Assessment of Various Control Techniques for Three Level H-Bridge Inverter in Grid Connected Solar PV

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Abstract

This paper depicts evaluations of various control technique for three level cascade H bridge inverter for grid connected solar pv system. The solar panel and inverter is modeled for unbalance and nonlinear loads with three control techniques (pq theory, dq theory, cpt theory) and its simulation is carried in the MATLAB environment using Sim Power System (SPS) toolboxes. The performance of model is compared and analyzed in terms of harmonics compensation, power factor correction along with active and reactive power support. Results obtained are reasonable under balanced and unbalanced nonlinear loads.

Keywords: Active power filters Compensation strategies Conservative power theory

1. Introduction

Combination of renewable energy source with multilevel inverter is becoming very popular in past few years. The several multilevel power converter topologies, control techniques, and maximum power tracking methods are introduced to harvest the highly efficient power from renewable energy sources [1],[2]. Conventional two-level inverters are not suitable for high power applications because of their high voltage stress, high temperature, and low efficiency. Multilevel inverters are the best choice for high-power and large-scale grid-connected renewable energy system because it produces low total harmonics distortion and low maintenance [3]. Cascade H bridge inverter overcome the disadvantage of conventional two level inverter by combining H bridge module together and increases voltage level. Cascaded H-Bridge (CHB) configuration more preferred for solar power applications because isolated input DC sources are available in this configuration [4]. Thus CHB multilevel inverter can be used as an ideal interface between an ac grid and a DG or a renewable energy power supply which usually consist of several separate power sources[5]. For the grid-connected systems, voltage quality at the point of common coupling (PCC) is very important. Cascaded H-bridge (CHB) based active power filters (APF) can compensate high order harmonics in medium and high voltage systems and improves power quality at PCC[6]. Several control techniques have been introduced for the control of grid-connected CHB inverters. The control method must assure a stable circuit operation even in case of unbalanced conditions due to cells' different temperature and solar radiation. The power conditioning stage interfacing the PV modules to the grid has attracted attention of researchers since [9]'[10], it must account for maximum power extraction from the energy source account for maximum power extraction from the energy source and an optimal energy transfer to the grid.

This work deals with a transformer less operation of three phase three level H bridge configuration and with no need of a dc-dc boost stage. The objective of this paper is to show the performance of three-phase three level CHB used as an APF for grid-connected solar applications while different control methods(pd,dq and cpt) are applied for power conditioning. The paper is organized in following manner Section II present small

description of proposed system with block diagram. The Section III describes three control algorithm for propose CHB inverter based grid connected system.. Section IV presents simulation results Section V concludes the paper.

2. System description

In this paper operation of three-phase, three-level cascade H bridge inverter for the grid-connected PV system with active power filtering functionality is investigated. General diagram of the proposed system is shown in figure 1. Three control strategy PQ, DQ, CPT has been used for CHB multilevel inverter based APF for grid connected solar PV. Hysteresis PWM is used for switching of inverter. Modulation technique has been used for switching of the inverter. Incremental (In&Co) conductance method is used for MPPT. Three phase thyristor bridge rectifier is chosen as a non-linear load with RL, RC and two single-phase bridge in two arms in output (unbalance as well as nonlinear).Model is simulated for both equal and unequal irradiance values. Matlab Simulink based modeling has been done to show performance of thee three control technique. A comparative study is carried out about its performance as active power filtering by means of total harmonic distortion (THD) value measured for injected grid currents after compensation.

