DESIGN AND ANALYSIS OF FLEXIBLE POWER ELECTRONIC TRANSFORMER

Major Project Report

Submitted in Partial Fulfillment of the Requirements for
the Degree of

Master of Technology

In

Electrical Engineering
(Electrical Power Systems)

By

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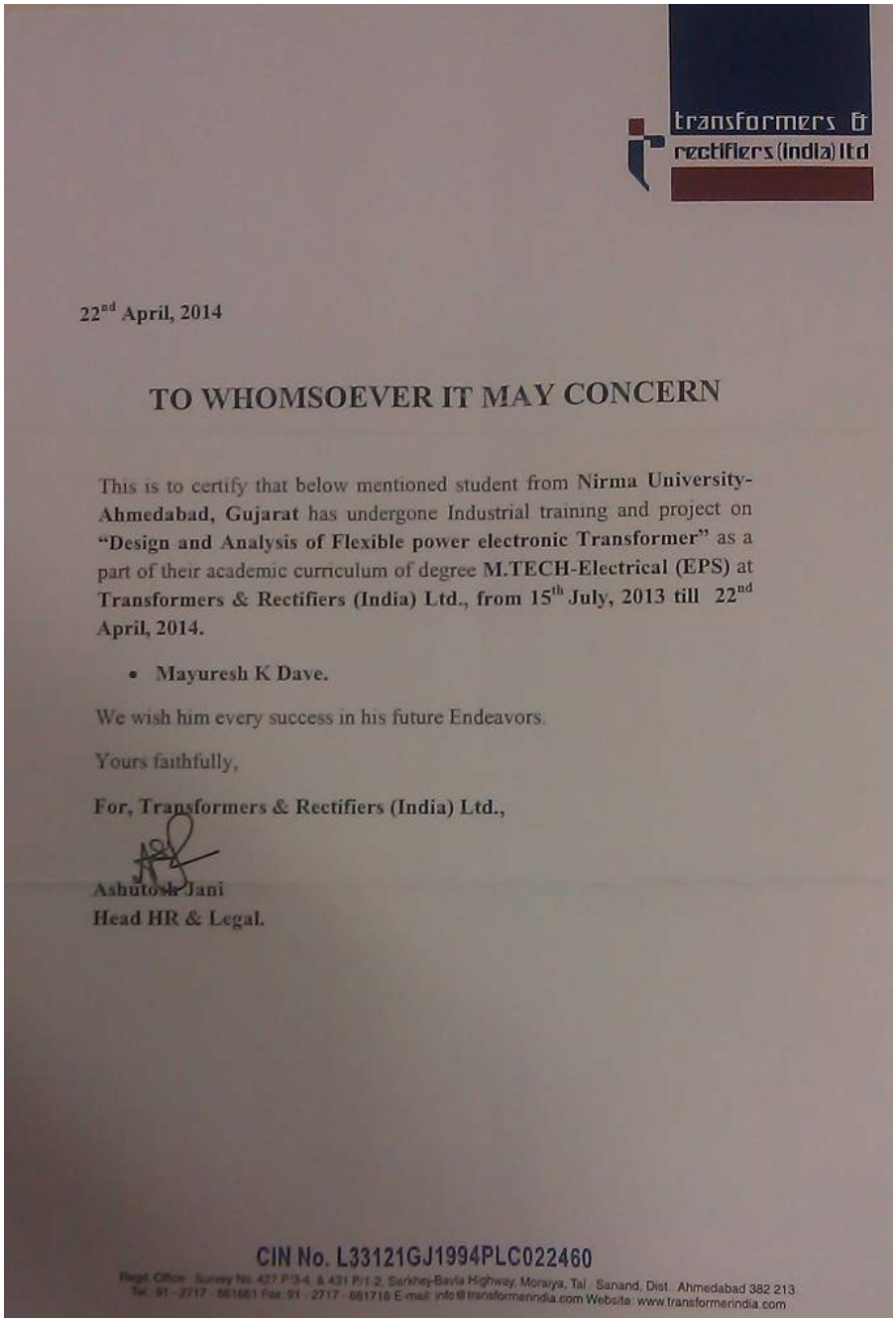

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22nd April, 2014

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This is to certify that below mentioned student from **Nirma University-Ahmedabad, Gujarat** has undergone Industrial training and project on **"Design and Analysis of Flexible power electronic Transformer"** as a part of their academic curriculum of degree **M.TECH-Electrical (EPS)** at **Transformers & Rectifiers (India) Ltd., from 15th July, 2013 till 22nd April, 2014.**

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We wish him every success in his future Endeavors.

Yours faithfully,

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Abstract

Conventional copper and iron based transformers are one most expensive and heaviest devices in electrical system. The conventional transformers are sufferind from the disdavantages like they are heavy and bulky, sensitive to harmonics, voltage drop under load and environmental concerns regarding mineral oil. To over come these disadvantages new power electronic based transformers are developed. Most of the disadvantages of conventional copper and iron based have been removed by Power Electronic Transformer (PET). Still PETs are suffering from disadvantages like less effective for power quality improvement, bidirectional power flow is not possible, not expandable to achieve higher ratings and independent operation of ports are not possible.

