# Chapter 5

# Experimental verification

## 5.1 Introduction

The objective of the conducted experiment is to verify the 12 pulse converter operation under equal and unequal firing angle of mode to get constant active and constant reactive power operation. The converter has been developed and been operated under both mode. The Hybrid Active Filter is incorporated for harmonic elimination.

## 5.2 Experimental System

Three Phase supply is applied to 12 pulse converter which consists of two six pulse converter connected in series through star star and star delta transformer. The firing angle of individual converter can be controlled and output is connected in series. The 12 pulse converter is considered as a load for Hybrid Active Filter. The control algorithm for hybrid active filter using P Q Theory has been implemented using DSP processor.

## 5.3 Results for 12 pulse converter

Figure 5.1 shows the power circuit diagram of 12 pulse converter consists of two six pulse converter connected in series through star-star and star-delta converter.

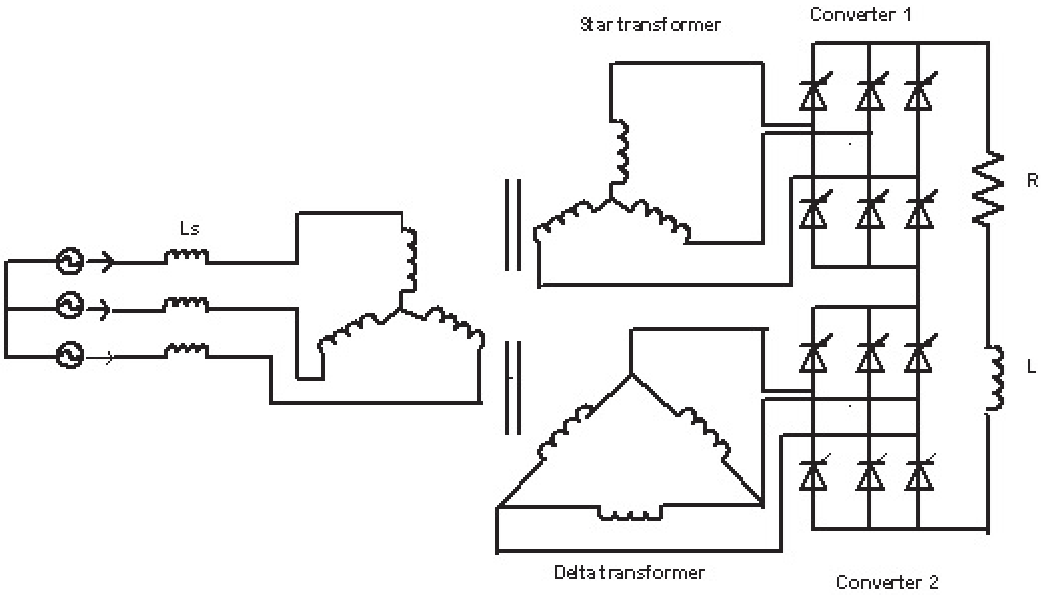


Figure 5.1: Power circuit diagram for 12 pulse converter

### 5.3.1 Power circuit diagram for 12 pulse converter

The converter 1 is operated individually and waveform for load voltage and supply current for different firing angle is shown in figure 5.2. The supply current waveform is matching with the simulation results discussed in chapter 2.

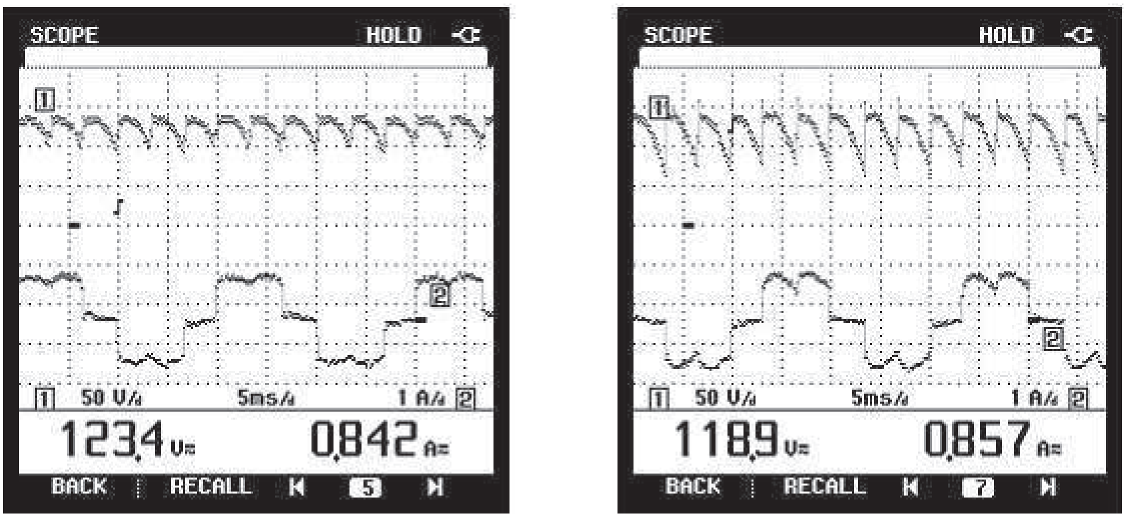


Figure 5.2: Six pulse converter star  star connected

### 5.3.2 Results of Six pulse Star Delta connected converter 2

The converter 2 is operated individually and waveform for load voltage and supply current for different firing angle is shown in figure 5.3. The supply current waveform is matching with the simulation results discussed in chapter 2.