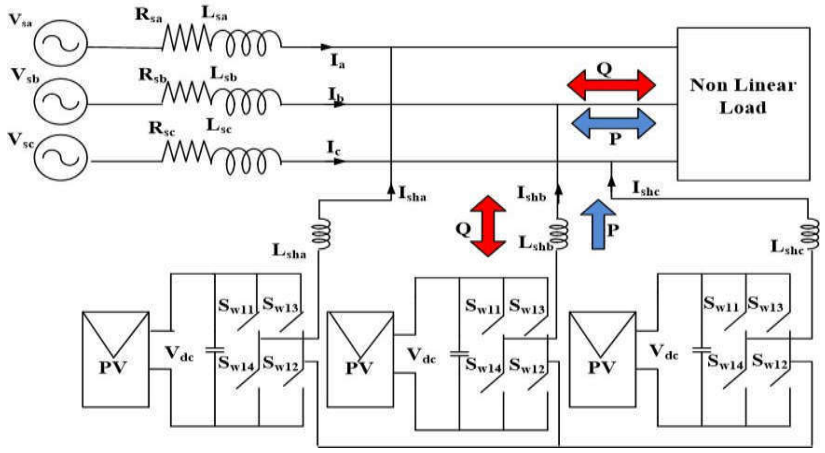

Figure 1 Three phase three level H bridge inverter

Figure 1 shows three phase three level H Bridge connected at point of common coupling of utility grid and non linear load. Active and reactive power exchange is being taking place between grid, load and PV inverter. In proposed system the photovoltaic system which incorporates PV panels and H bridge inverter connect directly to grid without dc-dc converter i.e single stage conversion. In Fig. 2 we can see that between the PV farm and the inverter only one capacitor exists.Based on the incremental conductance MPPT algorithm, when the output voltage of PV farm is changed the MPP changes simultaneously. For the implementation of incremental conductance algorithm directly to the inverter, the switching elements of the inverter must be given pulses appropriately so that every instance the voltage capacitor of the dc bus is equal to the reference voltage which is given by MPPT algorithm. For the control strategy of the grid-connected PV system the pq,/dq/,cpt is applied. To control the inverter's output current and the hysteresis band current control technique is used for providing gate pulses to inverter. The feasibility of the proposed system is verified through Matlab/Simulink simulations.

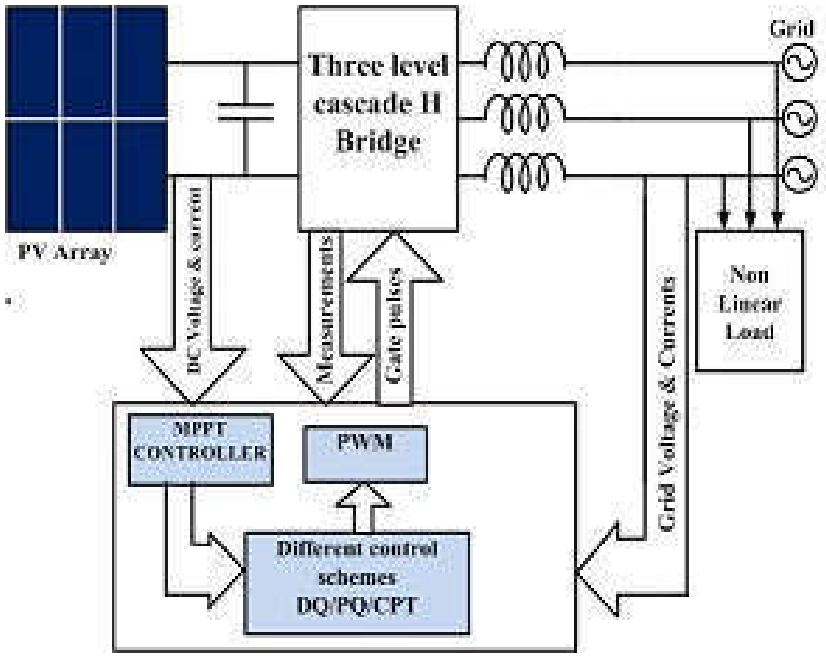

Figure 2 Block diagram of system

3. Reference current generation

In this work three different theories are used for reference current generation and then results of simulation are compared for variable irradiations/ temperature for different combination of non linear load.

3.1 dq control: Reference [14] is used for current control using dq control theory .In this combined system one of active current reference components $\mathbf{i_{dvdc}}^*$ is provided for active power injection, the dc link voltage is control by a PI controller which compares the actual dc-link voltage and the reference generated by the incremental conductance MPPT method. Also, in order to generate another active current reference component $\mathbf{i_{dapf}}^*$, for active filtering first, the measured load currents converted to general synchronous dq coordinates using equation (1). Then this d-axis component is passes through low pass filter (LPF) to remove the load current harmonic components.. Thus the active current reference $\mathbf{i_{dapf}}^*$ is extracted finally, active current reference is calculated shown in (2).