The topology of Power Electronic Transformer (PET) can be developed in such a way to achieve multiport electrical system that converts input waveform to the desired output waveform. This project proposes a new modular Flexible Power Electronic Transformer (FPET). It is constructed based on modules and a common dc link. Each module consists of three main parts, including modulator, demodulator and High Frequency Isolation Transformer (HFIT). Here proposed topology can be expanded by connecting modules in series or parallel to obtain higher voltage or current ratings and to form star/delta connections for three phase applications. Here each port is composed of a full bridge dc-link inverter (FBDCI), HFIT and a cycloconverter. The proposed FPET is flexible enough to meet future needs of power electronic base systems. The main feature of the FPET is the independent operation of modules each of which contains one port. Each port can be considered as input or output because bidirectional power flow is provided. The voltage regulation is performed by the FBDCI using Phase Shift Modulation (PSM) method. The cycloconverter chooses the Phase Shift Modulation (PSM) pulses in such a way to provide positive or negative voltage polarity at the output. The modules are connected to a common dc link that facilitates energy transfer among modules as well as ports. Therefore, a multiport system is proposed in which the ports can operate independently. The simulation results are provided to clarify the advantages of the proposed FPET over the recently developed PETs.

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With immense pleasure, I would like to present this report on "Design and Analysis of Flexible Power Electronic Transformer". To practically know anything, project work plays an important role. I am very grateful to every person who helped me for completion of my dissertation work and providing me their valuable guidance.

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-Mayuresh K. Dave
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Abbreviations

AC ..... Alternating Current
AF ..... Active Filter
COMFET ..... Conductively Modulated Field Effect Transistor
DC ..... Direct Current
D-EPT ..... Distribution Electronic Power Transformer
DVR ..... Dynamic Voltage Restorer
EPRI ..... Electric Power Research Institute
ETD ..... Economical Transformer Design
FACTS ..... Flexible Alternating Current Transmission System
FBDCI ..... Full Bridge DC-link Inverter
FFT ..... Fast Fourier Transform
FPET ..... Flexible Power Electronic Transformer
GEMFET ..... Gain Modulated Field Effect Transistor
HF ..... High Frequency
HFIT ..... High Frequency Isolation Transformer
IFBPFC ..... Isolated Full Bridge Power Factor Controller
IGBT ..... Insulated Gate Bipolar Transistor
IGT ..... Insulated Gate Transistor
IPFC ..... Interline Power Flow Controller
LCD ..... Liquid Crystal Display
M2C ..... Modular Multilevel Converter
MF ..... Medium Frequency
MOSFET ..... Metal Oxide Field Effect Transistor
MOSIGT ..... Metal Oxide Insulated Gate Transistor
PCB ..... Printed Circuit Board
PET ..... Power Electronic Transformer
PFT ..... Power Factor Controller
PM ..... Phase Modulation
PSK ..... Phase Shift Keying
PSM ..... Phase Shift Modulation
SOA ..... Safe Operating Area
UPQC ..... Universal Power Quality Conditioner
VSC ..... Voltage Source Converter

Nomenclature

V_s ..... Voltage Source (V)
ω ..... Angular Frequency (rad/s)
V_o ..... Output Voltage (V)
$\frac{di}{dt}$ ..... Rate of Change of Current (amps/sec)
$\frac{dv}{dt}$ ..... Rate of Change of Voltage (volts/sec)
f ..... Frequency (Hz)
K ..... Copper Fill Factor
A_c ..... Core Area (m^2)
A_e ..... Winding Area (m^2)
J ..... Current Density of the Conductor (A/m^2)
B_m ..... Peak Flux Density (T)
G_i ..... Gate Driving Signal of S_i where i=1,2,3,4 and 5
G_a and G_b ..... Gate Driving Signal of S_a and S_b
T_s ..... Switching Period (s)
T_{on} ..... Turn-on Duration Time in $T_s/2$ (s)
T_{cd} ..... Cycloconverter Switching Delay Time (s)
V_c ..... Output Voltage of the Cycloconverter (V)
N ..... Transformer Winding Ratio N_s/N_p
V_{ref} ..... Reference Voltage (V)
D_{max} ..... Maximum Duty Cycle (s)
I_e ..... Effective Magnetic Path Length (mm)
A_e ..... Effective Magnetic Cross Section (mm^2)
A_{min} ..... Minimum Core Cross Section (mm^2)
V_e ..... Effective Magnetic Volume (mm^3)
P_D ..... Power Dissipation (W)
T_{STG} ..... Storage Temperature Range (C)
T_{OP} ..... Operating Junction Temperature Range (C)
T_{opr} ..... Operating Temperature (C)
f_{clock} ..... Clock Frequency (MHz)
t_h ..... Hold Time (ns)
V_{CBO} ..... Collector-base Voltage (V)
V_{CEO} ..... Collector-emitter Voltage (V)
V_{EBO} ..... Emitter-base Voltage (V)
I_C ..... Collector Current (A)
I_{CM} ..... Collector Peak Current (A)
I_B ..... Base Current (A)
T_j ..... Maximum Operating Junction Temperature (C)
V_{DS} ..... Drain-source Voltage (V)
I_D ..... Drain Current (A)
$V_{CE(SUS)}$ ..... Output Sustaining Voltage (V)
V_R ..... Clamp Diode Reverse Voltage (V)
I_F ..... Clamp Diode Forward Current (mA)
VF ..... LED Forward Voltage (V)
IF ..... LED Forward Current (mA)

