“DEVELOPMENT OF MODEL FOR SERIES ACTIVE POWER FILTER AND ITS INTEGRATION WITH DSP”

Major Project Report

Submitted in Partial Fulfillment of the Requirements for the Degree of

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING
(Power Electronics, Machines & Drives)

By

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I **Supraja Giddaluru**, Roll No. **12MEEP06**, give undertaking that the Major Project entitled **"Simulation Studies of series Active power Filter"** submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in **Power Electronics Machines** & **Drives, Electrical Engineering**, under Institute of Technology of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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CERTIFICATE

This is to certify that the Major Project Report entitled **" Simulation studies of series active power filter"** submitted by **Mrs.Supraja Giddaluru** (**Roll No.: 12MEEP06**) towards the partial fulfillment of the requirements for Master of Technology (Electrical Engineering) in the field of Power Electronics, Machines & Drives of Nirma University, is the record of work carried out by her under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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Lastly I would like to thank Almighty, without whom all of us are nothing.
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Abstract

. The power quality problem issues which arises in power system devices are because of the switching frequency and non-linear characteristics. power quality issues are becoming stronger because of increased non-linear loads and the sensitive equipment.For competition reasons between industries the industrialists are using them in a bulge so these are going to effect the power system a lot. The pollution and compactness of the size increases a lot in this competitive world.Efficiency and cost are almost considered at the same level.Active power filters have been arrived to solve these practical problems.one among them is series active power filter which has been discussed .The entire topology which earlier discussed [1] had considered had been taken for the detailed investigations.The simulation results for series hybrid active power filters(SHAPF) was done and the various theories like instantaneous reactive power theory(IRP),modified instantaneous reactive power theory,synchronous reference frame theory(SRF) had been studied and logic circuits had been developed and implemented in simulation.Finally,integration with Digital signal processor (DSP) had been made with MATLAB and with code composer studio (CCS). The code has been generated for SHAPF.

Abbreviations

ADC .... Analog to Digital Converter
APF .... Active Power Filter
ARAU .... Auxiliary Register Arithmetic Unit
CALU .... Central Arithmetic and Logic Unit
CAN .... Controller Area Network
CAP .... Capture
CCS .... Code Composer Studio
CMP .... Compare
CSI .... Current Source Inverter
DAC .... Digital to Analog Converter
DARAM .... Dual Access Random Access Memory
DSP .... Digital Signal Processor
EPROM .... Erasable Programmable Random Access memory
EVA, EVB .... Event Manager A, Event Manager B
IRP .... Instantaneous Reactive Power Theory
IGBT .... Insulated Gate Bipolar Transistor
MOSFET .... Metal Oxide Field Effect Transistor
MCR .... Mux control Registers
MIPS .... Million Instruction per second
MUX .... Multiplexed
PCC .... Point of common coupling
PE .... Power Electronics
PWM .... Pulse Width Modulation
PREG .... Product Register
RTDX .... Real Time Data Exchange
SHAPF .... Series Hybrid Active Power Filter
SCI .... Serial Communication Interface

SPI .... Serial Peripheral Interface

THD .... Total Harmonic Distortion

TREG .... Temporary Register

UPS .... Uninterrupted Power Supply

VSI .... Voltage Source Inverter

WD .... Watchdog Timer

Nomenclature

D_{max} .... Maximum Duty Cycle

D_{min} .... Minimum Duty Cycle

f_{sw} .... Switching Frequency

f_{sw} .... Switching Frequency

I_l .... Load Current

i .... Current

i_{wa} .... Active currents phase a .... [A]

i_{wb} .... Active currents phase b .... [A]

i_{wc} .... Active currents phase c .... [A]

$i_{\overline{wa}}$ .... Generalized Fryze currents .... [A]

$i_{\overline{wb}}$ .... Generalized Fryze currents .... [A]

$i_{\overline{wc}}$ .... Generalized Fryze currents .... [A]

i_α .... α axis current .... [A]

i_β .... β axis current .... [A]

$i_{c\alpha}$ .... α axis compensating current .... [A]

$i_{c\beta}$ .... β axis compensating current .... [A]

i_a, i_b, i_c .... Phase currents .... [A]

P_o .... Output Power

p_{in} .... input power p .... Active Power .... [W]

$\overline{p}$ .... Mean value of the instantaneous real power .... [W]

p_{loss} .... Alternating value of the instantaneous real power .... [W]

$\overline{p}_{3\phi}$ .... Three phase average active power .... [W] q .... Reactive Power .... [IVA]

$\overline{q}$ .... Mean value of instantaneous imaginary power .... [IVA]

q_{loss} .... Alternating value of instantaneous imaginary power .... [IVA]

S_1 .... Switching in IGBT one

S_2 .... Switching in IGBT two

S_3 .... Switching in IGBT three

S_4 .... Switching in IGBT four

T_{sw} .... Switching Period

s .... Instantaneous complex power .... [W]

v_{comp} .... Compensating .... [V]

v_{ca}^*, v_{cb}^*, v_{cc}^* ... Reference Compensating voltages of phases a, b, c respectively ... [A]

$v_{q\alpha}$ .... α axis reactive .... [V]

$v_{q\beta}$ .... β axis reactive .... [V]

v_{qa}, v_{qb}, v_{qc} .... Reactive of phases a, b, c respectively .... [V]

v_{la} .... a phase non-linear load voltage .... [V]

v_{lb} .... b phase non-linear load voltage .... [V]

v_{lc} .... c phase non-linear load voltage .... [V]

v_{sa} .... a phase source current .... [V]

V_{out} .... Output Voltage

V_{in} .... Input Voltage

V .... Total voltage or Voltage summation

v .... voltage

v_α .... α axis voltage .... [V]

v_β .... β axis voltage .... [V]

v_a .... Voltage of phase a .... [V]

v_b .... Voltage of phase b .... [V]

v_c .... voltage of phase c .... [V]

V_{dc} .... DC link Voltage .... [V]

V_s .... Desired output voltage vector .... [V]

ϕ .... Phase

η .... Efficiency of inductor

α .... α axis component

β .... β axis component

0 .... Zero axis component

comp .... Compensating value (usually current)

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Chapter 1

Introduction

Early instruments was made to withstand disturbances like arcing,corona ,lightning,short circuits(sc), sudden overloads .power electronics(PE) devices will be much costlier with same equipment for that robustness.transformers and saturable coils are the main non-linear devices which causes pollution.But now the perturbation level has reached to the maximum extent.Due to fast switching rate and easy operation the PE instruments got a world wide reputation but its another side is very harmful due to its non-linear characteristics. The approximate energy wasted due to PE are 10% to 20% at 1990,but it has been increased to 50% to 60% by 2014.If we are going to do the statistical analysis between sensitivity and pollution the pollution is reaching to a higher level which leads to low efficiency η and poor power factor(P.F.).Hence, it is very much necessary to protect ourselves from the above problems.There arise the topic of filters.

1.They are classified into shunt passive filters or tuned LC filters which are going to suppress the harmonics and the capacitors are used to improve the P.F.They have some disadvantages like fixed compensation,large size and resonance phenomenon.

2.Alternative one is active power filter these are used to compensate harmonics and reactive power usage to non-linear load.

1.1 Literature Survey

The decomposition of a voltage vector into multi - dimensional analysis has been carried out. control strategy has been discussed and elimination of sag and swell has been discussed [1].The switching of inverter by using instantaneous power theory has been discussed without the use of energy storing elements [2].simulation and experimental results for shunt active power filter has been carried out using instantaneous reactive power theory [3].The un-functionality of the IRP has been discussed in [4].The study of active power filters haad been carried out using quad series PWM inverters[5].Simulation studies on shunt active power filter had been carried out in [6].The three phase active filter for the harmonic compensation and reactive power explained [7].Computer aided designing of active power filters discussed[8].The power quality issues with the help of active power filters [9].The compensation scheme for series active power filter has been discussed in [10, 11, 12].Unbalances in the voltages like sag or swell elimination has been made with the help of series active power filter [13].Literature for ezDSP has been studied from [15, 14].

1.2 Power Quality

Power quality issues arrived due to the deviation of voltage,current or frequencies from their original manifestation.These are going to result in the damage ,disoperation or failure of the device at user-end.In each and every aspect like industries ,commercial,domestic applications the power quality issues are arrived due to power electronic equipment.
1:TV,PC (house hold appliances)
2:copiers,printers,scanners,weighing machines(business applications) 3:electric drives,inverters ,rectifiers etc., (industrial applications)

Depending on the usage of power electronic devices the power quality issues has been arrived.

- Locations
- Sensitive-equipment frequent dropouts
- Frequent blackouts
- Lamp flicker
- Voltage to ground in unexpected
- Frequent blackouts
- Overheated elements and equipment.
- Overheated elements and equipment.

power electronic devices are the most important aspect for harmonics,notches,inter harmonics and finally neutral currents. Sources of harmonics are ASDs,starters,electronic ballast,switched-mode power supplies,rectifiers,inverters.The equipment really going to get effected are TVs,motors etc.,the electronic controller devices are going to be affected because of the notches produced by converter.Neutral currents are the dangerous one which is generally produced from switched-mode power supply like ink-jet printers,scanners etc.,will generate triplen harmonics.These triplen harmonics increases the in-built temperatures and finally results in the transformer degradation.Induction motors,static frequency converters and cyclo-converters produces inter harmonics. The power electronic devices which we are using now-a-days are so much advantageous because of their well bound structure .The computers are occupied a huge space at their starting of invention but later on palm tabs are also available to us.This drastic change is taking place with the invention of power electronic devices but at the same time the hazardous affects are also appearing .So many control strategies are building their ways to solve these problems .Researchers are concentrated in this field .The final result from this analysis is PE can solve the power quality problem

and it can create its own problem.Modern life has been moved to an extreme level with the help of these micro-electronics and power electronics.At the same time conflict is going on among these two results in costing millions of rupees in lost customer productivity.
voltage source inverters are considered to be more efficient than that of the current source inverters.

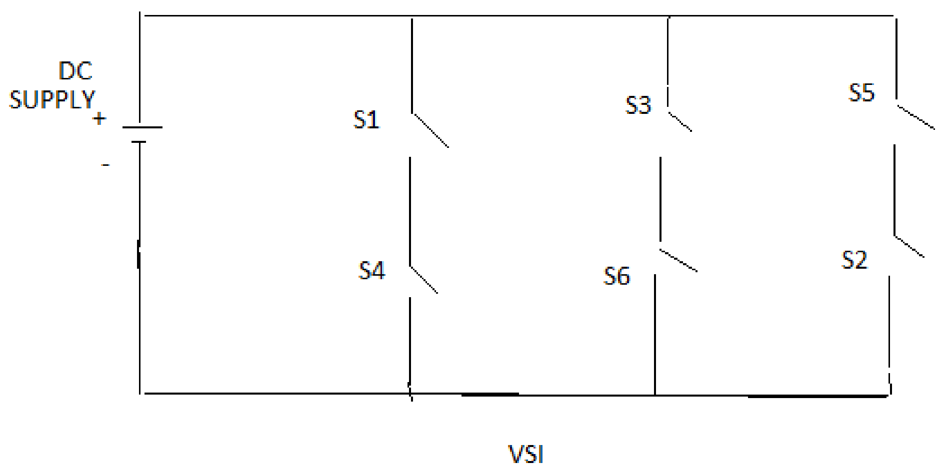


Figure 1.1: VOLTAGE SOURCE INVERTER

1.3 PWM

The important two techniques which are seldom used for controlling the active power filters are sinusoidal PWM,hysteresis PWM.

1.3.1 Sinusoidal PWM

The modulation techniques not only allow to control the inverters as voltage sources but also as current source inverters.The most efficient method to control the output

voltage is PWM.In this technique a fixed d.c input is given to inverter and an a.c output is going to get across the output of inverter with varying the on and off time periods of the inverter.Advantages of PWM are:
1.output voltage is obtained without any additional components. 2.We can reduce all the lower order harmonics by its switching and filtering components have been reduced . Finally ,higher order harmonics can be eliminated very easily with LC filters. In this scheme the width of each pulse is varied proportional to the amplitude of sine-wave evaluated at the centre of same pulse.By comparing the carrier wave of frequency f_c with the reference wave gating signals are produced.
f_r defines the inverter output frequency and peak amplitude.
v_{ref} determines the modulation index and also RMS value of the output voltage.
number of pulses per half-cycle depends on carrier frequency.
In any inverters the two switches in a single are not going to be on for the same time period. Turn-on ,Turn-off period should be different.By varying modulation index the output voltage can be varied .From the equation mentioned below implies that:

$$V_{out} = V_{dc}(\Sigma p_m/\Pi)^{0.5} \tag{1.1}$$

where p_m indicates width of the pulse
The important features revealed by SPWM are:
1.For modulation index less than one the largest harmonic amplitude in output voltage is $f_c/f_r \pm 1$ or $2N_p \pm 1$
The corresponding waveform is shown in fig 1.2

1.3.2 Hysteresis PWM

The hysteresis band is going to operate when error exceeds its magnitude.Hysteresis band is more efficient than the other because it follows more accurately the voltage

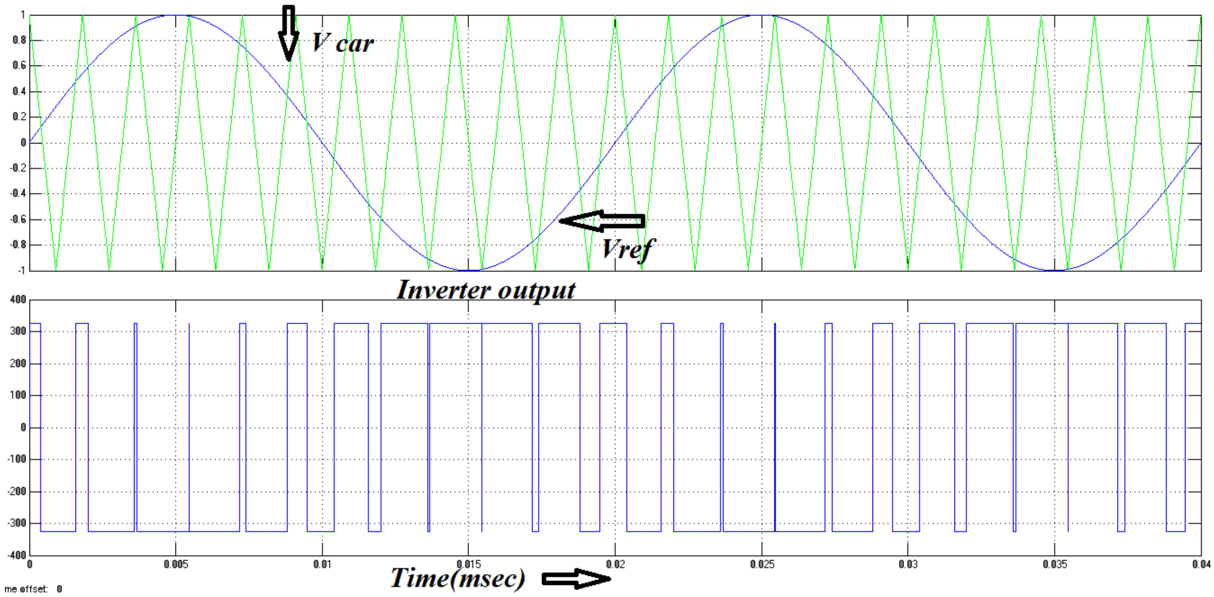


Figure 1.2: The PWM carrier Technique (triangular carrier).

reference of the filter.

1.4 Project Definition

To enhance performance of load voltage using series active power filter and to make it integrated with the DSP. Designing of a series active power filter to get compensation for both voltage and current harmonics as well as implementation of series active power filter model in embedded target folder in MATLAB,after that its integration with DSP processor were carried out.

1.4.1 Expected Outcome of the Work

Series active power filter along with the passive filter eliminates the lower order harmonics and finally which reduces the overall Total Harmonic Distortion(THD).The entire control strategy with load voltages and source currents are used to calculate the oscillating active and reactive powers to get the corresponding reference voltages.Finally,it compensates load voltage and source currents. The active filter along with the various harmonic generating loads under different operating condition has been simulated with MATLAB/ SIMULINK. The simulink model has been prepared considering the ezDSP28335 by using embedded target in the MATLAB.The entire model has been made compatible with the code composer studio (CCS) and finally generated the code for (SHAPF).

