SIMULATION AND EXPERIMENTS ON ONE PHASE AND THREE PHASE SHUNT ACTIVE POWER FILTERS

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SIMULATION AND EXPERIMENTS ON ONE PHASE AND THREE PHASE SHUNT ACTIVE POWER FILTERS

A thesis submitted for the completion of degree of

Bachelor of Technology(B.Tech) in "Electrical Engineering"

By-

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MAY-2015

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CERTIFICATE

This is to certify that the Thesis titled "**SIMULATION AND EXPERIMENTS ON ONE PHASE AND THREE PHASE SHUNT ACTIVE POWER FILTERS**", submitted to NATIONAL INSTITUTE OF TECHNOLOGY,ROURKELA,769008 by Mr. **ABINASH AGRAWAL** , Roll No-**111EE0192** & Mr. **MD JAVED** , Roll No-**111EE0212** for the requirement of the degree " **Bachelor of Technology(B.Tech)"** in **Electrical Engineering** is a bona fide record of research work carried out by them under my active guidance and supervision.

The students fulfill all the desired necessetites and requirements prescribed for the award.. This Thesis report depicts candidate's own work which is based on Shunt Active Power Filters and has been not submitted anywhere else for any degree/diploma. As per my opinion, this thesis report is of desired standard as prescribed for the award of 'Bachelor of Technology', in Electrical Engineering.

Prof. Kanungo Barada Mohanty

Supervisor

ACKNOWLEDGEMENTS

With the submission of our thesis entitled ”Shunt active power filter design for 1-phase and 3 phase” we would express our gratitude and sincere thanks to **Prof. K.B Mohanty sir**, Electrical Engineering department, NIT Rourkela for providing us the every possible help and his tremendous motivation which resulted in the completion of our thesis. We appreciate his encouragement and excellent guidance from the beginning to the end of our work. We will remember his knowledge and help at the time of crisis, for our entire lifetime.

We are also very thankful to **Prof. P.K Ray** and **Prof. G.K Gopalakrishna Srungavarapu f**or their suggestions and guidance during the entire project duration. They are truly an inspiration to us and we would like to thank them all from deep of our heart.

Last but not the least we would also like to thank the **entire staff members of department of electrical engineering** for letting us know the knowledge we aspired for.

Md Javed
Abinash Agrawal

DEDICATED TO

Teachers of Electrical Department, NIT Rourkela.

ABSTRACT

Based on synchronous detection method a shunt active power filter for a single phase has been developed. Harmonic pollution is increasing day-to-day by the use of non-linearity devices such as power electronics rectifier, inverters and many other device. Improvement in the quality of power has become the big task for the present electrical society. So we modelled a 1-phase SAPF(shunt power filter active in nature) using the synchronous detection method under which the hysteresis and triangular current controller technique was shown and total harmonics distortion was shown for both the cases. Results based on simulation were highlighted to depict the working of 1-phase SAPF due to non-linearity in the load. To prove the simulation results an experimental setup was also developed using various components in the project work.Also an instantaneous reactive power technique was developed for the compensation of reactive power and reduction in harmonics, and the results of the total harmonic distortion was compared for every case.

CONTENTS

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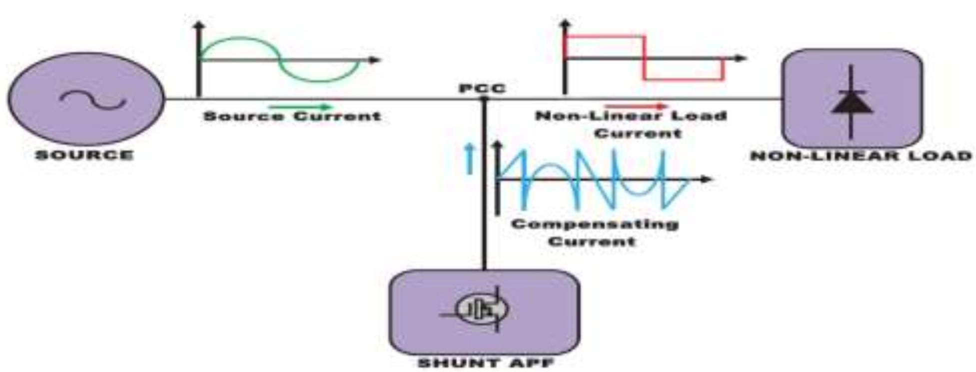
ABBREVIATIONS

PCC	-	Point of Common Coupling
THD	-	Total Harmonic Distortion
SCR	-	Silicon Controlled Rectifier
APF	-	Active Power Filter
SAPF	-	Shunt Active Power Filter
IGBT	-	Insulated Gate Bipolar Transistor
VSI	-	Voltage Source Inverter
PWM	-	Pulse Width Modulation

Chapter 1 Introduction

1.1 Background

The power quality improvement is a major task now a days. Twenty years back, passive and linear loads were used with less non-linear loads, thus it was having no or almost zero impact on the network of power. Because of easier controllability of power electronics and semiconductor device, non linear loads like rectifier, SMPS and choppers etc are used in every system. The handling limit for power of the devices like power diode, Metal oxide semiconductor field effect transistor (MOSFET), silicon controlled rectifier (SCR), Insulated gate bipolar transistor (IGBT), are very large which makes it suitable for domestic use. Due to the use of the power device, the reactive power disturbances and harmonics becomes notable in the power network. The harmonics and reactive power leads to various problems like distortion of feeder voltage, overheating of transformers, low power factor, excessive neutral current, damage to power electronic devices. The active power filters (APF's) are installed at point of common coupling (PCC) to eliminate the disturbances in the power network. APF's injects compensating current at PCC to make the source current sinusoidal by eliminating harmonics. The power factor and harmonic pollution can be improved by installation of APF's. The APFs can be implemented in the single phase, by some changes in the scheme of control, thus harmonics is minimised.



I.(i)-Active power filter block diagram.

1.2. Motivation of Project Work

It is a huge challenge for reactive power compensation in the power network and to nullify undesirable current harmonics. Because of use of loads which are nonlinear (Printers, Battery charger, etc.) the harmonics in high voltage side is less compared to low voltage side ,which is unacceptable. The shunt APF based up on appropriate control algorithms provides encouraging results. Because of its serious drawback the use of filters with the combination of L and C are not used. For better dynamic performances of the APF we use a different control strategy. In modern days three phase active shunt power filters are developed. For single phase system. We can develop a control platform by little changes or modification.

The power filter which gives a better dynamics is active shunt power filter rather than passive power filter which uses different combination of frequency for eliminating harmonics for multiple frequency. The SAPF provides a robust performance but needs an excellent algorithm for control. The use of VSI in the shunt wherewith the gate control of the switching devices mainly IGBT can be controlled from the control algorithm adopted. Here we would like to compare the different total harmonics distortion for the Hysteresis current control technique, triangular current control technique and instantaneous reactive power theory.

1.3. Project work objectives

- Discussion on harmonics.
- Study on power filters (shunt).
- Simulation and modelling of single phase active power filter using SIMULINK environment with synchronous detection technique.
- Simulation and modelling of three phase active shunt power filter using SIMULINK environment with PQ method.

- Current controller hysteresis method.
- Current controller triangular method.
- PQ method for three phase active shunt power filter.
- Experimental setup of simulation work.

1.4 Review on Literature

Going through different papers it was concluded that there are a lot of work and papers on shunt active power filters based on synchronous detection method, instantaneous active and reactive power theory developed on three phase supply. We presented a model for a single phase active power filter design using synchronous detection technique. Wherewith we also did the two comparisons based on hysteresis and triangular current control method. Where the total harmonic distortion was reduced to a good extent in hysteresis current control method but it has a disadvantage of variable switching frequency so we opted for triangular current control method where the total harmonics was reduced to a good extent but not a better result than hysteresis control.

The synchronous technique generates reference current from the algorithm and this reference current so generated is compared with the source current given and thus the gate pulse is developed for the IGBTs for the voltage source inverter.

1.5. Thesis organisation

Our thesis is divided as such:-

Chapter 1 Introduction

Chapter 2 schemes of harmonic compensation

Chapter 3 presents study on shunt active power filter.

Chapter 4 presents simulation block diagram and mathematical modelling of 1-phase and 3-phase shunt active power filter.

Chapter 5 hardware setup.

Chapter 6 results on simulation for hysteresis and triangular current control method for 1-phase and results and comparison on total harmonic distortion based on instantaneous power theory.

Chapter 2 Schemes for harmonic compensation

2.1. Sources

One of the significant reasons for current and voltage harmonics are because of vitality change procedures and control in the power electronics gadgets, like rectifier, chopper and so on. The expression "Harmonics" alludes a part of frequency that is an indispensable different from principal frequency. The harmonics in force framework emerges because of wide utilization of nonlinear burdens. Energy transformation gadgets like voltage controller gadgets of engine, HVDC power converters, battery-charging frameworks, force component change gadgets, footing, static-var compensators, direct vitality gadgets energy units, wind and sun powered fuelled dc/air conditioning converters, control of warming components can cause consonant contamination in power network.

2.2. Reduction in harmonics and compensation in reactive power.

The SAP filter attached in the line has objectives like

1. Harmonic reduction within an acceptable limit.
2. Compensation in reactive power required by the loads.

Type of harmonic filters implemented are

- Active power filter
- Passive filter

2.2.1 Active Power Filter

It is constructed with both active and passive elements which requires and additional external power for its working. Active power filter system has been proved to be most prominent to eliminate harmonics and compensate the reactive power. Pulse width modulation based current source inverter cancel out the harmonic current produced by nonlinear load, but its application is very limited till low power only. Voltage source inverter which is based on active power filter consist of good rating power and low exchanging cycles per second.

Active power filter is divided into 3 categories with respect to PCC connection,

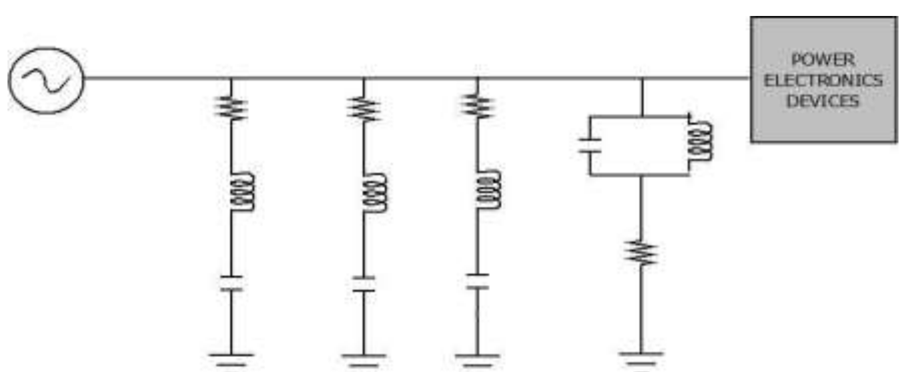
- Hybrid
- Shunt
- Series

The shunt filter is mainly used because of its robustness and it is simpler in construction.

2.2.2 Passive Filter

The passive filter consists of inductors, capacitors and resistors. They are independent of external power source.For eliminating a harmonics component different combinations of L and C is used. For eliminating higher order harmonics multiple filters required as shown in Fig.1.The performances of Passive filters is not satisfactory due to following reasons:

- The *LC* filter's compensation characteristics is affected by source impedance.
- For each harmonic frequency a separate filter is required.
- The filter will be loaded.
- Current provided by nonlinear load must be considered while designing passive filters.



