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SARVAJANIK COLLEGE OF ENGINEERING AND TECHNOLOGY

A

PROJECT REPORT ON

"POWER QUALITY IMPROVEMENT USING SHUNT ACTIVE POWER FILTER"

UNDER SUBJECT OF
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ELECTRICAL (SHIFT-1)
(ELECTRICAL Branch)
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SARVAJANIK COLLEGE OF ENGINEERING AND TECHNOLOGY

Certificate

This is to certify that the project report entitled POWER QUALITY IMPROVEMENT USING SHUNT ACTIVE POWER FILTER has been carried out by, **Mr. Patel Saurav Y. of 8th Semester; Enrollment no: 150420109050** Under guidance in partial fulfilment for the degree “Bachelor of Engineering” in electrical engineering studying in semester 8th of Gujarat Technological University, Ahmedabad during the academic year 2018-2019. The project work has been undertaken under my supervision and found satisfactory.

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Last but not the least, we would like to thank our parents without them none of this would indeed be possible.

Abstract

In recent years, power electronics devices have evolved, and used for various applications. Also, this device caused the problem of power quality in electrical system. In the utility side arc furnaces, variable frequency drives (VFD), personal computer, fluorescent lamp such non-linear load produces current harmonics. For consumer and distributed side, the power quality is an important issue.

The active power filter which is capable for improving the power quality and reactive power compensation. In this paper the harmonics problem which is created by non-linear load is discussed. Shunt active power filter (SAPF) is used for eliminating the harmonics from non-linear load and in the retrieval technique for controlling the current hysteresis current controller is used. In this paper for producing the reference current instantaneous reactive power (PQ) theory is used. The simulation results of shunt active power filter using PQ theory is carried out using MATLAB / Simulink.

We have implemented one of many control strategies of controlling the SAPF so the new control strategies for the compensation, including the other conditions in the power system such as 4 wire balanced and unbalanced system. So that the effect of various conditions and a comparative study can be done among the various control methodologies.

With the same hardware we can implement we can compare different control strategies used in the shunt active filter for different conditions. So that a comparative analysis can be obtained.

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1 Introduction

In the modern era, the sudden growth in power electronic devices (such as, Variable Frequency Drives (VFDs), switch mode power supplies (SMPS), etc.) to increase the controllability and efficiency of the system are the main sources for harmonic distortion on power system network. These devices draw harmonic non-linear sinusoidal currents because of switching. Therefore, generation of harmonics that causes power quality disturbances has become a significant problem for the distributors and consumers of electric power. To eliminate such issues and improve the quality of power supply, active power filters (APFs) are used. The most commonly used power circuit for power disturbances nullification and compensating reactive power is the shunt active power filter.

1.1 Objectives of the Project

- Study the operation of shunt active power filters and its mathematical model.
- Developing a basic 3 – phase shunt active filter in MATLAB – SIMULINK using different control strategies.
- Evaluating the filter performance on various types of load.
- To study firing scheme of converter i.e. Hysteresis Current Control and its SIMULINK model.
- To implement the control strategy developed in MATLAB using dSPACE.

1.2 Problem Specifications

Due to the wide spread of power electronics equipment in modern electrical systems, the increase of the harmonics disturbance in the ac mains currents has become a major concern due to the adverse effects on all equipment.

This adverse effect of harmonics can be measured by the Total Harmonic Distortion (THD) of the supply. The maximum and minimum values of THD in voltage and dominant voltage harmonics in typical power system are given in Table 1.1[1]

Also, the harmonics distortion in residential and commercial area for low voltage levels are shown in Table 1.2[2].

From the below data it can be observed that the resulting THD in high voltage transmission system is less than those in 6.6 kV distribution system. The main reason is that the expansion and interconnection of high voltage transmission system has made it stiffer with an increase of short circuit capacity. In commercial area, the maximum value of 5th harmonic voltage exceeded its allowable level of 3 %.

	Over 187 kV		22 – 154 kV	
	THD	5^{th} harmonic	THD	5^{th} harmonic
Maximum	2.8 %	2.8%	3.3 %	3.2 %
Minimum	1.1 %	1.0%	1.4 %	1.3 %

Table 1.1 THD Limits For High Voltage

	Below 6.6 kV			
	Residential Area		Commercial Area	
	THD	5^{th} harmonic	THD	5^{th} harmonic
Maximum	3.5 %	3.4 %	4.6 %	4.3 %
Minimum	3.0 %	2.9 %	2.1 %	1.2 %

Table 1.2 THD Limits for low Voltage

The different loads producing the THD can be classified into identified (commercial) and non – identified (residential). Table 1.3[3] shows the list of identified and unidentified harmonic producing loads.

SOURCES	HARMONIC POLLUTION
Identified	• Thyristor Rectifier • Cycloconverters • Arc Furnaces
Unidentified	• TV Sets • Personal Computers • Inverter based home appliances • Adjustable Sped Motor drives

Table 1.3 Harmonic Sources

Effects of harmonic distortion can be given as:

- Overheating of transformers and electrical motors
- Overheating of capacitors for power factor correction
- Voltage waveform distortion
- Voltage flicker
- Interference with communication systems

1.3 Basic Principle of Harmonic compensation

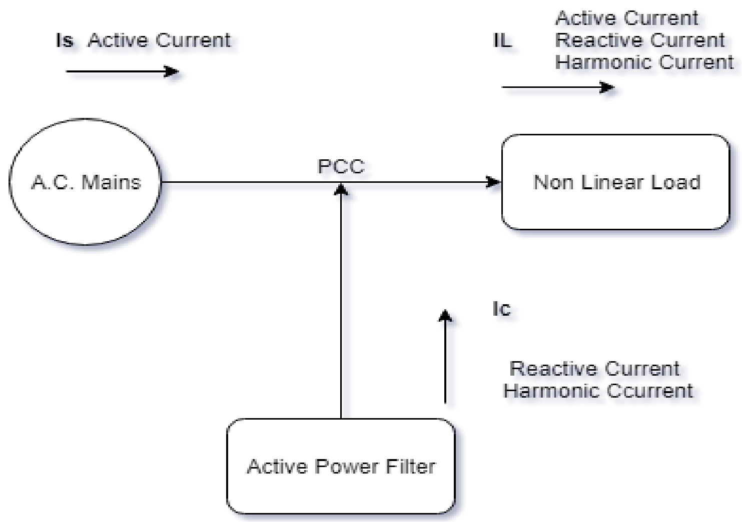

Figure 1.1 Basic Working of SAPF

The basic block diagram for the compensation in a SAPF is illustrated in Fig 1.1. The SAPF is controlled for generating compensating I_c such that it not only cancels harmonics that are predominant in the AC mains, but also adjusts the supply current to be in phase and sinusoidal in nature.

The current waveforms generated are shown below for phase “A”.

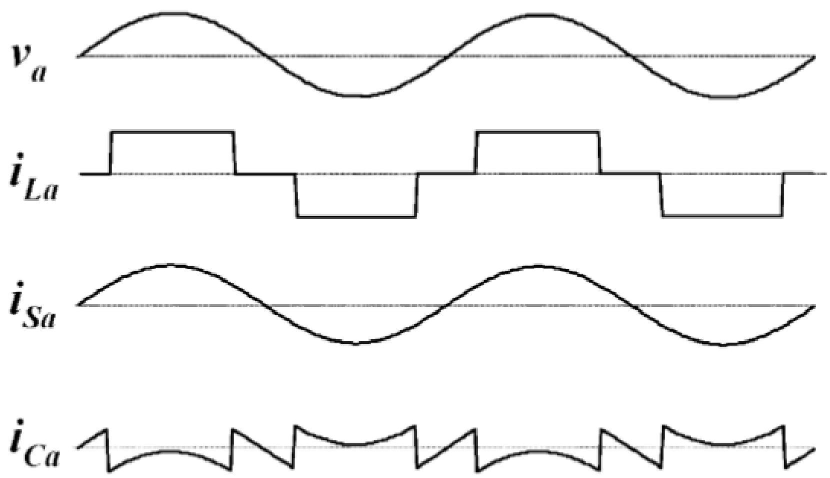

Figure 1.2 Waveforms of Phase A

1.4 The Instantaneous Power Theory

Research on the calculation and physical interpretation of energy flow in an electric circuit date back to the 1920s. But the development of Power electronics devices and their associated converters has brought new boundary conditions to the energy flow problem. This is not exactly because the problem is new, but because these converters behave as nonlinear loads and represent a significant amount of power compared with other traditional linear loads.

The theories that deal with instantaneous power can be mainly classified into the following two groups. The first one is developed based on the transformation from the *abc* phases to three-orthogonal axes, and the other is done directly on the *abc* phases.

The first one is what is called ***p-q*** **Theory** and is based on the *abc* to *αβ0* transformation. The second one has no specific name. Because it deals directly with the *abc* phases, it is called the ***abc*** **Theory.**

1.4.1 Basics of *p-q* Theory

The ***p-q*** **Theory** is based on a set of instantaneous powers defined in the time domain. No restrictions are imposed on the voltage or current waveforms, and it can be applied to 3 -phase systems with or without a neutral wire for 3 – phase generic voltage and current waveforms. Thus, it is valid not only in the steady state, but also in the transient state. So, it is very efficient and flexible in designing controllers for power conditioners based on power electronics devices,

Other traditional concepts of power are characterized by treating a 3 – phase system as 3 single phase circuits. The *p-q* Theory first transforms voltages and currents from the *abc* to *αβ0* coordinates, and then defines instantaneous power on these coordinates. Hence**,** this theory always considers the 3-phase system as a unit, not a superposition or sum of 3 single phase circuits.

1.4.2 Clarke Transformation (Alpha – beta transformation)

The αβϒ transform applied to 3 – phase quantities as used by *Edith Clarke.* Can be given by the below matrix. It should be noted that the below matrix is the power invariant transformation so that the active and reactive power computed can be same as per standard reference frame.

$$i_{\alpha\beta\gamma}(t) = Ti_{abc}(t) = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix}\begin{bmatrix} i_a(t) \\ i_b(t) \\ i_c(t) \end{bmatrix}$$

Here T is a unitary matrix and the inverse coincides with its transpose. In this case the amplitudes of the transformed current are not the same of those in the standard frame, i.e.

$$\begin{aligned} i_\alpha &= \sqrt{3} I \cos\theta(t), \\ i_\beta &= \sqrt{3} I \sin\theta(t), \\ i_\gamma &= 0. \end{aligned}$$

The inverse in this case can be given as

$$i_{abc}(t) = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 & \frac{1}{\sqrt{2}} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & \frac{1}{\sqrt{2}} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_\alpha(t) \\ i_\beta(t) \\ i_\gamma(t) \end{bmatrix}.$$

One major advantage of applying the Clarke transformation is to separate zero – sequence components from the *abc* phase components. The α and β axes make no contribution to zero sequence components. No zero-sequence current exists in a 3 – phase, 3 – wire system, so that I_0 can be eliminated from the above equations, thus results in simplification

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

Also, the inverse Clarke transformation will be deduced to.