Chapter 2

Harmonics

Harmonics created by power electronic devices has been existing in this world since from 1980's .HArmonic distortion is not a new concept.The vast usage of these PE devices has lead to researchers to focus on these areas as a result to improve the power quality issues. The voltage and current waveforms are perfect sinusoids in ideal conditions.It os not possible now because of the increased non-linear loads.So,the waveform is going to get distorted or it is appeared in some other waveform like square wave and stepped wave etc., This deviation from a perfect sine wave can be represented by harmonics. Harmonics are sinusoidal components having a frequency that is an integral multiple of fundamental frequency. A nonsinusoidal wave has distortion and harmonics.There arise the concept of THD.The overall THD of a sine wave is zero.if it gets distorted from its shape the THD is going to increase a lot.

2.1 Effects of harmonics

With the Progress of semiconductor switching devices and high speed superior control techniques, power electronic related equipment has been widely used in various areas. However, the input current of power electronic related equipment contains serious

current harmonics and the input power factor is poor unless wave shaping circuits are provided at the input side. The adverse effects of these equipment places increasing demands on the power plant generation. Thus, harmonic contamination has become a serious problem due to the increase of non linear loads such as static power converters, arc furnaces etc. In general, harmonic current content in input current changes with the load frequency needs. The effects of harmonics on a distribution system are:
1. Interference with other electronic devices
2. Over heating of transformers, switch gear, cables etc.
3. Overheating of fixed speed electric motors
4. Interference with measurement apparatus.
The schemes implemented to eliminate the harmonics are
1. By using transformers in a three phase system it is possible to limit the harmonic injection through non-linear loads.Transformers normally used are wye-delta or wye-wye for achieving 12-pulse operation.Delta connected transformers are used to block Triplen harmonics.
2. The harmful resonances can be detinue by adding some capacitive banks.They can also eliminated by some filters.System frequency responce has to be adjusted properly to avoid adverse harmonic currents interaction with the power system.so,feeder sectionalizing has come into picture to solve the problems. .
3. By using some filters the load side harmonics are eliminated directly suppressing or blocking of these harmonics also can be made.based on the nature of the harmonics introduced we have to select the corresponding reduction equipment.

2.2 Harmonic reduction

There are three commonly employed devices used to achieve the standards of harmonic reduction. They are :
1. Multi pulse transformers

2. Passive filters
3. Active filters

2.3 Multi pulse transformers

Standard variable frequency drives use a six pulse diode bridge rectifier causing six pulses of current to be drawn from the electrical system for every cycle, For a n pulse diode bridge rectifier the lowest harmonics that are produced are of $(n \pm 1)^t h$ order. So, for a six pulse diode bridge 5th and 7th order harmonics are produced. The approximate total harmonic distortions for different orders of harmonic are stated in the following table :

Harmonic Order	Approx current distortion
5^{th}	24%
7^{th}	9%
11^{th}	6%
13^{th}	3%

Table I: Harmonic order and current distortion

2.3.1 Passive Filter

Conventionally, passive LC filters are used to eliminate current harmonics and to improve the power quality. There are many forms of passive harmonic filters commercially available today and are typically inductor or capacitor networks designed to manipulate the shape of the current. A passive filter can be effective over a narrow load range. The application of these passive tuned filters creates new system resonances, which are dependent on the specific system conditions. Passive filter ratings must be coordinated with reactive power requirements of the loads and it is often difficult to design the filters to avoid leading power factor operation.Design procedure of passive filters is a very difficult task as so many conditions like resonance phenomenon and interfacing of source impedance all these has to keep in mind. passive following disadvantages:

- Source impedance plays an vital role in the filtering characteristics.
- As both the harmonic and the fundamental current components flow into the filter, the filter must be rated by taking into account
- Filter can be overloaded with harmonics.
- The parallel resonance between the shunt filters and power system leads to amplify the source current with some frequency.
- The series resonance will have the possibilities of producing un-balances in the voltages leads to increase the flow of harmonic currents through the passive filter.

Chapter 3

Active power filter

3.1 Principle and Theory

The increased severity of harmonic pollution in power networks has attracted the attention of the power electronics and power system engineers to develop dynamic and adjustable solution to the power quality problems. In that way, active filters have become a variable alternative for controlling harmonic levels. The active filters are also called as active power filters (APF) or active power line conditioners (APLC).

Type of influences	LC	APF
Influence of an increase in current	Risk of overload and damage.	No risk of over load, but less effective
Added equipment	In certain cases, requires modifications to the filter	No problem if Ih>Iload
Dimension	LARGE	SMALL
weight	high	low
Modification in fundamental frequency	Can not be modified	Possible via reconfiguration
Harmonic Control by filter order	Very difficult	Possible via parameters
modification of impedance	risk of resonance	no effect

Table I: Comparison between active and passive filter.

3.1.1 Active Filter Theory and Principle

Generally, an active filter has been considered as a current source connected in parallel to the load (harmonic source). The basic principle of an active power filter is that it generates a current equal and opposite in polarity to the harmonic current drawn by the load and injects it at the point of common coupling, thereby forcing the source current to be a sinusoidal. The fundamental block diagram of shunt active power filter is shown below in fig. 3.1.

3.2 Active power filters classification

There are different classifications based on different topologies.Current source inverters,voltage source inverters,Two wire active filters Three wire active filters.

3.3 CONVERTER BASED CLASSIFICATION

3.3.1 CURRENT SOURCE INVERTER FILTER

There are two types of converters used in development of active filters i.e. current source converter and voltage source converter. The following fig3.5 shows the current fed pulse width modulation inverter bridge structure. It behaves as a non sinusoidal current source to meet the harmonic current requirement of the nonlinear load. A diode is used in series with the self commutating device for reverse voltage blocking

3.3.2 VOLTAGE SOURCE INVERTER FILTER

The other converter used as an active filter is a voltage fed PWM inverter structure as shown in the fig. 3.6 it has a self supporting d.c. voltage source. It has become more dominant since it is lighter, cheaper and expendable to multi step versions to enhance the performance with lower switching frequencies. It is more popular in UPS based applications because in the presence of mains the same inverter bridge can be used as an active filter to eliminate harmonics of critical non-linear loads.

3.4 Supply system based classification

3.4.1 2 WIRE ACTIVE FILTERS

This topology can be used for series,shunt and hybrid power filters.In this topology it can also be used as power line conditioner.

3.4.2 3 WIRE ACTIVE FILTERS

Three phase three wire non-linear loads such as adjustable speed drives are major applications of solid state power converters. All the configuration shown below are three wire active filters with three wires on the a.c. side and two wires on the d.c side. Active shunt filters can also be designed with three single phase active filters with isolation transformers for proper voltage matching.It consists of a VSI PWM,Capacitive energy storage element,inductive storage element.

3.4.3 4 WIRE ACTIVE FILTERS

A large number of single phase loads may be supplied from three phase mains with neutral converter. They caused excessive neutral currents, harmonic and reactive power burden and unbalanced. Four wire active filters can be used to activate the above problems in three phase distribution networks with unbalance loads.

3.5 Topology based classification

A parallel active filter is a pulse width modulation inverter to be placed in parallel with a load to inject a harmonic current with the same amplitudes as that of the load

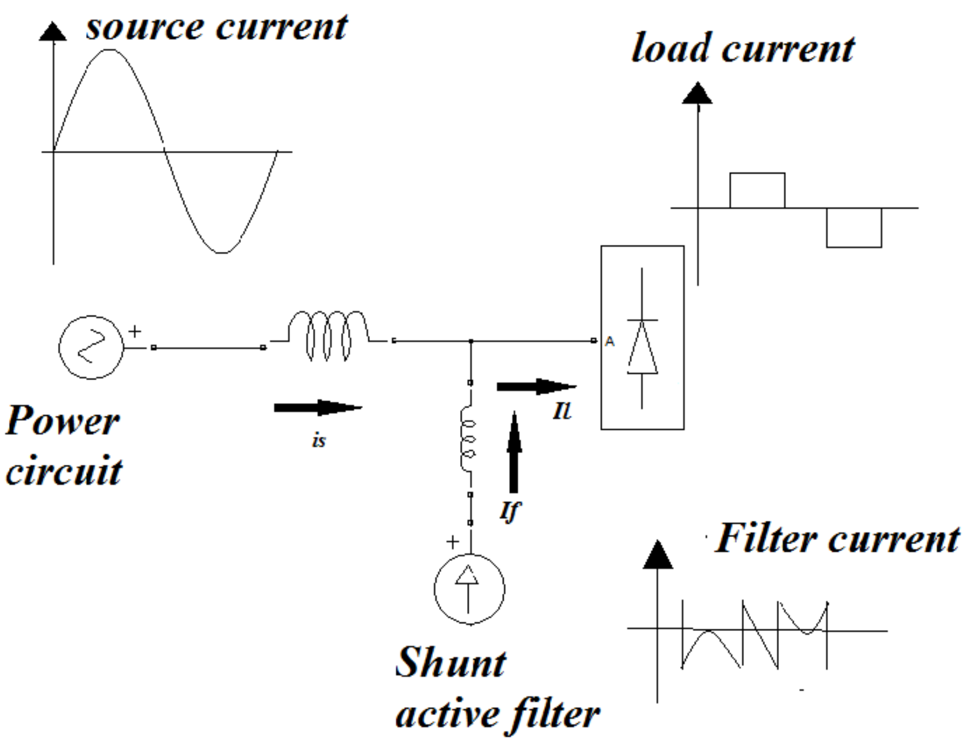


Figure 3.1: Active shunt filter

in to the a.c. system. Its control is implemented through a detection and extraction circuit of the load harmonic current.

3.6 SERIES ACTIVE FILTERS

The series active power filter design is complex than shunt active power filter.so,its design gains only prototype level value in industries.At first everyone thought that series active power filters are good alternatives for voltage regulators.Series active power filter acts as a harmonic isolator not as harmonic eliminator. Active power filter produces the harmonics in opposite direction so that any un balances in the voltages at source side are compensated finally,sinusoidal waveforms are going to come across the load side.

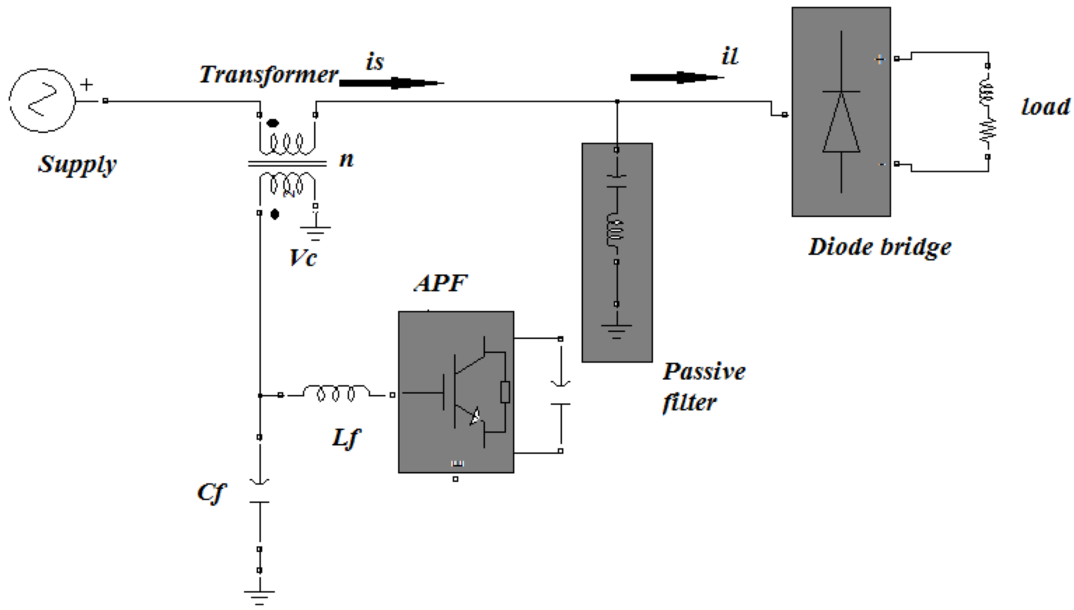


Figure 3.2: Active series power filter

Chapter 4

Series and hybrid active power filter

Figure4.1 shows the power schematic of SHAPF topology.The voltage which is coming from the grid may not be sinusoidal all the times.It injects some harmonics into it as a result the waveform is going to destructed from its original shape.Those are nothing but the unbalanced voltages created in the grid.This leads to affect the load parallel so,in order to protect the so many protection techniques had already discussed [2].one among the theory is instantaneous reactive power theory which was proposed by Akagi[2].In two ways we can mitigate these harmonics:Load conditioning and line conditioning.The series active power filter design is complex than shunt active power filter.so,its design gains only prototype level value in industries.At first everyone thought that series active power filters are good alternatives for voltage regulators.Series active power filter acts as a harmonic isolator not as harmonic eliminator. Active power filter produces the harmonics in opposite direction so that any un balances in the voltages at source side are compensated finally,sinusoidal waveforms are going to come across the load side.Here,series active power filter acts as a controllable voltage source.

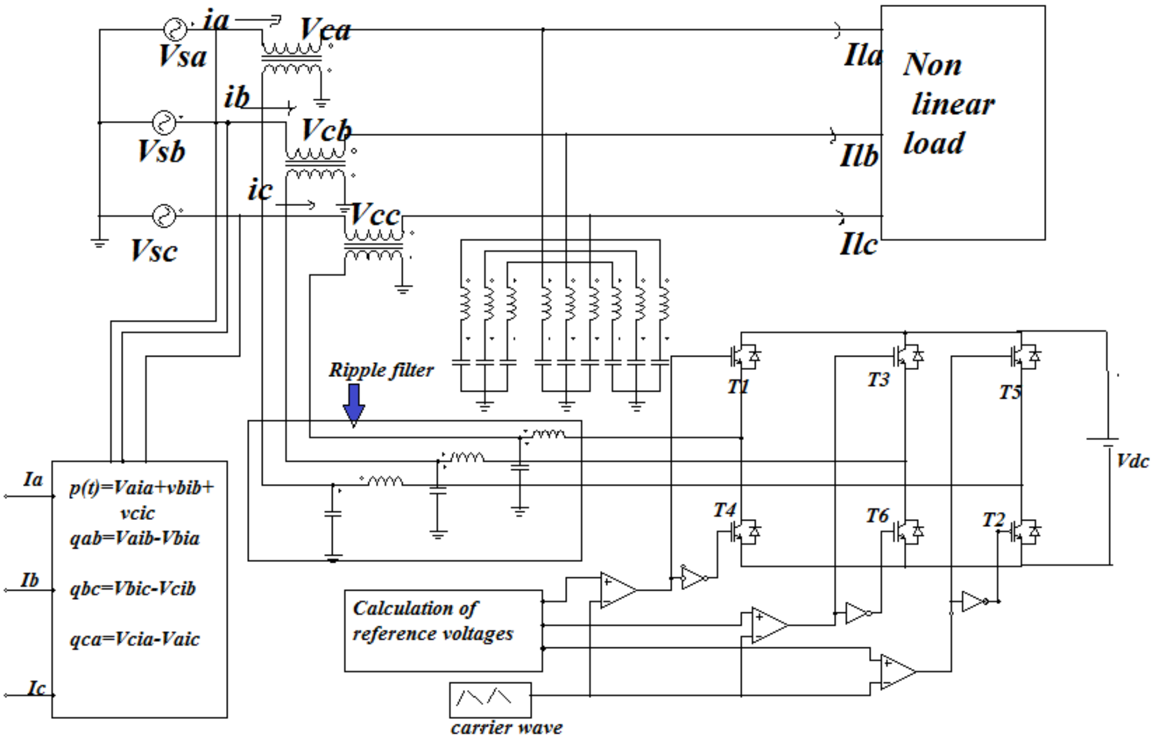


Figure 4.1: Series hybrid active power filter

4.0.1 Construction details

SHAPF consists of a unbalanced voltage source,an ideal Transformer,ripple filter,voltage source inverter,Shunt passive filter,non-linear load.Voltage source would able to produce the unbalanced voltages wether they are sag or swells.The aim of ideal transformer is to make the active filter voltages to reach to the Grid voltage.It also provides isolation to the active power filter from the Grid.Ripple filter is going to remove the un-wanted d.c. component from the inverter output and also switching losses of inverter has been eliminated. VSI has to be switched in such a way that it can eliminate all the lower order harmonics from the grid so that, load voltages are almost sinusoidal.Shunt passive filter has to be tuned in such a way that it has to provide low-impedance path to fundamental and high-impedance to all other lower order harmonics.The details of my Selection of values of all these are mentioned in the table below.The value of dc-link has to be chosen that the value has to be constant .so that it can improve the system voltage gain and reduce the . passive filter is used to cancel the most relevant harmonics of the load,active filter is dedicated to improving the passive filter to cancel all the lower order harmonics and to improve the system efficiency .Active filter forces the harmonics to pass through the passive filter rather than in power system.Tuninig of passive filter is also not important in SHAPF.As the active power filter is going to improve the passive filter efficiency .so,cost reduction also possible as the big LC filters were replaced by active power filters.Reactive power compensation is achieved.Voltage control is achieved with constant switching frequency of the active filter.This [2] is valid for balancing un balances in the voltages.

