with previous value to determine the change of power .By increasing the voltage of a cell increases the power output of a cell, then the system increases the operating voltage until the power outside begins to decrease[4]. This process is continues repeated until the MPP is reached.MPPT block designed in MATLAB/Simulink is shown in fig 3.2

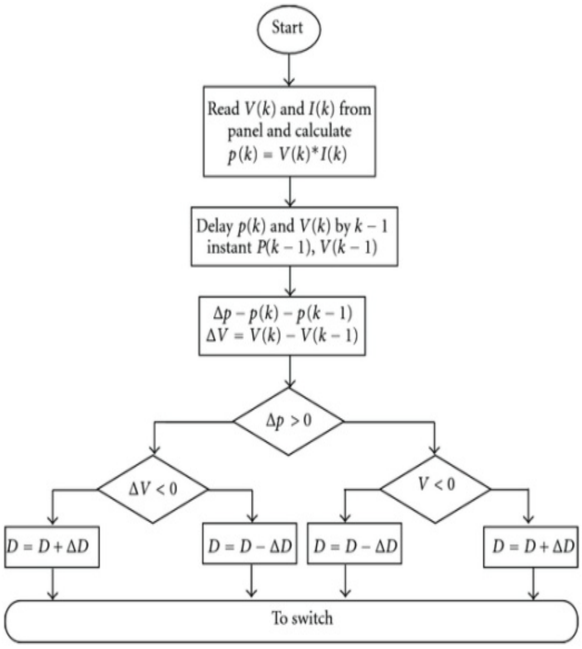

Fig.3.1 Flow chart of P&O algorithm

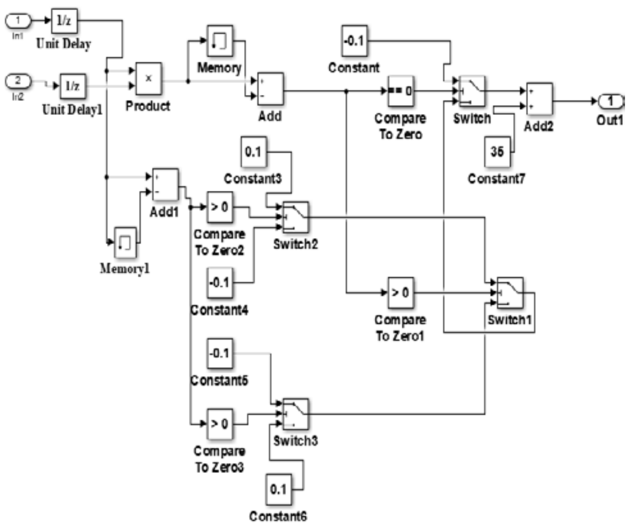

Fig.3.2 Simulink block of MPPT (P&O)

IV. CASCADED H-BRIDGE FIVE LEVEL MULTI LEVEL INVERTER

Cascaded multiple level inverters are the main important topologies in the family of multilevel. The series connected methodology allows the importance of somelevels of DC voltages to synthesize a required AC voltage. The DC levels from fuel cells or photovoltaic, batteries are should be identical .It needslow number of components related to diode-clamped and flying capacitors multilevelinverters-bridge cells are connected to every phase such that the output terminal is connected to other cell. Two output terminals of the uppermost H-bridge cell one is connected to the load and other one is connected to lower H-bridge cell. Similarly, in case of lower H-bridge cell where one output terminal is connected to upper cell and other terminal is connected to neutral point. Same for other two phases, suchconnection is known as cascading [6].

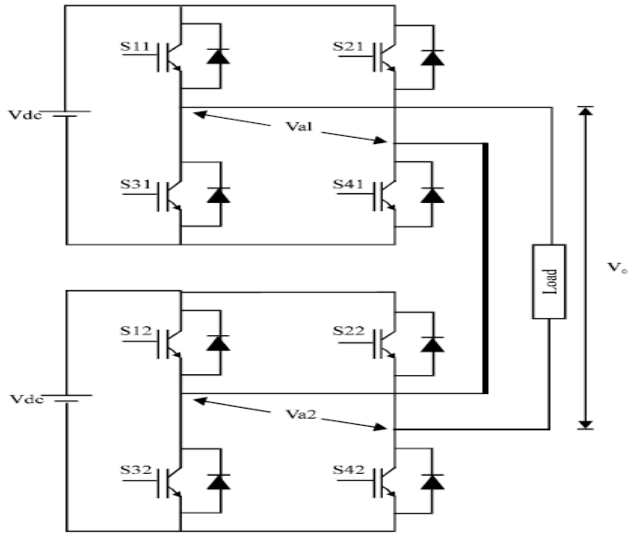

Fig. 4.1Cascaded H-bridge five levelcircuit

The no. of output phase voltage magnitude levels m in a cascaded connected in series multilevel inverter is presented by

$$m = 2s+1 \quad (4.1)$$

Where‘s’ is the no. of multiple dc sources.