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

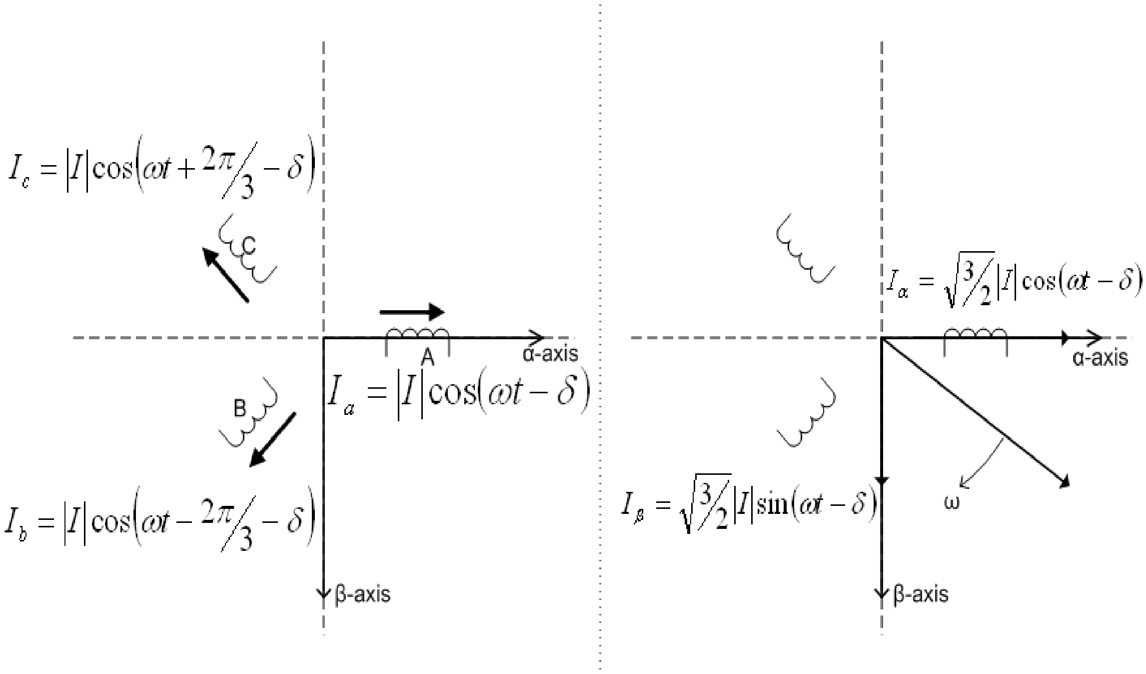

Figure 1.3 Geometric Representation of Clarke Transformation

1.5 The *p-q* Theory in 3 – phase, 3- wire systems

Another way to introduce the *p-q* Theory for 3 phase, 3 wire system is to use the instantaneous voltage and current vectors. The conventional concept of the complex power uses a voltage phasor and the conjugate of a current phasor. Thus, it is valid only for a system in the steady state with a fixed line frequency. A new definition of *instantaneous complex power* is possible, using the instantaneous vectors of voltage and current. The instantaneous complex power **s** is defined of the voltage vector **e** and the conjugate of the current vector **i***, given in the form of complex numbers,

$$\mathbf{s} = \mathbf{e} \cdot \mathbf{i}^* = (v_\alpha + jv_\beta)(i_\alpha - ji_\beta) = \underbrace{(v_\alpha i_\alpha + v_\beta i_\beta)}_{p} + j\underbrace{(v_\beta i_\alpha - v_\alpha i_\beta)}_{q}$$

So, the definition of *p* and *q* from above equation can be given as:

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

Now the αβ currents can be a set as functions of voltages and the real and imaginary powers *p* and *q*.

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

The following important conclusions can be made by the above equations;

- The instantaneous current i_α is divided into the instantaneous active components $i_{\alpha p}$ and the instantaneous reactive component $i_{\alpha q}$. This same division is made for the currents on the β – axis.
- The sum of the α axis instantaneous active power $p_{\alpha p}$, and the β axis instantaneous active power $p_{\beta p}$ corresponds to the instantaneous real power *p.*
- The sum of $p_{\alpha q}$ and $p_{\beta q}$ is always zero. Therefore, they neither contribute to the instantaneous nor average energy flow between the source and the load in a three – phase circuit. This is the reason that they were named instantaneous reactive power on the α and β axes. The instantaneous imaginary power q is a quantity that gives the magnitude of the power $p_{\alpha q}$ and $p_{\beta q}$.
- Because the sum of $p_{\alpha q}$ and $p_{\beta q}$ is always zero, their compensation does not need any energy storage system.

The imaginary power q is a new quantity and needs a unit to distinguish this power from the traditional reactive power. The use of unit "Volt – Ampere Imaginary" and the symbol “vai”, making an analogy to the symbol “var” of the traditional unit “Volt – Ampere Reactive.”

It is important to note that the conventional power theory defined reactive power as a component of the instantaneous (active) power, which has an average value equal to zero. Here, it is not so. The imaginary power means a sum of products of instantaneous three phase voltage and current portions that do not contribute to the energy transfer between two subsystems at any time.

1.6 Selection of Power Components to be Compensated

One significant advantage of using the *p-q* Theory in designing controllers for active power – line conditioners is the possibility of independently selecting the portions of real, imaginary, and zero – sequence powers to be compensated. Sometimes, it is convenient to separate these powers into their average and oscillating parts, that is,

$$\begin{array}{llcccc}
\text{Real power:} & p & = & \bar{p} & + & \tilde{p} \\
\text{Imaginary power:} & q & = & \bar{q} & + & \tilde{q} \\
\text{Zero-sequence power:} & p_0 & = & \bar{p}_0 & + & \tilde{p}_0 \\
 & & & \text{Average powers} & & \text{Oscillating powers}
\end{array}$$

The idea is to compensate all undesirable power components generated by non – linear loads that can damage or make the power system overloaded or stressed by harmonic pollution. In this way, it would be desirable for a 3 – phase balanced power generating system to supply only the average real power of the load. Thus, all other power components required by the non – linear load should be compensated by a shunt compensator.

1.7 Shunt Active Filters

The concept of shunt active filtering was first introduced by Gyugyi and Strycula in 1976. The controllers of SAPF should determine in real time the compensating current reference and force a power converter to synthesize it accurately. In this way, the active filtering can be selective and adaptive. In other words, a shunt active filter can compensate only for the harmonic current of a selected nonlinear load and can continuously track changes in its harmonic content.

1.7.1 General Description of Shunt Active Filters

Shunt active filters generally consist of two distinct main blocks

- The PWM converter (power processing)
- The active filter controller (signal processing)

The PWM converter is responsible for power processing in synthesizing the compensating current that should be drawn from the power system. The active filter controller is responsible for signal processing in determining in real time the instantaneous compensating current references, which are continuously passed to the PWM converter. The Fig. 1.4 shows the basic configuration of a shunt active filter for harmonic current compensation of a specific load. It consists of a voltage fed converter with a PWM current controller and an active filter controller that realizes an almost instantaneous control algorithm. The shunt active filter controller works in a close loop manner, continuously sensing the load current I_L and calculating the instantaneous values of the compensating current reference I_c* for the PWM converter.

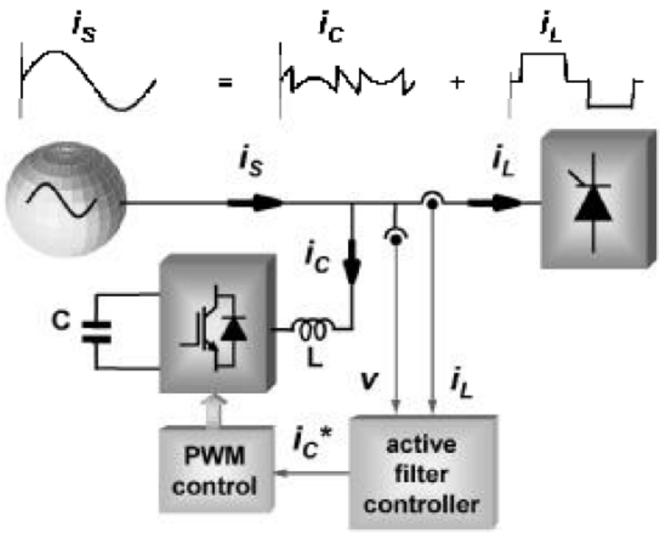

Figure 1.4 Basic Configuration of Shunt active Filter

1.8 Three Phase, Three Wire Shunt Active Power Filter

A characteristic of three phase, three wire systems is the absence of the neutral conductor and consequently, the absence of zero sequence current component. Thus, the zero – sequence power is always zero in these systems.

Fig. 1.5 shows the most important parts of a 3 – phase, 3 – wire shunt active filter for current compensation. The control block that calculates the instantaneous power takes as inputs the phase – voltages at the point of common coupling (PCC) and the line currents of the nonlinear load that should be compensated. This means that the shunt active filter has a selective compensation characteristic.

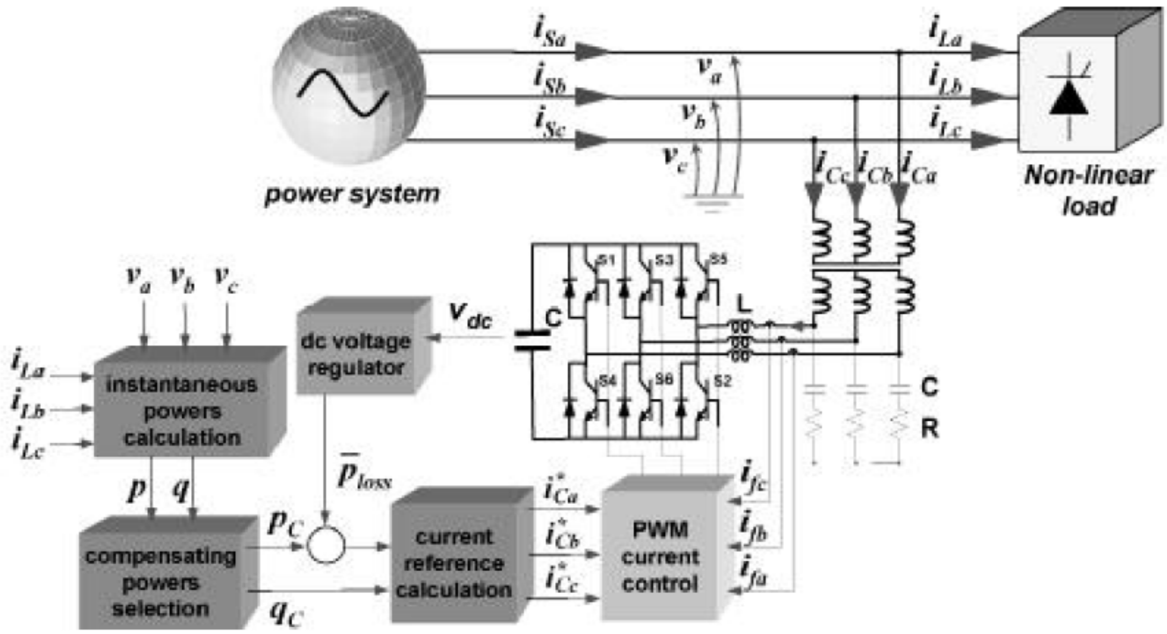

Figure 1.5 Three phase three wire shunt active filter

The active filter controller consists of four functional control blocks:

- Instantaneous power Calculation
- Power compensating selection
- DC Voltage Regulator
- Reference Current Calculation

1.8.1 **Active Filters for Constant Power Compensation**

The constant power compensation strategy for a shunt active filter was the first strategy developed based on the *p-q* Theory and was introduced by Akagi in 1983. The principles of this compensation method are described in Section 1.4. In terms of real and imaginary power, to draw a constant instantaneous power from the source, the shunt active filter should be installed as close as possible to the nonlinear load and should compensate the oscillating real power of this load. Note that a 3 – phase system without neutral wire is being considered so the zero-sequence power is zero.

To compensate the oscillating flow of energy, the dc capacitor of the PWM converter must be made large enough to behave as an energy storage element, so as not to experience large voltage variations. If the dc voltage gets lower than the amplitude of the ac voltage, this kind of PWM converter loses its controllability.

If the shunt active filter compensates the oscillating real and imaginary power of the load, it guarantees that only a constant real power (average power of the load) is drawn from the power system.

Therefore, the *constant instantaneous power control strategy* provides optimal compensation from a power flow point of view, even under non-sinusoidal or unbalanced system voltages. The Fig. 1.6 illustrates the idea in terms of "αβ wires" and the *p-q* Theory.