4.1 Instantaneous reactive power theory

The instantaneous reactive power theory has been well established by Akhagi[2].Akhagi believes that passive filters inside the controllers are not going to avoid the active fil-

System name	Value
Supply voltage	110v,50Hz
Dc-link capacitor	2.2mf
Ripple filter	1.35mH,0.05mf
Transformer	20:1
Carrier frequency	25kHz

Table I: Values of SHAPF

ters to act in time domain analysis.He approached his analysis towards shunt active power filters. There the non-sinusoidal wave forms of current at source side are going to be sinusoidal with the help of this active filter.IRP is well valid for shunt active filters.Researchers mentioned in[3, 5, 6]had discussed about the IRP theory application part in series active power filters.The control algorithm place a very important role in this filters.Thus, different control techniques are emerged mentioned in the literature[1, 2, 7]. IRP theory uses Clarkes transformation i,e.,conversion of three phase abc to two phase co-ordinates($\alpha\beta$).But this application in series filter is now also a big issue.so,the considerations of series filter is limited to prototype model in the industry. Now studies are carried out for series active power filter only that un balances in the voltages are reduced but still sag or swell conditions are not yet eliminated which results are exhibited in chapter 8.The mathematical description of IRP is shown below:

$$v = [va, vb, vc]^T i = [ia, ib, ic]^T \tag{4.1}$$

v_a = phase to ground voltage i_a = phase current.

$$\begin{pmatrix} v_\alpha \\ v_\beta \\ v_o \end{pmatrix} = 0.471 * \begin{pmatrix} .707 & .707 & .707 \\ 1 & -0.5 & -0.5 \\ 0 & 0.866 & -0.866 \end{pmatrix} \begin{pmatrix} v_a \\ v_b \\ v_c \end{pmatrix} \tag{4.2}$$

$$\begin{pmatrix} i_\alpha \\ i_\beta \\ i_o \end{pmatrix} = 0.471 * \begin{pmatrix} .707 & .707 & .707 \\ 1 & -0.5 & -0.5 \\ 0 & 0.866 & -0.866 \end{pmatrix} \begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} \tag{4.3}$$

Instantaneous powers are then defined as follow:

$$\begin{pmatrix} p \\ q \\ p_o \end{pmatrix} = \begin{pmatrix} i_\alpha & i_\beta & 0 \\ -i_\beta & i_\alpha & 0 \\ 0 & 0 & i_o \end{pmatrix} * \begin{pmatrix} v_\alpha \\ v_\beta \\ v_o \end{pmatrix} \tag{4.4}$$

$$p = \bar{p} + \tilde{p} = v_\alpha i_\alpha + v_\beta i_\beta \tag{4.5}$$

$$q = \bar{q} + \tilde{q} = v_\alpha i_\alpha - v_\beta i_\beta \tag{4.6}$$

$$\tilde{p} = p - \bar{p} \tag{4.7}$$

$$\tilde{q} = q - \bar{q} \tag{4.8}$$

$$v_{c\alpha} = (1/(i_\alpha^2 + i_\beta^2)) * (i_\alpha * \tilde{p} + i_\beta * q) \tag{4.9}$$

$$v_{c\beta} = (1/(i_\alpha^2 + i_\beta^2)) * (i_\beta * \tilde{p} - i_\alpha * q) \tag{4.10}$$

$$v_{ca}^* = \sqrt{2/3} * (v_{co} + v_{c\alpha}) \tag{4.11}$$

$$v_{cb}^* = \sqrt{2/3} * (\sqrt{1/2}v_{co} - 0.5v_{c\alpha} + \sqrt{3/2}v_{c\beta}) \tag{4.12}$$

$$v_{cc}^* = \sqrt{2/3} * (\sqrt{1/2}v_{co} - 0.5v_{c\alpha} - \sqrt{3/2}v_{c\beta}) \tag{4.13}$$

The IRP is based on that sensing of load side voltages and source currents and the product of those terms displays two quantities of powers one is active power and another is reactive power.Based on the theory explained the model has been built and implemented.From theory point of view IRP uses both voltages and currents for the generation of voltage compensation.But these voltages and currents are instantaneous values.so,it has to generate a compensated voltage for series filter with these instantaneous values.so it makes the system as un-stable one.As load voltage depends on its terminal voltage there a infinite loop is going to be generated.Nothing but positive feedback.If load is independent on the terminal voltage then there are chances to implement pq theory to series filter.so,here two possibilities are there to mitigate the above mentioned problems.One is assuming source voltage as sinusoidal with varying i.e., distorted load current or viceversa.Finally this theory [5] gives the limitations of this theory to series compensation.Finally the powers calculated from above theory are used in such a way that it has to provide unity power factor.It has to reduce the overall THD.The inverse clarkes transformation is also used again for converting two phase to three phase co-ordinate system.

4.1.1 Importance of DC side capacitor

The DC side capacitor serves two main purposes:

1. it maintains a DC voltage with small ripple in steady state

2. serves as an energy storage element to supply real power difference between load and source during the transient period.

The power is same at both the receiving end or at the sending end.Here consideration of dc-link reference voltage is very much necessary.At some circumstances due to variation in load or supply voltages power balancing may not be possible which is going to have adverse affects on the power system.Active power filter is operated at a safe zone if this dc-link voltage is maintained constantly.closed loop has to be made that comparison of reference voltage with dc-link voltage along with a PI controller to extract the error has been used shown in fig4.2
Small value of Dc-link may not be able to supply the reactive power demand of the filter.large value leads to make the reference voltage quite smaller than reference current at source side.This leads to ripples in the dc-link voltage.These ripples are eliminated by using some low-pass filters. Hence, this voltage is sampled at the zero crossing of one of the phase voltage, which makes the compensation instantaneous. Sampling only twice in cycle as compared to six times in a cycle leads to a slightly higher DC capacitor voltage rise/dip during transients, but settling time is less. Hence, this voltage is sampled at the zero crossing of one of the phase voltage, which makes the compensation instantaneous.

4.1.2 L_c AND $V_{dc,ref}$ Selection procedure

- Assume that AC source voltage is sinusoidal.
- The AC side line current distortion is assumed to be less than 5%.
- Fixed capability of reactive power compensation of the active filter.
- The PWM converter is assumed to operate in the linear modulation mode (i.e.$0 \leq ma \leq 1$).

the active filter can compensate the reactive power from the utility only when $Vc1 > Vs$. If the PWM converter is assumed to operate in the linear modulation mode (i.e.$0 \leq ma \leq 1$), the amplitude modulation factor m_a is

$m_a = v_m/(v_{dc}/2)$ Where $vm = \sqrt{2}Vc$, and hence $Vdc = 2\sqrt{2}V_{c1}$ for $m_a = 1$.

4.1.3 DESIGN OF DC SIDE CAPACITOR (C_{dc})

Selection of cs side capacitor is decided based on the ripple quantity to be eliminated.[8] As per the specification of the peak to peak voltage ripple ($V_{dcp-p(max)}$) and rated filter current ($I_{c1}, rated$), the DC side capacitor Cdc can be found from equation $c_{dc} = (\prod *i_{c1rated})/(\sqrt{3}\omega v_{dcp-pmax}$

4.1.4 DC VOLTAGE CONTROL LOOP

The block diagram of the voltage control loop is shown in figure 4.4. Where,$G_c$is the gain of the PI controller and K_c is the transfer function of the PWM converter.

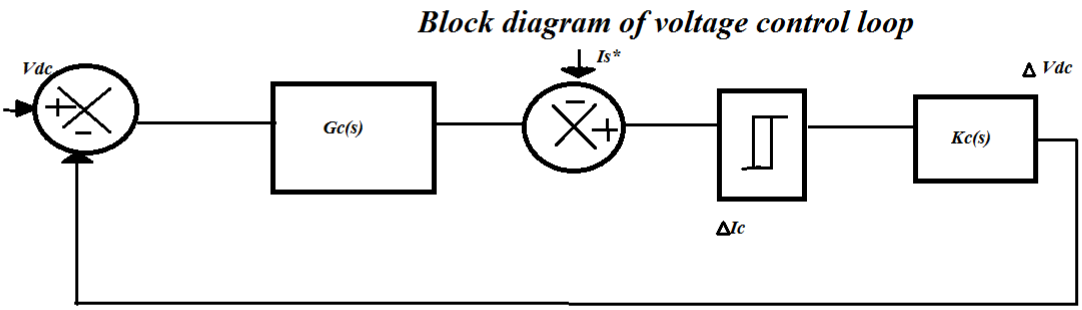


Figure 4.2: Block diagram of voltage control loop.

4.1.5 SELECTION OF PI CONTROLLER PARAMETERS

PID controller is nothing but proportional derivative integral controller.For any system the values of these controllers should be very specific so that,they are producing the error signals between a desired value and a set point value.The entire closed loop is based on the PID controller.So,the error detected by controller has been corrected

and again feedback is started. PID controllers are divided into PI,PD,P controllers:
PI is proportional + integral
PID is proportional + derivative + integral.
P is proportional
I is Integral
All these are the different kinds of controllers available now. Now no one are using these controllers manually just code is built in DSP processors and that generates the error and everything is online only.overshoot,magnitude-gain,amplitude-gain,Steady state error all the parameters we can observe across the controllers.By changing the k_p,k_i,k_d constant values one can vary the error signal.proportional mode is going to be measure across current error value.
The characteristic equation of the voltage control loop is used to obtain the constants of PI controller can be written as :
$1 + (k_p + k_i/s)(3(v_s - L_s I_{co} s - 2 i_{co} R_c)/c_{dc} v_{dco} s) = 0$
second order transfer function for closed loop. The current controller has been designed on the basis of 5% overshoot, to step the change in the amplitude of current reference. The analysis of this characteristic equation shows thatk_p determines the voltage response and K_i defines the damping factor of the voltage loop.

Chapter 5

Modified instantaneous reactive power theory

As mentioned drawbacks in the Instantaneous reactive power theory the modifications were made [1] to achieve sag and swell concept in the series active power filter.But proper reference scheme for SHAPF is very important.The objective of this scheme is to extract load voltage harmonics or source current harmonics.Series active power filter along with the passive filter eliminates the lower order harmonics and finally which reduces the overall Total Harmonic Distortion(THD).The control scheme is performed on Load voltage and source current to calculate components of load voltage that represents oscillating active power and oscillating inactive power. This is used as a reference voltage for deciding the switching of inverter switches.Akhagi[2] showed a valued results for active power filter but due to drawbacks of the theory this[1] is considered.

The IRP is based on that sensing of load side voltages and source currents and the product of those terms displays two quantities of powers one is active power and another is reactive power.Based on the theory explained the model has been built and implemented.From theory point of view IRP uses both voltages and currents for the generation of voltage compensation.But these voltages and currents are instantaneous values.so,it has to generate a compensated voltage for series filter with these instantaneous values.so it makes the system as un-stable one.As load voltage depends on its terminal voltage there a infinite loop is going to be generated.Nothing but positive feedback.If load is independent on the terminal voltage then there are chances to implement pq theory to series filter.so,here two possibilities are there to mitigate the above mentioned problems.One is assuming source voltage as sinusoidal with varying i.e., distorted load current or viceversa.Finally this theory [5] gives the limitations of this theory to series compensation.Finally the powers calculated from above theory are used in such a way that it has to provide unity power factor.It has to reduce the overall THD.The inverse clarkes transformation is also used again for converting two phase to three phase co-ordinate system.

5.1 System configuration

SHAPF consists of a unbalanced voltage source,an ideal Transformer,ripple filter,voltage source inverter,Shunt passive filter,non-linear load.Voltage source would able to produce the unbalanced voltages wether they are sag or swells.The aim of ideal transformer is to make the active filter voltages to reach to the Grid voltage.It also provides isolation to the active power filter from the Grid.Ripple filter is going to remove the un-wanted d.c. component from the inverter output and also switching losses of inverter has been eliminated. VSI has to be switched in such a way that it can eliminate all the lower order harmonics from the grid so that, load voltages are almost sinusoidal.Shunt passive filter has to be tuned in such a way that it has to provide low-impedance path to fundamental and high-impedance to all other lower order harmonics.The details of my Selection of values of all these are mentioned in the table below.The value of dc-link has to be chosen that the value has to be constant .so that it can improve the system voltage gain and reduce the . passive filter is used to cancel the most relevant harmonics of the load,active filter is dedicated to improving the passive filter to cancel all the lower order harmonics and to improve the system efficiency .Active filter forces the harmonics to pass through the passive filter rather than in power system.Tuninig of passive filter is also not important in SHAPF.As the active power filter is going to improve the passive filter efficiency .so,cost reduction also possible as the big LC filters were replaced by active power filters.Reactive power compensation is achieved.Voltage control is achieved with constant switching frequency of the active filter.This [2] is valid for balancing un balances in the voltages.

5.2 control scheme

[1] The reference voltage has been generated with voltage vector and current vector.the supply voltage and source voltages are sensed and the voltage has been divided into multi-phase dimensions and then unit template vector is generated for deciding positive ,negative and zero components of the system. This analysis provides the basic information of the instantaneous power ad their formulations and their calculations as [1]

$v = [v_a, v_b, v_c]^T$

$i = [i_a, i_b, i_c]^T$.

instantaneous power is a multiple of instantaneous voltages and currents

$s(t) = v(t)i(t) = v(t) * i(t) + v(t) \bigotimes i(t)$

The inner product of voltages and currents gives the instantaneous power

$p(t) = v(t) * i(t) = v^T i = v_a i_a + v_b i_b + v_c i_c$

In this thesis, control scheme compensating the source voltage unbalance and the harmonic current for the combined system of the series active and shunt passive power filter system is made based on [1].

$$v(t) * i(t) = \begin{pmatrix} v_a & v_b & v_c \end{pmatrix} \begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} = \begin{pmatrix} i_a v_a & i_a v_b & i_a v_c \\ i_b v_a & i_b v_b & i_b v_c \\ i_c v_a & i_c v_b & i_c v_c \end{pmatrix} \tag{5.1}$$

Subtracting (5.4) from (5.3) formula for instantaneous inactive power is expressed as

$$q(t) = \begin{pmatrix} 0 & -(v_a i_b - v_b i_a) & (v_c i_a - v_a i_c) \\ (v_a i_b - v_b i_a) & 0 & -(v_b i_c - v_c i_b) \\ -(v_c i_a - v_a i_c) & (v_b i_c - v_c i_b) & 0 \end{pmatrix} \tag{5.2}$$

this can be expressed as

$$q(t) = \begin{pmatrix} 0 & -q_{ab} & q_{ac} \\ q_{ab} & 0 & -q_{bc} \\ -q_{ac} & q_{bc} & 0 \end{pmatrix} \tag{5.3}$$

with each component being defined as,$q_{ab} = v_a.i_b - v_b.i_a$; $q_{bc} = v_b.i_c - v_c.i_b$; $q_{ca} = v_c.i_a - v_a.i_c$. The power quantities defined Reference voltages for SHAPF are derived as:

$$s(t) = v_p(t).i(t) + v_q(t) \bigotimes i(t) \tag{5.4}$$

5.2.1 Decomposition of voltage vector

Two voltage vectors are generated one is instantaneous active voltage vector and another is instantaneous inactive voltage vector. Substituting$v(t) = v_p(t).v_q(t)$. we obtains$s(t) = [v_p(t)+v_q(t)]*i(t)+[vp(t)+vq(t)].i(t)$. After simplification s(t)expressed as:

$$s(t) = v_p(t).i(t) + v_q(t) \bigotimes i(t) \tag{5.5}$$

instantaneous load voltage vector v_p, can be expressed as

$$s(t) = i^{-1}(t)p(t) = i(t)/||i||^2 p(t) \tag{5.6}$$

where$vp = [v_{pa}, v_{pb}, v_{pc}]T$and the vector v_p is denoted as instantaneous active voltage tensor. The instantaneous inactive voltage vectorv_q as follows:

$$q(t) = v_q(t)i(t) \tag{5.7}$$

by performing the things vq(t) can be expressed as:

$$i(t)*q(t) = i(t)*v_q(t)*i(t) \; i(t)*q(t) = (i(t)*i(t))v_q(t) - (v_q(t)*i(t))i(t) \; i(t)*q(t) = ||i||^2 v_q(t) - 0 \tag{5.8}$$

product $i(t)q(t)$can be calculated as

$$v_q(t) = [v_{qa}, v_{qb}, v_{qc} = [q]^T * i(t)/i^2 \tag{5.9}$$

$$\begin{pmatrix} v_{qa} \\ v_{qb} \\ v_{qc} \end{pmatrix} = \begin{pmatrix} 0 & q_{ab} & -q_{ca} \\ -q_{ab} & 0 & q_{bc} \\ q_{ca} & -q_{bc} & 0 \end{pmatrix} * \begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} \tag{5.10}$$

v_p represents instantaneous active voltage
v_q represents instantaneous inactive voltage.
These voltages directly related with the instantaneous voltages and currents finally decides the instantaneous power.Which are going to establish the relation in three phase co-ordinate system.

