USE OF SUPER CONDUCTING MAGNET FOR ENERGY STORAGE IN SHUNT ACTIVE POWER FILTER

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Certificate

This is to certify that the thesis entitled, "**Use of Super Conducting Magnet for Energy Storage in SAPF**" submitted by Mr**. Pravesh Kumar** to National Institute of Technology Rourkela, during the academic session 2013-2015 is a record of bonafide research work carried out by him under my supervision and is worthy of consideration for the award of the degree of Masters of Technology in Electrical Engineering with specialization in **Cryogenics & Vacuum Technology.** The embodiment of this thesis has not been submitted to any Other University and/or Institute for the award of any degree or diploma.

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Abstract

Huge application of non-linear load and electronics apparatus in power system generates harmonics. That makes the current wave form distorted and causes huge power loss in power system. This problem can be overcome by application of Shunt Active Power Flitter (SAPF). Shunt Active Power Filters in an electric power network can improve the quality of power system by removing harmonics which are generated by non- linear load. In this project, a voltage-source PWM converter, and a Super Conductor Magnet for energy storage is used to design a Shunt Active Power Filter. Earlier use of copper inductor to store the energy for compensation the harmonics in Shunt Active Power Filter causes a power loss, to reduce these power losses instead of copper inductor a Superconductor Magnet is placed in Shunt Active Power Filter. Shunt Active Power Filter is designed by using ‘Instantaneous Power Theory’ or ‘*p-q* Theory’. Switching pulses for Voltage source converter is generated by using Hysteresis Band Controller. DC/DC is also designed to control the Super Conductor Magnet. Charging and Discharging of Magnet is base switching operation of DC/DC converter. Total Harmonic Distortion (THD) in wave, during charging and discharging of Magnet is calculated and presented in this paper .The results of simulation are satisfied with all the property explained by the theory. This paper describes simulation and evolution of SAPF for removing the harmonics. Simulations are done using **MATLAB/Simulink Software** and results are presented.

Index Terms:PWM converter,*p-q* Theory, Total Harmonic Distortion (THD)

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CHAPTER 1:

INTRODUCTION

There is large use of non-linear loads such as CFL (compact fluorescent lamps) and LED (Light emitting diode) lamps etc. These cause harmonics in power system which is undesirable [30]-[31]. Harmonic distortion, which is created by the use of these loads is responsible for many problems such as power loss is occurring in electrical apparatus, transmission lines, power transformer, and flickering in power system also which affects chemical insulation. It is necessary to remove these undesirable harmonic distortion and compensation of the reactive power flowing in the power network. This is achieved by using SAPF in parallel with power line. SAPF (Shunt active power filter) gives encouraging results by using proper control technology. The control technique is principle key for better working of the SAPF. Three phase quantity is included in most of the control technique applied for SAPF. Here the p-q theory introduced by Akagi [25] is used for the control strategy of the SAPF, and a superconductor magnet is used to store the energy for compensation in SAPF.

Current harmonics are generated by the huge application of power electronics apparatus and nonlinear loads in the power network. Harmonic generated by these nonlinear loads are responsible for the distortion in the current waveform. Power factor is reduced, and there is reduction in efficiency, and there is problem related to changing in the voltage and interference with communication line also. So harmonics are regarded as a major problem which disturbs the whole power network. Usually an LC filter bank was applied to face this problem occurred by the system harmonics, because these are designed easily, construction is simple, better efficiency and cost of it is very low. Synchronous capacitors were also used for increasing the quality of power system. However there are a lot of disadvantages in using of traditional controllers. These are bulky in size, and provide only fixed compensation, create resonance problems. To remove these drawbacks, SAPF are placed in parallel with transmission line through coupling inductor which mitigate the harmonics in current wave

1.1 SUPER CONDUCTIVITY

When the temperature of any material decreases below a certain critical temperature, condition of superconductivity is occurred which is a phenomenon of exactly zero resistance. For storing the energy, a long super conducting coil is used .This energy is stored in the form of magnetic field which is produced by the direct current flowing in it. This coil is located across the voltage source converter, charging and discharging is done by using DC to DC converter. The Study is done related to use of Shunt active power filter and Superconducting Magnetic Energy Storage system which is described in various research papers. The requirement of electric power has been varying continuously from interval to interval according to the consumer and industry. Apart from, superconducting magnetic energy storage system, there are a lot of energy storage system is used like battery storage. But there are so many disadvantages in this storage system, life of this system is very short and they create dangerous supplies into the environment. In the superconductor magnet, the process of storing the energy is performed by the dc current which is flowing into the coil.

1.2 COMPONENT REQUIRED

A voltage source converter (VSC) and a DC/DC, bidirectional converter is used in power system for the designing of Shunt Active Power Filter. The VSC is a voltage controlled device, DC/DC converter is used to connect the voltage controlled converter to the current controlled magnet. These converters are decoupled by DC-link. DC-link is connected by the voltage source converter to the AC supply system. Source current is made in phase with Source voltage by the controlling of the voltage source converter. Superconductor magnet coil is charged and discharged by controlling the DC/DC bidirectional converter. Interchanging of power between coil and power system is done after keeping the system voltage constant. These two converters are regulated by the Hysteresis band controller [33]. Controlling of the voltage source converter is done by generating pulse after comparing source current and reference current with the help of Hysteresis Band Controller. A limit is made by hysteresis controller to fix the controlled variable. Switching pulses are produced according to controlled variable when it is reached the upper or lower limit. Energy in the magnetic coil is regulated by PI controller, AC current losses is occurred due to use of pulse signal for the operation of superconducting magnet coil. At the time of making Refrigeration system for the superconductor magnet these losses should be considered.

1.3 LITERATURE REVIEW ON SHUNT ACTIVE POWER FILTER

Hirofumi Akagi et al [1] installed a line conditioner to remove the distortion generated by AC to AC converter which is used for steel mill drives he classified the line conditioners into shunt and series. Instead of shunt line conditioner, active line conditioner is used by him because shunt power line can be used at lesser impedance than the source impedance for removing the harmonics at adjusted frequency. Harmonic Magnification is occurring at the definite frequency as a result of parallel resonance between Shunt passive line conditioner and source impedance.

Fukuda and MasuruYamagi [2] proposed a paper in which they described a current source Active Power Filter and uses PWM current source inverter to suppress harmonics in Power system .They used high pass active filter along with Active Power Filter to remove unwanted harmonics. The Current in the inductor is regulated to minimize the losses of PWM inverter

Molekutty George and Kartic Prasad basu et al [3] designed a three phase SAPF based on MRC , and active power system is simulated in MATLAB 6.1 toolbox for several firing angle in the range of 0^o to 180^o .

Chen Chao and Colin Grantham [4] proposed that by replacing inductor with super conductor Magnet in active power filter can reduce the power losses and make active power filter more efficient .BSCCO-2223 tape have been made for the HTS magnet that has an inductance of0.5 H for this application and liquid nitrogen cooling is used to cool the magnet.

Joao Afonso et al [5] designed active power filter which is very low price. In this paper digital control is used for compensation of harmonics and zero sequence current and for improvement in power factor also. This solution can remove voltage drops and the power lines losses, and reduces voltage distortions at the loads terminals.

Anzari M, et al [6] proposed a paper in which they simulated active power filter with indirect control method. In this control method there is phase difference of 90^0 between input voltage and input current. In shunt active power filter, using this regulating method reference current is produced effectively. By using this technique total harmonic distortion is mitigated from 37.90% to 8.65% after compensation, and there is improvement in power factor also.

MetinKesler, Engin Ozdemira [7] analyzed and simulated Shunt Active Power Filter which is used for distorted load conditions and under unbalanced condition. Instantaneous Reactive Power theory (IRP) is applied for removing of current harmonics. In this paper current which is equal but opposite in phase is fed in power lines to neutralize the harmonics

Mrs.R.S.Udgave et al [9] designed Hysteresis band controller. Hysteresis band controller helps in suppression of harmonic by generating the switching pulses for the active power filter. This active power filter system is simulated and tested in MATLAB software. This improves the performance of power system, and there is reduction in THD from 28.17% to 1.35%.

Sincy et al [10] discovered Shunt Active Filter based on DSP optimal algorithm. This is used when there is Unbalanced Load Conditions and Non sinusoidal Source. The model of the technique is composed of an unbalanced nonlinear load and 3 phases- non sinusoidal source voltage connected to nonlinear load. Center of two DC capacitors is linked to the neutral wire of the power network, which works as input to the inverter.DSP is used as a controller. With the help of DSP, the reference signal is produced. And the hysteresis band controller is applied to create the pulses for triggering the switching devices of the inverter

M. Aziz [11] proposed that the condition of power is improved when Current Harmonics is removed with the help of the Hysteresis band Control Technique .By this technique triggering pulse is generated by relating the error signal with the of hysteresis band. And this pulse is used to control the voltage source inverter.

Helder J. Azevedo et al [12] presented a paper in which they proposed that Active Power Filter is controlled by the direct current control method for removing the harmonics, and there is improvement in Power Factor also by this Technique. Load Unbalancing is also removed. Operation of this active power filter is established on a current Voltage Source Inverter. The control procedure creates the reference current which is based on the voltage of DC link.

Chennai Salim [13] described the performance of Three-phase Three-level (NPC) Shunt Active Power Filter .For this filter a Control Technique on the basis of PWM and ANN is designed. The simulation is by Matlab-Simulink.

1.4 RESEARCH MOTIVATION

- SAPF are placed in parallel with transmission line through coupling inductor which mitigate the harmonics in current wave.
- A three phase voltage source converter (VSC) and DC link capacitor is used to construct the SAPF

- Compensation current, created by SAPF is in 180 degree in phase opposition and gets fed back into the power line in order to get rid of the harmonics generated by non –linear loads. Hence harmonic, existing in the power system can be mitigated and the current waveform would be free from harmonic content.
- So the procedure of this operation consists of discover the harmonic existing in power system, producing the reference current, producing the switching pulses for the inverter and DC/DC chopper, after that compensating current is achieved and get passed back into the power system to suppress the harmonic .
- In this paper a three phase voltage source is connected to nonlinear load. SAPF is placed in parallel with the power lines so that harmonics existing in power system are suppressed.
- Here reference current is generated on the basis of p-q theory. By using this reference current switching signal for the VSC is produced with the help of Hysteresis Band Current Control Technique (HBCC). This technique is very effective.
- Here Instead of inductor Superconductor magnet is used for energy storage. Charging and discharging of magnet is done by DC to DC chopper.
- Discharging of the coil is done immediately because it has zero time delay due to having zero resistance. Due to this assets magnet can be discharged in milliseconds.
- The voltage source converter, we are using in this project is (IGBT) type.
- PI controller is applied to control the superconductor magnet energy storage system. Source current should be in phase with the sourer voltage without taking into account of nonlinear loads. To obtain the gain of controller, control loops were evaluated. All the control system till 2003 for controlling the energy of magnet was based on voltage control.

- In this type of controller maximum time is consumed. So to remove the time delay and increase the response of magnet related to charging and discharging .the magnet should be charge under constant current mode, and discharge under constant voltage mode.

1.5 AIM OF THIS PROJECT

- The aim of this work is as following.
- To generate reference current by using Clarke transformation or inverse Clarke transformation base on instantaneous p-q theory.
- To generate switching pulses for converter using reference current and source current with the help of hysteresis controller.
- For exchanging the energy between source and superconductor magnet voltage of DC link is kept constant
- Charging and discharging of superconductor magnet is controlled by DC/DC Converter.
- v- Find the THD (total harmonic distortion) in source current

1.6 THESIS ORGANIZATION

CHAPTER-1 In this chapter shunt active power filter is described. Why active power filter is used in power line is discussed in this chapter. The reason and causes why this research is done is discussed in this chapter. Since recent year many research related to active power filter is studied and described in literature review.

