

Chapter 5

Design of Power Circuit: Shunt Active Power Filter

Literature survey of previous chapters indicate that ^VVarious types of active filters have been proposed. Classification of active filter is made from different point view. Active filters are divided into ac and dc filters active dc filters have been designed to compensate for current and/or voltage harmonics on the DC side of thyristor converters for HVDC systems and on the dc link of a PWM rectifier/inverter for traction system. However term active filter refers to the ac filters in most cases.

- **System Configuration**
 - Shunt active filters
 - Series active filters
 - Hybrid active/passive filters
 - Hybrid shunt/series active filters
- **classification by power circuit**
 - voltage-fed PWM inverter
 - current fed PWM inverter.
- **classification by control strategy**
 - Operational Domain
 - Time Domain: FFT
 - Frequency Domain: p-q- Thoery; d-q Theory
- **Harmonic Detection Methods: Time Domain**
 - load current detection $i_{AF} = i_{Lh}$
 - supply current detection $i_{AF} = K_s * i_{Sh}$
 - voltage detection $i_{AF} = K_v * v_h$
- **PWM Converters**
 - Pulse-width modulated inverters
 - Square-wave inverters
 - Programmed harmonic elimination switching (selective harmonic elimination)
 - Sinusoidal pulse width modulation
 - Space vector modulation
 - Feedback PWM control (hysteresis current controlled PWM)
 - Random pulse width modulation

PWM converters for three phase four wire active filter system configurations of voltage source inverters (VSI) used in three-phase four wire systems have two configurations.

A conventional **three leg** converter, ac neutral wire is connected directly to the mid point of the dc bus, while Four leg system the ac neutral is provided through a *fourth leg*.

Since the configuration has PWM current control, they behave as controlled current source. The ac current generated by the VSI has some high-order harmonics at the switching frequency, which can be easily filtered using a small passive filter. Ideally the currents track accurately their reference i_{ck}^* ($k = a, b, c$). The controllability of the "four switch-leg" inverter topology is better than the "split-capacitor" inverter topology.

Due to the problems related to the dc capacitor voltage control by using the topology of split-capacitor, a four leg topology (Fig 5.1) is used in the project. Instantaneous active reactive power theory is used to implement the shunt active filter.

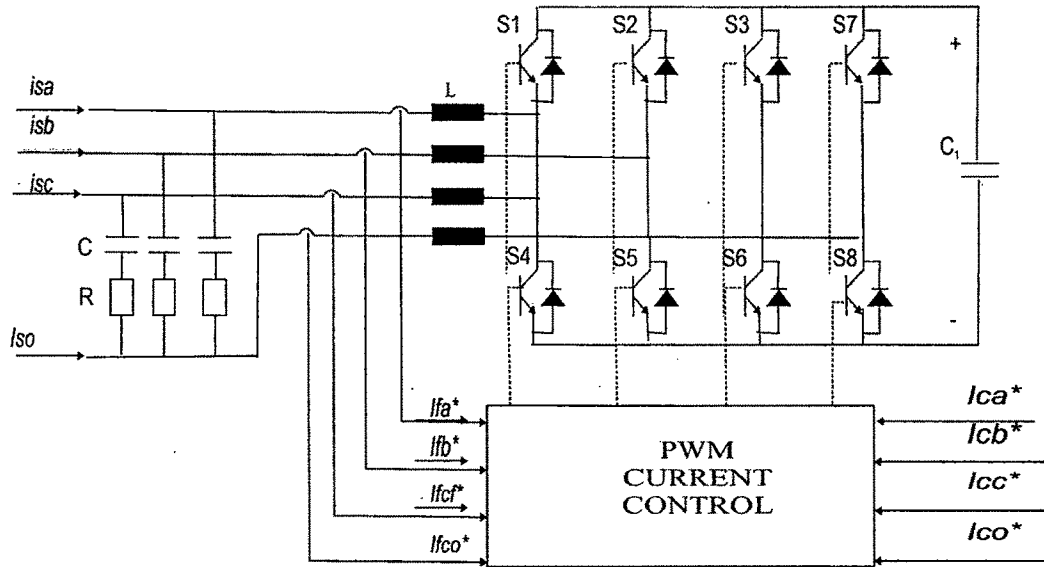


Fig 5.1: Three Phase Four Leg Converter

The implementation of shunt type active filter is simpler if the type of inverter used is of the "current regulated" type. This is because of the ultimate function of the controller is to make the output current of the inverter follow an input reference waveform. The current regulated type of inverter employs a switching technique in which the output current of the inverter is continuously sensed and compared against an input reference waveform. When the comparison shows that the instantaneous inverter output current exceeds the reference input by a small but finite value, the inverter elements are switched so as to reduce the output current. Then when the inverter output current decreases and falls below the reference waveform and the error magnitude exceeds a small but finite value, the inverter elements are again switched so as to increase the output current. Therefore, the inverter switching take place repetitively to make the output current waveform follow the reference waveform within an upper and lower hysteresis limit.