The cascaded multilevel inverter topology consists of n-H-bridge inverters connected nonparallel as shown in fig 4.1. The power electronic switches (S11, S21) are in the on-state, and in this manner the power electronic switches (S31, S41) are inside the off-state all through the +ve half pulse. In actuality, the power electronic switches (S11, S21) are in the off-state, and subsequently the power electronic switches (S31,S41) are inside the on-state all through the negative half cycle and the other way around. The output voltage has five voltage levels 0,+Vdc, +Vdc/2,−Vdc, −Vdc/2. The ac outputs of every ofthe completely different full-bridge electrical converter levels are connected inseries specified the synthesized voltage waveform is thesum of the multiple level converteroutputs.

This high-quality voltage wave allows thereduction of the harmonics within the generated current,reducing the filtering effort at the input. The serial structure multilevel inverter is connected to the grid through a L filter, which is employed to reduce the switch harmonics. Among the varied strategies of PWM, level-shift PWM technique is extensively used for neglecting harmful low-order harmonics in inverters. In PWM technique, the multiple level converter switches are turned ON and OFF so many times. Phase opposition disposition (POD) is employed during this paper as it has less harmonic distortion on the line voltage. It uses identical reference curved signal because the standard SPWM whereas the carrier signal which is triangular one is a changed one. To implement an m-level electrical converter, (m-1) carriers are used.

Phase Opposition Disposition(POD) has been proposed for five – level cascaded -H-bridge inverter as it has minimum THD level. Stage resistance manner (POD) adjustment all bearer waveforms over zero reference are in eliminate and are 180° of stage with those beneath zero [7]. The tenets for the POD technique,when the number of level N = 5.The N –1 = 4 transporter waveforms are organized so all bearer waveforms over zero are in eliminate and are 180 of stage with those beneath zero. The input DC supply voltage of 5-level series connected h-bridge inverter for grid connected is connected to PV system and phase opposition and disposition (POD) pulse widthModulation is used for series connected –H-bridge inverter as the THD level for POD technique is less compared to other techniques.Implementation of POD technique for 5-level CHB MLI is simulated in MATLAB/Simulink shown in fig 4.2.

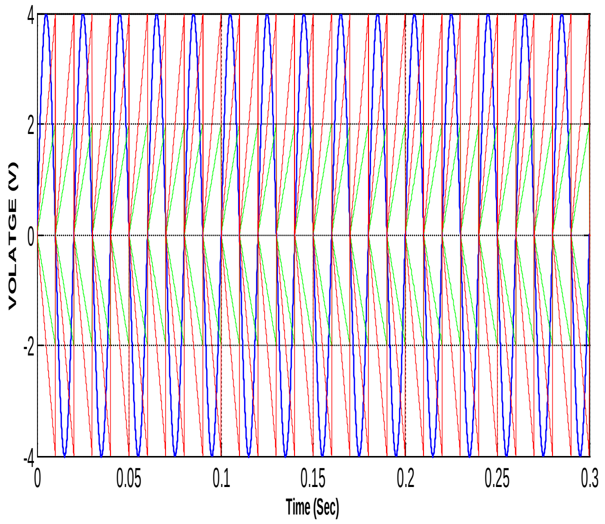

Fig.4.2 Phase opposition disposition of PWM technique

V. PROPOSED SYSTEM FOR ACTIVE AND REACTIVE POWER CONTROL

The major task of grid connected inverter is to have the capability of controlling real and reactive power initiated to the grid side control the DC bus voltage(obtained from pv panel) in variable light intensity and temperature condition, and also submit quality of power to the grid side under different load operations [9] .

A photovoltaic array is used to convert sunlight into DC current. The output of the array is connected to a three phase transformer for boosting up the array terminal voltage to a higher value so it can be interfaced to the three -phase grid (415v, 50 Hz) and a DC link capacitor is used after the PV array acts as energy storage element [10]. And the output current of five level cascaded–h-multilevel inverter is controlled by PWM current control techniquein order to inject a controllable three phase supply goes to the main-grid as given below in fig 5.1.

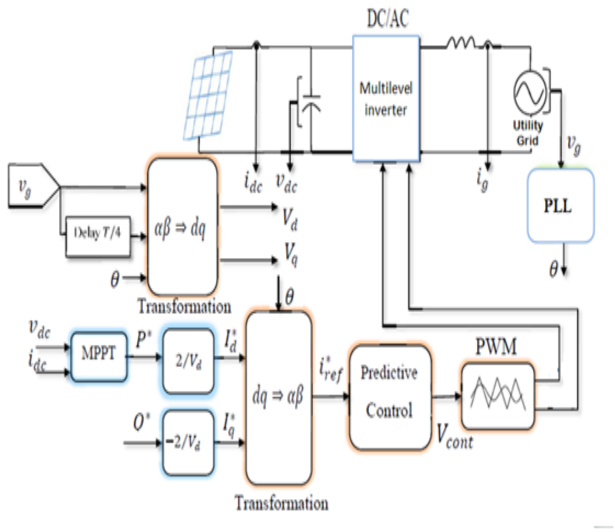

Fig.5.1 Overall control configuration of the proposed system

Mathematic analytical development for active and reactive power control

The power fed into the grid (P_{grid}) is equal to:

$$P_{grid} = V_g I_g = \frac{V_g I_g}{2}(1 - \cos wt) \qquad (5.1)$$

I_g = amplitude of the injected current

V_g = amplitude of grid voltage

Assume thatV_g isout of the control. The average power P_{av} fed into the grid ismaintained constant and can be given as:

$$P_{av} = \frac{1}{T}\int_0^T \frac{V_g I_g}{2}(1 - \cos wt) = \frac{V_g I_g}{2} \qquad (5.2)$$

