Chapter 7

Analog controller card for Shunt Active Power Filters

In this section, detailed description of control and power circuit realized using analog approach is described. Each block describes working principle and actual circuit realization. According to instantaneous reactive power theory six signals (three voltages and three currents) are required for the calculation of the three compensation currents. These voltages signals are derived from the phase voltage using potential transformer, similarly current signals are derived from line using current transformer. The responses obtained are used as the benchmarks for the DSP controller. The mathematical equations are same as in the previous chapters used for the simulation purpose. They are repeated for the ready reference.

7.1 Transformation of Signals into Orthogonal Coordinates :

Using p-q theory voltage and current signals are transformed into orthogonal coordinate system

$$V_{\alpha} = 0.816va - 0.41vb - 0.41vc \quad \ldots 7.1$$

$$V_{\beta} = 0.707vb - 0.707vc \quad \ldots 7.2$$

$$i_{o} = 0.577ia + 0.577ib + 0.577ic \quad \ldots 7.3$$

$$i_{\alpha} = 0.816ia - 0.41ib - 0.41ic \quad \ldots 7.4$$

$$i_{\beta} = 0.707ib - 0.707ic \quad \ldots 7.5$$

Relations 7.1 ..7.5 are used in the analog control circuit realization (Fig 7.1) for a three phase to Two phase transformation, using linear components such as operational amplifiers, multipliers.

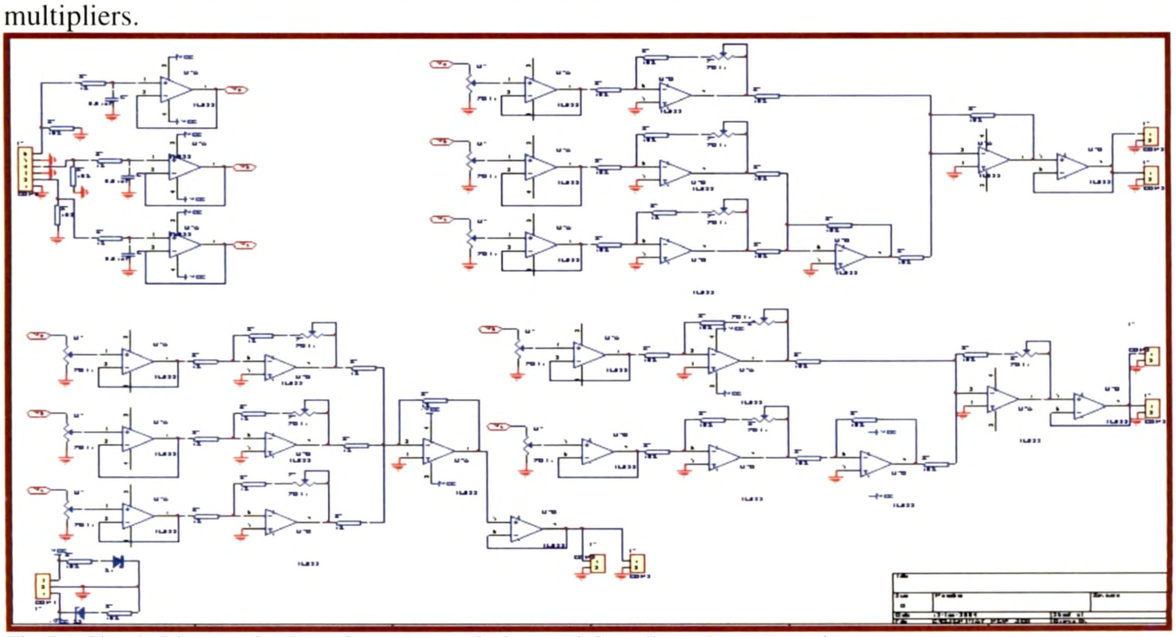

Fig 7.1 Circuit Diagram for Transformation to Orthogonal Coordinate Representation