V_{RRM} ..... Maximum Recurrent Peak Reverse Voltage (V)
V_{RMS} ..... Maximum RMS Voltage (V)
V_{DC} ..... Maximum DC Blocking Voltage (V)
I_O ..... Max. Avg. Forward Rectified Current (A)
C_J ..... Typical Junction Capacitance (pF)
D_{OUT} ..... Serial Data Out
CLK ..... Serial Clock
V_{SS} ..... Ground

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Chapter 1

Introduction

Transformers are widely used in electrical power system to perform the primary functions, such as voltage step up/down and isolation. Transformers are one of the heaviest and most expensive devices compare to other equipments in an electrical system because of the large iron cores and heavy copper windings.

A new concept using high frequency transformers based on Power Electronics has been introduced, which performs the primary functions like voltage transformation, galvanic isolation, and power quality improvements in a single device. The Power Electronic Transformer (PET) provides a better, more useful, different and complete approach in transformer design by using power electronic converters on the primary and secondary sides of the transformer. Several Features such as instantaneous voltage regulation, voltage sag and swell compensation, input current in phase, legged or lead in order to absorb or to inject reactive power while the load is non-reactive and power factor correction can be combined into PET.

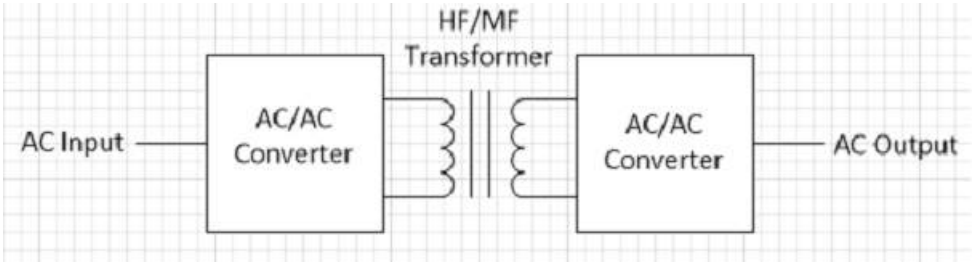


Figure 1.1: Block Diagram of Power Electronic Transformer using High Frequency AC link

Fig.1.1 shows the basic block diagram of the PET using Ac-link and High Frequency (HF)/Medium Frequency (MF) transformer without DC-link capacitor. In this type of system, the conventional input side voltage is converted in to high frequency square wave with the help of converter and on the other side with the help of other converter this high frequency voltage is again converted in to the fundamental frequency.

This type of system does not provide any benefits in terms of protection of the critical loads from the instantaneous power interruptions due to lack of energy storage

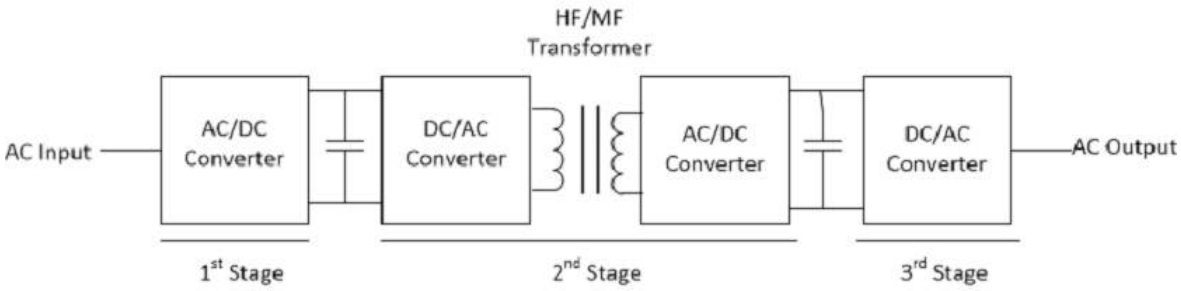


Figure 1.2: Block Diagram of Power Electronic Transformer with DC link

system/device also this kind of system doesn't have bi-directional power flow and also the expension of the system for high ratings is not possible. Fig.1.2 shows the basic block diagram of a PET with DC link capacitor which includes three stages. First stage is an AC/DC converter (Rectifier) which is used to shape the input current, to correct the input power factor, and to regulate the voltage of primary DC bus. Second stage is an isolation stage which provides the galvanic isolation between the primary and secondary side. In the isolation stage, the DC voltage is converted to a high-frequency square wave voltage, coupled to the secondary of the HF / MF transformer and is rectified to form the DC link voltage. The output stage is a voltage source inverter which produces the desired AC waveforms.

1.1 Objective of the Project

Demand of power supply is increasing day by day and also due to variation in load power quality is becoming the major issue. It is important to improve power quality to provide better power supply. The conventional Power Transformers or Distribution Transformers are not able to fulfill this type of requirements. Power Electronics Transformer (PET) is one of the solutions.

