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Power Quality Improvement by Using Synchronous Virtual Grid Flux Oriented Control of Grid Side Converter

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1. Introduction

The conventional energy sources are limited and have pollution to environment as more attention and interest have been paid on the utilization of renewable energy sources such as wind energy, fuel cells and solar energy. Distributed power generation system (DPGS) is alternative source of energy to meet rapidly increase energy consumption. These DPGS are not suitable to be connected directly to the main utility grid. Rapid development of power electronic devices and technology, double sided converters are used to interface between DPGS and utility grid as they match the characteristics of the DPGS and the requirements of the grid connections. Power electronics improves the performance of DPGS and increase the power system control capabilities, power quality issues, system stability [1].

Rapidly increase in number of DPGS's leads to complexity in control while integration to grid. As a result requirements of grid connected converters become stricter and stricter to meet very high power quality standards like unity power factor, less harmonic distortion, voltage and frequency control, active and reactive power control, fast response during transients and dynamics in the grid. Hence the control strategies applied to DPGS become of high interest and need to further investigated and developed [3].

In this chapter, a virtual grid flux oriented vector control [2] (outer loop controller) and three different types of current controllers such as hysteresis current controller, current regulated delta modulator, modified ramp type current controller (inner current loop) techniques are proposed, with main focus on DC link voltage control, harmonic distortion, constant switching frequency, unity power factor operation of inverter. Vector control of grid connected inverter is similar to vector control of electric machine. Vector control uses decoupling control of active and reactive power. The control system for the vector control of grid connected converter consists of two control loops. The inner control loop controls the active and reactive grid current components. The outer control loop determines the active current reference by controlling the direct voltage. A cascaded control system, such as vector control is a form of state feedback. One important advantage of state feedback is that the inner control loop can be made very fast. For vector control, current control is the inner control loop. The fast inner current control nearly eliminates the influence from parameter variations, cross coupling, disturbances and minor non-linearity in the control process. Vector control uses PI-controllers in order to improve dynamic response and to reduce the

cross coupling between active and reactive powers. Hysteresis current controller is used as inner current control loop to provide switching pulses to inverter, it has good dynamic response it is more suitable as inner current controller where we need fast acting inner current loop, but drawback of this hysteresis current controller is variation of switching frequency with parameters of grid voltage, filter inductor and output current is having lower order harmonics. In current regulated delta modulator switching frequency of inverter is limited by using latch circuit, but in this case also switching frequency is not maintaining constant during fundamental period. In Modified ramp type current controller switching frequency is limited, also maintain switching frequency constant. This controller ramp signal is generated at particular frequency to maintain switching frequency constant [4],[5],[6].

2. Configuration of DPGS and its control

The configuration of Distributed Power Generation System depends on input power sources (wind, solar etc) and different hardware configurations are possible. The basic structure of DPGS is shown in fig.1. The system consists of renewable energy sources, two back-to-back converters with conventional pulse width modulation techniques, grid filter, transformer and utility grid [1].

The input-side converter, controlled by an input side controller, normally ensures that the maximum power is extracted from the input power source and transmits the information about available power to the grid-side controller.

The main objective of the grid-side controller is to interact with the utility grid. The grid-side controller controls active power sent to the grid, control of reactive power transferred between the DPGS and the grid, control of the DC-link voltage, control of power quality and grid synchronization. Grid filter and transformer eliminates harmonics in inverter output voltage and ensures proper synchronization of inverter with grid.

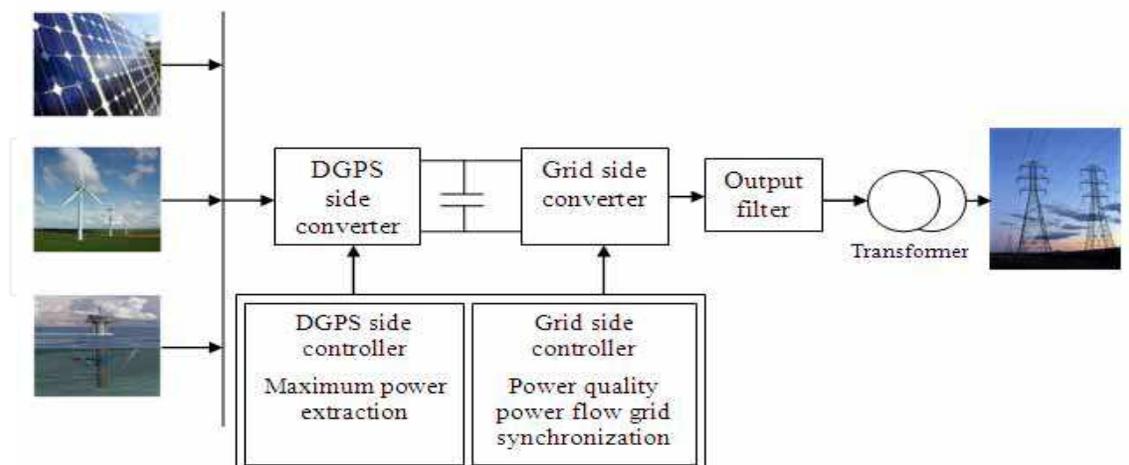


Fig. 1. General structure of distributed power generating system

2.1 Grid connected system requirements

The fundamental requirements of interfacing with the grid are as follows, the voltage magnitude and phase must equal to that required for the desired magnitude and direction

of the power flow. The voltage is controlled by the transformer turn ratio and/or the rectifier inverter firing angle in a closed-loop control system. The frequency must be exactly equal to that of the grid, or else the system will not work. To meet the exacting frequency requirement, the only effective means is to use the utility frequency as a reference for the inverter switching frequency.

Earlier, control and stabilization of the electricity system as taken care only by large power system like thermal, nuclear etc. due to large penetration of DPGS the grid operators requires strict interconnection called grid code compliance. Grid interconnection requirements vary from country to country. Countries like India where the wind energy systems increasing rapidly, a wind farm has to be able to contribute to control task on the same level as conventional power plants, constrained only by limitation of existing wind conditions. In general the requirements are intended to ensure that the DPGS have the control and dynamic properties needed for operation of the power system with respect to both short-term and long-term security of supply, voltage quality and power system stability. In this paper most significant requirement is power quality. The power quality measurement is mainly the harmonic distortion and unity power factor [2].

3. Virtual grid flux oriented control

Virtual grid flux vector control of grid connected Pulse Width Modulated (PWM) converter has many similarities with vector control of an electric machine. In fact grid is modeled as a synchronous machine with constant frequency and constant magnetization[2]. A virtual grid flux can be introduced in order to fully acknowledge the similarities between an electric machine and grid. In space vector theory, the virtual grid flux becomes a space vector that defines the rotating grid flux oriented reference frame, see in fig.2. The grid flux vector is aligned along d-axis in the reference frame, and grid voltage vector is aligned with q-axis. Finding the position of grid flux vector is equivalent to finding the position of the grid voltage vector. An accurate field orientation can be expected since the grid flux can be measured. The grid currents are controlled in a rotating two-axis grid flux orientated reference frame. In this reference frame, the real part of the current corresponds to reactive power while the imaginary part of the current corresponds to active power. The reactive and active power can therefore be controlled independently since the current components are orthogonal. Accurate field orientation for a grid connected converter becomes simple since the grid flux position can be derived from the measurable grid voltages. The grid flux position is given by

$$\cos(\theta_g) = \frac{e_{g\beta}}{|e_g|}, \quad \sin(\theta_g) = -\frac{e_{g\alpha}}{|e_g|} \quad (1)$$

3.1 Action of Phase lock loop (PLL)

The implementation of the grid voltage orientation requires the accurate and robust acquisition of the phase angle of the grid voltage fundamental wave, considering strong distortions due to converter mains pollution or other harmonic sources. Usually this is accomplished by means of a phase lock loop (PLL). PLL determines the position of the virtual grid flux vector and provides angle (θ_g) which is used to generate unit vectors $\cos(\theta_g)$, $\sin(\theta_g)$ for converting stationary two phase quantities in stationary reference frame

into rotating two phase quantities in virtual grid flux oriented reference frame. PLL ensures the phase angle between grid voltages and currents is zero. That means PLL provides displacement power factor as unity.

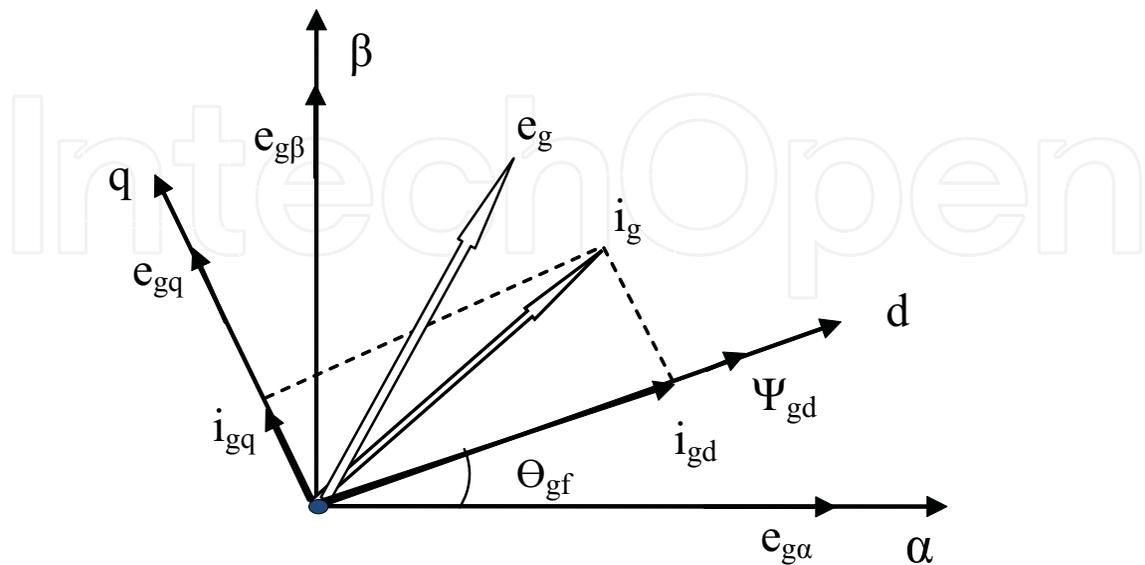


Fig. 2. Virtual grid flux oriented reference frame

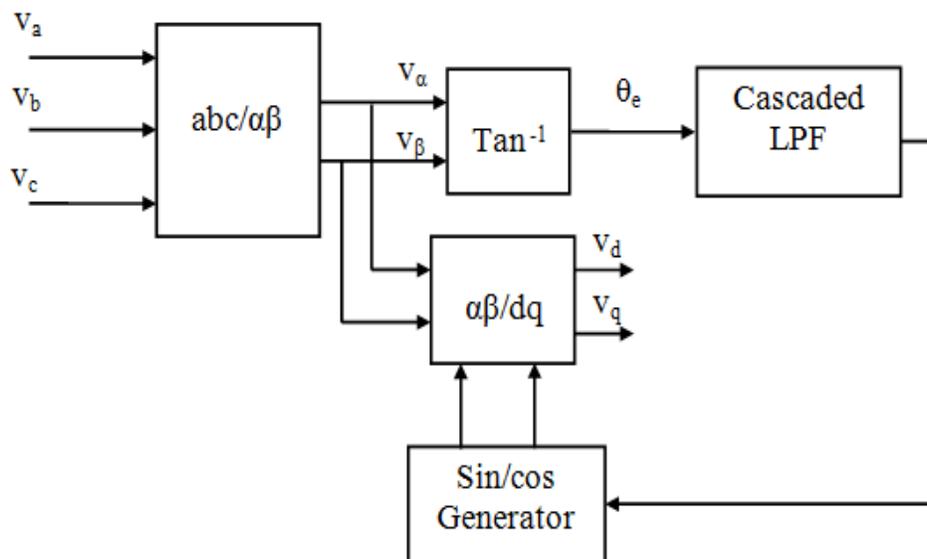


Fig. 3. Instantaneous PLL circuit

3.2 Control scheme for grid connected VSI

The block diagram of purposed system is shown in fig .4. The control system of vector controlled grid connected converter here consisting two control loops. The inner control loop having novel hysteresis current controller which controls the active and reactive grid current components. The active current component is generated by an outer direct voltage control loop and the reactive current reference can be set to zero for a unity power factor. The grid currents are controlled in a rotating two-axis grid flux orientated reference frame.

