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Simulation Study of Indirect Current Control Technique for Shunt Active Filter

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ABSTRACT

Solid state control of ac power using thyristors and other semiconductor devices are used extensively in number of applications such as adjustable speed drives (ASD's), furnaces, computers power supplies and asynchronous ac–dc–ac links. These power converters behave as nonlinear loads to ac supply system and cause harmonic injection, lower power-factor, poor voltage regulation, and utilization of ac network. There is a great need to mitigate these harmonic and reactive current components. Active Power Filters are a viable solution to these problems. In this project work a three-phase shunt active filter is used to eliminate supply current harmonics, correct supply power-factor, and balance the nonlinear/linear loads. A three-phase insulated gate bipolar transistor based current controlled voltage source inverter with a dc bus capacitor is used as an active filter. The firing pulses to the shunt active filter will be generated by using Indirect current control technique. In the indirect control algorithm of the Active filter, the three-phase reference supply currents are obtained using a closed loop PI controller. A Hysterisis PWM current controller is employed over the reference and sensed supply currents to generate gating pulses of IGBT's of the Active filter. But Hysterisis current control having disadvantage like the switching frequency varied during fundamental period, this may be results in increased switching losses and phase angle errors. To overcome problems in the Hysterisis current control, a Ramp-comparator current controller is used. Results of both Hysterisis current control method and Ramp comparator current control method are compared, which shows the Ramp-comparator current control method is better than Hysterisis current control method for harmonic reductions.

Keywords – Shunt active filters, indirect current control, harmonics, voltage stability, current control

I. INTRODUCTION

The main objective of electric utilities is to supply its consumers continuous sinusoidal voltage of constant magnitude. However this is becoming increasingly difficult, because of the rapid growth of non-linear and poor power factor loads. The use of the modern electronic equipments has changed our lives and has introduced wide variety of loads in the power systems. This has changed the load characteristics of the electric supply networks, all the electronic loads are "non-linear" and this is because of the way they draw the power from the supply. These types of loads are used for the conversion, variation and regulation of the electrical power in commercial, industrial and residential installations. The continuous usage of non- linear loads injects current and voltage harmonic components into the power system and increases reactive power demands and power system voltage fluctuations. Harmonic current components create several problems like Increase in power system losses. Oscillatory torques in rotating machinery. Significant interference with communication circuits that share common right-of-ways with AC power circuits. Overheating and insulator failures in transformers, rotating machinery, conductor and cables. Generates noise on regulating and control circuits causing erroneous operation of such equipment. Reactive power burden, low system efficiency, poor power factor , system unbalance and causes excessive neutral currents. Malfunctioning of the protective relays and untimely tripping. Failure of capacitor banks. Most commonly used non-linear loads are switch mode power supply systems found in personal computers. Microwave ovens, laser printers, medical instrumentation systems, stereos, televisions and electronic lighting are also examples of equipments using switch mode power supplies. Other types of non-linear loads include rectifiers, both controlled and uncontrolled, and phase angle controlled power supplies. Power system contamination with harmonics deteriorates power quality and it has become a major concern for the power system engineers due to its adverse effects on sensitive loads connected to the power distribution system. There are two approaches to mitigate the power quality problems. The first approach is called load conditioning, which ensure that the equipment is made less sensitive to the power disturbances, allowing the operation of equipments even under significant voltage distortion. The other solution is to install line-conditioning systems that suppress or counteract the power system disturbances. Power electronic equipment can be designed to provide harmonicfree performance. But in most applications, the economic incentives have not been sufficient to bring about design improvements. The sinusoidal nature of the power system voltage should be preserved, while protecting components from added harmonic loadings. The electrical utilities are quickly adopting the philosophy and constraints proposed in IEEE 519-1992, a recommended practice (one level short of a mandatory standard), limiting the both utility voltage and end-user current distortions. In order to maintain good power quality, various international agencies recommended limits of harmonic current injection into the utility. According to IEEE-519 standards the limits on the magnitudes of harmonic currents and harmonic voltage distortion at various harmonics frequencies are specified, as given in Tables1.1 and 1.2.The amount of distortion in the voltage or current waveform is quantified by means of an index called the total harmonic distortion (THD).

$$THD = \sqrt{\sum_{h=2}^{\infty}\left(\frac{I_{sh}}{I_{s1}}\right)^2} * 100\ \%$$

I_{sc}/I_1	<11	11<h<22	23<h<35	>35	THD
<20	4.0	1.5	1.0	0.5	5.0
20-50	7.0	2.5	1.5	0.8	8.0
50-100	10.0	4.0	2.0	1.2	12.0
100-1000	12.0	5.0	2.5	1.5	15.0
>1000	15.0	8.0	4.0	1.8	20.0

Table 1.1:Harmonic current at various harmonic frequencies at PCC

Voltage range	2.3-69KV	69-138
Max for individual harmonics	3.0	1.5
Total harmonics distortion (THD)	5.0	2.5

Table.1.2: Harmonic voltages at various harmonic frequencies and voltages at PCC

It is based on the voltage level at which the user is supplied. Filters are used for line conditioning and there are two types of filters, passive filters and active filters.

1.1 Passive Filters

Passive filters are the conventional filters used for filtering harmonics in low power levels. They comprise of an inductor and a capacitor, thus forming a second order filter. These filters have advantages like: Their performance is satisfactory for a set of given loads. · They are cheap and economical. · Their configuration and analysis are simple.Maintenance of these filters are simple[18] However these filters also have drawbacks like: ·The source impedance strongly affects filtering characteristics. These are not suitable for fast varying loads, because of their inherent sluggish response time. When the harmonic current components increase, the filter can be overloaded. Parallel resonance between the power system and the passive filter causes amplification of harmonic currents on the source side at a specific frequency. The passive filter may fall into series resonance with the power system so that voltage distortion produces excessive harmonic currents flowing into the passive filter. Under light load conditions these filters generate excessive reactive power, which is undesirable. There exists difficulty in tuning, due to finite tolerance of components used. Because of these difficulties the use of passive filters is limited to low voltage and harmonics insensitive loads. But because of the increase in the loads that cause harmonics and their increased harmonics levels, the power system engineers are attracted to other dynamic and adjustable solutions to the power quality problems, such as Active Power Filter (APFs) also called Active Power Line Conditioners (APLCs).

1.2 Active Power Filters

Active filters have been recognized as a valid solution to harmonic and reactive power compensation due to the presence of non-linear loads. The principle of operation of active filters is based on the injection of the harmonics required by the load. An active filter generates a current equal and opposite in polarity to the harmonic current drawn by the load and injects it to the point of coupling and forces the source current to be pure sinusoidal. As a consequence, the characteristics of the harmonic compensation are strongly dependent on the filtering algorithm employed for the calculation of load current harmonics[19]

1.3 Literature Survey

The literature survey is done to collect material, which would focus on the basic theory of active filters, different network topologies and different control concepts available. Solid-state control of ac power using thyristors and other semiconductor devices are used extensively in a number of applications such as adjustable speed drives (ASD’s), furnaces, computers power supplies and asynchronous ac–dc–ac links. These power converters behave as nonlinear loads to ac supply system and cause harmonic injection, lower power-factor, poor voltage regulation etc. The harmonic currents and voltages can create so many problems. To eliminate these harmonic currents and voltages filters are used. Conventional passive LC filters are used to eliminate the harmonics and capacitor banks are used to improve the power factor. Hower, these passive filters have many problems to discourage their applications [1]. The active filters (AF) are used to over come the problems of passive filters. AF’s can be classified based on converter type, topology and the number of phases. The converter type can be either CSI or VSI bridge structure. The topology can be shunt, series or a combination of both. The third classification is based on the number of ph ases, such as two-wire (single phase) and three- or four-wire three-phase systems [2]. The firing pulses to the shunt active filter will be generated in such way that it will reduce the harmonics and improve the power factor. There so many control techniques are there to generate firing pulse. Those are instantaneous reactive power theory, indirect and direct current control technique, power balance theory, synchronous frame based controller, sliding mode controller and flux-based controller [3][4][5]. Among all these methods the indirect current control method have some advantages [6]. The indirect current control algorithm of the AF uses two closed loop PI controllers. The dc bus voltage of the AF and three-phase supply voltages are used as feed back signals in the PI controllers. The control algorithm of the AF provides threephase reference supply currents [7]. After getting the reference currents a carrier wave pulse width modulation (PWM) current controller is employed over the reference and sensed supply currents to generate gating pulses of IGBT's of the AF. Hysteresis current control technique is used to generate the firing pulses to the inverter switches. But hysteresis current control have some drawbacks like the switching frequency variation during fundamental period and the zero voltage vectors (V 0 and V7) are applied. This results in increased switching losses and phase angle errors. To overcome these problems in the hysteresis current control, a ramp-comparator current controller is used. A ramp comparator is proposed in which the current error signals are compared to three 1200 phase shifted triangular waveforms. This eliminates the zero voltage vector applied to the inverter and reduces the inherent amplitude and phase errors [8].

1.4 Outline of thesis

Chapter 2 describes the classification of active power filters. Shunt active power filter is used in this work inorder to improve the power factor and eliminating the harmonics.

Chapter 3 describes the indirect current control technique inorder to provide the reference current for active filter circuit. This also explains the advantages of using this control technique. Chapter 4 describes the PWM techniques for voltage source converters (VSC) among which hysteresis current control technique and ramp comparator current control techniques are used in generating the switching pulses to the VSC.

Chapter 5 involves the simulation studies using both the switching techniques and the corresponding results are compared for different load conditions. Chapter 6 includes the conclusions and scope for future work.

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III. ACTIVE POWER FILTERS

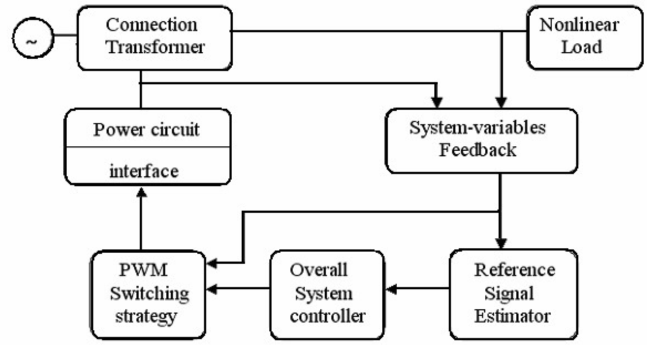


Fig.2.1. block diagram for active power filter

Fig. 2.1 shows the components of a typical active-power-filter system and their interconnections. The information regarding the harmonic current, generated by a nonlinear load, for example, is supplied to the reference current/voltage estimator together with information about other system variables. The reference signal from the current estimator, as well as other signals, drives the overall system controller. This in turn provides the control for the PWM switching pattern generator. The output of the PWM pattern generator controls the power circuit via a suitable interface. Thus the voltage or current generated by the power circuit will be coupled to the power system through a connection transformer. The power circuit in the generalized block diagram can be connected in parallel, series or parallel series configurations, depending on the connection transformer used.

2.1 Classification of Active Power Filters:

Active power filters can be classified using the following criteria.

(a) Classification based on the Converter type
(b) Classification based on the supply system
(c) Power-circuit configuration and connections
(d) System parameters to be compensated

2.1.1 Classification on the Converter type:

There are two types of converters used in the development of APFs. Fig 2.2 shows the current fed pulse width modulation (PWM) inverter bridge structure. It behaves as a non-sinusoidal current source to meet the harmonic current requirement of the nonlinear load. A diode is used in series with the self commutating device (IGBT or MOSFET) for reverse voltage blocking. It uses a large DC inductor (which acts like a current source) for energy storage. The other converter used as an APF is a voltagefed PWM inverter structure, as shown in Fig 2.3 has a self - supporting dc voltage bus with a large dc capacitor. It has become more dominant, since it is lighter, cheaper and expandable to multi step versions, to enhance the performance with lower switching frequencies. It is more popular in UPS-based applications because in the presence of mains the same inverter bridge can be used as an APF to eliminate harmonics of critical nonlinear loads.