In this project, the main objective is to design and analyze Flexible Power Electronic Transformer (FPET) and with the help of simulation result to verify the prooven advantages of FPET. And to prepare prototypr model of FPET to understand it's basic working principle.

1.2 Problem identification & Project Planning

The conventional copper-and-iron based transformers are suffering from following disadvantages:

1. Very heavy and bulky
2. Sensitivity to harmonics
3. Voltage drop under load

4. Environmental concerns regarding mineral oil

5. Low performance under dc-offset load unbalances

6. Not flexible enough to improve the power quality

The conventional Power Electronic Transformers are suffering from following disadvantages:

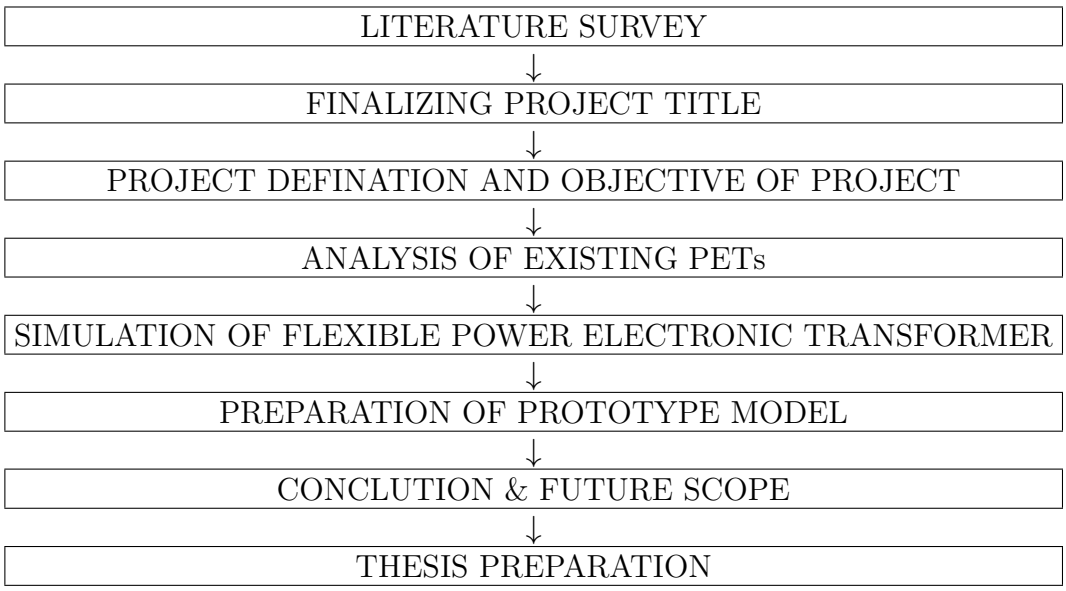
1. Expandability to achieve higher rating is not possible

2. Not much effective to improve power quality

3. Bidirectional power flow is not possible

4. Independent operation is not possible

1.2.1 Project Planning



1.3 AC/DC Converter (Rectifier)

Rectifier is a device which is used to convert AC supply in to DC supply. There are many possible ways to construct rectifier circuit. The three basic types of rectifier circuits are:

1. Half wave rectifier

2. Full wave rectifier

3. Bridge rectifier

Half wave rectifier

The easiest rectifier to understand is the half wave rectifier. A simple half-wave rectifier using an ideal diode and a load is shown in Fig. 1.3

Circuit operation:

Single diode rectifier when connected across an alternating voltage source V_s. Since the diode only conducts when the anode is positive with respect to the cathode, current will flow only during the positive half cycle of the input voltage.

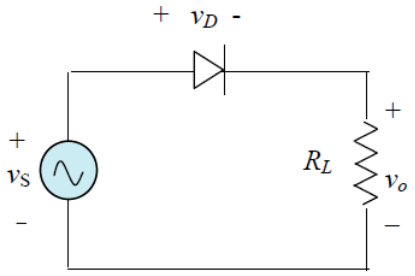


Figure 1.3: Simple Half Wave Rectifier Circuit

The supply voltage is given by,

$V_s = V_m \sin\omega t$

where ω ($=2\pi f = 2\pi/T$) is the angular frequency in rad/s.

We are interested in obtaining DC voltage across the load resistance R_L.