If we consider that the multilevel inverter has no losses (ideal case), which means the output power is equal to the input power and thus the reference power generated by setting the MPPT function (P). In the rotating frame using *d-q* transformation, the active power control depends on the current component I_d (*d* axis) while the reactive power control dependson the current component I_q(*q* axis) [12].Therefore, the active output power of the multilevel inverter can be determined as:

$$P = \frac{1}{2}(V_d I_d + V_q I_q) \qquad (5.3)$$

Where V_d,V_q,I_d&I_q,are generator currents and generator voltage with respect to the direct (*d*) and quadrature(*q*) axis.Similarly, the reactive output power injected in the gridbecomes:

$$Q = \frac{1}{2}(-V_d I_q + V_q I_d) \qquad (5.4)$$

When the rotating is synchronized with the grid voltage$V_q$becomes equal to zero,subsequently the active power and the reactive power outputs are

$$P = \frac{1}{2}(V_d I_d)$$

$$Q = -\frac{1}{2}(V_d I_q)(5.5)$$

From the above equationsthe d-axis current$I_d$control theactive power. Similarlythe q-axis current$I_q$controls the reactive power as shown in the following equations.

$$I_d^* = \frac{2P_{ref}^*}{V_d}$$

$$I_q^* = \frac{-2Q_{ref}^*}{V_d} \quad (5.6)$$

The estimated currents in the rotating system (dq) are converted to steady state reference frame using Inverse Park transformation and compensated by the estimated current controller. The opposite Park transformation defines the transformation from rotating frame to stationary frame (dq to $\alpha\beta$).

$$I_{ref}^* = I_d^* \cos\theta - I_q^* \sin\theta \quad (5.7)$$

ϴ is the angle of the grid voltage given by PLL.

A. ABC TO DQ TRANSFORMATION

The dq transformation is used to transform three phase system quantities like voltages and currents from the synchronous reference frame (abc) to a synchronously rotating reference frame with three constant components when the system is balanced. The relationship that govern the transformation from the abc to dq frame is

$$\begin{bmatrix} x_d \\ x_q \\ x_0 \end{bmatrix} = T \times \begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix} \quad (5.8)$$

$$T = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos wt & cos\left(wt - \frac{2\pi}{3}\right) & cos\left(wt + \frac{2\pi}{3}\right) \\ -\sin wt & -sin\left(wt - \frac{2\pi}{3}\right) & sin\left(wt + \frac{2\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} (5.9)$$

Where x is either a collection of 3 phase voltages or currents to be remodeled, T is the transformation matrix .ω is the angular rotation frequency of the frame the angle between the direct axis (d-axis) and section a-axis is outlined as θ [13].

The relationship that governs the inverse transformation from the dq to abcframe is:

$$\begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix} = T^{-1} \times \begin{bmatrix} x_d \\ x_q \\ x_0 \end{bmatrix} \quad (5.10)$$

$$T^{-1} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos wt & -sinwt & \frac{1}{\sqrt{2}} \\ cos\left(wt - \frac{2\pi}{3}\right) & -sin\left(wt - \frac{2\pi}{3}\right) & \frac{1}{\sqrt{2}} \\ os\left(wt + \frac{2\pi}{3}\right) & -sin\left(wt + \frac{2\pi}{3}\right) & \frac{1}{\sqrt{2}} \end{bmatrix} \quad (5.11)$$

The results of these conversion techniques are three constant rotating components: the direct (d), quadrature (q) and nil (0) elements In balanced three phase systems, the zero element is neglected since.

$$x_a + x_b + x_c = 0 \quad (5.12)$$

This transformation is helpful in implementing the system for the electrical converter underneath current management to control the output of the PV system. Active and reactive powers injected from the PV system may be calculated using the subsequent relationships

$$P = \left(V_d I_{d,injected} + V_q I_{q,injected}\right)$$

$$Q = \left(-V_d I_{q,injected} + V_q I_{d,injected}\right) \quad (5.13)$$

Where V_d, V_q are the dq voltages at PCC and the grid side of the transformer.

$I_{d,\ injected}$ and $I_{q,\ injected}$are the dq components of the injected current at the grid side.

B. PHASE-LOCKED-LOOP

A phase-locked loop (PLL) is an electronic converter block with a voltage-driven modulator that continuously compensates to match the frequency of an input signal [14].