5.1 Hysteris Current Controller

Fig.5.2 depicts the feedback PWM scheme to generate the switching sequences inherently in a closed control loop for a sinusoidal reference current i_A^* , where the actual phase current i_A is compared with the tolerance band around the reference current associated with that phase. If the actual current in Fig.(5.2) tries to go beyond the upper tolerance band, T_{A-} is turned

on (i.e., T_{A+} is turned off). The opposite switching occurs if the actual current tries to go below the lower tolerance band. Similar actions take place in the other two phases.



Fig 5.2 Feedback PWM Scheme

Fig 5.3 shows block diagram for implementation.. If the hysteresis limits are made smaller, the repetitive switching frequency is higher and the output waveform approaches the input reference waveform more closely.

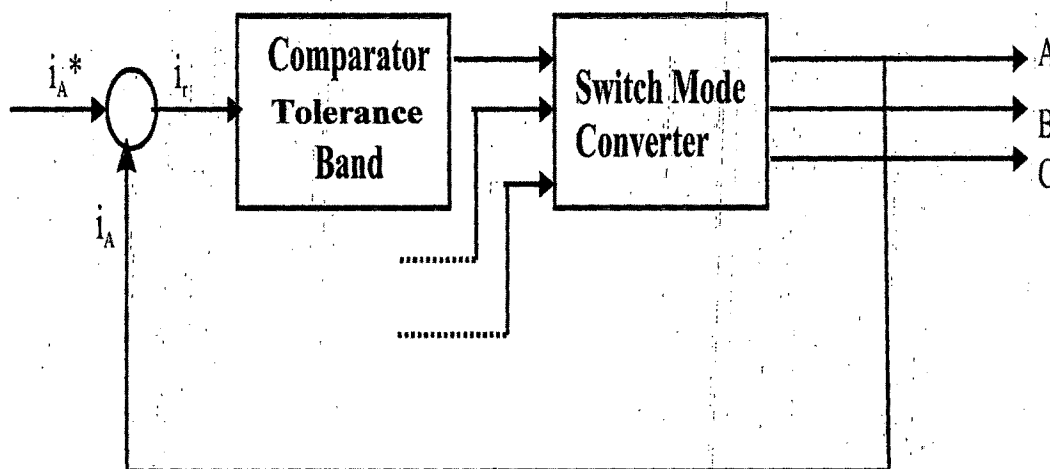


Fig 5.3 Hysteresis Current Controller: Block Diagram

Fig.5.4 depicts the realization of hysteresis current controller using low offset operational amplifier. In a active filter application, with presently available switching elements which have fast repetitive switching capability, we can make the hysteresis limits sufficiently low so that the output waveform of the inverter can be treated as a replica of the input reference waveform with negligible error.

The feedback signal is sensed and this signal is condition to the level of reference signal. This signal is compared with reference signal and error of the same is given to hysteresis controller whose band can be adjusted through pot. When error is positive the output of the hysteresis is negative which goes to upper switch. Inverted of the same is given to lower switch. Dead band circuit is provided between upper and lower MOSFET, which is necessary to protect the device from shunt through. The dead band between upper and lower switch is set to 20 μ second. The hysteresis circuit is tested with sinusoidal reference current and the actual current.