II.(i)- shunt connection of passive filters in the power system network

It is for this disadvantages the passive filter are not preferred over active power filter. Because of its excellent dynamic characteristics, the use of active power filter is the future trend of improvement in harmonic in power system distribution. The active power filters provides a flexible solution of harmonics reduction and power compensation.

Chapter 3 Study On Filters

3.1. Shunt active power filters.

It is broadly utilized as a part of the power system to eliminate harmonics in current and reactive power compensation. It can likewise assume the part enhancing and balancing out profile of voltage. SAPF's compensate harmonics in current by injecting a reference current opposite in nature to that of the current which is to be compensated. The reference current is phase shift by 180 degree. So the harmonics component from the source is reduced. APF also improves the system power factor.

3.2. Synchronous detection technique

Here we will develop a method which deals with single phase active power design using the reference current algorithm. The reference current can be generated by using any one of the triangular or hysteresis control then the error signal is fed to the gate of the inverting circuit. The P_{dc} is obtained from the active power passed through the low pass filter. Then the active power is divided into three phases as follows (3)

$$P_r = \frac{P_{dc} . E_r}{E}$$

$$P_y = \frac{P_{dc} . E_y}{E}$$

$$P_b = \frac{P_{dc} . E_b}{E} \qquad (3)$$

The symbols used have their as usual meaning like E_r, E_y, and E_b denote the peak amplitudes of voltage source. And E being calculated as the sum of E_r, E_y, and E_b.

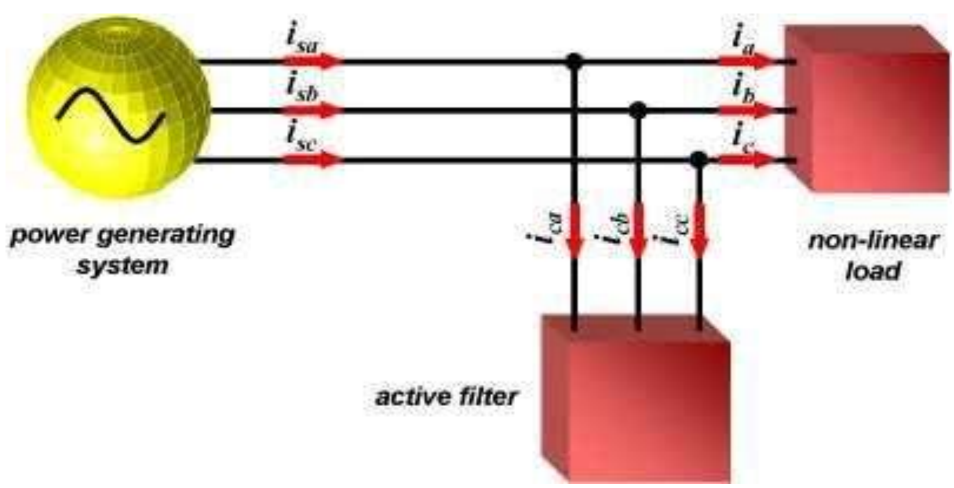
$$I_r^* = \frac{2 * e_r . P_r}{E_r^2}$$

$$I_y^* = \frac{2 * e_y . P_y}{E_y^2}$$

$$I_b^* = \frac{2 * e_b . P_b}{E_b^2} \qquad (4)$$

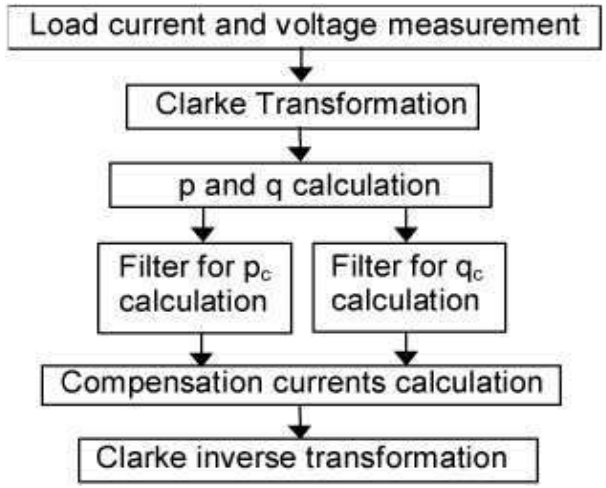
3.3 Instantaneous p-q theory

This gives a better result for a 3 phase circuit and here firstly the 3 phase voltage and current are transformed into 2 phases then the instantaneous power is calculated and with this power and other 2 phase source calculated above we do inverse Clarke transformation. Here the harmonics is reduced to a great extent.



III.(i)- SAPF at PCC

The Clarke transformation is shown below.



III.(ii)- Clarke table way transformation technique

This quick responsive hypothesis performs quickly as the receptive force is distinguished in light of the prompt voltage and streams of 3 stage circuits. This will give better harmonic compensation due to reaction of harmonic discovery phase with little postpone.

Present system assumes an essential part in quick reaction.

3.4. Synchronous reference algorithm.

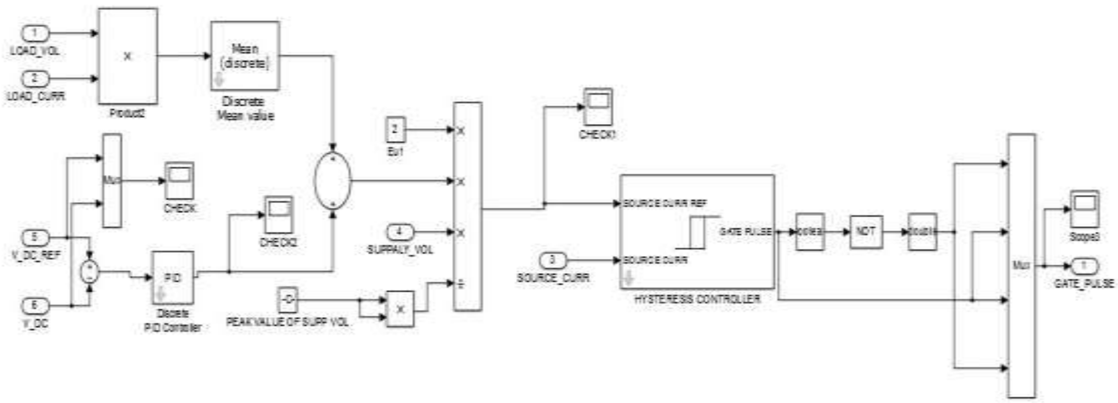
The strategy is truly like Instantaneous power technique. Vital highlights of this calculation is obliged for creating reference current and henceforth voltage bending and disturbance of source have zero impact to the exhibitions of APF system. Here reference current synchronisation with voltage is must.

3.5. Detection of peak Technique

In this technique the fundamental of load current is extracted from the distorted load current. Now the phase of the extracted component is shifted by 180 degree. If this current is included with distorted current, a waveform of current which removes harmonics present the load current.

Chapter 4 Block diagram and simulation

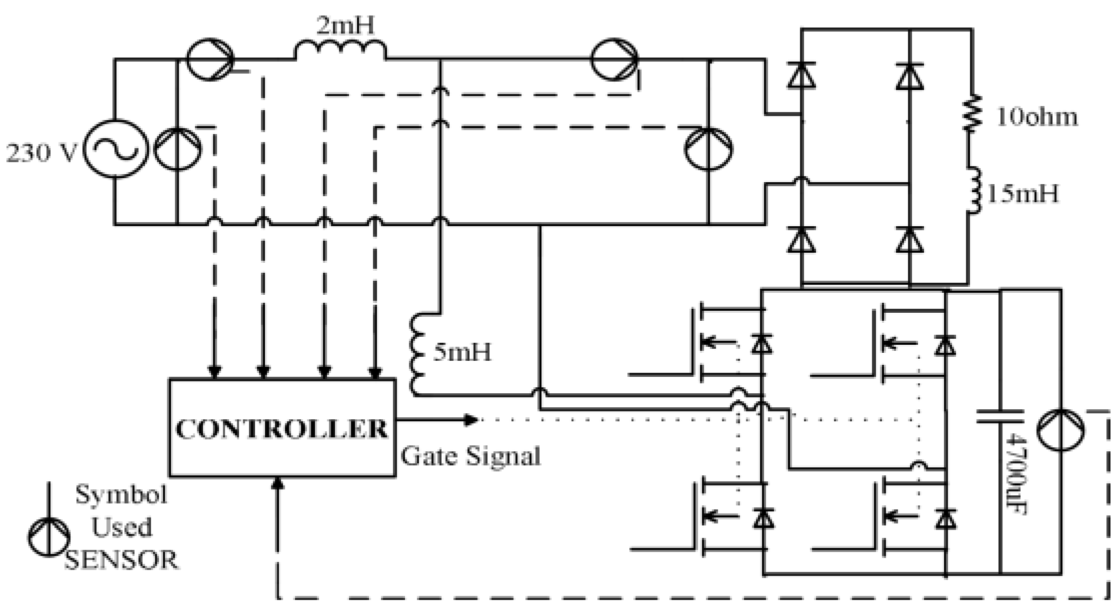
4.1 Block diagram



IV.(i)- reference current generation and gate pulse

4.2. SAPF (one phase)

It comprises of single phase IGBT based VSI, controller and load and single phase bridge rectifier. The desired block diagram for the APF system is shown below.



IV.(ii)- block diagram for APF system

4.3 Controller

The filter design is the main part of the controller. It is due to the efficient control design which makes the harmonic elimination and compensation of reactive power.

The controller is divided in two parts namely

1. Voltage controller(DC link)
2. Current controller

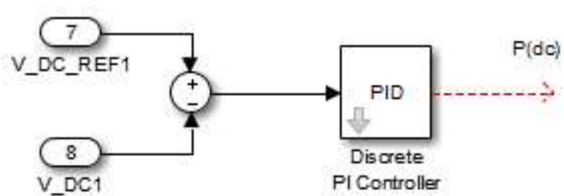
4.3.1 Voltage controller(DC link)

The voltage control(DC link) circle need not to be quick as it react to working . To control it is obliged to deal a little measure of power streaming into capacitor, therefore adjusting for misfortunes. The Voltage DC link along with a reference voltage are went through a PID controller where Kd=0.

$$P_{dc\_link}=K_p(V_{dc_{ref}} - V_{dc})+ K_i \int (V_{dc\_ref} - V_{dc})\text{dt} \qquad (7)$$

Where the proportional and integralconstants used in the equation are K_p and K_i respectively.

Figure IV.(iii)- shows the block diagram.