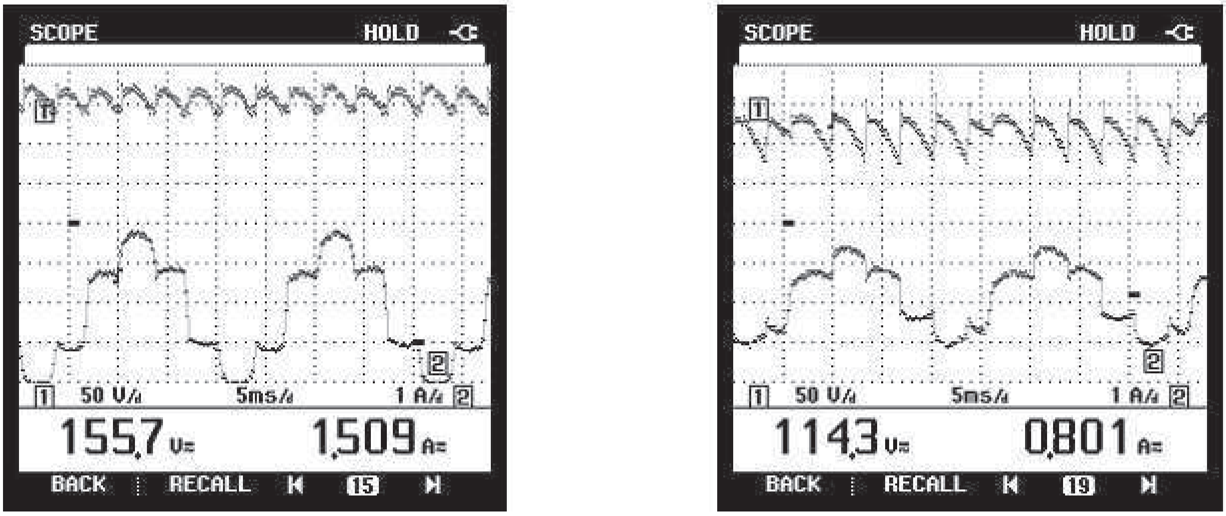


Figure 5.3: Six pulse converter star- delta connected

### 5.3.3 Results of 12 pulse converter for equal firing angle

Both converter 1 and converter 2 are connected in series through star-star and star-delta transformer and results are obtained for different equal firing angle as shown in figure 5.4. The experimental results is matching with the simulation results. Figure 5.4 shows output voltage and supply current waveform for RL load. The %THD observed is about 15% for equal firing angle mode.

### 5.3.4 Results of 12 pulse converter for equal firing angle

Both converter 1 and converter 2 are connected in series through star-star and star-delta transformer and results are obtained for different combination of unequal firing angle as shown in figure 5.5. The experimental results is matching with the simulation results. Figure 5.5 shows output voltage and supply current waveform for RL load. The %THD observed is about 30% for unequal firing angle mode.