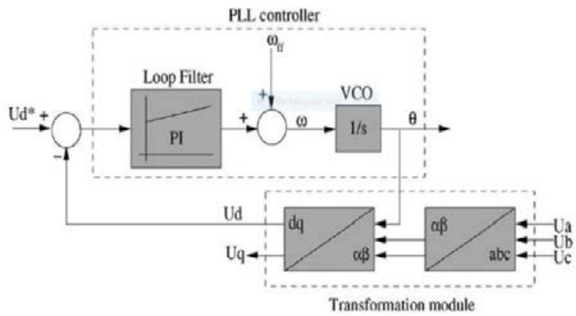

Fig.5.2 General block of Phase Locked Loop

Toensure power flow between the natural resource generator and utility network, the injected current has to be synchronic with the grid voltage. Different algorithms are used for grid synchronization. The main purpose of these algorithms is to get the phase angle of grid voltages. Zero crossing technique, Filtering of grid voltages and PLL are the strategies that are used for grid synchronization. Among these 3, PLL is that the most generally used technique. Three- phase PLL techniques are used a lot of usually for grid .The generalmode of the PLL is shown in Fig 5.2. PI controller is included in the PLL structure which is designed to make ɵPLLequals to θ_{grid} at steady state operation [18].

C. PREDICTIVE CONTROL

Predictive control, which is developed in this paper, as it is receiving recent remarkable improvement in industry, and its implementation is simple, fast and very accurate.

To ensure the power flow into the grid, control of multilevel inverter current is needed since grid voltage is out of the control. There are various linear control techniques such as hysteresis controller Predictive controller, PI, PR controller .The hysteresis control is defined on boundary region which has fast response time, but it has irregular switching frequency. As for the conventional linear PI and PR controller, they have a limited performance.

The aim of the controller is to calculate the multilevel inverter voltage required to force the grid current to follow the pre-calculated trajectory in order to optimize the controller. L filter placed between the electrical converter output and also the grid as a filter to decouple the output voltage and also the grid [15].

The system can be designed as:

$$v = L\frac{di}{dt} + V_{grid} \qquad (5.14)$$

v is the output voltage of electrical converter

The estimation of the load current is depends on the discontinuous model. The derivative in (4.14) can be modified by its discontinuous approximation

$$\frac{di}{dt} = \frac{i(k+1)-i(k)}{T_S} \qquad (5.15)$$

$T_S$is the sampling time.

k is the current sample time

By subtitling (5.15) in (5.16), the discrete model of the systemis obtained:

$$V = \frac{L}{T_S}\big(i(k+1) - i(k)\big) + V_{grid} \qquad (5.16)$$

The equation (5.16) is used to estimate the future value of the load current to maintain grid voltage.

VI. SIMULATION RESULTS

Simulation of connected in series-H-bridge 5-level multiple level converter as presented in fig 6.1 .Phase – neutral and phase –phase voltages are obtained with PV system with 5-level CHB MLI are plotted in MATLAB/Simulink. Total voltage obtained from multilevel inverter is 200V connected to grid of 415V/50Hz with three phase transformer for proposed control system.

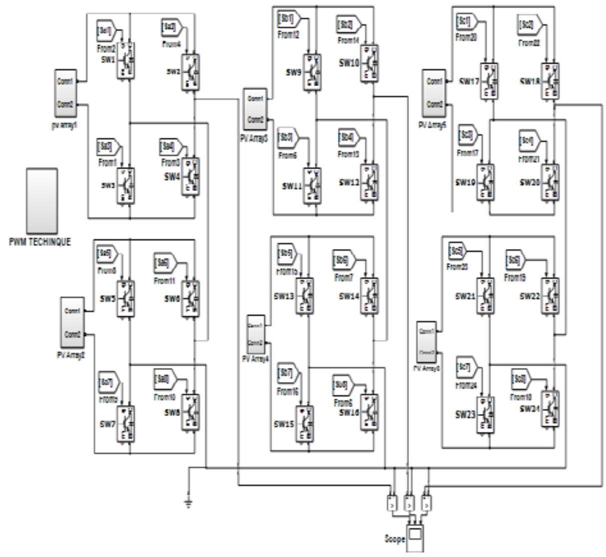

Fig .6.1 simulation of 5-level cascaded –h-bridge MLI with PV array in MATLAB/Simulink

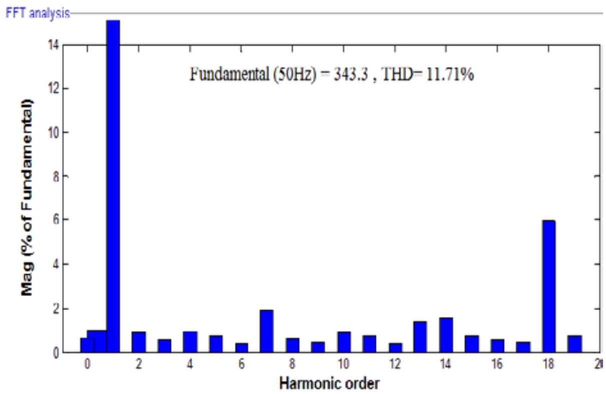

Fig.6.2 THD observation of 5-level cascaded-h-bridge multiple level with POD scheme