2.1.2 Classification Based on Supply System:

This classification of APFs is based on the supply and/or the load system

[1]. Two-wire APFs: Two wire (single phase) APFs are used in all three modes as active series, active shunt and a combination of both as unified line conditioners. Two converter configurations, current-source PWM bridge with inductive energy storage element and voltage-source PWM bridge with capacitive dc-bus energy storage elements, are used to form two-wire APF circuits.

[2]. Three-wire APFs : Driving three-phase three-wire nonlinear loads, such as Adjustable Speed Drives (ASDs), are major applications of solid-state power converters.All the configurations shown in Fig 2.2 to Fig2.6 can be used to realize three wire APFs, with three wires on the ac side and two wires on the dc side. There is configuration with 3 wires on the AC side and 3 wires and 2 capacitors on the DC side also present as shown in Fig. 2.7.Active shunt APFs are also can be designed with three single-phase APFs with isolation transformers for proper voltage matching, independent phase control and reliable compensation with unbalanced systems.

[3]. Four-wire APFs: A large number of single-phase loads may be supplied from threephase mains with neutral conductor. They cause excessive neutral current, harmonics and reactive power burden and unbalance. To reduce these problems, four-wire APFs have been developed as shown in figure Fig. 2.8 and Fig. 2.9

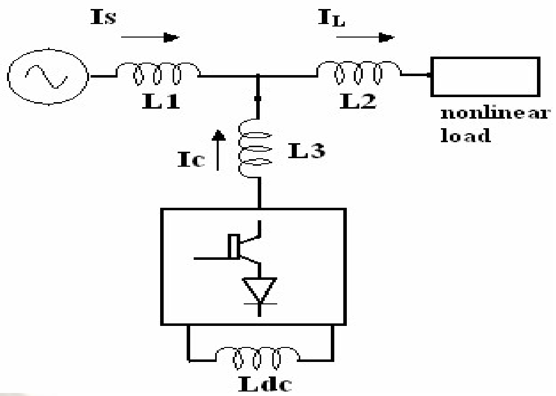


Fig.2.2.Current Fed Type APF

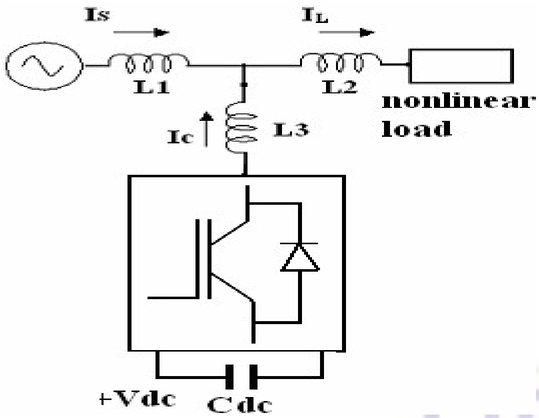


Fig.2.3.Volteg Fed Type APF

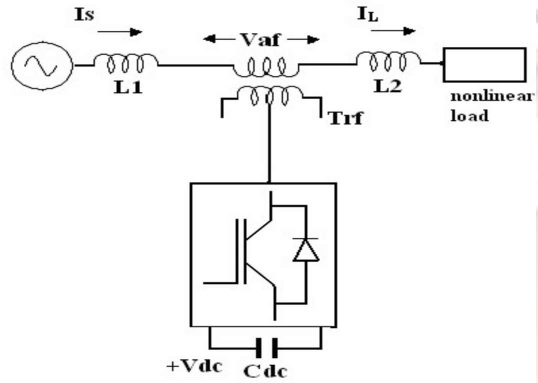


Fig.2.4.Series Type APF

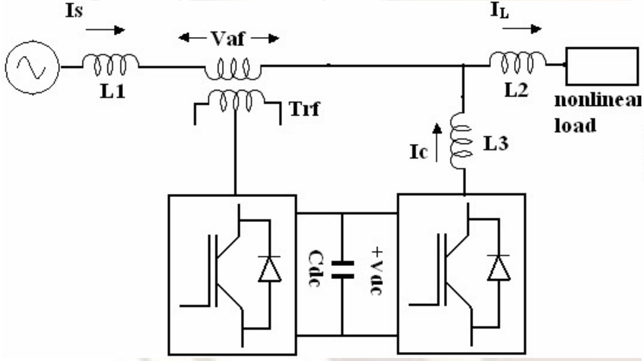


Fig.2.5.Universal Active Filter (UPQC)

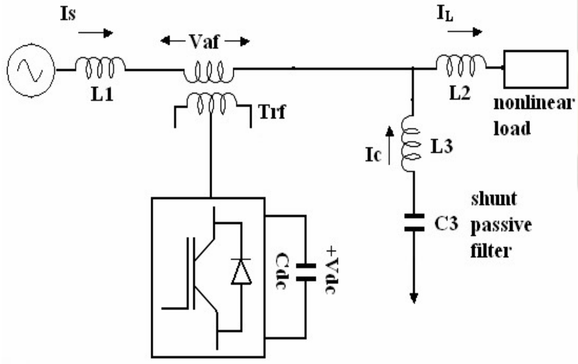


Fig.2.6.Hybrid Active Filter

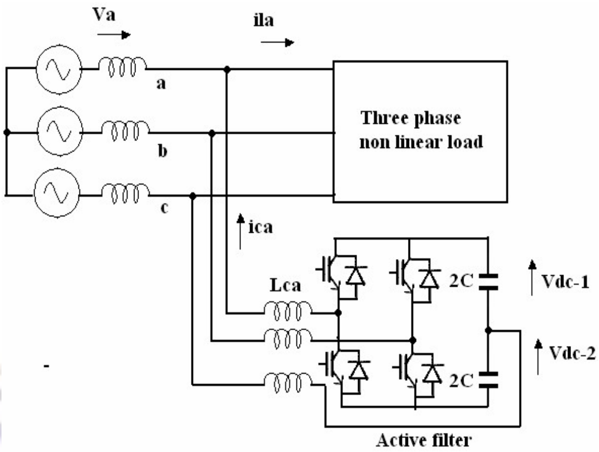


Fig.2.7.Reduced Switch APF

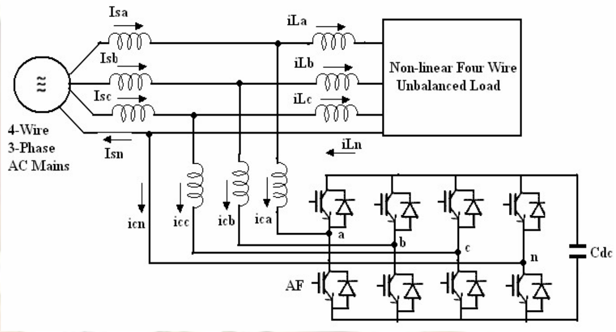


Fig.2.8.Four-Pole Four Wire Shunt APF

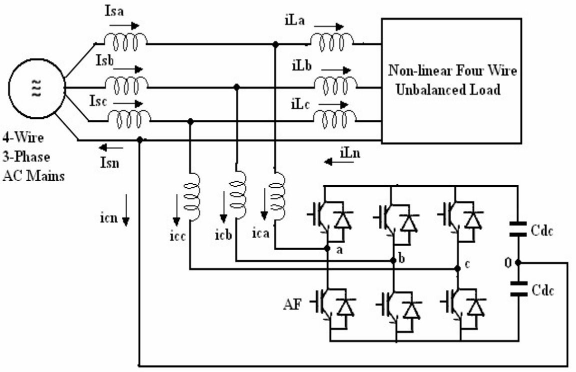


Fig.2.9.Capacitor midpoint four-wire Shunt APF

2.1.3 Power-circuit configuration and connections based classification:

APFs can be classified based on the topology used as series or shunt filters and unified power quality conditioners which uses a combination of both. Combinations of active series and passive shunt filtering is known as Hybrid filters.

1. Shunt Active Power Filter: Fig 2.3 is an example of an active shunt filter, which is most widely used to eliminate current harmonics, reactive power compensation and balancing unbalanced currents. It injects equal compensating currents, opposite in phase, to cancel harmonics and /or reactive components at the point of common coupling (PCC). It can also be used as a static VAR generator

(STATCON) in the power system network for stabilizing and improving the voltage profile.

2. Series Active Power Filter: Fig 2.4 shows the basic block of a stand-alone active series filter. It is connected before the load in series with the mains, using matching transformer, to eliminate voltage harmonics and to balance and regulate the terminal voltage of the load or line.

3. Mixed Type Active Power Filter: Fig 2.5 shows a unified power quality conditioner (also known as Universal APF), which is a combination of active shunt and active series filters. The dc-link storage element (either inductor or capacitor) is shared between two current- source or voltage source bridges operating as active series and active shunt compensators.

4. Hybrid Active Power Filter: Fig 2.6 shows the hybrid filter, which is a combination of an active series filter and passive shunt filter. It is quite popular because of the solid state devices used in the active series part can be of reduced size and cost, and a major part of the hybrid filter is made of the passive shunt L-C filter used to eliminate lower order harmonics.

2.1.4 Classification based on the system parameters to be compensated:

1. Harmonic compensation: This is the most important system parameter requiring compensation in power systems and it is subdivided into voltage- and current-harmonic compensation as follows.

Compensation of voltage harmonics:

The subject of compensating voltage harmonics is not widely addressed because power supplies usually have low impedance. The terminal voltage at the consumer point of common coupling (PCC) is normally maintained within the standard limits for voltage sag and total harmonic distortion and does not normally vary much with loading. Note that the compensation of voltage and current harmonics are interrelated. The reduction of voltage harmonics at the PCC helps a great deal to reduce current harmonics, especially for the particular cases of nonlinear loads with resonance at the harmonic frequencies. However, the compensation of the voltage harmonics at the PCC does not eliminate the need for current-harmonic compensation for the nonlinear loads. Compensation of current harmonics:

Compensation of current harmonics is very important in low and medium-power applications. As mentioned above, the compensation of current harmonics reduces to a great extent the amount of distortion in the voltage at the PCC. The imposition of harmonic standards will soon oblige factories and establishments to control the harmonics they inject into the power system.

Multiple compensation: Different combinations of the above systems can be used to improve the effectiveness of filters. The following are the most frequently used combinations.

(a) Harmonic currents with Reactive power compensation:

The most common and popular filters are those which compensate for both the reactive power or the harmonic currents in order to maintain the supply current completely free of harmonics and in phase with the supply voltage. The techniques employed for this have several advantages over other alternatives as only one filter is needed to compensate for everything, which is much more attractive than using many different types of compensators. However, because of the limits imposed by the ratings of power switches, one can only use this application for low power levels. The resulting switching frequency would need to be lower for high-power applications, which restricts the filter under consideration to low power levels.

(b) Harmonic voltages with Reactive power compensation:

This combination, however rare, takes place in certain configurations for controlling the voltage harmonics, which would normally affect indirectly the reactivepower compensation. This compensation system is suitable only for low-power applications.

(c) Harmonic currents and voltages:

The problem of addressing harmonic currents and voltages simultaneously can only be treated by using the series/parallel Combination of active-filter configurations. This, of course, is very important and very beneficial in making both the supply and the load free from harmonic effects. However, this complex type is normally used only for very sensitive devices such as power-system protection equipment and super conducting magnetic-energy storage systems.