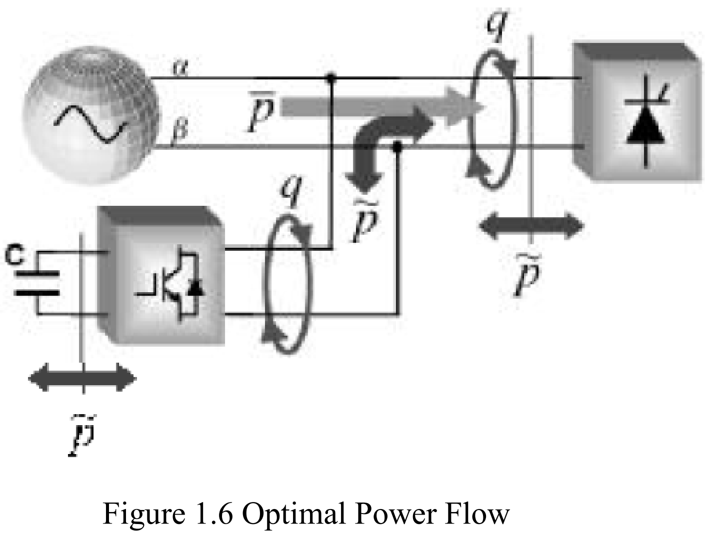

Figure 1.6 Optimal Power Flow

A DC voltage regulator should be added to the control strategy in a real implementation Fig. 1.4. So, a small amount of average real power must be drawn continuously. The power converter of the shunt active filter is a boost type converter. This means that the dc voltage must be kept higher than the peak value of the ac bus voltage.

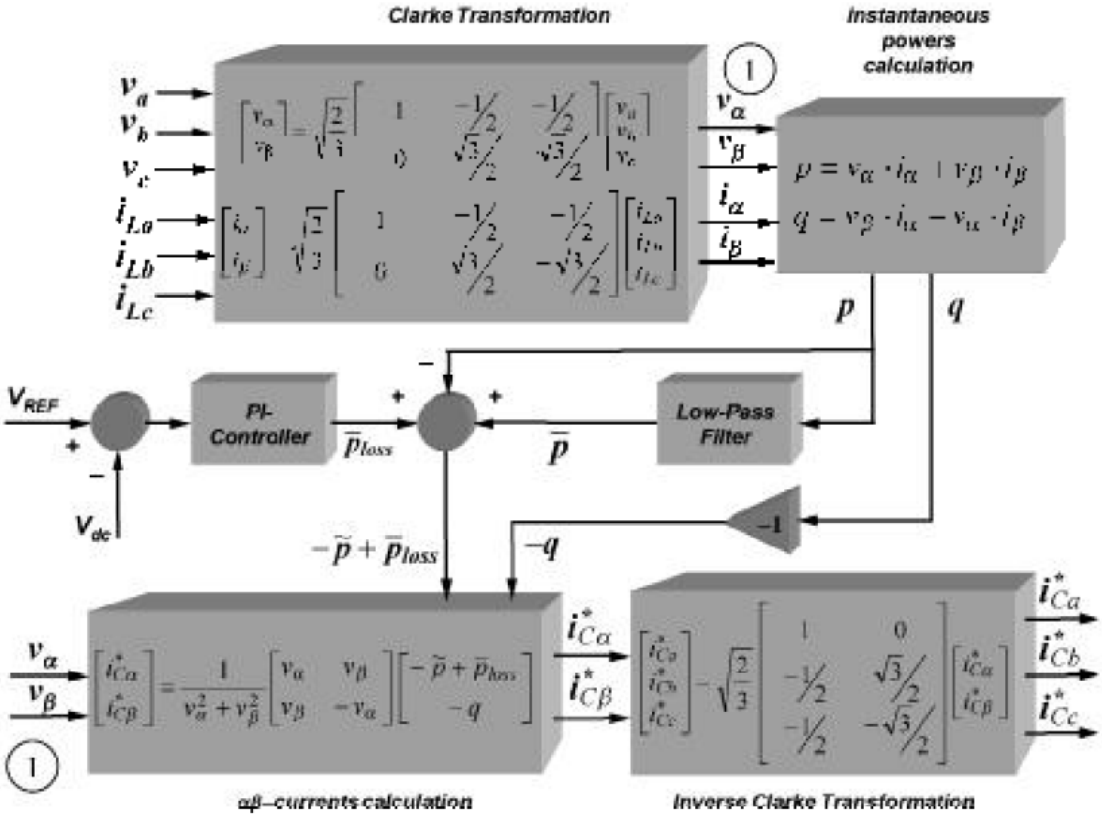

Figure 1.7 Control block for the constant instantaneous power control startegy

Here as a low pass filter is used for separation of oscillating and real part of the power there will be an unavoidable inherent delay in the calculation. So, in practice a 5th order Butterworth low pass filter with a cut off frequency between 20 and 100 Hz can be used for separation of average and oscillating power. The Fig. 1.7 summarizes the complete algorithm of a controller for a 3 phase, 3 wire shunt active filter that compensates the oscillating real power and the imaginary power of the load (constant instantaneous power control strategy).

1.9 Hysteresis Current Controller

As seen in above section the compensating current is calculated. Now this compensating current is a non-sinusoidal waveform. For the compensation this current needs to be drawn by the converter. So, for generating the gate pulses for the converter "Hysteresis Current Control" strategy is used.

By using the hysteresis – control, lower limit and an upper limit are created on either side of a signal representing the desired output waveform. The switches of the converter are operated as the signal generator within the limits. Hysteresis band PWM is originally an instant feedback control method of PWM. Here the actual signal will continuously track the command signal within the hysteresis band. In Fig. 1.8 the operation principle of the hysteresis band PWM for a half bridge inverter has been shown. The control circuit will generate a sine wave which is a reference signal wave with the required amplitude and frequency, and it is verified with the actual signal. If the signal goes beyond the hysteresis band, the upper switch in the half bridge is turn OFF and the lower switch is turned ON. This results in the output changes rapidly in time form +0.5Vdc to -0.5Vdc and the signal start to decay. If the signal crosses the lower limit, the lower switch is turned OFF and the upper switch turned ON.

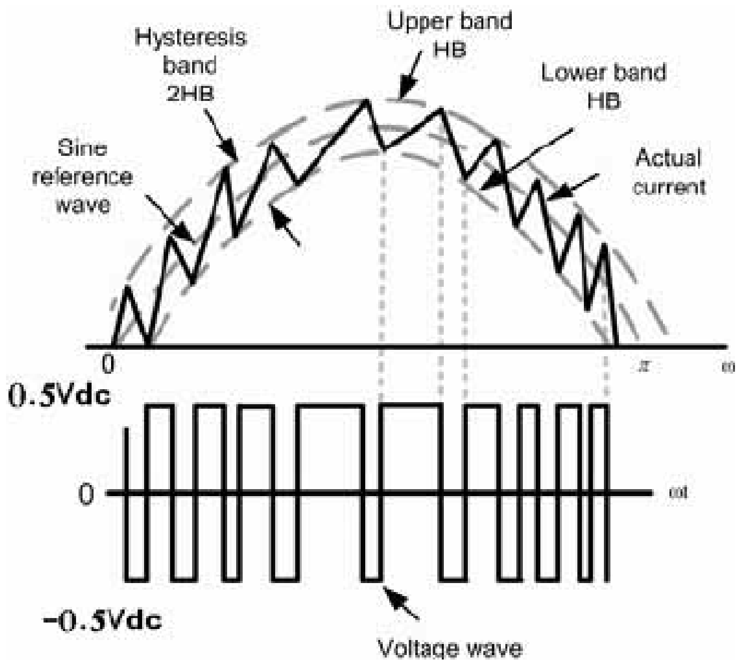

Figure 1.8 Hysteresis Current Control

2 Design Engineering Canvas

2.1 2.1 AEIOU

AEIOU Summary: Group ID: 9168 Domain Name: Power System Date: 04/09/18 Version: 1.0

Environment:	Interactions:	Objects:
Power Plants Sub station Simulation	Power Supply -- Consumers Industry -- Machines Power Plants -- Distributions Sub station -- Control Room	Machines Circuit Breakers Insulator Transformer Capacitor Bank Danger Plate

Activities:	Users:
Searching Visiting Sub station Simulation Observation Planning Group Discussion	Students Civilians Workers Engineers Industry Laboratory Hospital

Figure 2.1 AEIOU Canvas

- **Environment:**
  Our product is economical, it has capacity to eliminate all harmonic produced due to non-linear load. So, it is useful to get better power quality and it includes Power Plants, Substation, Simulation, Observation Planning and Group Discussion.

- **Interactions:**

  We interacted with
  - Power Supply – Consumers
  - Industry – Machines
  - Power Plants – Distributions
  - Substation – Control Room

- **Users:**
  Our product users are Students, Civilians, Workers, Engineers, Industry, Laboratory, Hospital etc.

- **Activities:**

For better understanding and working we are doing many activities like – Referred IEEE papers, reading books related to our project area, searching simulation, observation, planning, group discussion.

- **Objects:**

3-phase power supply, Non-linear load, Reactive power compensator, P-I controller and Low pass filter, Measurement devices, Machines Circuit Breakers Insulator Transformer Capacitor Bank Danger Plate.

2.2 Empathizing canvas

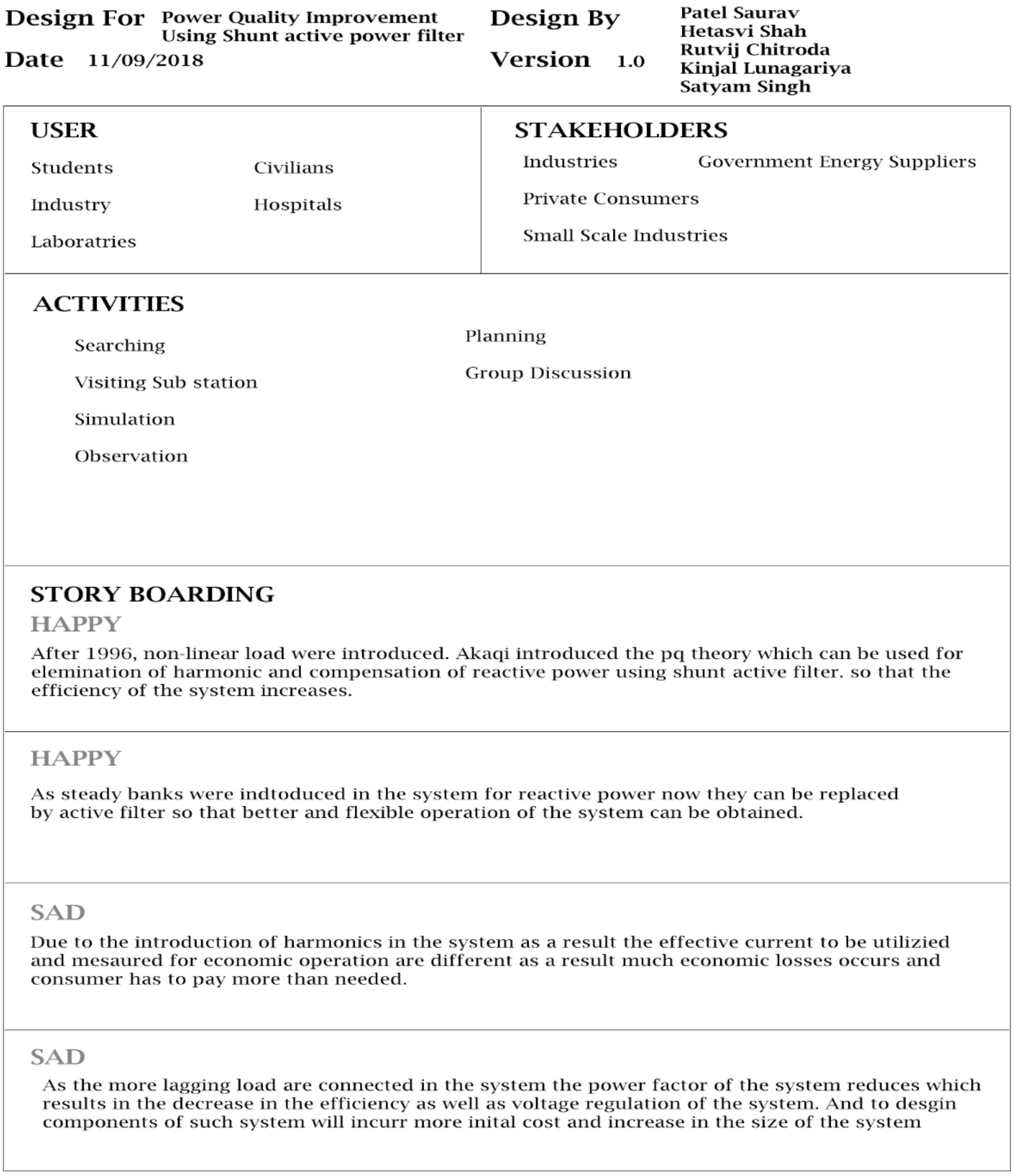

Figure 2.2 Empathizing Canvas

- **Users:**
  Our product user are engineers, Students, Industry, Laboratories, Civilians, Hospitals, technician, etc.