During the positive half cycle of the source, the ideal diode is forward biased and operates as a closed switch. The source voltage is directly connected across the load. During the negative half cycle, the diode is reverse biased and acts as an open switch. The source voltage is disconnected from the load. As no current flows through the load, the load voltage vo is zero. Both the load voltage and current are of one polarity and hence said to be rectified. The waveforms for source voltage V_s and output voltage V_o are shown in Fig. 1.4

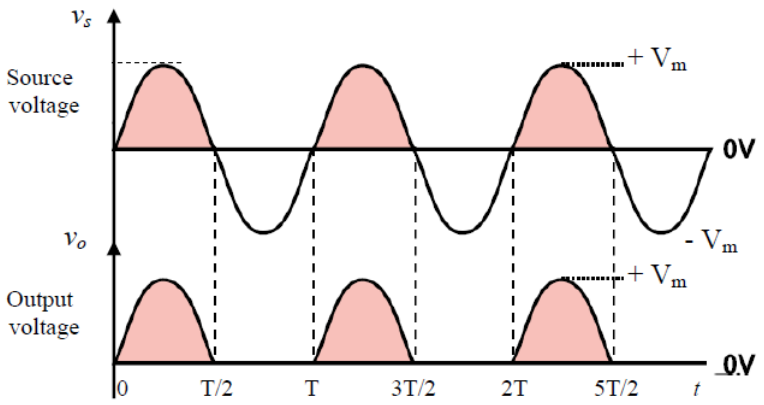


Figure 1.4: Source and Output Voltages

1.4 DC/AC Converter (Inverter)

A power inverter, or inverter, is an electronic device or circuitry that changes direct current (DC) to alternating current (AC). The input voltage, output voltage and frequency, and overall power handling, are dependent on the design of the specific device or circuitry.

The four basic types of inverter circuits are:

1. Single phase half bridge inverter
2. Single phase full bridge inverter
3. Three phase voltage source inverter
4. Current source inverter

Single phase half bridge inverter

Single phase half bridge inverter, as shown in Fig. 1.5 consists of two diodes, two SCRs and three wire supply. It is seen from Fig. 1.5 that for the first half cycle thyristor T1 conducts and the load is subjected to a voltage $V_s/2$ due to the upper voltage source $V_s/2$. At t = T/2, thyristor T1 is commutated and T2 is gated on.

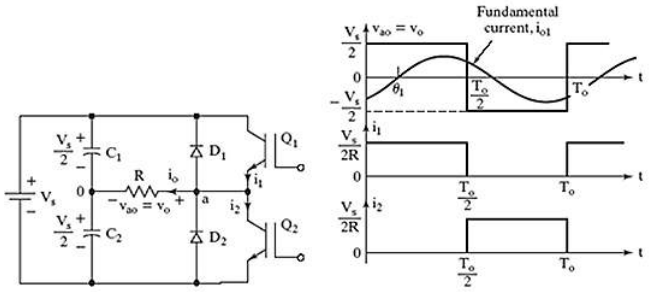


Figure 1.5: Single Phase Half Wave Inverter Circuit & Waveform

During the next half cycle, thyristor T2 conducts and the load is subjected to a voltage (-$V_s/2$) due to the lower voltage source $V_s/2$. It is seen from Fig. 1.5 that load voltage is an alternating voltage waveform of amplitude $V_s/2$ and of frequency 1/T Hz. Frequency of the inverter output voltage can be changed by controlling T.

1.5 Isolation Transformer

An isolation transformer is a transformer used to transfer electrical power from a source of alternating current (AC) power to some equipment or device while isolating the powered device from the power source, usually for safety. Isolation transformers provide galvanic isolation and are used to protect against electric shock, to suppress electrical noise in sensitive devices, or to transfer power between two circuits which

must not be connected together. Suitably designed isolation transformers block interference caused by ground loops. Isolation transformers with electrostatic shields are used for power supplies for sensitive equipment such as computers or laboratory instruments.

Strictly speaking any true transformer, whether used to transfer signals or power, is isolating, as the primary and secondary are not connected by conductors but only by induction. However, transformers whose primary purpose is to isolate circuits (opposed to the more common transformer function of voltage conversion), are routinely described as isolation transformers. Given this function, a transformer sold for isolation is often built with special insulation between primary and secondary, and is tested, specified, and marked to withstand a high voltage.

1.6 Galvanic Isolation

Galvanic isolation is a principle of isolating functional section of electric systems to prevent current flow; no direct conduction path is permitted.

Galvanic isolation is used where two or more electric circuits must communicate, but their grounds may be different potential. It is an effective method of breaking ground loops by preventing unwanted current from flowing between two units sharing a ground conductor. Galvanic isolation is also used for safety preventing accidental current from reaching ground through a person's body.

1.7 Snubber Circuit

Switching devices and circuit components may fail due to the following reasons:

1. Overheating - thermal failure
2. Overcurrent
3. Overvoltage - usually happens during turn - off
4. Excessive $\frac{di}{dt}$
5. Excessive $\frac{dv}{dt}$
6. Switching loss - excessive switching loss is a major contributing factor of overheating

Power electronic circuit and their switching devices and components can be protected from overcurrent by placing fuses at suitable locations. Heat sink and fans are used to take the excess heat away from switching devices and other components. Snubber circuits are required to limit $\frac{di}{dt}$, $\frac{dv}{dt}$ and overvoltage during turn-on and turn-off.

RC Snubber Circuit

RC snubber circuits are normally connected across a switching device to limit the dv/dt. An RC snubber circuit can be polarized or unpolarized. A forward-polarized RC snubber circuit shown in Fig. 1.6 is appropriate when a thyristor or a transistor

is connected with an anti-parallel diode. R limits the forward dv/dt and R_1 limits the discharge current of the capacitor when Q1 is turned on.