In this reference frame, the real part of the current corresponds to reactive power while the imaginary part of the current corresponds to active power. The reactive and active power can therefore be controlled independently since the current components are orthogonal [2].

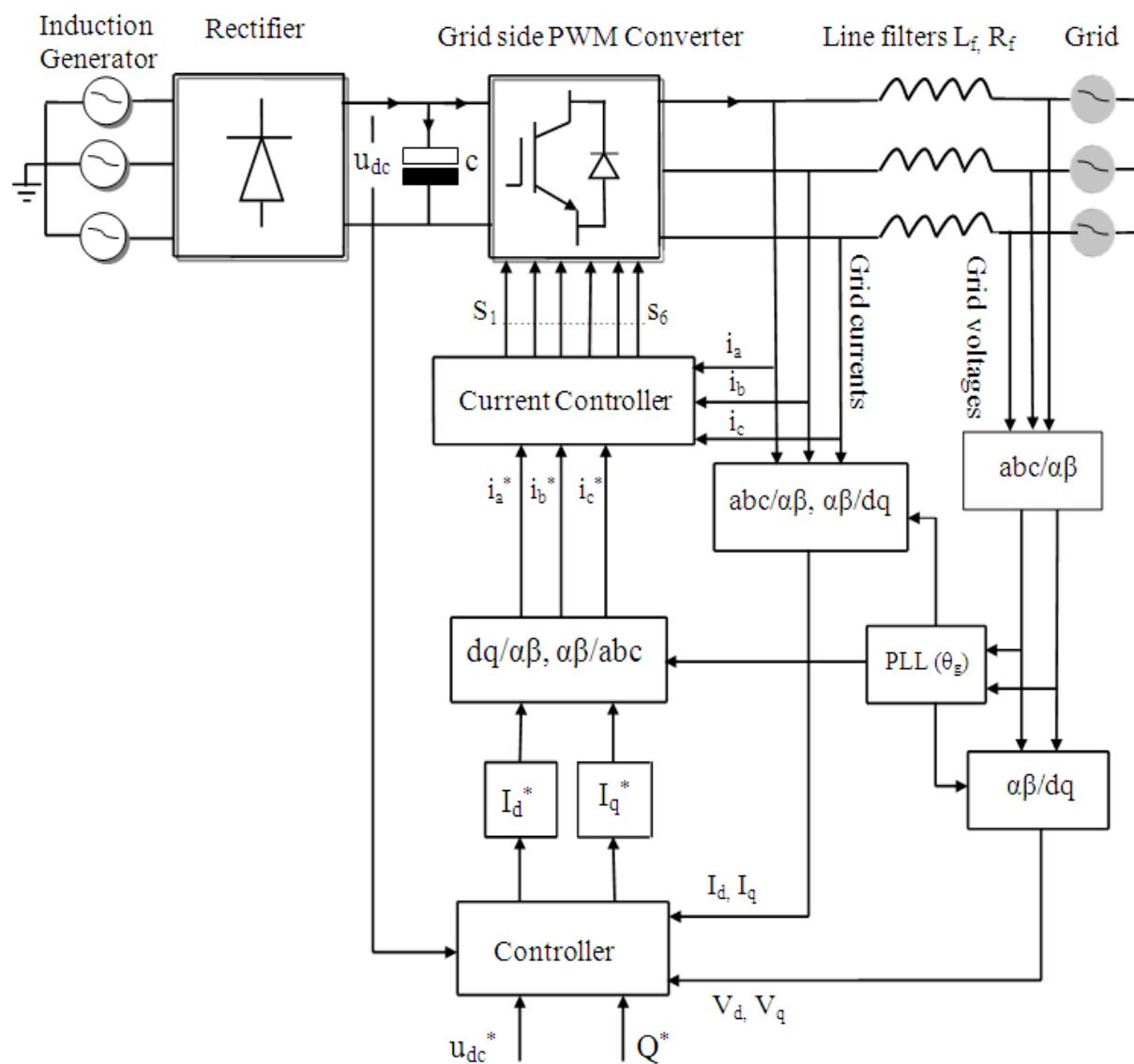


Fig. 4. Block diagram of virtual grid flux oriented control of grid connected VSI

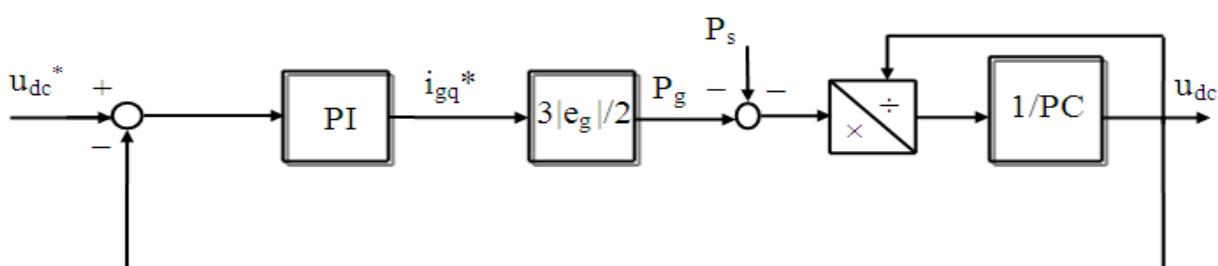


Fig. 5. Block diagram of closed loop control of dc link voltage

3.2.1 DC voltage controller (outer loop)

The following derivation of direct voltage controller assumes instantaneous impressed grid currents and perfect grid flux orientation. The instantaneous power flowing into grid can be written as

$$S_g = P_g + jQ_g = \frac{3}{2} e_g i_g^* = \frac{3}{2} (|e_g| i_q + j |e_g| i_d) \quad (2)$$

$$S_g = \frac{3}{2} (|e_g| i_q + j |e_g| i_d) \quad (3)$$

The active power is real part of equation.3.

$$P_g = \frac{3}{2} |e_g| i_{gq} \quad (4)$$

When neglecting capacitor leakage, the direct voltage link power is given by

$$P_{DC} = u_{DC} i_{DC} = u_{DC} C \frac{du}{dt} \quad (5)$$

Assuming the converter losses are neglected, the power balance in the direct voltage link is given by

$$u_{DC} C \frac{du_{DC}}{dt} = -P_s - P_g = -P_s - \frac{3}{2} |e_g| i_{gq} \quad (6)$$

Where P_s is the distributed energy system power is assumed to be independent of the DC voltage. A transfer function of between direct voltage and active grid current I_g is obtained as

$$u_{DC} \approx -\frac{3|e_g|}{2pCu_{DC}} i_{gq} \quad (7)$$

The transfer function is non-linear. It is acceptable to substitute the direct voltage with the reference set value since the objective is to maintain a constant direct voltage. The assumption gives linearized transfer function.

$$u_{DC} \approx -\frac{3|e_g|}{2pCu_{DC}^*} i_{gq} \quad (8)$$

Applying internal model control gives the direct voltage link controller as

$$F = \frac{\alpha}{p} G^{-1} = -\alpha \frac{2Cu_{dc}^*}{3|e_g|} \quad (9)$$

From eq.8, a P-controller is obtained for regulating the direct voltage. The P- controller is optimal for an integrator process in the sense that the P- controller eliminates the remaining error for steps in the reference value. However, there will be a remaining error for steps in

the reference value. However, there will be a remaining error when the grid is loaded and active power flows between the direct voltage link and the grid. The remaining error can be eliminated by adding an integrator to the direct voltage link controller. The following is often adapted for selecting the controller integration time in traditional PI-controller design.

$$T_i = \frac{10}{\omega_c} \approx \frac{10}{\alpha} \quad (10)$$

The active reference current of the grid connected converter can be written as

$$i_{gq}^* = K_p \left(1 + \frac{1}{T_i p}\right) (u_{dc}^* - u_{dc}) \quad (11)$$

$$k_p = -\alpha \frac{2Cu_{dc}^*}{3|e_g|} \quad (12)$$

Negative proportional gain is because the distributed energy source references are used for grid. A block diagram that represents the direct voltage control is shown in Fig. 5. Note that closed-loop bandwidth of the current control is assumed to be much faster than the closed-loop bandwidth of the direct voltage link.

3.2.2 Open loop reactive power control (outer loop)

The reactive power flowing into grid is controlled by the reactive current component. Simplest form of controlling reactive power is through open loop control. Taking imaginary part of eq.3 reactive reference current as

$$i_{gd}^* = \frac{2}{3e_{gq}} Q_g^* \quad (13)$$

The i_{gq}^* and i_{gd}^* current references are converted into three phase current references i_a^* , i_b^* , i_c^* which are given to current controller.

4. Current control approach to VSI

4.1 Objectives

The current control methods play an important role in power electronic systems, mainly in current controlled PWM voltage source inverters which are widely used in ac motor drives, active filters, and high power factor, uninterruptable power supply (UPS) systems, and continuous ac power supplies [5]. The performance of converter system is largely dependence on type of current control strategy. Therefore current controlled PWM voltage source inverters are one of the main subjects in modern power electronics. Compared to conventional open loop PWM voltage source inverter, the current controlled PWM voltage source inverters have following advantages:

1. Control of instantaneous current waveform and high accuracy.
2. Peak current protection.
3. Overload rejection.
4. Extremely good dynamics.

5. compensation of effects due to load parameter variations(resistance and reactance).
6. Compensation of semiconductor voltage drop and dead times of converter.
7. Compensation of DC link and AC side voltages.

4.1.1 Basic scheme of current controlled PWM

The main task of current controller in PWM VSI is to force the load current according to the reference current trajectory [6] by comparing to command phase currents with measured instantaneous values of phase currents, the current controller generates the switching states for the converter power devices in such a way that error current should be minimized. Hence current control implements two tasks, error compensation (decrease in current error) and modulation (determination of switching states).

4.1.2 Basic requirement and performance criteria

Basic requirements of current controller are as follows [16]

1. No phase and amplitude errors (ideal tracking) over a wide output frequency range.
2. To provide high dynamic response of system.
3. Limited or constant switching frequency of converter to ensure safety operation of converter semiconductor power devices.
4. Low harmonic content
5. Good dc-link voltage utilization.