CHAPTER-2 This chapter contain how reference current is generated by using p-q theory by converted in α, β reference frame from a,b,c reference frame with the help of CLARKE transformation. Hysteresis controller and PI controller are also explained.

CHAPTER-3 SAPF with magnet is demonstrated and control technique used for filter and magnet is described in this chapter.

CHAPTER-4 Results and simulation diagram are presented in this final chapter .Conclusion and future work also proposed in this chapter.

CHAPTER-5 Conclusion and Future scope is proposed in this chapter.

1.7 SUMMARY

- Nonlinear loads such as CFL (compact fluorescent lamps) and LED (Light emitting diode) lamps create harmonics in power system.
- These loads are responsible for many problems such as power loss is occurring in electrical apparatus, transmission lines, power transformer, and flickering in power system.
- A voltage source converter (VSC) and a DC/DC, bidirectional converter is used in power system for the designing of Shunt Active Power Filter.
- It is necessary to remove these undesirable harmonic distortion and compensation of the reactive power flowing in the power network. This is achieved by using SAPF in parallel with power line.
- Here the p-q theory introduced by Akagi is used for the control strategy of the SAPF.
- When the temperature of any material decreases below a certain critical temperature, condition of superconductivity is occurred which is a phenomenon of exactly zero resistance
- Charging and Discharging of magnet is controlled by DC to DC converter.

CHAPTER 2:

DESIGNING AND CONTROLLING OF SAPF WITHOUT SUPER CONDUCTING MAGNET

In this chapter Shunt Active Power Filter without super conducting Magnet is designed. Reference current generation on the basis of p-q theory introduced by Akagi is also described. Comparing this reference current with real current switching pulse is generated for the Voltage source converter. Application of Hysteresis controller and PI controller is also described in this chapter.

2.1CONFIGURATION OF SAPF WITHOUT SUPER CONDUCTING MAGNET

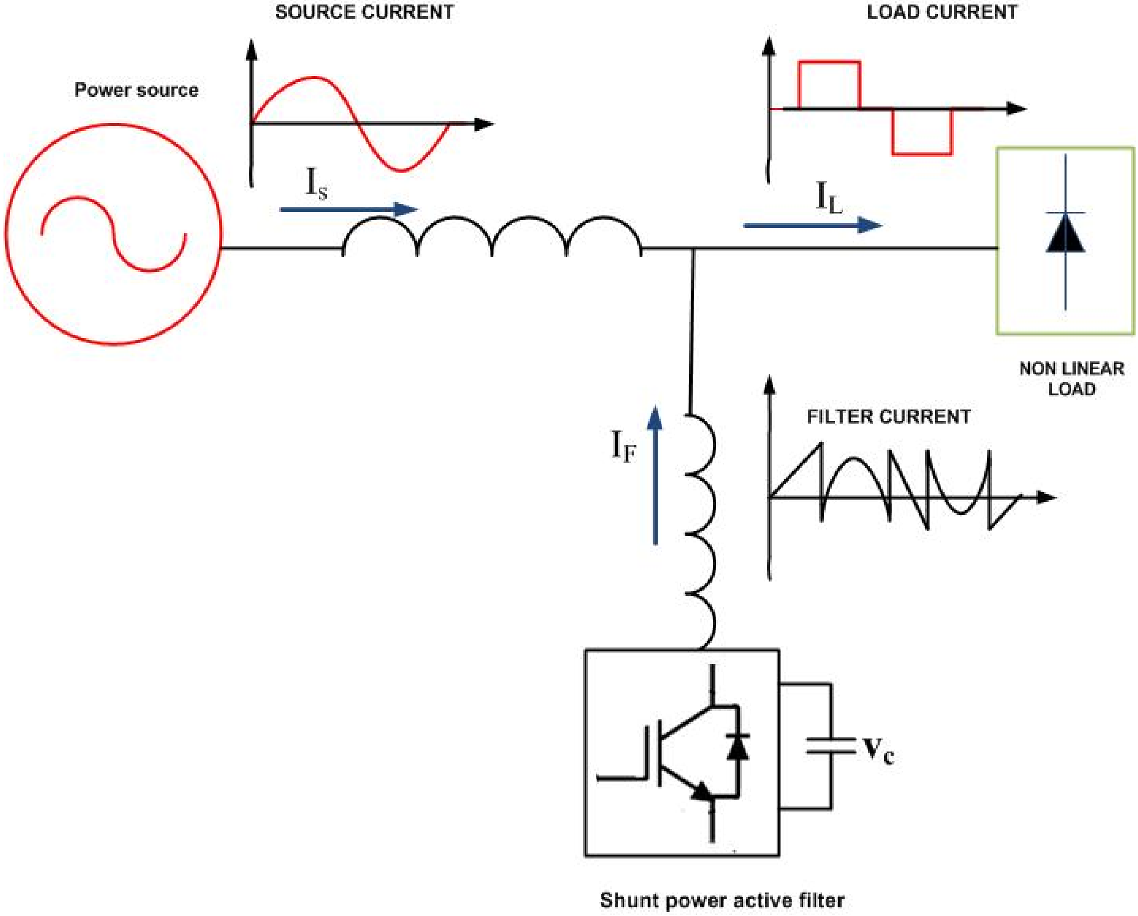


Figure 2.1: Configuration of SAPF without superconducting magnet.

Here nonlinear load is coupled to power system .SAPF is placed in parallel with power line and generates Filter current I_F to compensate the harmonic. The current which is fed by SAPF is phase shifted by $180^{0.}$

In Fig2.1

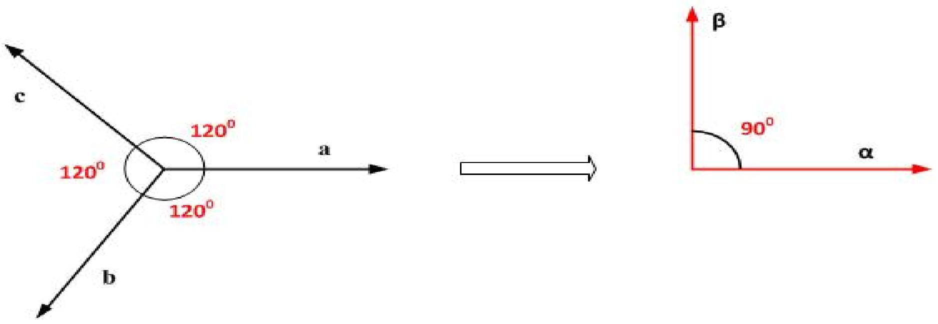
I_s = Source current which is flowing from source to load.

I_L = Load current

I_F = Filter current which is injected in Power System by Shunt Active Power Filter.

2.2 GENERATION OF REFERENCE CURRENT

This concept is very well-known that generation of reference current is done by converting three phase stationary frame a, b,c to α, β,0 stationary frame. The transformation equations for this operation can be obtained from the Phasor diagram.



For doing this transformation the Clarke and inverse Clarke technique is used .Three phase line currents i_{la},i_{lb},$i_{lc}$is converted on the αβ axis by using this transformation. This transformation is valid only if the source voltages are not non -sinusoidal and unbalanced. The product of voltage and conjugate of current gives the instantaneous complex power.

Instantaneous power theory:

This Constant power control strategy was the first strategy developed for Active power filters by Akagi et al.[25] in 1983**.**This theory uses Clarke's transformation which consists of real matrix that transform three phase '*v*' or '*i*' into αβ stationary reference frames.

$$s = v * i^* = (v_\alpha + jv_\beta) * (i_\alpha - ji_\beta) = (v_\alpha i_\alpha + v_\beta i_\beta) + j(v_\beta i_\alpha - v_\alpha i_\beta) \quad (1)$$

From this active and reactive power components are

$$p = v_\alpha i_\alpha + v_\beta i_\beta \quad (2)$$

$$q = v_\beta i_\alpha - v_\alpha i_\beta \quad (3)$$

Mathematical equation in the form of matrix will be written as following if the neutral connection is absent in the power system.

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} \quad (4)$$

Similarly for voltage

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (5)$$

From this active and reactive components are

$$p = v_\alpha i_\alpha + v_\beta i_\beta \quad (6)$$

$$q = v_\beta i_\alpha - v_\alpha i_\beta \quad (7)$$

The active and reactive powers in matrix form are given below.

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (8)$$

Active and reactive powers will be separated in two component which are called AC component and DC component explained below.

$$p = \tilde{p}\ (ac) + \bar{p}\ (dc)$$

$$q = \tilde{q}\ (ac) + \bar{q}\ (dc)$$

For getting the DC component of the active and reactive power, the wave are passed in LPF (low pass filter).The LPF can completely remove the component of high frequency and deliver the basic component

Where

$\bar{p}$: DC part of p. it is responsible for the active current.

$\tilde{p}$: AC part of the power p, it will not comprise the average value of current .it causes the generation harmonic current.

$\bar{q}$: DC part of the imaginary power q, and it is associated to the reactive power produced by the primary parts of the voltages and currents. It will be affiliated to reactive power generated by voltage and current.

$\tilde{q}$: AC part of imaginary power q. and it will be related to harmonics of current which are generated by the ac part reactive power.

It is necessary for SAPF to have the component of p and q during the calculation of reference current to remove the harmonics current which is appeared by application of nonlinear load in the power system. This is achieved by following matrix.

$$\begin{bmatrix} i_\alpha * \\ i_\beta * \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} -\bar{p} \\ -\bar{q} \end{bmatrix} \tag{9}$$

The absolute compensating currents part in a, b, c reference frame in terms of αβ are expressed by the following matrix.

$$\begin{bmatrix} ic_a * \\ ic_b * \\ ic_c * \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_\alpha * \\ i_\beta * \end{bmatrix} \tag{10}$$

These are the reference current which is used to generate the pulse for VSC.