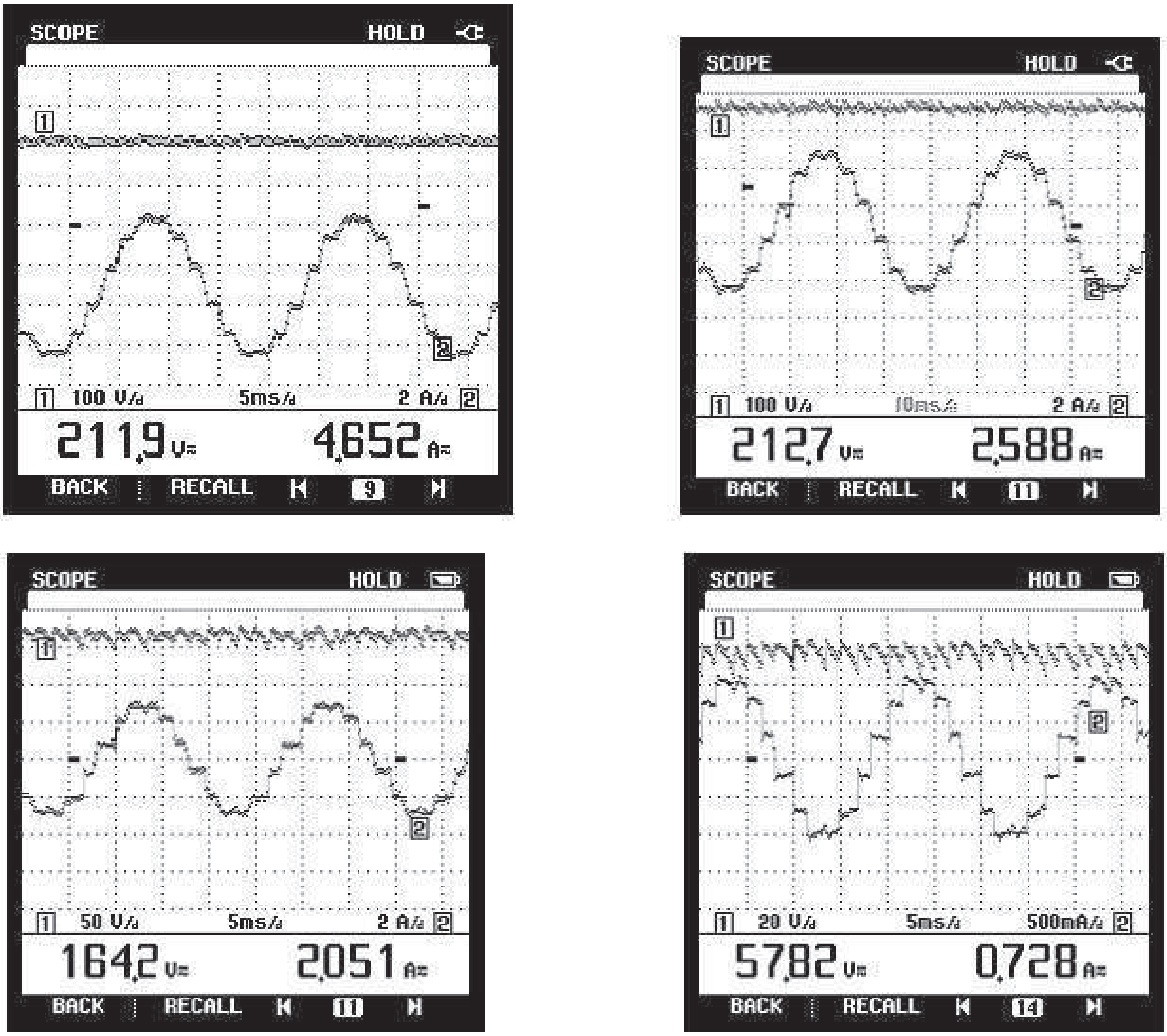


Figure 5.4: Equal firing angle mode

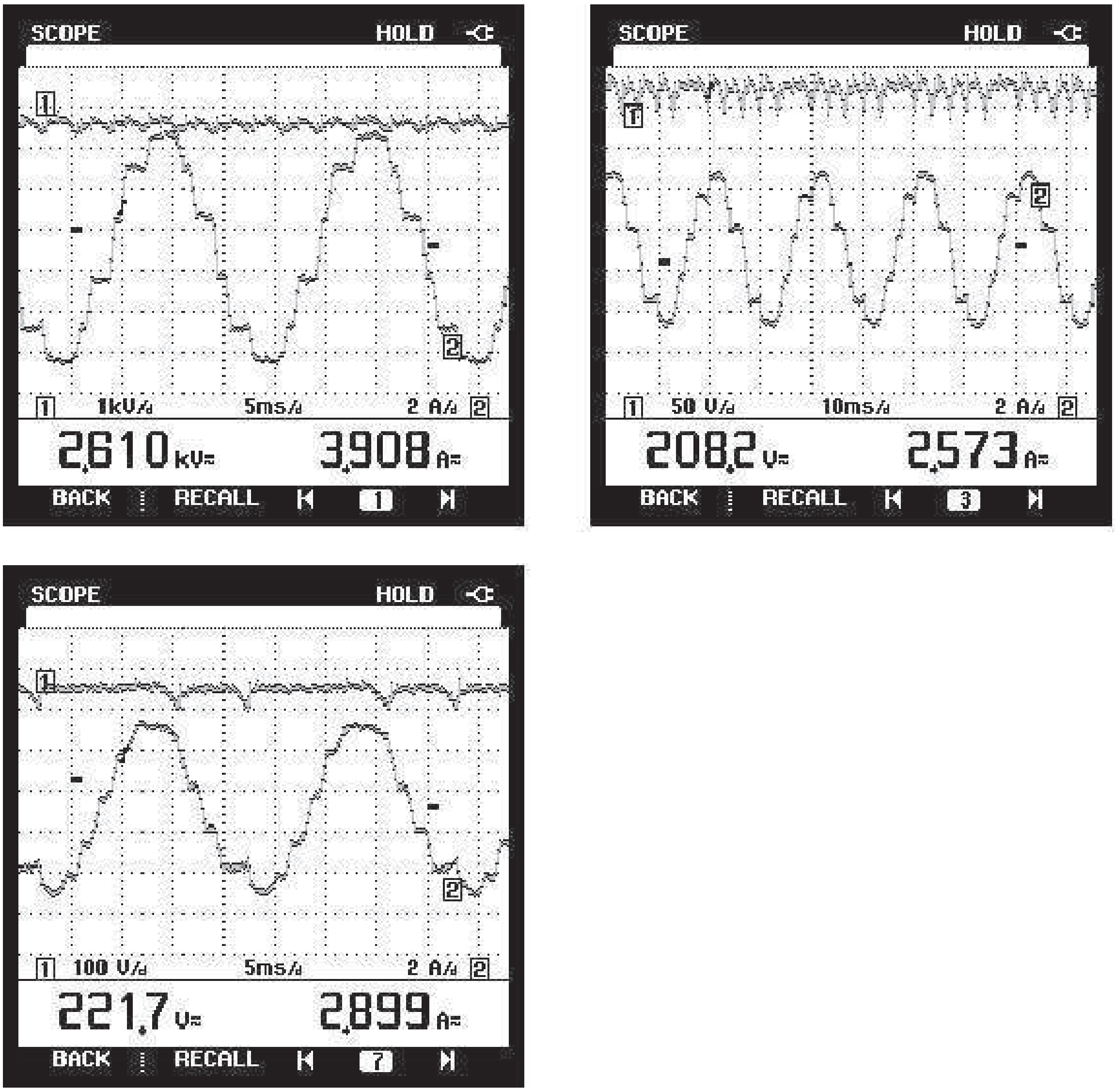


Figure 5.5: Unequal firing angle mode

## 5.4 Introduction of DSP Processor:

Since DSPs are used for processing continuous signals that come from and often go back into, the real world, they are constrained to operate in real time. This constraint is another key difference between DSPs and other microprocessors, not only in the application, but also in underlying architecture.