Some of the requirements like fast response and low harmonic distortion contradict each other.

4.2 Different current control techniques

4.2.1 Hysteresis current control technique

Hysteresis current controller is an instantaneous feedback system which detects the current error and produces driver commands for switches when error exceeds specified band.

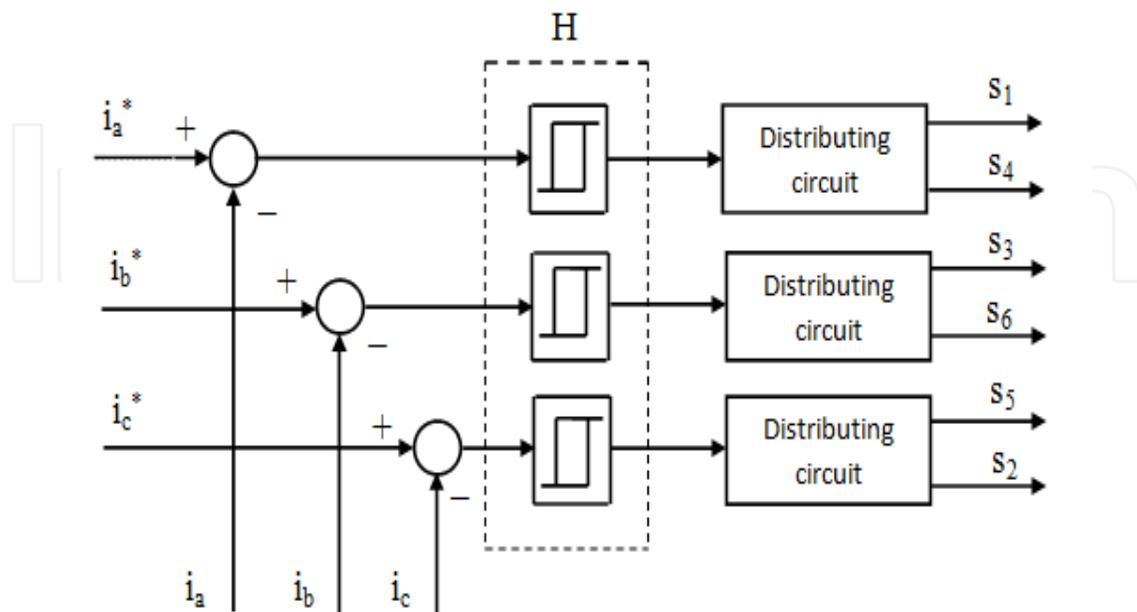


Fig. 6. Hysteresis current control scheme

The purpose of the current controller is to control the load current by forcing it to follow a reference one. This is achieved by the switching action of the inverter to keep the current within the hysteresis band. Simplified diagram of a typical three-phase hysteresis current controller is shown in fig. 6, The load currents are sensed and compared with the respective command currents using three independent hysteresis comparators having a hysteresis band H . the output signals of the comparators are used to active the inverter power switches. Based on the band, there are two types of current controllers, namely, the fixed band hysteresis current controller and sinusoidal band hysteresis current controller [5].

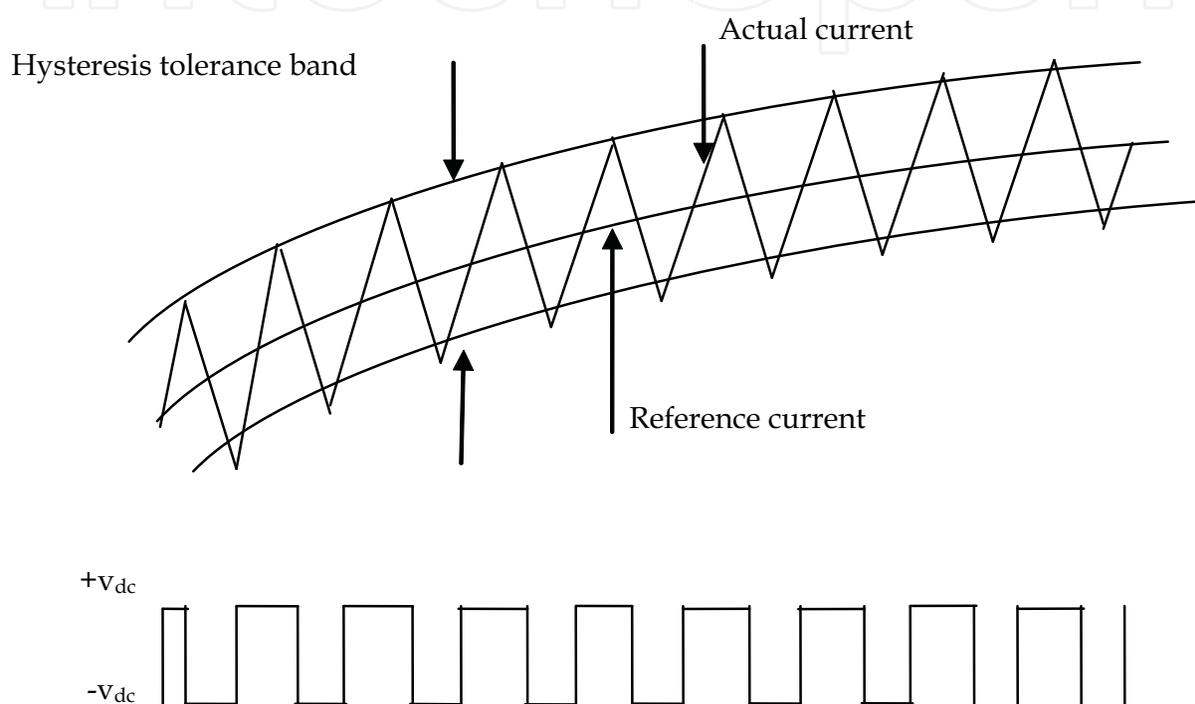


Fig. 7. Hysteresis current control operation

4.2.2 Current regulated delta modulator

Current regulated delta modulator operation is same as that of hysteresis current controller. Main advantage of delta modulator is switching frequency variation is very less and we can limit switching frequency to desirable frequency. Circuit diagram of current regulated delta modulator is shown in fig. 8. This consists of comparators and latch to limit switching frequency [7]. Actual grid currents compared with reference currents provides error currents, this error currents are flowing into comparator. These comparators are acting like hysteresis limiters which limit error current between two bands and generate pulses. These pulses are given to latching circuit as binary values 0 and 1. Latching circuit is operated when clock signal is enabling the latch. Switching frequency of inverter is decided clock frequency of latch. Operation of latch is that it holds the input until the clock signal enables the latch. When clock signal applied latch will enable and it will give output to gate drive circuit, which drives the inverter in such a way that error current should be minimized and grid current most follow the reference current value.

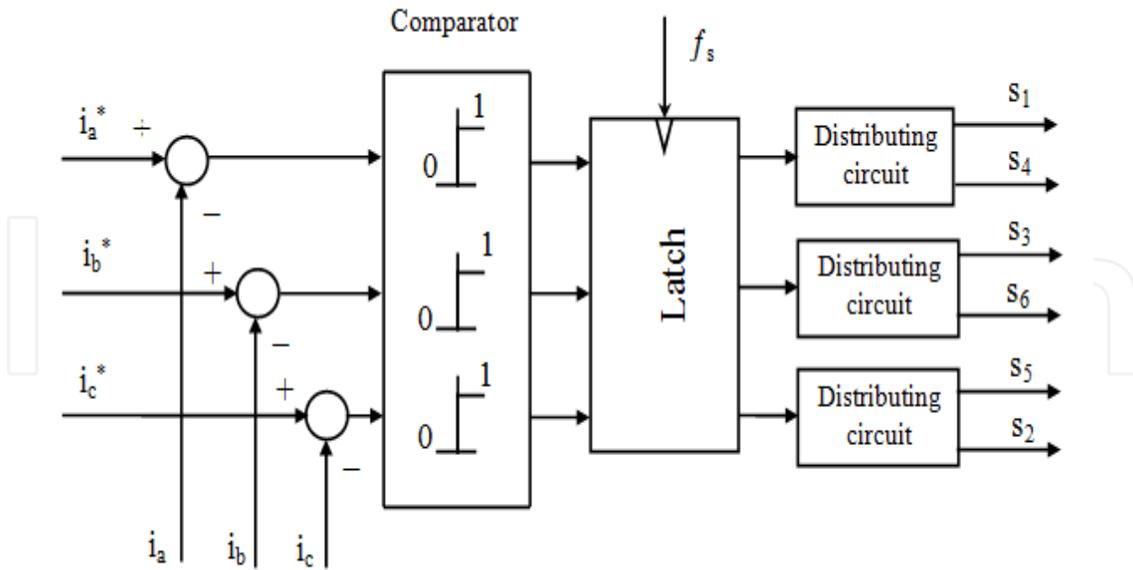


Fig. 8. Current regulated delta modulator scheme

The delta modulation offers an opportunity of on-line harmonic minimization of pulse width modulated inverter without conventional optimization processes, like selective harmonic elimination or harmonic weighting techniques.

4.2.3 Modified ramp type current controller

A conventional ramp-comparator controller is also shown in fig. 9, the phase shifters are bypassed. The actual values of the three-phase load currents are measured and compared to the references currents.

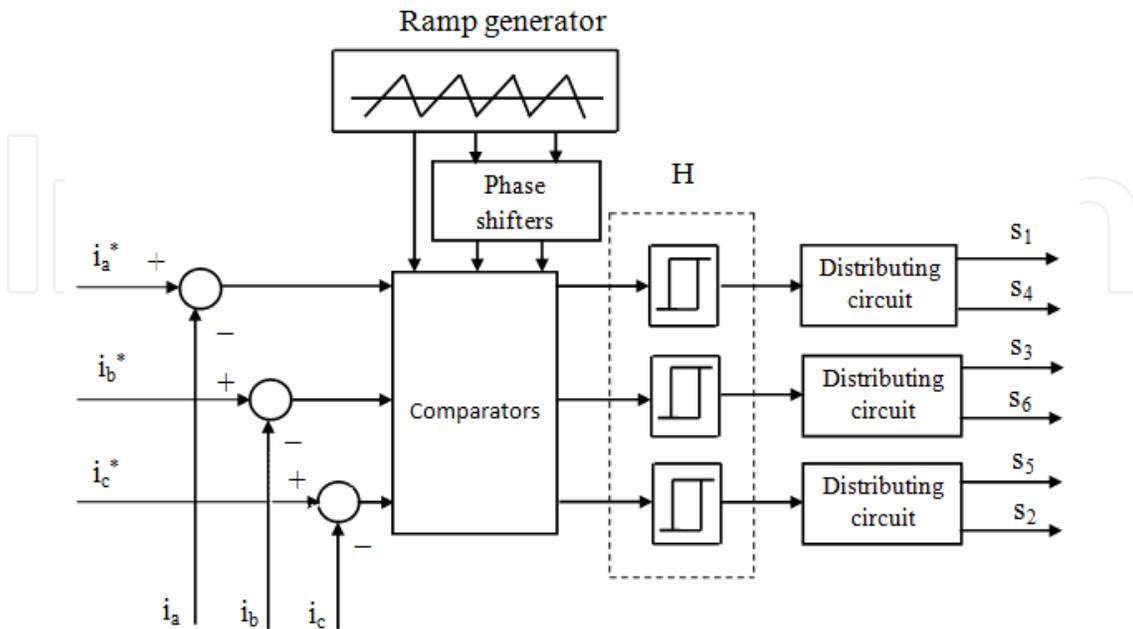


Fig. 9. Modified ramp type current control scheme

The generated error signals are compared to a triangular waveform of fixed frequency and amplitude. If the current error signal is positive and larger than the triangular wave, the switches are activated to apply +VB to the load. However, if current error signal is positive and smaller than the triangular wave, the switches are activated to apply -VB to the load. Some hysteresis has been added to the controller, in order to prevent multiple crossings of the error signals with the triangular wave. The ramp-comparator controller is a modulation system. The frequency of the triangular wave is the carrier frequency, while the error current signal is a modulated waveform.