- **Stakeholder:**
  Stakeholder associated with our project are Industries, Private Consumers, Small Scale Industries, Government Energy Suppliers, Manufactures, etc.

- **Activities:**
  For better understanding and working we have done many activities like -Referred IEEE papers, reading books related to our project area, Searching, Simulation, Observation, Planning, Group Discussion etc.

2.3 Ideation Canvas

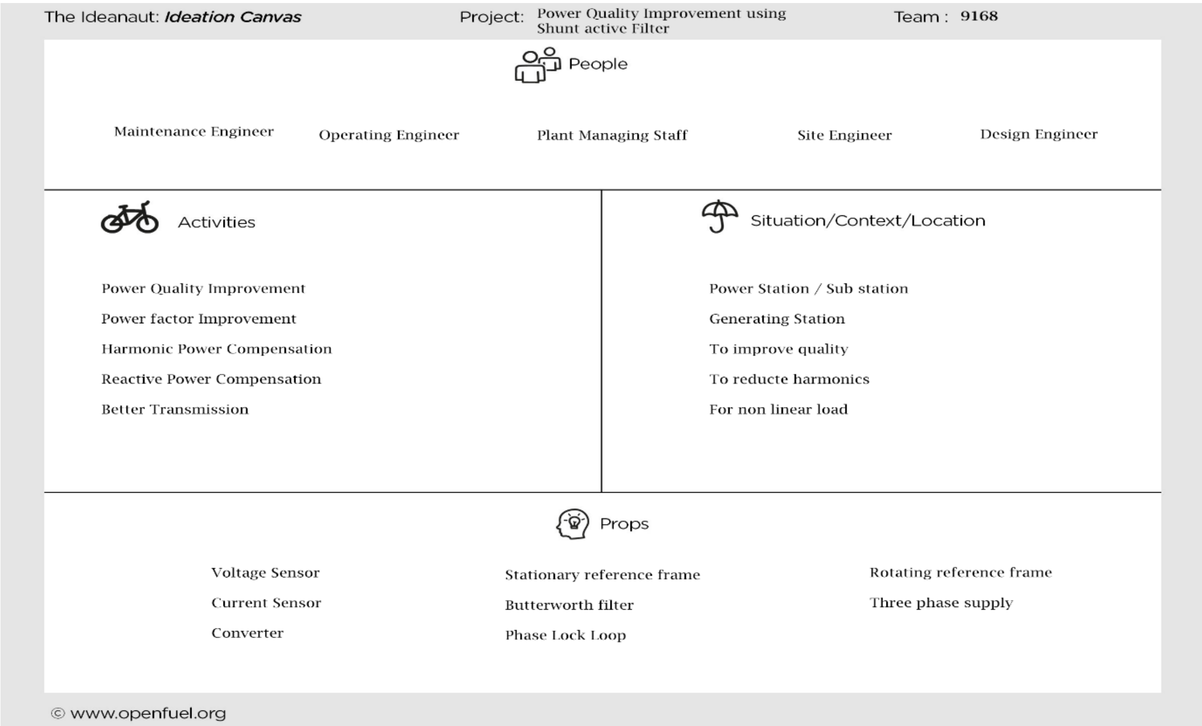

Figure 2.3 Ideation Canvas

Ideation canvas gives idea regarding the power quality improvement and it relates idea regarding people whose use this product, situation, activity relate to power quality improvement. For the long life of power system equipment’s and gives idea regarding improvement of efficiency of power system network.

- **People:**
  It is the list of people who are directly or indirectly connected with our project or area of power quality improvement. Those people are Engineers, manufactures of this type power quality equipment, technician etc.

- **Activities:**
  It gives information related to work that is going to be done by using Shunt Active Filter that are Power Quality Improvement, Power factor Improvement, Harmonic Power Compensation and Reactive Power Compensation Better Transmission.

- **Situation / Context / Location:**
  It gives idea in which environment product is going to be use i.e. we can use our product in industries where nonlinear load is connected in power system network. Context represents why we want to use this product and what is the advantage of using this product like in our case for improvement of power quality which degrades due to non-linear load connected in the industries. Location tell where we want to place our product like on transmission and distribution line, near to load, etc.

- **Props / Possible Solutions:**
  Listed below tools, theory is used in our project
  - Voltage Sensor
  - Current Sensor
  - Converter
  - Stationary reference frame
  - Butterworth filter
  - Phase Lock Loop
  - Rotating reference frame

2.4 Product Development Canvas

- **Purpose:**
  The purpose of our product is to avoid harmonics, Voltage fluctuation, harmonic filtering, power factor correction, Power quality improvement.

- **Product Experience:**
  It includes the experience of the product like reliability, longer life of system, Better power supply, Reduce electricity bill etc.

- **Product Functions:**
  Power Quality improvement, for stable system, Reduction of Harmonics.

- **Product Features:**
  Feature of our project are better power quality, Efficient, Less loss.

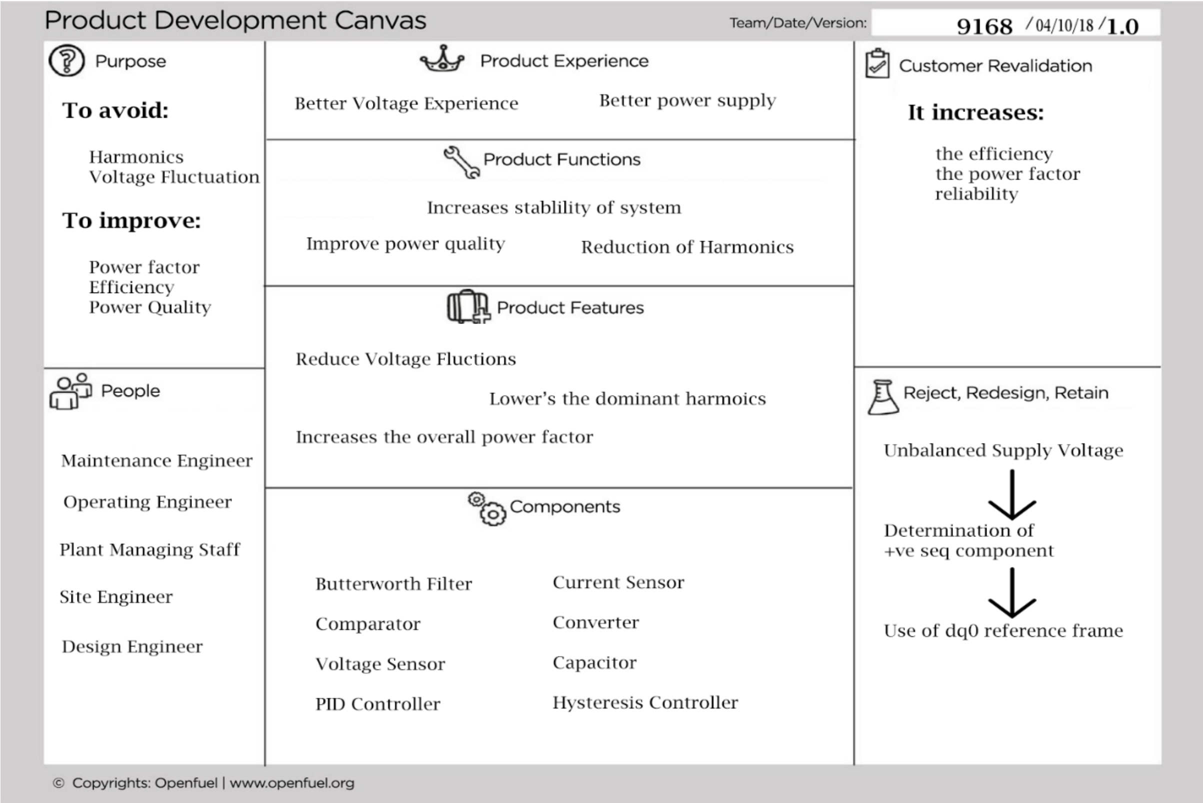

Figure 2.4 Product Development Canvas

- **Components:**
  P-I controller, Low pass filter, Reactive power compensator, Measurement devices, Butterworth Filter Comparator Voltage & Current Sensor Converter etc.

- **Customer Revalidation:**
  It increases the efficiency, the power factor, reliability of the system.

- **Reject / Redesign / Retain:**
  We try to avoid Unbalanced Supply Voltage, Determination of Positive sequence component, Use of dq0 reference frame.

2.5 Business Model Canvas

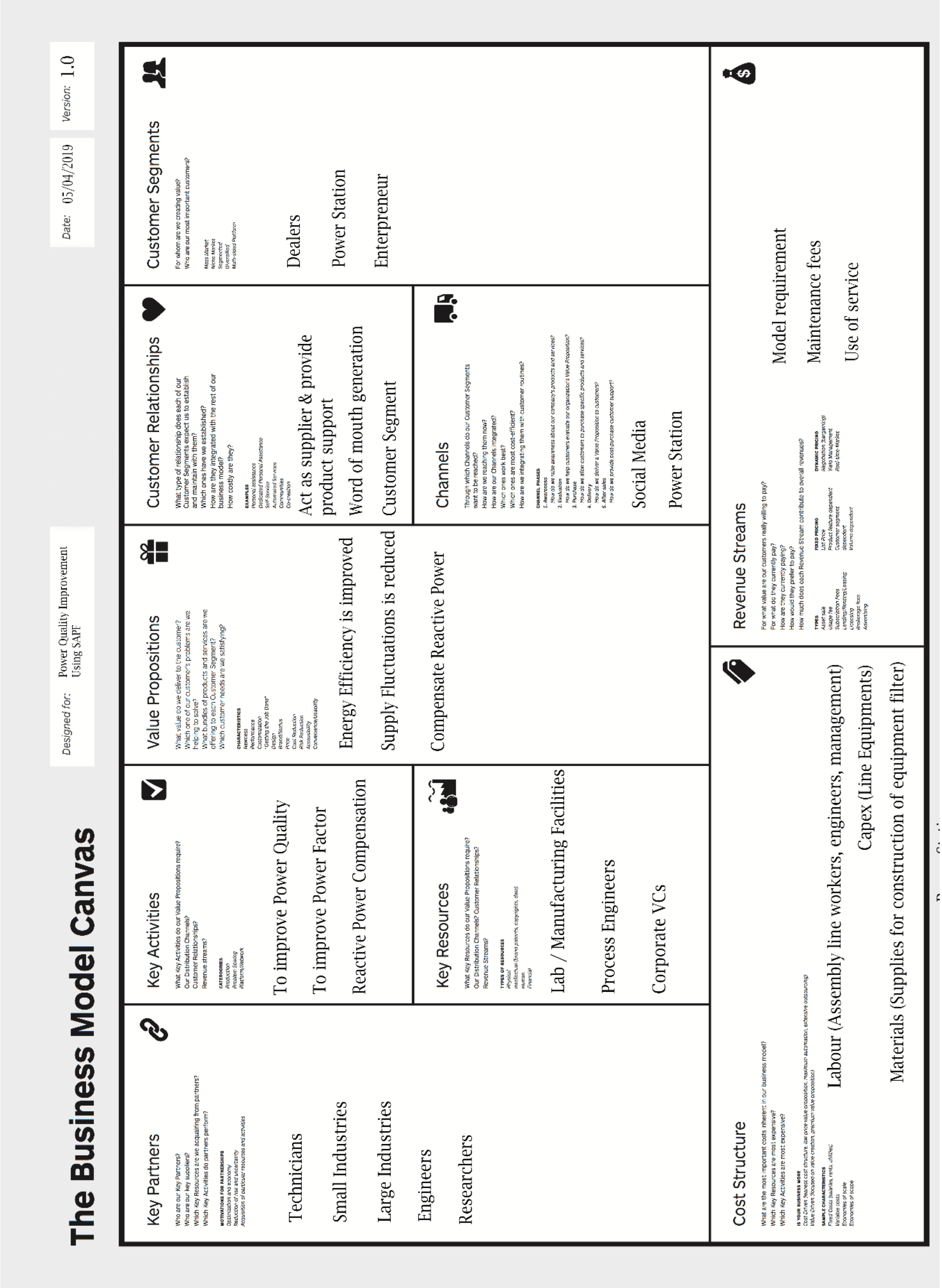

Figure 2.5 Business Model Canvas

3 MATLAB-Implementation

Here MATLAB / SIMULINK is used to implement the above discussed strategy for harmonic elimination of Shunt Active Power Filter.