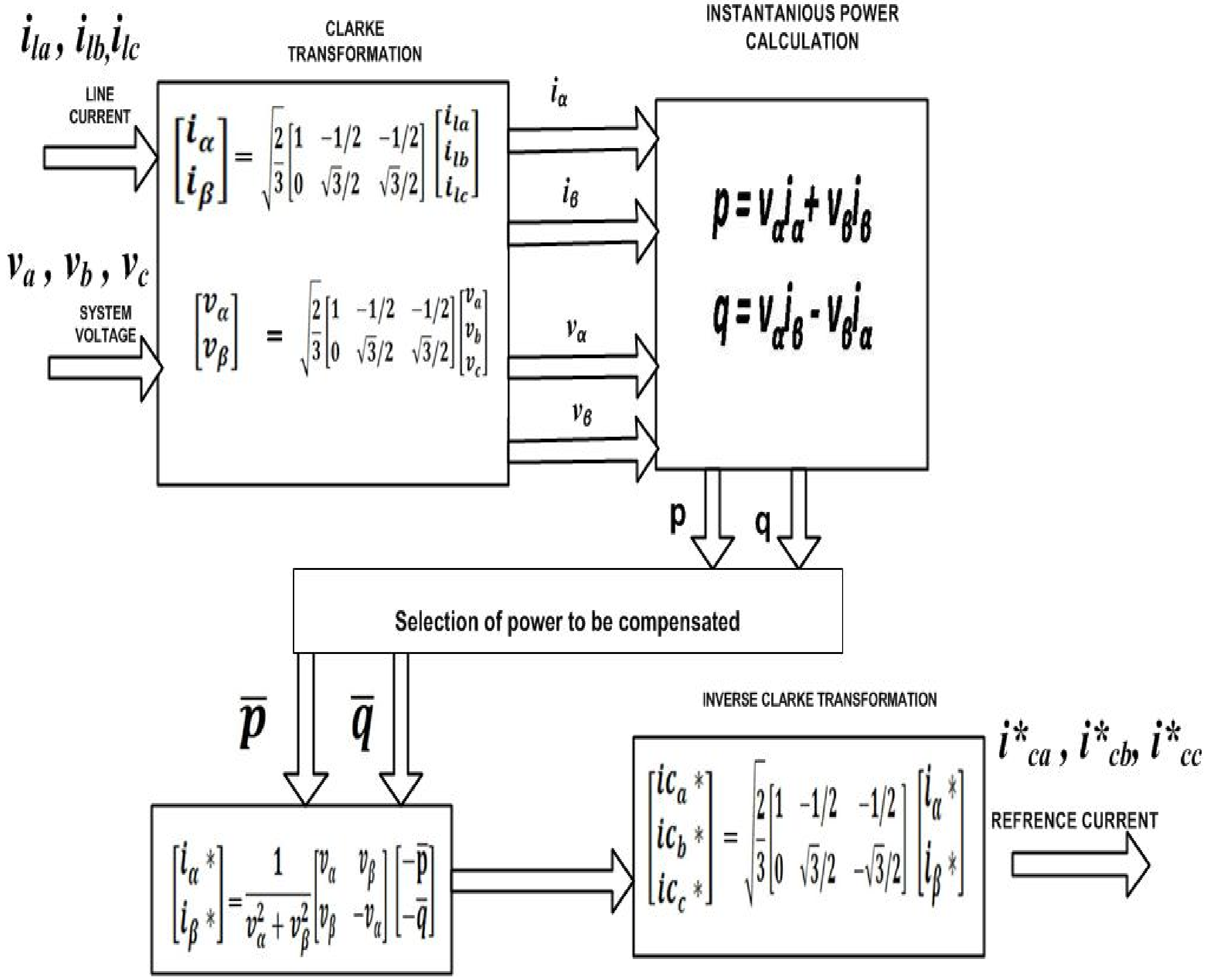


Figure 2.2: Block diagram for the reference current generation

In Fig 2.2, describes the complete strategy which is used for generation of reference current (i_{ca}^*,i_{cb}^*,i_{cc}^*). Firstly Line current and Source Voltage is converted in α β stationary reference frame from abc reference frame by using Clarke Transformation. Alternating component of real and imaginary power is compensated by passing through LPF (Low Pass Filter).i_α and i_β are current in α β stationary reference frame.i_{la},i_{lb},i_{lc}, andv_a ,v_b,v_c are current and voltage in abc reference frame.

2.3 CONTROL TECHNIQUE FOR SAPF

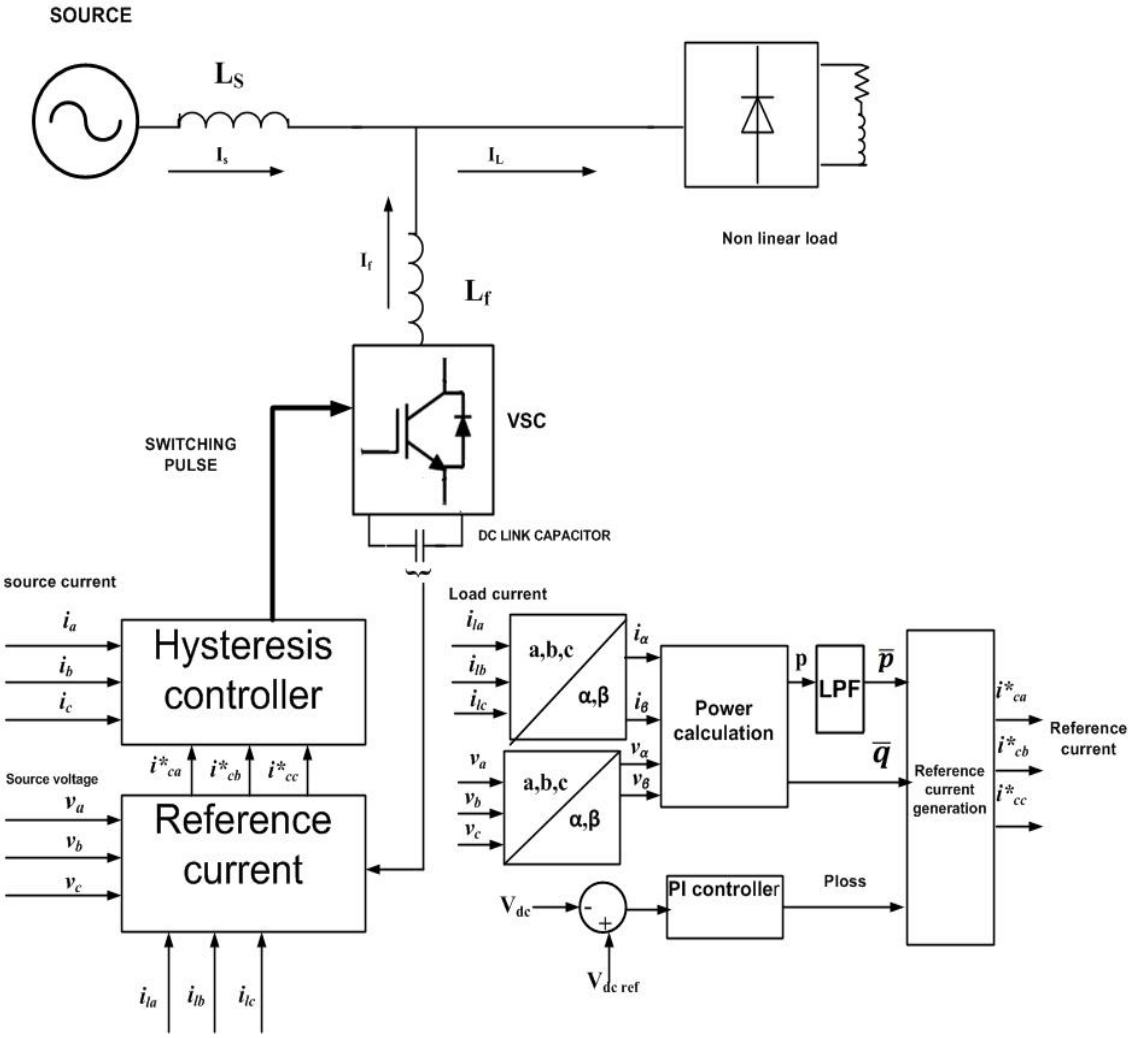


Figure 2.3: Control Technique for SAPF

In fig 2.3, a three phase non linear load is connected to three phase power supply. Shunt Active Power Filter is connected in parallel to transmission line. L_s is source inductance, L_f is Filter inductance. Switching pulses for VSC converter is generated by comparing source current and reference current with the help of Hysteresis Band current Controller. Error occurred between DC link Voltage and reference voltage is given to PI controller which causes generation of P_{loss} .This P_{loss} is used in power calculation and reference current generation.

2.3.1 HYSTERESIS BAND CURRENT CONTROLLER (HBCC)

There are so many linear and nonlinear control scheme .Which are used to control the needed physical quantity.PWM techniques are widely used. According to this technique reference wave will be compared with carrier wave. For this purpose Hysteresis controller is used which can be easily executed and it is simple also.

There are the other following advantages of this technique.

(a).It is stable.

(b).Response of this controller is very fast.

(c).Accuracy is good.

(d).Cost of this type of controller is low.

Instead of these advantages, there are so many unpleasant effect of using it. The major factor is that switching pulses generated by it produce main problems during modeling the input filter and undesirable resonances in the input part and creates audible noise. The other disappointing quality of this is that task of it is influenced by the interference between phase currents. [24]. various improvements to the original control design are suggested for industrial uses. [22] – [23]. Firstly phase current disconnecting method is originated. [22]. Secondly constant switching frequency is achieved by a changeable width of the hysteresis band.[Figure 4.1] describes the ordinary sinusoidal HBCC scheme applied for controlling the source current**.** It is composed of a hysteresis band all over the place of the reference source current. The reference source current is indicated as $\mathbf{I_S}^*$ and real source current is indicated as $\mathbf{I_S}$. The HBCC decides the order of switching signals of voltage source converter.

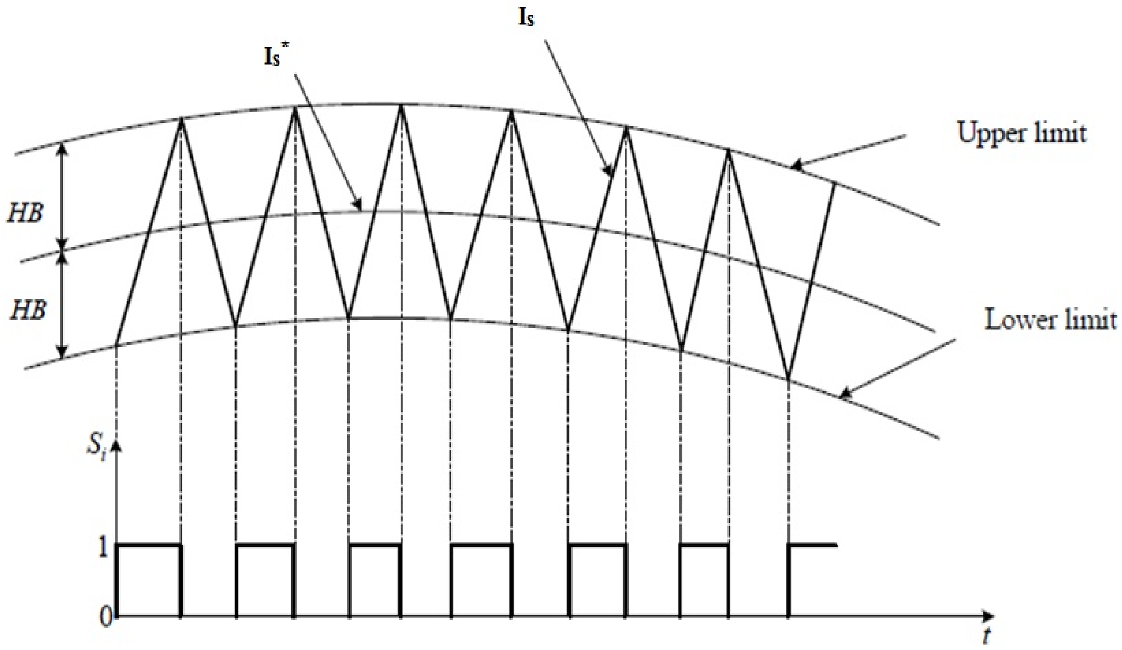


Figure 2.3.1(a): Function of Hysteresis Band Controller, Reference (24)

The switching logic formula is as following:

If $i_S < (i_S^* - HB)$ the output of upper switch is low (OFF) and the output of lower switch is high (ON) for the leg “a”: (SA=l).

And if, $i_S > (i_S^* + HB)$ the output of upper switch is high (ON) and the output of lower switch is low (OFF)for the leg “a”:(SA=O).

In the same way, the switching functions for phases B and C have been found using particular reference current, actual currents and hysteresis bandwidth (HB).

The switching rate of the hysteresis controller technique explained above is based on how quickly the current decreases from the upper limit to the lower limit of the hysteresis band, or vice versa. The switching frequency is calculated by the observing the rate of change in source current, so the switching rate cannot resolve at a constant value in the full switching program, In addition, inductance , DC link capacitor voltage of power system are the main element which govern the rate of change of source currents. Inductances and capacitor voltage of the entire design are also cause for the switching frequency of the system.