Since this controller uses a fixed-frequency triangular wave, it has the effect of maintaining a constant switching frequency of the inverter. This is the main advantage of this controller. However, it has some disadvantages, as the output current has amplitude and phase errors. This results in a transmission delay in the system. Moreover, a zero vector is applied to the load. This means load is disconnected several instants over the fundamental period of the output voltage. In order to overcome the above difficulties, a new ramp-comparator controller is proposed. Fig.9 shows the schematic diagram of this controller, in which the phase shifters are included. The actual values of the three phase load currents are measured and compared to the three 120° phase-shifted triangular waveforms having the same fixed frequency and amplitude. The performance of this scheme is considered identical to those for three independent single-phase controllers. It is to be noted that there is no interaction between the operations of the three phases. As a result, the zero voltage vectors will be eliminated for balanced operation. This does not necessarily lead to the possibility of creating the positive and/or negative sequence sets due to the controller alone. The zero voltage vectors eliminate the necessity of neutral connections for some applications and, in such cases; no harmonic neutral current can flow in the load. Thus, there is no problem of incorporating the proposed controller in industrial motor drives. For applications in UPS's and active filters, the higher harmonics lead to more losses. However, the shifting of current harmonics to higher orders does not usually create noticeable problems in motor drives, as the machine inductance filters out the higher harmonics and limits the associated detrimental effects[5].

5. Simulation results of grid connected VSI

Simulation of virtual grid flux oriented control of grid connected VSI was done by using MATLAB/Simulink and results for different types of current controllers has shown below

5.1 Simulation results of hysteresis current controller

For the simulation of virtual grid flux oriented control of grid connected inverter the following are the set values

DC link reference voltage (u_{dc}^*)	= 2200V
DC link capacitance (C)	= 600UF
Reference Reactive power (Q^*)	= 0 VAr
Hysteresis band width (H)	= 20 Amp
Ramp generator frequency	= 2 KHz
Proportional Gain (K_p)	= 0.01
Integral Gain (K_i)	= 60

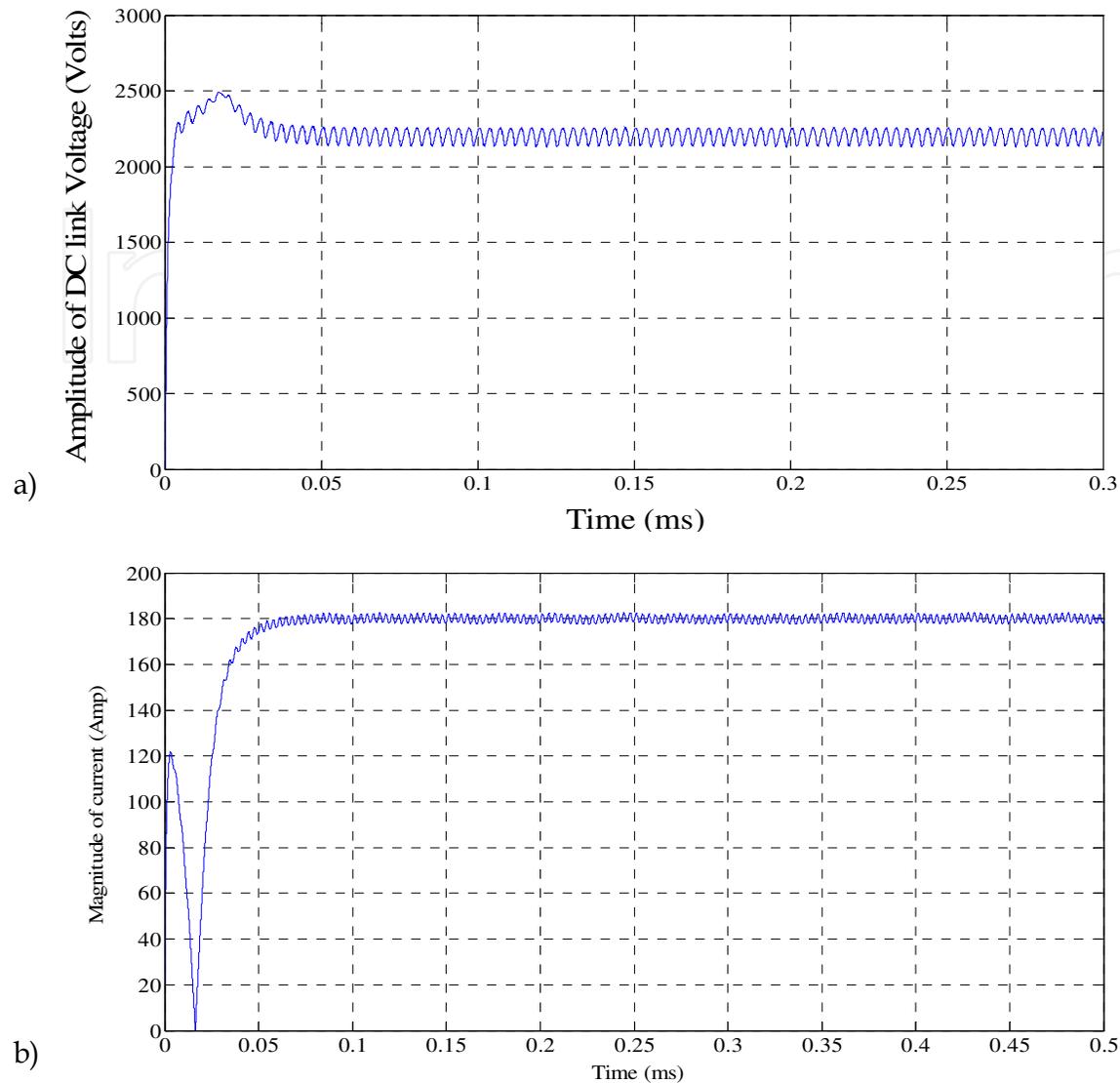


Fig. 10. (a) DC link voltage (b) Active component of grid current i_q^*

Above mentioned figures shows the waveforms of DC link voltage in fig. 10 (a) and active component of grid current reference I_q^* in fig. 10(b). The DC link voltage is maintained at its reference set value of 2.2KV which is shown in fig. 10(a). From fig. 10(b) active component of grid current i_q^* in synchronous reference frame is obtained from the PI controller using error of DC link voltage by controlling DC link voltage to its reference value. This grid current reached to steady state within 0.05sec this shows fastness of inner current control loop. The Form figures we can see that current reaches to zero value which is due to DC link voltage is more than the set reference value, then error is going to be negative which makes the current to decrease. Then PI controller will act on DC link voltage of maintained at its reference value then error is zero. Hysteresis current controller controls the current is flowing into the grid to maintain set value of DC link voltage.

Above mentioned figures shows the waveforms of reactive component of grid current in fig. 11(a) and three-phase reference current waveforms fig. 11(b). Reactive component of grid current is zero because of reactive power flowing to grid is taken as zero to maintain unity

power factor at grid. Three-phase references current are obtained from the active and reactive grid current components after dq to ABC transformations.

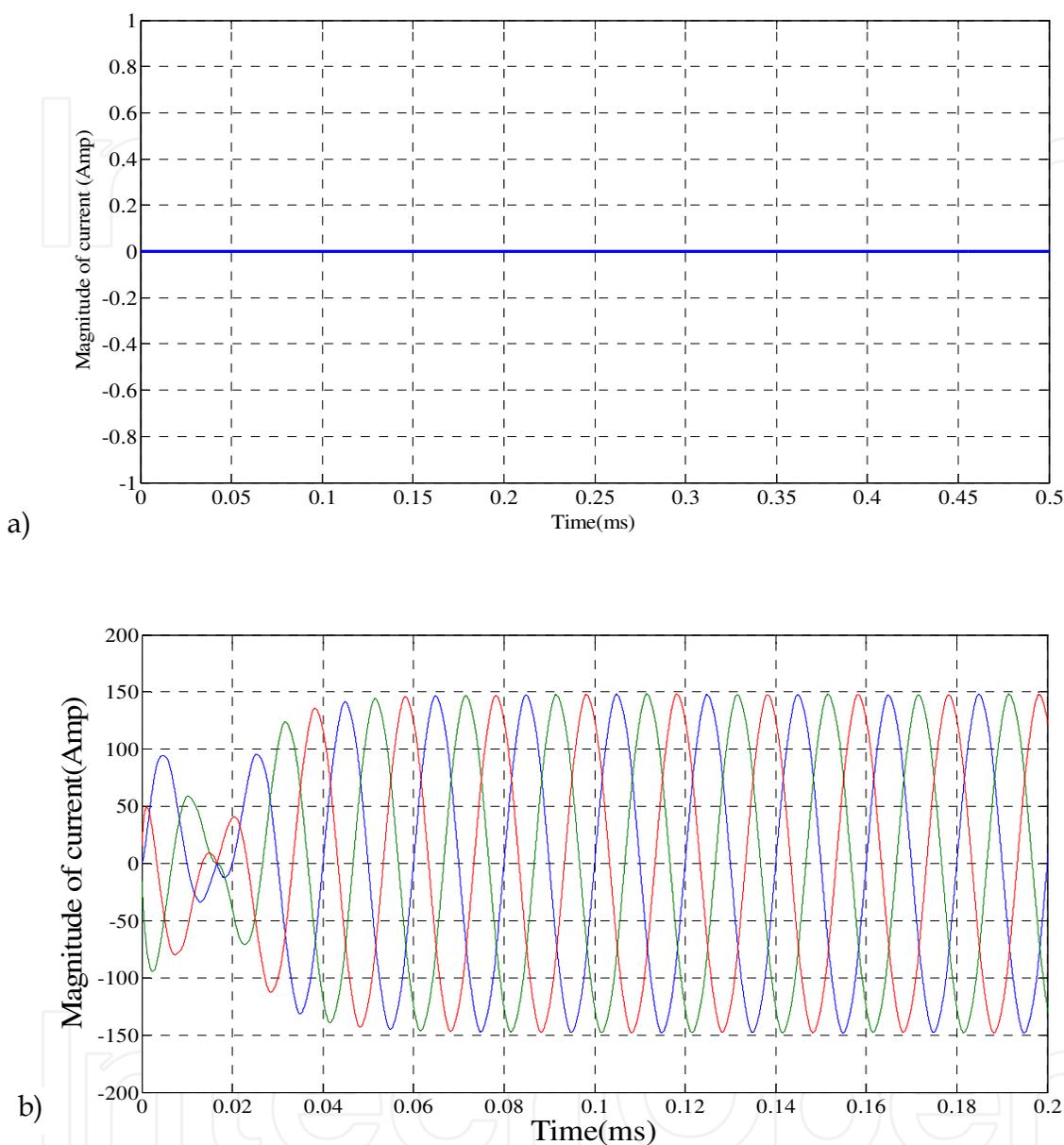


Fig. 11. (a) Reactive component of grid current (b) Three phase reference current waveform

Above mentioned figures shows the waveforms of three-phase grid current in fig. 12(a) and harmonic spectrum of grid current in fig. 12(b). the three phase grid current flows the actual reference current which we can see from figures 12(b), 12(a). THD spectrum of grid current is having percentage of THD is around 4.41 and having fundamental component of 144.4 amps. And it having few lower order harmonics which are due to ripple in DC link voltage at six times of supply frequency. This is because of reference current I_{gq}^* is generated from PI-controller through control of DC-link voltage if there is oscillation in DC link voltage which will inject into the reference current, their by load current is affected by this oscillations. Ripple in DC link voltage can be eliminated by using resonant DC link Inductor

which smoothness the current flowing in DC link capacitor their by ripple magnitude is decreased.