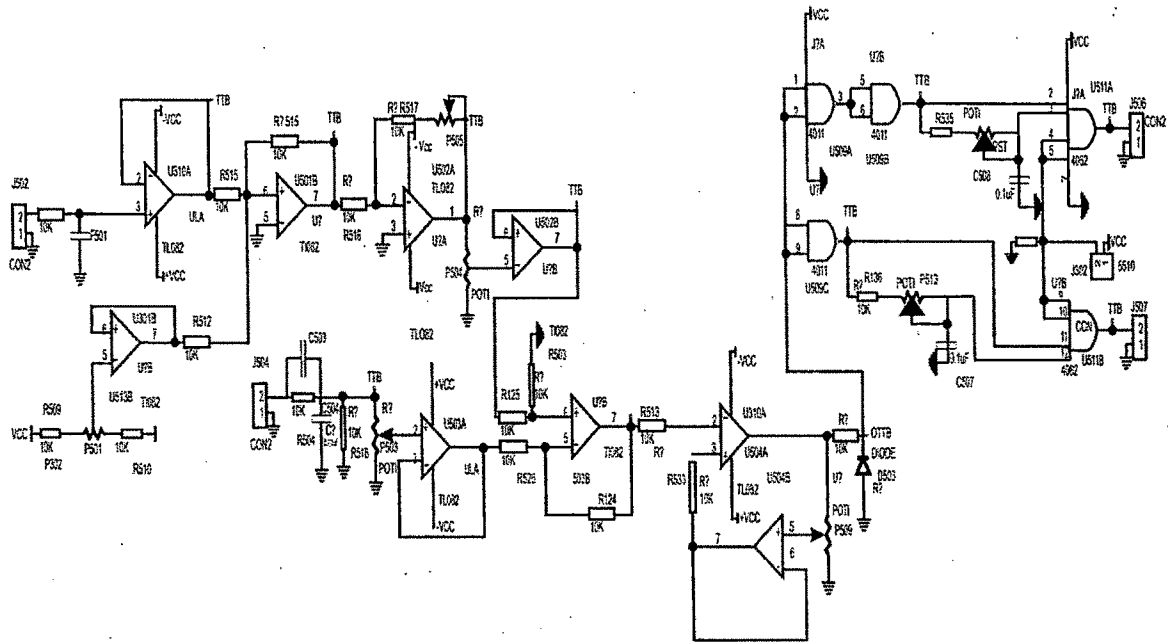


Fig 5.4 Typical Analog Implementation: Hysteris Controller

5.2 ISOLATION AND DRIVER CIRCUIT

The gate pulses, which are to be given to, the power device goes through two stages : isolation and driver stage. The isolation is must when gate pulses are given to power devices when connected in inverter configuration. The isolation is normally provided to gate pulses through optocouplers, which isolates power circuit and low power control circuit optically. Further this optically coupled signals are given to the driver circuit. The gate pulse, which is given to the IGBT, is with respect to the source terminal .To avoid short circuit of drivers four separate power supplies are designed for each driver of upper switches.

Since the power circuit consists of eight devices and lower dc bus is common to all devices in lower limbs of inverter so only single power supply is necessary for lower limb drivers but it must have current rating thrice than the upper limb driver power supply.

The driver circuit consists of transistors. The main advantage of using transistor driver is that it can be made useful according to application i.e. it can be used for transistor or MOS power devices though they belong to different category. In other words, it can be used with current controlled or voltage controlled devices. Further the negative voltage, which can be easily incorporated in Darlington transistor pair circuit, is useful in removing the charge on the capacitor in the MOS controlled devices and in transistor circuit in removing the storage charge in the base of the transistor. The diagram of the driver circuit used for the experimental purpose is shown in fig.5.5

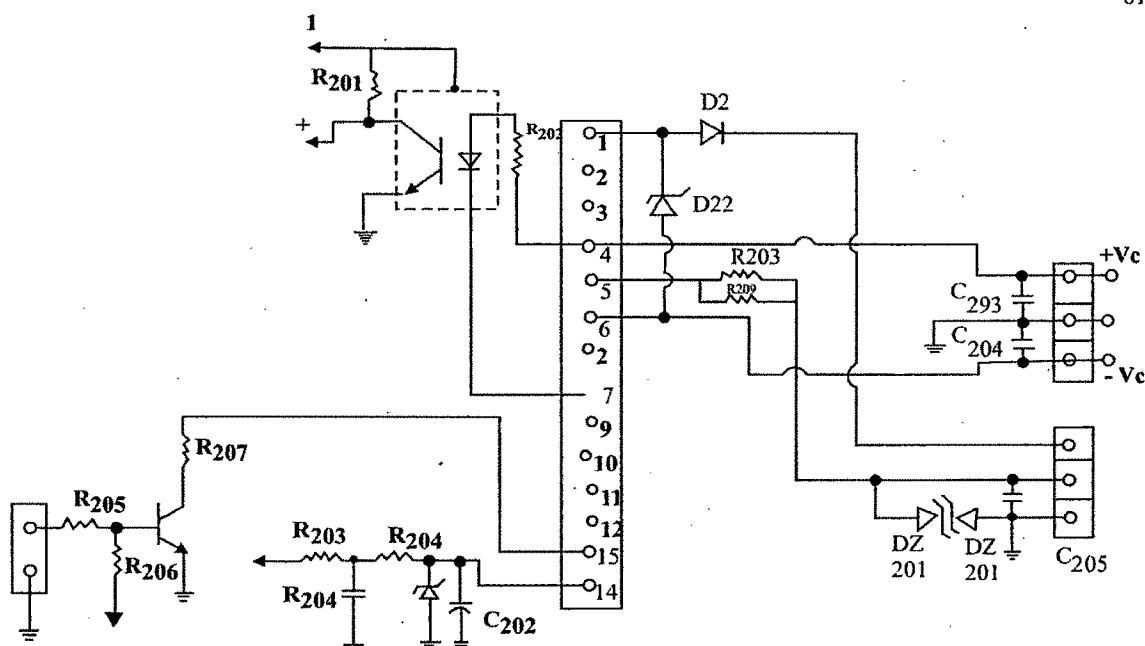


Fig 5.5 Typical Analog Implementation: Driver Circuit

5.3 POWER CIRCUIT

The schematic diagram of shunt converter is shown in fig.(5.6). It consists of eight power IGBT, capacitor (C1) and filter reactor(L). The harmonic currents, generated by the switching operation of IGBT, are suppressed by the filter reactor. Dc bus voltage is kept constant by The capacitors (C1). However the size depends on the switching frequency and rating of the active filter. Four leg voltage source inverter operating in hysteresis current control mode is used as active power filter.