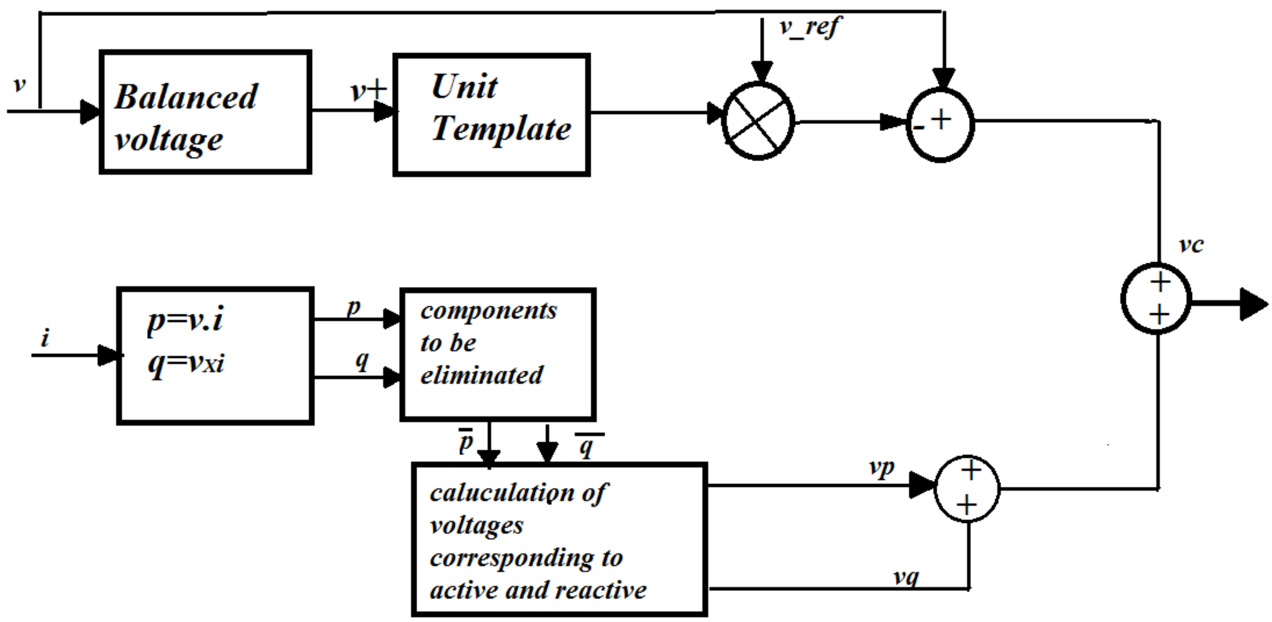


Figure 5.1: Logic circuit

Chapter 6

DSP Implementation

The DSC based kits allow us to perform experiments on MSK28335 boards.LF 28335 kits are used for motion control.ez28335 device is a low voltage i.e., 3.3v controller.It is used in advanced digital motion control equipments.it os a combination of on chip peripherals of a micro-controller and DSC core on a single chip.Two 3-phase a.c.motors can controlled at a single time .The processor has efficient peripherals to control the motors at a single time.It is the advanced processor.F28335 had features like developing DSC code using linker,assembler,debugger which are included in the DMC28xpro platform.The kit is basically designed for motion control and testing.It has its own in-built software.A professional integrated development environment(IDE) including:assembly and C language debugger,advanced graphical tools,debugger are there for real time applications and for reference generation.It also have reference generator and real-time data acquisition tools.

6.1 Installing the MSK28335 / MCK28335 kits

This section describes that how to install the MSK28335 kits or the MCK28xxts on an IBM pc or system running under Windows 95 / 98 / Me / NT / XP. Both hardware

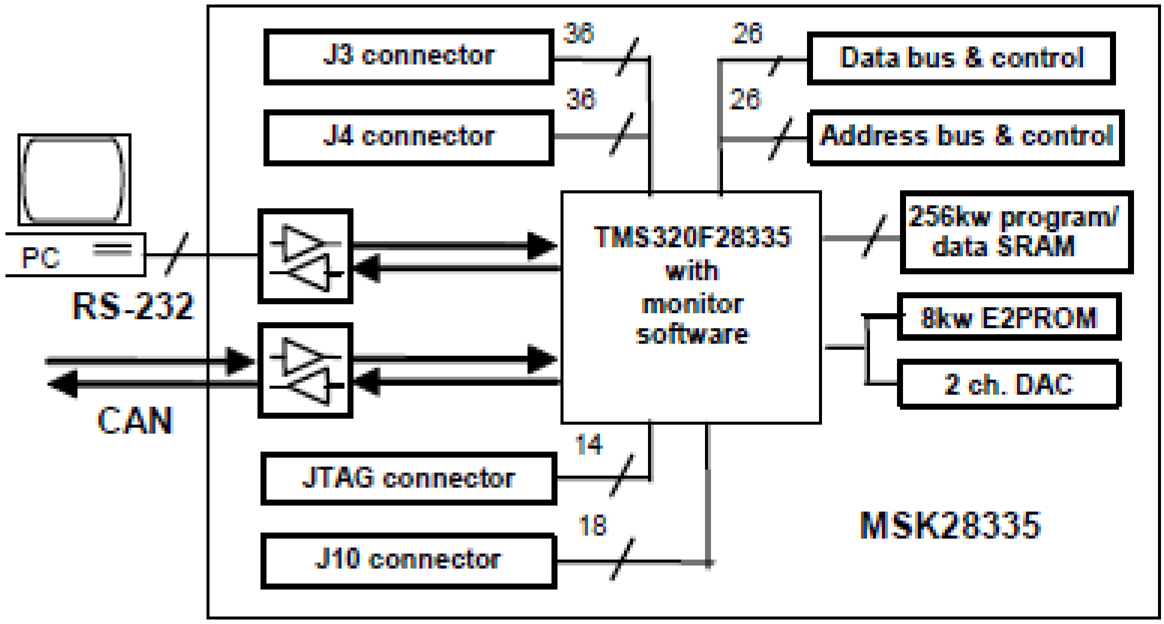


Figure 6.1: Block Diagram of MSK28335

as well as software procedure installation are described in successive steps.

6.1.1 Contents

[14]

a. host computer:An IBM PC or compatible, with hard disk, CD-ROM drive, running under Windows '95, 98, Me, NT 4.0 or XP, with a RS232 serial port available (or USB port + USB / RS232 converter)

b. power requirements:MSK28335 kits: a 5 VDC (±10%) power supply at minimum 0.5 A is needed to properly drive the MSK28335 DSC board alone

c. boards:MSK28335 kits: MSK28335 DSC board

d. serial cable:DB9 plug to DB9 or DB25 socket (depending on the PC connector)

e. setup CD:Containing the setup files for the kit to install: MSK28335 kit or MSK28335 kit Pro or MCK28335 kit or MCK28335 kit Pro

6.1.2 MSK28335 DSC board connections

Figure 6.2 The fig represents the entire components of a MSK28335 processor.connectors,jumpers, headers are outlined.All the components are mentioned clearly.

6.1.3 Connecting the MSK28335 DSC board to Your PC

Follow these steps to connect your MSK28335 DSC board to your PC:

a. Switch -off the power supply to DSP.

b. With the help of RS-232 serial port cable directly connect the DSP to the PC.If DB9 pin is not available on the PC then connect aa DB25-DB9 converter and install the corresponding drivers and make it compatible with the PC by making some changes in settings.

c. Attach the RS-232 cable to MSK28335 DSP to the J8 connector.

d. Connect the 5 VDC power supply to the J7 connector of the MSK28335 DSC board.

e. Apply the supply i.e., 5v across the DSP if LED green light glows then installation is proper otherwise refer the manual[14] for installation errors.

6.2 Generation of mdl file in simulink

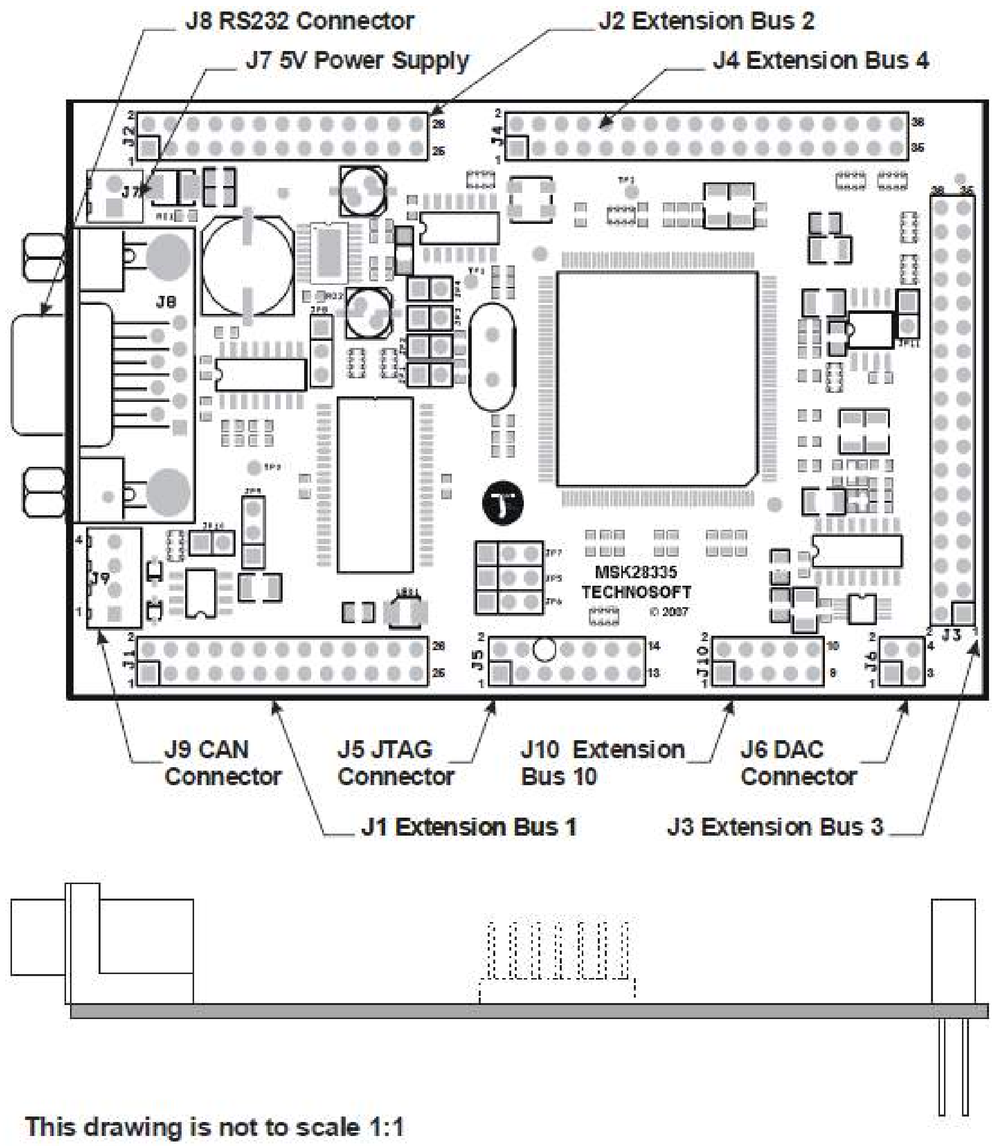


Figure 6.2: MSK28335 DSC board layout

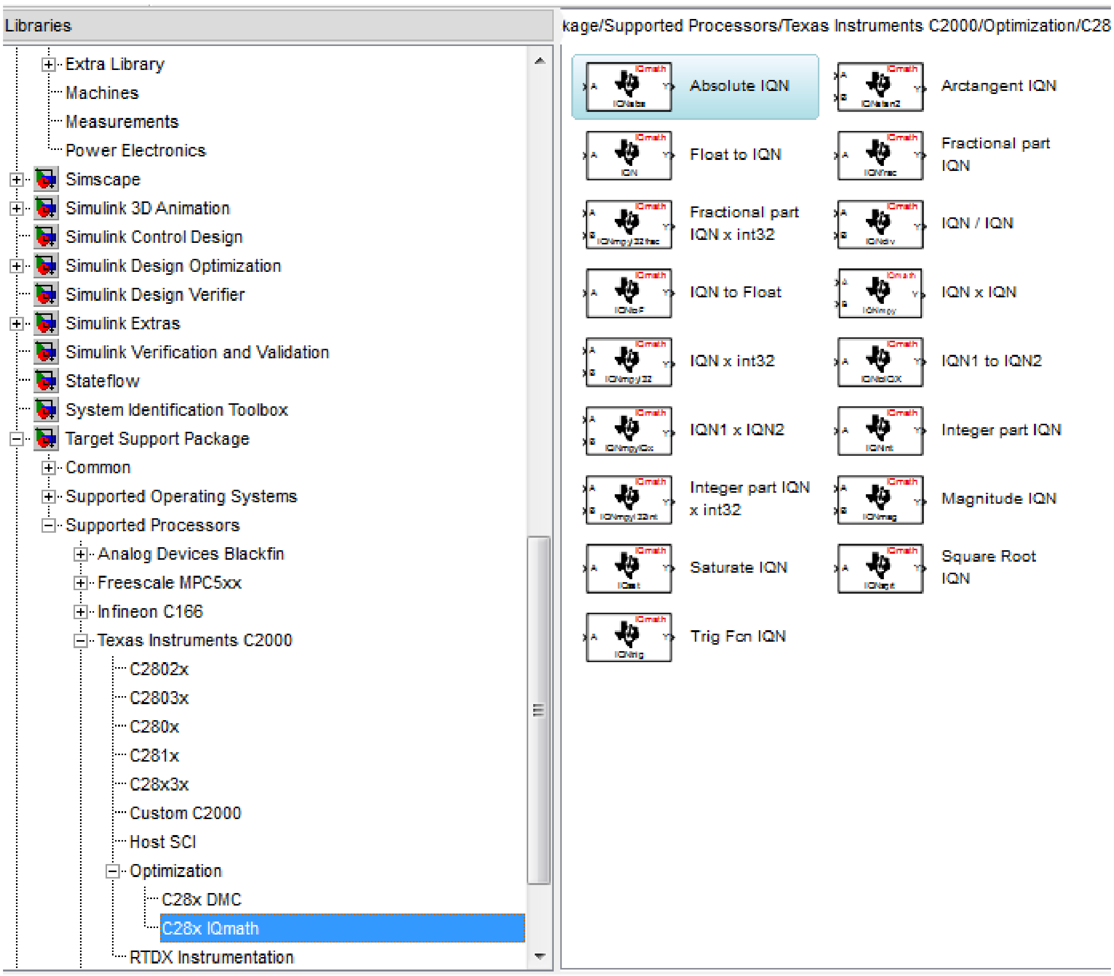


Figure 6.3: Embedded Target for TI C2000 DSP

6.3 Explanation of different blocks

6.3.1 Input block

Go to the simulink library browser in MATLAB.Embedded target for TI c2000 DSP was there.Inc28xx DSP chip support some special building blocks are introduced.There in the help Purpose of block has been discussed very clearly.This block is necessary whenever digital inputs are needed.so,the controllers working on DSP needs digital input to start the DSP.Example for that is computers on and off switch.The block has several digital input ports and each port is designed for its multi-functionality.