$$\begin{vmatrix} i_d \\ i_q \end{vmatrix} = \begin{bmatrix} \sin(wt) & \sin\left(wt - \frac{2\pi}{3}\right) & \sin\left(wt + \frac{2\pi}{3}\right) \\ \cos(wt) & \cos\left(wt - \frac{2\pi}{3}\right) & \cos\left(wt + \frac{2\pi}{3}\right) \end{bmatrix} \begin{vmatrix} i_a \\ i_b \\ i_c \end{vmatrix} \quad (1)$$

$$\mathbf{i_d}^* = \mathbf{i_{dvdc}}^* + \mathbf{i_{dapf}}^* \quad (2)$$

actual $\mathbf{i_q}$ for power factor control. By applying the inverse dq transformation as given by (3), the desired $\mathbf{i_{abc}}^*$ phase current references are obtained. These are given to a hysteresis band current controller to generate the inverter gating signals required to provide current references.

$$\begin{vmatrix} i_a^* \\ i_b^* \\ i_c^* \end{vmatrix} = \begin{bmatrix} \sin(wt) & \cos(wt) \\ \sin\left(wt - \frac{2\pi}{3}\right) & \sin\left(wt - \frac{2\pi}{3}\right) \\ \sin\left(wt - \frac{2\pi}{3}\right) & \cos\left(wt + \frac{2\pi}{3}\right) \end{bmatrix} \begin{vmatrix} i_d \\ i_q \end{vmatrix} \quad (3)$$

3.2Pq control: Reference [12][15] are used for reference current generation The p–q

theory based on instantaneous active and reactive power, calculates the reference currents in α-β system according to Eq. (4) $i^{*}_{c,\alpha}$

$$\begin{vmatrix} i_\alpha \\ i_\beta \end{vmatrix} = \frac{1}{u_{s\alpha}^2 + u_{s\beta}^2} \begin{bmatrix} u_{s\alpha} & u_{s\beta} \\ u_{s\beta} & -u_{s\alpha} \end{bmatrix} \begin{vmatrix} -p_{pv} + p_{los} \\ q \end{vmatrix} \quad (4)$$

Using the inverse transformation of Eq. (4) we calculate the reference currents in the a–b–c coordinates system according to the following equation

$$\begin{vmatrix} i_{ca}^{*} \\ i_{cb}^{*} \\ i_{cc}^{*} \end{vmatrix} = \sqrt{\frac{2}{3}} \begin{vmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{vmatrix} \begin{vmatrix} i_{c\alpha}^{*} \\ i_{c\beta}^{*} \end{vmatrix} \quad (5)$$

For the control of the inverter output current these references are apply the hysteresis band current controller. The hysteresis band control technique is very simple to apply and, it's dynamic behavior is very good, thus provides very fast response.

3.3 cpt control: Reference [13][16] are used for reference current generation cpt method allows for the decomposition of the instantaneous currents into different orthogonal current terms, valid for single phase as well as multiphase systems, independent of the voltage conditions. Such components can be applied as reference signals to shunt active filters. These compensation strategies are very flexible because the decompositions allow for the selective identification and minimization of different disturbing effects (nonlinearities, unbalances, reactive power). Thus, assuming a multiphase circuit where each phase of the system is denoted by the subscript "m," one may have.

(1) Balanced active currents (i_{amb}), which are related to the active power consumption.

(2) Balanced reactive currents (i_{rmb}), which are related to the reactive power circulation.

(3) Void currents (i_{vm}), which are related to the nonlinear (distortion) behaviour between voltages and load currents.

(4) Unbalanced currents ($i_{mu}=i_{amu}+i_{rmu}$), which are related to the unbalanced load behaviour.

(5) Non-active currents (i_{nam}), which represents all the unwanted terms of the Load currents ($inam=i_{rmb}+i_{vm}+i_{mu}$).

So By definition, the collective RMS current can be split into

$$I = \sqrt{I_a^{b2} + I_r^{b2} + I_a^{u2} + I_r^{b2} + I_v^{2}} \quad (6)$$

Similarly, apparent power (A) can be defined by

$A=\|v\|.\|i\|$ or

$$A=\|v\|.\sqrt{I_a^{b2} + I_r^{b2} + I_a^{u2} + I_r^{b2} + I_v^{2}} \quad (7)$$

$A=\sqrt{P^2 + Q^2 + N_a^2 + N_r^2 + D^2}$

Where $P= VI_a^b$ active power;

$Q = VI_r^b$ is reactive power;

$Na = VI_a^u$ is unbalanced active power;

$N_r r = VI_r^u$ is unbalanced reactive power and

$D = VI_v$ is distortion power

CPT also defined the global power factor (λ). This factor is affected not only by the circulation of reactive power (Q) but also by load unbalances (N) and nonlinearities (D). $\lambda=\frac{P}{A}$ .Thus some of the portions of Eq. (5) can be applied for purposes of power conditioning.