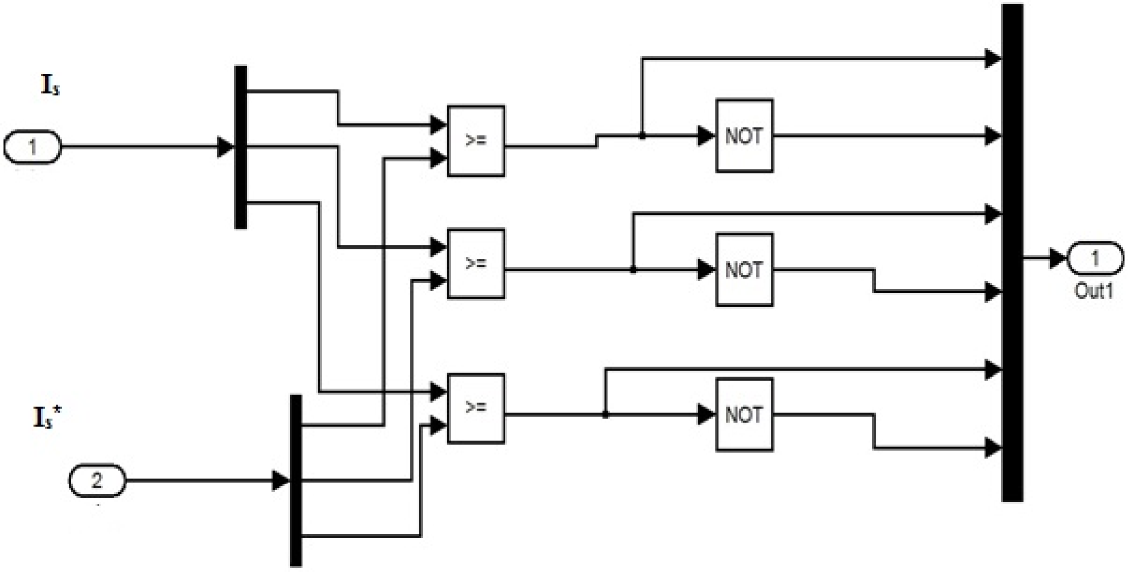


Figure 2.3.1(b): Simulation Diagram of HBCC

Fig 3.4.2 shows the simulation diagram of Hysteresis Band Current Controller. Here $I_s$is source current and I_s^* is reference current. These both currents are compared and generate switching pulses for Voltage Source Converter. Port 1and Port 2 is inputs and out1 is output.

2.3.2 PI CONTROLLER

The error is feed to PI controller. The output of it is supposed to be as crest value of the reference current. The sine vectors (v_a ,v_b ,v_c) are multiplied by the output of PI controller in such a way that it is supposed to be in the phase with source voltage. It is done to achieve the reference currents (i^*_{ca},i^*_{cb}, i^*_{cc}).These reference currents and Real currents are feed to a hysteresis band controller for producing the switching signals for the PWM voltage source converter.

The operation of switches is decided by the difference of reference current and real current. For increasing the current of certain phase, the lower switch of the PWM converter of that certain phase has been switched on, whereas for decaying the current, the upper switch of the particular phase has been switched on. After actual separation and amplification, these signals are feed to the VSC. After applying these switching signals current begin to flow in the coupling inductor (L_f) of SAPF for mitigating the current harmonics and reactive power of the power system, this action causes the flow of active power only in the power system.

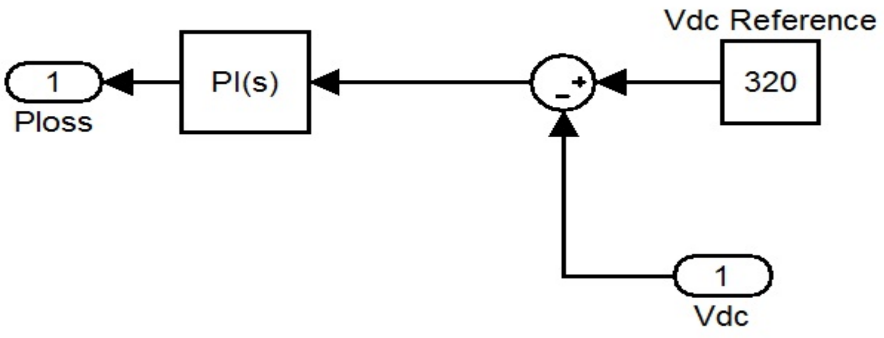


Figure: 2.3.2: Simulation Diagram PI controller

2.4 SUMMARY

- Three phase line currents i_{la}, i_{lb}, i_{lc} is converted on the αβ axis by using this Clarke Transformation.
- Source Voltage is also converted in α β stationary reference frame from abc reference frame by using Clarke Transformation.
- Reference current is generated on the basis of p-q theory introduced by Akagi.
- Comparing this reference current with real current with the help of HBCC switching pulse is generated for the Voltage source converter.
- Error occurred between DC link Voltage and reference voltage is given to PI controller which causes generation of P_{loss} .
- This P_{loss} is used in power calculation and reference current generation.

CHAPTER 3:

CONFIGURATION AND CONTROLLING OF SAPF WITH SUPER CONDUCTING MAGNET

In this chapter Shunt Active Power Filter with super conducting Magnet is designed. Controlling of Super Conducting Magnet is also described in this chapter. DC/DC converter is designed in this chapter which is used to control the Magnet. Control Technique to generate switching pulse for DC/DC converter is described here.

3.1CONFIGURATION OF SAPF WITH SUPER CONDUCTINMAGNET

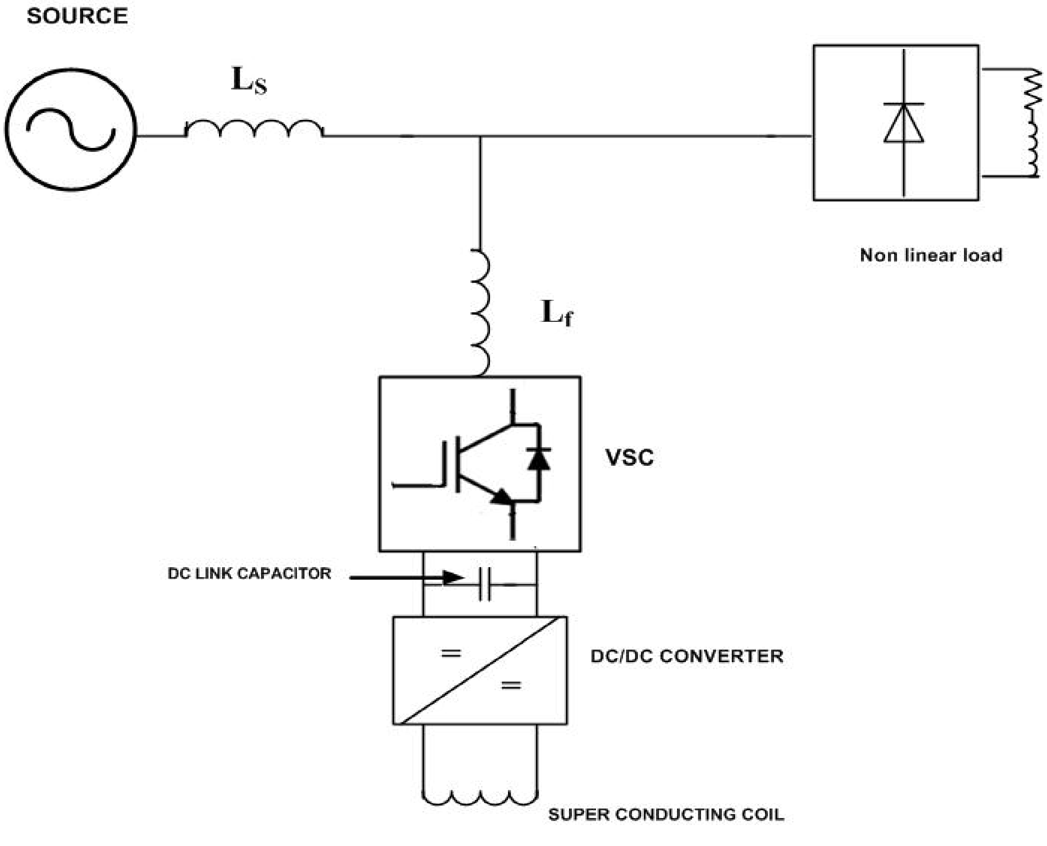


Figure 3.1: Configuration of SAPF with Super Conductor Magnet

The systemic figure of the superconductor magnet energy storage system unit with voltage source converter [15], [20], [21] is presented in the [Figure 3.1] where a primary six-pulse

PWM converter with (IGBT) is used as the switching device. It is also composed of a two quadrant DC-DC converter with IGBT and diode which is bidirectional, the inductor works as coil of superconducting magnet. A DC link capacitor is used as decoupling between VSC and DC/DC chopper. Connection between the ac supply power system and the magnet coil is constructed with the use of PWM VSC. PI controller estimates the reference current in α and β axis .PI controller works on error between real and reference voltage of DC link. After that the quantity in α and β axis are converted into abc transformation. The quantity which is achieved after conversion is compared with Triangular carrier signal of high frequency for getting switching pulse are generated for IGBT voltage source converter. During entire operation, the DC voltage is kept constant of the capacitor. [16], [17], [18], and [19].

In this thesis, the charging and discharging of magnet coil and controlling of source current is done by VSC and DC/DC chopper. Chopper is composed two IGBTs and two diodes as shown in the [Figure 3.1]. During the ON condition of switch the coil starts charging and non-negative voltage will be appeared on it and in the ‘OFF’ condition negative voltage will be produce on it and it is discharged by diode. In both procedures the current flows in one direction only. At the time of standby operation only one switch remains in ‘ON ‘condition and the current flows between one diode and that switch only. The operation of this is controlled to obtain a fix voltage of dc link. In this thesis voltage source converter is a six-pulse full bridge converter. The function of chopper is to achieve bidirectional current. it operates in both rectification and inverting mode.