(d) Harmonic currents and voltages with reactive-power compensation:

This scheme is the ultimate in sophistication since it controls harmonics and reactive power. This technique requires the use of the parallel/series active-filter combination. It is not employed very often because its control is rather complex and the information available on it in the literature is very limited.

(e) Balancing of source voltages in three-phase systems:

The degree of system imbalance depends on the amount of current imbalance and the magnitude of the supply impedance. These can cause the three-phase voltages to be unequal in magnitude phase. This is due to the presence of significant amount of supply impedance. The remedy to this problem is to add phase the corresponding amount of instantaneous voltage to each and force it to follow the reference sinusoidal waveform. The system, in such cases, is normally of the low power category because in medium and high power systems the supply impedance does not have any significant effect on system performance.

(f) Balancing of mains currents in three-phase systems:

As with balancing voltages, this compensation is mainly required in three-phase systems used for low-power applications. The reason is that the magnitudes of currents to be supplied to the grid depend entirely on the amount of imbalance in the system, which mostly occurs in low-voltage distribution systems for residential loads. The compensator under consideration would sometimes be forced to supply the rated value of current, which limits its power-handling capabilities. The power circuit of this system normally consists of three single-phase type (H-Bridge) inverters having the same energy-storage
element.

2.2 Three Phase Active Filtering System:

The active filtering system is based on a philosophy that addresses the load current distortion from a time domain rather than a frequency domain approach. The most effective way to improve the distortion power factor in a non-sinusoidal situation is to use a nonlinear active device that directly compensates for the load current distortion. The performance of these active filters is based on three basic design criteria.

1. The design of the power inverter (semiconductor switches, inductances, Capacitors, dc voltage)
2. Control method
3. Method used to obtain the current reference or the control strategy used to generate the reference template.

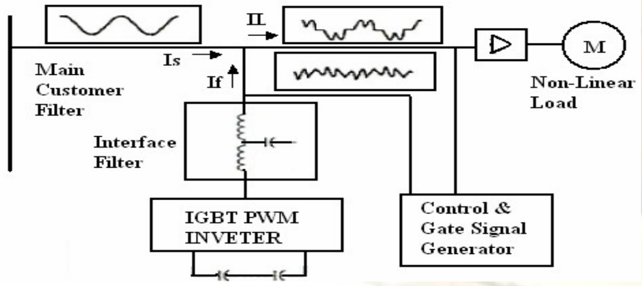


Fig.2.10.Shunt Active Power Filtering

The active filter concept uses power converters to produce harmonic current components that cancel the harmonic current components from the non-linear loads. The active filter configuration used in this study is based on a voltage source inverter connected to the system through a system interface filter as shown in Fig 2.10. In this configuration, the filter is connected in parallel with the load being compensated. Therefore, the configuration is often referred to as an active parallel or shunt active filter. The voltage source inverter used in the active filter makes the harmonic control possible. This inverter uses dc capacitors as the supply and can switch at a high frequency to generate a signal that will cancel the harmonics from the non-linear load. The active filter does not need to provide any real power to cancel harmonic currents from the load. The harmonic currents to be cancelled are shown as reactive power. Reduction in the harmonic voltage distortion occurs because the harmonic currents flowing through the source impedance are reduced. Therefore, the dc capacitors and the filter components must be rated based on the reactive power associated with the harmonics to be cancelled and on the actual current waveform (rms and peak current magnitude) that must be generated to achieve the cancellation. The current waveform for cancelling harmonics is achieved with the voltage source inverter in the current controlled mode and an interfacing filter. The filter provides smoothing and isolation for high frequency components. The desired current waveform is obtained by accurately controlling the switching of the switches in the inverter. Control of the current wave shape is limited by the switching frequency of the inverter and by the available driving voltage across the interfacing inductance. The Inverter (three-phase unit or single-phase unit as the case may be in the Shunt Active Power Filter is a bilateral converter and it is controlled in the Current Regulated mode i.e. the switching of the Inverter is done in such a way that it delivers a current which is equal to the set value of current in the current control loop. Thus the basic principle of Shunt Active Power Filter is that it generates a current equal and opposite in polarity to the harmonic current drawn by the load and injects it to the point of coupling thereby forcing the source current to be pure sinusoidal. This type of Shunt Active Power Filter is called the Current Injection Type APF.

2.3 Configuration of Three Phase Shunt Active Power Filter

The basic configuration of a three-phase three-wire active power filter is shown in Fig 2.11. The diode bridge rectifier is used as an ideal harmonic generator to study the performance of the Active filter. The current-controlled voltage-source inverter (VSI) is shown connected at the load end. This PWM inverter consists of six switches with antiparallel diode across each switch. The voltage which must be supported by one switch is uni-polar and limited by the DC voltage dc V . The peak value of the current which is bidirectional is imposed by the active filter current. Thus the appropriate semiconductor device may be an IGBT or a MOSFET with an anti-parallel diode and must be protected against over current. The capacitor is designed in order to provide DC voltage with acceptable ripples. In order to assure the filter current at any instant, the DC voltage dc V must be equal to 3/2 of the peak value of the line AC mains voltage.

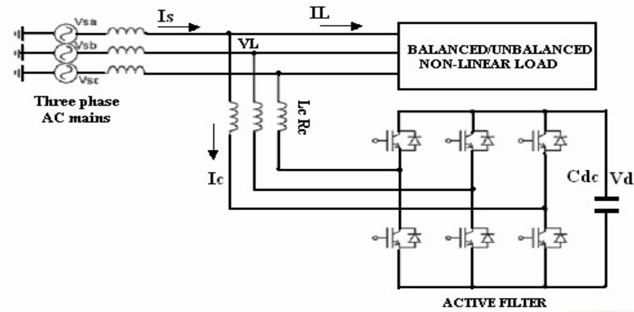


Fig.2.11.Configuaration of three-phase shunt active power filter

2.4 Configuration of Reduced Switch Count Active Power Filter:

The fig. 2.12 shows the reduced switch count VSI inverter. It uses the principle that in a balanced three-phase system if two-phase currents are controlled then the current in the third leg is automatically controlled. Hence the inverter shown uses only two legs, but uses an additional capacitor to provide a zero voltage return point for the third winding. Also, to provide the same current as in the case with conventional inverter, the initial voltage of the capacitors has to be equal to the voltage of the conventional inverter, i.e. the reduced switch inverter will use two capacitors of voltage dc V. This inverter performance is satisfactory and is economical for low and medium power applications. For high power applications the break down voltage of the switches and the size of the inductors will be more than that for the conventional inverter and makes the topology unsuitable from the cost point of view.

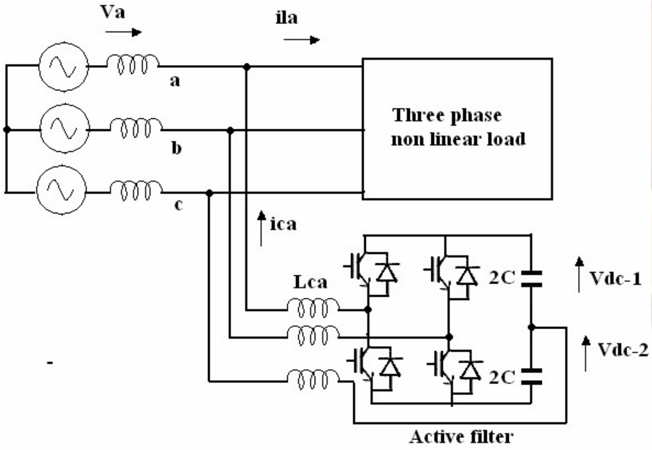


Fig.1.12.Reduced Switch APF

2.5 Summary

Active power filters are classified basing on converter type, supply system, power-circuit configuration and connections and system parameters to be compensated. Different classifications with their advantages are explained briefly. Shunt active power filter is used in this work inorder to provide the voltage regulation, improvement in the power factor and to eliminate the harmonics.

IV. INDIRECT CURRENT CONTROL TECHNIQUE

There are different control techniques available for obtaining the reference currents for active filter circuit. Those are

- ➔Instantaneous reactive power theory
- ➔Indirect current control technique
- ➔Power balance theory
- ➔Synchronous frame based controller
- ➔Sliding mode controller and
- ➔Flux based controller.

The main aim of these control techniques are to generate reference current waveform for generating the switching signals in such a way that it will improve the power factor and reduce the harmonics. Among these methods, indirect current control method is advantageous when compared to other methods.

3.1 The merits of indirect current control technique:

- ➔Switching ripples are eliminated
- ➔Requires less number of current sensors
- ➔Requires less number of transformations and
- ➔Easy to implement.

In this control algorithm the active filter uses two closed loop PI controllers. The dc bus voltage of the active filter and three phase supply voltages are used as feedback signals to PI controllers. The reference dc capacitor voltage is compared with actual capacitor voltage and the error is given to the PI controller. The output of the PI controller provides the reference in-phase components. The three-phase unit current vectors are derived in-phase with the supply voltage. The multiplication of in-phase reference components with the unit current vector results in in-phase components of three-phase reference supply currents. A carrier wave PWM current controller is used over reference supply currents and sensed supply currents to generate gating signals to IGBTs used in the VSI bridge working as the active filter.

3.2 Algorithm For Indirect Current Control Technique:

The block diagram of the indirect current control scheme of the AF is shown in Fig. 3.1. Three-phase voltages at PCC along with dc bus voltage of the AF are used for implementation of control scheme. In real time implementation of the AF a band pass filter plays an important role. The three-phase voltages (V_a ,V_b , V_c)are sensed at PCC using potential transformers and conditioned in a band pass filter to meet the range of ADC channels and to filter out any distortion.