7.2 Instantaneous Real And Imaginary Power Calculations

The resultant of these equations i.e. orthogonal voltages and current are used to define instantaneous real and power. The instantaneous real and imaginary power are defined as:

$$\begin{bmatrix} Po \\ P \\ q \end{bmatrix} = \begin{bmatrix} eo & 0 & 0 \\ 0 & e\alpha & e\beta \\ 0 & -e\beta & e\alpha \end{bmatrix} \begin{bmatrix} io \\ i\alpha \\ i\beta \end{bmatrix} \qquad \ldots 7.6$$

Representing in a scalar form:

$$p_o = V_o\, i_o \qquad \ldots\ 7.7$$

$$p = V_\alpha\, i_\alpha + v_\beta i_\beta \qquad \ldots\ 7.8$$

$$q = V_\alpha\, i_\beta - v_\beta i_\alpha \qquad \ldots\ 7.9$$

Above relations are used for the analog circuit (Fig 7.2) using linear components such as AD633JN multiplier, operational amplifiers.

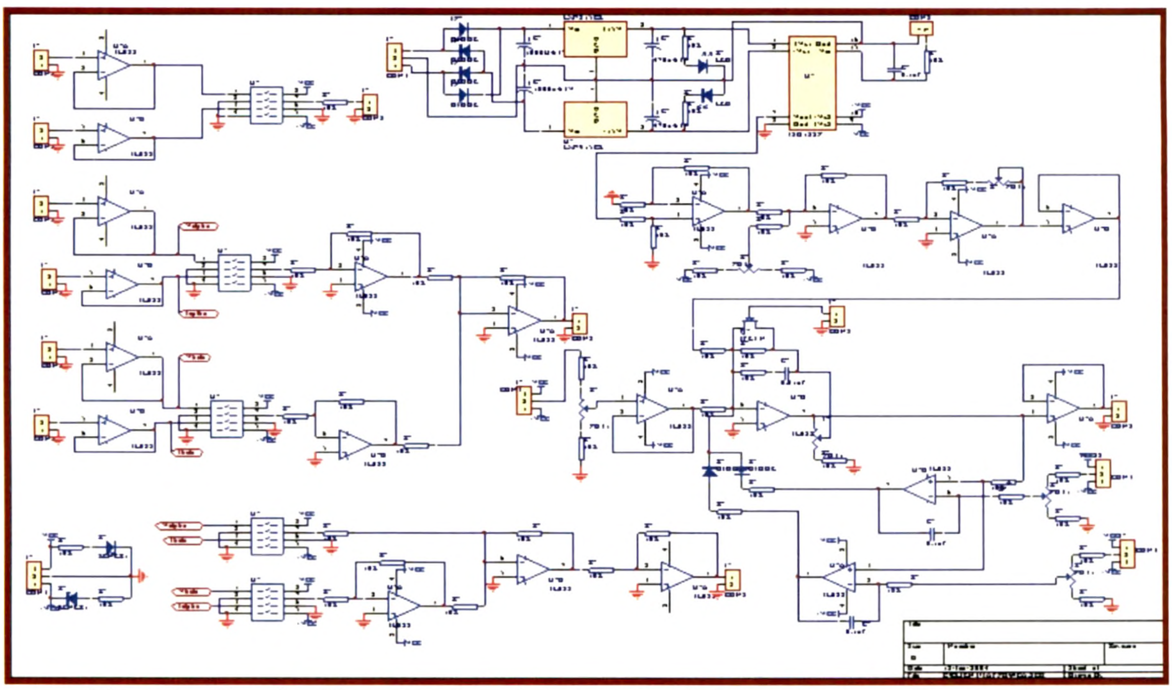

Fig 7.2 Circuit Diagram for Calculation of Instantaneous Power Component

7.3 Orthogonal Compensation Currents

To eliminate harmonics and the calculated real power p is passed through high pass second order Butterworth filter. The cutoff frequency for the filter is 45Hz. In this system cascading two first order filter makes this second order filter. The ac component is eliminated giving,

$$Pac = P - P_{dc} \qquad \text{… 7.10}$$

The filter used introduces phase in the input and output signal. To compensate this phase shift a phase shifter is used in the system. Further, to compensate reactive power must be made negative in matrix equations,

$$\begin{bmatrix} ic\alpha \\ ic\beta \end{bmatrix} = \begin{bmatrix} e\alpha & -e\beta \\ e\beta & e\alpha \end{bmatrix}^{-1} \begin{bmatrix} -pac \\ -qac \end{bmatrix} \qquad \text{… 7.11}$$