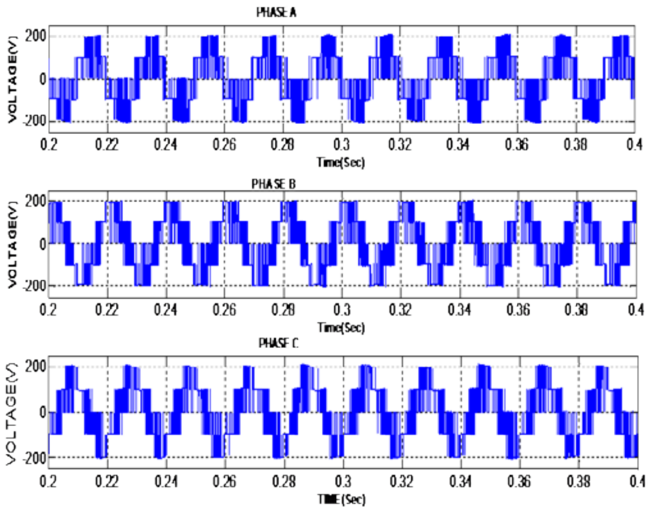

Fig.6.3 Phase to neutral voltage of 5-level cascaded –H-bridge MLI

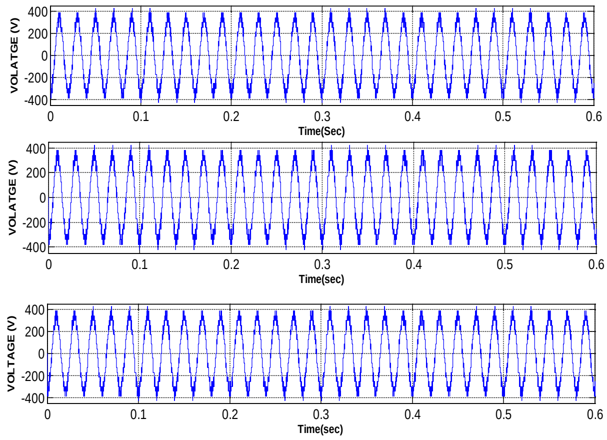

Fig.6.4 Line-Line voltage of 5-level cascaded h-bridge multilevel inverter

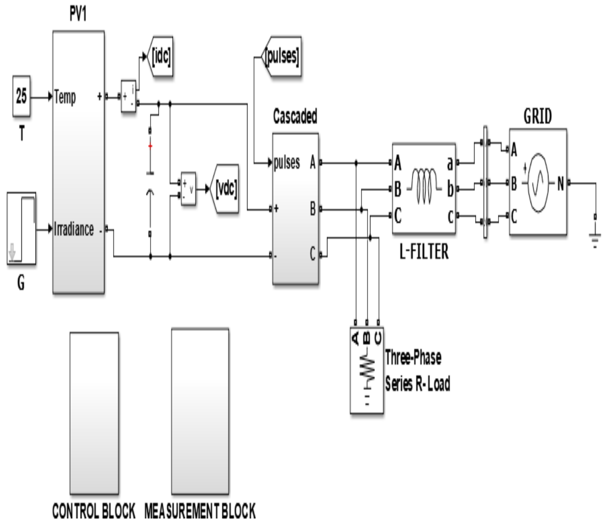

Fig.6.5 Proposed control system simulation in MATLAB/Simulink

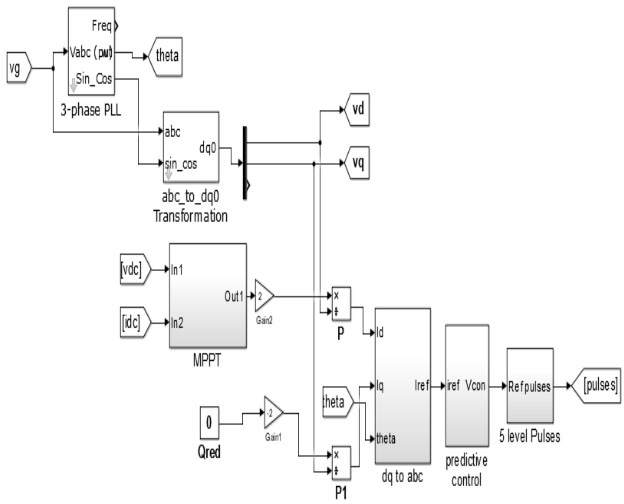

Fig.6.6 Compensating circuit for real and reactive power

The proposed system for control of real and reactive power for the grid attached PV system using five-level cascaded–h-bridge converter is simulated in MATLAB/Simulink is presented in fig 6.5.and the control technique is shown in fig 6.6.