TMS320C2000 digital signal controller platform combines the control peripheral integration and ease of use of microcontroller and processing power and C efficiency (Texas Instruments, 2008). C2000 digital signal processors are well suited for industrial applications such as digital motor control, digital power supplies and intelligent sensor applications.

Digital control of power conversion systems results in lower overall cost due to the consolidation of functions into a single programmable controller in place of dedicated discrete components. A single C2000 digital signal processor can provide full loop control at over 2 MHz switching frequencies or control multiple output levels and simplify the sequencing of multiple supplies through software rather than dedicated components. A software based solution enables intelligent monitoring of load conditions in real time and can lead to system reliability, efficiency and operating cost. C2000 DSP controllers are suitable for applications such as uninterrupted power supplies, solar inverters and industrial equipments (Texas Instruments, 2008). TMS320F2812 kit is used in the implementation of Instantaneous Reactive Power Theory.

## 5.5 TMS320F2812 Digital Signal Processor Kit

1. Based on TMS320LF2812 DSP processor.
2. 256KW external memory.
3. Battery backup for on-board RAM
4. 16*2 LCD display stand alone operation
5. On board IBM at keyboard interface.
6. Built in 230V AC at 50HZ SMPS power supply.

7. Connection provision for ADC inputs and PWM outputs.
8. On chip serial port interface.
9. Dual channel DAC with 12 bit resolution.
10. Isolated serial port.
11. 16 bit digital output lines

The F2812 ezDSP is a standalone card allowing evaluators to examine the TMS320F2812 DSP to determine if it meets their application requirements. Furthermore, the module is an excellent platform to develop and run software for the TMS320F2812 processor. The F2812 DSP is shipped with a TMS320F2812 DSP. The F2812 DSP allows full speed verification of F2812 code. Two expansion connectors are provided for any necessary evaluation circuitry. To simplify code development and shorten debugg time, a C2000 Tools Code Composer driver is provided. In addition, an on-board JTAG connector provides interface to emulators, operating with other debuggers to provide assembly language and C high level language debugger (Spectrum Digital, 2003). Figure 5.6 shows the F2812 ezDSP kit.

The Central Processing Unit (CPU) is the core of the DSP. This core offers single cycle 32x32 bit multiply and accumulate (MAC) operations or dual 16x16 bit MAC. Its the atomic Arithmetic Logic Unit is capable of single cycle read- modify-write operations. The DSP core has three 32 bit timers. The memory subsystem offers 100-120 million instruction per second (MIPs) speed and 150 MIPs for time critical operations. The DSP has two Event Managers, 12 bit, 16 channels Analog to Digital Converter (ADC).

## 5.6 Flow chart of the Instantaneous Reactive Power Theory

The Instantaneous Reactive Power Theory described in section 4. 22 is implemented using MATLAB as shown in Figure 5.7. The supply voltage and supply current is fed to the Analog To Digital converter and used for algorithms.