6.3.2 output block

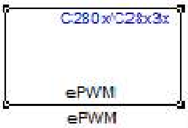
Go to the simulink library browser in MATLAB.Embedded target for TI c2000 DSP was there.Inc28xx DSP chip support some special building blocks are introduced.There in the help Purpose of block has been discussed very clearly.This block is necessary whenever digital outputs are needed.Example for that is on and off switch of motors.The output block of DSP is going to drive only small loads like LEDetc., but for driving high loads like motors external electronic circuits has to be added.

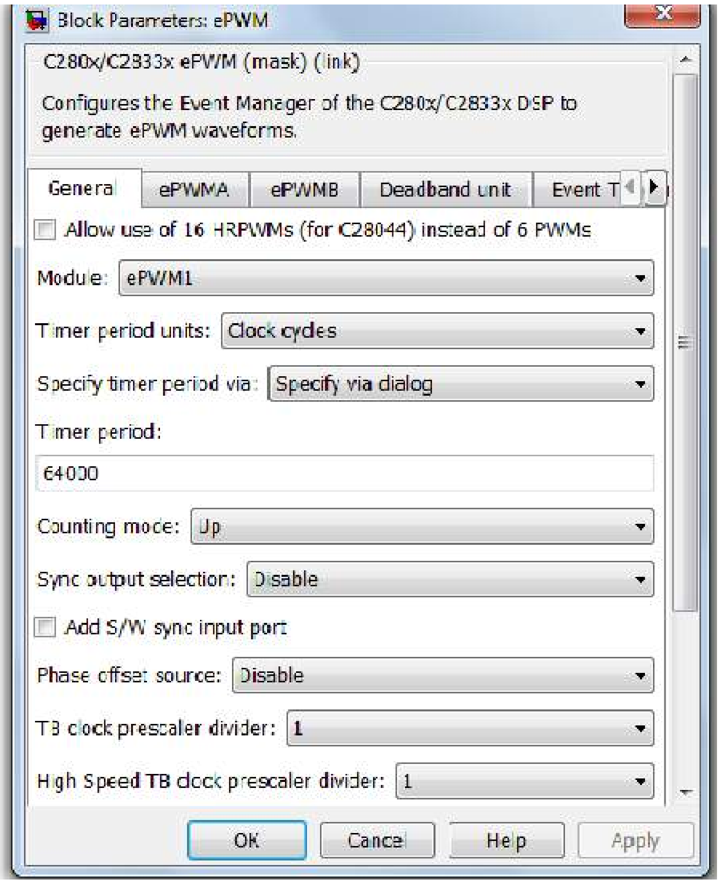
6.3.3 ADC (Analog to Digital Converter)

The most important part of DSP is ADC .Where providing the signals in analog form and getting results in the digital form.c28xx has two groups of analog to digital converters .so,finally 16 pins are there.The sufficient voltage to converter is 3.3v if more than that needed so additional equipment has to be added to protect the DSP from the attenuated signal.

6.3.4 PWM (Pulse Width Modulation)

PWM technique is needed to save the power .It is taking the signals in digital form and producing signals in analog form just opposite to that of ADC.switch will be on for some time period and it will be off for some other time period finally power is going to saved.





6.3.5 Hardware Interrupt

One of the basic important concepts of DSP.The thorough knowledge is necessary for its understanding.one should have a brief knowledge on the architecture to use this interrupt.

6.3.6 What is an Interrupt?

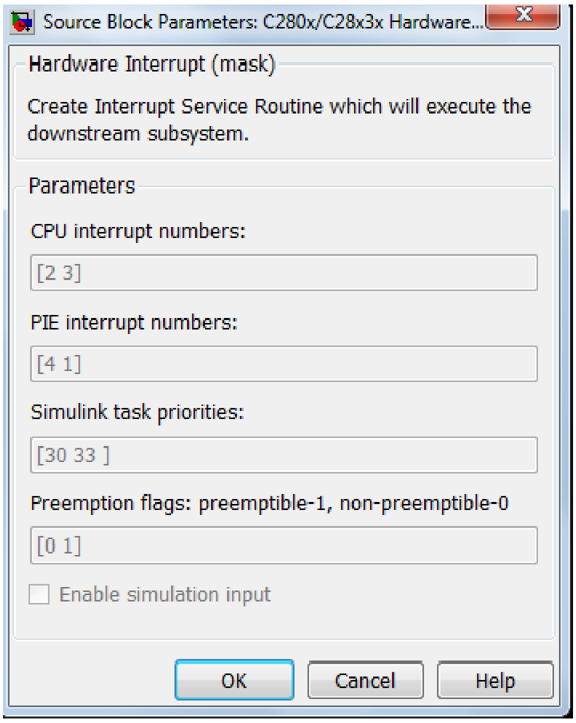
Interrupt is nothing but a disturbance caused to stop the work for a while or for a longer duration.Example for an interrupt is phone.If some one gets a call he stop doing the work nothing but an interrupt and again few seconds later he continues his work.

6.3.7 Hardware Interrupt

Hardware interrupt is nothing but if once hardware set up connected to DSP,due to some switching frequency of the switches a sudden interrupt will occurs for some milli seconds .A hardware interrupt is a one generated by the dedicated function inside the c28xx chip.

6.3.8 Timers

The timers in the C2812 are contained within the Event Managers EVA and EVB. Each contains 4 timers. Timers can be used for a whole range of different purposes: 1.To turn outputs on and off at pre-determined times 2.To generate output waveforms 3.To measure input waveforms



6.3.9 Extended CAN Interface

controller area network . It works in all the environmental conditions.The interface was used for maintaining Transmission,car engines which was developed by RObert Bosch. The F28xx has a single CAN interface.is one of the most important communication methods available for industrial process control and automotive.

6.3.10 SCI Interface

SCI stands for serial communications interface. Before USB ports are made the interaction is made to system cpu through DB9 SCI.

6.3.11 SPI Interface

Serial port interface which can connect the DSP to interact with the system.It is the only device which have the interaction between central processing unit and analog to digital converters and digital to analog converters. synchronous method of communication. Two lines are provided one for data and a second for clock. It can send data in one direction and at the same time receive data going the other way.

6.3.12 IQ Maths and Scaling

Actually we have two kinds of processors available with us: one is fixed point another is floating point.C28xx is a fixed-point processor.It is not going to take decimal values directly .so.conversion has to be made from decimals to integers.It will take round integers like for ex.,1.567 so it will take the value as 1.Scaling has to be made for rounding -off these decimal values . In MATLAB a Embedded target for TI c2000 DSP was there to support IQ maths.This block will do the perfect scaling to the design which makes the work to be very easier.We can covert fixed to floating point and viceversa using this IQ Maths block.

Chapter 7

Compatibility

7.1 Introduction

Texas instruments are producing so many DSPs among them C28xx series has been made for the motion control purpose and UPS.

7.1.1 Objectives

Design the project in MATLAB simulink by using Embedded Target folder and Texas Instruments c28xx .Run the project with the help of code composer studio(CCS) and generate the code and se the result across DSP.

7.1.2 Necessary things needed

Requirements for building the project are:

a. MATLAB R2013a with Embedded Target for TI C2000.

b. Code Composer Studio (CCS) 3v1.

c. Spectrum Digital ezDSP F28335 Hardware

7.2 Starting a New Project

Steps to be followed to get the project are: Start Code Composer Studio for F28335 ezDSP and use Debug − > Connect

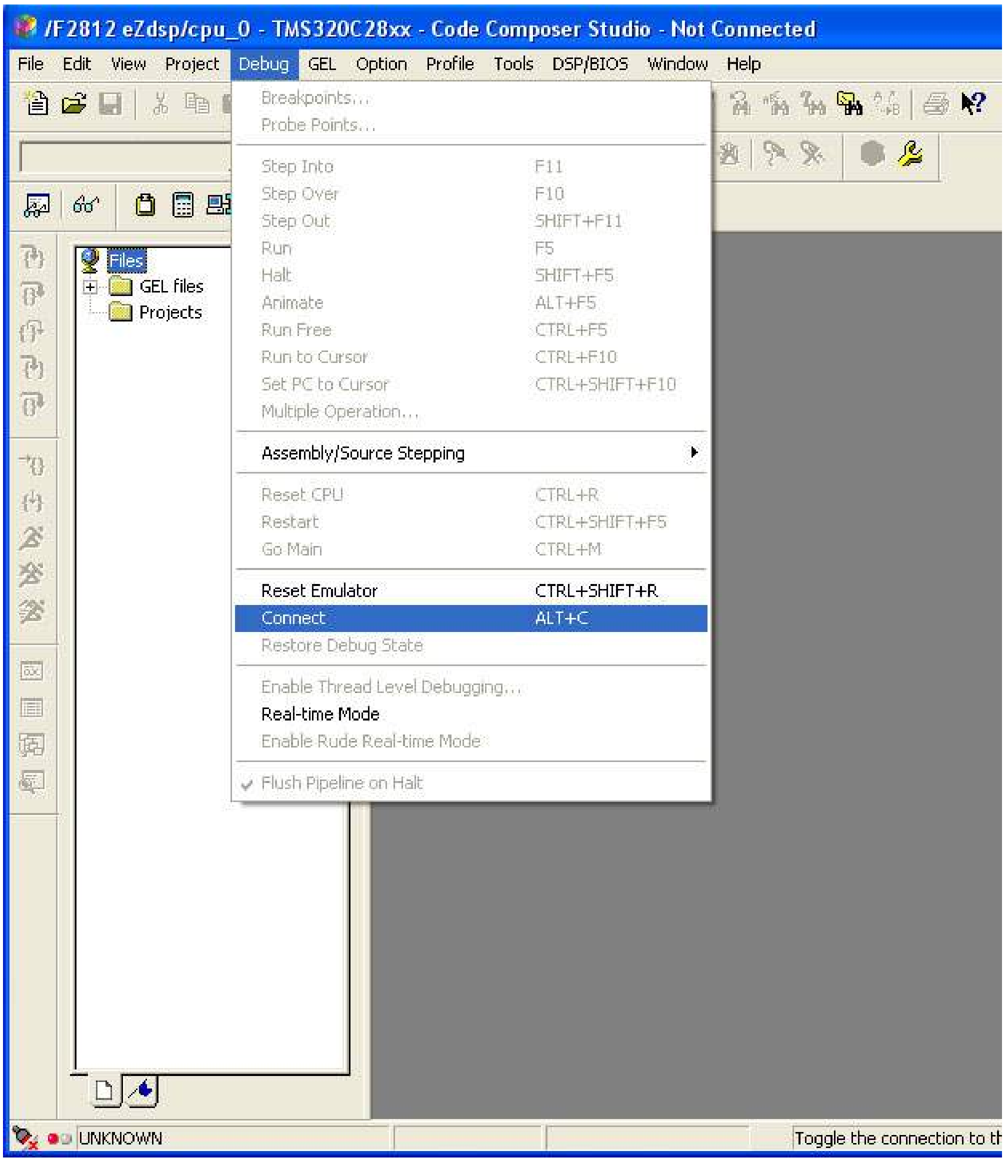


Figure 7.1: Code Composer Studio (CCS screen

7.3 Model file

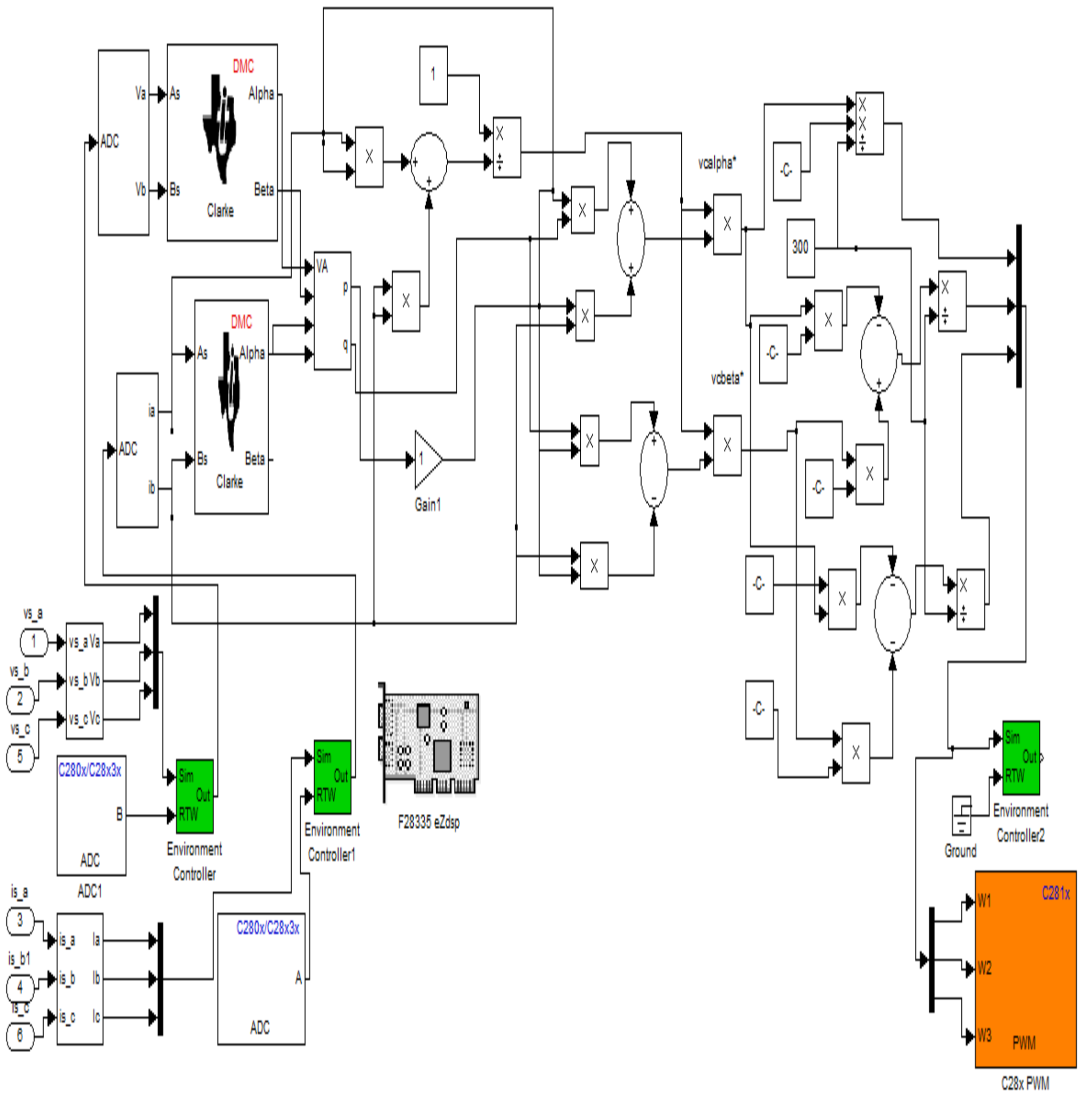


Figure 7.2: mdl file

7.4 Building model

Select Tools − > Real-Time Workshop − > Build Model.MATLAB will create a new project in Code Composer Studio and generate the code for it. There is no need to do any programming.The model has now been built and is running on the F28xx eZDSP. Expand the File name.pjt(Custom-MW)window. Click on *Filename.c*. This contains the generated code for the project. The code composer studio 3.3 is supportive with