3.2PRACTICAL UTILITIES OF SUPERCONDUCTING MAGNET

Energy in superconductor magnet is stored in the form of magnetic field. In this project a superconducting coil is wounded on a long magnetic core and magnetic field is created by this coil. Stored energy in this magnet can be used up during the sudden operation. Cryostat or Dewar is placed to uphold the temperature below cryogenic temperature of the coil of super conducting magnet energy storage system. Dewar is filled either with liquid nitrogen or helium as a coolant. To minimize the energy losses at the time of stand by condition a by switch is used. There are some merits of using this switch such as it protect the coil by pass disconnecting from the power system when cooling is lost. There are several factors should be considered during designing the coil i.e. operating temperature, fabrication energy reserve capability. Magnet coil can be designed either in Toroid or Solenoid. Solenoid type is mostly used for having its simplicity and economical. Superconductor magnet energy storage system unit is rated by its requirement. Low temperature super conductor coil (LTS) is mostly used. But in the respect of efficiency and cost high temperature superconductor coil (HTS) is best

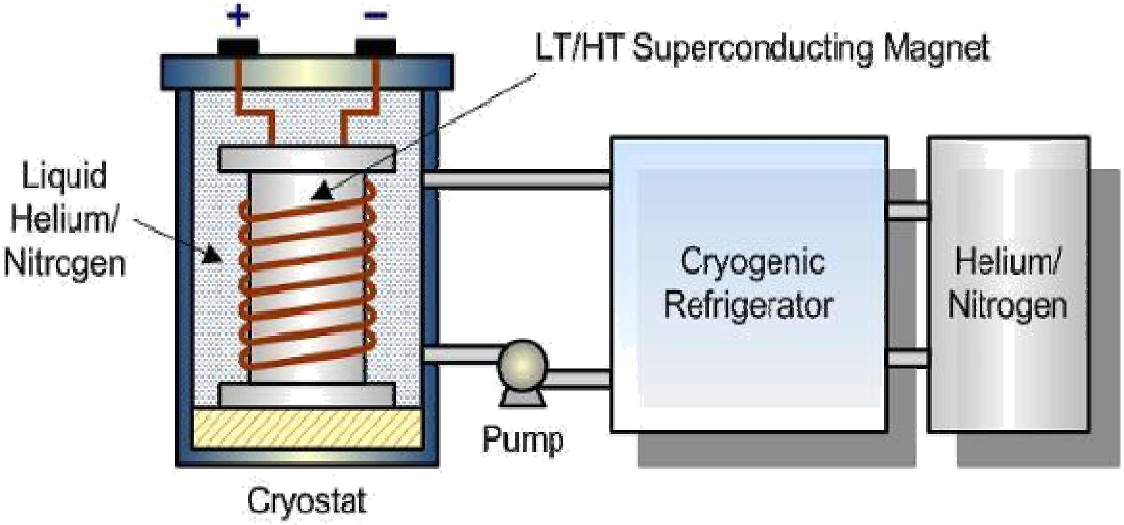


Fig 3.2 Construction of Superconducting Magnet Energy Storage System, Reference (27)

3.3DC/DC CONVERTER

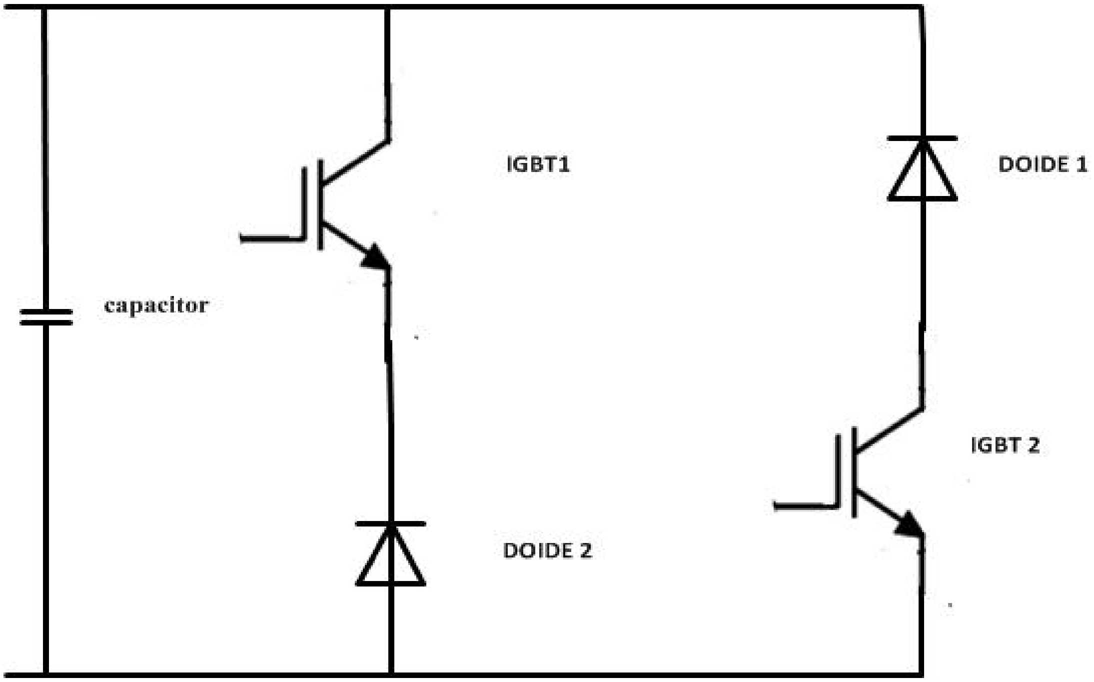


Figure 3.4: DC/DC Chopper

The major work of the DC/DC converter is to regulate the energy in Superconducting Magnet Coil by charging and discharging of it. At the charging time of super conductor magnet the DC/DC chopper joints the magnet to the voltage of DC link. When we have to discharge the magnet DC/DC converter joints the magnet to the voltage of DC link but in opposite polarity, so power can flow in reverse direction. The charging and discharging rate will be governed by the voltage of coil. We can say that a changeable voltage will be put on the coil by the chopper to get the preferred energy flow out or in the storage system. A complete arrangement of the DC/DC converter is revealed in [Figure 3.4]. The operation mode of the DC/DC converter chopper is explained as following.

In [Figure 3.4], as both the IGBTs are switched on at the same time and the diodes is in reverse-biased condition, the current starts flowing into coil from power system during this operation voltage appeared across magnet coil is positive and coil is getting charged.

Another time, these IGBTs are in off condition and the diodes are in forward biased. The current starts flowing in the same direction in the coil and voltage of negative polarity is appeared through it and coil is discharged now. The voltage of the coil is adjusting by regulating the operation time of the IGBT during the switching period. When the duty cycle will be 0.5.The average voltage of the superconductor magnet coil average and current in the voltage source converter will be zero. And total power flowing in one complete cycle is zero. When duty cycle is larger than 0.5, the magnet coil begin to get charged. But when it is less than 0.5, the coil is discharged. As a result, charging and discharging of the magnet coil is dependent on the chopper. A voltage source converter (VSC) and a DC/DC, bidirectional converter is used in power system for the designing of Shunt Active Power Filter. The VSC is a voltage controlled device, DC/DC converter is used to connect the voltage controlled converter to the current controlled magnet. These converters are decoupled by DC-link. DC-link is connected by the voltage source converter to the AC supply system. Source current is made in phase with Source voltage by the controlling of the voltage source converter. Superconductor magnet coil is charged and discharged by controlling the DC/DC bidirectional converter. Interchanging of power between coil and power system is done after keeping the system voltage constant. These two converters are regulated by the Hysteresis band controller. Controlling of the voltage source converter is done by generating pulse after comparing source current and reference current with the help of Hysteresis Band Controller. A limit is made by hysteresis controller to fix the controlled variable. Switching pulses are produced according to controlled variable when it is reached the upper or lower limit. Energy in the magnetic coil is regulated by PI controller, AC current losses is occurred due to use of pulse signal for the operation of superconducting magnet coil. At the time of making Refrigeration system for the superconductor magnet these losses should be considered.

3.4CONTROL TOPOLOGY

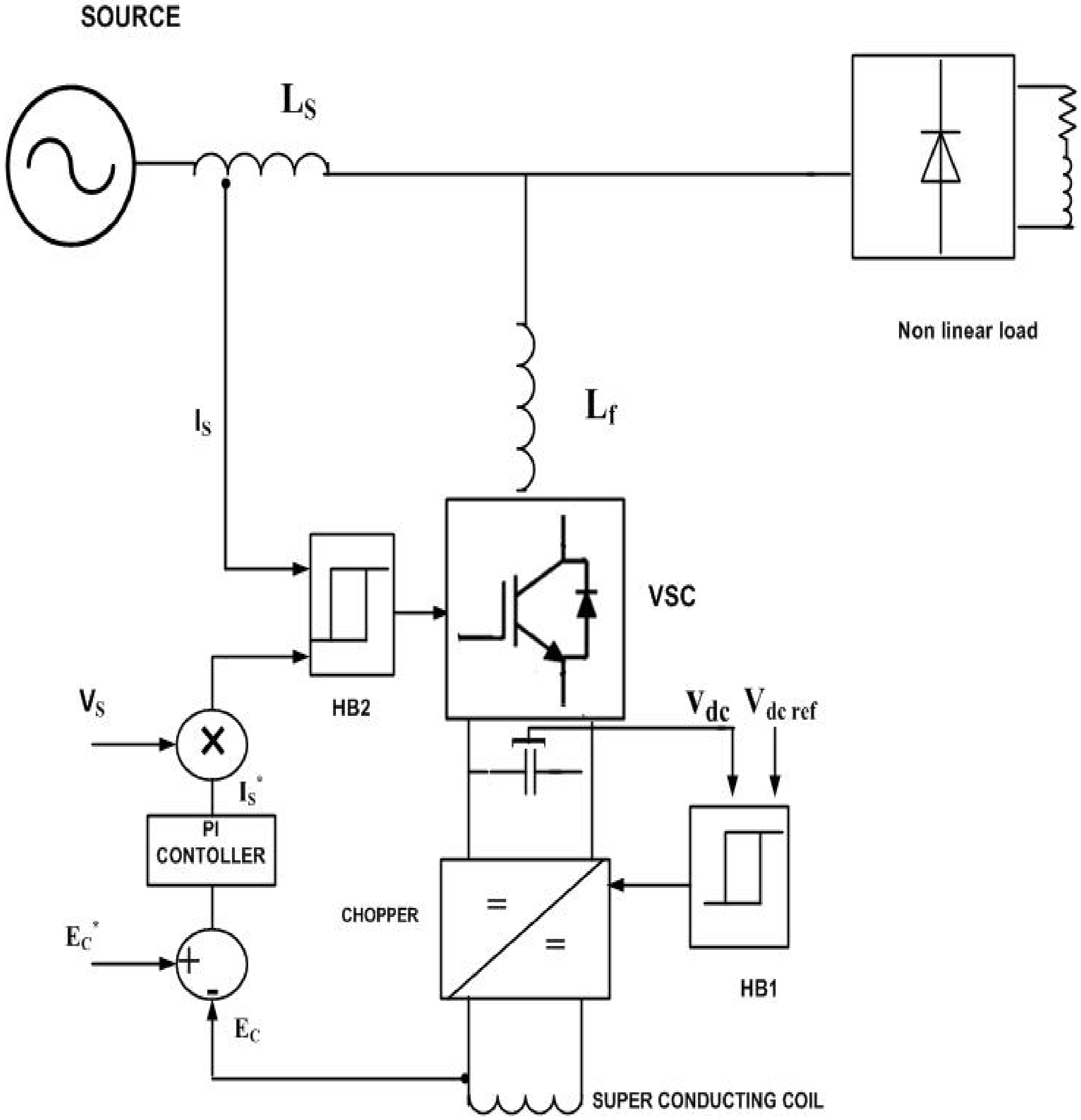


Figure 3.5: Control topology of SAPF with Superconductor Magnet

The voltage source converter and chopper both are regulated by Hysteresis band controller. It is simple in designing and does have excellent precision. The controller strategy of Voltage Source Converter is described in Figure 3.5 which is proposed for regulating the source current. The error occurred between source and reference current will be feed to hysteresis controller for producing the switching pulses for Voltage source converter.

While the error is at the higher bound of controller the upper switch gets ‘OFF’

And when it reaches to lower the lower switch gets ‘ON’.

The switching operation is performed by hysteresis controller to adjust the voltage of DC link. The error occurred between reference and dc link voltage is feeding to the input of hysteresis controller for producing the pulse to trigger the chopper.

The quantity of power achieved by Super conductor magnet is depended on the value of source current .The current in the coil is increased as increment in the source current. And it begins to discharge when current is reduced with the source current. The active power given by super conductor magnet is depended on the capability of load and source condition. When it is charged, the current in the magnet coil does not change at its rated quantity. At standby time, Energy is neither consumed nor delivered by the coil but there is loss owing to circulating current.