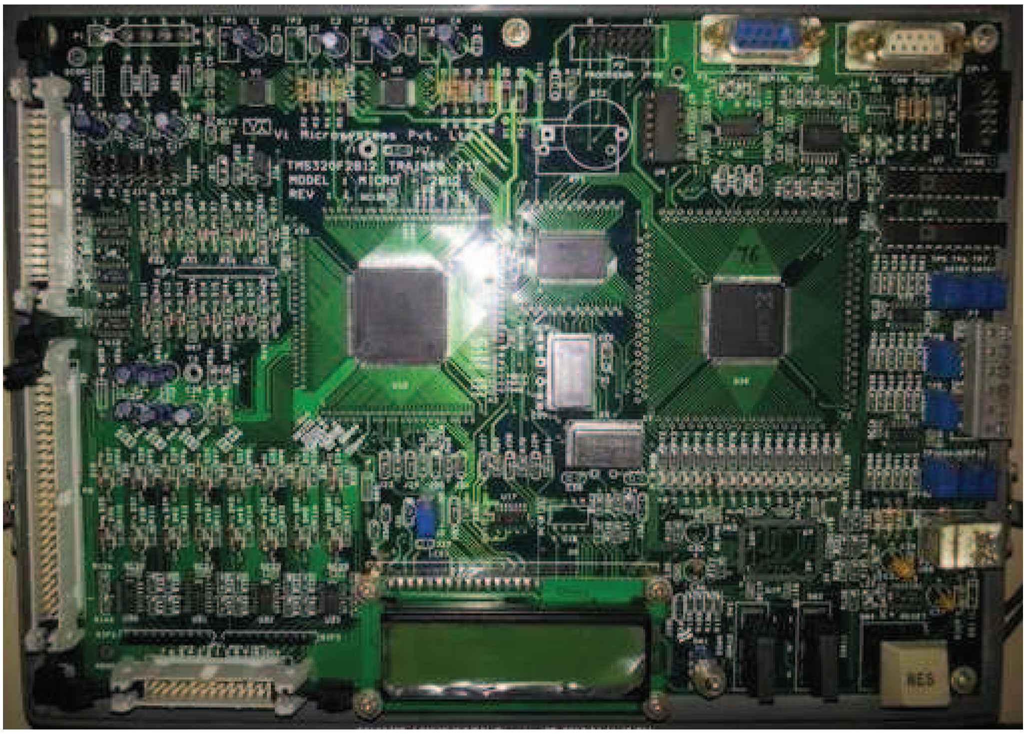

Figure 5.6: The view of DSP F2812 kit

## 5.7 Hybrid Active Filter

The detailed experimental hardware development for the proposed hybrid Series active power filter is explained. It gives details about sensors (current and voltage), power circuit and control circuit. The power circuit of the HAPF includes voltage source inverter and passive filter. The control circuit of HAPF is implemented on the TMS320F2812 DSP. Which includes Clarke transformation, p-q transformation, low pass filter, p-q to alpha-beta converter, inverse Clarke transformation and hysteresis current control etc.

The heart of the active power filter is the controller part. For providing harmonic suppression and reactive power compensation, the shunt active power filter is a suitable choice. The controller of active power filter mainly divided into two parts i.e. reference current generation and PWM current controller. In reference current generation scheme, reference current is generated by using the distorted wave form. Many control schemes are there for reference current generation, such as p-q theory, PI control, PLL controller and neural network etc. The HCC current controller is principally used for providing gating pulse to the active power filter.

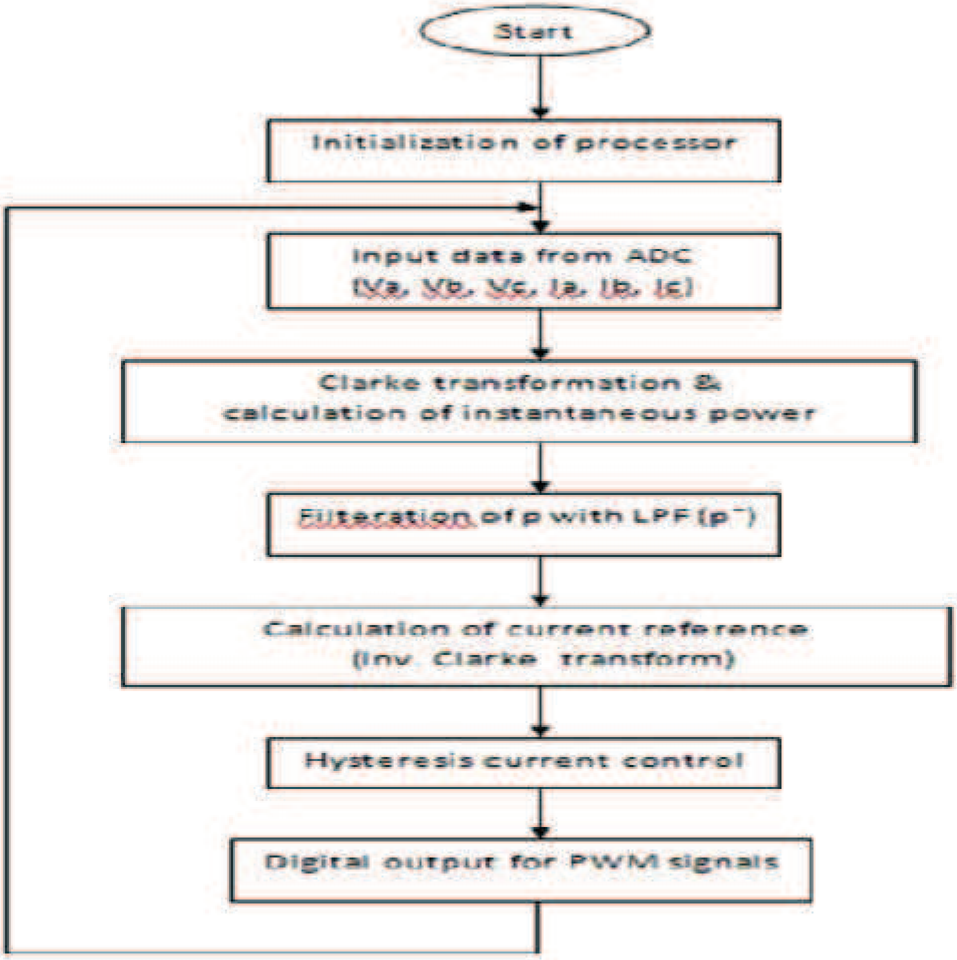


Figure 5.7: Flow chart

## 5.8 Overall General Arrangement:

The overall arrangement of the experimental setup for the proposed hybrid active power filter includes (i) supply and load (ii) current and voltage sensors (iii) power circuit of HAPFs (iv) control circuits of HAPF, which is shown in Figure 5.8

#### 5.8.0.1 Supply and Load

#### 5.8.0.2 Current and Voltage Sensors

The current transformers (CT) are used as current sensors and potential transformers (PT) are used as voltage sensors. A variable potentiometer is connected across the secondary of the CT for adjusting the gain of the CT. The gain of the PT can be adjusting by arrangement of the potential divider across the secondary of the PT.