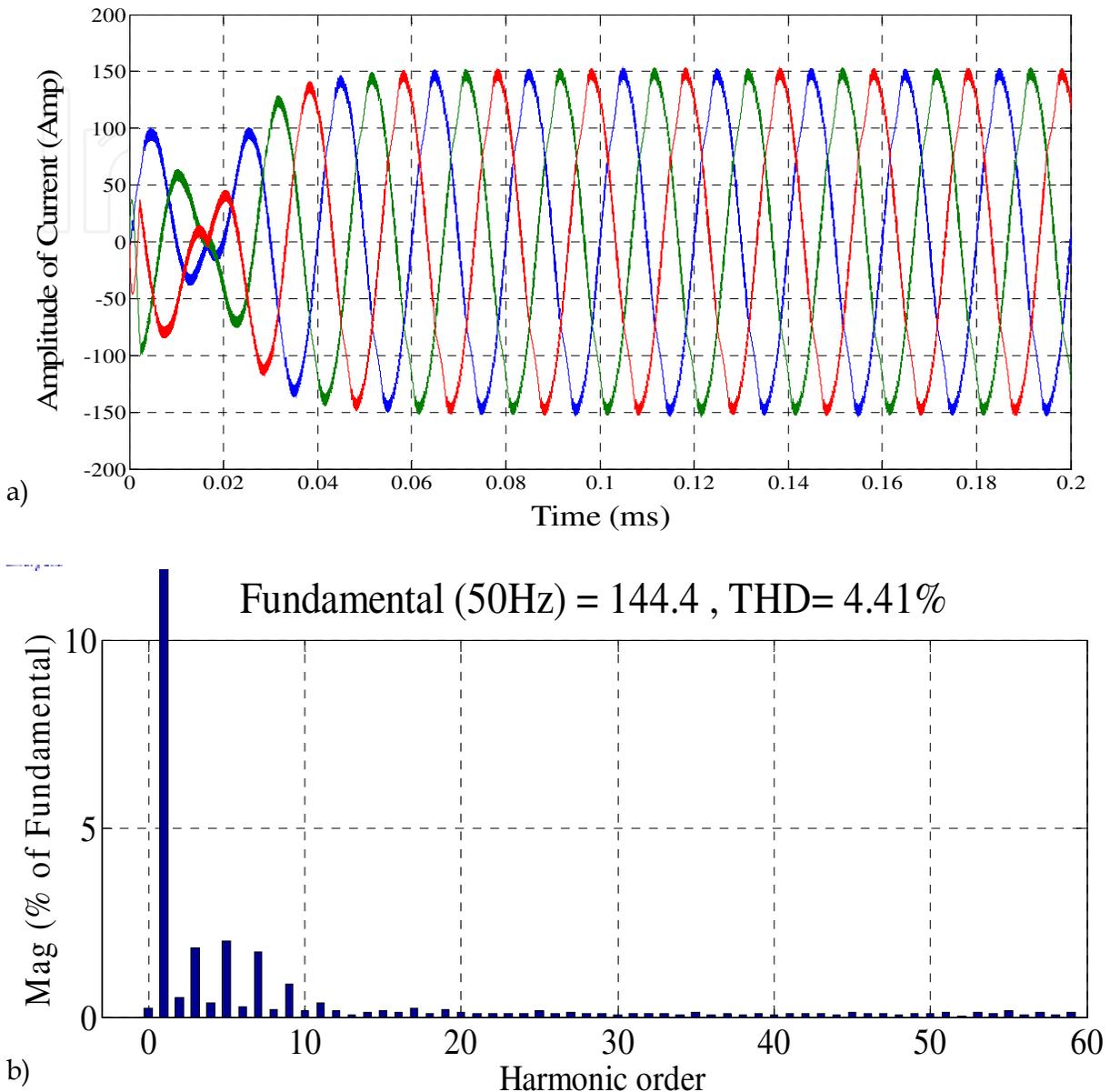


Fig. 12. (a) Three phase grid current waveform (b) Harmonic spectrum of grid current

Above mentioned figures shows the waveforms of output line voltage of VSI before filter in fig. 13(a) and grid line voltage waveform after filter inductor in fig. 13(b). Fig. 13(a) is output of inverter which is having some oscillations in the edges of inverter voltage around 2200V. This oscillation can be decreased by decrease ripple in DC link voltage. The inductor filter eliminates all harmonics present in output line voltage of VSI and produces pure sinusoidal voltage as that of grid voltage. And it ensures the proper synchronism between the VSI and Grid. We need to design the filter inductor and capacitor properly to synchronize inverter output with grid and drop across the filter elements should be very less. And these filter elements cannot make resonance with

transmission line parameters like series line inductance and line to ground capacitance otherwise there is large power oscillation in the grid which leads to power quality problem in the system.

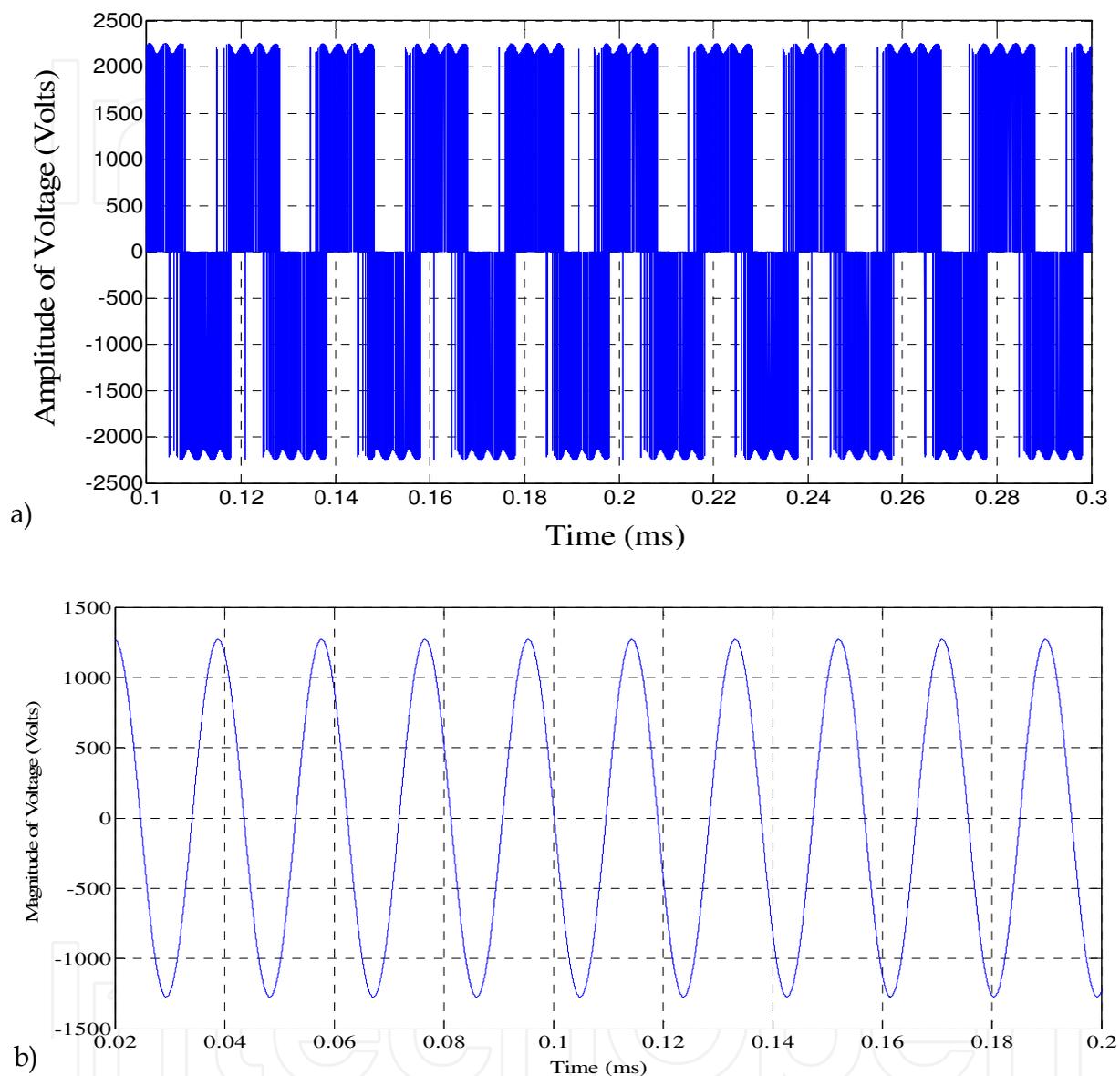


Fig. 13. (a) Output voltage of VSI before the filter (b) Grid voltage waveform

Figure 14 shows the waveforms of DC link capacitor current, inverter output voltage and displacement factor. Selection of capacitor is choice on basis of less ripple current in DC link capacitor. In fig. 14(a) capacitor is having fewer current ripples. And fig. 14(b) is displacement power factor, which is having value of 0.999999 almost unity power factor. This is because almost zero-phase angle difference between reference currents and Grid voltages. (i.e. reference currents follows the same phase as grid voltages).