DC-link voltages of each H-bridge cell, and to compensate current load terms related to disturbing effects. The voltage controller output, from H-bridge cells, is multiplied by the PCC voltage ($\mathbf{V_{pabc}}$), so as to define an additional current reference ($\mathbf{i_{pabc}^{*}}$) which will be added to the reference of the disturbance currents ($\mathbf{i_{fabc}^{*}}$). The resulting current reference ($\mathbf{i_{abc}^{*}}$) is given to the hysteresis band current controller output of the active filter. In this

method there is no need to apply any type of coordinate transformation or synchronization algorithm to provide the reference signals.

Table 1 Simulation Parameter

Grid	Voltage	440V
	Frequency	50Hz
PV Panel	Output	2KW
	Open circuit voltage	86V
	Short circuit current	1.74A
	No of series connected cell	60
	Irradiance(G)	1000~13000
	Temperature	350C
	Source resistance	1x10-3Ω
	Source inductance	1x10-7mH
Load	Three-Phase Diode Bridge Rectifier With RL as output	R=450Ω L=50mH
	Three-Phase Diode Bridge Rectifier With RC as output	R=15 Ω C=150µF
	Two single-phase Diode Bridge as output in two arms(unbalance load)	R=15 Ω,20mH R=10 Ω,1000 µF

4. Simulation results and discussion

The performance of the three-phase three level H bridge inverter as an active filter for pq, dq and CPT control technique is simulated in Matlab Simulink platform for various nonlinear as well as unbalanced loads. The parameters of the photovoltaic system and the electrical power system which were simulated are given in Tables 1. As shown in Fig 4 each H-bridge of the inverter is supplied with separate d.c. source i.e. solar pv . In the first case each solar panel produces power with equal irradiance value (1000W/m2). Then irradiation values are randomly chosen between 1000~13000W/m2 (partial shading effect) in different H-bridges (unequal irradiance) and simulation results are discussed below.

4.1 Performance of Control Algorithm-pq

Based on the block diagram of the control strategy in Fig.2-the proposed system was simulated. Fig. 6, 7, 8 depicts grid's current, loads current, and inverters' current for the non-liner load (three phase controlled rectifier) with RL.RC and unbalanced load at the rectifier output terminal and equal insolation as well as unequal insolation respectively. Inverter integrates the PV array to the grid and control system operates according to Fig 2. The PV system supplies with active power the power system and compensates the harmonics of the load, simultaneously. THD waveforms of the source for the various loads are shown in Fig, 11, 12, 13

4.2Performance of Control Algorithm-dq

Similarly based on the block diagram of the control strategy in Fig.2 the proposed system was simulated. Fig.3, 4, 5 depicts grid's current, loads current, and inverters' current for the non-liner load (three phase controlled rectifier) with RL.RC and unbalanced load at the rectifier output terminal and equal. insolation as well as unequal insolation respectively. The inverters control system operates according to Fig.2 The PV system supplies with active power the electric power system and eliminates current harmonics from the all type of non-linear loads, simultaneously. THD waveforms of the source current for the various loads are shown in Fig 14 15, 16.

4.3Control Algorithm-CPT

The Proposed system is also simulated using CPT control technique [15]. All similar loads and different irradiance values (both equal and unequal) also simulate for this technique and waveform of the load current, source current and inverter current shown Fig.9,10 THD waveforms of the source current for the various loads are shown in Fig.17, 18, 19 THD values for the various load and different irradiance values are shown in table 3.It is observed that the THD of the source current is within IEEE-519-1992 standard limit of 5%.

Table 2 shows the summarized results demonstrating the performance of H-bridge grid-connected inverter as an active filter. These results show satisfactory performance of H-bridge grid-connected inverter as an active filter for harmonic elimination as well as active and reactive power integration for varieties of the load. Active and Reactive power values are calculated for various loads and shown in table 3 it is observed that for lower values of load currents, PV inverter is capable of supplying both active and reactive power alone. For higher values of load currents both PV inverter and Grid is supplying the load demand. Active and reactive power for (one particular load) grid, inverter and load is also shown in figure 20-21.