IV.(iii)- PID controller with Kd=0(DC link)

4.3.2 Current control through hysteresis.

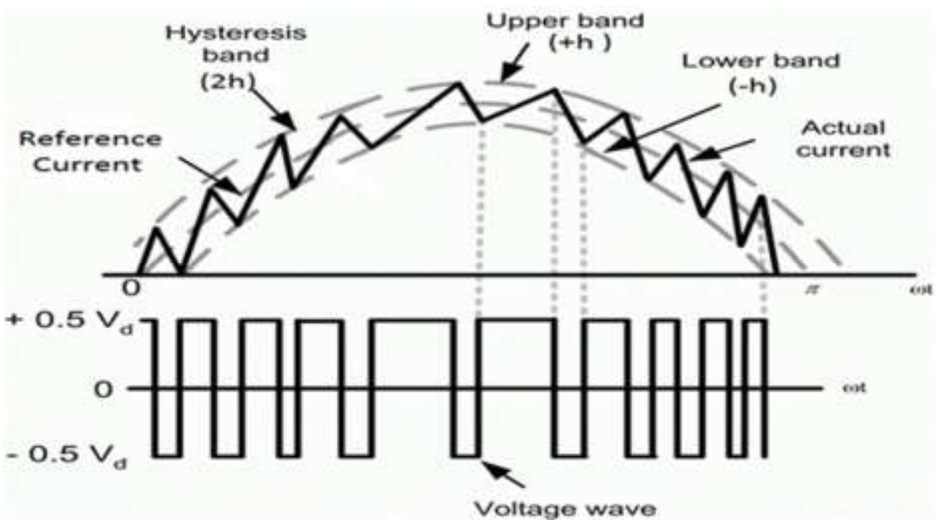
The gate pulse of the inverter is provided by the hysteresis current control method. There are many current control methods, hysteresis current control method is easily employed and quick control of current. The advantages of hysteresis method are

1. Robustness.

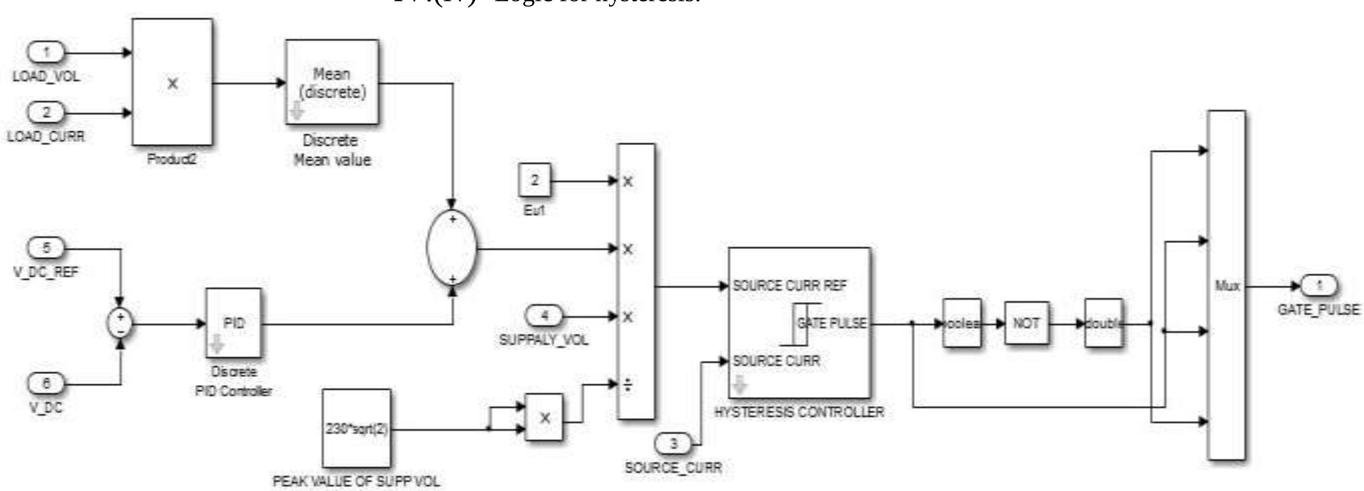
2. With minimum hardware it has fastest control

Disadvantages of hysteresis method is variable switching frequency.

Whenever the current error fed to it exceeds the fixed band then the switching operation starts. For better accuracy the band should be smaller. The switch present inside the upper inverter arm becomes turned off if limit of current is over reached and that of the switch inside the lower arm gets turned on if the current limit is below limit. Now there is a decrease in current. The working principle is shown below.



IV.(iv)- Logic for hysteresis.

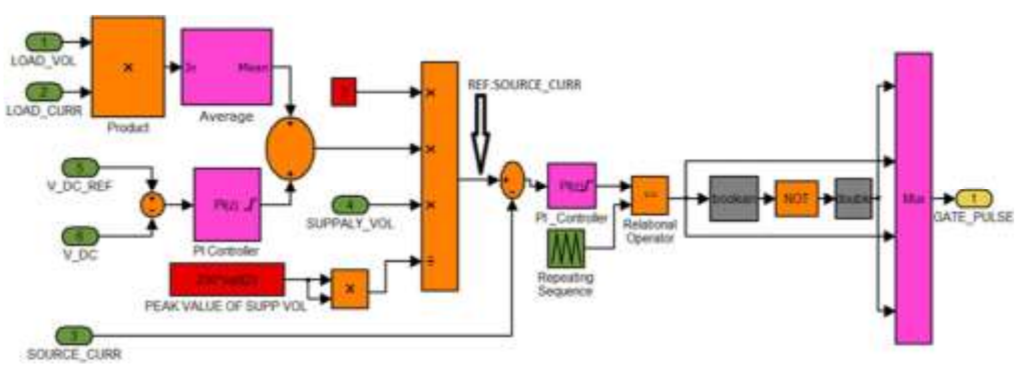


IV.(v)- current controller through hysteresis logic block diagram in simulink

4.3.2 Current controller for triangular

Here in triangular carrier wave fixed amplitude is compared with that of the fixed frequency. When the error signal is more than the carrier wave then upper arm of the switch gets turned on and lower part of the switch will become off. Similarly when the carrier wave exceeds the error, upper switch gets off and simultaneously lower switch becomes on. (K_p) → steady state error and rise time decreases but overshoot and settling time increases. (K_i)→ here for integral controller steady state error reduces but settling time and overshoot increases.

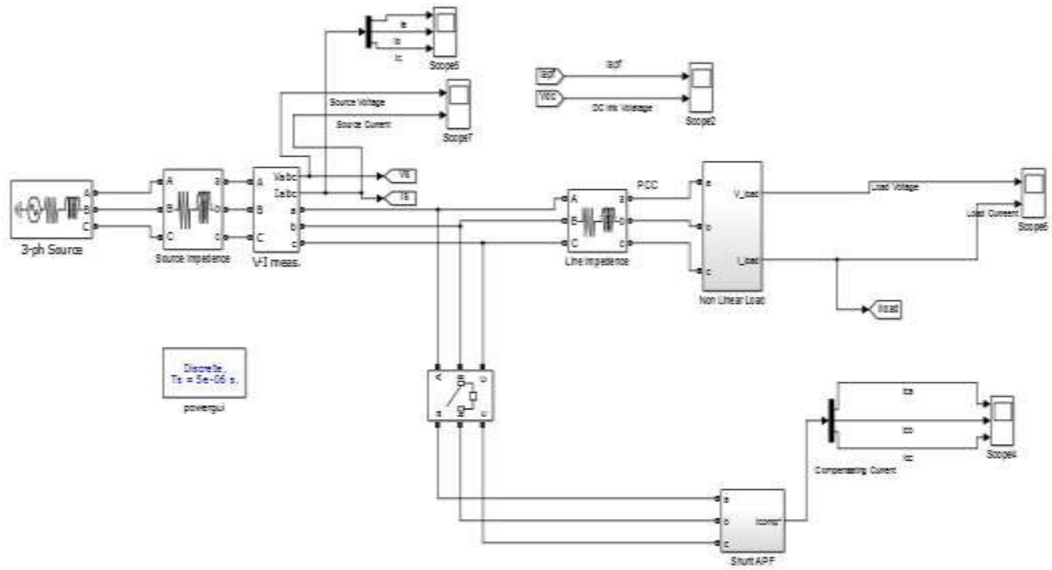
The losses on switching can be calculated as frequency of switching is known. Block diagram is shown below.



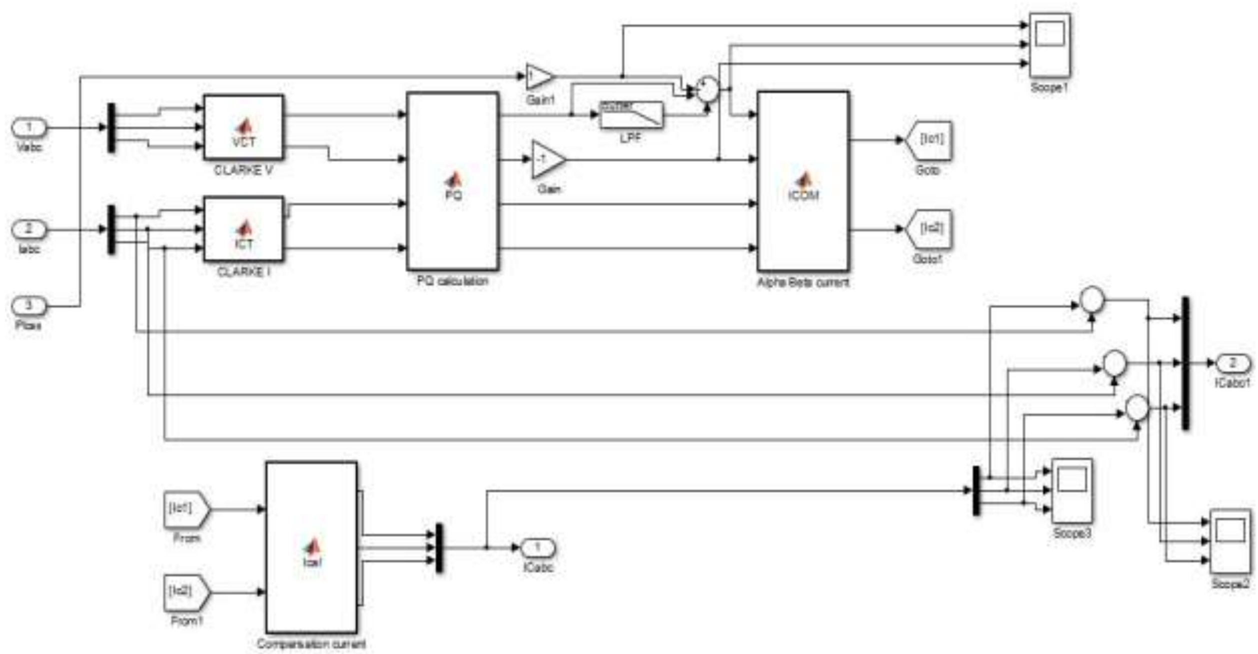
IV.(vi)- Current controller for triangular.

4.4 Instantaneous power theory

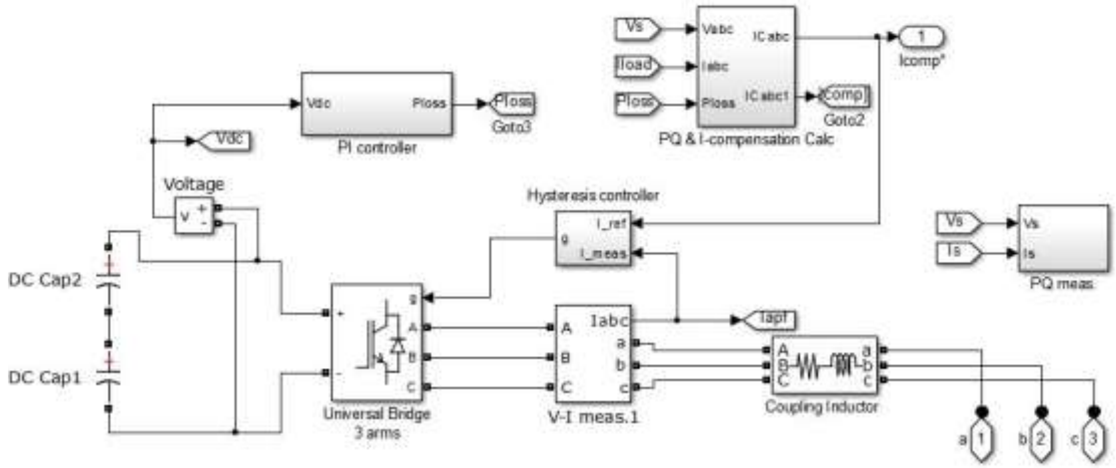
Here the clark transformation is the basis of the theory. The 3 phase load current and voltages are converted to 2 phase system (α, β) and then calculation is done. Now low pass filters are used for active and reactive power calculation. Then the compensating current is calculated which is to be fed back to the point of common coupling and then inverse Clarke transformation (from 2 phase to 3 phase transformation).