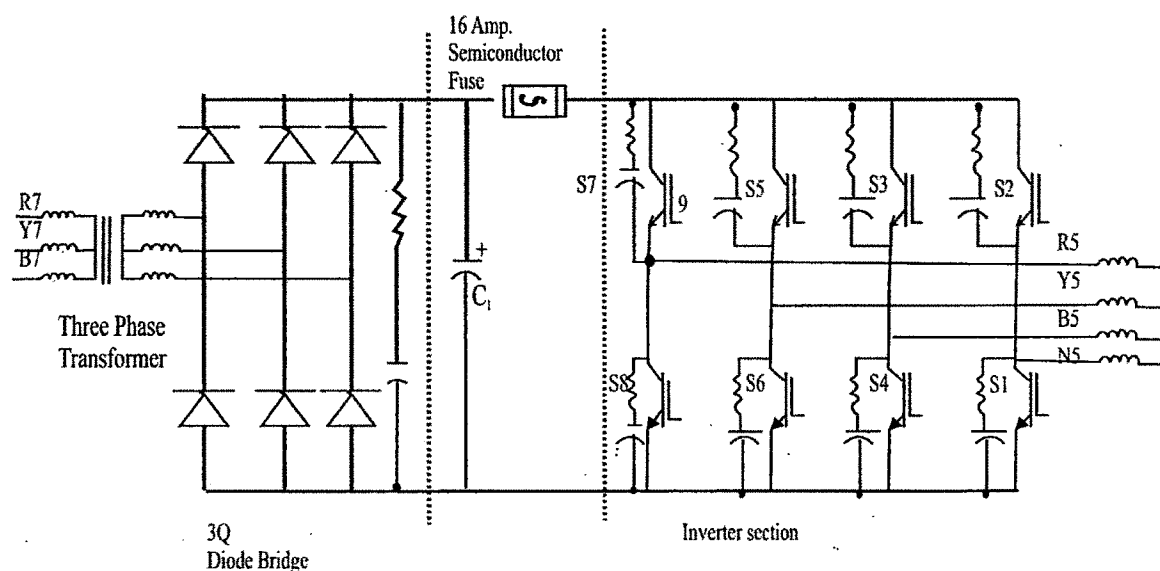


Fig 5.6 Shunt Active Filter

5.3.1 DESIGN OF INDUCTOR

The design of the reactor is performed with the constraint that for a given switching frequency the minimum slope of the inductor current is smaller than the slope of the triangular waveform that defines the switching freq. In this way the intersection between the current error signal and the triangular waveform always exists. The slope of the triangular waveform λ is defined by

$$\lambda = 4\xi f_t \quad \dots 5.1$$

where ξ is the amplitude of the triangular waveform, which has to be equal to the maximum permitted amount of ripple current, and f_t is the frequency of the triangular waveform (i.e. the inverter switching freq.). The maximum slope of the inductor is equal to the

$$\frac{di}{dt} = \frac{V_{an} + V_{dc}}{L} \quad \dots 5.2$$

Since the slope of the inductor current has to be smaller than the slope of the triangular waveform, and the ripple current is known from equations 5.1 and 5.2

$$L = \frac{V_{an} + V_{dc}}{4\xi f_t} \quad \dots 5.3$$

The value of Inductor in our project is decided by the simulation results

5.3.2 DESIGN OF THE DC CAPACITOR

Transient changes in the instantaneous power absorbed by the load generates voltage fluctuations across the dc capacitor the amplitude of these voltage fluctuations can be controlled effectively with an appropriate dc capacitor value. The dc voltage control loop stabilizes the capacitor voltage after cycle, but it is not so fast enough to limit the fast voltage variations. Since the capacitor value obtained with this criteria is bigger than the value obtained based on the maximum dc voltage ripple constraints, the voltage across the dc capacitor generated across the dc capacitor is given by,

$$V_{C_{max}} = \frac{1}{C} \int_{\frac{\theta_1}{\omega}}^{\frac{\theta_2}{\omega}} i_c(t) dt + V_{dc} \quad \dots 5.4$$

Where $V_{C_{max}}$ is the maximum voltage across the dc capacitor, V_{dc} is the steady state dc voltage and $i_c(t)$ is the instantaneous dc bus current.

$$C = \frac{1}{\Delta V} * \int_{\frac{\theta_1}{\omega}}^{\frac{\theta_2}{\omega}} i_c(t) dt \quad \dots 5.5$$

This equation gives the value of the dc capacitor C , that will maintain the dc voltage fluctuation below the ΔV p.u. The instantaneous value of the dc voltage is defined by the product of the inverter line currents with the respective switching functions. The mean value of the dc current that generates the maximum over voltage can be estimated by

$$\int_{\frac{\theta_1}{\omega}}^{\frac{\theta_2}{\omega}} ic(t) dt = \lim_{\frac{\theta_1}{\omega} \rightarrow \frac{\theta_2}{\omega}} \int [\sin(\omega t) + \sin(\omega t + 120)] dt \quad \dots 5.6$$

The inverter ac current is assumed to be sinusoidal, which represents the worst case. Different values of capacitor were tried during simulation for optimization and was decided based on the simulation results.

5.4 . Instantaneous active-reactive power theory

The instantaneous power in three-phase is defined on the basis of instantaneous concept for arbitrary voltage and current waveforms including transient states.

To deal with instantaneous voltages and current in three phase circuits mathematically, it is adequate to express these quantities as the instantaneous space vectors.