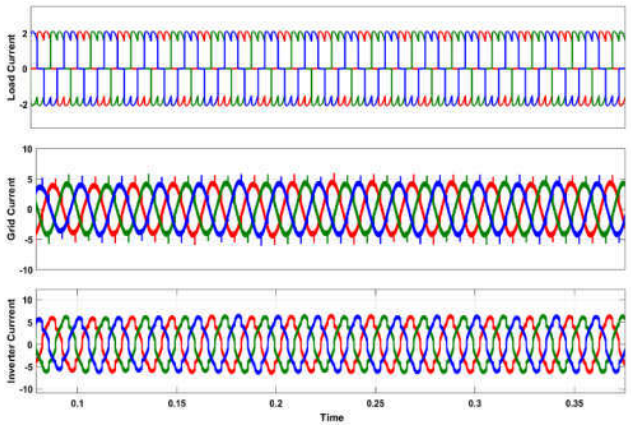

Figure 3 current wave forms for RL load in dq control

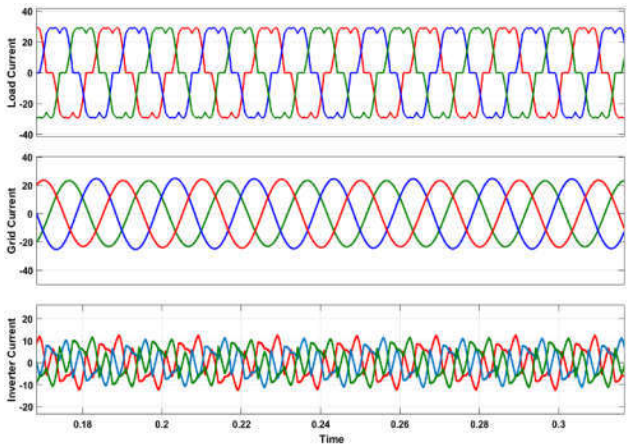

Figure 4current wave forms for RC load in dq control

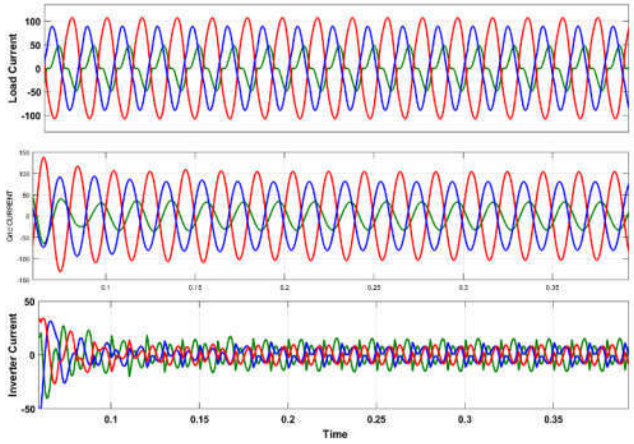

Figure 5 current wave forms for unbalance load in dq control

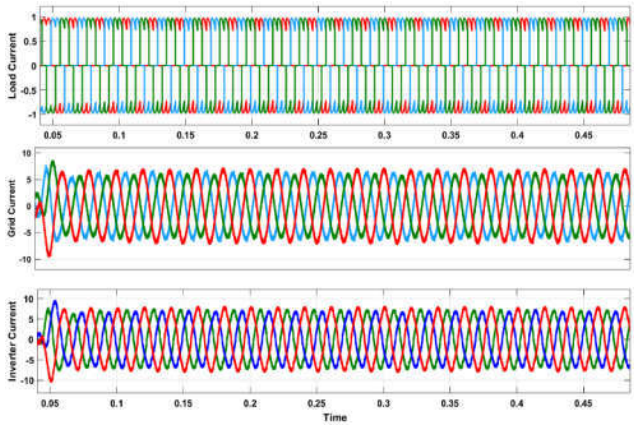

Figure 6 current wave forms for RL load in pq control

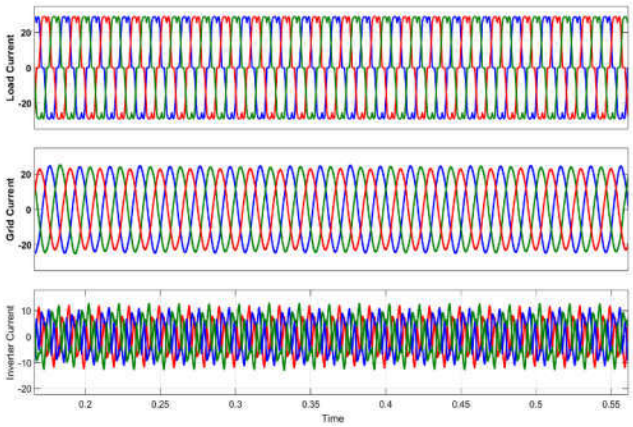

Figure 7 current wave forms for RC load in pq control

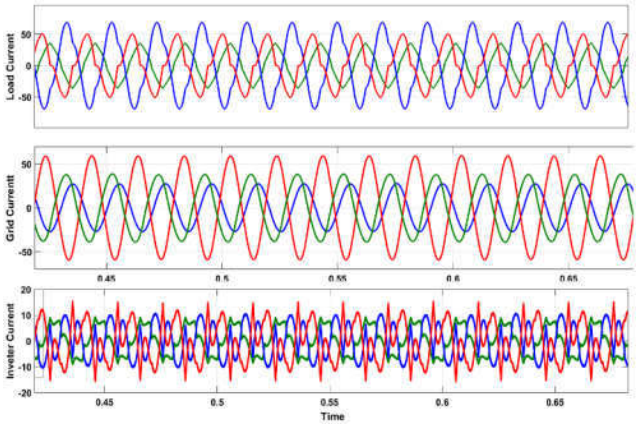

Figure 8 current wave forms for unbalance load in pq control

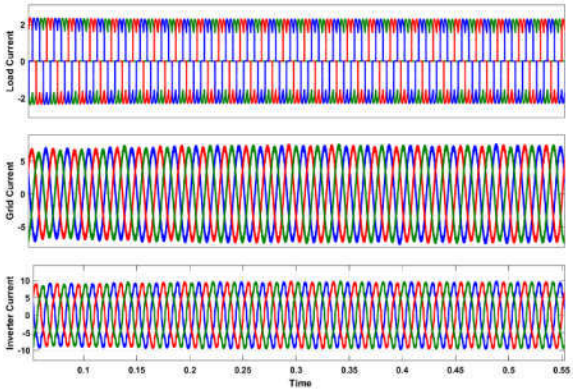

Figure 9 current wave forms for unbalance load in cpt control

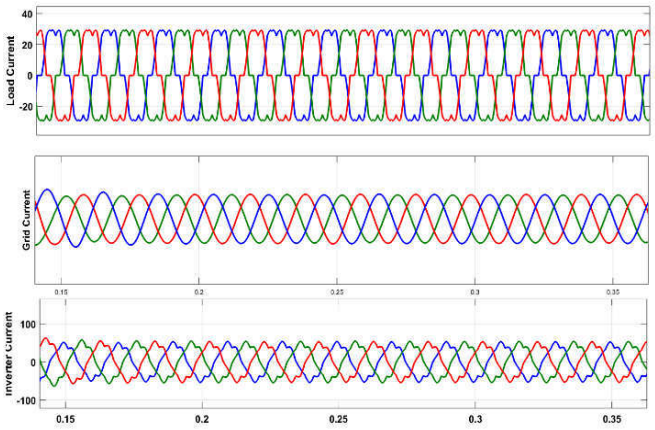

Figure 10 current wave forms for rc load in cpt control

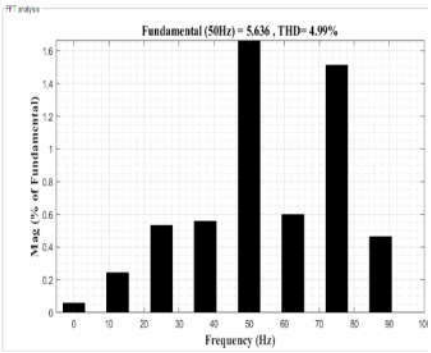

Fig. 11 FFT of Grid current for RL load in pq control

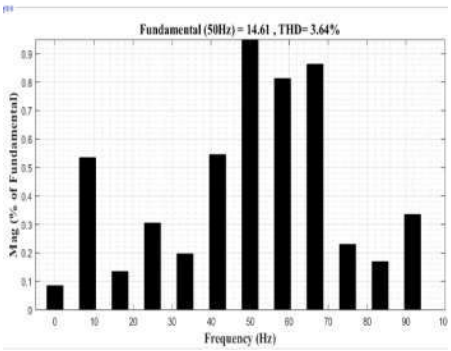

Fig. 12 FFT of Grid current for RC load in pq control

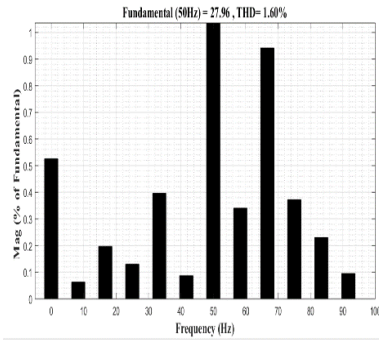

Fig. 13 FFT of Grid current for unbalance load in pq control