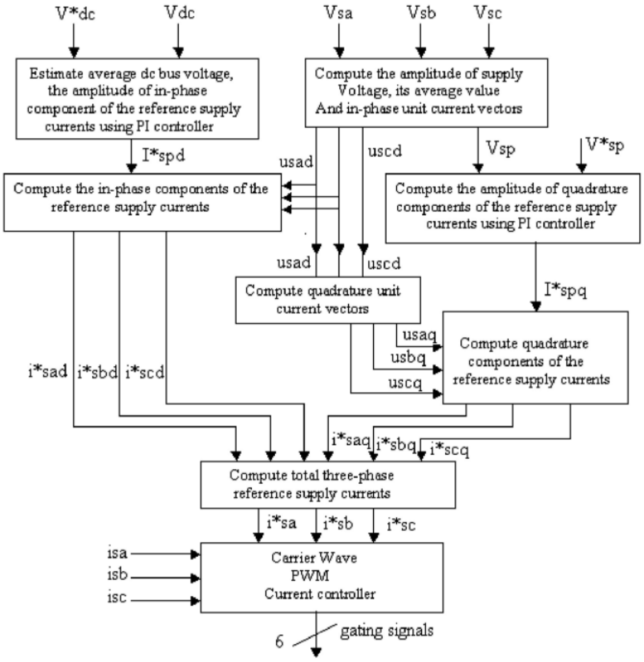


Fig. 3.1 PCC

The three-phase voltages (V_a ,V_b , V_c)are inputs and three-phase filtered voltages (V_a ,V_b , V_c)are outputs from band pass filter. The voltages (V_a ,V_b , V_c) here in after are termed as the supply voltages. In real time control of the AF, a self-supporting dc bus of the AF is realized using a PI controller over the sensed Vdc values of dc bus voltage of the AF. The PI voltage controller on the dc bus voltage of the AF provides the amplitude Id of in-phase components of Isa,b,c reference supply currents. The three-phase unit current vectors are derived in-phase with the supply voltage. Another PI controller is used over the reference V and sensed V values of peak supply voltage. The output of this PI controller is considered as amplitude I of quadrature components of reference supply currents. The three-phase quadrature unit current vectors '**u**' are derived from in-phase unit current vectors '**u**' . The multiplication of in-phase amplitude I with in-phase unit current '**u**' results in the in-phase components I of three-phase reference supply currents I . Similarly, multiplication of quadrature amplitude I with quadrature unit current vectors '**u**' results in the quadrature components I of three-phase reference supply I. Algebraic sum of in-phase I and quadrature I components results in the three-phase reference supply currents I. For regulation of voltage at PCC, the three-phase reference supply currents have two components. The first component is in-phase with the voltage at PCC to feed active power to the load and the losses of the APF. The second component is at quadrature with the voltage at PCC to feed reactive power of load and to compensate the line voltage drop by reactive power injection at the PCC. Improvement of the power-factor to unity, harmonic elimination and balancing of nonlinear load, can be achieved by setting the quadrature component of reference supply currents to zero by assigning a zero value to the quantity. For the voltage regulation at PCC, the supply currents should lead the supply voltages but for the power factor to be maintained at unity, the supply currents should be in phase with the supply voltages. Since these two conditions, namely, voltage regulation at PCC and unity power-factor cannot be achieved simultaneously. Therefore, the control algorithm of the AF is made flexible to achieve voltage regulation, harmonics compensation, load balancing or power - factor correction to unity, harmonics compensation, and load balancing. With three – phase supply voltages V and dc bus voltage Vdc as feedback signals, the control algorithm of the AF provides the three-phase reference supply currents I as output signals. A carrier wave PWM current controller is used over reference supply currents I and sensed supply currents I to generate gating signals to the IGBT's used in the VSI bridge working as the AF. In response to gating pulses to the APF, it regulates the voltage at PCC, eliminates harmonics, correct the power-factor at PCC and balances the unbalanced nonlinear load while maintaining a self-supporting dc bus of the APF.

3.3 Basic Equations of Control Algorithm of the APF:

The three-phase reference supply currents are computed using three-phase supply voltages and dc bus voltage of the AF. These reference supply currents consist of two components, one in-phase and another in quadrature with the supply voltages.

3.3.1 Computation of In-Phase Components of Reference Supply Currents:

The amplitude I of in-phase component of reference supply currents is computed using PI controller over the average value of dc bus voltage (Vdca) of the AF and its reference counterpart Vdc . Comparison of average and reference values of dc bus voltage of the AF results in a voltage error, which is expressed as, Vdcl at nth sampling instant
V dcl (n) V dc * (n) V dca (n) -- (3.1)

The error signal, Vdcl (n) , is processed in PI controller and output n at nth sampling instant is expressed as
n = y n- +K V n -V n- +K V =I (3.2)
where pdc K and idc K are proportional and integral gains of the dc bus voltage PI controller. The quantities, yo (n -1) and V dcl (n -1) are the output of the voltage controller and voltage error, espectively, at (n-1)th sampling instant. The output of PI controller is taken as amplitude I of in-phase component of the reference supply currents. Three-phase in-phase components of the reference supply currents are computed using their amplitude I and in-phase unit current vectors derived in-phase with

the supplyvoltage

$$\left.\begin{aligned} I^*_{sad} &= I^*_{spd}\, u_{sad} \\ I^*_{sbd} &= I^*_{spd}\, u_{sbd} \\ I^*_{scd} &= I^*_{spd}\, u_{scd} \end{aligned}\right\} \qquad (3.3)$$

Where Usad, Usbd and Uscd are in-phase unit current vectors

3.3.2 Computation of Unit Current Vectors:

$$\left.\begin{aligned} u_{sad} &= v_{sa} / V_{sp} \\ u_{sbd} &= v_{sb} / V_{sp} \\ u_{sbd} &= v_{sc} / V_{sp} \end{aligned}\right\} \qquad (3.5)$$

Where sp V is the amplitude of supply voltage and it is computed as

$$V_{sp} = \{2/3(v^2_{sa} + v^2_{sb} + v^2_{sc})\}^{1/2} \qquad 3.5$$

3.3.3 Computation of Quadrature Components of Reference Supply Currents:

The amplitude I spq of quadrature component of reference supply currents is computed using another PI controller over the average value of amplitude Vspa of supply voltage and its reference counterpart Vsp . Comparison of average and reference values of amplitude of the supply voltage results in a voltage error, which is expressed as, V spl (n), at nth sampling instant

v spl (n) = v sp * (n) - v spa (n) …3.6

The error signal, v spl (n) , is processed in PI controller and output {z (n)} o at nth sampling instant is expressed as

$$z_o(n) = z_o(n-1) + K_{psp}\{v_{spl}(n) - v_{spl}(n-1)\} + K_{isp} v_{sp}(n) = I^*_{spq} \qquad (3.7)$$

Where psp K and isp K are proportional and integral gain constants of ac voltage PI controller. The quantities, z (n - 1) o and v (n-1) lsp are the output of voltage controller and voltage error, respectively, at (n-1)th sampling instant. The output {z (n -1)} o of PI controller is taken as amplitude I of quadrature component of the reference supply currents. Three-phase quadrature components of the reference supply currents are computed using their amplitude Ispq and quadrature unit current vectors as

$$\left.\begin{aligned} I^*_{saq} &= I^*_{spq}\, u_{saq} \\ I^*_{sbq} &= I^*_{spq}\, u_{sbq} \\ I^*_{scq} &= I^*_{spq}\, u_{scq} \end{aligned}\right\} \qquad (3.8)$$

Where u saq , u sbq , and u scq are quadrature unit current vectors

3.3.4 Computation Of Quadrature Unit Current Vectors:

The quadrature unit current vectors are derived from the in-phase unit current vectors

$$\left.\begin{aligned} u_{saq} &= (-u_{sbd} + u_{scd}) / \sqrt{3} \\ u_{sbq} &= (u_{sad}\sqrt{3} + u_{sbd} - u_{scd}) / (2\sqrt{3}) \\ u_{scq} &= (-u_{sad}\sqrt{3} + u_{sbd} - u_{scd}) / (2\sqrt{3}) \end{aligned}\right\} \qquad (3.9)$$

3.3.5 Computation of Total Reference Supply Currents:

Three phase instantaneous reference supply currents are computed by adding in-phase and quadrature components expressed in (3) and (8)

$$\left.\begin{aligned} I^*_{sa} &= I^*_{sad} + I^*_{saq} \\ I^*_{sb} &= I^*_{sbd} + I^*_{sbq} \\ I^*_{sc} &= I^*_{scd} + I^*_{scq} \end{aligned}\right\} \qquad (3.10)$$

For ac voltage regulation along with harmonic elimination and load balancing these reference supply currents are used directly. However, for power-factor correction along with harmonic elimination and load balancing, amplitude of quadrature components I is set to zero and in this condition the in-phase components I become the total reference supply currents I.

3.4 Design of input Inductor used in APF power circuit:

The inductors (RC and LC) of the AF system are designed with information on the carrier signal frequency and hysteresis bandwidth of the AF current. The equation governing the dynamics of the AF power circuit is expressed as:

$$R_c i_c + L_C \frac{di_c}{dt} + v_f = v_s \qquad …3.11$$

Where vf is the instantaneous value of the PWM voltage at the inverter -pole point and vs is the instantaneous voltage at the PCC. Design of the AF inductor is done for maximum possible operating voltage at the PCC, which occurs when vs is passing through its peak value. Considering a drop of 10% voltage across the AF inductor due to current ic, therefore, $v_f = 1.1 V_{sm}$

Also in the AF power circuit, the value of RC is very small and it can be neglected. Therefore,

$$L_c \frac{di_c}{dt} = -v_f + v_s = -1.1V_{sm} + V_{sm} \quad 3.12$$

Taking a Hysterisis bandwidth of 1000mA and maximum switching frequency of 10KHz

$$Lc = \frac{0.1*(240\sqrt{2})}{10*1000} = 3.39mH$$

3.5 Design of DC bus Capacitor of AF power circuit:

It is desired that the APF system should have at least 2.0 times boost in DC bus voltage with respect to peak of phase AC voltage at the PCC, this is an important condition to avoid violation of current distortion and current control limits. Therefore, the energy storage capability of the DC bus of the APF should be sufficient to sustain disturbances arising due to load perturbation. The DC bus capacitance of the APF system can be computed from following equation:

$$\left.\begin{aligned}\Delta e_{dc} &= \frac{1}{2}C_{dc}\left[\left(V^*_{dc}\right)^2 - \left(V_{dc}\right)^2\right] \\ &= \frac{1}{2}C_{dc}(V^*_{dc} + V_{dc})(V^*_{dc} - V_{dc})\end{aligned}\right\} \quad 3.13$$

And taking Vdc is to be controlled to within a 5% range around its reference value and taking a delay time of 5ms, during which the energy transfer to 10KW load is 50J, Cdc = 1266μF.

3.6 Summary

Different current control techniques available for obtaining the reference currents for active filter circuit are discussed in this chapter. Indirect current control technique is used in this work, which is easy to implement, and requires less number of current sensors and transformations.

V.PWM TECHNIQUES FOR VOLTAGE SOURCE CONVERTERS:

In many applications it is desirable to have a nearly sinusoidal output. In order to achieve sine wave output from square wave output waveform, large filters are required to filter out the low order harmonic contents from the square wave output. With PWM control it is possible to achieve sinusoidal outputs.

In voltage source converters (VSC), variables to be controlled are the amplitude and frequency of the converter output voltage. PWM techniques enable the modulation of the controllable switches of the converter. By proper modulation of the controllable switches, a high frequency converter output voltage can be generated, whose low frequency or localized average during each switching cycle is same as that of the desired output voltage of the converter at that cycle. Following are the desired characteristics of the PWM techniques.

1. Good utilization of the converter DC bus voltage.

2. Wide linear modulation range.

3. Low amplitudes of lower order harmonics in output voltage to minimize harmonics in output current.
4. Low switching losses in the converter switches.

5. Easy implementation and less computation time.

Various PWM techniques are there for getting sinusoidal output, they are

1. Sine triangle PWM

2. Selective harmonic elimination method of PWM

3. Stair case PWM

4. Current control PWM

5. Space vector PWM

4.1 Sine- triangle PWM:

In Sine-triangle modulation scheme, a high frequency triangular carrier is compared with three sinusoidal control signals (modulating signals) that are phase displaced by an angle of 120 degrees. By comparing the triangular carrier signal with each of the three phase modulating signals, the switching pulses for the three phase legs of the converter are generated (Refer Fig.4.1). Frequency of the modulating signals must be same as that of the frequency of the desired output voltages and the magnitude of converter output voltage can be controlled by controlling the amplitude of the modulating signal. Time period of the high frequency triangular signal defines one switching period.

Relation between line-to-line rms output voltage V_{LL} and the DC bus voltage Vdc of the VSC in linear modulation range is given by,

$$V_{LL}\,rms = 0.612 * m_a * V_{dc} \quad \text{for } (0 \text{ £ } m_a \text{ £ } 1)$$

With a modulation index value, 1 in the linear region, V_{LL} rms = 0.612 *V_{dc} , which is the maximum achievable value of line-to-line rms output voltage in the linear region with sine triangle modulation technique.