5.4.1 Negelcting zero sequence components

In a-b-c coordinates, the a,b and c axes are fixed on the same plane, apart from each other by $2\pi/3$. The instantaneous space vectors, e_a and i_a are set on the a axis, and their amplitude and (+,-) direction vary with passage of time. In the same way, e_b and i_b are on the b axis, and e_c and i_c are on the c axis. These space vectors are easily transformed into alpha-beta-zero coordinates as follows :

$$\begin{bmatrix} e\alpha \\ e\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad \dots 5.7$$

$$\begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad \dots 5.8$$

Where the α and β axes are the orthogonal coordinates. Necessarily, $e\alpha$ and $i\alpha$ are on the α axis, $e\beta$ and $i\beta$ are on the β axis. Their amplitude and (+,-) direction vary with passage of the time. The conventional instantaneous power on the three-phase circuit can be defined as follows.

$$p = e\alpha \cdot i\alpha + e\beta \cdot i\beta \quad \dots 5.9$$

Where p is equal to the conventional power:

$$p = e_a \cdot i_a + e_b \cdot i_b + e_c \cdot i_c \quad \dots 5.10$$

To define the instantaneous reactive power, let the space vector be defined by

$$q = e\alpha \cdot i\beta - e\beta \cdot i\alpha \quad \dots 5.11$$

This space vector is the imaginary axis vector and is perpendicular to the real plane on the α - β coordinates, to be in compliance with right hand rule. Taking into consideration that e_α is parallel to i_α , and that e_α is perpendicular to i_β and e_β to i_α , the conventional instantaneous imaginary power q , which of amplitude q , are expressed by

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad \dots 5.12$$

Since $e_\alpha i_\alpha$ and $i_\beta e_\beta$ are defined by the product of the instantaneous voltage in one axis and the instantaneous current in the same axis, they represent instantaneous power. p is the real power in the three-phase circuit, and its dimension is (W). Conversely, $e_\alpha i_\beta$ and $e_\beta i_\alpha$ are not instantaneous power because they are defined by the product of the instantaneous voltage in the in one axis and the instantaneous current not in the same axis but in the one axis and the instantaneous current not in the same axis but in the perpendicular axis. Accordingly q cannot be dealt with conventional quantity. definition and physical meaning of instantaneous reactive power in equation 5.12 is changed into the following equation :

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p \\ q \end{bmatrix} \quad \dots 5.13$$

The instantaneous currents on the α - β coordinates, i_α and i_β are divided into two kinds of instantaneous current components, respectively

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p \\ 0 \end{bmatrix} + \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ q \end{bmatrix} \quad \dots 5.14$$

$$= \begin{bmatrix} i_{\alpha p} \\ i_{\beta p} \end{bmatrix} + \begin{bmatrix} i_{\alpha q} \\ i_{\beta q} \end{bmatrix} \quad \dots 5.15$$

α - axis instantaneous active current

$$i_{\alpha p} = \frac{e_\alpha}{e_\alpha^2 + e_\beta^2} * p \quad \dots 5.16$$

α axis instantaneous reactive current

$$i_{\alpha q} = \frac{-e_\beta}{e_\alpha^2 + e_\beta^2} * q \quad \dots 5.17$$

β axis instantaneous active current

$$i_{\beta p} = \frac{e_\beta}{e_\alpha^2 + e_\beta^2} * p \quad \dots 5.18$$

β axis instantaneous reactive current

$$i_{\beta q} = \frac{e_\alpha}{e_\alpha^2 + e_\beta^2} * q \quad \dots 5.19$$

Let the instantaneous powers in the α axis and the β axis is p_α and p_β respectively, they are given by the conventional definition as follows.

$$\begin{bmatrix} p_\alpha \\ p_\beta \end{bmatrix} = \begin{bmatrix} e\alpha^* i\alpha \\ e\beta^* i\beta \end{bmatrix} = \begin{bmatrix} e\alpha^* i\alpha p \\ e\beta^* i\beta p \end{bmatrix} + \begin{bmatrix} e\alpha^* i\alpha q \\ e\beta^* i\beta q \end{bmatrix} \quad \dots 5.20$$

Using relations 5.14 and 5.20, the instantaneous real power in the three phase circuit p is given by:

$$p = p_\alpha + p_\beta = \frac{e^2 \alpha}{e\alpha^2 + e\beta^2} * p + \frac{e^2 \beta}{e\alpha^2 + e\beta^2} * p + \frac{-e\alpha^* e\beta}{e\alpha^2 + e\beta^2} * q + \frac{e\alpha^* e\beta}{e\alpha^2 + e\beta^2} * q \quad \dots 5.21$$

From 5.19 and 5.20 following equations are obtained

$$p = e\alpha^* i\beta p + e\beta^* i\beta p = p_{\alpha p} + p_{\beta p} \quad \dots 5.22$$

$$0 = e\alpha^* i\alpha q + e\beta^* i\beta q = p_{\alpha q} + p_{\beta q} \quad \dots 5.23$$

where,

$$\alpha \text{ axis reactive power : } p_{\alpha p} = \frac{e^2 \alpha}{e\alpha^2 + e\beta^2} * p \quad \dots 5.24$$

$$\alpha \text{ axis instantaneous reactive power: } p_{\alpha q} = \frac{-e\alpha^* e\beta}{e\alpha^2 + e\beta^2} * q \quad \dots 5.25$$

$$\beta \text{ axis instantaneous active power: } p_{\beta p} = \frac{e^2 \beta}{e\alpha^2 + e\beta^2} * p \quad \dots 5.26$$

$$\beta \text{ axis instantaneous reactive power: } p_{\beta q} = \frac{e\alpha^* e\beta}{e\alpha^2 + e\beta^2} * q \quad \dots 5.27$$

It can be concluded that the sum of the instantaneous power $p_{\alpha p}$ and $p_{\beta p}$ coincides with the instantaneous real power in the three-phase circuit. $p_{\alpha p}$ and $p_{\beta p}$ are named as instantaneous active power. The instantaneous powers $p_{\alpha q}$ & $p_{\beta q}$ cancels each other and make no contribution to the instantaneous power flow from source to the load.