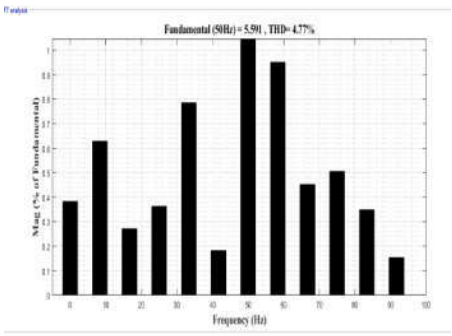

Fig. 14 FFT of Grid current for RL load in dq control

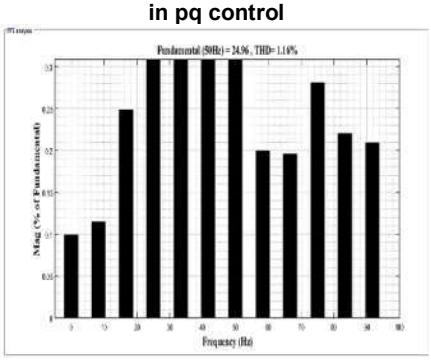

Fig. 15 FFT of Grid current for RC load in dq control

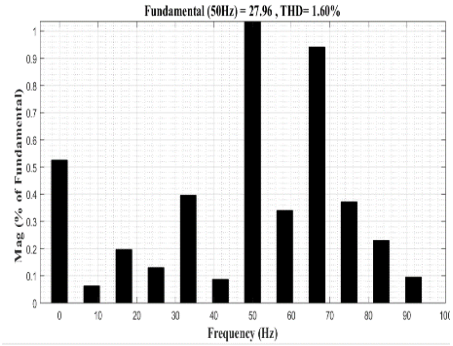

Fig. 16 FFT of Grid current for unbalance load in dq control

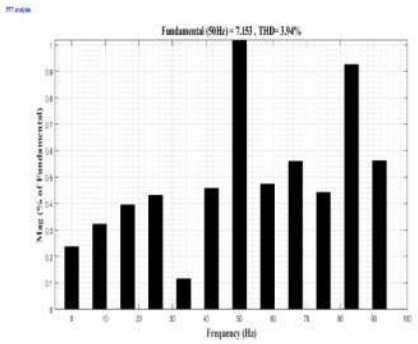

Fig. 17FFT of Grid current for RL load in dq control

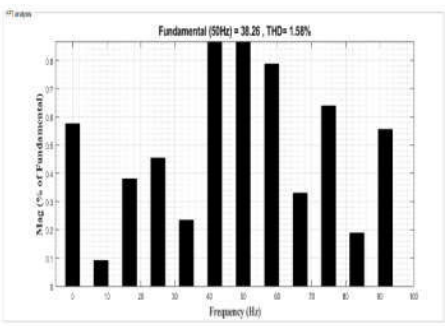

Fig. 18 FFT of Grid current for RC load in dq control

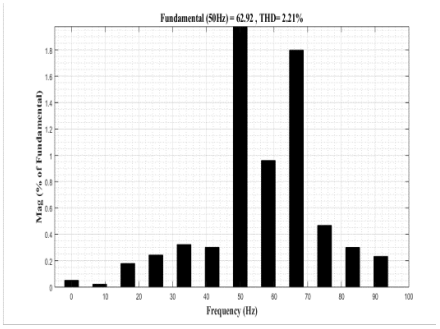

Fig. 19 FFT of Grid current for unbalance load in dq control

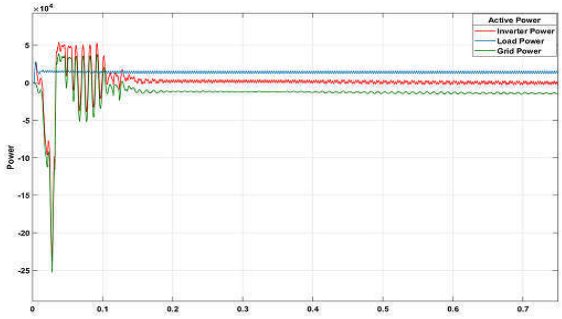

Figure 20 Active power in cpt control for RC load

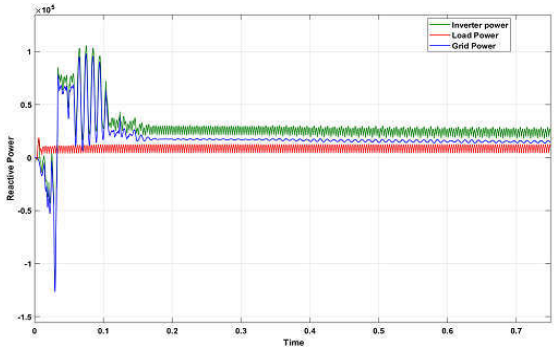

Figure 21 Active power in cpt control for RC load

Table 2 THD of Grid Current

	Load	%THD Grid Current		%THD Load Current
		Equal Insolation	Unequal Insolation	
PQ	RL	4.79%	4.66%	31.38
	RC	1.33%	1.38%	16.96%
	Unbalance load	3.27%	3.99%	5.05%
DQ	RL	4.67%	4.56%	30.16
	RC	1.36%	1.24%	16.96%
	Unbalance load	3.21%	3.10%	5.05%