- **Simulation Parameters**

Parameters	**Value**	**Symbol**
Supply Voltage	110 V	Vabc
Supply Frequency	50 Hz	F
DC Link Capacitor Voltage	300 V	Vdc
DC Link Capacitance	2350 μF	C
Filter Inductor	2.5 mH	L
Capacitor Ref. Voltage	300 V	Vdc_ref
Load (Rectifier)	90 Ω	Load

Table 3.1 Simulation Paramenters

3.1 Circuit Diagram:

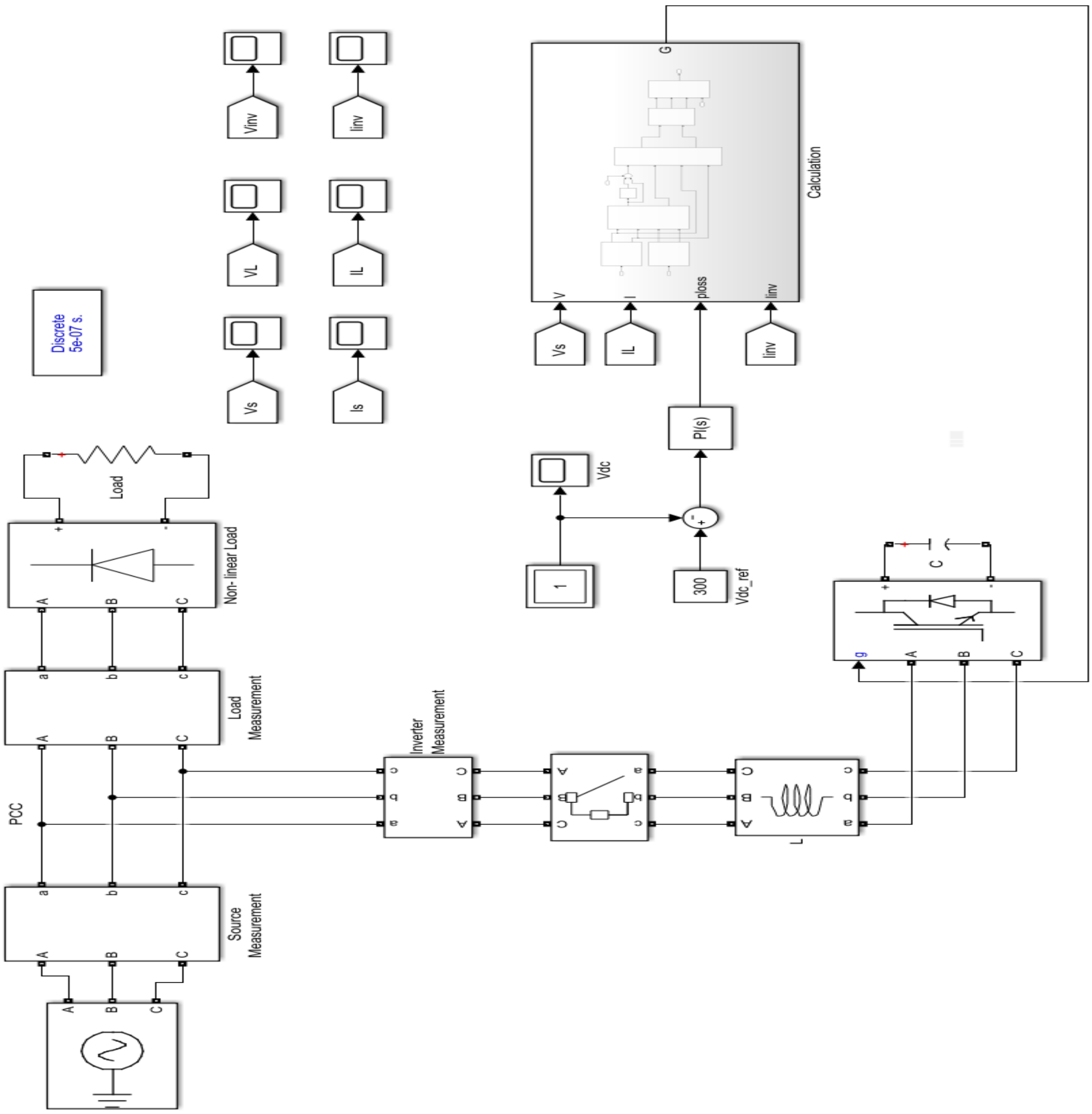

Figure 3.1 Circuit Diagram (MATLAB)

3.2 Control Block for Constant Instantaneous Power Control Strategy

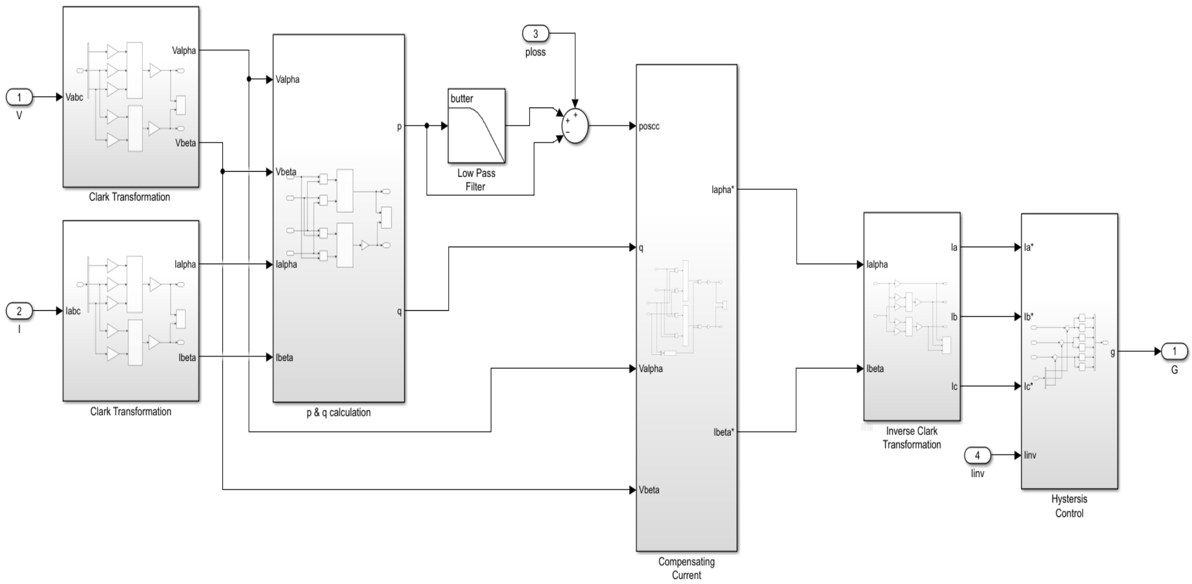

Figure 3.2 Control Block

3.3 Waveforms

- **Source Current Before Compensation**

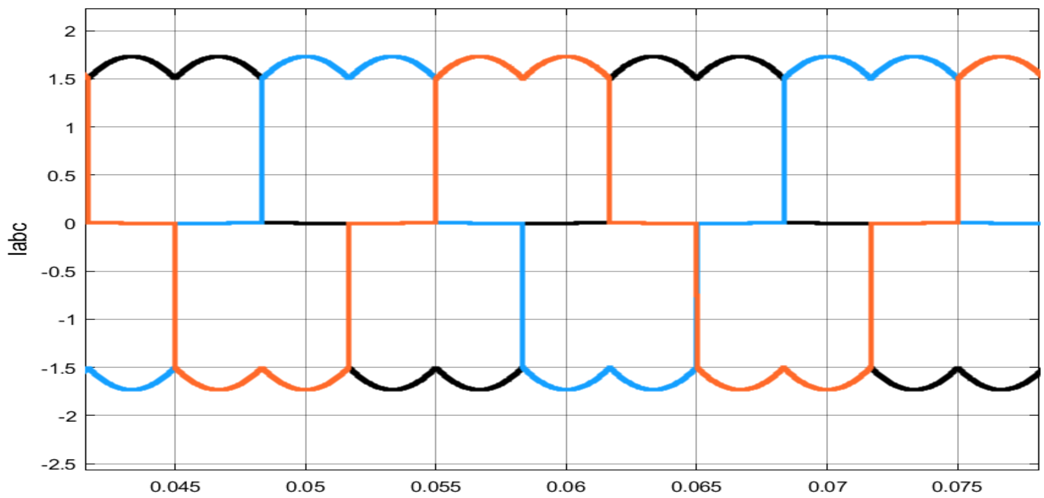

Figure 3.3 Load Current

- **Calculated Compensated Current for phase A**

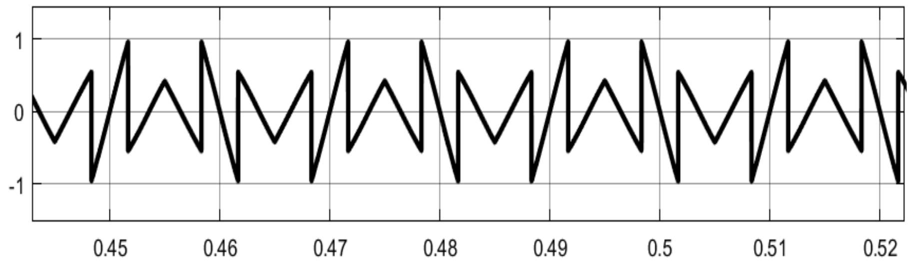

Figure 3.4 Compensated Current

- **Capacitor Voltage**

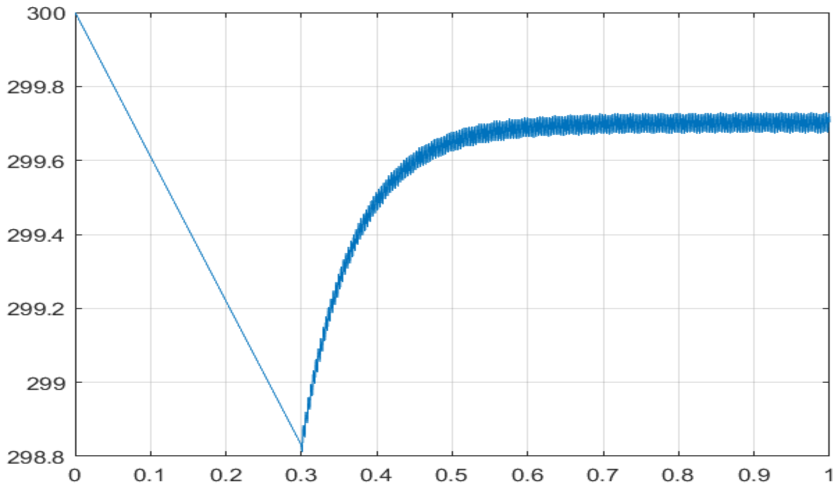

Figure 3.5 Capacitor Voltage

- **Source Current After Compensation**

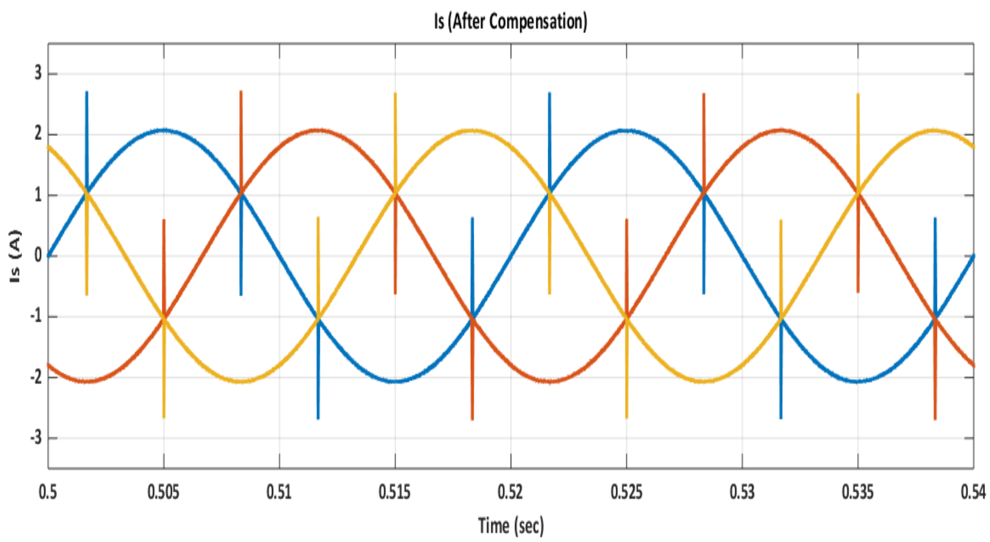

Figure 3.6 Source Current (After Compensation)