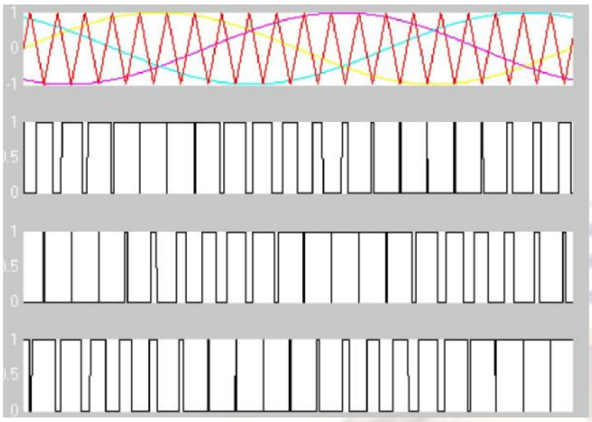


Fig.4.1.Switching sequence generation for 3-phase VSC in sine-triangle modulation.

With this method the inverter's DC bus voltage is not utilized completely and the asymmetrical nature of the PWM switching characteristics produces relatively high harmonic distortion in the supply.

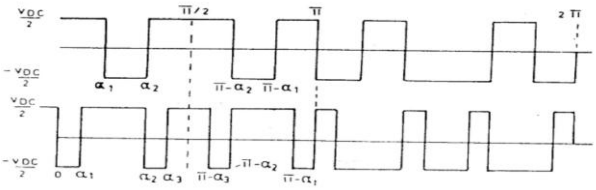
4.2 Selective Harmonic Elimination:

Among the pulse width modulation schemes, sine-triangle comparison is the oldest and best known. But this scheme is extremely complicated as far as the hardware implementation is concerned. Sine-triangle comparison with synchronization for variable frequency operation will increase the complexity of the hardware. Moreover fixed frequency modulation ratio (m_f) with large (m_f) will not be possible at large frequencies of operation. In practice the frequency ratio (m_f) is varied at different intervals in a variable frequency operation in order to limit the switching losses at high frequencies and also to take care of the finite switching time of the power devices. Selective harmonic elimination technique combines the square wave switching and the pulse width modulation scheme. In order to control the fundamental output voltage as well as to eliminate certain predominant low order harmonics. In this scheme the basic square wave produced by the pole voltage is modified by introducing notches in each quarter cycle. While still maintaining the quarter wave symmetry, during this interval, the output pole voltage swings between

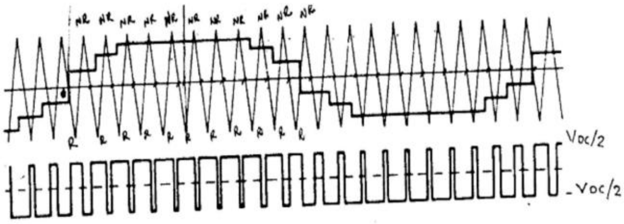
$$+\frac{V_{DC}}{2} \text{ and } -\frac{V_{DC}}{2}$$

The number of notches and the duration of notches are determined by the fundamental output voltage required and the harmonics to be eliminated.

Fig.4.2 shows the output voltage of the inverter with different notch widths per quarter cycle with selective harmonic elimination.



4.3 Staircase PWM: The sine triangular comparison method is widely used for variable frequency applications, but it is very complicated to implement. Harmonic elimination technique required extensive off line computation to find out the notch widths and requires large memory space for storing the pattern for variable frequency operation. So harmonic elimination technique is only used for discrete output control rather than for continuous output control over a wide range. Staircase PWM technique is a combination of the sine triangle PWM method and the harmonic elimination scheme. Here the pattern of triangle waveform is retained but the sine wave is replaced by a staircase waveform. In which the staircase levels are determined by the order of harmonics to be eliminated from the output. A typical waveform for the present technique is shown in fig.4.3.



4.4 Current controlled PWM:

The function of the current controllers is to force the load current to follow as closely as possible as the reference current. The current controllers have become an intensive research subject because they offer substantial advantages in eliminating the dynamics in high-performance ac drive systems under field-orientation control. The current controllers can be classified into two types

1.Hysterisis current controller

2.Ramp-comparator current controller

4.4.1. Hysteresis Current Controller:

Hysteresis band PWM control is basically an instantaneous feedback current control method of PWM, where the actual current continuously tracks the command current within a hysteresis band. A reference sine wave current wave is compared with the actual phase current wave. When the current exceeds a prescribed hysteresis band, the upper switch in the inverter bridge is turned off and the lower switch is turned on, and the current starts to decay. As the current crosses the lower band limit, the lower switch is turned off and the upper switch is turned on. The actual current is forced to track the sine reference within the hysteresis band by back and forth (or bang-bang) switching of the upper and lower switches. The inverter then essentially becomes a current source with peak-to-peak current ripple, which is controlled within the hysteris band, which makes the source current to be sinusoidal. The switching logic is realized by three hysteresis controllers, one for each phase (figure.4.4). The hysteresis PWM current control, also known as "bang-bang"control, is done in the three phases separately. Each controller determines the switching -state of one inverter half-bridge in such a way that the corresponding current is maintained within a hysteresis band Di .

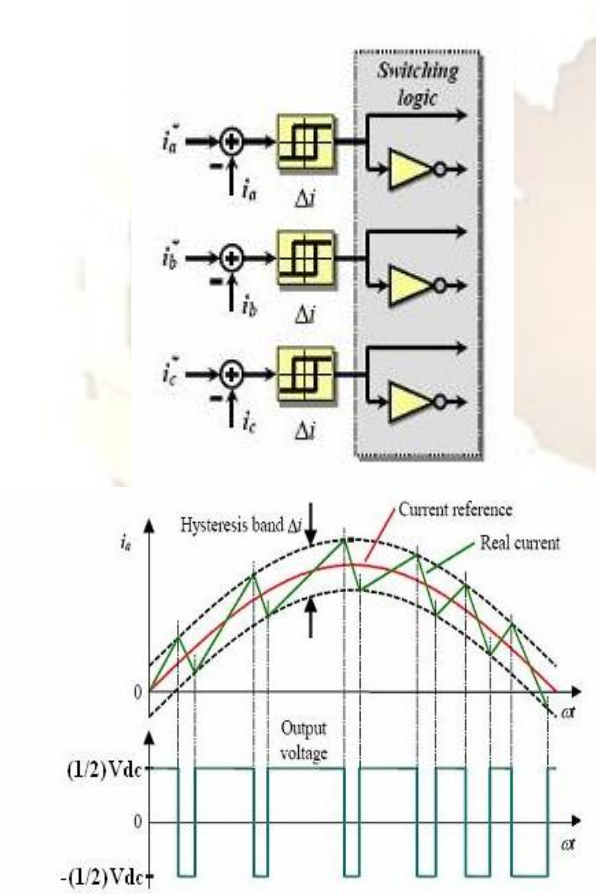
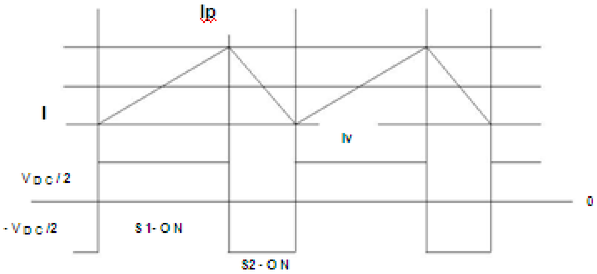


Fig4.4. Hysteresis PWM Current Control and Switching.

Fig 4.5.shows the waveforms with a constant current hysteresis controller



$$\frac{di}{dt} = \frac{V_{DC}/2 - E_c}{L} \qquad (4.1)$$

$$i_{ON} = I_v + \frac{V_{DC}/2 - E_c}{L}(t - t_v)$$

Where t_v is the starting time for T_{ON} period and I_V is the initial load current. At

$$t = T_{ON}\ ,\ I = Ip$$

$$\text{i.e} \qquad Ip = I_v + \frac{((V_{dc}/2) - E_c)T_{on}}{L} \qquad (4.2)$$

$$T_{ON} = L\frac{Ip - Iv}{V_{DC}/2 - EC} \qquad (4.3)$$

When the ripple current reaches the hysteresis top band S1 is closed and S2 is ON. The ripple current starts falling till it reaches the bottom limit. During Toff period the load current is

$$i_{Toff} = Ip + \frac{V_{dc}/2 - E_c}{L}(t - T_p) \qquad (4.4)$$

Where tp is the initial time of the Toff period. From the above euation the Toff

$$T_{off} = L\frac{I_p - I_v}{V_{dc}/2 - E_c} \qquad (4.5)$$

Where Ip-Iv = D I is the tolerance band.

The total period is

$$T = Ton + Toff = \frac{L\,D\,I}{V_{dc}/2 - E_c} + \frac{L\,D\,I}{V_{dc}/2 + E_c} \qquad (4.6)$$

And the inverter switching frequency is

$$\frac{1}{T} = f = \frac{(V_{DC}/2)^2 - Ec^2}{2(V_{DC}/2)L\,DI} = \frac{(V_{DC}/2)^2 - Ec}{V_{DC}\,L\,DI} \qquad (4.7)$$

$$DI = \frac{(V_{DC}/2)^2 - Ec^2}{V_{DC}\ Lf}$$

With a fixed tolerance band D I the switching frequency f depends on the output voltage required, and for a sinusoidal output voltage (i.e., Ec = Emax Sin wt) the inverter switching frequency varies. The inverter switching frequency will be maximum when the output voltage is zero and the maximum switching frequency is

$$fm = \frac{V_{dc} / 4}{L\,DI}$$

$$f = fm \left[1 - \left(\frac{Edc}{Vdc/2} \right)^{2} \right]$$

From equation (28) the frequency variation with variation in the output voltage can be written as This method is easy to implement and will provide excellent dynamic performance but it is also having some drawbacks.

1. No fixed PWM frequency: The switching frequency varies during the fundamental period, resulting in irregular operation of the inverter at times.
2. Moreover, a zero voltage vector is applied to the load as a result the load is disconnected at several instants over the fundamental period of the output voltage.

To over come the above problems the Ramp-comparator current controller is used.

4.4.2 Ramp-comparator current controller:

In this method the actual values of the three-phase load currents are measured and compared to the reference currents. The generated error signals are compared to a triangular waveform of fixed frequency and amplitude. The fallowing fig4.6 shows the block diagram of the Ramp-comparator current controller

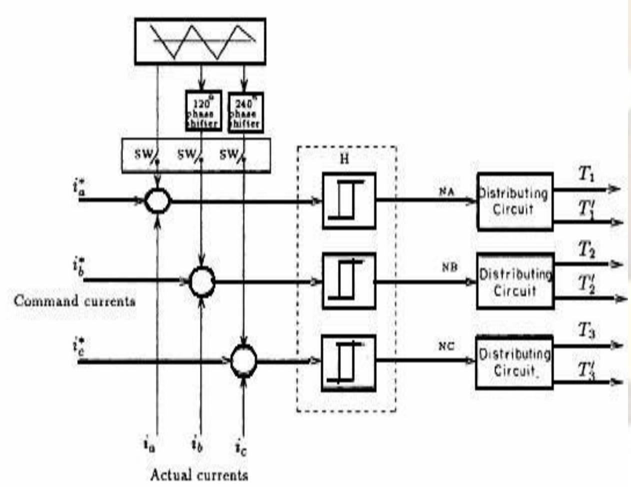


Fig.4.6.The block diagram of Ramp-comparator current controller

Here i_a^* , i_b^* , and i_c^* are the reference currents, i_a , i_b , and i_c are the actual currents. The reference currents are compared with actual currents, the generated error signals are compared to a triangular waveform of fixed frequency and amplitudes. The current error signals are compared to three 120^0 phase-shifted triangular waveforms having the same fixed frequency and amplitude. This phase shift is achieved using phase shifters. If the current error signal is positive and larger than the triangular wave, the transistor switches are activated to apply $+V_B$ to the load. However, if the current error signal is positive and smaller than the triangular wave, the transistor switches are activated to apply $-V_B$ 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 the modulated waveform. Since this controller uses a fixed-frequency triangular wave, it has the effect of maintaining a constant switching frequency of the inverter. 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 operation of 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.