CPT	RL	3.94%	3.73%	30.16%
	RC	1.58%	1.48%	16.96%
	Unbalance load	2.27%	2.57%	5.06%

5. Conclusion

Assessments of H-bridge grid-connected inverter as an active filter for various control technique have been carried out in this paper and found the satisfactory operation of all three control technique for the different kind of load in steady state condition of equal and unequal irradiance condition. From simulation results, it is found, that proposed system apart from the active the load uninterruptedly for various control where the load is non-linear and unbalance. After Investigations of all three control technique, it is found that CPT control technique is more suited for this type of application. Also, this control strategy regulates the output current by tracking references provided by CPT, without implementing any reference frame theory. The proposed system, due to its simplicity and

ability to provide many functions to the photovoltaic system simultaneously is a great solution for future smart grids Use of three phase three- level converters has several merits, like, the modularity in the system configuration with increased reliability, also allowing the use of independent DC link voltages, no need to used additional dc- dc boost cover/transformer. These features by themselves already make this topology to best interface medium and high power grid connected applications.

Table 3 Active and reactive power for different load

Control strategies	load	Active Power(RMS)			Reactive Power(RMS)			Load Current(RMS)		
		P(Grid)	P(PV)	P(Load)	Q(Grid)	Q(PV)	Q(Load)	I_a	I_b	I_c
PQ	RL	1682	2784	1131	2287	2573	412.6	1.67	1.41	1.56
	RC	11190	3015	13920	6320	3701	9401	23.96	21.13	20.9
	Unbalance load	16160	2981	18510	16260	3272	17640	25.18	43.72	28.85
DQ	RL	1242	2339	1108	1922	2244	418	1.64	1.40	1.50
	RC	11590	2660	13920	6978	3255	9401	23.98	21.13	20.9
	Unbalance load	14570	2856	16820	13620	2357	14420	24.87	37.73	22.25
CPT	RL	1245	2340	1108	3669	3984	418	1.65	1.43	1.53
	RC	13920	2720	15050	6899	2501	9401	20.05	20.05	20.05
	Unbalance load	19910	2229	20410	21930	36400	17220	23.5	45.73	32.25

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