- **THD in supply Current** (before compensation)

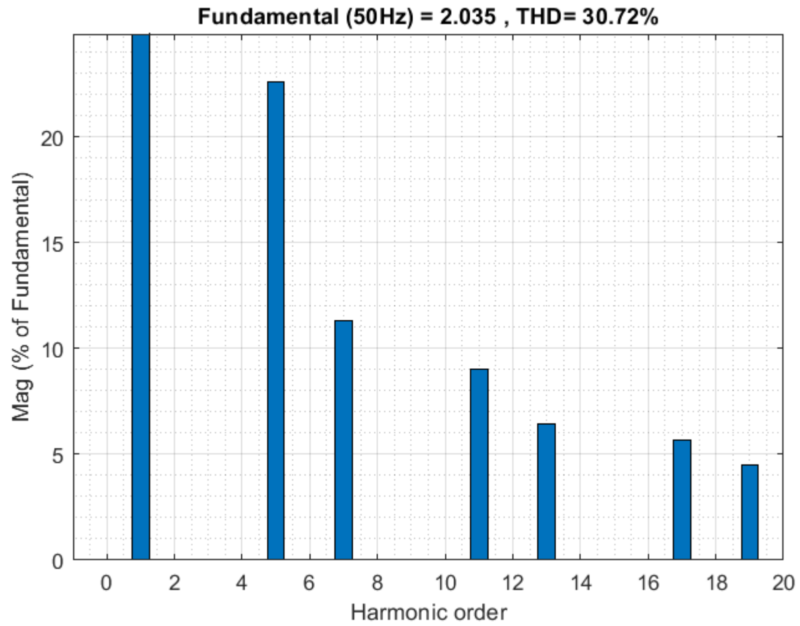

Figure 3.7 THD Before Compensation

- **THD in supply Current** (after compensation)

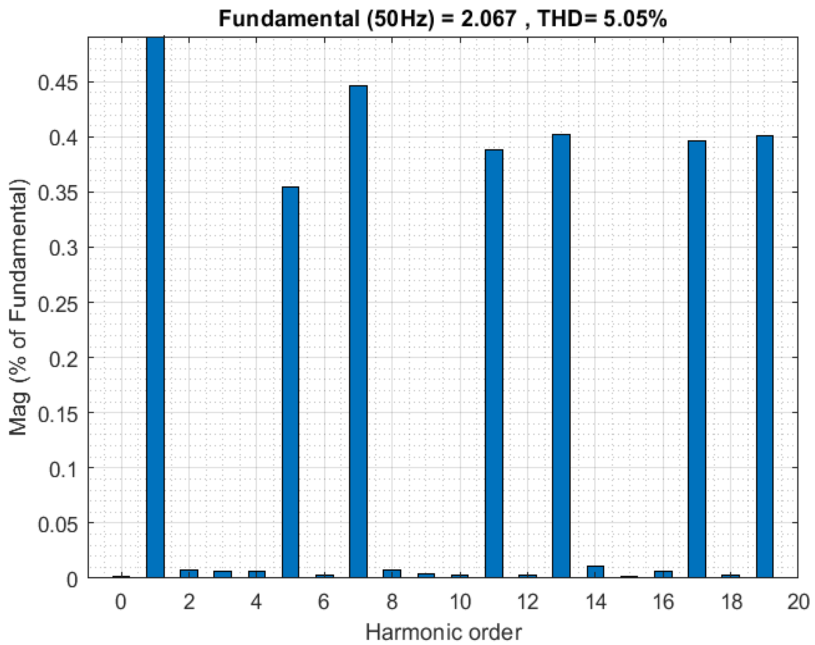

Figure 3.8 THD After Compensation

4 Hardware Set up

4.1 An Overview of Set up

The overall block diagram of the hardware set up for compensating the harmonic current, produced due to the presence of non linear load, by Shunt Active Power Filter (SAPF) as shown in Fig .3.1. To implement the control algorithm in real time, we have used dSPACE 120, which interfaces the hardware part with the host computer. It is a popular DSP in which code can be dumped using the Simulink model.

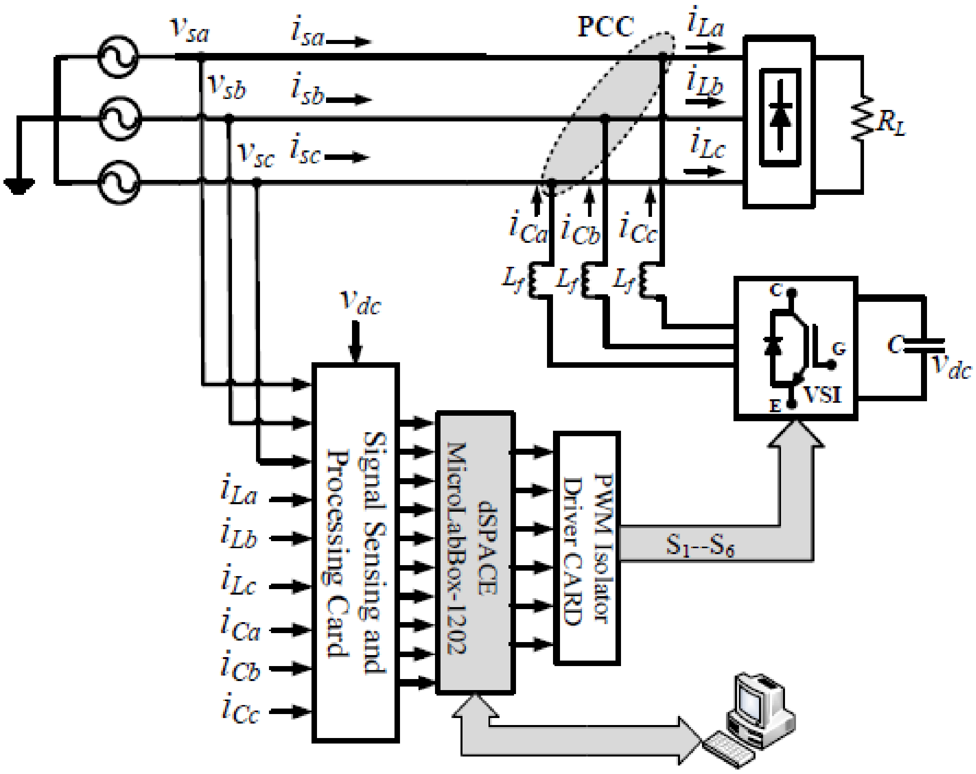

Figure 4.1 Block Diagram of Hardware Set up

The three phase power quantities (voltage and current) which are required for generation of the gate signal are converted to low-level voltage signals using voltage and current sensors. These signals are then given to the ADC on the dSPACE 1202 (MicroLab Box). The control algorithm developed in Simulink is dumped (built) into the dSPACE 1202 using ‘Control Desk’. Using the signal given to its ADCs as input signal, dSPACE 1202 generates the required switching pulses for the VSI. These pulses are taken from the PWM ports on the dSPACE 1202, which are then passed to the PWM Isolator card so that the VSI can be fired.

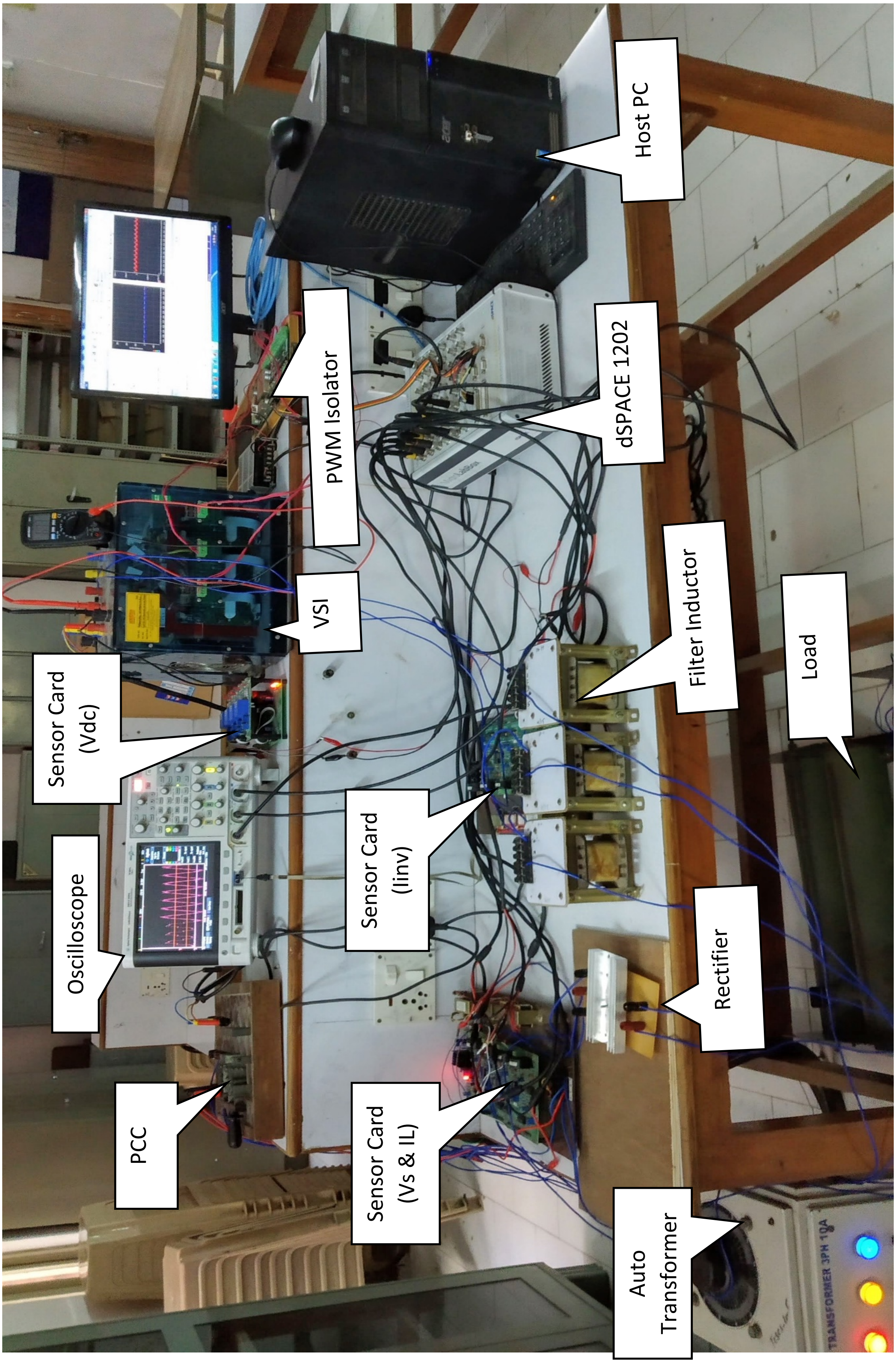

Figure 4.2 Hardware Setup

The major components used for the hardware setup are given as follows:

- Auto Transformer
- Non - linear Load
- Voltage Source Inverter
- Filter Inductors
- dSPACE 1202
- Current and Voltage Sensor Circuit
- Opto Isolation Circuit

The design details of the above-mentioned components are provided below

4.2 Auto Transformer

A continuously variable three phase auto-transformer has been used which act as variable voltage source, by which we can change the voltage level and so that the compensating characteristic of the SAPF can be tested at various voltage range. The three phase auto-transformer has a maximum Current capacity of 10 A per phase and voltage range of 0-230V.