To cancel harmonics in the power system and reactive power the p_{ac} and q_{ac} is made negative. Solving we get,

$$ic\alpha = \frac{1}{e^2\alpha + e^2\beta} * (-e\alpha * pac + e\beta * qac) \qquad \text{… 7.12}$$

$$ic\beta = \frac{1}{e^2\alpha + e^2\beta} * (-e\beta * pac - e\alpha * qac) \qquad \text{… 7.13}$$

Where: $i_{c\alpha}$and $i_{c\beta}$ are compensating current in the orthogonal coordinates. The corresponding circuit is shown in Fig 7.3

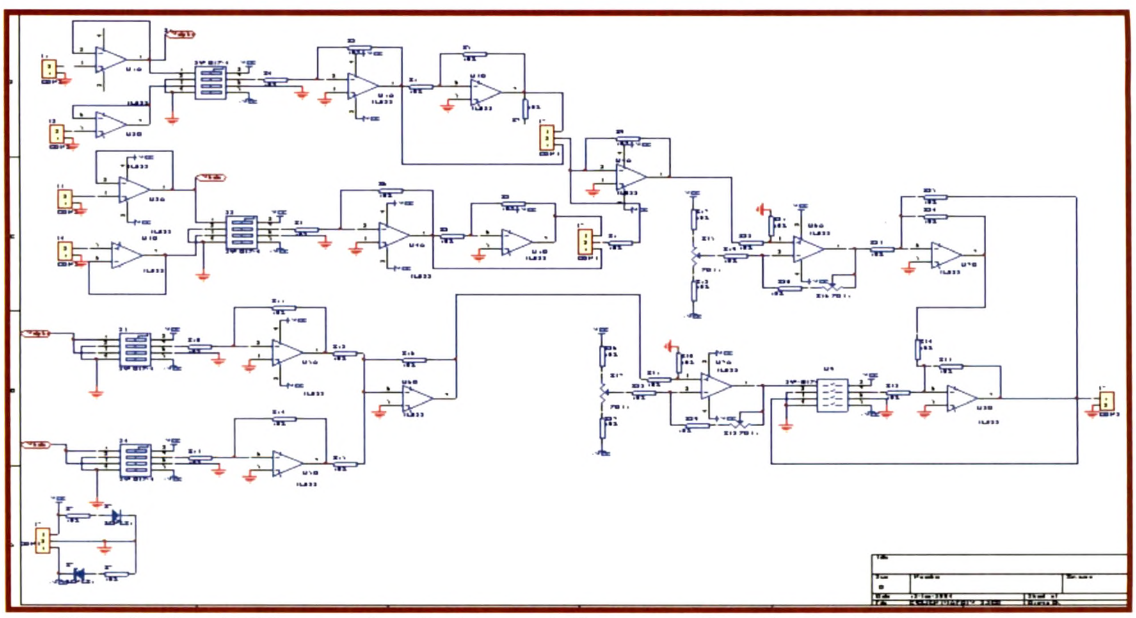

Fig 7.3 Circuit Diagram for Orthogonal Compensation Current Calculation

7.4 Transformation of Orthogonal Currents in Three Phase Coordinates

This icα and icβ compensated orthogonal currents are transformed back into three phase currents by transformation matrix as

$$\begin{bmatrix} ica \\ icb \\ icc \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} -io \\ ic\alpha^{*} \\ ic\beta^{*} \end{bmatrix} \qquad \ldots 7.14$$

Simplification leads to;