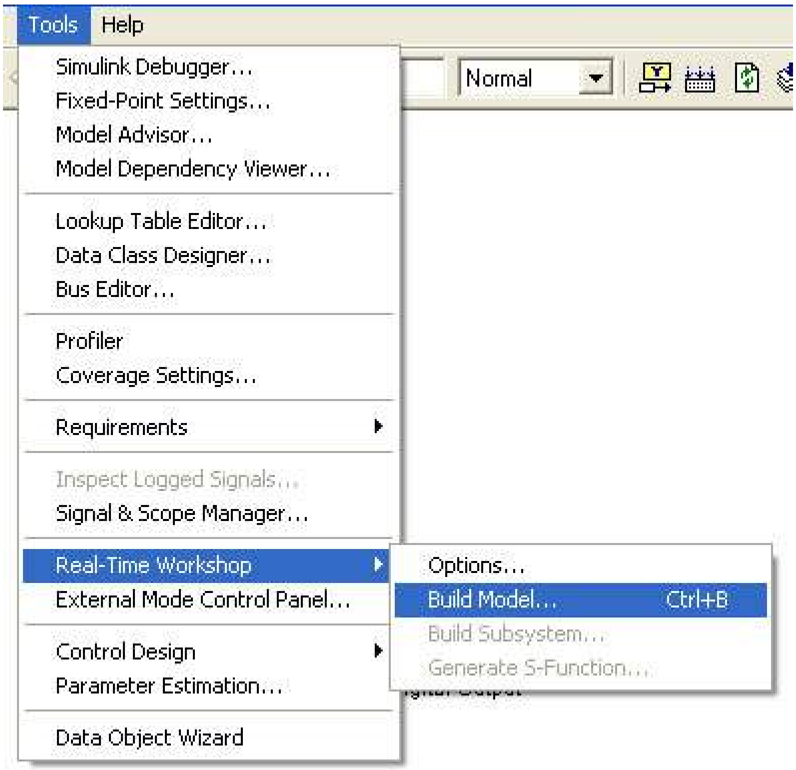


Figure 7.3: Building the Model

windows XP.so,install the code composer studio in the PC.Then MATLAB file would be already generated as shown in fig7.2 use that file to generate the code.go to matlab enter tools and in that open incremental build block .first of all set the code composer studio parameters for c28xx DSP processor.Add the DSP block in code composer studio. Build the block.If once mdl file is generated then remaining compatibility is easier only to inplement.Then Generated code was already there for SHAPF and use it to run the DSP.

```
........................................
.......................
### Writing header file result.h
### Writing header file result_types.h
.
### Writing header file rtwtypes.h
### Writing header file rt_look1d.h
### Writing source file rt_look1d.c
.
### Writing header file rt_look.h
### Writing source file rt_look.c
.
### Writing header file rt_nonfinite.h
### Writing source file rt_nonfinite.c
.
### Writing header file rt_SATURATE.h
### Writing header file rtGetInf.h
.
### Writing source file rtGetInf.c
### Writing header file rtGetNaN.h
.
### Writing source file rtGetNaN.c
### Writing source file result.c
.
### Writing header file result_private.h
### Writing source file result_data.c
### Writing source file result_main.c
.
### TLC code generation complete.
..
```

Figure 7.4: build in progress in matlab

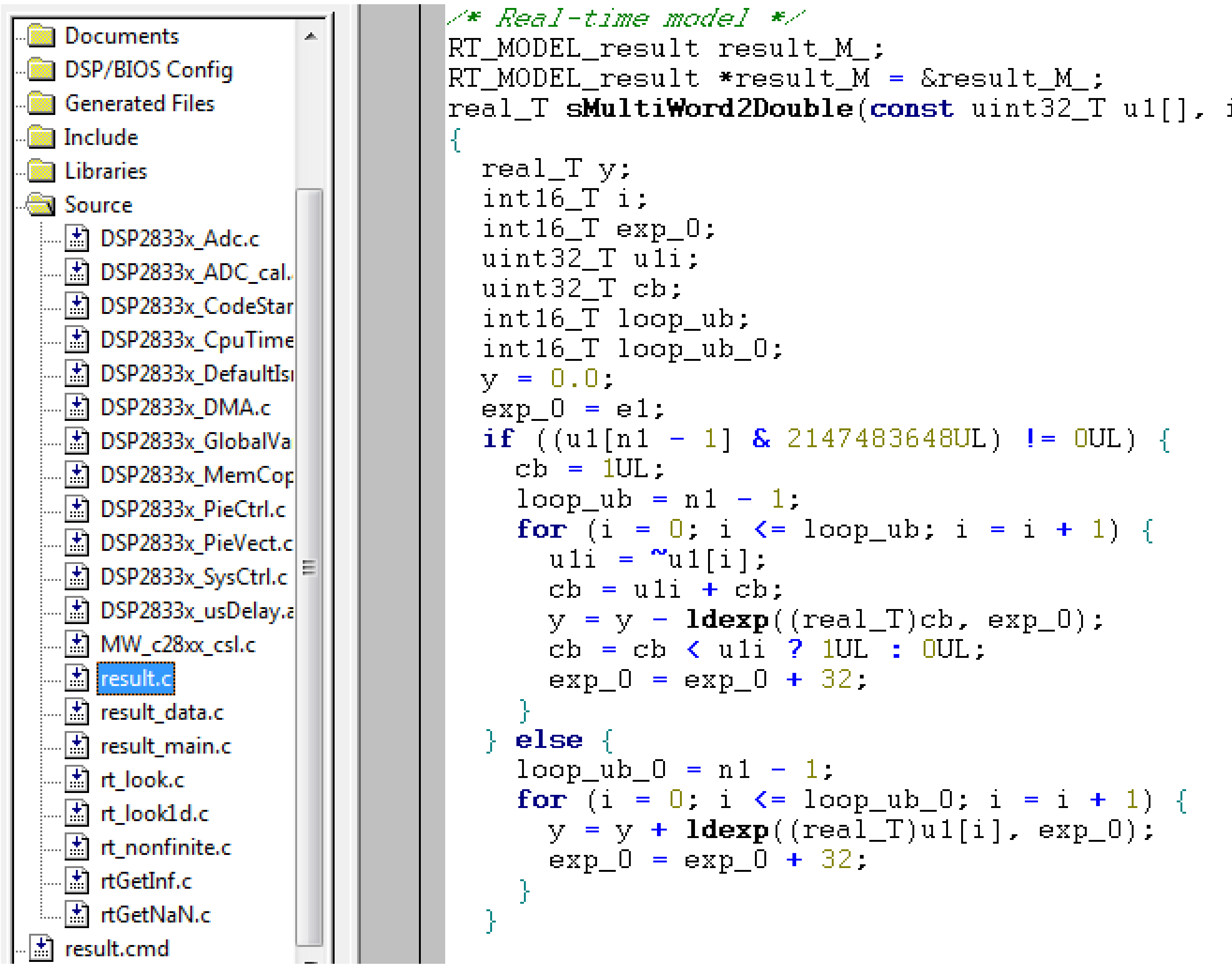


Figure 7.5: Checking the Generated Code in CCS

Chapter 8

Simulation Results

A program is developed to simulate the series active power filter in MATLAB. The complete active power filter system is composed mainly of three-phase source, a non-linear load, a voltage source PWM converter, a PI controller. All these components are modeled separately, integrated and then solved to simulate the system. Figures 8.1.- 8.8 show the simulations results of the proposed series active power filter controlled by a conventional PI controller with MATLAB program. The parameters selected for simulation studies are given in chapter 5. The three phase source voltages are assumed to be balanced and sinusoidal. The source voltage waveform of the reference phase only (phase-a,b,c in this case) . A load with highly nonlinear characteristics is considered for the load compensation.The THD in the load voltage is 28.05% and highly distorted with 5^{th} and 7^{th}. The phase-a,b,c load current are shown .

fig 8.1-8.4 shows the simulation results of SHAPF using hysteresis controller, so that the unbalance in the load voltages and currents are minimised to a better level with the injection of 5^{th} and 7^{th} harmonics at the source voltage.

with the cloed loop scheme the dc-link voltage has been maintained constant and the compensated voltage had been showed in fig 8.3

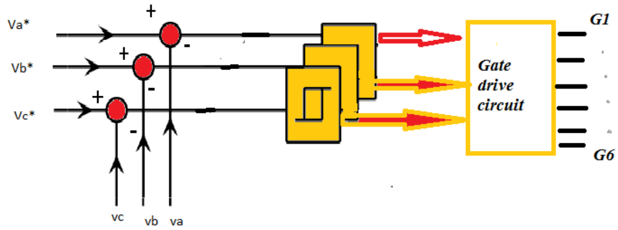
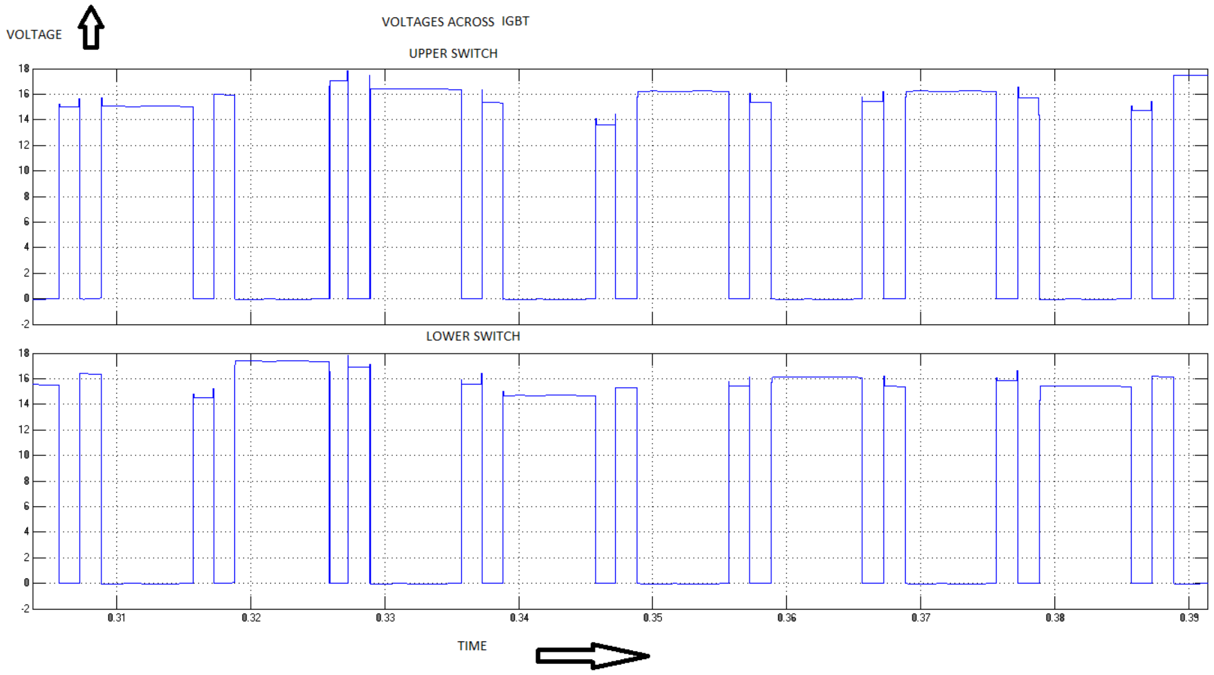


Figure 8.1: Gating pulses to inverter with Hysteresis

The fft analysis has been carried out for the source voltage with hysteresis controller with 5^{th} and 7^{th} harmonics had been introduced at the source side.The THD of the resulting waveform is so high and magnitudes of harmonics are nearly 33 and 17 as shown in fig 8.6. The fft analysis has been carried out for the load voltage with hysteresis controller with 5^{th} and 7^{th} harmonics has been introduced at the source side.The THD of the resulting waveform is so low after compensation with series active power filter and magnitudes of harmonics are nearly 2.5 and .75 as shown in fig 8.7

From the responses it is depicted that the Compensated waveforms improved alot compared with the waveforms before the compensation by using Hysteresis PWM with both IRP,Modified IRP,Generalised IRP. . The sourceVoltage THD is reduced form 34.88% to 2.41% which is below IEEE standard with both the controllers. After compensation both source voltage and current are in phase with each other means that the harmonics are eliminated and reactive power is compensated to make power factor close to unity. As the load voltage is becoming sinusoidal after compensation power quality is improved.

The fft analysis has been carried out for the source voltage with hysteresis controller with 5^{th} and 7^{th} harmonics had been introduced at the source side.The THD of the resulting waveform is so high and magnitudes of harmonics are nearly 18 and 15 as shown in fig 8.12. The fft analysis has been carried out for the load voltage with hysteresis controller with 5^{th} and 7^{th} harmonics has been introduced at the source

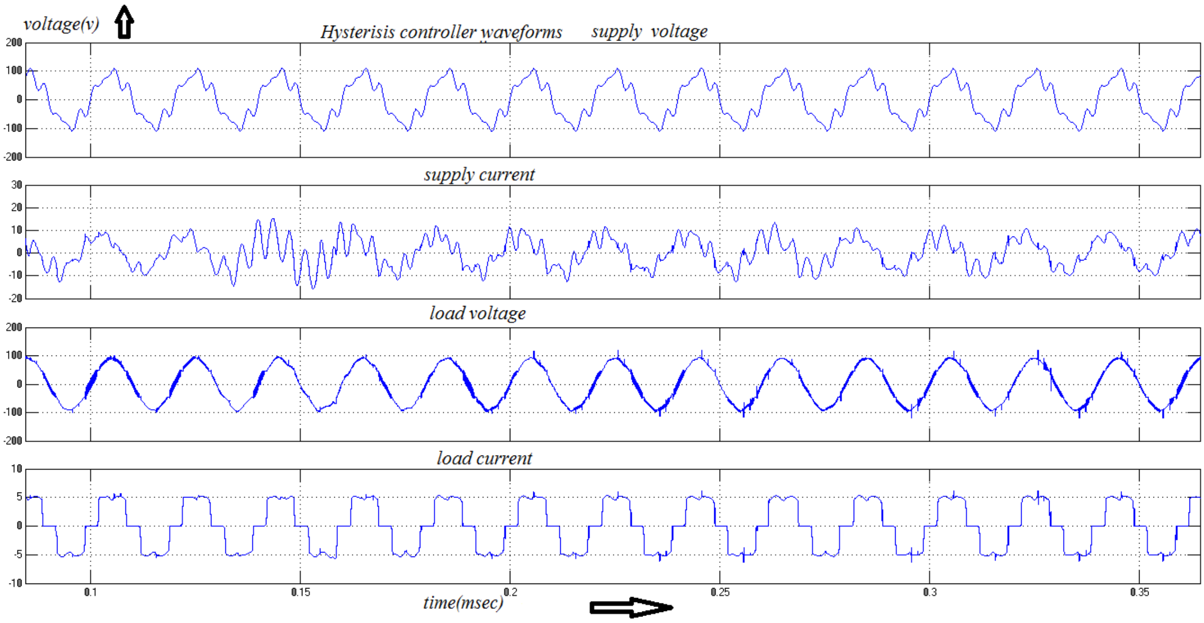


X-axis :1div:10msec/div,Y-axis:1div:2v/div

Figure 8.2: Switching of IGBT in single leg

side.The THD of the resulting waveform is so low after compensation with series active power filter and magnitudes of harmonics are nearly 2 and .75 as shown in fig 8.13

From the output it is resembled that the Compensated waveforms improved a lot compared with the waveforms before the compensation by using Hysteresis PWM with both IRP,Modified IRP,Generalised IRP. . The source Voltage THD is reduced form 22.92% to 3.78% which is below IEEE standard with both the controllers. After compensation both source voltage and current are in phase with each other means that the harmonics are eliminated and reactive power is compensated to make power factor close to unity. As the load voltage is becoming sinusoidal after compensation power quality is improved.