5.4.2 With zero sequence components

This section extends the instantaneous reactive power theory developed for three phase circuit including zero phase sequence components. The instantaneous space vectors e_a , e_b and e_c are transformed to 0- α - β co-ordinates as follows:

$$\begin{bmatrix} e_0 \\ e_\alpha \\ e_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad \dots 5.28$$

like wise, the instantaneous space vectors i_0 , i_α , and i_β on the 0- α - β co-ordinates are given as follows:

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad \dots 5.29$$

another instantaneous power p_0 which is defined as the product of instantaneous space vectors, e_0 and i_0 on the zero axis:

$$p_0 = e_0 * i_0 \quad \dots 5.30$$

$$\begin{bmatrix} p_0 \\ p \\ q \end{bmatrix} = \begin{bmatrix} e_0 & 0 & 0 \\ 0 & e_\alpha & e_\beta \\ 0 & -e_\beta & e_\alpha \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \quad \dots 5.31$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} e_0 & 0 & 0 \\ 0 & e_\alpha & e_\beta \\ 0 & -e_\beta & e_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p_0 \\ p \\ q \end{bmatrix} = \begin{bmatrix} e_0 & 0 & 0 \\ 0 & e_\alpha & e_\beta \\ 0 & -e_\beta & e_\alpha \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ p \\ 0 \end{bmatrix} + \begin{bmatrix} e_0 & 0 & 0 \\ 0 & e_\alpha & e_\beta \\ 0 & -e_\beta & e_\alpha \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ 0 \\ q \end{bmatrix}$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} i_0 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ i_{\alpha p} \\ i_{\beta p} \end{bmatrix} + \begin{bmatrix} 0 \\ i_{\alpha q} \\ i_{\beta q} \end{bmatrix} \quad \dots 5.32$$

from equation 5.31 the instantaneous currents on the a-b-c coordinates are divided in the following three components, respectively:

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_0 \\ 0 \\ 0 \end{bmatrix} + \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} 0 \\ i_{\alpha p} \\ i_{\beta p} \end{bmatrix} + \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} 0 \\ i_{\alpha q} \\ i_{\beta q} \end{bmatrix} \quad \dots 5.33$$

$$= \begin{bmatrix} i_{a0} \\ i_{b0} \\ i_{c0} \end{bmatrix} + \begin{bmatrix} i_{ap} \\ i_{bp} \\ i_{cp} \end{bmatrix} + \begin{bmatrix} i_{aq} \\ i_{bq} \\ i_{cq} \end{bmatrix} \quad \text{where : } i_{a0} = i_{b0} = i_{c0} = i_0 / \sqrt{3} \quad \dots 5.34$$

Using equation 5.33

$$\begin{bmatrix} p_a \\ p_b \\ p_c \end{bmatrix} = \begin{bmatrix} e_a * i_{a0} \\ e_b * i_{b0} \\ e_c * i_{c0} \end{bmatrix} + \begin{bmatrix} e_a * i_{ap} \\ e_b * i_{bp} \\ e_c * i_{cp} \end{bmatrix} + \begin{bmatrix} e_a * i_{aq} \\ e_b * i_{bq} \\ e_c * i_{cq} \end{bmatrix} = \begin{bmatrix} p_{a0} \\ p_{b0} \\ p_{c0} \end{bmatrix} + \begin{bmatrix} p_{ap} \\ p_{bp} \\ p_{cp} \end{bmatrix} + \begin{bmatrix} p_{aq} \\ p_{bq} \\ p_{cq} \end{bmatrix} \quad \dots 5.35$$

The instantaneous reactive power in each phase P_{aq} , P_{bq} and P_{cq} make no contribution to the instantaneous power flow in the three phase circuit which is represented by P_0 and P , because the sum of the instantaneous power is always zero.

5.5 Control strategy

The active filter eliminates the instantaneous reactive power on the source side and harmonics, which are caused by the instantaneous power on the load side. The active power filter consists of only switching devices without energy storage components, because p_c is always zero. The instantaneous compensating currents on the α - β coordinates $i_{c\alpha}$ and $i_{c\beta}$ are given by

$$\begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} = \begin{bmatrix} e\alpha & e\beta \\ -e\beta & e\alpha \end{bmatrix}^{-1} \begin{bmatrix} -pac \\ -q \end{bmatrix} \quad \dots 5.36$$

The instantaneous active and the reactive currents are divided into the following two kinds of instantaneous currents, respectively :

$$i\alpha = \frac{e\alpha}{e\alpha^2 + e\beta^2} * p_{dc} + \frac{e\alpha}{e\alpha^2 + e\beta^2} * pac + \frac{-e\beta}{e\alpha^2 + e\beta^2} * q_{dc} + \frac{-e\beta}{e\alpha^2 + e\beta^2} * q_{ac} \quad \checkmark \text{ check it.} \quad \dots 5.37$$

where p_{dc} and p_{ac} are the dc and ac components of the instantaneous real power and q_{dc} and q_{ac} are the dc and ac components of the instantaneous imaginary power. The first term of the right hand side of equation is the instantaneous value of the conventional fundamental active current.