$ica^{*} = -0.577\ io + 0.816\ ic\alpha$ … 7.15

$icb^{*} = -0.577\ io - 0.408\ ic\alpha + 0.707\ ic\beta$ … 7.16

$icc^{*} = -0.577io - 0.408\ ic\alpha - 0.707\ ic\beta$ … 7.17

$in^{*} = 1.73io$

These ica*,icb*,icc, icn* are compensated three phase four wire reference currents. The corresponding realization is shown in Fig 7.4

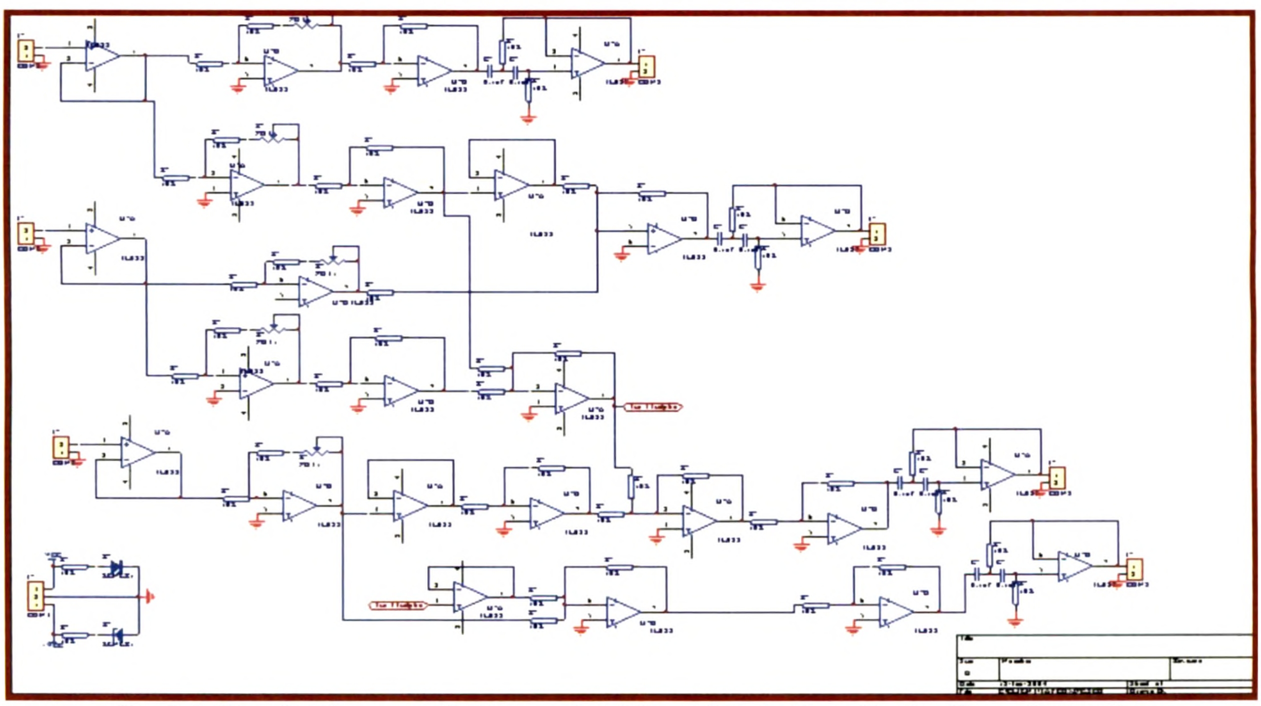

Fig 7.4 Circuit Diagram: Orthogonal to Three Phase Coordinates Transformation

7.5 Compensating current generation

The compensation currents derived from previous block is used to generate compensate current signals to eliminate harmonic.