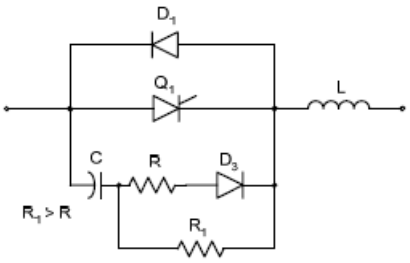


Figure 1.6: A Forward Polarized Snubber Circuit

A reverse polarized snubber circuit as shown in Fig. 1.7 is used to limit the reverse dv/dt. R_1 limits the discharge current of the capacitor. An unpolarized snubber circuit as shown in Fig. 1.7 should be used when a pair of switching devices is connected in anti-parallel.

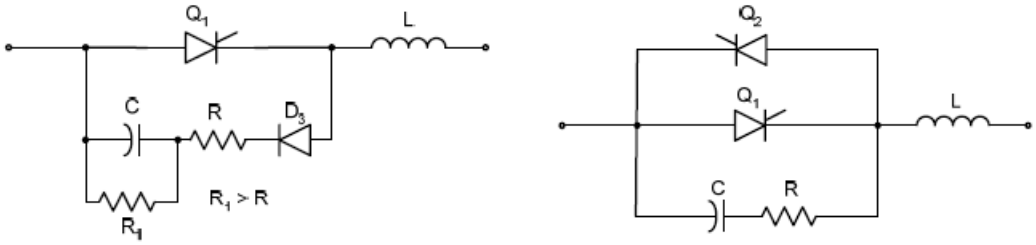


Figure 1.7: A Reverse Polarized & an Unpolarized Snubber Circuit

1.8 Insulated Gate Bipolar Transistor(IGBT)

1.8.1 Why IGBT?

IGBT has been developed by combining into the best quality of both BJT and PMOSFET. Thus an IGBT possesses high input impedance like a PMOSFET and has low on - state power loss as in BJT. Further, IGBT is free from second breakdown problem presented in BJT. It has wide safe operating area(SOA) and superior current conduction capability compare to the bipolar transistor. It can be easily controlled compared to current controlled devices (thyristor, BJT). All these merits have made IGBT very popular amongst power electronics engineers. IGBT is also known as metal oxide insulated gate transistor (MOSIGT), conductively modulated field effect transistor (COMFET) or gain modulated FET (GEMFET). It was also initially called insulated gate transistor (IGT).

1.8.2 Basic Structure & Operation

Fig. 1.8 illustrates the basic structure of an IGBT. It is constructed virtually in the same manner as a power MOSFET. There is however a major difference in the substrate. The n^+ layer substrate at the drain in a PMOSFET is now substituted in the IGBT by a p^+ layer substrate called collector C. Like a power MOSFET, an IGBT has also thousands of basic structure cells connected appropriately on a single chip of silicon.

In IGBT, p^+ substrate is called injection layer because it injects holes into n^- layer. The n^- layer is called drift region. As in other semiconductor devices, thickness of n^- layer determines the voltage blocking capability of IGBT. The p layer is called body of IGBT. The n^- layer in between p^+ and p regions serves to accommodate the depletion layer of pn^- junction, i.e. junction J_2.

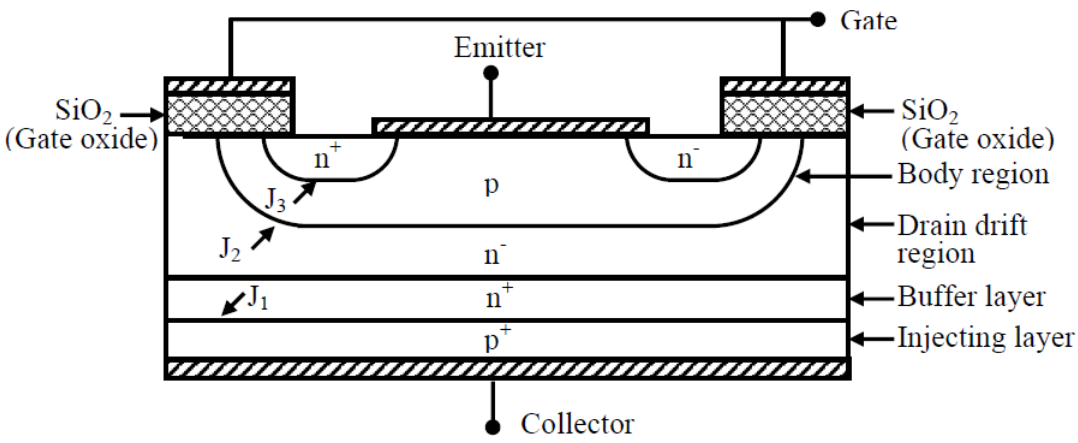


Figure 1.8: Basic Structure of IGBT

Turn on

The structure of the silicon die is evidently similar to that of a Power MOSFET with the fundamental difference of the addition of a p^+ substrate and an n^+ buffer layer (absent in NPT-non-punch-through-IGBT technology). This is represented in the equivalent schematic (Fig. 1.8), with a MOSFET driving two bipolar devices. The presence of the substrate creates a junction J1 between the p^+ and the N zone of the body.