Which consist of PV array connected to three phase transformer for boost up voltage and for coupling between grid and L filter is used for coupling between grid and PV system. The active power is controlled by PV system MPPT controller and the reactive power is injected according to grid demand and the parameters used for proposed system are tabled below in table 6.1.

TABLE 6.1requirements of presented control frame

Parameters	**values**
Capacitor(C)	20×10^{-4} F
Filter	5e-3
Grid voltage(Vg)	415V
Grid current(Ig)	30A
Transformer primary secondary voltage ratio	15.8V:415V
Three- phase R- load power(RL)	10kW
Grid frequency(Fg)	50Hz

In the fig 6.7 the two components of grid voltage in the rotating frame, we can notice as previously that *Iqequals* to zero and I_d equals to the amplitude of the grid voltage V_{grid}

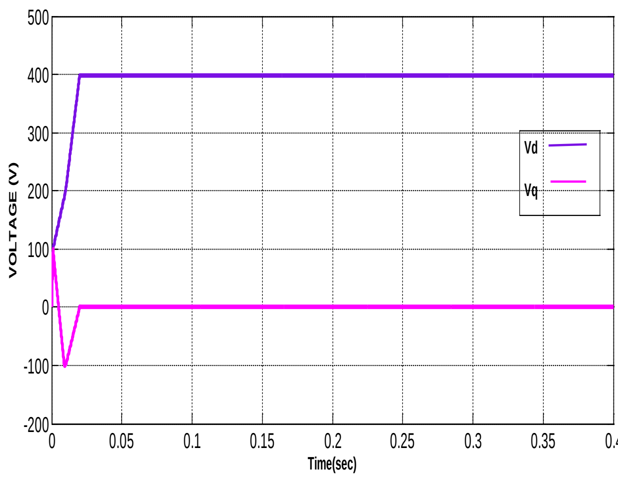

Fig.6.7 Grid components in the rotating frame

Different simulations are plotted in graphs with proposed control system which is designed in MATLAB/Simulink as shown in fig 6.5 for different reactive power references under standard irradiation of 1000 W/m^2, which implies a constant active power in the beginning the reactive power command is set to 0Var, and then is changed to, 200Var,-200var and 250Var at time 0.2sec.

CASE 1: Reactive power reference set to 200var with continuousreal power**.**

Reactive power injected to grid according to grid demand at step change from 0var to 200var at 0.2sec with continuous real power at standard whether strategies as presented in fig 6.8.

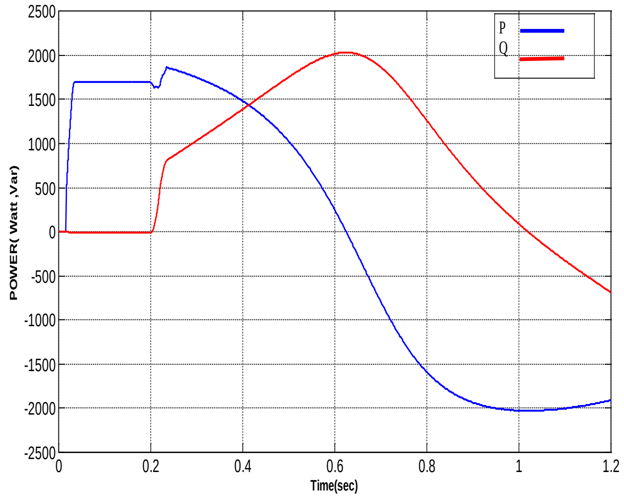

Fig.6.8 Active and reactive power of grid at step change from 0var to 200var at 0.2sec

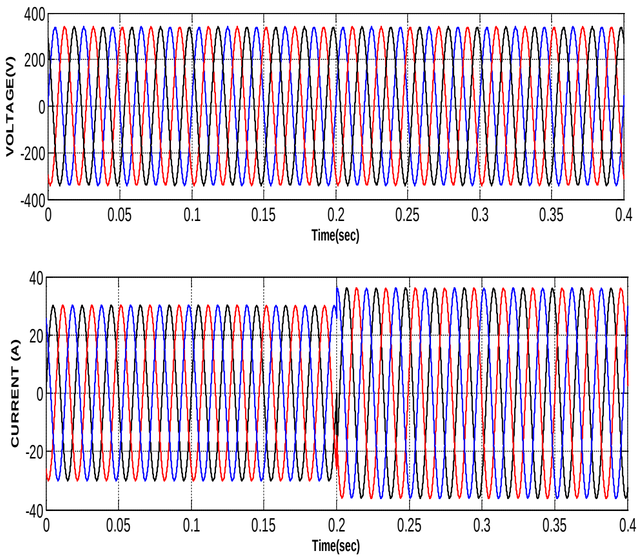

Fig .6.9Grid Voltage & current waveforms during dynamic step changes from 0Var to 200Var at time 0.2s

In Grid Voltage and current waveforms whereVgrid= 340V,I_{grid}= 30A.We can observe that during dynamic step changes from 0Var to 200Var at time 0.2s there is increase in grid current from 30A to 32A when reactive power is injected into grid as shown in fig 6.9.