IV.(vii)- Main circuit diagram for IPR theory



IV.(viii)- PQ and I compensation block diagram



IV.(ix)- control circuit for instantaneous power theory

4.5. Results and simulation

Ts=1*exp(-4) and the simulation was run for 1 second.

No.	Parameters	Ratings
1	source Voltage	230V(r.m.s)
2	Source Inductance	1mH
3	Single Phase bridge rectifier	----
4	R-L load	10ohm,50mH
5	Filter Inductance	5mH
6	Igbt	semikron
7	DC Link capacitor	4700uF
8	DC Link reference voltge	400V
9	Sampling frequency(Ts)	1e-4
10	DC link PI controller	Kp=25, Ki=20
11	Hysteresis current controller	Hysteresis band =0.1
12	Triangular carrier current controller	Switching Freq=1e+4 Sampling

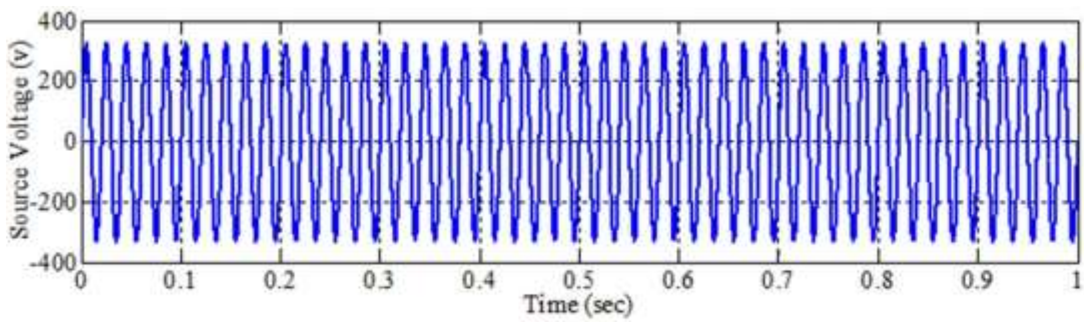
Table 1

Parameters for active power filter for Instantaneous reactive power theory.

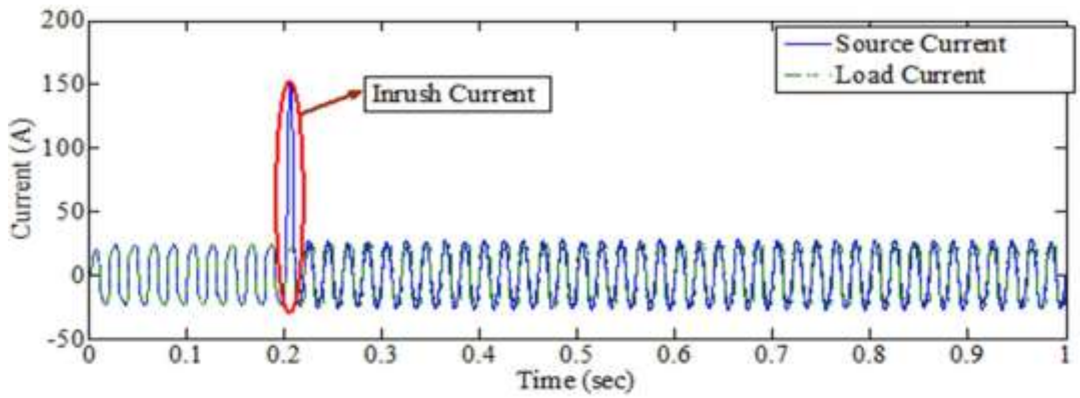
Coupling Inductance	1mH
Coupling Resistance	0.01Ω
Capacitance (DC)	1100μF
Inductance(AC)	0.05mH
Resistance(AC)	0.1Ω
Resistance(Load side)	0.001Ω
Inductance(Load side)	1μH