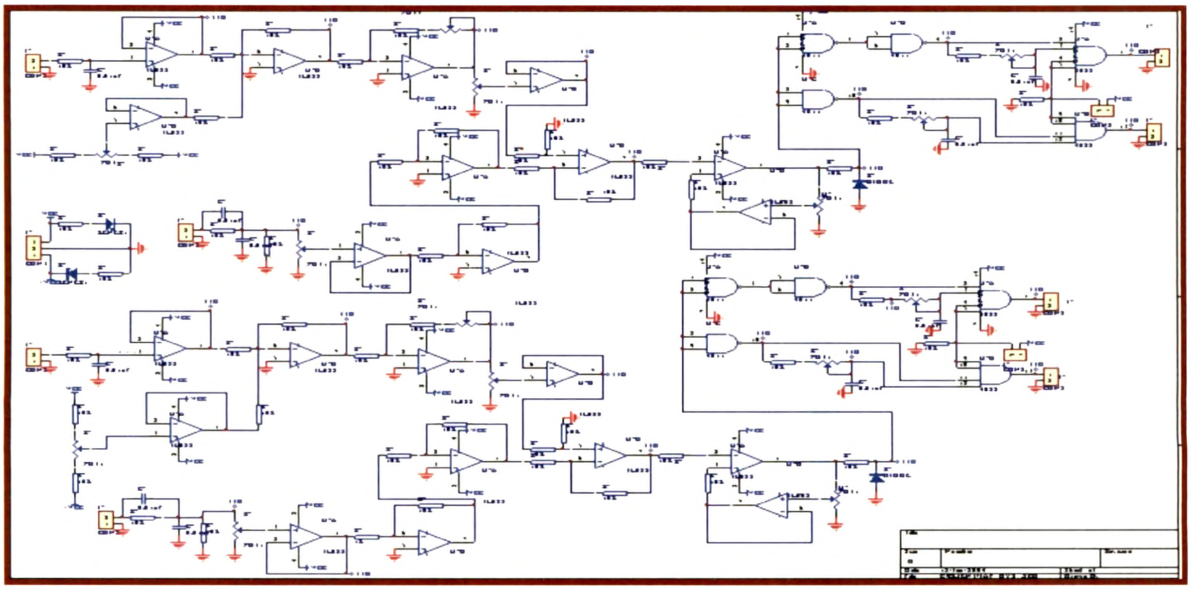

Fig 7.5 Circuit Diagram: Compensation Current Generator

7.6 Experimental results

Fig. 7.6 shows the complete experimental setup of three-phase four-wire active filter module., while Fig 7.7 shows actual 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 values of components used along with active filter are :

- L = 5mH
- C1 = 7050 µF (4700 µF, 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

The active power filter was 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 2 ohm. Inverter current is also sense through the CT to feedback the current for hysteresis current control. Such seven nos of CT used in this project. The PT with 440/3.0 Volt ratio and burden of 0.2 VA is used for sensing the line to neutral voltage. The control circuit tested with three-phase diode rectifier as nonlinear load. The compensating reference generated for this type of non-linear load is fed to the voltage source inverter operated in hysteresis current control mode with star connected reactor as load. After checking the performance as hysteresis current control inverter the output of the inverter is fed to the AC source through same reactor and the performance of the active filter is checked. The results are discussed in subsequent chapters.