Power factor

Distortion factor (DF) is given by formula

$$DF = \frac{1}{\sqrt{1 + THD^2}} \quad (14)$$

$$\text{Total power factor} = DF * DPF \quad (15)$$

$$DF = \frac{1}{\sqrt{1 + 0.0441^2}} = 0.999029011$$

$$\text{Total power factor} = 0.999029011 * 0.999999 = 0.9989.$$

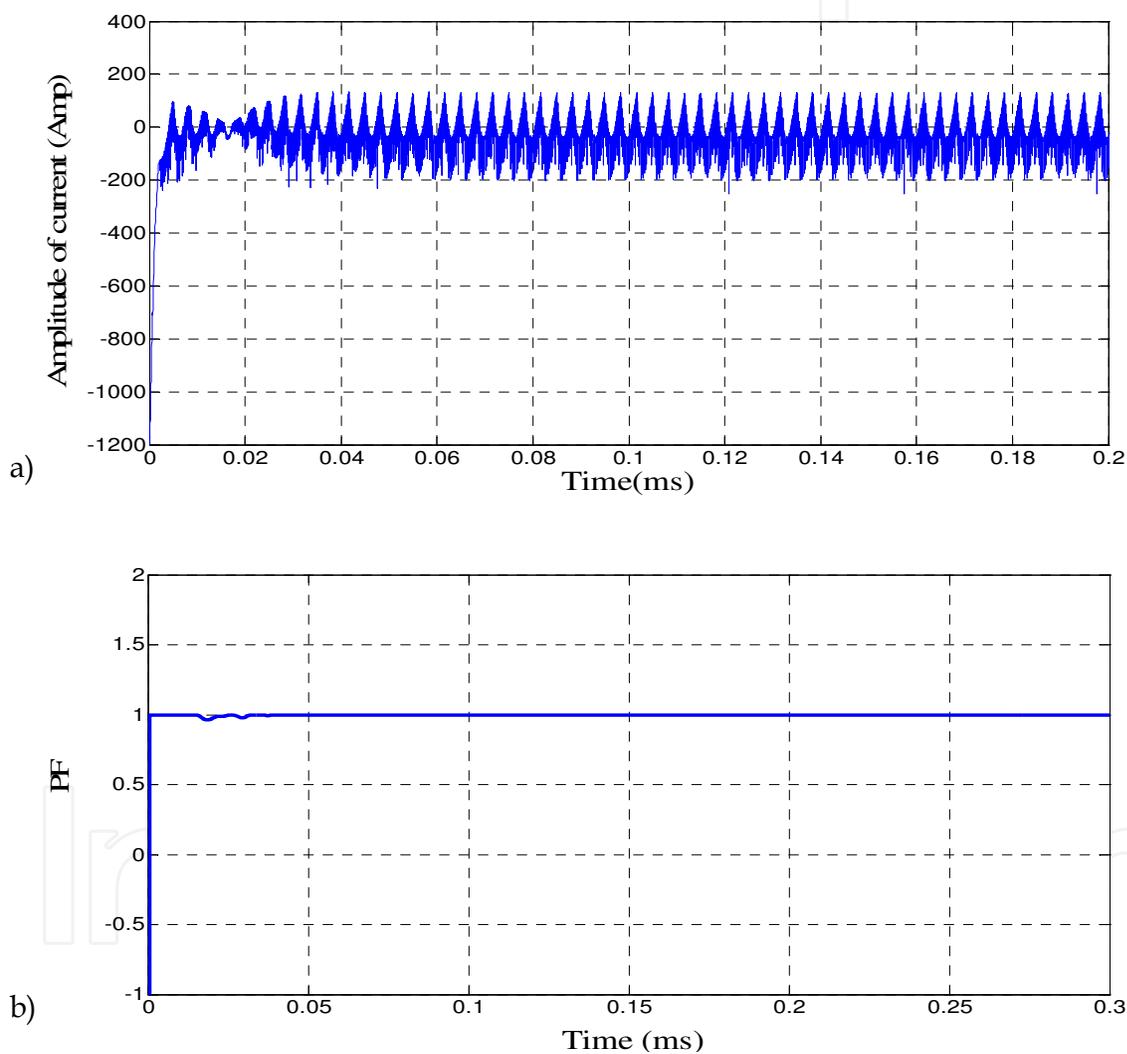


Fig. 14. (a) DC link Capacitor Current (b) Displacement power factor

Fig. 15(a) shows single phase instantaneous power and fig. 15(b) shows three phase average active power flowing into grid. The instantaneous power 'S' which is equal to active power flowing into grid this is due to zero phase angle difference between grid currents and grid voltages, from fig. 15(a) we can easily observe this fact (i.e. instantaneous power will not crossing zero that means reactive component of current flowing into grid is zero, only active component of current flowing). Fig. 15(b) shows the

three phase active power flowing into grid which is around 160 KW. The oscillatory nature of the power is because of the harmonics present in currents which are flowing into the grid. The harmonic content (oscillatory nature of power) can be reduced by reducing the hysteresis band width. But by reducing band switching frequency in hysteresis current controller is going high.

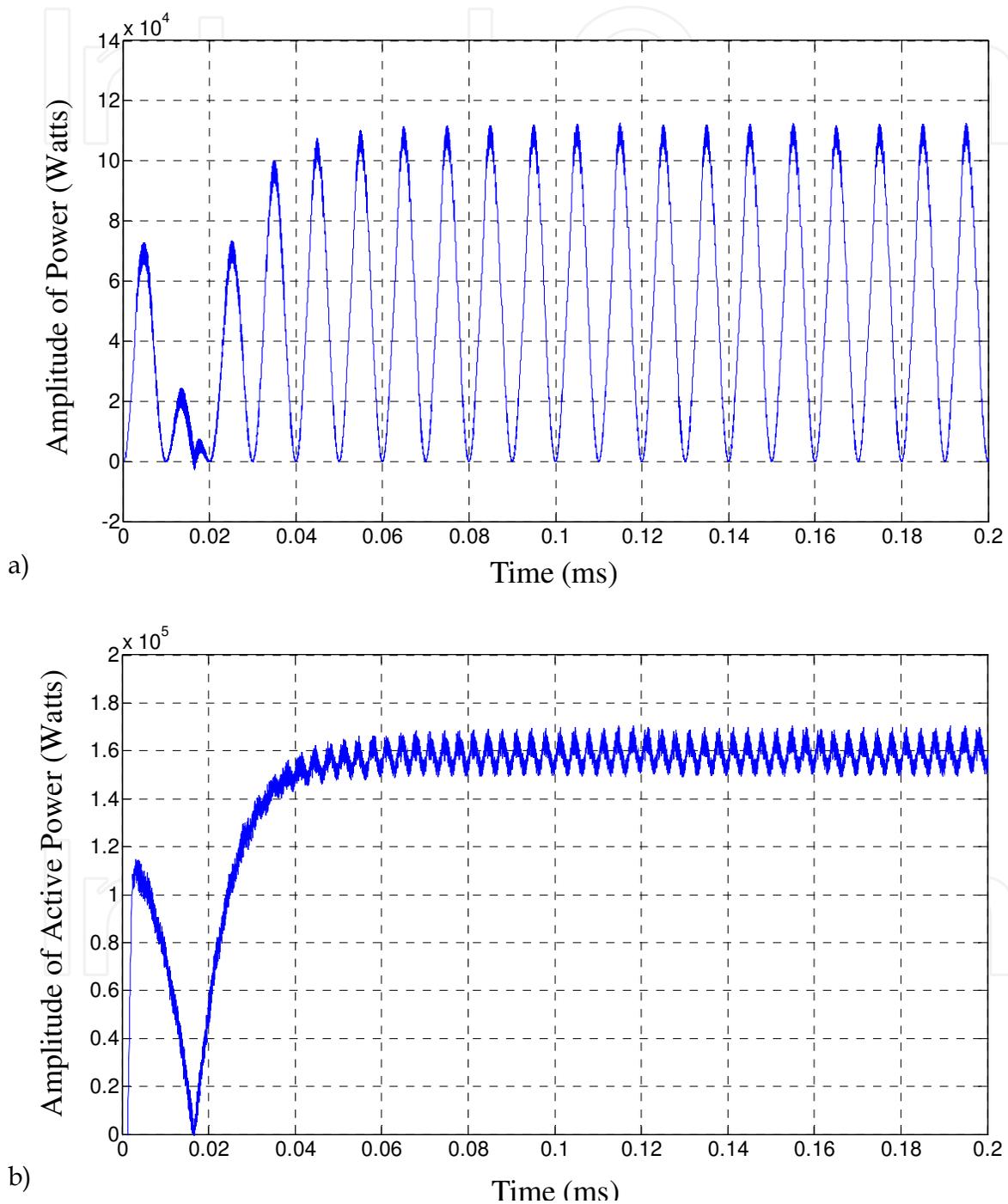


Fig. 15. (a) Single Phase Instantaneous Active Power (b) Three Phase Active Power

Figure 16 shows single phase instantaneous reactive and three phase reactive power flowing into grid. Fig. 16(a) shows instantaneous reactive power flowing into grid which

is oscillating around zero. Fig. 16(b) shows three phase reactive power flowing into grid which having average zero value, this because of reference set value of reactive power is zero (i.e. $Q^* = 0$ VAr). This ensures unity power factor operation of grid connected inverter. In such a case we are supplying only active power to the grid. The reactive power needed by the loads which are connected to the grid can be supplied from other generating stations or bulk capacitors connected to grid to maintain grid power factor almost unity.

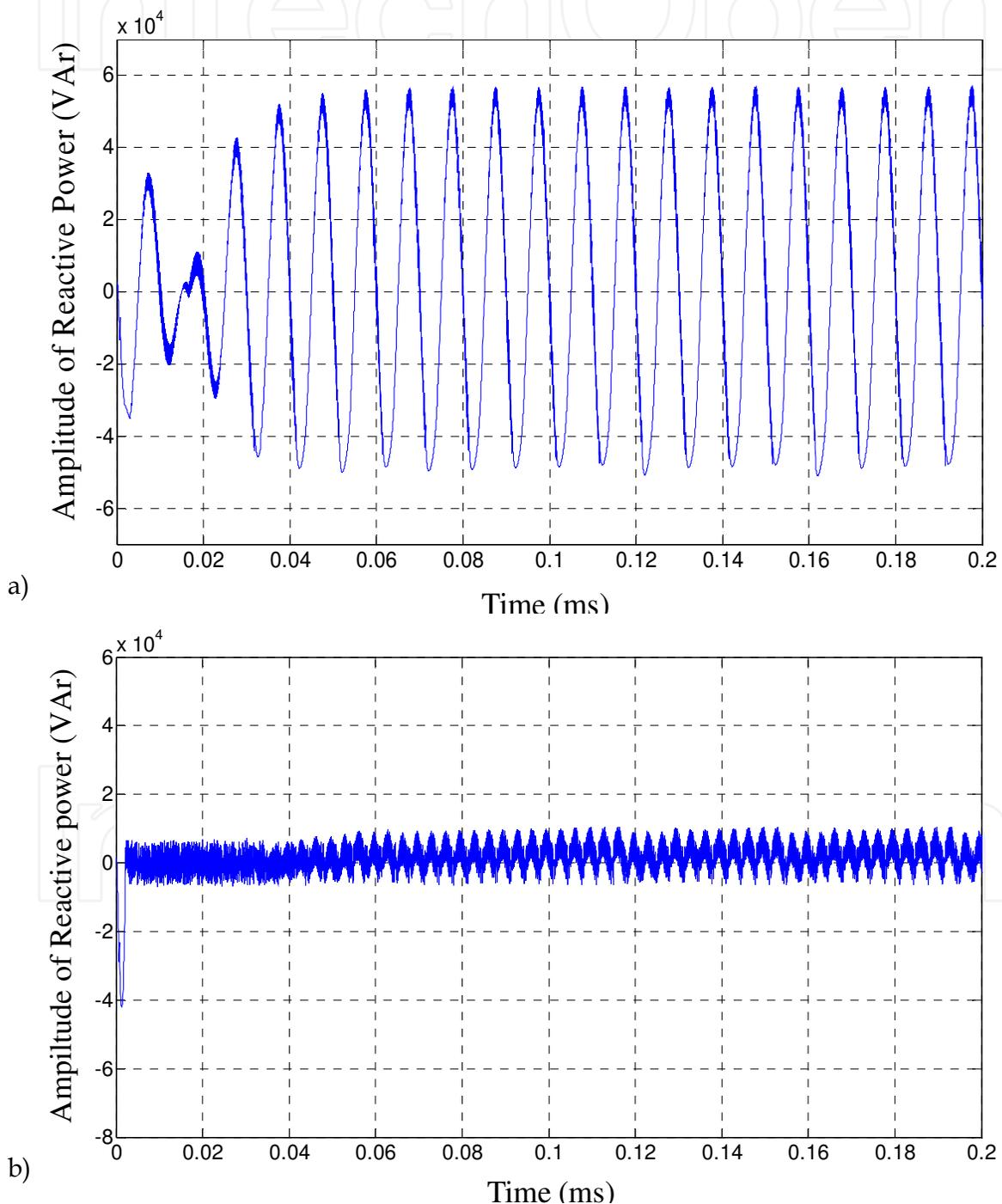


Fig. 16. (a) Single phase instantaneous reactive power (b) Three phase reactive power