4.5 Summary

Different types of PWM techniques for VSC are discussed in this chapter. Hysteresis current control technique and ramp comparator current control technique are explained with their corresponding advantages and disadvantages and it is explained that the ramp comparator current control technique is more efficient in providing switching pulses than the hysteresis current control technique.

V. SIMULATION RESULTS

The simulation was performed on the MATLAB/SIMULINK package. Simulink is a software package for modeling, simulating and analyzing dynamic systems. It supports linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. Systems can also be multirate, i.e., having different parts that are sampled or updated at different rates. In this chapter the simulink models of the shunt active filter with hysteresis current controller, ramp comparator current controller are given along with simulation results.

To observe, both the steady state and dynamic performance of the shunt active filter, different types of loading conditions has been considered. Detailed simulink models of the test system along with the active power filter is shown below.

Three-phase supply	**Line voltage: V_{LL}=415V,Frequency:f=50 Hz**
Three-phase source parameters	**Source inductance: Ls=0.5mH, Source resistance: Rs=0.1 W**
DC-link Capacitance	**C_{dc}=1500 mF**
DC-link Voltage	**680V**
Inverter Coupling parameters	**Coupling inductance Lc=3.25mH Coupling Resistance Rc=0.4 W**
Non-linear Load Details	**Diode bridge rectifier with R=30 W ,L=30mH**

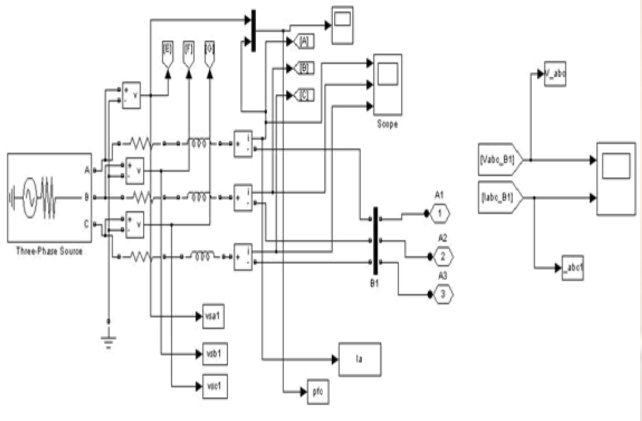


Fig.5.3.Simulink Model for Three-phase Source Subsystem

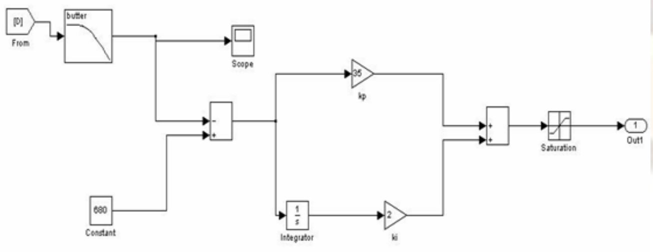


Fig.5.4.Simulink Model for DC Bus Voltage PI controller Subsystem

PI Controller Gain Constants:

Proportional controller gain = 0.35. Integral Controller gain value = 2.
The Capacitor Reference Volt = 680 V.

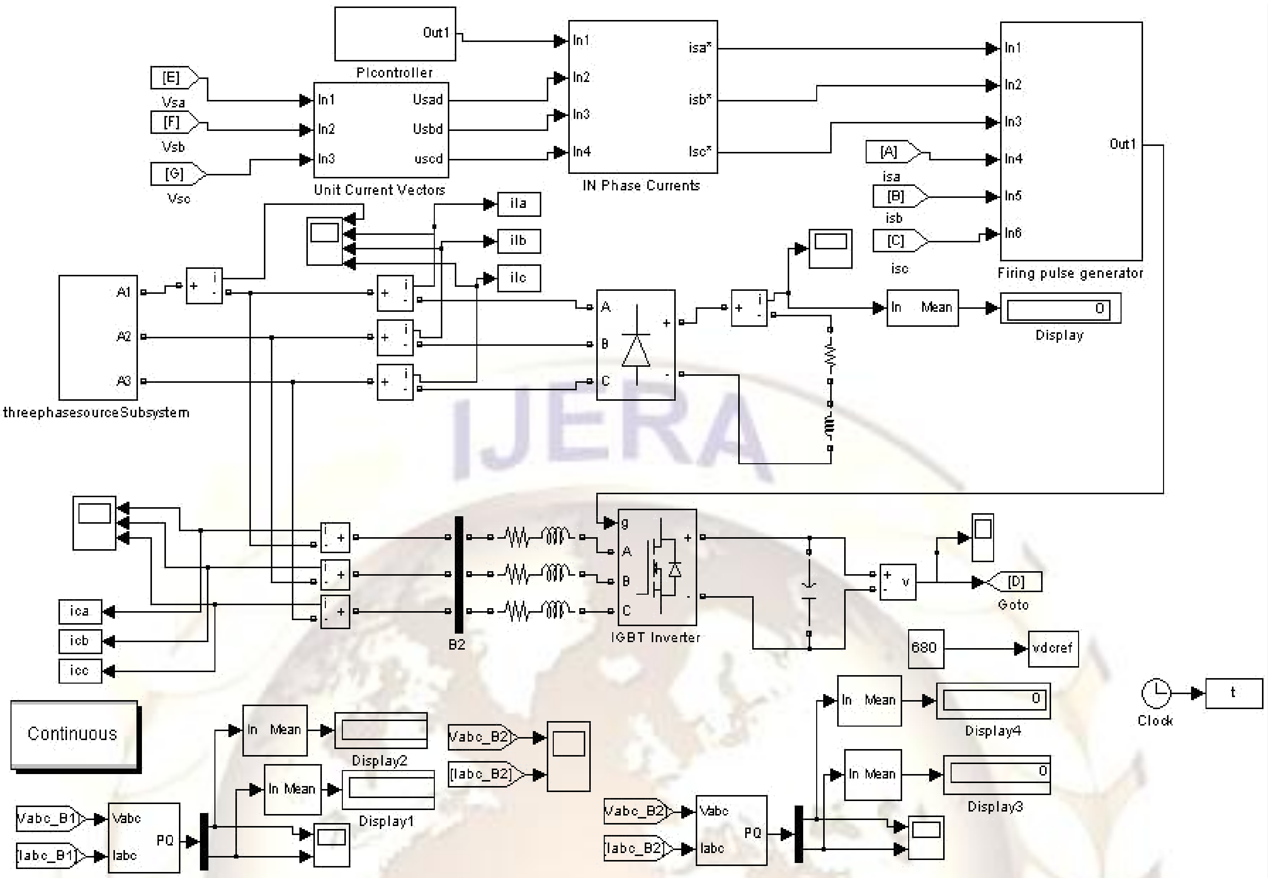


Fig.5.1.The Simulink Model for Power Factor correction

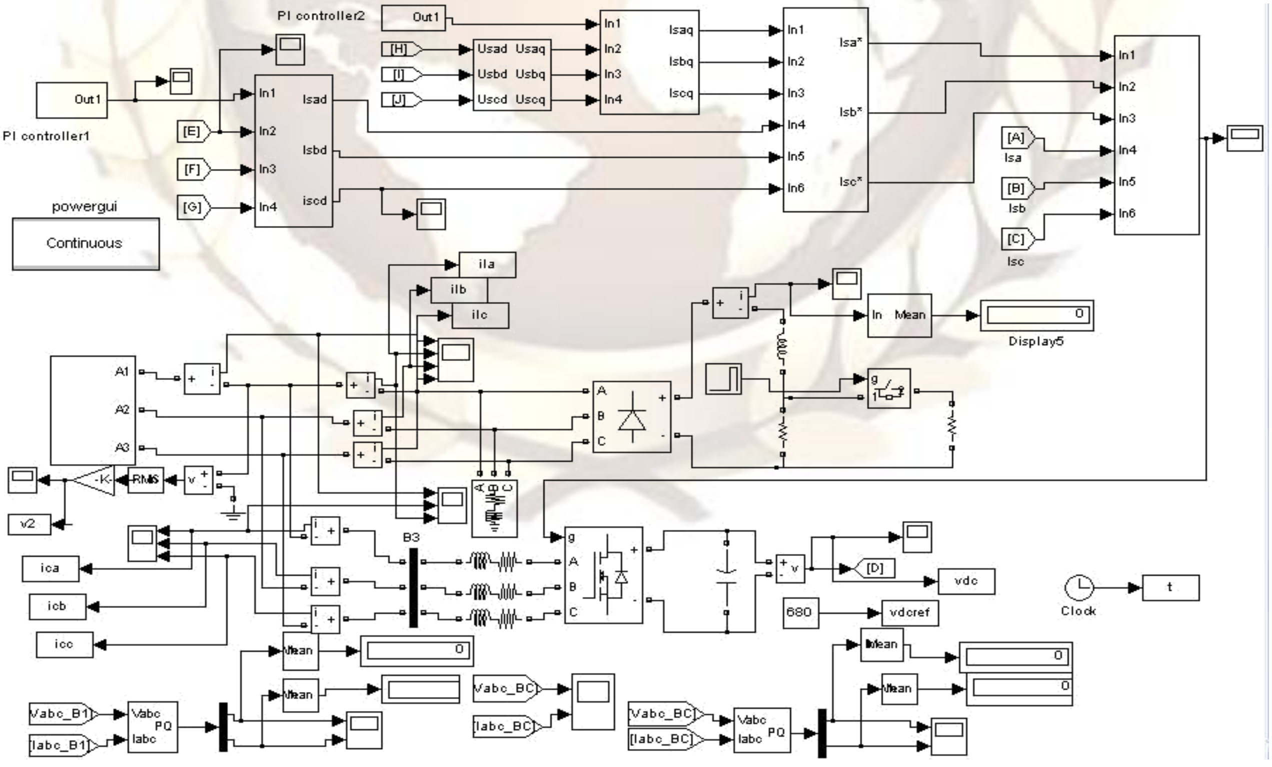


Fig5.2. voltage regulation

5.2 Simulation Results

Results with Hysterisis current controller: The steady state performance of AF for power-factor correction and Harmonic Elimination is shown below for two different load conditions.