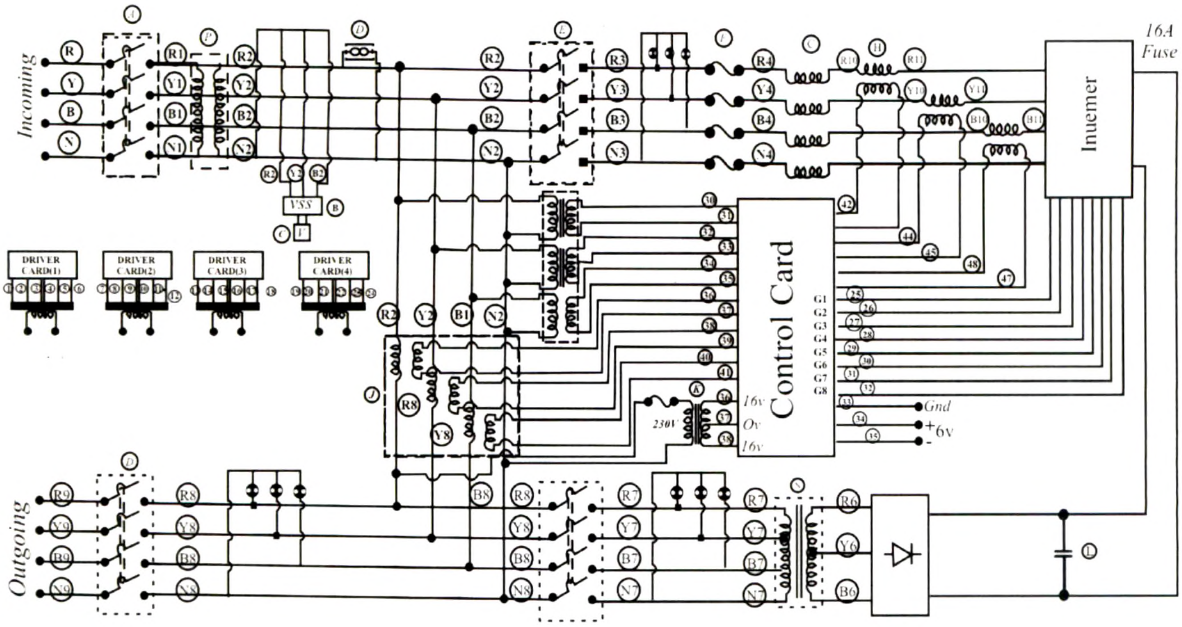

Fig 7.6 Experimental Test Set up

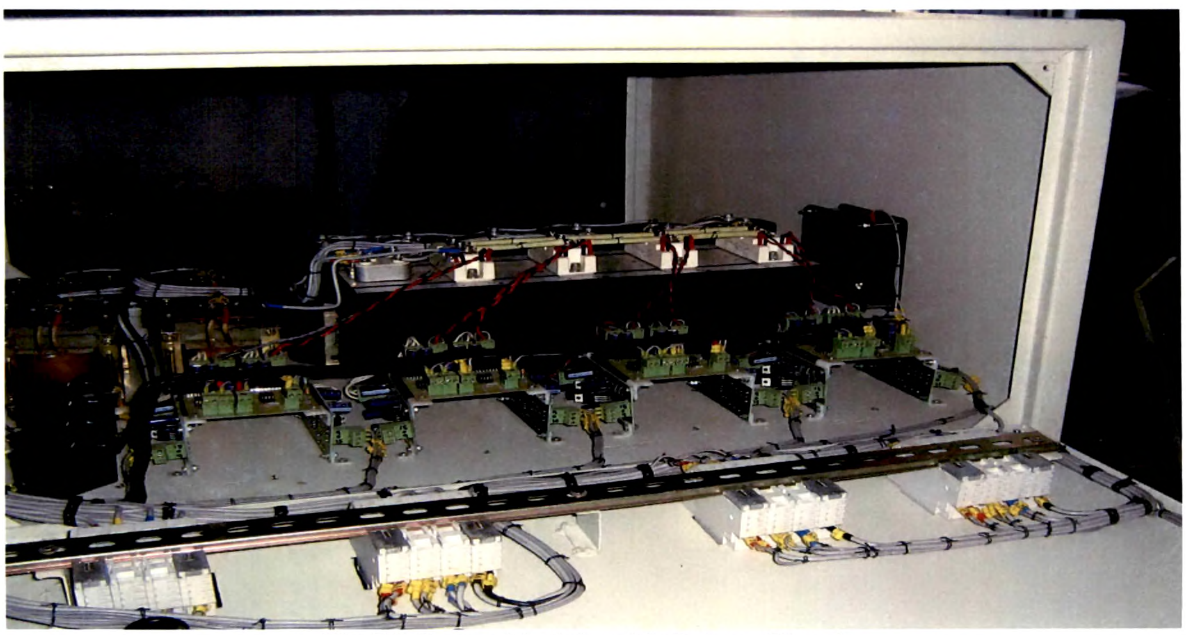

Fig 7.7 Power Module with Driver Circuits


MAINS ON
V
400
200