CASE 2: Reactive power reference set to -200var at 0.2secwith constant active power.

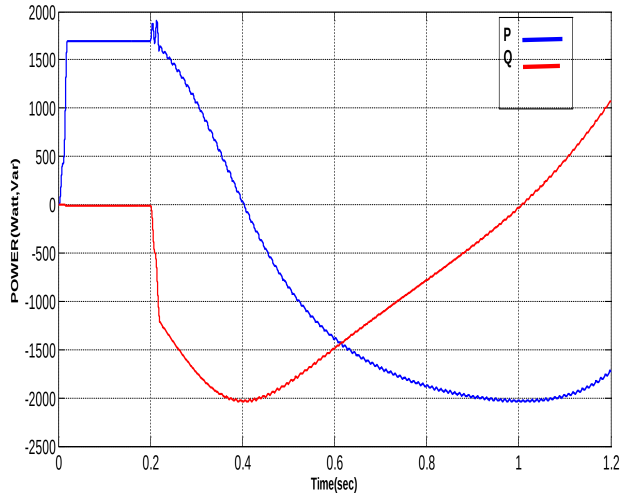

Fig.6.10 Real and reactive power of grid at step change from 0var to -200var at 0.2sec

Reactive power injected to grid according to grid demand at step change from 0var to -200var at 0.2sec with constant active power at standard atmospheric condition (1000W/m^2) as shown in fig 6.10.

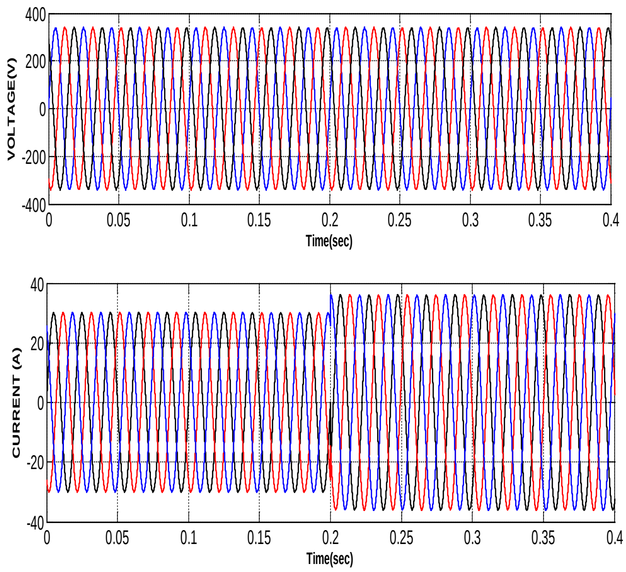

Fig.6.11Grid Voltage & current waveforms during dynamic step changes from 0Var to-200Var at time 0.2s

Grid Voltage& current waveforms during dynamic step changes from 0Var to -200Var at time 0.2s as shown in fig 6.11 it is observed that current is increased from 0.2 sec due to change in reactive power with constant grid voltage.

CASE 3: Reactive power reference set to 250var at 0.2secwith constant active power.

Reactive power injected to grid according to grid demand at step change from 0var to 250var at 0.2sec with constant active power at standard atmospheric condition (1000 W/m^2) as shown in fig 6.12.

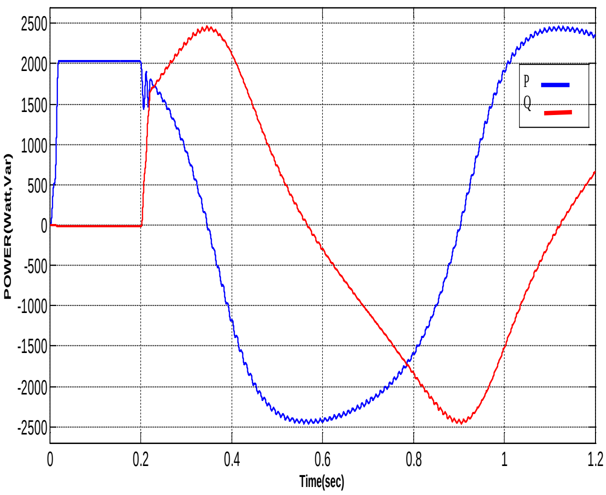

Fig.6.12 Real and reactive power of grid at step change from 0var to250var at 0.2sec

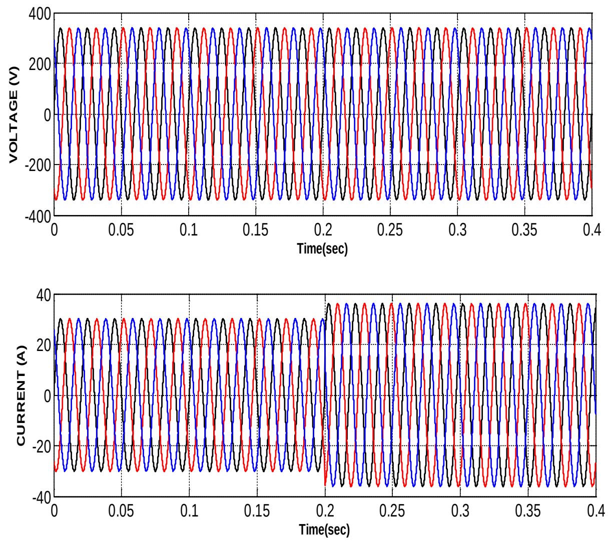

Fig.6.13 Grid Voltage & current waveforms during dynamic step changes from 0Var to 250Var at time 0.2s