The third term is the instantaneous value of the conventional fundamental reactive current. The second term is the instantaneous value of the harmonic current which represents the ac component of the instantaneous real power.

The fourth term is the instantaneous value of the harmonic currents, which represents the ac components of the instantaneous imaginary power. Accordingly, the sum of the second and fourth terms is the instantaneous value of the conventional harmonic currents.

It is clear from equation 5.29 that the active filter eliminates both the third and fourth terms, so the displacement factor is unity not only in steady states but also in transient states. The harmonic currents represented by them can be eliminated by the active filter comprising switching devices without energy storage components.

5.6 Power Circuit Implementation

Fig 5.7 depicts the wiring of proto type setup for three-phase four-wire active filter module. A three-phase diode rectifier system with resistive load is connected as harmonic producing loads for experimental purpose using eight power-IGBTs. The filter capacitor (C) suppresses harmonic currents and maintains constant dc bus voltage.

These passive components size depends on the switching frequency and rating of the active filter. Diode bridge rectifier with resistive load is treated as nonlinear load and a harmonic generating source.

Four leg voltage source inverter operating in hysteresis current control mode is used as active power filter. The RC snubber circuit is connected across IGBT for dv/dt protection. RC

snubber across the diode bridge module is used to charge the DC bus capacitor and supply the active energy absorbed by the IGBTs of voltage source inverter, reactor and snubber. Bleeder resistor is connected across the DC bus capacitor to balance the voltage with in the voltage rating.

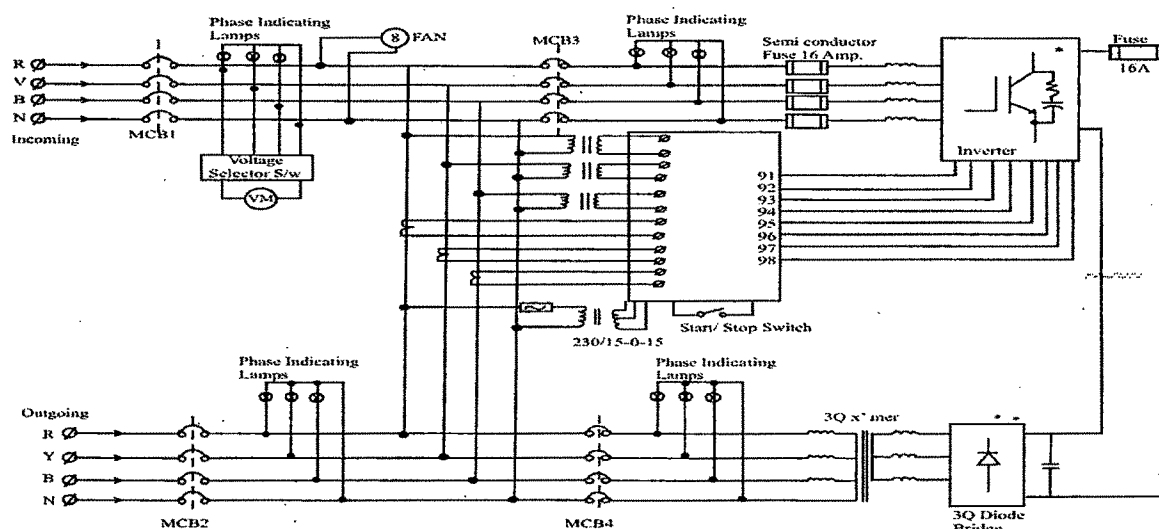


Fig 5.7: Active Power Filter –Schematic

Two capacitor of $4700\mu\text{F}$, 450V DC with ripple current of 10 amp are connected in series to increase the voltage rating upto 900V DC. The design criteria for inductor is based on the constraint than for a given switching frequency the minimum slope of the inductor current is smaller than the slope of the triangular waveform that defines the switching freq. The value of Inductor and capacitor is selected based on the simulation results.

The shunt active filter consists of four dual module each module having two IGBT: SKM50 GB123 B (50 amp, 1200 V, dual Module, with anti-parallel diode). Other components are; $L = 5\text{mH}$, $C1 = 7050\mu\text{F}$ ($4700\mu\text{F}$, 450 VDC), Driver IC = M57962L The active power filter is tested at 5 amp, 415Vac, and 50Hz three-phase four wire supply and DC voltage of 725 Vdc.

The load current is sensed using CT of the rating 12.5/1 amp ratio and 2.5 VA. The burden across the CT is 2Ω . Inverter current sensed through the CT is feedback for hysteresis current control. The PT with 440/3.0 Volt ratio and burden of 0.2 VA is used for sensing the line to neutral voltage.