The energy in the coil for the duration of charging and discharging is governed by PI Controller. It keeps energy at its reference quantity. The error occurred by comparing actual and reference magnet energy is given to PI controller to achieve the variation in the value of reference source current.

3.5 SUMMARY

- Connection between the ac supply power system and the magnet coil is constructed with the use of PWM VSC.
- A bidirectional two quadrant DC-DC converter with IGBT and diode is used here to control the Superconducting Magnet Coil.
- A DC link capacitor is used as decoupling between VSC and DC/DC chopper.
- Switching pulses are produced according to controlled variable when it is reached the upper or lower limit

CHAPTER 4:

SIMULATION RESULT AND DISCUSSION

The simulation of this power system is done using MATLAB/Simulink. A nonlinear load, three phases six pulse Diode Rectifier is connected to three phase star connected power supply of 400 rms voltage.

4.1PARAMETER USED

Source voltage (V)	400V
Frequency (F)	50 HZ
Source inductance (L)	1e-8H
Source resistance (R)	1e-3ohm
Load inductance (L)	10e-3H
Load resistance (R)	10ohm
V_{dc} Reference	320 volt
DC link Capacitor (C)	250e-6 F
Inductance of coil	0.5H
Branch Resistance	0.01 ohm
Branch inductance	1e-6 H
Rating of coil	400 amp,40KJ

4.2 SIMULATION DIAGRAM

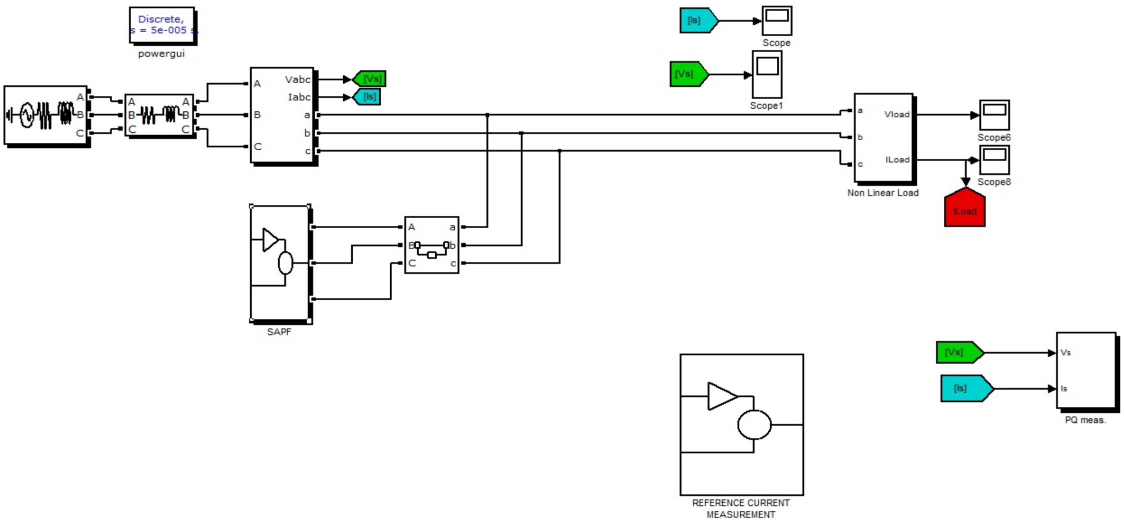


Figure 4.2.1: Simulation Diagram of SAPF

In fig 4.2.1, a three phase non linear load is connected to three phase power supply. Shunt Active Power Filter is connected in parallel with transmission line to remove the harmonics generated by non linear load.

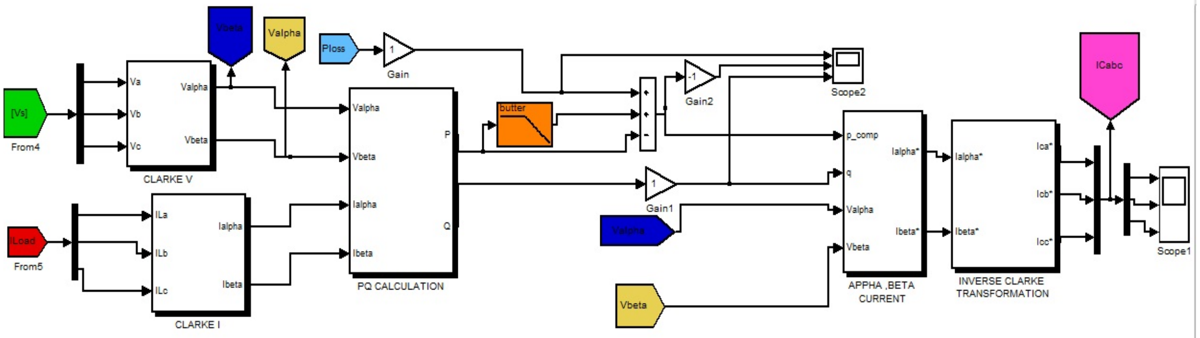


Figure 4.2.2: Simulation Diagram of Reference current Generation

In fig 4.2.2, Reference current (Ic_{abc}) is generated by using Clarke and inverse Clarke Transformation. P_{loss} occurred in PI controller is used in power calculation and reference current generation.

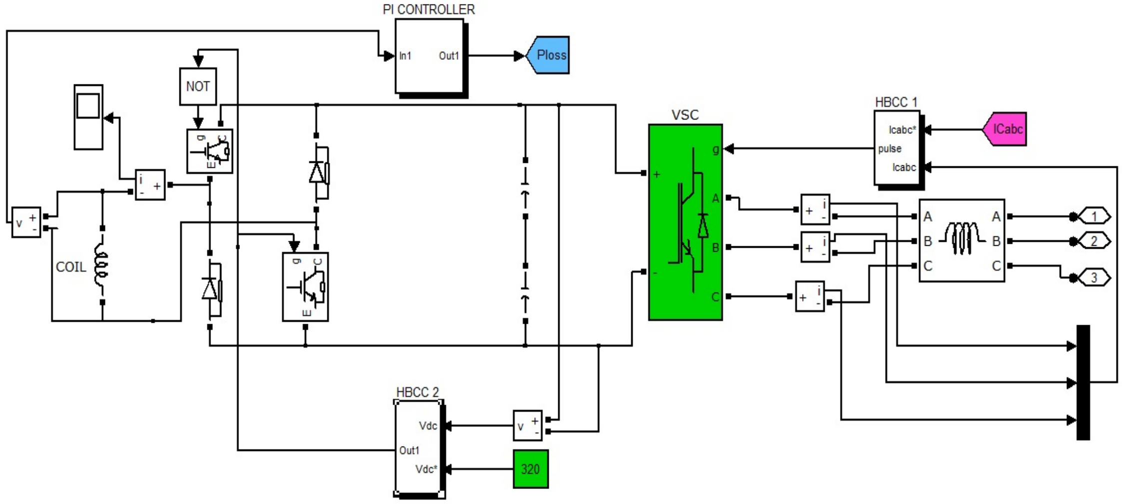


Figure4.2.3: Simulation Diagram of Coil with VSC

In fig 4.2.3,coil is connected to DC/DC converter.VSC connects the whole system to AC network. Here VSC works as both rectifying and inverting mode. Source current (IC_{abc}) is compared with reference current (IC_{abc}^{*}) by using Hysteresis Band Controller to generate the pulse for Voltage Source Converter.

4.3 SIMULATION RESULTS WITHOUT SUPER CONDUCTING MAGNET

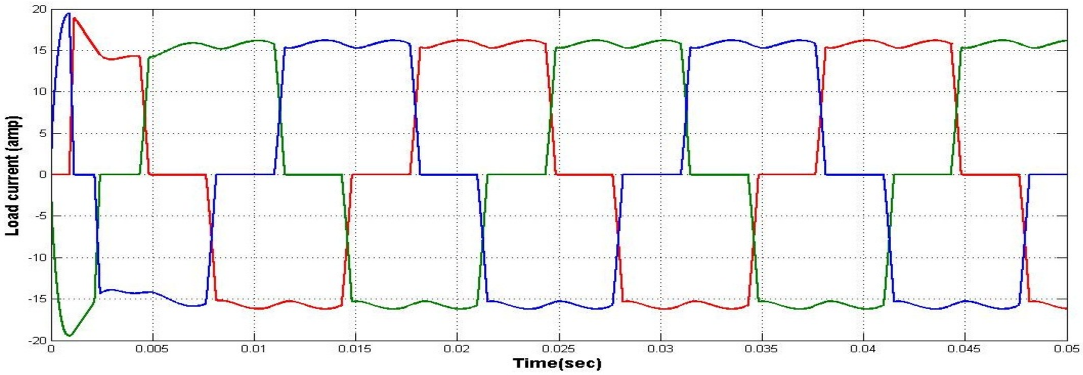


Figure 4.3.1: Load Current

Fig 4.3.1 shows the load current when a non linear load (Rectifier) is connected to three phase power supply. Magnitude of this current is18 ampere.

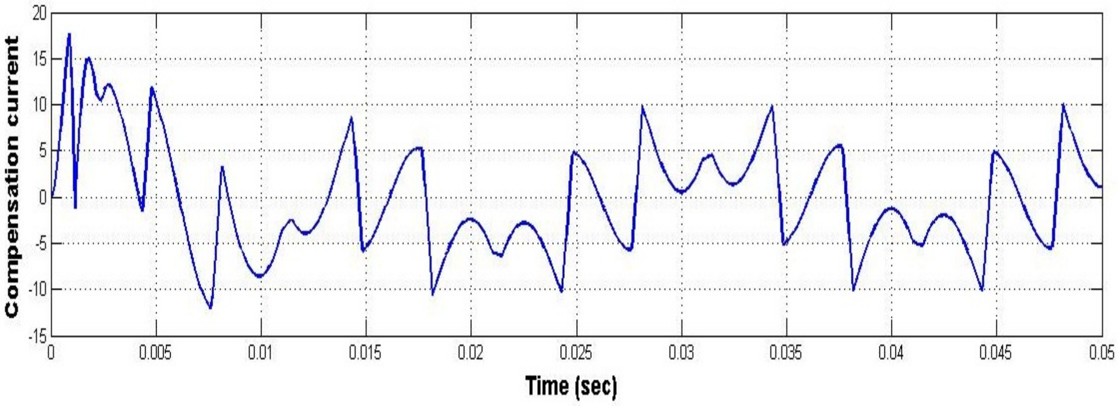


Figure 4.3.2: Compensation Current

Fig 4.3.2 shows the compensation current which is injected by Shunt Active Power Filter into power system.