Table 2

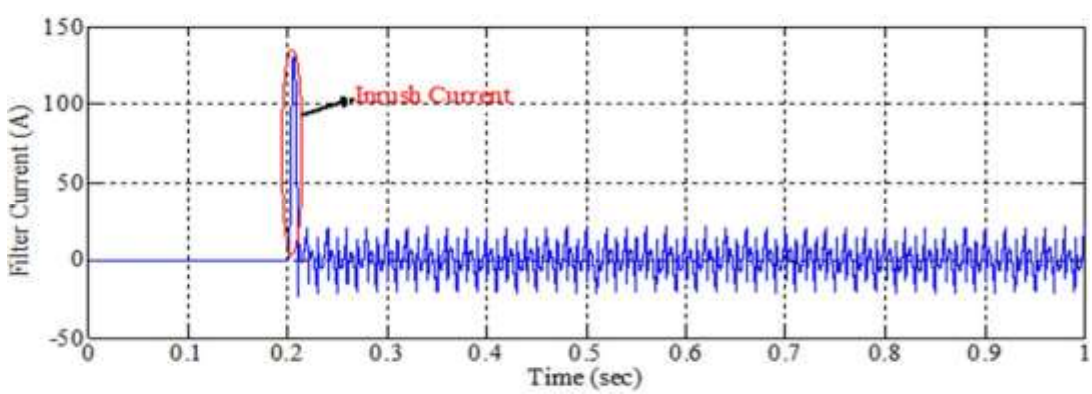
4.6 *Hysteresis controller results*



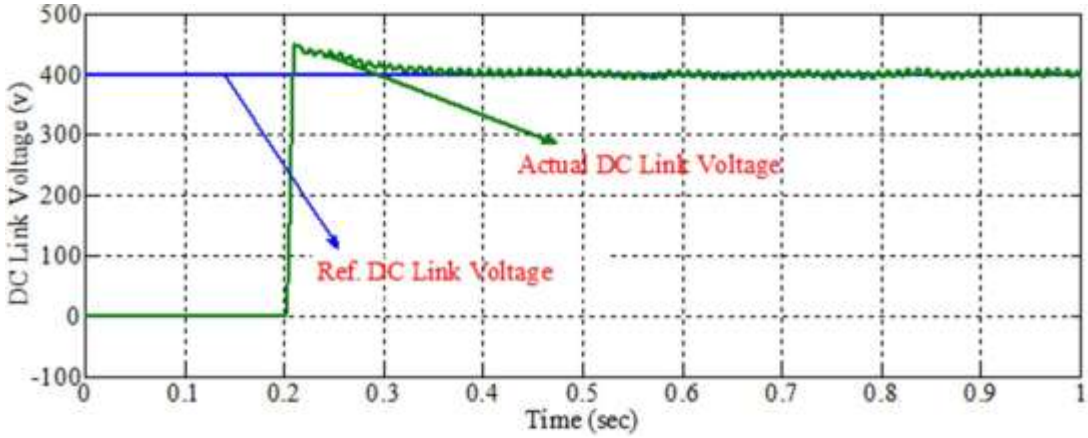
IV.(x)- source voltage



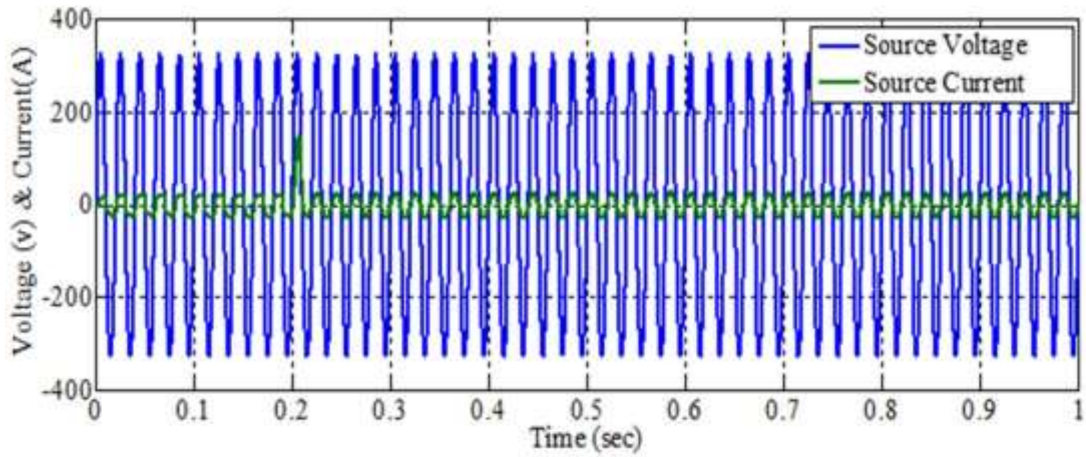
IV.(xi)- Source current & load current



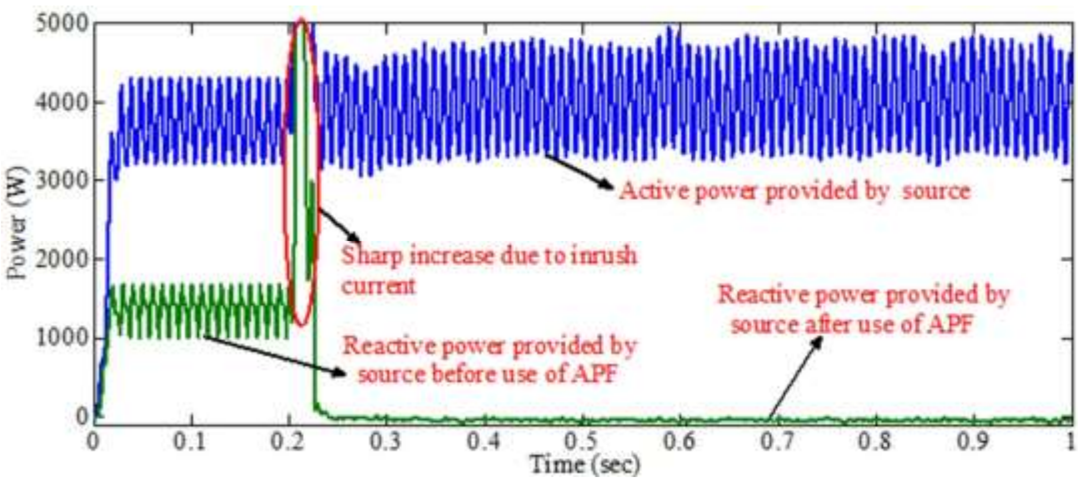
IV.(xii)- Filter current



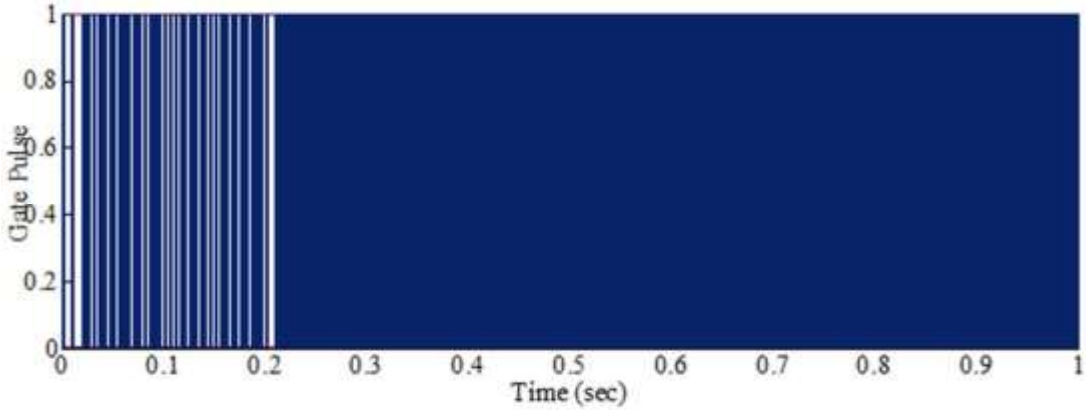
IV.(xiii)- DC link voltage



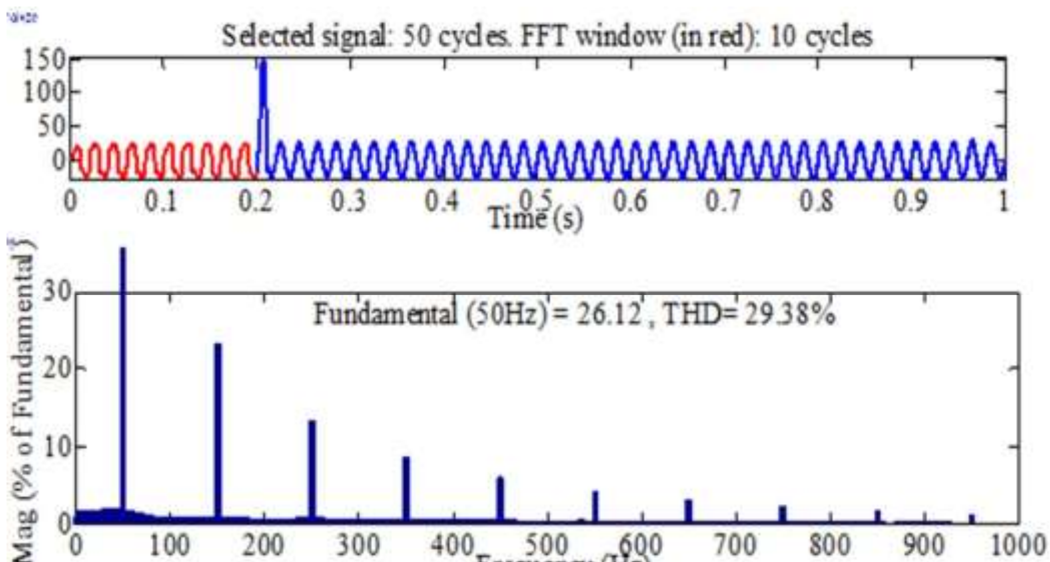
IV.(xiv)- source current and voltage relationship



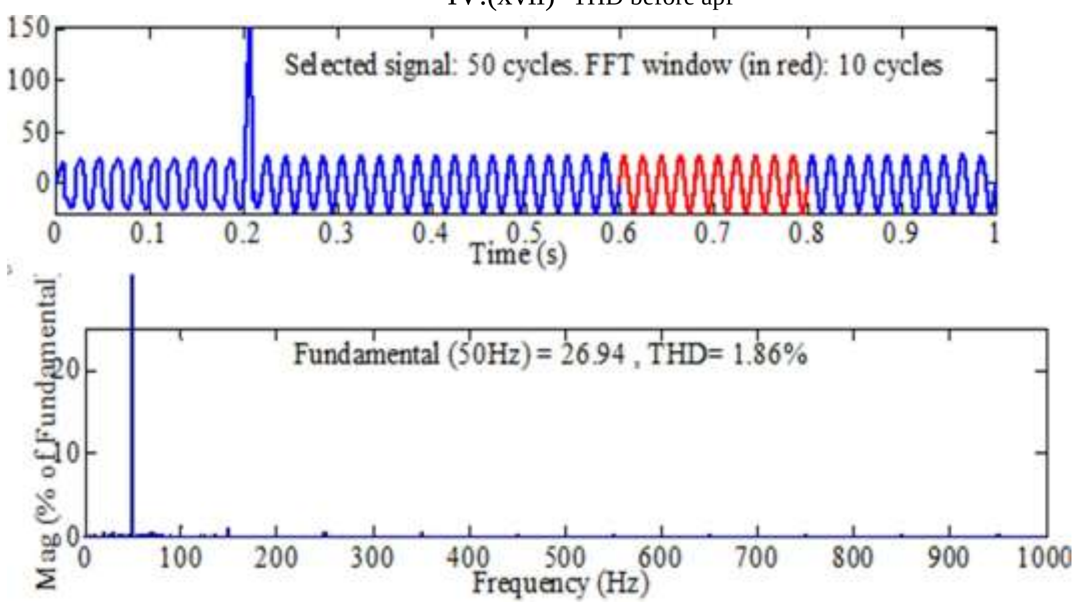
IV.(xv)- active and reactive power



IV.(xvi)- waveform of gate

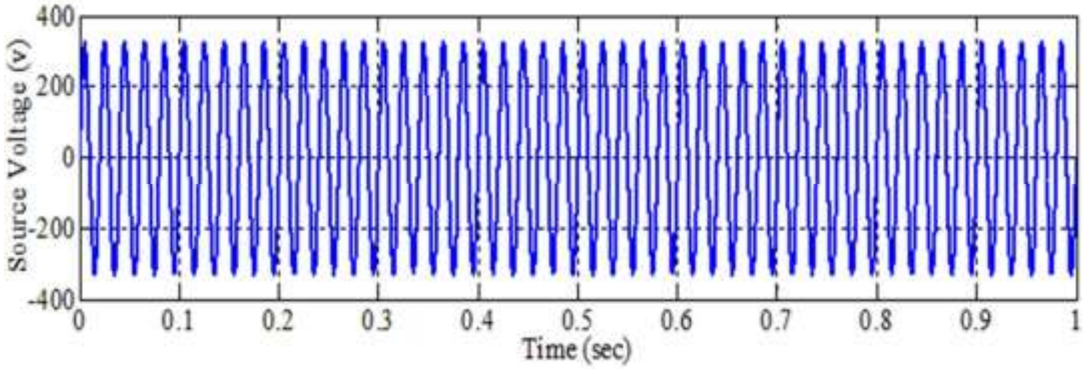


IV.(xvii)- THD before apf

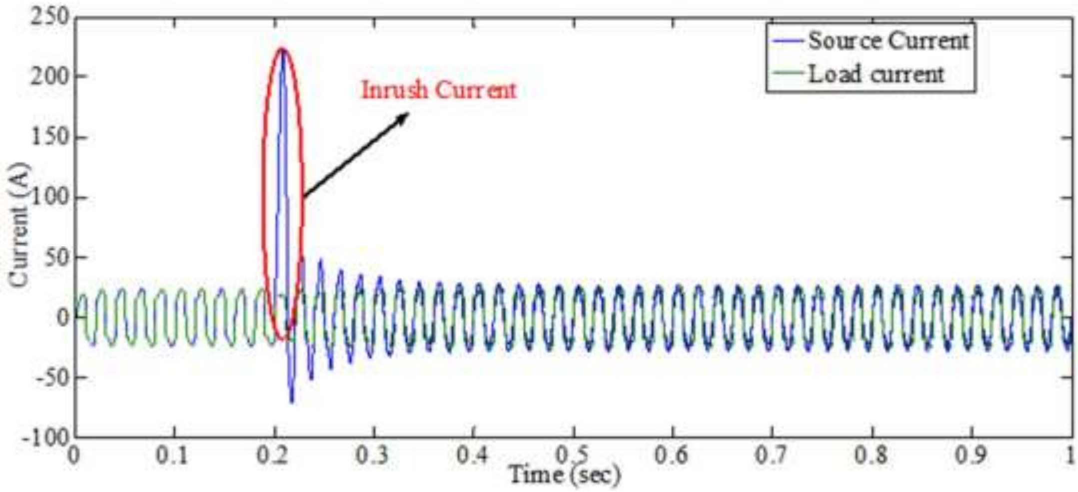


IV.(xviii)- THD after apf

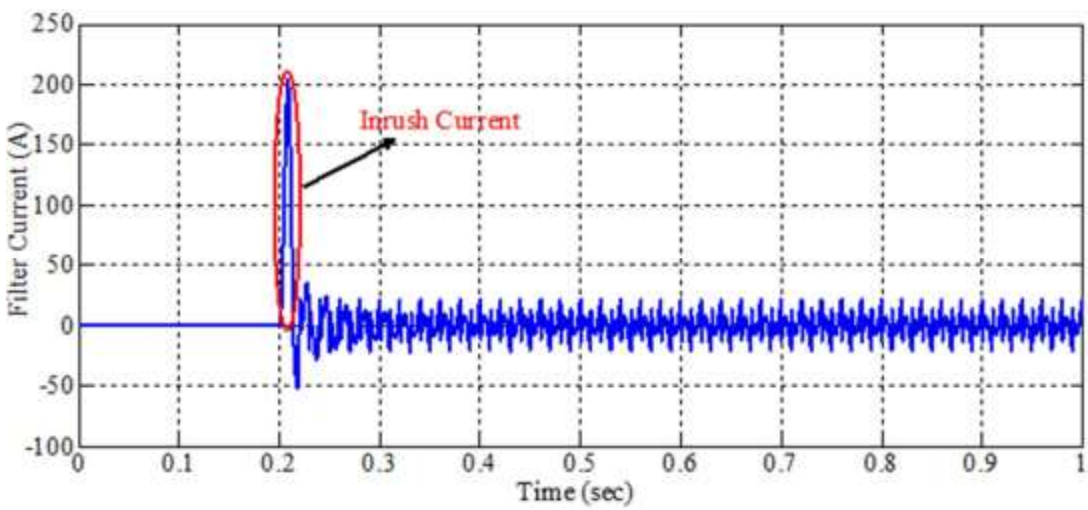
4.6 *Triangular controller simulation results.*