The nominal voltage level for the operation of this circuit is chosen to be 110 V per phase. With maximum current of 5A.

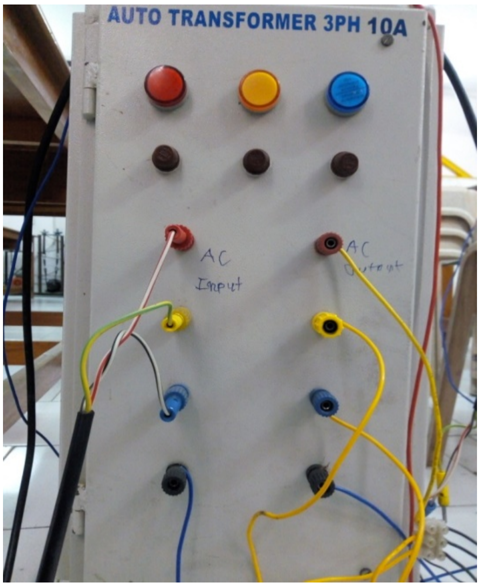

Figure 4.3 Auto Transformer

4.3 Nonlinear Load

We have used a full bridge diode rectifier having current capacity of 35 A, with a R load on DC Side, for generation of non-sinusoidal current from the supply. The R load chosen has a maximum current capacity of 12 A.

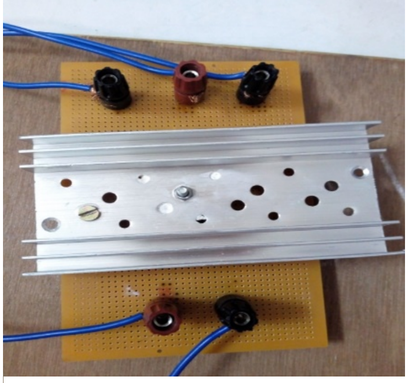

Figure 4.4 Full bridge Rectifier

4.4 Voltage Source Inverter (VSI)

A Semikron made 3-Phase IGBT based voltage source inverter has been used as shown in Figure 3.5. It has 415 V max. AC output voltage and 35 A max. AC output current with a frequency of 50 Hz. It has a max. Switching frequency of 25 kHz. On the DC side 2 capacitors are connected in series which has a equivalent capacitance of 2350 μF/900 V. The voltage source inverter generates the required compensating current by using the gate signal generated by the control algorithm.

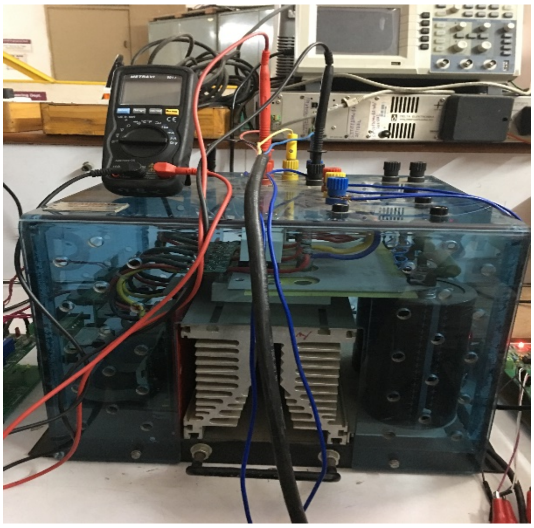

Figure 4.5 VSI

4.5 Filter Inductor

The filter inductors L_f are connected in the AC side of the VSI. Small value L_f may inject larger switching ripples into the supply current, while a larger value of L_f would cause poor tracking of the compensating current. An optimum value of L_f is necessary to obtain better compensation. We have used variable inductors as shown in Figure 3.6, so that optimum value of L_f is chosen according to voltage and current level. The variable inductor has inductance range is 0-5 mH with 5 tapping to vary the inductance value.

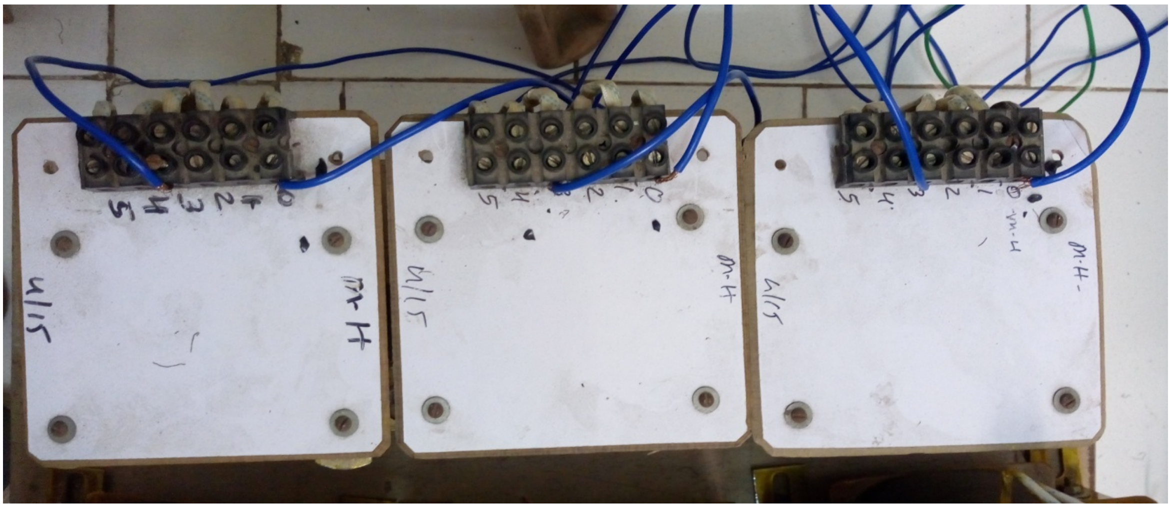

Figure 4.6 Filter Inductor

4.6 dSPACE 1202

MicroLab Box, top panel variant with BNC connectors i.e. dSPACE 1202 is used for the generation of the gate pulses for the VSI. dSPACE is a hardware interface which takes real time signals at the input channels and then give these real time signals to the connected computer at fix sampling time. It also gives real time signals at the output channels. To convert the real time signals into digital signal, it is having ADCs inbuilt at its input channels. To convert the digital signals coming out from the computer, it uses DAC which is inbuilt at its output channels.

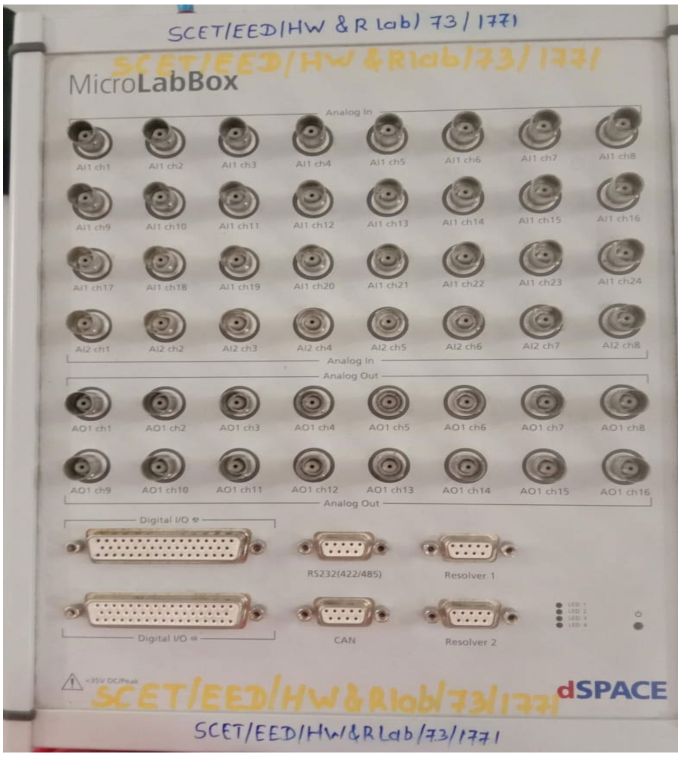

Figure 4.7 MicroLab Box

Thus, it is possible for the user to view the real process while the experiment is in progress. Control Desk developer version 3.5, dSPACE’s experiment software, provides all the functions to control, monitor and automate experiments and makes the development of controllers more effective.

4.7 Voltage and Current sensor

The sensor card is used for sensing the required quantitates from the real time environment so that it can be given to the ADC of the dSPACE. The sensor cards used has combine capabilities of sensing the voltage and current if connected for. Mainly two adjustments are given for varying the output of the sensor, i.e. gain and offset.

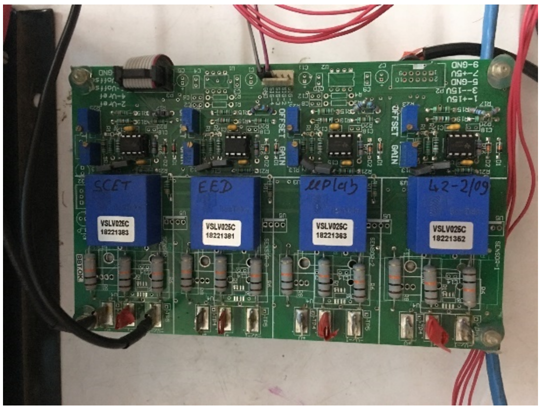
Figure 4.8 Hall Effect Sensor

The gain of both sensor cards are set for voltage and current so that they can be safely given to the ADC of the MicroLab box.

We have also used a Hall Effect sensor for the measurement of the DC capacitor voltage.

This sensor provides isolation of the power and control circuit and acts as the input to the control block so the required computation can be done in real time.