Case 1: A 10KW Non linear Uncontrolled rectifier load:

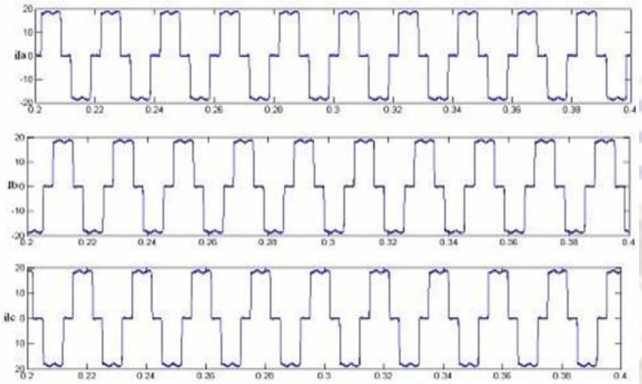


Fig.5.10.Load currents I_{la}, I_{lb}, I_{lc}

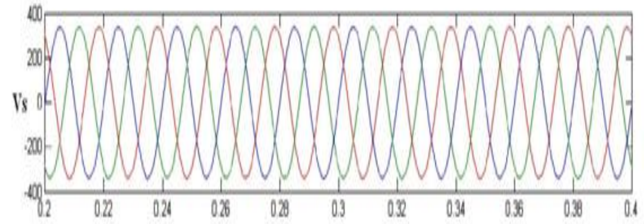


Fig.5.7.Source voltage

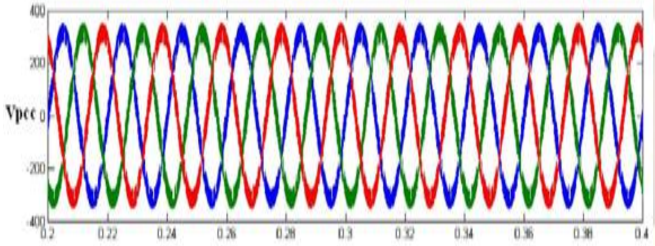


Fig.5.8.Voltage at the point of common coupling

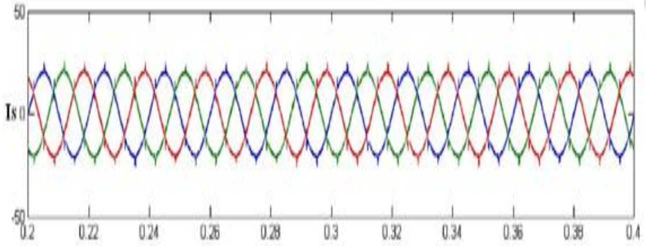


Fig.5.9.Three phase source currents

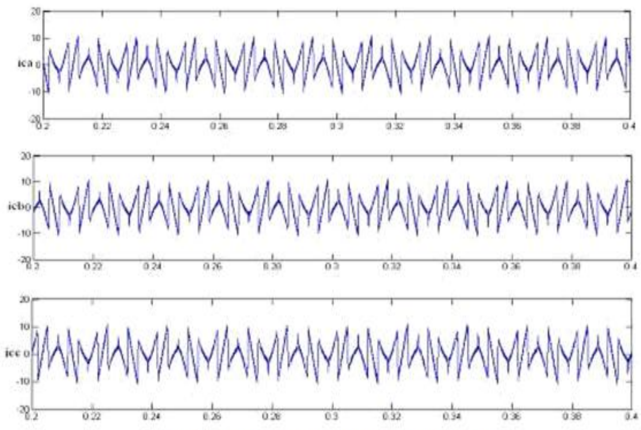


Fig.5.11.Compensating currents I_{ca},I_{cb},I_{cc}

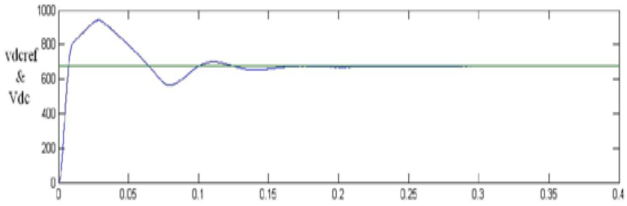


Fig.5.12. Reference voltage and the actual voltage of the capacitor

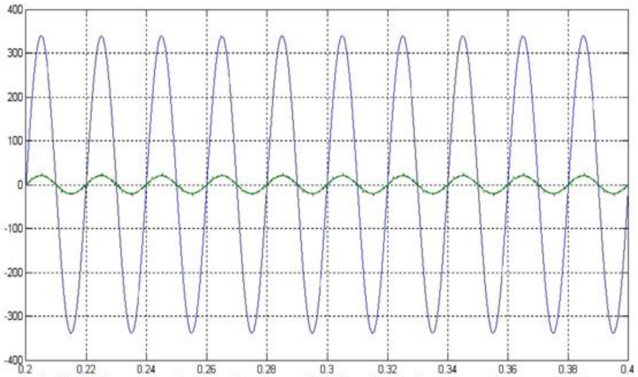


Fig.5.13.Phase A voltage and current showing the unity power factor operation

Vs(RMS)	Is(RMS)	I_L(RMS)	THD(Is)	THD(I_L)	Load
415V	14.54A	15.10A	2.97%	27.43%	10KW

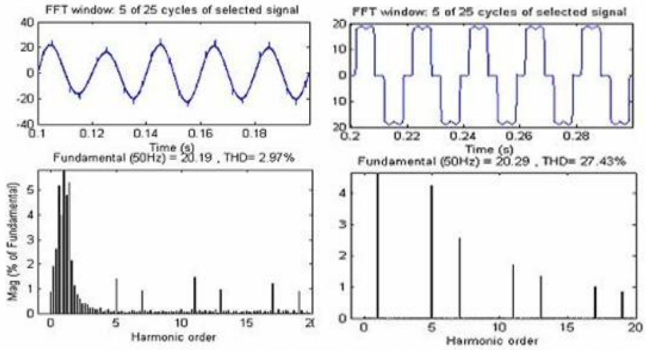


Fig.5.14. Source current and Load current THD waveforms

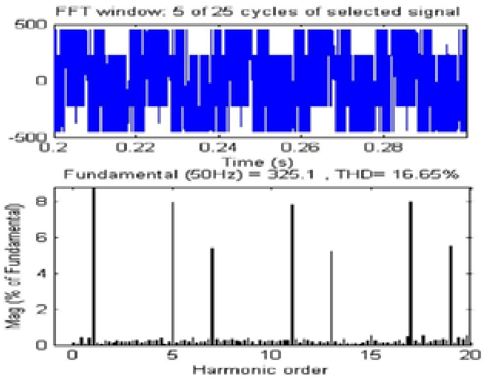


Fig.5.15.Inverter output voltage THD waveform

The source voltage and currents, the load currents are shown in Fig (5.7), Fig (5.9) above with a shunt active filter compensation in which the pulses to the inverter are generated by hysteresis current controller. It can be observed that the voltage of the capacitor on the input side of the shunt active filter is being maintained at the reference value from Fig (5.12) .The Fig (5.13) shows unity power factor operation of the 10KW nonlinear load. The THD of source and load currents is shown in Fig (5.14). Thus by using the shunt compensator, the THD in supply current is reduced to a level which is below the IEEE-519 standard and also the supply power factor is improved to unity.

Case 2: 10KW Non-linear Controlled rectifier load operated at firing angle,a = 30^0

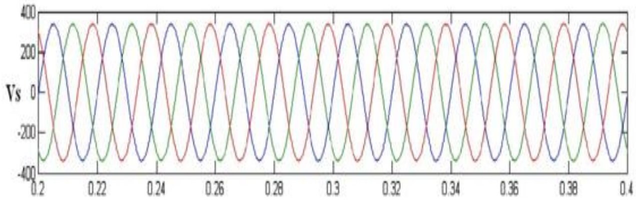


Fig.5.16.Source voltage

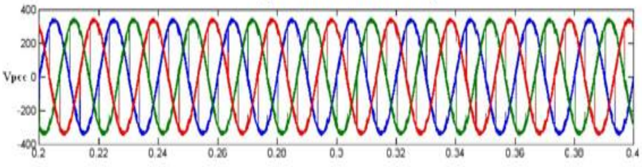


Fig.5.17.Voltage at the point of common coupling

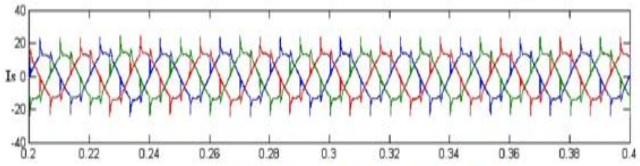


Fig.5.18.Three phase source currents

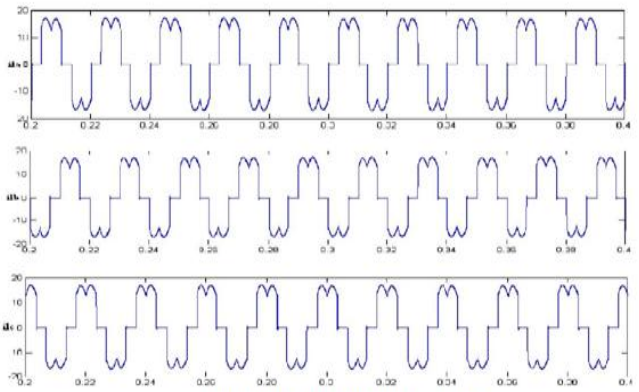


Fig.5.19.Load currents I_{la}, I_{lb}, I_{lc}

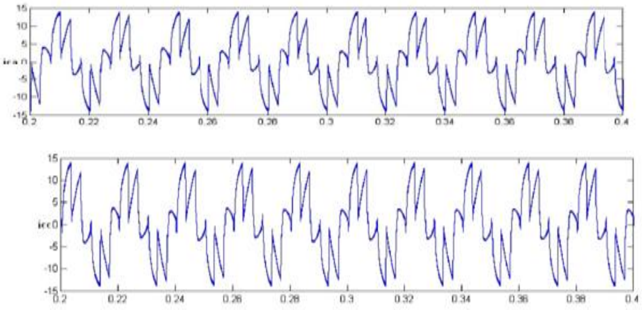


Fig.5.20.Compensating currents I_{ca},I_{cb},I_{cc}

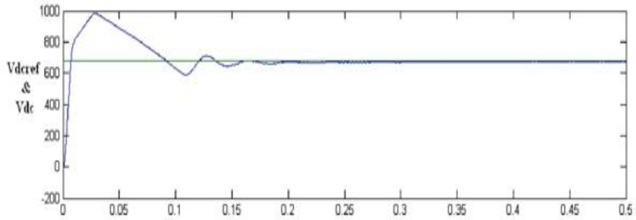


Fig.5.21. Reference voltage and the actual voltage of the capacitor

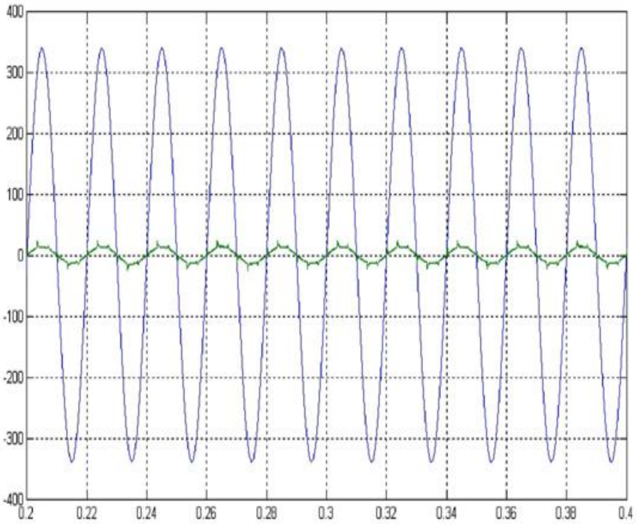


Fig.5.22.Phase A voltage and current showing the unity power factor operation

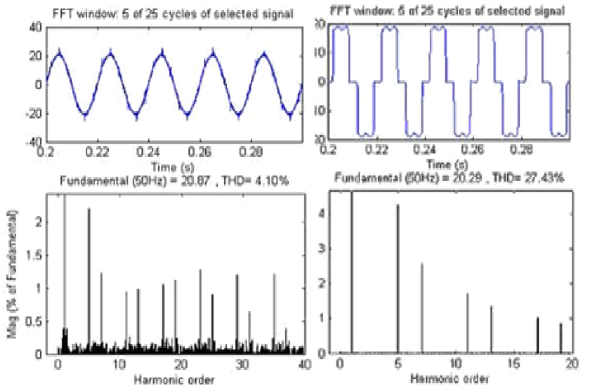


Fig.5.23. Source current and Load current THD waveforms

The Fig (5.22) shows unity power factor operation of for a 10KW nonlinear controlled rectifier load. The THD of source and load currents is shown in Fig (5.23). The THD in supply current is reduced to a level which is below the IEEE-519 standard and also the supply power factor is improved to unity. The dynamic performance of AF, with a non-linear load change from 5KW to 10KW and back to 5KW is shown below.