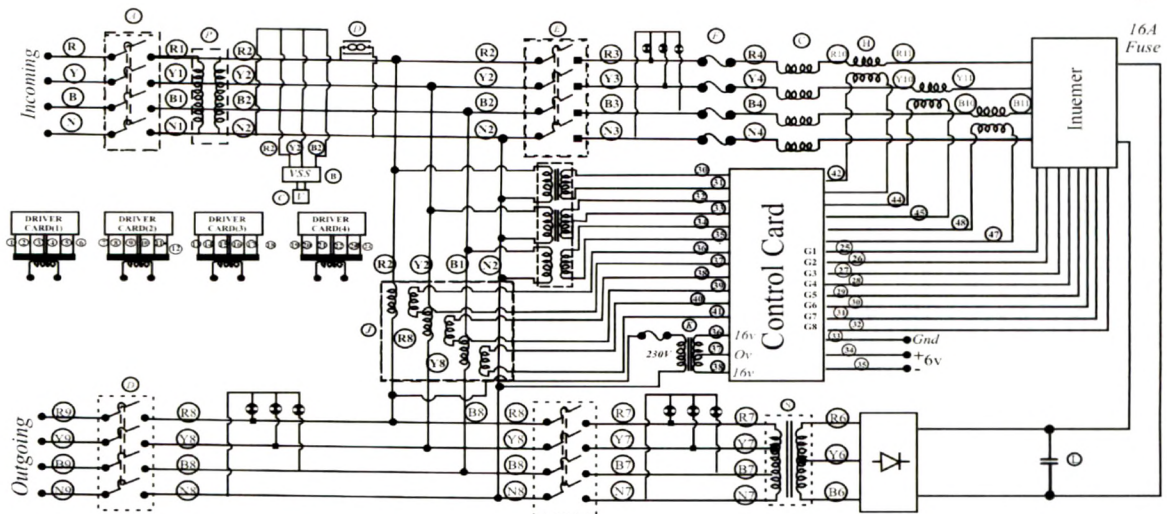


Fig 5.8: Active Power Filter – Actual Wiring Diagram

- Fig. 5.8 shows the complete experimental setup of three-phase four-wire active filter module. A three-phase diode rectifier system with resistive load as harmonic producing loads for experimental purpose. The shunt active filter consists of four dual module each module having two IGBT hence total eight IGBT in three-phase four-wire inverter configuration.

The fig 5.9 depicts the mechanical dimension of the Power module of the active power filter. The detailed control circuits and other modules are described in subsequent chapters.

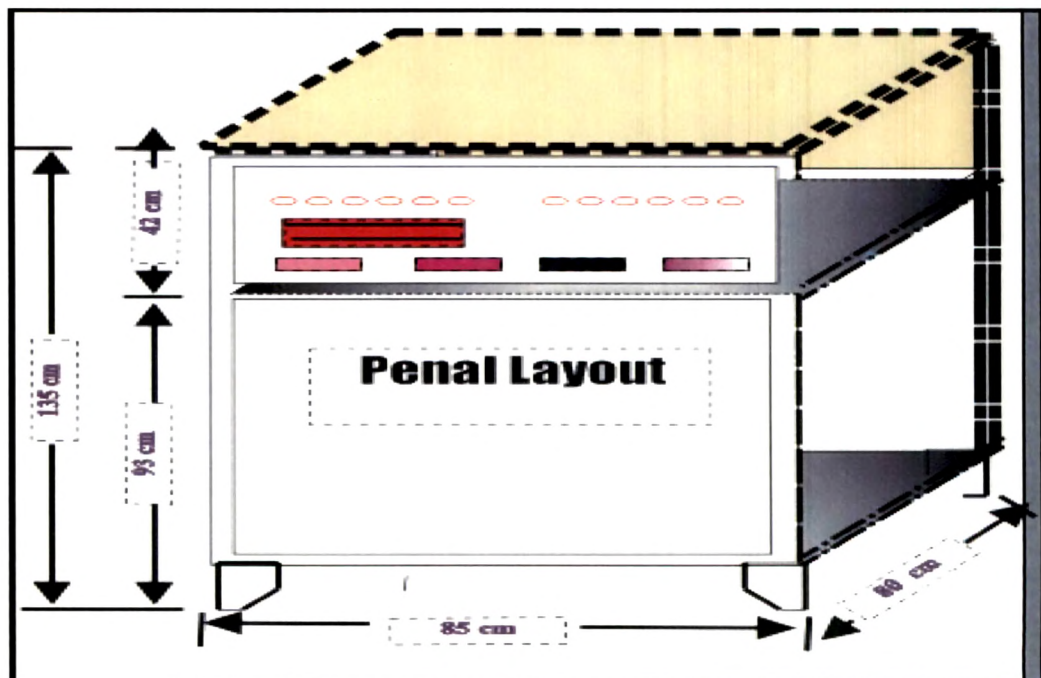


Fig 5.9: Mechanical Specification of APF Power Module Panel

The values of components used along with active filter are :

- $L = 5\text{mH}$
- $C1 = 7050\ \mu\text{F}$ ($4700\ \mu\text{F}$, 450 VDC Capacitor two in series and such three branch connected in parallel ALCON make
- IGBT= SKM50 GB123 B (50 amp, 1200 V, dual Module, with anti-parallel diode)

Driver IC = M57962L