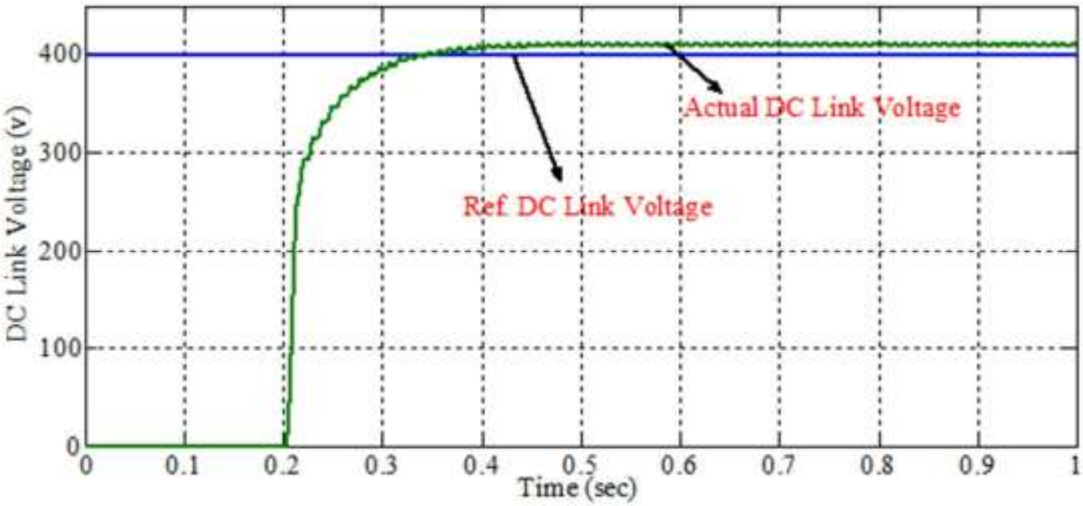
IV.(xix)- source voltage



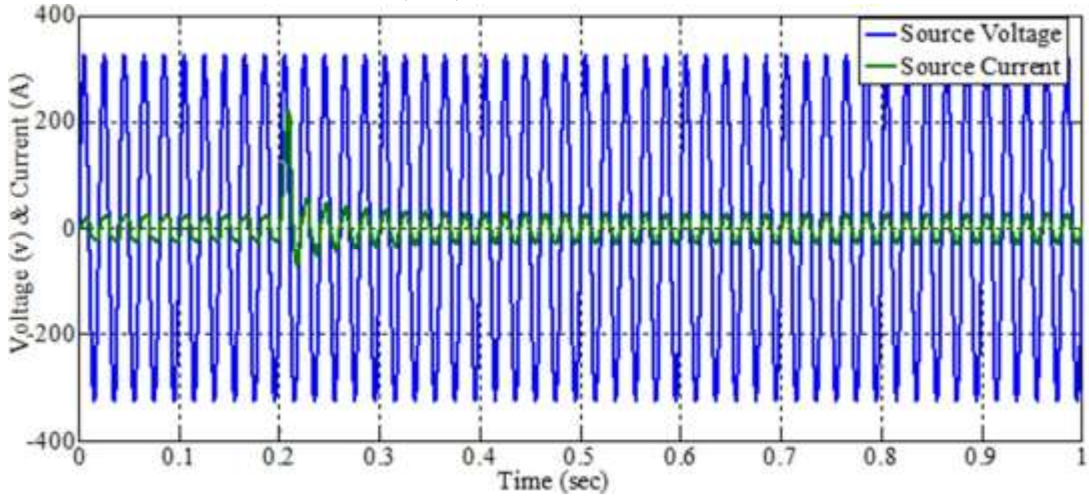
IV.(xx)- source current & load current



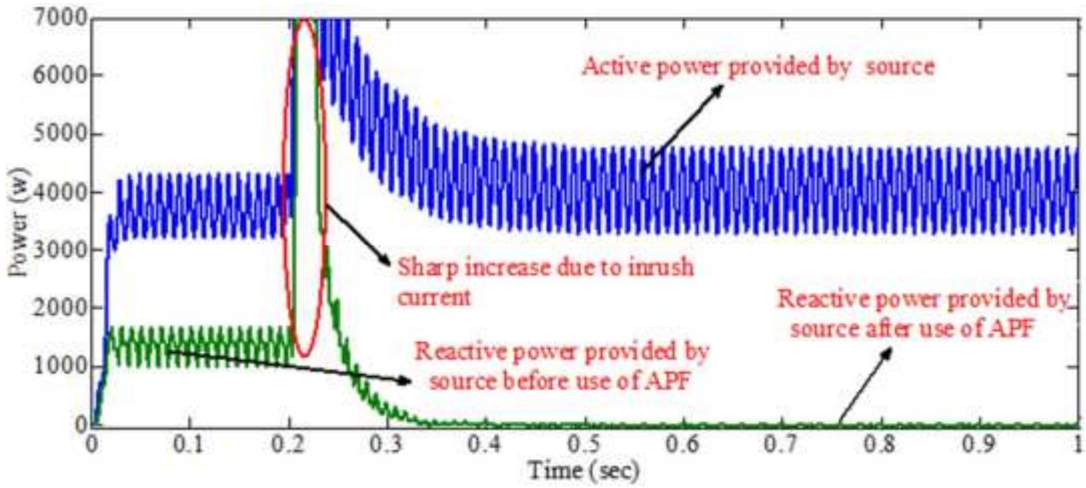
IV.(xxi)- Filter current



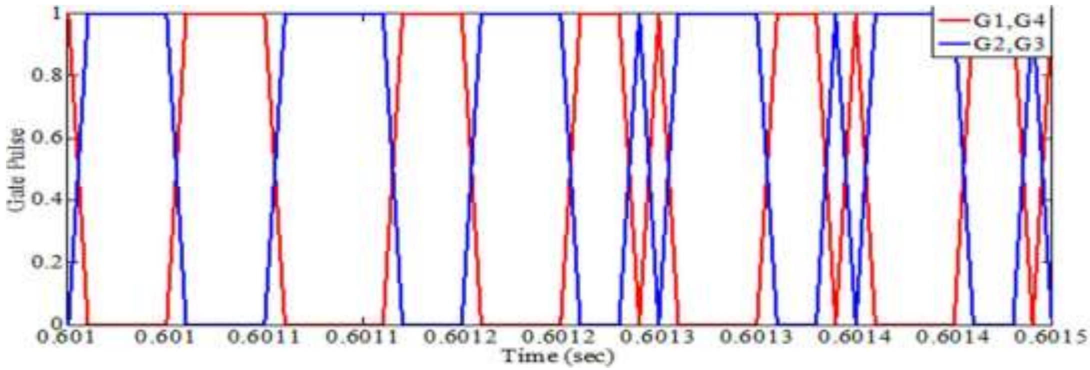
IV.(xxii)- DC link voltage



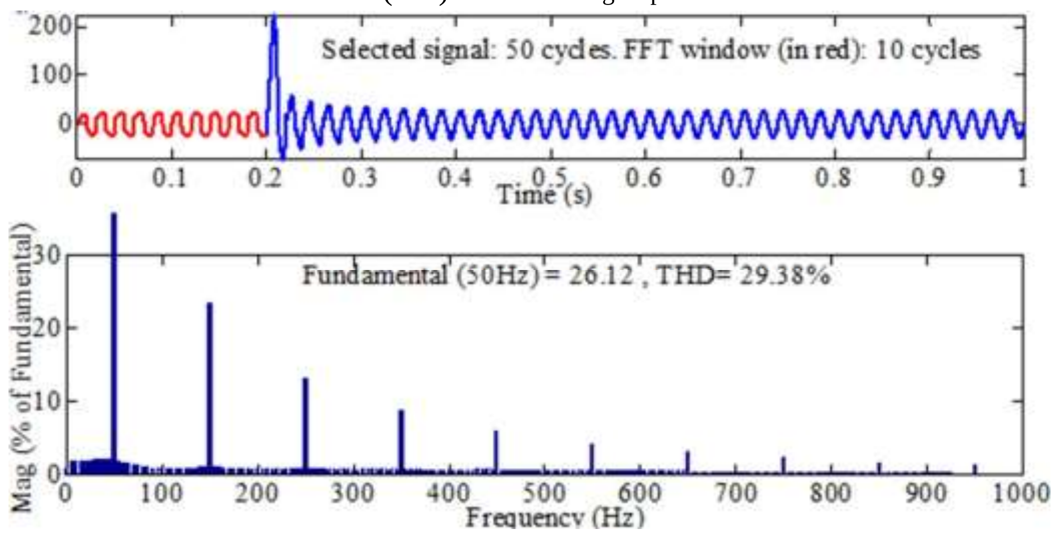
IV.(xxiii)- source current and voltage phase relationship



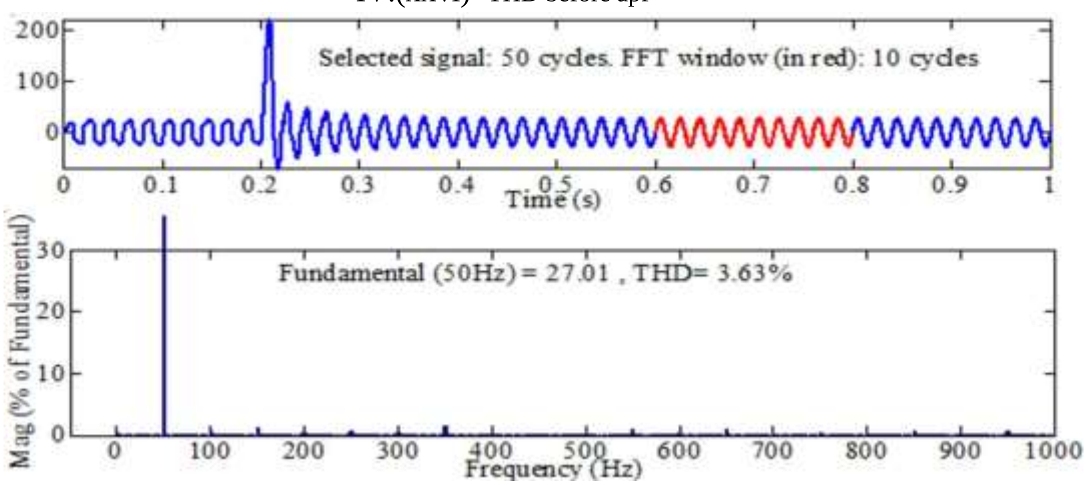
IV.(xxiv)- active and reactive power.