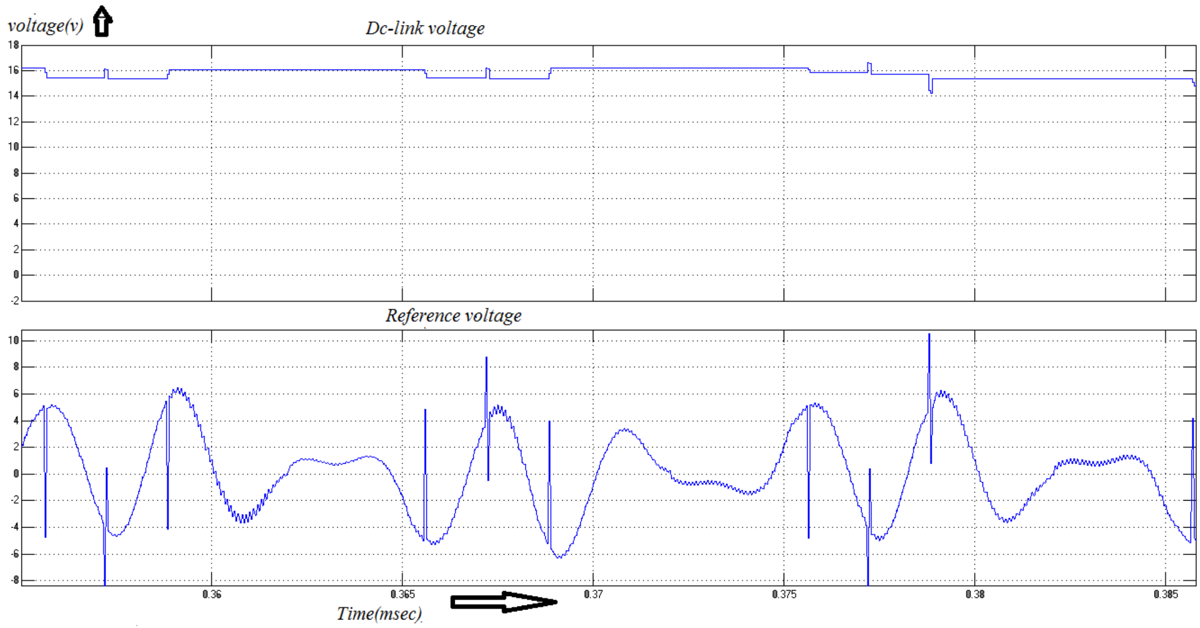


a.waveform of supply voltage: X-axis:1div:50msec/div,Y-axis:1div:100v/div
b.waveform of supply current: X-axis:1div:50msec/div,Y-axis:1div:10A/div
c.waveform of Load voltage: X-axis:1div:50msec/div,Y-axis:1div:100v/div
d.waveform of Load current: X-axis:1div:50msec/div,Y-axis:1div:10A/div

Figure 8.3: Waveforms of hysteresis controller

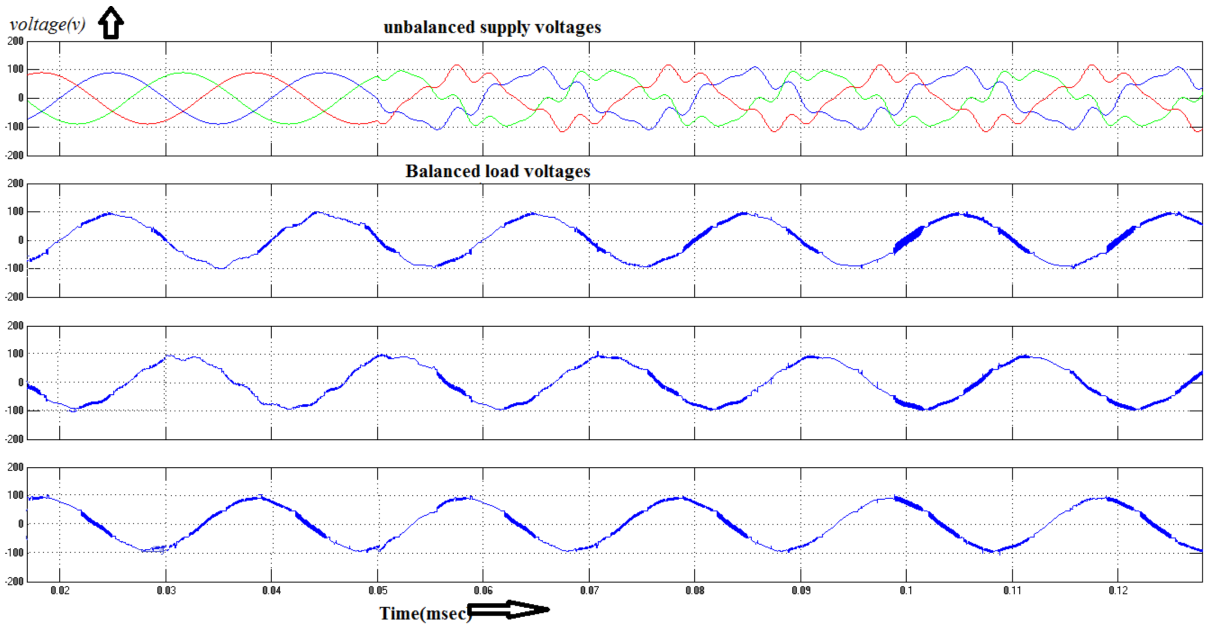
X-axis 20msec:Y-axis:1v/div

Figure 8.4: Gating pulses to inverter with Hysteresis



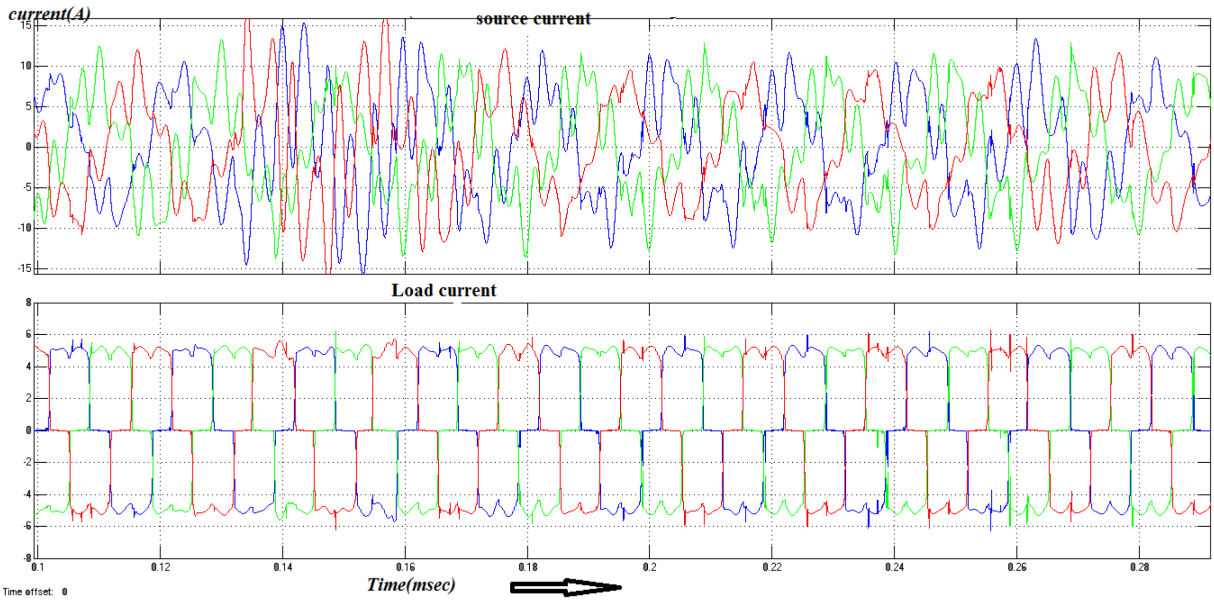
Inverter output voltage X-axis 20msec/div:Y-axis:2v/div
Dc-link voltage X-axis 5msec/div:Y-axis:2v/div

Figure 8.5: Waveforms with hysteresis controller



a.supply voltage:X-axis 50msec/div:Y-axis:100v/div
b.Load voltage of a-phase:X-axis 10msec/div:Y-axis:100v/div
c.Load voltage of b-phase:X-axis 10msec/div:Y-axis:100v/div
d.Load voltage of c-phase:X-axis 10msec/div:Y-axis:100v/div

Figure 8.6: Supply and load voltage waveforms



a.Supply Current of a-phase:X-axis 20msec/div:Y-axis:5v/div
b.Load Current of a-phase:X-axis 20msec/div:Y-axis:2v/div