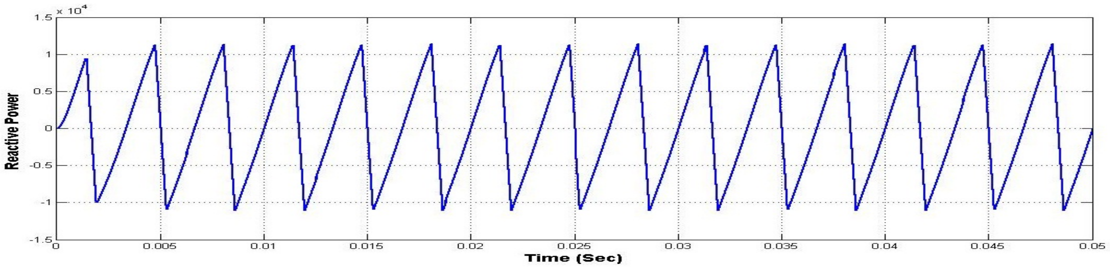


Figure 4.3.3: Reactive Power

Fig 4.3.3 shows the average reactive power which is got after compensating the alternating component by passing through LPF

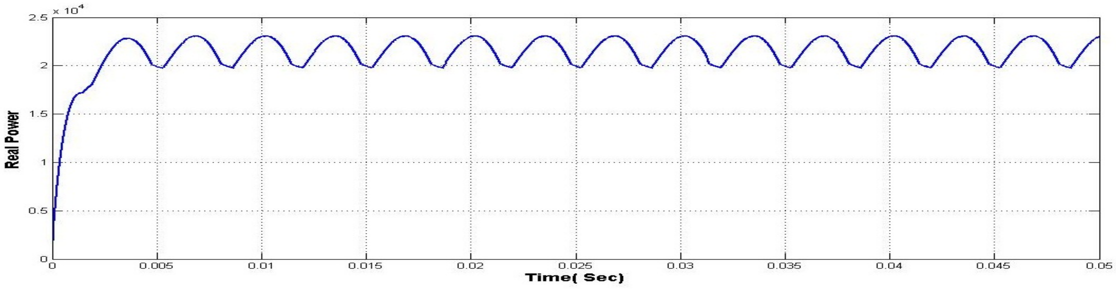


Figure 4.3.4: Real Power

Fig 4.3.4 shows the average real power which is got after compensating the alternating component by passing through LPF

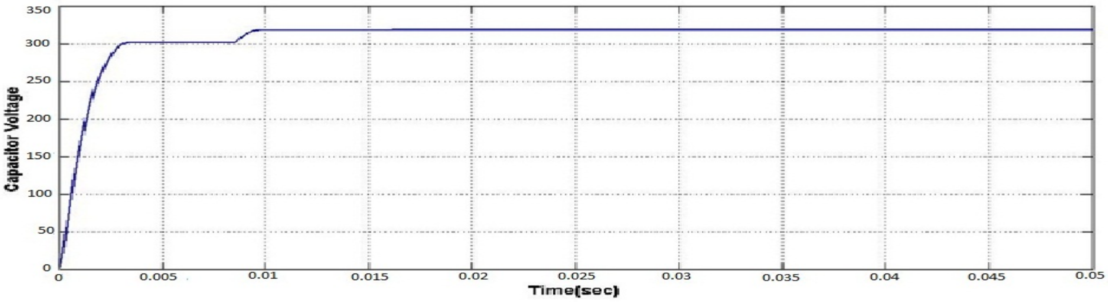


Figure 4.3.5: Capacitor Voltage

Fig 4.3.5 shows the DC link capacitor voltage .This voltage remains constant throught the operation of the SAPF.

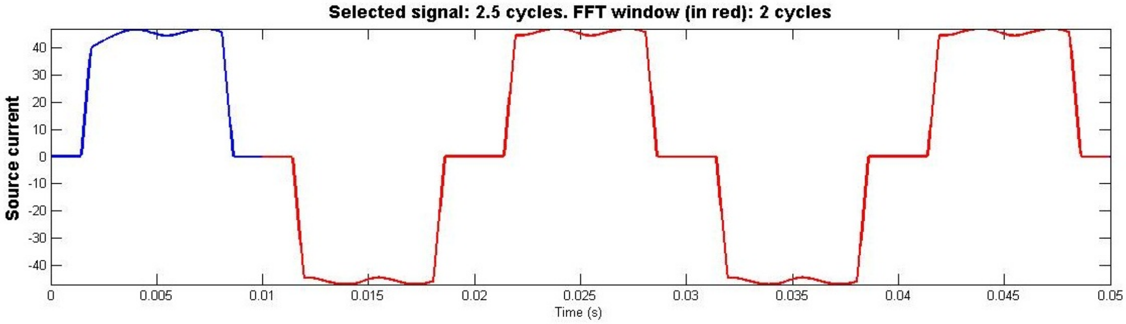


Figure 4.3.6: Source Current before SAPF

Fig 4.3.6 shows the distortion in source current when Shunt Active Power Filter is not connected with power line.

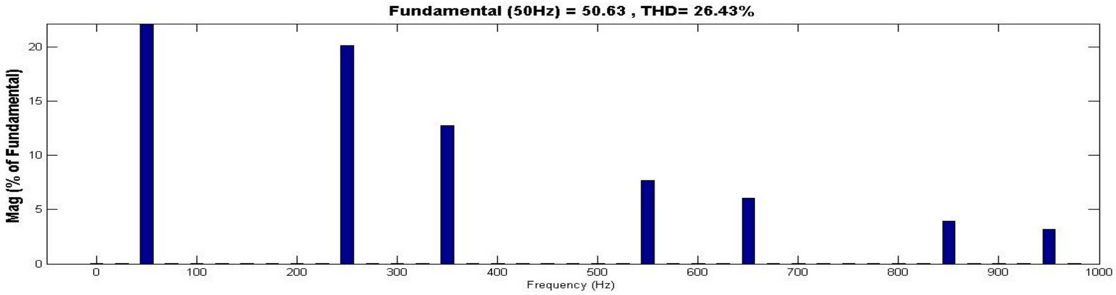


Figure 4.3.7: THD (Total Harmonic Distortion) in source current before SAPF

Fig 4.3.7 shows the FFT analysis of source current to find the distortion in source current.THD is found 26.43% in source current when Shunt Active Power Filter is not connected with power line.

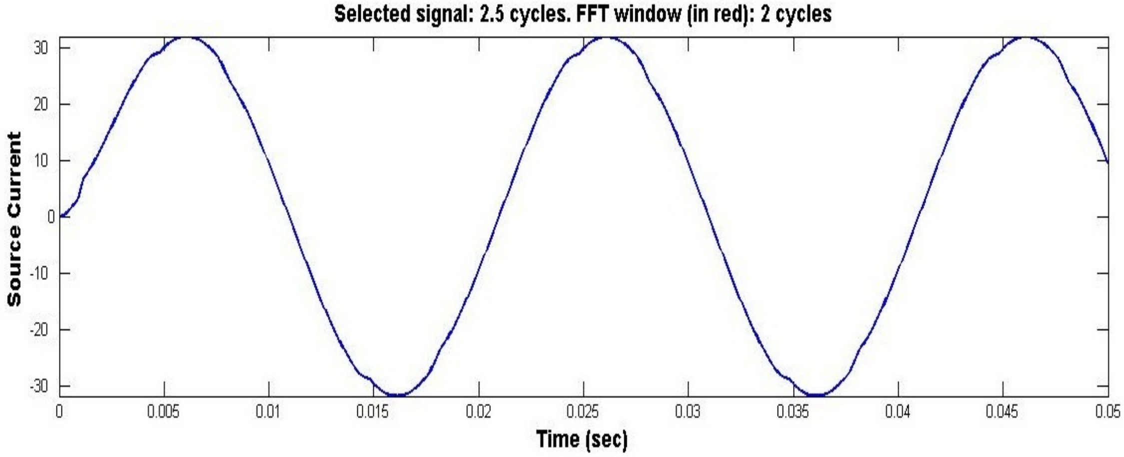


Figure 4.3.8: Source current With SAPF

Fig 4.3.8 shows Source current when Shunt Active Power Filter is connected with power line. It is seen that distortion is removed from source current by using Shunt Active power Filter.

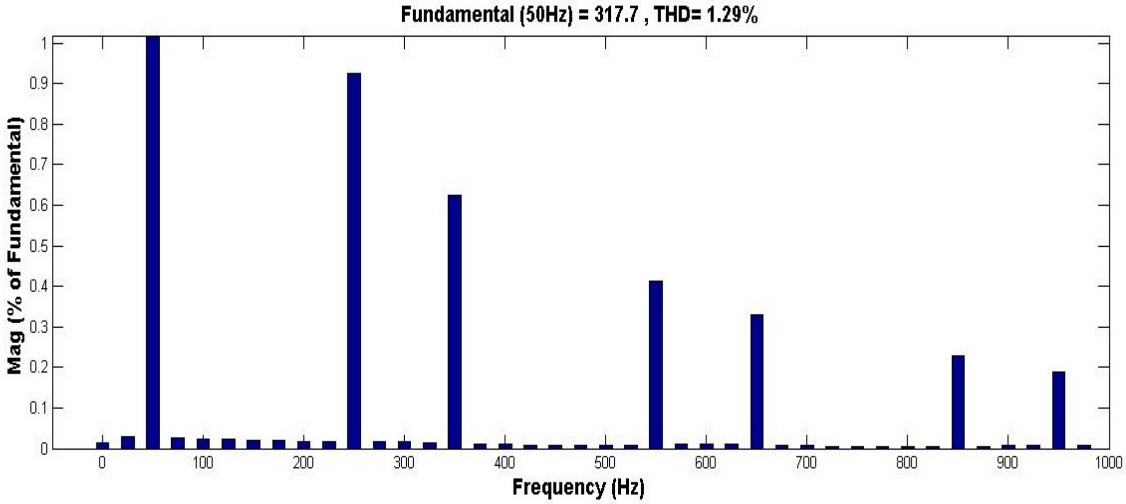


Figure 4.3.9: THD in source current after applying SAPF

Fig 4.3.9 shows the FFT analysis of source current when Shunt Active Power Filter is connected with power line. Total Harmonic Distortion is reduced to 1.29%.

4.4 SIMULATION RESULTS WITH SUPER CONDUCTING MAGNET

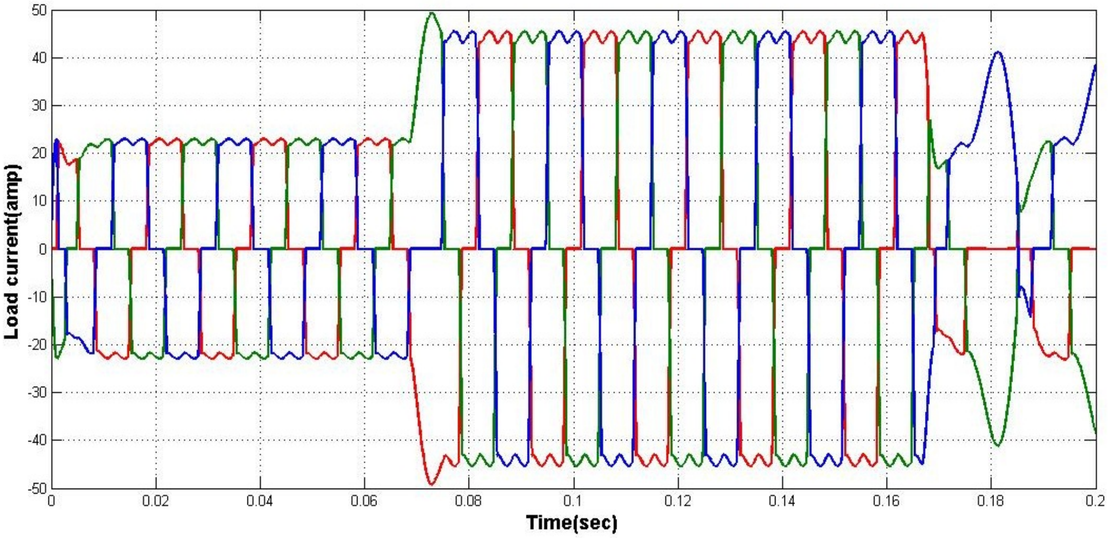


Figure 4.4.1: Variation in all phases of load current with time

Fig 4.4.1 shows the load current when super conducting magnet coil is placed in Shunt Active Power Filter.