5.2 Simulation results of current regulated delta modulator

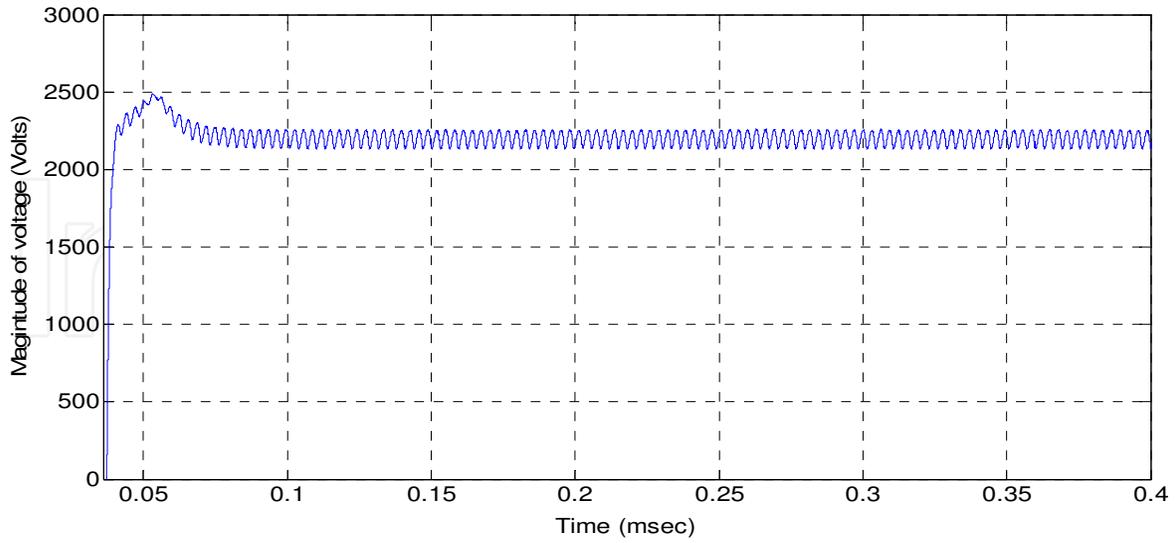
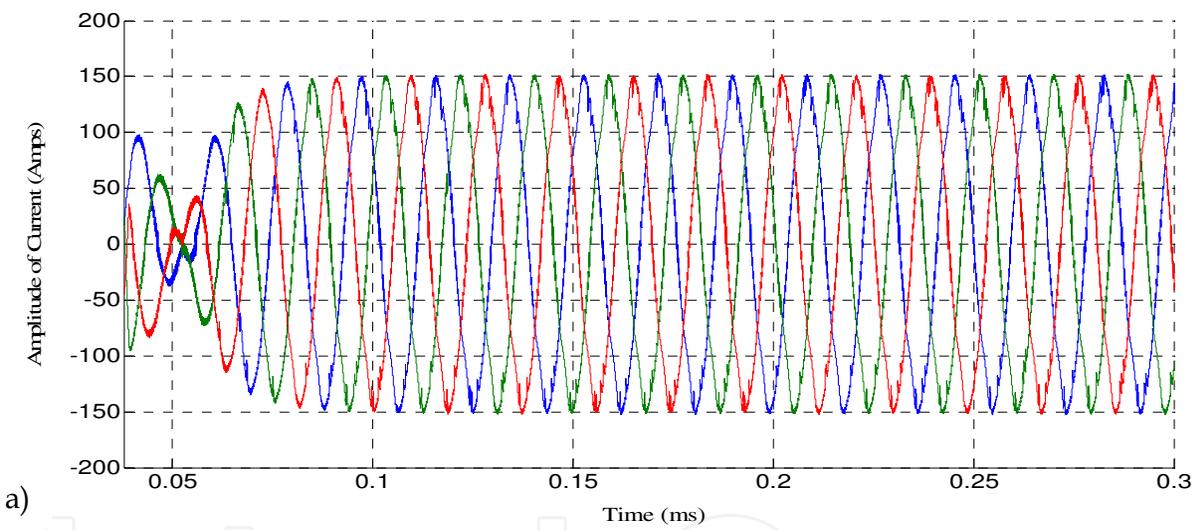
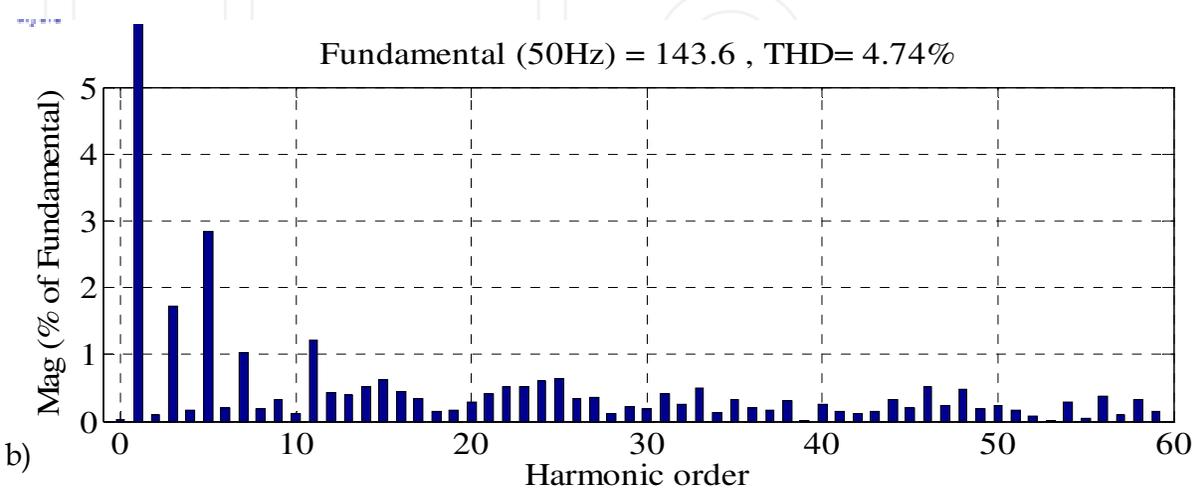


Fig. 17. DC link voltage



a)



b)

Fig. 18. (a) Three phase grid current waveform (b) Harmonic spectrum of grid current

5.3 Simulation results for ramp type current controller

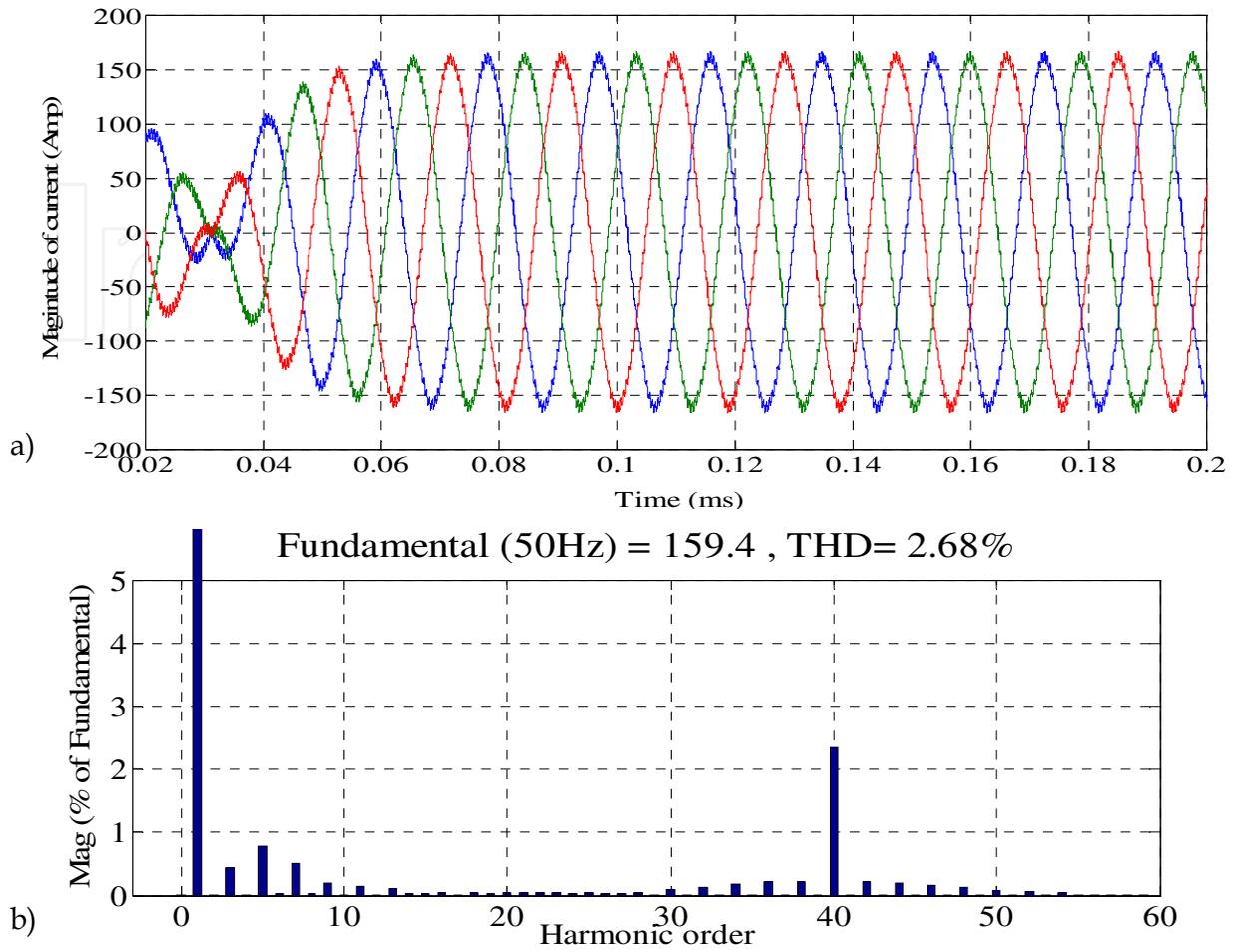


Fig. 19. (a) Three phase grid current waveform (b) Harmonic spectrum of grid current