Figure 5.9 shows the assembly of PTs and CTs for voltage and current sensor. The waveform for voltage and supply current is shown.

#### 5.8.0.3 Signal conditioning circuit

The control circuit is performed using TMS320F2812 DSP. The ADC of the DSP is operating on 3.3V unipolar. So the source voltage & current sensed by sensors are further converted into unipolar with the help of TLO61 IC. It is quad OPAMP IC . The circuit and relevant waveforms are shown in figure 5.10. and Figure 5.11

#### 5.8.0.4 Inverter:

The voltage source inverter (VSI) topology is used in the experimental setup. The three-phase inverter module is utilized for the HAF. As shown in figure 5.12 Three-phase inverter module is a discrete module designed to provide ready bridge hardware, which can be directly interfaced with the gate pulse generating circuit. Six IGBT and IR2130 based isolated gate drive circuit for IGBT switches are used in the inverter module.

## 5.9 Conclusion

The 12- pulse converter is developed using two 6-pulse converter is developed. The 6-pulse waveform is with resistive load and R L load and THD is observed is 29%. THD is also

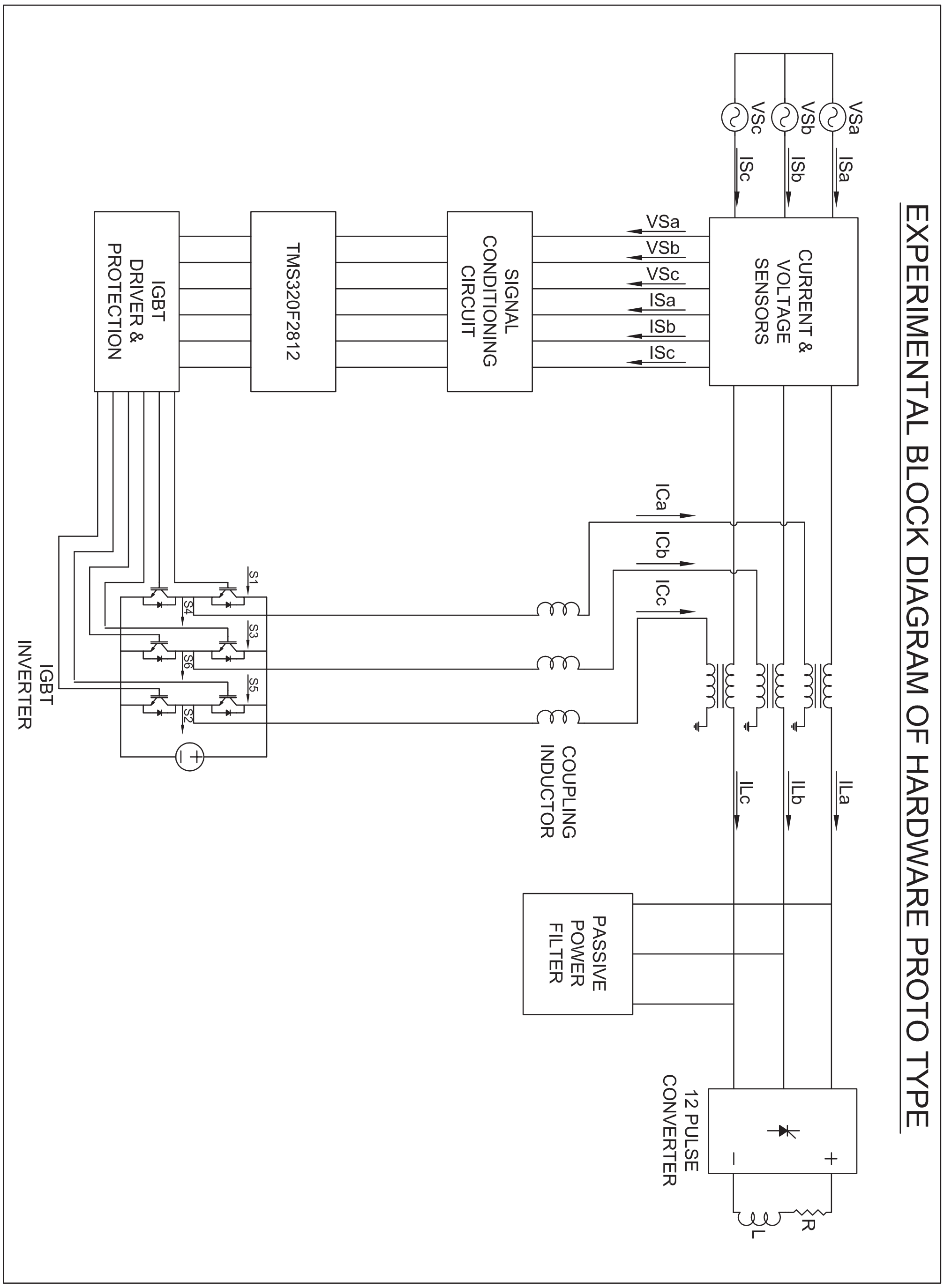


Figure 5.8: General arrangement

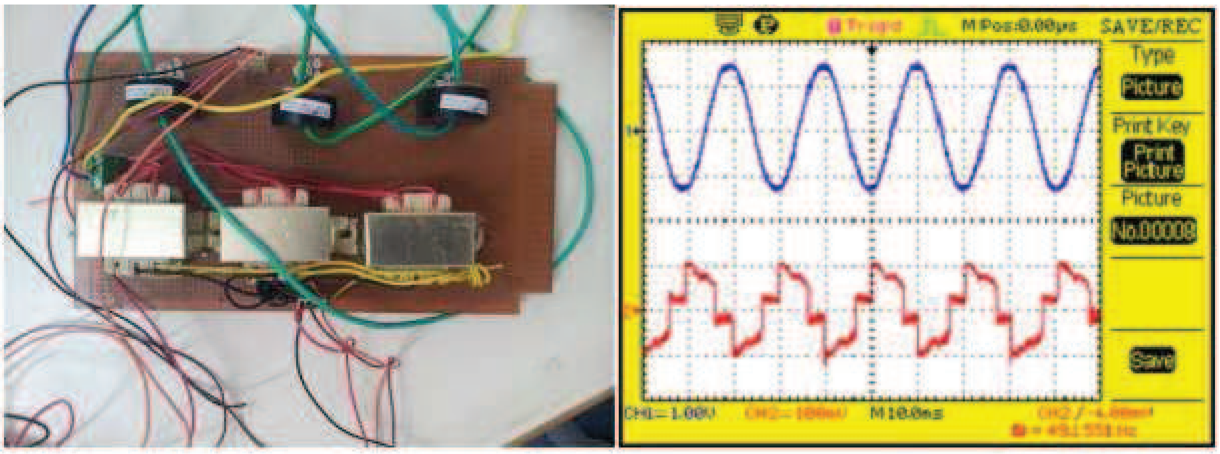


Figure 5.9: Current and voltage sensors CTs & PTs along with waveforms

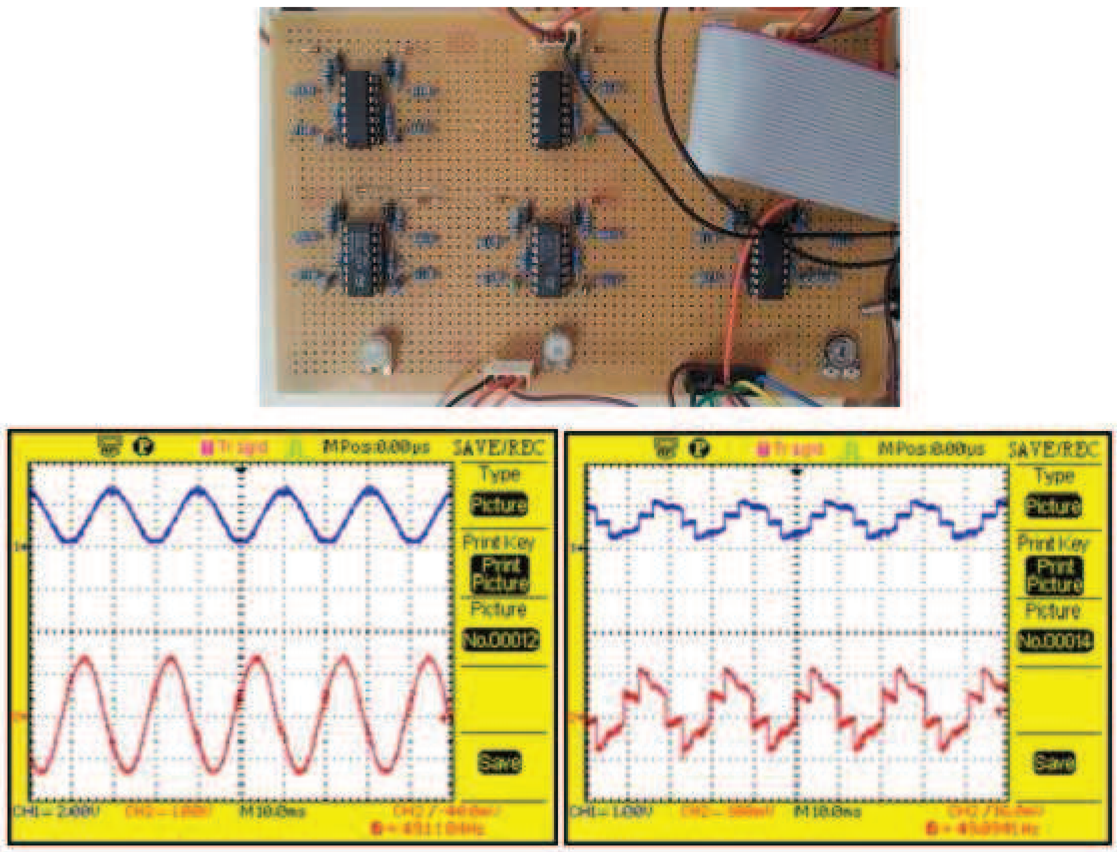


Figure 5.10: Signal conditioning circuit with waveforms