Figure 8.7: Supply and load Current waveforms

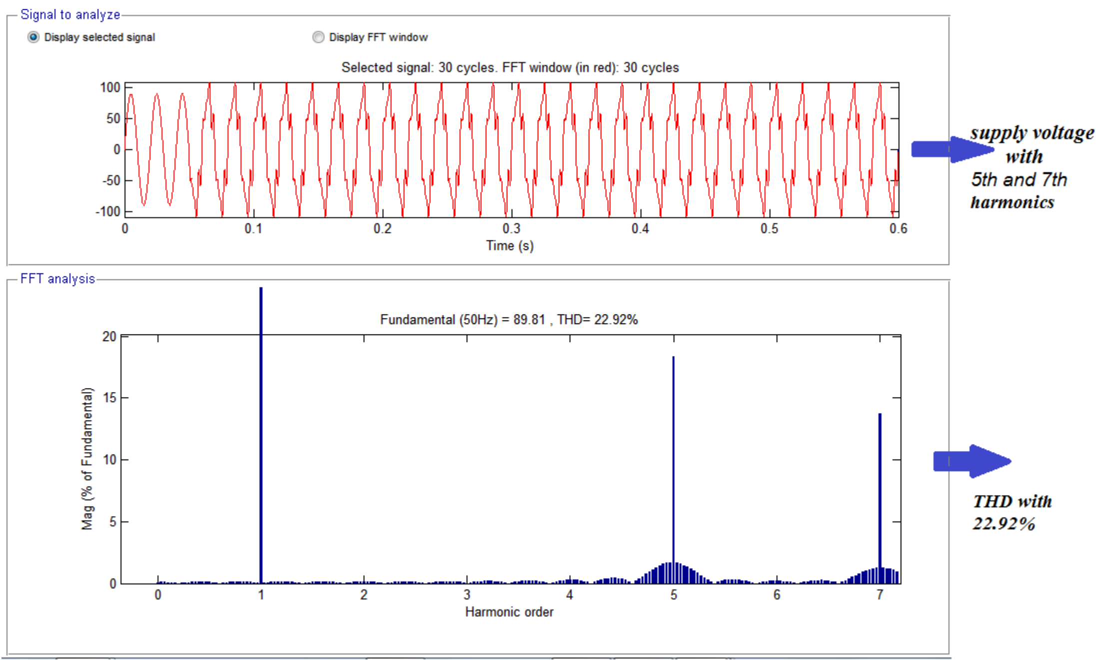


Figure 8.8: FFT Waveforms with hysteresis controller before compensation

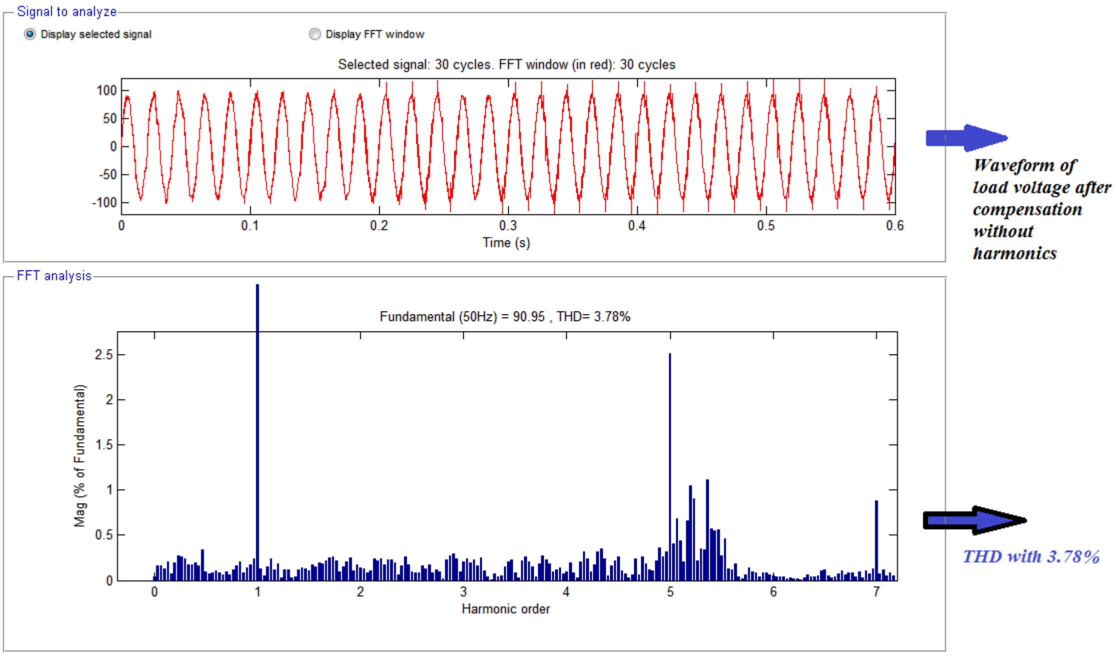


Figure 8.9: FFT Waveforms with hysteresis controller After compensation

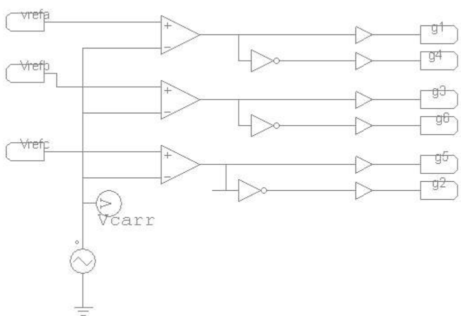


Figure 8.10: PWM controller

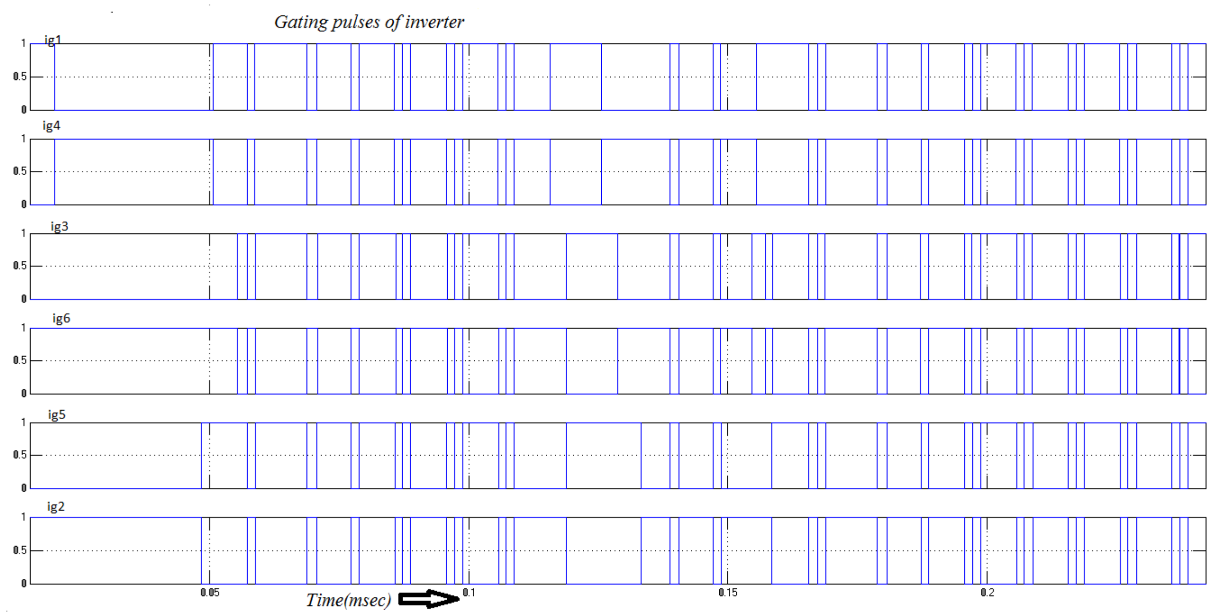


Figure 8.11: Gating pulses to inverter with PWM

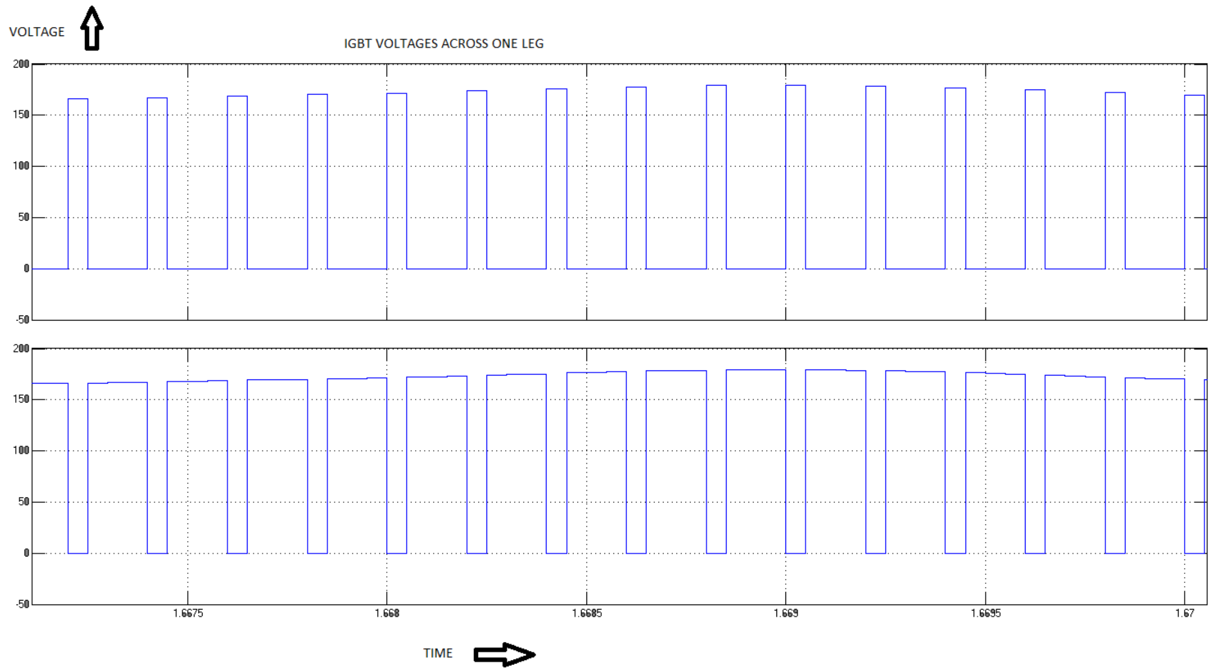
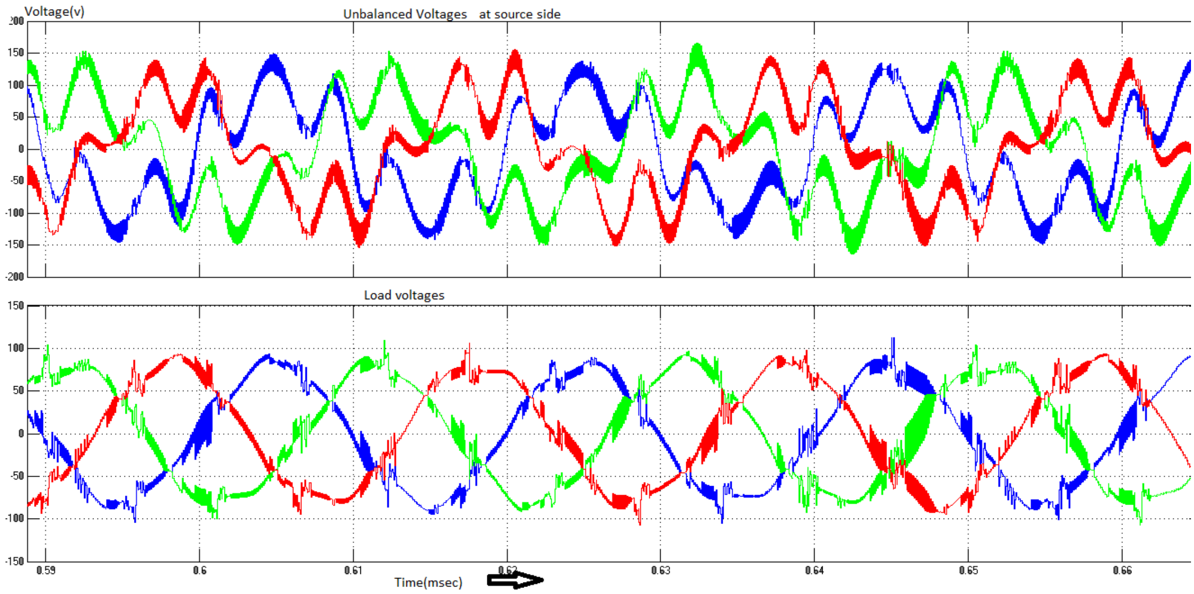
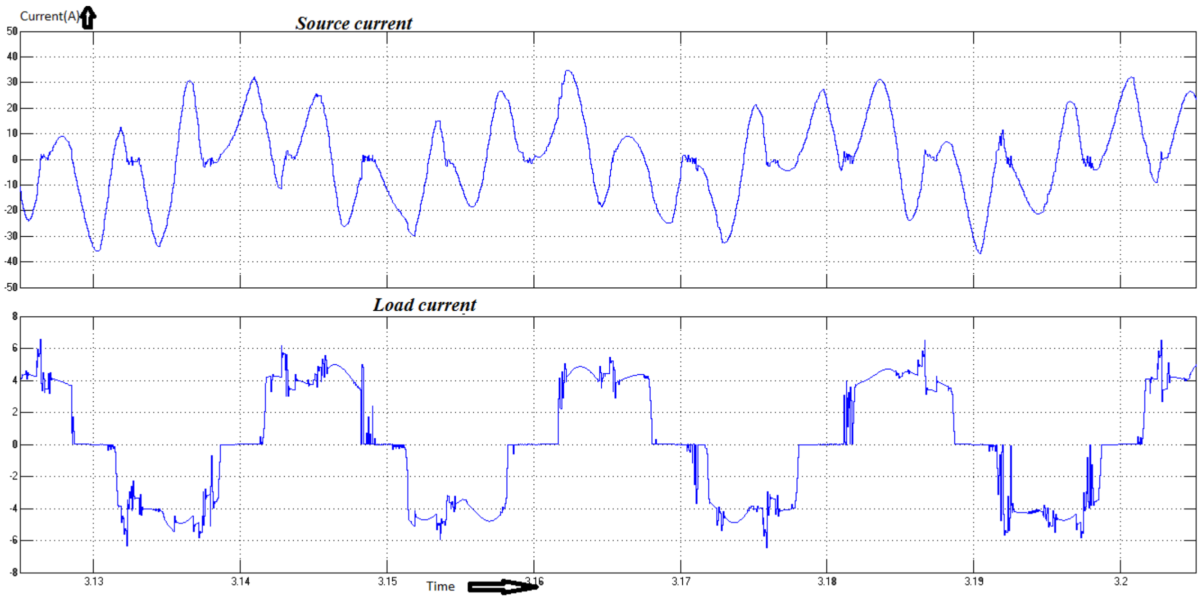


Figure 8.12: IGBT voltage across single leg PWM controller



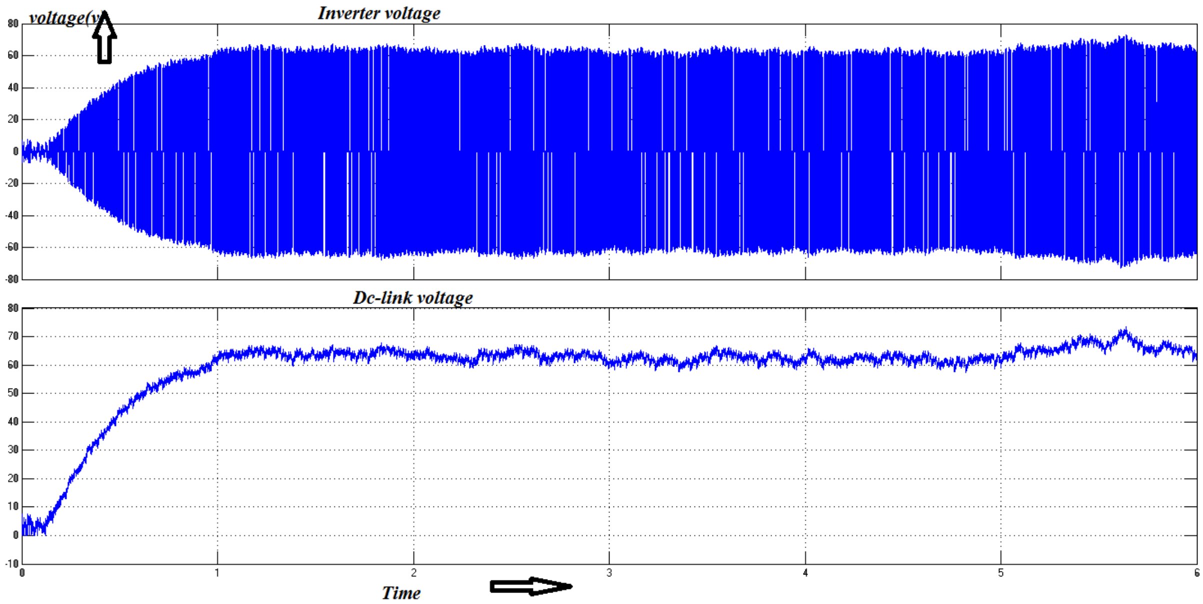
a.waveform of supply voltage: X-axis:1div:10msec/div,Y-axis:1div:100v/div
b.waveform of balanced Load voltage: X-axis:1div:10msec/div,Y-axis:1div:100v/div

Figure 8.13: voltage Waveforms of source and load with PWM controller before and after compensation



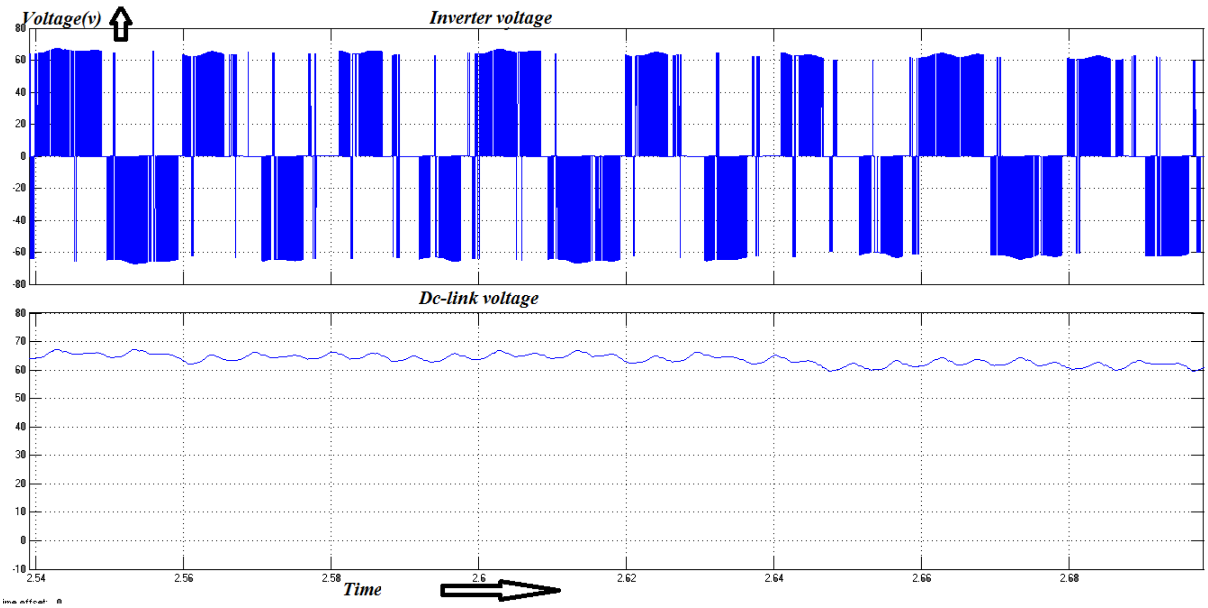
a.Supply Current of a-phase:X-axis 10msec/div:Y-axis:10v/div
b.Load Current of a-phase:X-axis 10msec/div:Y-axis:2v/div

Figure 8.14: Current Waveforms of source and load with PWM controller before and after compensation



Inverter output voltage X-axis 1sec/div:Y-axis:20v/div
Dc-link voltage X-axis 1sec/div:Y-axis:10v/div

Figure 8.15: Inverter and DC -Link voltages



Inverter output voltage X-axis 1sec/div:Y-axis:20v/div
Dc-link voltage X-axis 1sec/div:Y-axis:10v/div

Figure 8.16: Inverter and DC -Link voltages

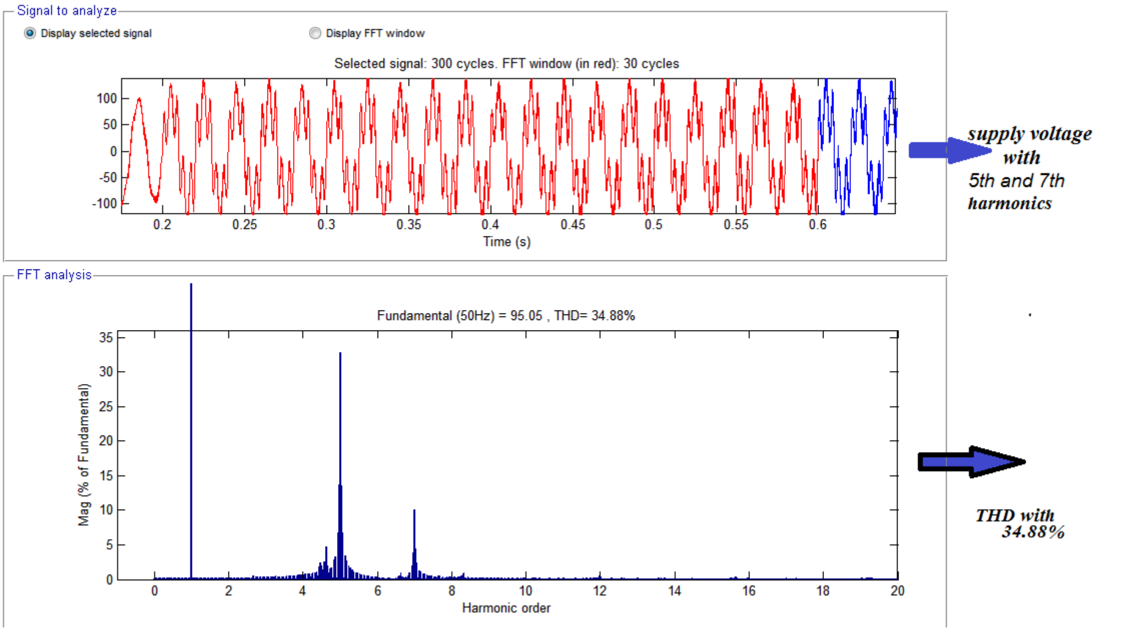


Figure 8.17: FFT Waveforms with PWM controller before compensation

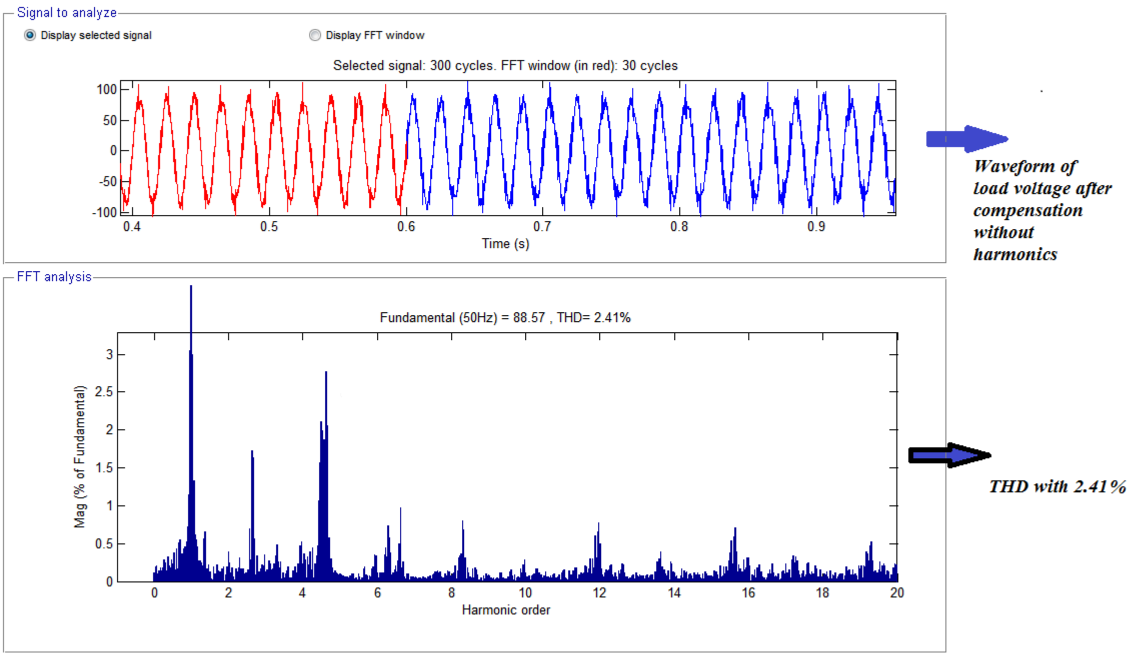


Figure 8.18: FFT Waveforms with PWM controller After compensation

Chapter 9

Conclusion and Future Work

9.1 Conclusion

Series hybrid active power filter topology was investigated for different modes of operation both in closed loop as well as open loop.The simulation work results are observed with theoretical ones.Almost the results are matched with each other. DSP coding for series hybrid active power filter also done in code composer studio in windows XP.

9.2 Future Work

The future work in this project includes the following things :

a. To develop and fabricate the Series active power filter.

b. For that design Ideal transformer design is needed.

c. To develop the IGBT driver circuitry.

d. Testing the results after developing the hardware prototype.

e. DSP programming dumping has to be done to observe closed loop hardware results.

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