IV.(xxv)- waveform of gate pulse



IV.(xxvi)- THD before apf

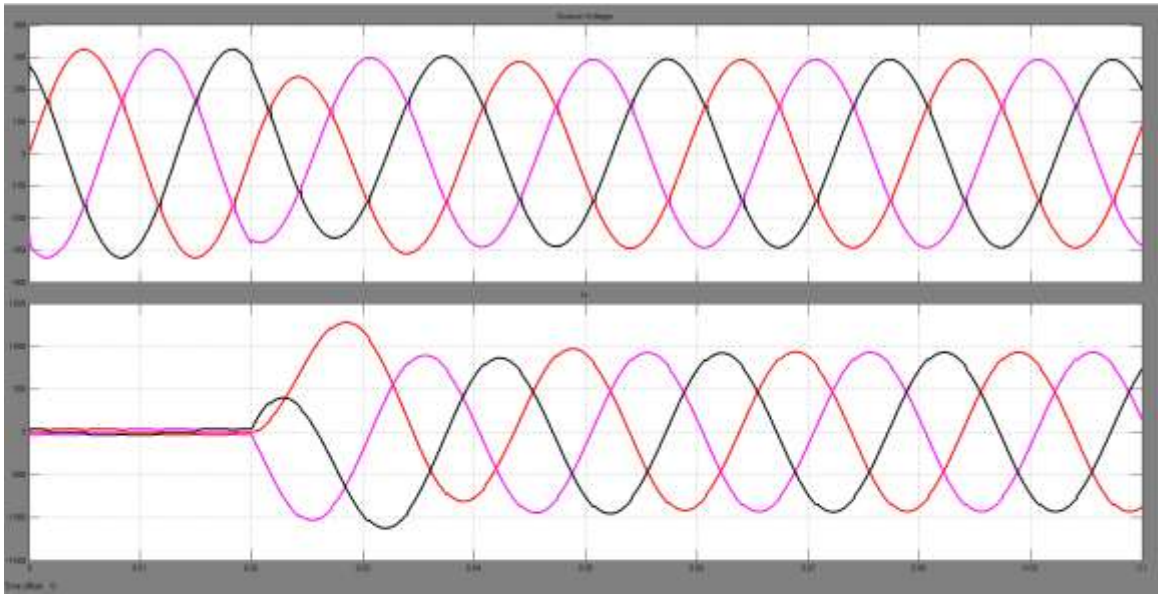


IV.(xxvii)- THD after apf

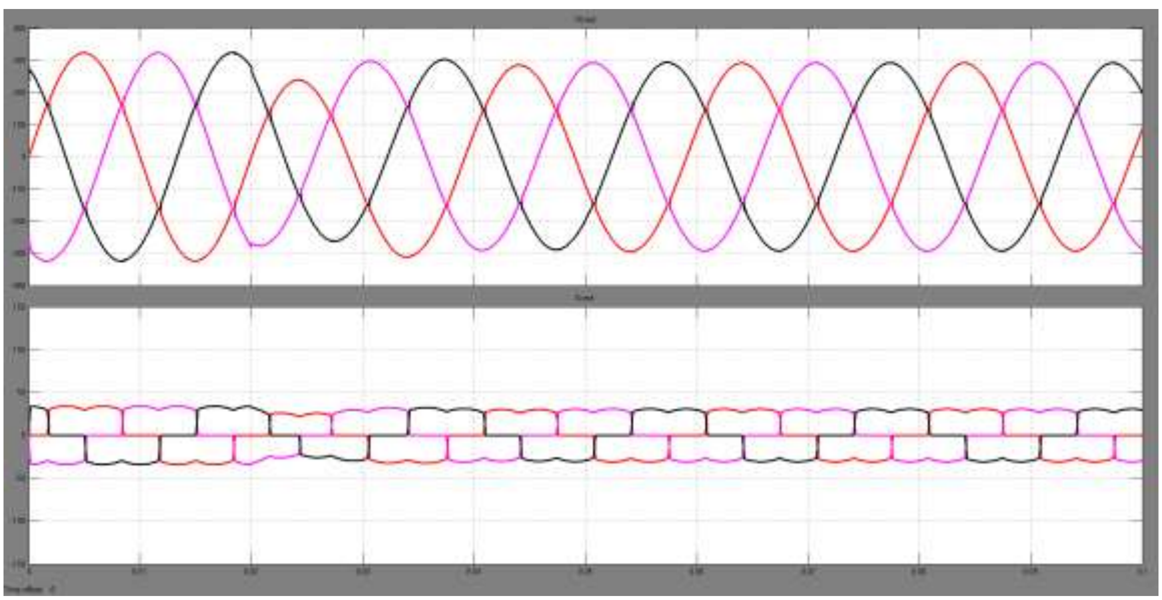
Method	THD(Total harmonics distortion)(before)%	THD(Total harmonics distortion)(after)%
Hysteresis current controller	29.38	1.86
Triangular carrier current controller	29.38	3.63

Table 3

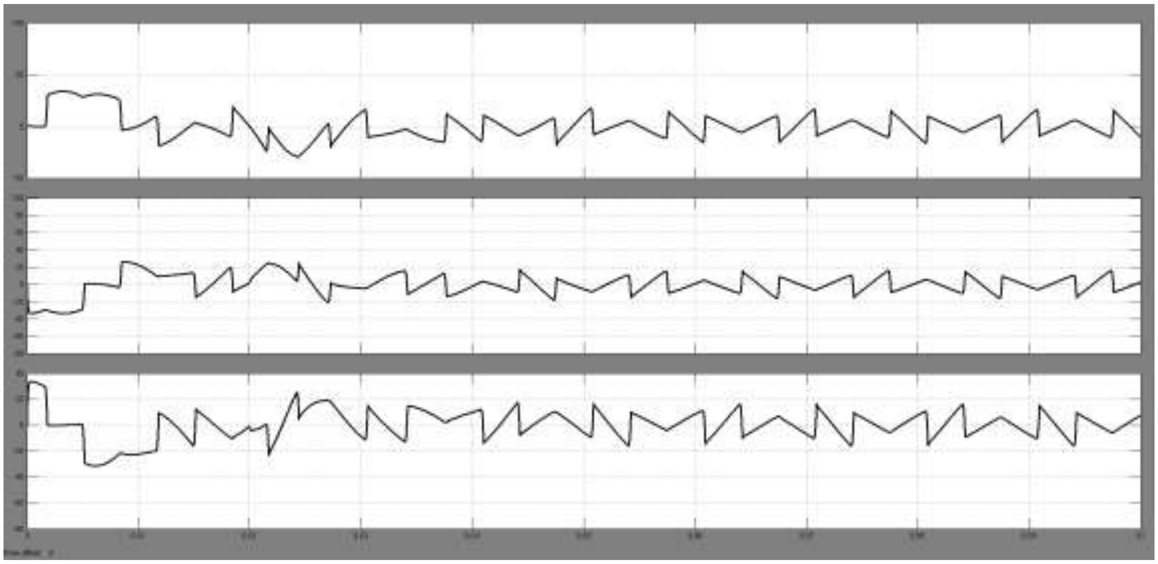
4.7 ***Result for Instantaneous power theory***



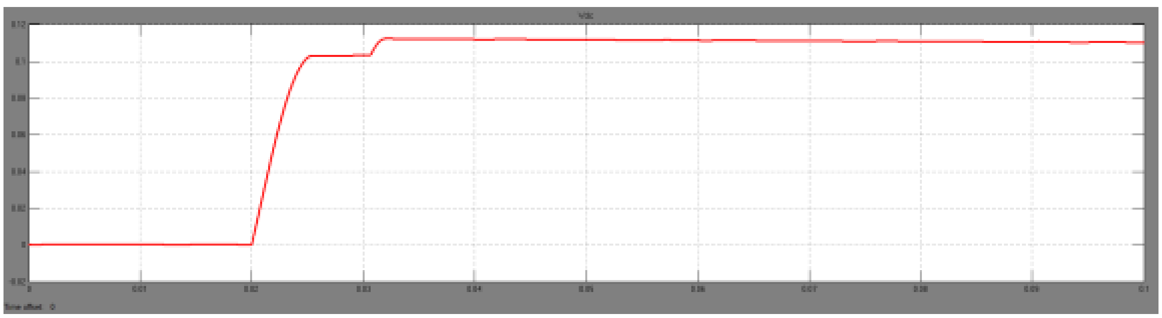
IV.(xxviii)- Source Voltage and Source Current



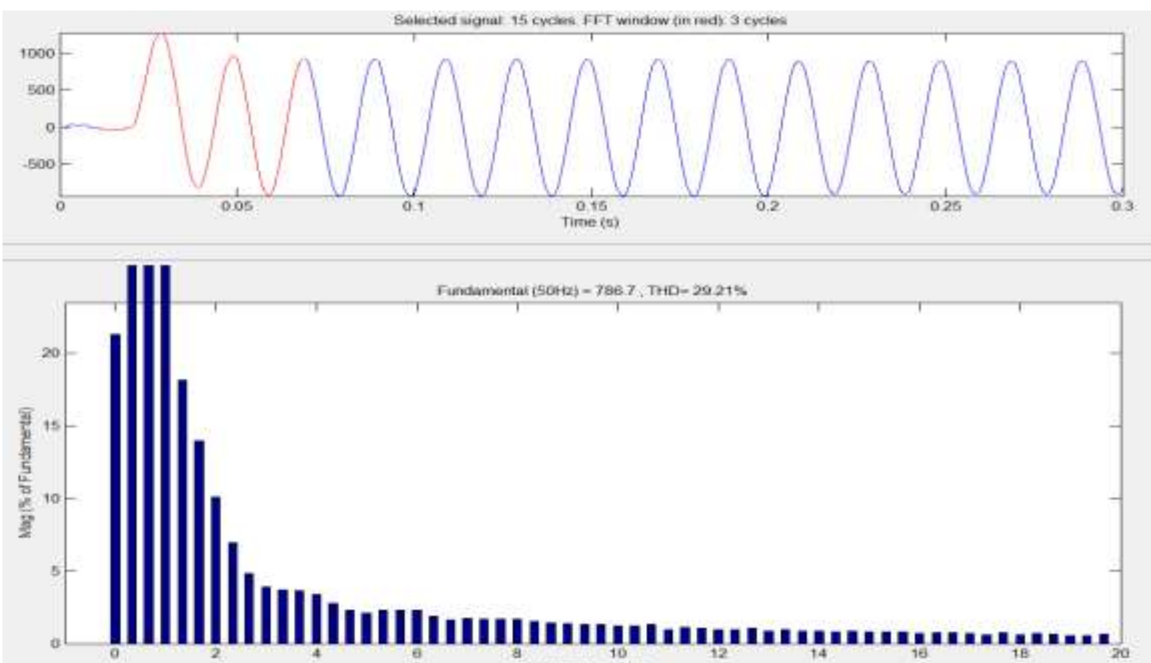
IV.(xxix)- Load Voltage and Load Current



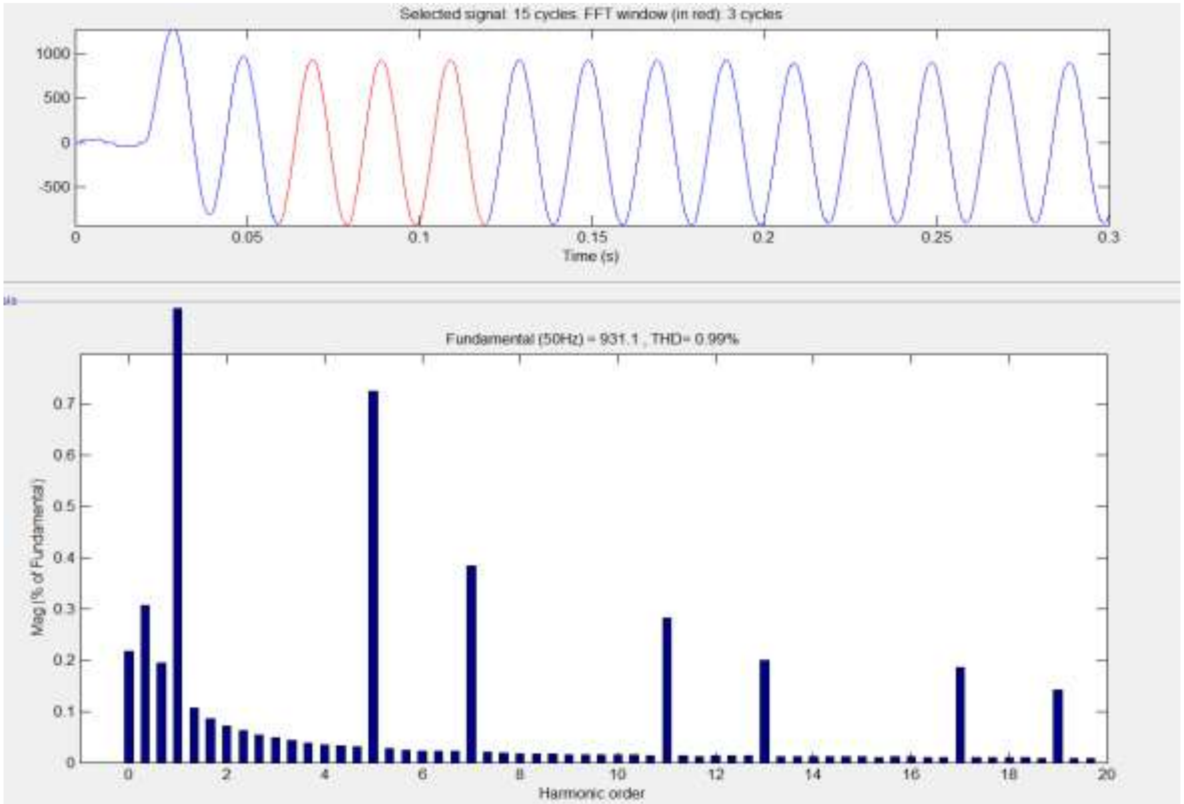
IV.(xxx)- Compensating Current for the three phases.



IV.(xxxi)- DC Link Voltage



IV.(xxxii)- THD before apf.



IV.(xxxiii)- THD after apf.

Method	THD(Total harmonics distortion)(before)%	THD(Total harmonics distortion)(after)%
Instantaneous reactive power theory	29.21	0.99

Table 4

Chapter 5 Description of setup

The components used during the project are discussed below and we were able to setup a model for the above project.