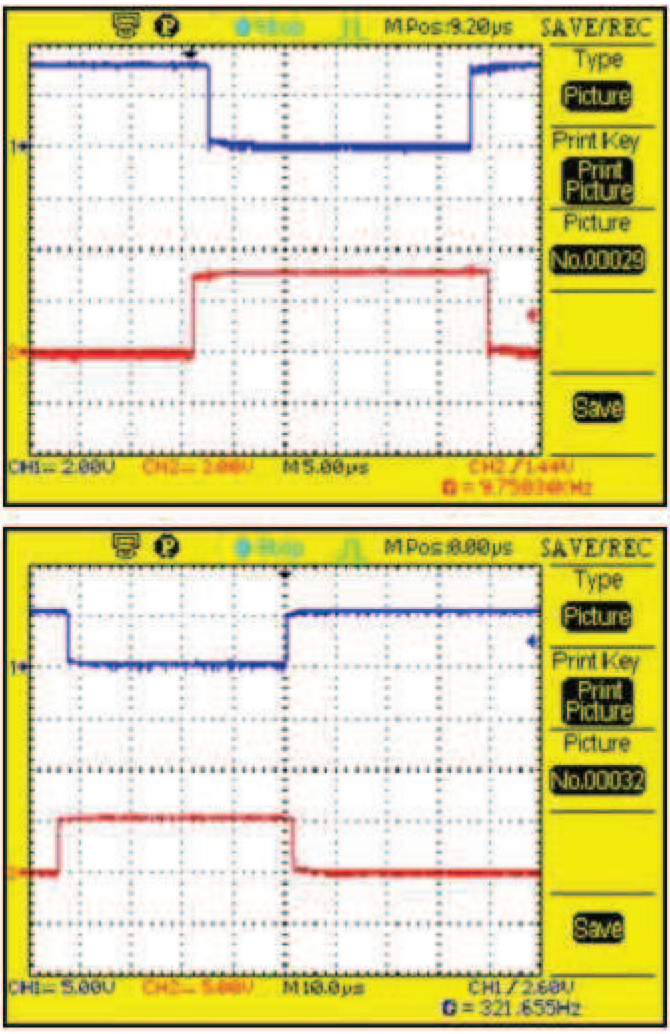


Figure 5.11: Control signals of 3.3 V & 5 V with dead time.

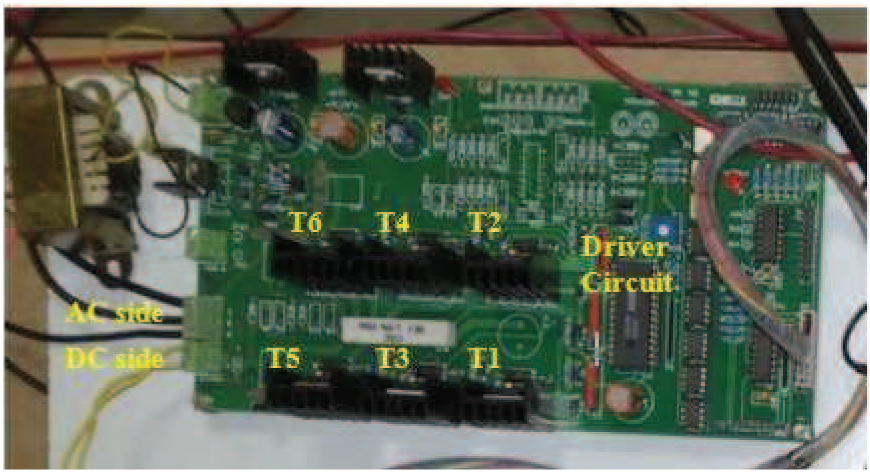


Figure 5.12: Inverter module

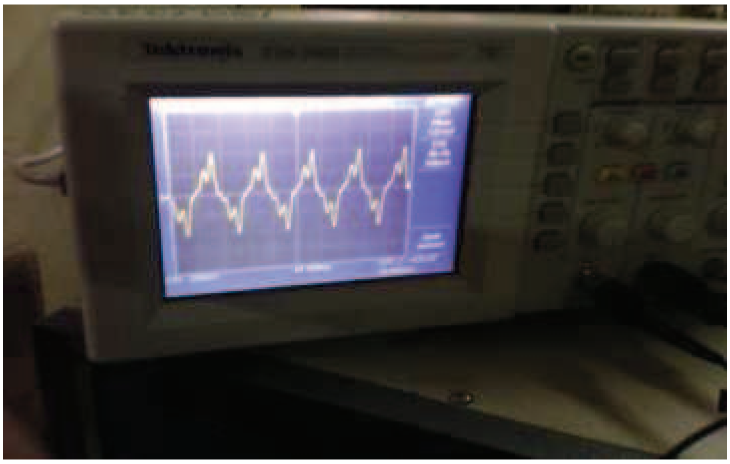

Figure 5.13: Supply current waveform with HAF

measured with different firing angle. Two 6-pulse converters are connected in series and a 12-pulse converter waveform is achieved. The THD is 13% achieved with resistive load and 10% for R L load The waveforms for different firing angle are recorded.

The Hybrid Active filter has been developed. TMS320F2812 DSP kit is used to generate control signal for three phase inverter and output is fed in series. The supply current waveform is found nearly to be sinusoidal.