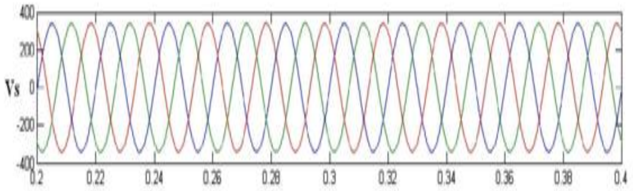


Fig.5.24.Source voltage

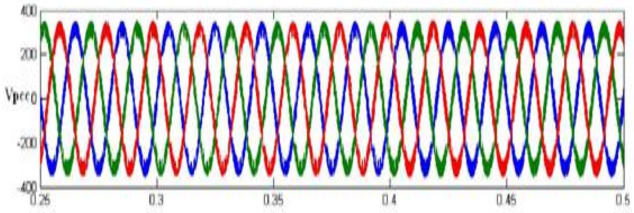


Fig.5.25.Voltage at the point of common coupling

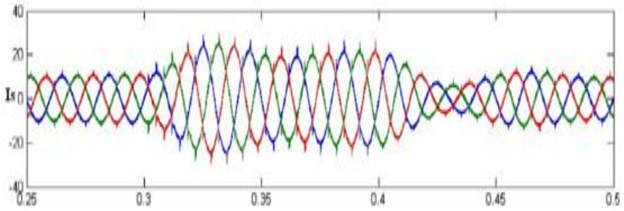


Fig.5.26.Three phase source currents

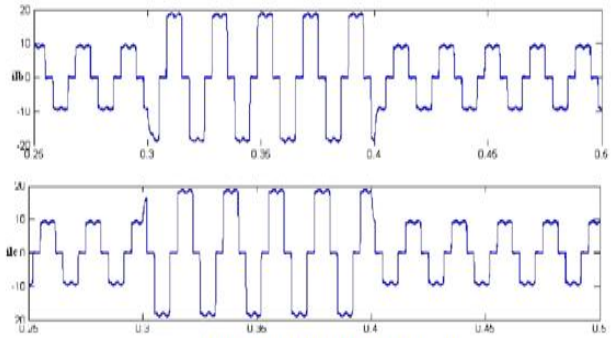


Fig.5.27.Load currents I_{la}, I_{lb}, I_{lc}

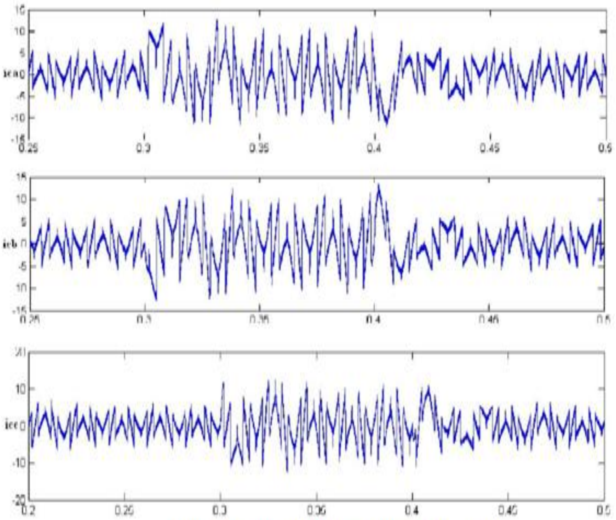


Fig.5.28.Compensating currents I_{ca},I_{cb},I_{cc}

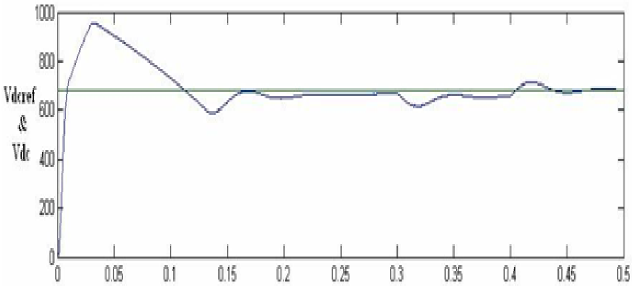


Fig.5.29. Reference voltage and the actual voltage of the capacitor

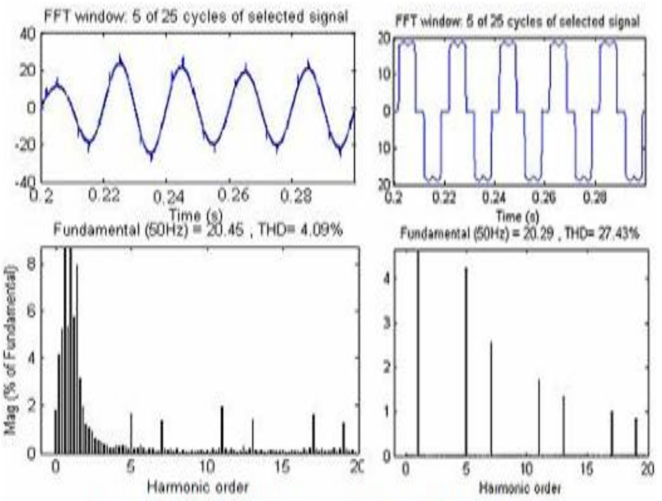


Fig.5.31. Source current and Load current THD waveforms

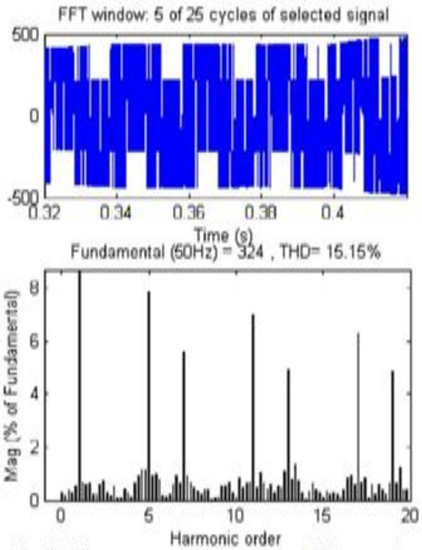


Fig.5.32.Inverter output voltage THD waveform

In this case, the load is increased from 5KW to 10KW at around 0.3 seconds and again 0.4 seconds the load is reduced to 5KW. The increase in the load current can be seen in Fig (5.27) at 0.3 seconds. Corresponding to the increase the load current, the compensating current injected is also increased as shown in Fig (5.28) which shows that the shunt active filter is responding well during dynamic load conditions also. In this case also it has been observed that the power factor is improved to unity and the THD is below the acceptable level. The response of AF, for 10KW 0.8pf linear balanced load, together with a 10KW non-linear load is shown below.

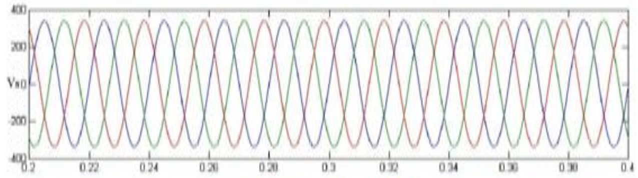


Fig.5.33.Source voltage

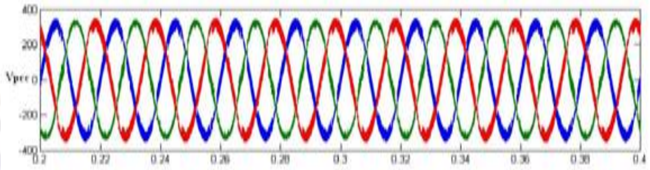


Fig.5.34.Voltage at the point of common coupling

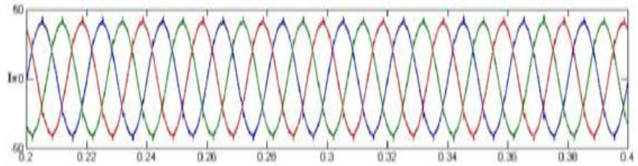


Fig.5.35.Three phase source currents

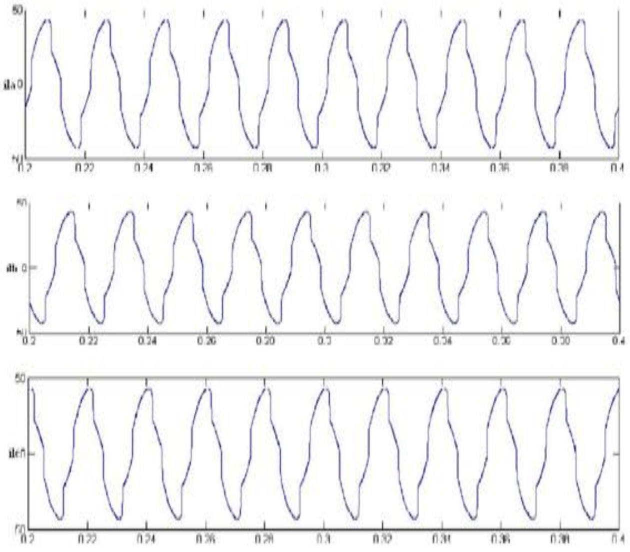
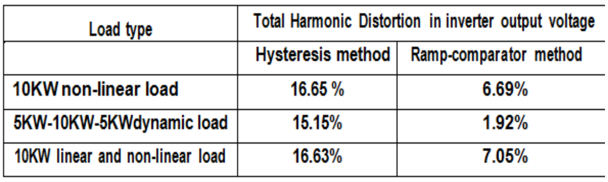


Fig.5.36.Load currents I_{la}, I_{lb}, I_{lc}

VI. CONCLUSION

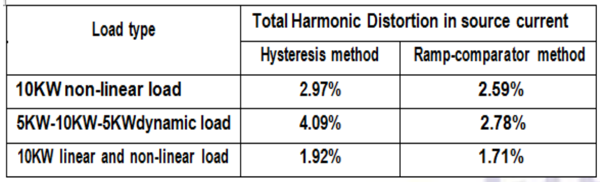
Here the system is simulated using both Hysteresis and Ramp-comparator current controllers. In case of Hysteresis current control method because of the variable switching frequency, THD is more when compared to ramp comparator current controller, as shown in the Table 5.4 and Table 5.5 below.

Table.5.2.Comparison of THD's in Inverter output voltage:



Load type	Total Harmonic Distortion in inverter output voltage	
	Hysteresis method	Ramp-comparator method
10KW non-linear load	16.65 %	6.69%
5KW-10KW-5KWdynamic load	15.15%	1.92%
10KW linear and non-linear load	16.63%	7.05%

Table.5.3. Comparison of THD's in Source current:



Load type	Total Harmonic Distortion in source current	
	Hysteresis method	Ramp-comparator method
10KW non-linear load	2.97%	2.59%
5KW-10KW-5KWdynamic load	4.09%	2.78%
10KW linear and non-linear load	1.92%	1.71%

The shunt active compensator eliminates the supply current harmonics and improves supply power-factor for both nonlinear and linear loads with different load characteristics.

It can also be concluded that, by using Indirect current control technique the maximum switching frequency of the IGBT's of the Active filter is reduced, because this technique controls the compensating currents of AF, by sensing the source current, which are slow varying (sinusoidal) in nature compared to the harmonic components, which are very fast varying.

In this work a Hysteresis current controller and amp-comparator current controller are simulated in Simulink. It is observed that both the controllers have satisfactory performance. With both the controllers, the supply power factor is improved to unity, with the harmonics in the supply current being eliminated for different types of loading conditions. As the switching frequency is fixed in the case ramp comparator current control method it has better performance when compared with hysteresis current control method.

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