When the positive gate bias allows the inversion of the P base region under the gate, an N channel is created, with a flow of electrons, generating a current in the exact same way as a Power MOSFET. If the voltage caused by this flux is in the range of 0.7V, then J1 is forward biased and some holes are injected in the n^- region, modulating the resistance between anode and cathode, in this way decreasing the overall power conduction losses and a second flow of charges starts.

Turn off

When a negative bias is applied to the gate or the gate voltage falls below the threshold value, the channel is inhibited and no holes are injected in the n^- region.

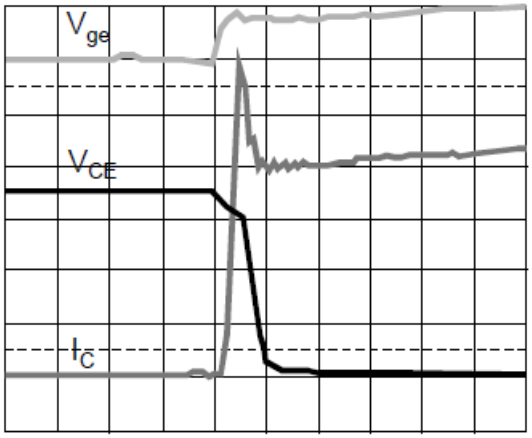


Figure 1.9: Typical Turn on Waveform

In any case even if the MOSFET current decreases rapidly in the switching off phase, the collector current gradually reduces because there are minority carriers still present in the N layer, immediately after the start of commutation. The decrease in value of this residual current (tail) is strictly dependent on the density of these charges in turn-off that is linked to several factors as the amount of dopant, dopant typology, layers thickness and temperature.

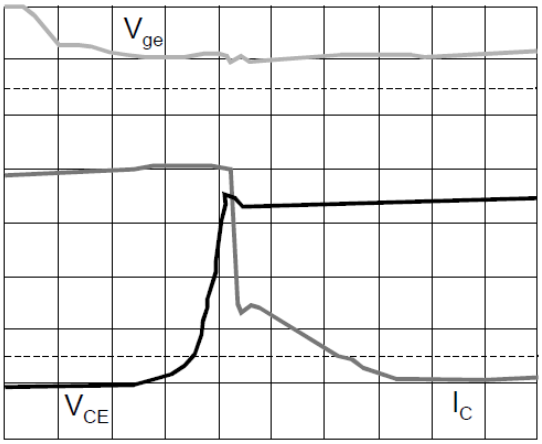


Figure 1.10: Typical Turn off Waveform

Reverse Blocking

When a negative voltage is applied to the collector then J1 is reverse biased and the depletion layer expands to the n^- region. This mechanism is fundamental because an excessive reduction of this layers thickness does not obtain a valid blocking capability. On the other hand increasing the dimension of this region too much consistently elevates the voltage drop.

Forward Blocking

When gate and emitter are shorted and a positive voltage is applied to the collector terminal the P/N- the J3 junction is reverse biased. Again it is the depletion layer in the N- drift region that withstands the voltage applied.

1.8.3 Comparison of IGBT with MOSFET

The relative merits and demerits of IGBT over PMOSFET are enumerated below:

1. In PMOSFET, the three terminals are called gate, source, drain whereas the corresponding terminals for IGBT are gate, emitter and collector.
2. Both IGBT and PMOSFET possess high input impedance.
3. Both are voltage controlled devices.
4. With rise in temperature, the increase in on-state resistance in PMOSFET is much pronounced than it is in IGBT. So, on-state voltage drop and losses rise rapidly in PMOSFET than in IGBT, with rise in temperature.
5. With rise in voltage rating, the increment in on-state voltage drop is more dominant in PMOSFET than it is in IGBT. This means IGBTs can be designed for higher voltage ratings than PMOSFETs.

In view of the above comparison, (a) PMOSFETs are available upto about 500 V, 140 A ratings whereas state of the art IGBTs have 1200 V, 500 A ratings and (b) operating frequency in PMOSFETs is upto about 1 MHz whereas its value is upto about 50 kHz in IGBTs.

1.9 Thesis Organization

1. Chapter 1 is the introduction of the project, main objetive of the project, identifying the problem and planning of the complete work to be done.
2. Chapter 2 gives literature reffered for the design of FPET.
3. Chapter 3 gives basic operating principle of the PET.
4. Chapter 4 explains the new proposed FPET with its circuit and controller used for the simulation work.
5. Chapter 5 shows the simulation and case study results.
6. Chapter 6 gives comparison study of FPET with other PETs.
7. Chapter 7 shows different types of Ferrite cores and their designs.
8. Chapter 8 explains the driver circuit used for prototype model with the components used in the circuit.
9. Chapter 9 explains the LCD interfacing circuit used for prototype model with the components used in the circuit.