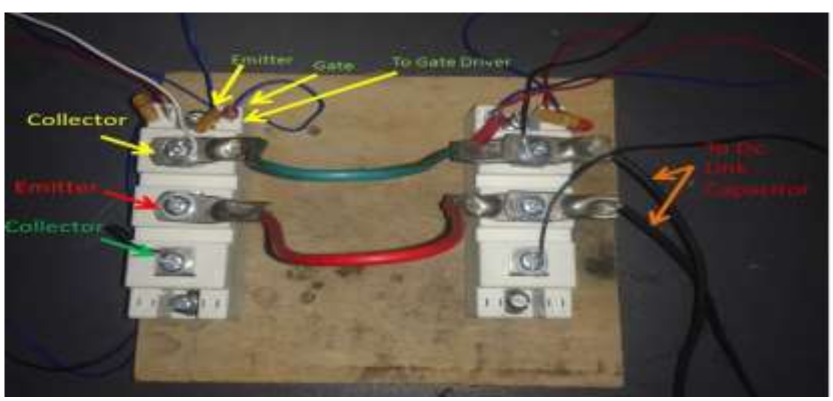
5.1. EXPERIMENTAL SETUP

The entire modelling of hardware used for experimental activities can be mainly put into

1. Inverter based on IGBT
2. 1-ϕ Variac
3. Capacitor dc link
4. Rectifier circuit single phase.
5. Gate driver

5.1.1 Inverter circuit

Four IGBTs were used for the development of single phase voltage source. Igbt used have 1600 V and 175 A and the gate driver card VLA517-01R was used for generation of gate pulse.



V.(i)- Voltage Source Inverter

5.1.2 1-ϕ Variac

It is implemented as a sinusoidal voltage source to give required necessary voltage for experimental hardware set up. It is taken into consideration that the output voltage waveform behaves ideal sinusoidal.

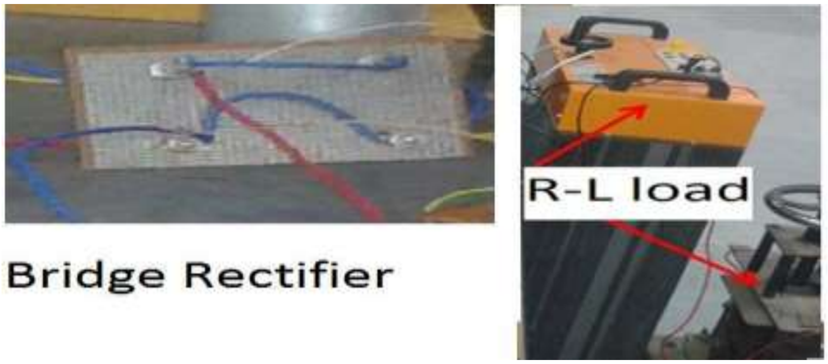
V.(ii)- variac single phase 1-ϕ

5.1.3 Capacitor dc link

V.(iii)- capacitor dc link

5.1.4 1-Phase converter

A Resistive and Inductive load is used in the rectifier circuit. Diode Specification- 15A and 500V.



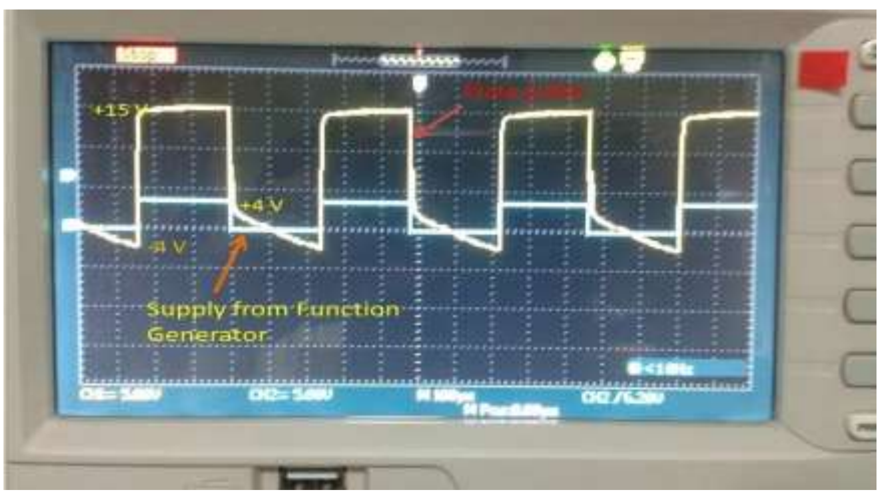
V.(iv)- Rectifier load

5.1.5 Gate Driver

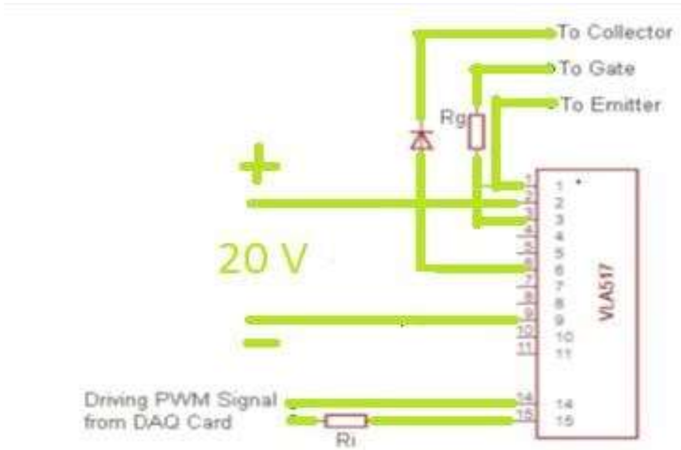
The Fujis Igbt driver VLA-517-01R was used as a driver circuit. An electrical isolation between the power side and the signal side is provided by an optocoupler.

Input - +5 and 0V

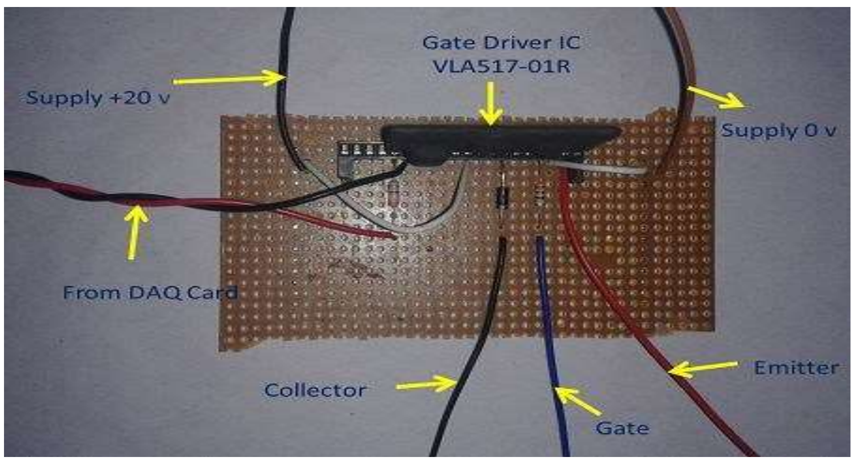
output- +15 and -5V



V.(v)- Output of gate driver .



V.(vi)- Driver circuit for gate



V.(vii)- Driver card for gate

Chapter 6 Conclusion and Future activity

6.1 CONCLUSION

So our Matlab/Simulink for the SAPF was prepared using hysteresis current controller and triangular current controller and the THD in case of hysteresis controller was decreased from 29.38% to 1.86% and by the use of triangular current controller the total harmonic distortion was reduced from 29.38% to 3.63%.Due to the late procurement and unavailability of some of the components the hardware part was done as a setup for future activity.

While calculating the THD for IPR theory it was found that the THD was reduced from 29.21% to 0.99%.Hence the harmonics component of current can be eliminated by any of the method shown above and simultaneously the reactive power compensation is also done.

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Appendix A:

IGBT Module(Semikron) -SKM 75GB063D

Table D1: IGBT Module Characteristics

Absolute Maximum Ratings		T_c = 25 °C, unless otherwise specified	
Symbol	**Conditions**	**Values**	**Units**
IGBT			
V_{CES}		600	V
I_C	T_c = 25 (75) °C	100 (75)	A
I_{CRM}	t_p = 1 ms	150	A
V_{GES}		± 20	V
T_{vj}, (T_{stg})	$T_{OPERATION} \leq T_{stg}$	- 40 ... + (125) 150	°C
V_{isol}	AC, 1 min.	2500	V
Inverse diode			
I_F	T_c = 25 (80) °C	75 (50)	A
I_{FRM}	t_p = 1 ms	150	A
I_{FSM}	t_p = 10 ms; sin.; T_j = 150 °C	440	A
Freewheeling diode			
I_F	T_c = 25 (80) °C	100 (75)	A
I_{FRM}	t_p = 1 ms	200	A
I_{FSM}	t_p = 10 ms; sin; T_j = 150 °C	720	A

Characteristics		T_c = 25 °C, unless otherwise specified			
Symbol	**Conditions**	**min.**	**typ.**	**max.**	**Units**
IGBT					
$V_{GE(th)}$	$V_{GE} = V_{CE}$, I_C = 1 mA	4,5	5,5	6,5	V
I_{CES}	V_{GE} = 0, $V_{CE} = V_{CES}$, T_j = 25 (125) °C		0,1	0,3	mA
$V_{CE(TO)}$	T_j = 25 (125) °C		1,05 (1)		V
r_{CE}	V_{GE} = 15 V, T_j = 25 (125) °C		14 (18,7)		mΩ
$V_{CE(sat)}$	I_{Cnom} = 75 A, V_{GE} = 15 V, chip level		2,1 (2,4)	2,5 (2,8)	V
C_{ies}	under following conditions		4,2		nF
C_{oes}	V_{GE} = 0, V_{CE} = 25 V, f = 1 MHz		0,5		nF
C_{res}			0,3		nF
L_{CE}				30	nH
$R_{CC'+EE'}$	res., terminal-chip T_c= 25 (125) °C		0,75 (1)		mΩ
$t_{d(on)}$	V_{CC} = 300 V, I_{Cnom} = 75 A		60		ns
t_r	$R_{Gon} = R_{Goff}$ = 15 Ω, T_j = 125 °C		50		ns
$t_{d(off)}$	V_{GE} = ± 15 V		350		ns
t_f			35		ns
E_{on} (E_{off})			3 (2,5)		mJ
Inverse diode					
$V_F = V_{EC}$	I_{Fnom} = 75 A; V_{GE} = 0 V; T_j = 25 (125) °C		1,55 (1,55)	1,9	V
$V_{(TO)}$	T_j = 125 () °C			0,9	V
r_T	T_j = 125 () °C		10	13,3	mΩ
I_{RRM}	I_{Fnom} = 75 A; T_j = 125 ( ) °C		30		A
Q_{rr}	di/dt = 800 A/µs		3,7		µC
E_{rr}	V_{GE} = 0 V				mJ
FWD					
$V_F = V_{EC}$	I_F = 100 A; V_{GE} = 0 V, T_j = 25 (125) °C		1,55 (1,55)	1,9	V
$V_{(TO)}$	T_j = 125 () °C			0,9	V
r_T	T_j = 125 () °C		8	10	mΩ
I_{RRM}	I_F = 100 A; T_j = 125 ( ) °C		44		A
Q_{rr}	di/dt = 0 A/µs		6		µC
E_{rr}	V_{GE} = V				mJ
Thermal characteristics					
$R_{th(j-c)}$	per IGBT			0,35	K/W
$R_{th(j-c)D}$	per Inverse Diode			1	K/W
$R_{th(j-c)FD}$	per FWD			0,6	K/W
$R_{th(c-s)}$	per module			0,05	K/W
Mechanical data					
M_s	to heatsink M6	3		5	Nm
M_t	to terminals M5	2,5		5	Nm
w				160	g