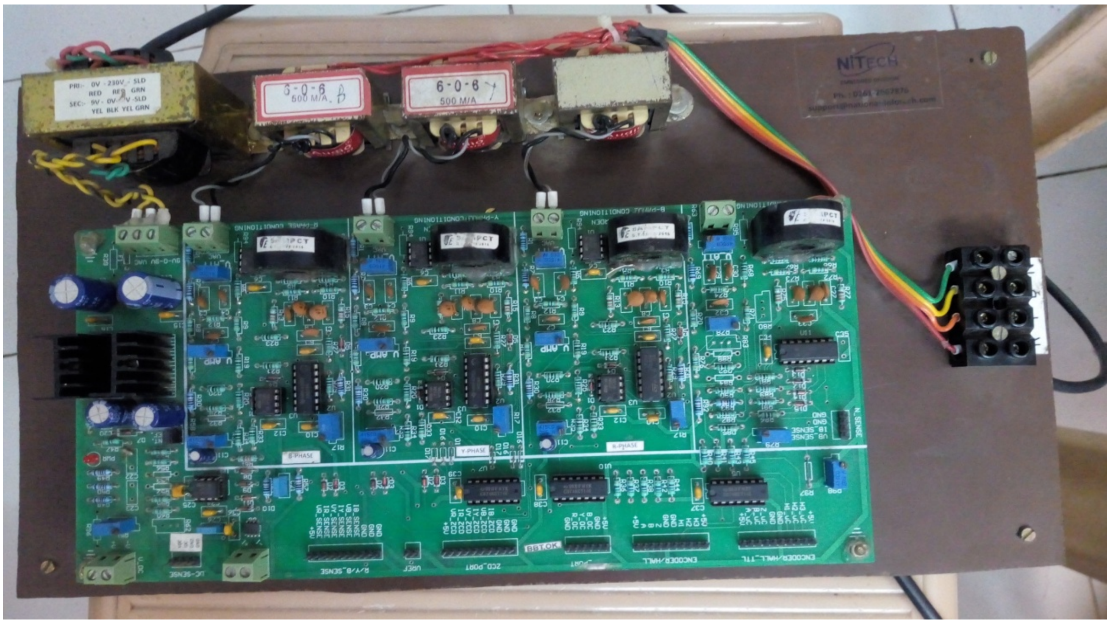

Figure 4.9 Sensor card

4.8 Opto Isolator card

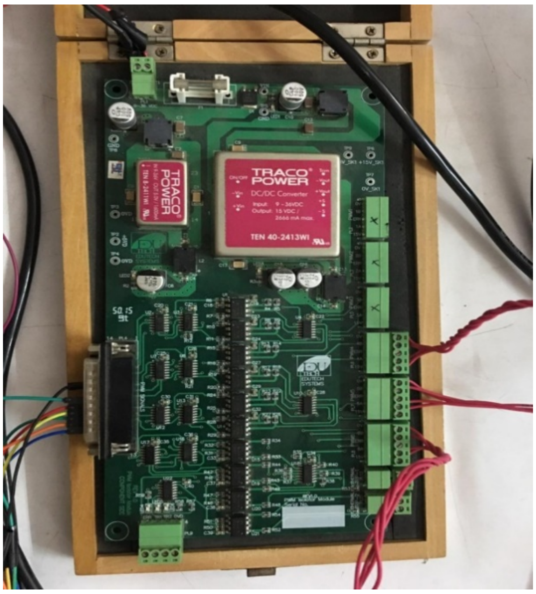

Figure 4.10 PWM Isolator

The PWM Signals generated form the dSPACE are at 2.5 V. So for firing the VSI from this gate pulses opto Isolator card is used. Which amplifies the gate pulses voltage level to the required threshold so that the IGBT’s can be fired in the VSI.

It also serves as an isolator for the power and control circuit.

PIN no. 7 to 12 are used in the input given by the MicroLab Box. The output pluses are then given to the VSI.

4.9 Hardware Results

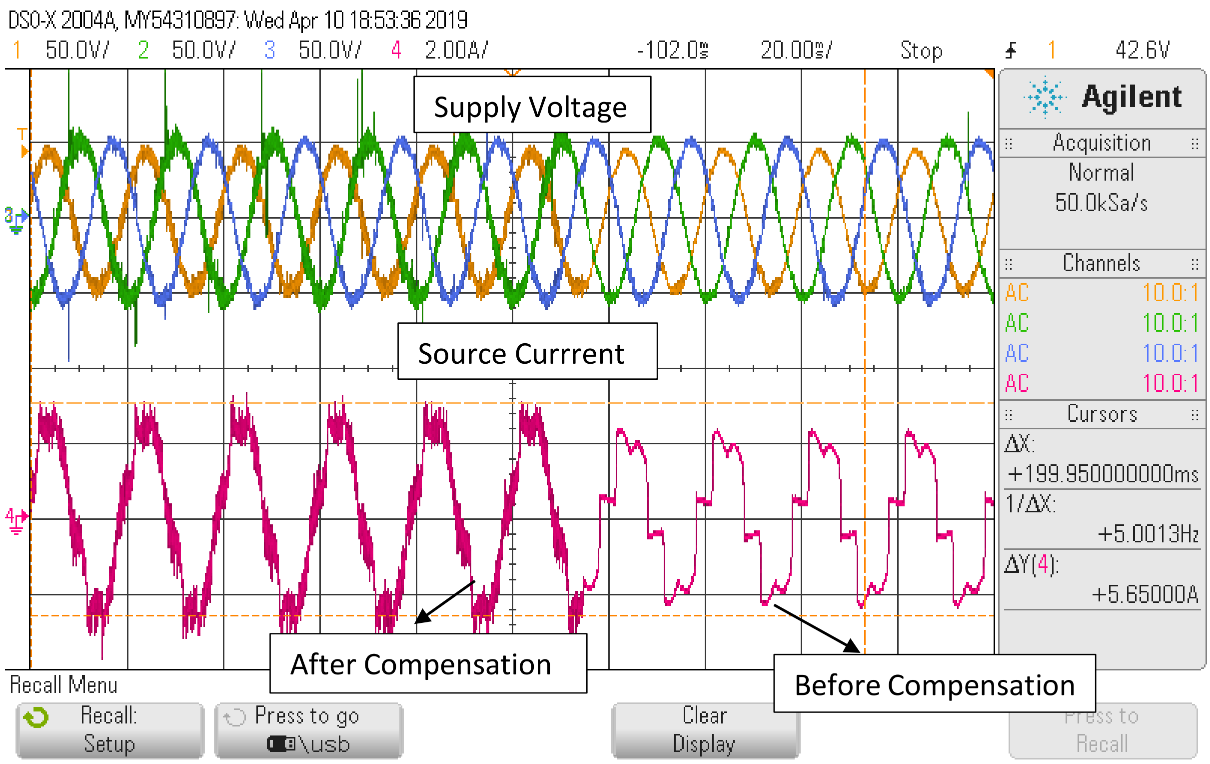

Figure 4.11 Compensating Current

- Control Desk Results

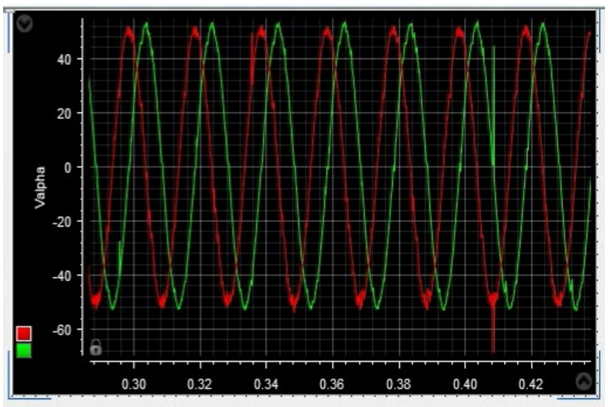

Figure 4.12 V_alpha & V_beta

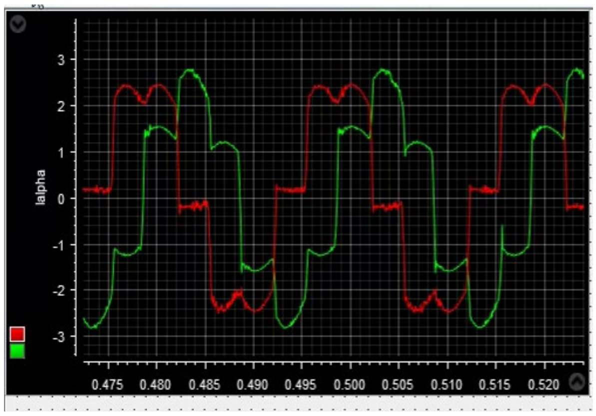

Figure 4.13 I_alpha & I_beta

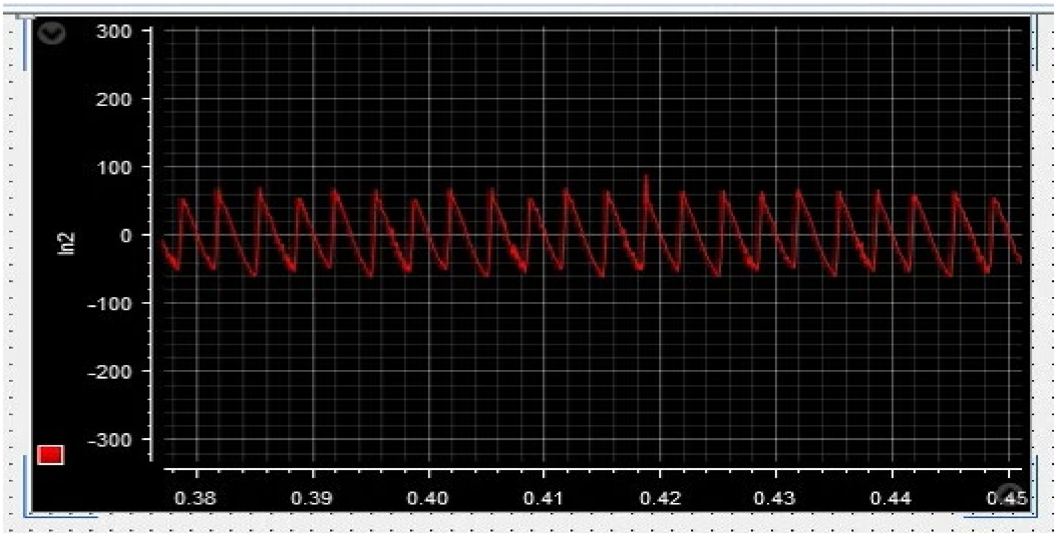

Figure 4.14 q (vari)

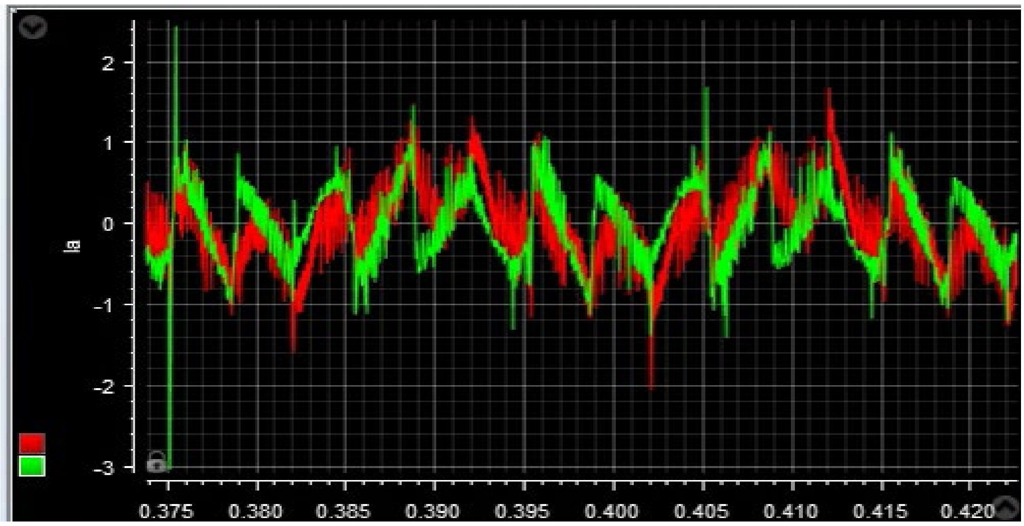

Figure 4.15 I_calc & I_inv

5 Summary

The project represents one of the basic power definition ***p-q*** **Theory** and its usefulness and in designing the control strategy for the calculation of compensating current for the nonlinear load. Also, the operation of SAPF for the 3 phase 3 wire system under balanced load condition are simulated using MATLAB / SIMULINK.

PID control for maintaining the DC link voltage at the SAPF end is employed so that controllability of the system is maintained. The generation of gate pulses of converter for compensating current is done by using the Hysteresis Current Controller. The entire MATLAB model is presented in Chapter 2 and the THD of the load is considerably reduced to the desired limit.

Chapter 3 describes the hardware implementation along with the result for the lower value of voltage. With the necessary required components for the implementation of control strategy.

5.1 Usefulness with respect to existing Solutions

- The reactive compensator used in the SAPF are much smaller than the those in the SVC.
- The characteristics of SAPF are superior.
- The output current of SAPF can be controlled up to the rated maximum capacitor or Inductive range.
- Reduction of the capacity of semiconductor power converter and capacitor Bank to one half of those for the convectional SVC.
- Better transient response of the order of quarter cycle.
- Reduction of harmonic filter capacity.
- Reduction of size of high value air-cored reactor.
- Reduction of equipment volume and foot-print.

5.2 Future Scope

We have implemented one of many control strategies of controlling the SAPF so the new control strategies for the compensation, including the other conditions in the power system such as 4 wire balanced and unbalanced system. So that the effect of various conditions and a comparative study can be done among the various control methodologies.

With the same hardware we can implement we can compare different control strategies used in the shunt active filter for different conditions. So that a comparative analysis can be obtained.

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