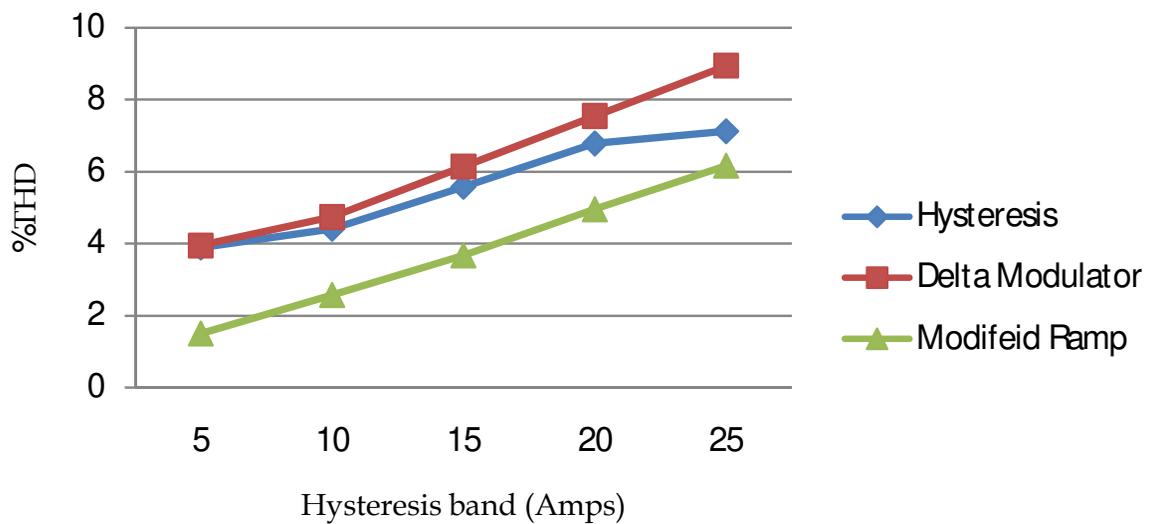


Fig. 20. Variation of % THD with hysteresis band

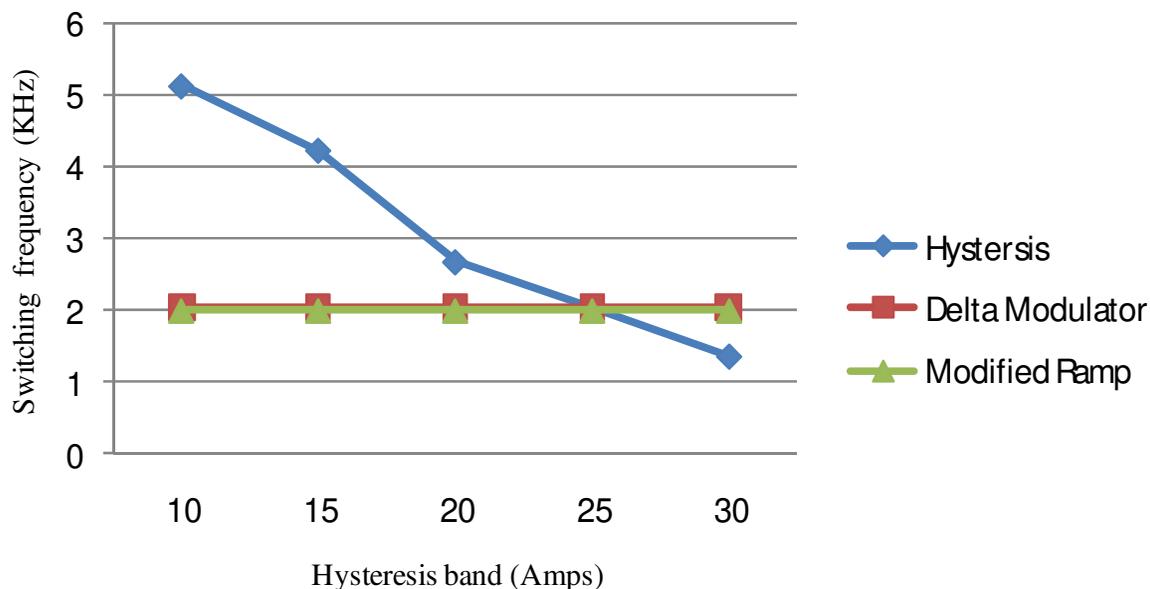


Fig. 21. Variation of switching frequency with hysteresis band

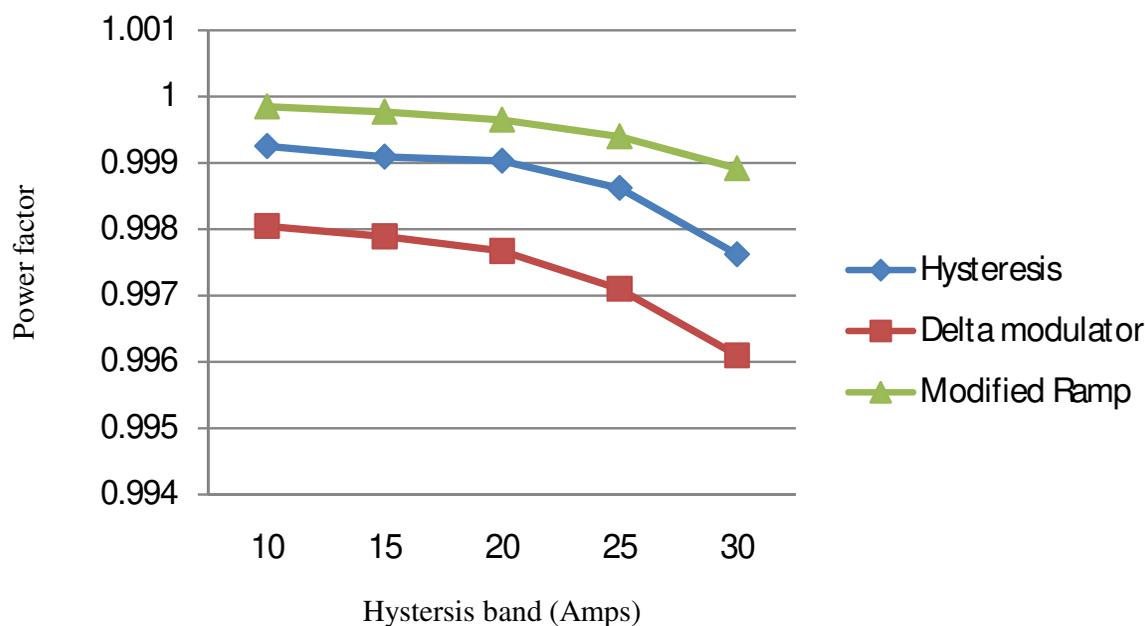


Fig. 22. Variation of power factor with hysteresis band

Above graphs shows the variations in %THD, Switching frequency, power factor, dynamic response, error current with hysteresis band. From the above graphs we could say that % THD variation is less in modified ramp type current controller. Switching frequency is

constant in modified ramp type current controller, delta modulator as limited switching frequency. Switching frequency is varying more with hysteresis band in hysteresis current controller. Modified ramp type current controller is giving good system power factor compared to other controllers.

6. Discussion

Vector control of grid connected voltage source inverter is implemented in MATLAB/simulink. Simulation results are obtained for different current controllers. The discussion of the results as follows: vector control in virtual grid flux oriented reference frame is having an capability to decouple the active and reactive powers flowing into grid, which we can see from the waveforms of active and reactive powers for three current controllers. Reactive power flowing into grid is almost zero in all the controllers to ensure unity power factor operation of grid. Total harmonic distortion of three current controllers is as follows 1. For hysteresis current controller percentage of THD is 4.41 2. For current regulated delta modulator percentage of THD is 4.74 and 3. For modified ramp type current controller percentage of THD is 2.68. Among all the current controllers modified ramp type current controller is having fewer harmonics in grid current, which ensures fewer ripples in three phase active power following into grid, and current regulated delta modulator having more harmonics in grid current which leads to more ripple in three phase active power following into grid. The switching frequency of modified ramp type current controller is 2 KHz it is a constant value at its ramp generator frequency. In Current regulated delta modulator switching frequency is limited to 2 KHz, but the variation of frequency with in fundamental period cannot be controlled. In hysteresis current controller the switching frequency is varies with load parameters and hysteresis band, switching frequency when hysteresis band 20 is equal to 2.72 KHz. From the above discussion modified ramp type current controller has constant switching frequency. The power factor by using modified ramp type current controller is very good then compared to other current controllers. The following table 1 shows the switching frequency, THD, power factor for three current controllers.

Current control	THD	Switching frequency	Power factor
Hysteresis	4.41	2.72 KHz	0.9989
Delta modulator	4.74	2 KHz	0.9973
Modified ramp type	2.68	2 KHz	0.9996

Table 1. Comparison of three current control techniques of grid connected VSI

7. Conclusion

Analysis of different current control techniques for synchronous grid flux oriented control of grid connected voltage source inverter is presented in this chapter. For effectiveness of the study MATLAB/simulink is used here in GUI environment. Vector control in grid flux oriented reference frame is having capable of decoupling active and reactive powers following into grid, which we could see from figures of active and reactive powers for three current controllers. Reactive power following into grid is zero for all current control techniques to ensure the grid at unity power factor operation. There is a slight variation in power factors of three current controllers which is due to variation of percentage of THD in three current controllers. The DC link voltage is maintained at 2200V which is the set value of DC link voltage by using DC link voltage controller which controls the active current reference flows in the grid. The total harmonic distortion is less in modified ramp type current controller compared to other two current controllers. The switching frequency of modified ramp type current controller is maintained at 2 KHz which decreases the switching losses of power semiconductor devices compared to other current controllers where the switching frequency varies with load parameters. There is a less ripple in three phase active power for modified ramp type current controller compared to other two current controllers. From the above discussion modified ramp type current controller is more advantages than other two current controller in grid connected voltage source inverter.

8. References

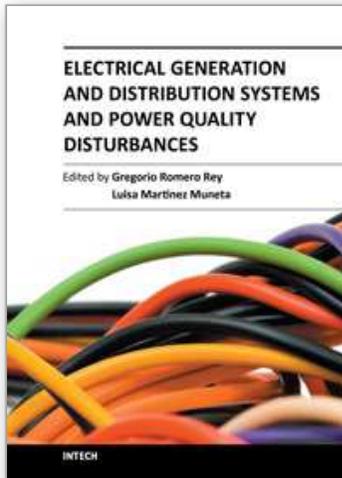
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The utilization of renewable energy sources such as wind energy, or solar energy, among others, is currently of greater interest. Nevertheless, since their availability is arbitrary and unstable this can lead to frequency variation, to grid instability and to a total or partial loss of load power supply, being not appropriate sources to be directly connected to the main utility grid. Additionally, the presence of a static converter as output interface of the generating plants introduces voltage and current harmonics into the electrical system that negatively affect system power quality. By integrating distributed power generation systems closed to the loads in the electric grid, we can eliminate the need to transfer energy over long distances through the electric grid. In this book the reader will be introduced to different power generation and distribution systems with an analysis of some types of existing disturbances and a study of different industrial applications such as battery charges.

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