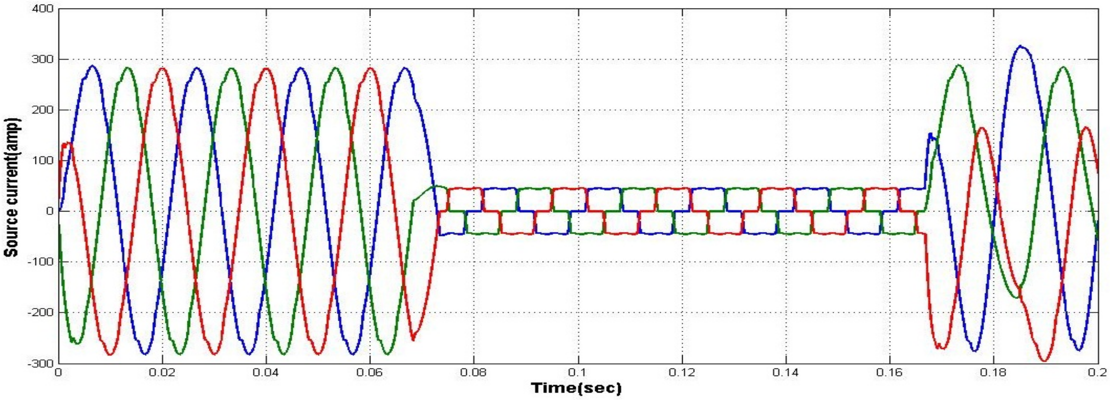


Figure4.4.2: Variation in all phases of source current with time

Fig 4.4.3 shows the variation in source current during charging and discharging mode of super conducting magnet coil.

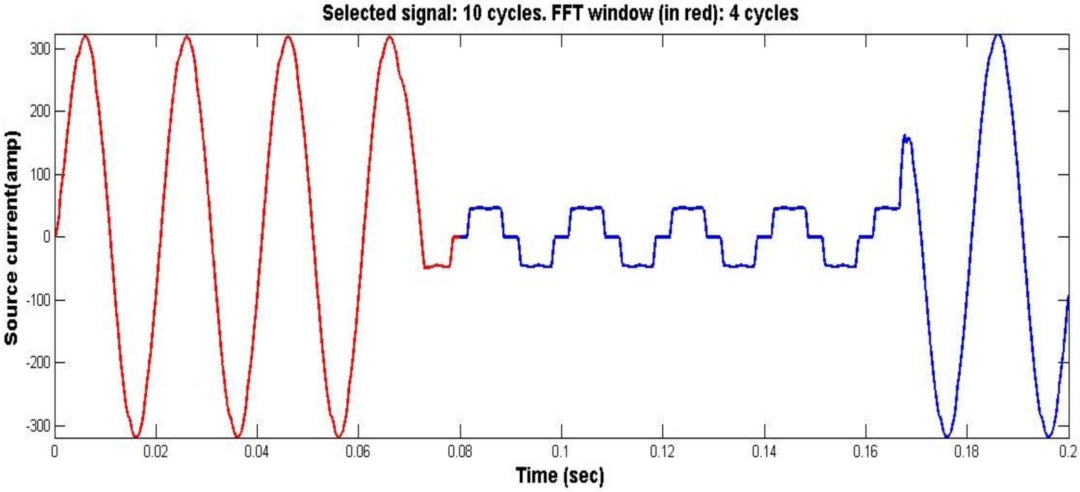


Figure4.4.3: Source current during charging mode

Fig4.4.4 shows the source current during charging .From 0 to 0.07 sec the value of source current is 280 ampere which is greater than load current whose value is 22 ampere. So magnet begins to charge.

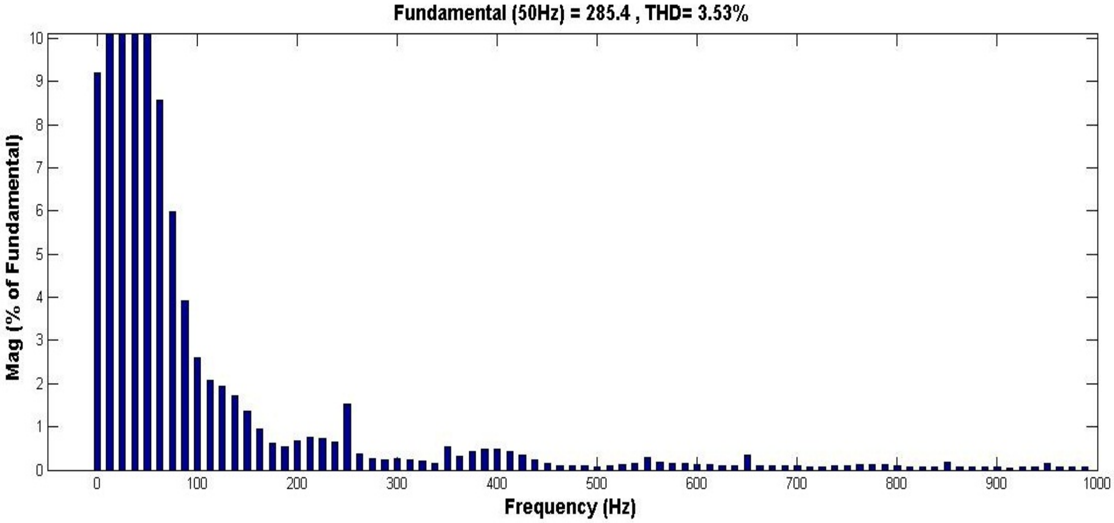


Figure 4.4.4: THD in source current during charging

Fig 4.4.5 shows the FFT analysis of source current during charging mode. Total Harmonic distortion during charging mode is found 3.53%.

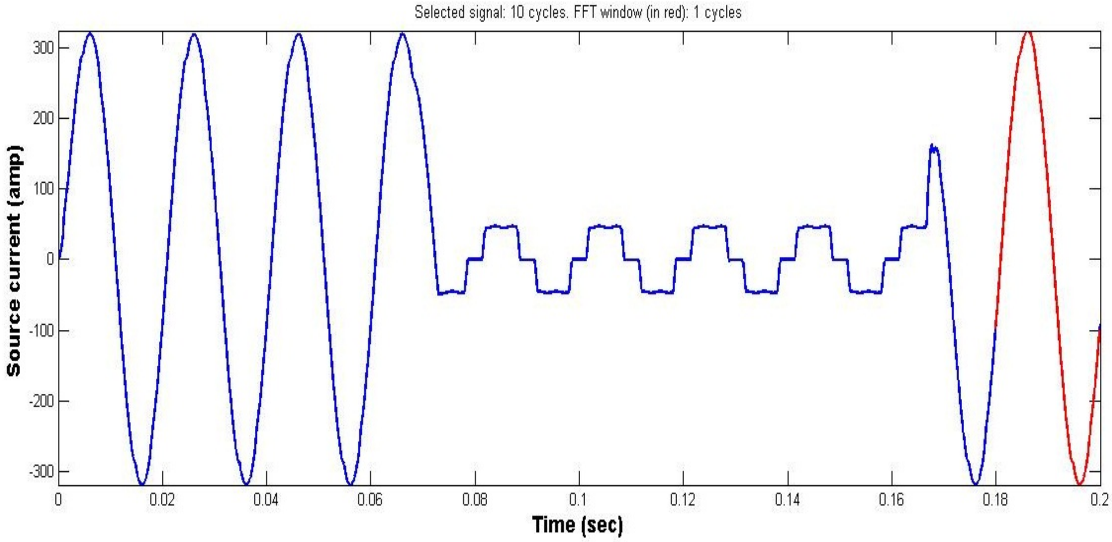


Figure 4.4.5: Source current during discharging mode

Fig 4.4.6 shows the current during discharging mode. After 0.16 sec magnet coil begins to discharge.

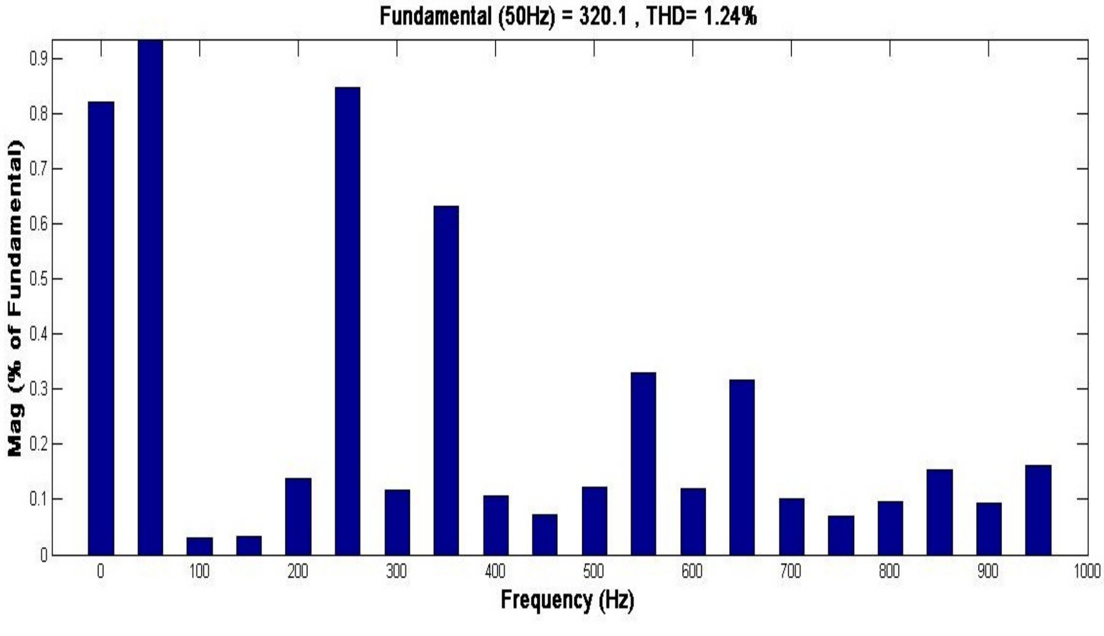


Figure 4.4.6: THD in Source current during discharging mode

Fig 4.4.7 shows the FFT analysis of source current during the discharging mode .Total Harmonic Distortion is found 1.24% during discharging mode.

4.6 SUMMARY

- THD is found 26.43% in source current when Shunt Active Power Filter is not connected with power line
- When Shunt Active Power Filter is connected with power line. Total Harmonic Distortion is reduced to 1.29%.
- From 0 to 0.07 sec the value of source current is 280 ampere which is greater than load current whose value is 22 ampere. So magnet begins to charge.
- Total Harmonic distortion during charging mode is found 3.53%.
- After 0.16 sec magnet coil begins to discharge.
- Harmonic Distortion is found 1.24% during discharging mode

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1CONCLUSION

The SAPF not only reduces harmonic current but also balances three-phase current .THD is reduced from 26.43 % to 1.29 %. After placing Super Conductor Magnet, complete cycle of coil that is charging, standby, and discharging is controlled. A 0.5H superconducting coil with the rating of 400A, 40 KJ is used here. At the start the coil began to charge when source current having the maximum value of 280 A is more than load current of 22A. Hence, the magnet coil has been charged fully in 0.07 sec and current in the coil becomes steady at 400A. At this moment source current starts decreasing and it is almost equal to the load current. At 0.16 sec Magnet coil begins to discharge.THD during different mode of magnet is calculated. During charging mode THD is 3.53 %. And during discharging mode THD is 1.24%.

5.2 FUTURE SCOPE:

Here, I have used PI controller .Total Harmonic Distortion at the time of discharging and steady mode is reduced by using Fuzzy Logic Controller instead of PI controller. Adaptive Hysteresis controller is also used instead of Hysteresis controller to make the switching frequency of IGBT constant.

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