In Grid Voltage and current waveforms whereVgrid= 340V,I_{grid}= 30A.We can observe thatduring dynamic step changes from 0Var to 250Var for three phase R-Load at 0.2sec there is increase in grid current from 30A to 36A due to change in reactive power according to grid demand with constant grid voltagesin fig 6.13.

CASE 4: Reactive power reference is set around to200Var constant but under different active power

Reactive power reference is set around to200Var and is chosen constant but under different active power by altering the irradiation by step from 800 W/m^2 to 1000 W/m^{2}at time 1 second in the first case, and from 1000 W/m^2 to800 W/m^{2}at the time of 2 second. MPPT algorithm is reaching the maximum power point also, which means that is no effect of injecting the active power on the reactive power.

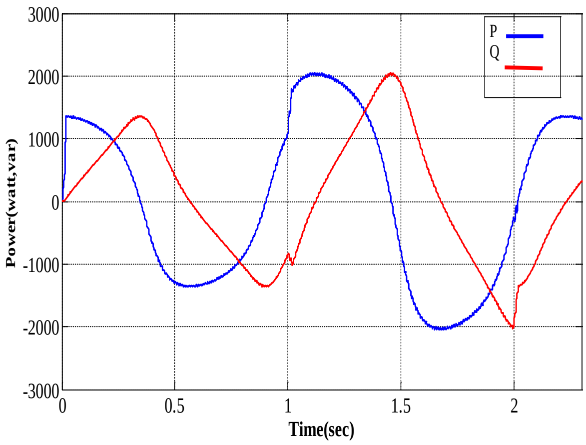

Fig .6.14 Constant Reactive power but with various Active power injected into the grid

In the fig 6.14 we can observe that the real power injected is increased at 1sec due increase in irradition from 800W/m^2 to 1000W/m^{2}and reactive power at 200var which is maintained constant.

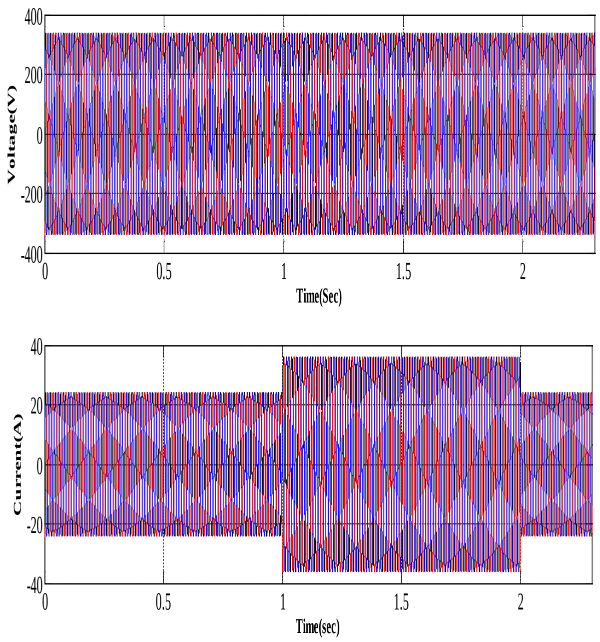

Fig .6.15 Grid Voltage & current waveforms during step changes from 1sec to 2sec forConstant Reactive power but with various Active power injectedinto the grid.

In the fig 6.15 Grid Voltage and current waveformswhereVgrid= 340 V, I_{grid}= 24A.We can observe that for different active power by altering the irradiation by step from 800 W/m^2 to 1000 W/m^{2}at time 1 sec in the first case, and from 1000 W/m^2 to800 W/m^{2}at time 2 sec there is increase in current during from 1sec to 2sec from 24A to 42A due to change in Active powerwith constant reactive power with constant grid voltage.

VII. CONCLUSION

The compensation of real and reactive power for three-phase main grid-attached PV system with 5-multiple level connected in series -h-bridge multiple level converters is presented here. I-V and P-V Characteristics of PV array are plotted with different irradiance and temperature and to track maximum power from PV array (P&O) MPPT technique is implemented .Analysis of 5-level cascaded h-bridge inverter with phase opposition and disposition of PWM technique issimulated and obtained THD value of 11.71%. After determining the amount of reactive power to inject or to absorb according to grid demand, the active power is also determined according to the change of irradiation by MPPT function. Then we consider two components of currents in the rotating frame to transform them into the stationary frame in AC reference current to make it pass into the current controller to control the output current of CHB MLI. Different simulation waveforms are presented to verify the performance of the proposed control strategy.

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