10. Chapter 10 includes HFT, driver circuit and LCD interfacing circuit to show prototype model of FPET.

11. Chapter 11 includes conclusion and future scope of this project work.

Chapter 2

Literature Survey

Reference [1] explores the suitability of electronic transformer in power distribution systems. The size of a transformer and its volt-ampere (VA) rating has the following relationship:

$$VA = 2.22KfA_cA_eJB_m \tag{2.1}$$

where VA = VA rating of the transformer [VA], K = copper fill factor, f= frequency of excitation [Hz], A_c = core area [m^2], A_e = winding area [m^2], J = current density of the conductor [A/m^2] and B_m = peak flux density [T].

The product of A_c and A_e, which represents the size of the transformer, can be expressed as a function of frequency and peak flux density

$$A_c.A_e \propto \frac{VA}{B_m f J} \tag{2.2}$$

Equation 2.2 shows that the transformer size is inversely proportional to the frequency and flux density. Therefore, transformer size can be reduced by increasing the operating frequency.

Reference [2] deals with the past approach made for preparing solid-state transformers which are ac/ac buck converters based transformer proposed by Navy researchers and the same followed in 1995 by EPRI. But they are working at below utility distribution levels. Also the design of ac/ac buck converter is costly for very high voltage level. Also the blocking of full primary voltage and conduction of full secondary current is difficult at very high level. Simple model of PET with single phase supply and full bridge rectifier as input stage, medium frequency transformer as isolation stage and full bridge inverter as output stage is presented in the paper.

Reference [3] deals with design and material used for the construction of PET. It is a new type of energy conversion device in power system. The electronic transformer used in PET play an important role in performance of the overall power electronic system, including efficiency, size and cost. In the proposed circuit topology 30 KW medium frequency transformer is used. Design of the transformer is divided in to the following points:

1. Selection of Core Material

2. Determination of Core Size

3. Calculation of the winding number
4. Selection of Winding Model
5. Check for Temperature Rise
6. Check for electronic insulation
7. Efficiency calculation of the designed transformer

Reference [4] deals with the optimum design of a PET based on topology of Modular multilevel converter (M2C). The proposed M2C is divided in to three sections 1) input section which consists of the rectifier. 2) isolation stage consists of DC/DC converter and medium or high frequency transformer and 3) the output stage consists of inverter. M2C is very attractive for High voltage D.C. transmission & FACTS which may be its ability of processing both active power and reactive power with its terminal directly connected to high voltage network.

Reference [5] modifies Sudhoff's PET structure by combining Power Factor Controller (PFC) and DC-DC converter. This idea leads to the loss reduction, by processing the power in one stage instead of two stages. Also the electrical isolation will be gained by high frequency transformer in the proposed isolated full bridge PFC converters (IFBPFC's). The PFC converter programs the input current waveform and makes the power factor near to one. The DC-DC converter regulates the output DC voltage ad makes the electrical isolation using HF transformer.

Reference [6] In many circumstances, three-phase AC power supply is not always the best choice for utility applications. There are rating of three-phase to single-phase and three-phase to multiphase transformers being in operation around the world. Inspite of their good efficiency they have some disadvantages. In this paper a special type of transformer has been proposed composed of input three-phase rectifier, medium frequency transformer and output single-phase inverters. Single-phase source are used in many applications like in railway system and in steel-making plants to operate furnaces. Here in this type of design each cell composed of a voltage stabilizing capacitor.

Reference [7] deals with the distribution power system, the 3-phase and 4-wire power source is necessary in order to meet the requirement of the single phase load. So D-EPT must be designed as a 3-phase and 4-wire transformer.

This is a three-stage design that includes an input stage, an isolation stage and an output stage. In the input stage, there is a 3-phase high frequency rectifier, which converts the primary ac voltage to dc voltage.

The isolation stage consists of a front-end H-bridge, a multi-windings medium frequency transformer and three back-end H-bridges. The dc voltage from the input stage is fed to the front-end converter and is modulated to a high frequency square wave. Then the square wave is provided to the medium frequency transformer and is rectified as dc voltage by the back-end converters in the second side of the medium frequency transformer.

Reference [8] provides PET based on Power Quality Improvement. As can be seen from the block diagram this is a three-stage design that includes an input stage, an isolation stage and an output stage.

The input stage is a three or single phase rectifier, which is used to convert the primary low frequency voltage into the DC voltage. The main functions associated with the rectifier control are shaping the input current, controlling the input power factor and keeping the DC-link voltage at the desired reference value.

Isolation stage is contained a single-phase high frequency voltage source converter (VSC), which converts the input DC voltage to AC square voltage with high (or medium) frequency and HF (MF) transformer. The main functions of the HF (MF) transformer are voltage transformation and isolation between source and load.

Output stage contained a matrix converter with novel function for square to sinusoidal voltage converter. Matrix converter topology employs six bidirectional switches to convert high frequency single-phase input directly to a power frequency (50/60 Hz) three- phase output.

Reference [9] provides PET based on multilevel converter. First stage contains n cascaded H-bridges in line side, and each H-bridge consists of four switches with anti-parallel diodes and one capacitor (series connection of two equal capacitors). Total AC terminal voltage of rectifier is defined as:

$V_{an} = V_{ab} + V_{bc} + ... + V_{xn}$

Each H-bridge on the AC side can generate three voltage levels: V_{ci}, 0, $-V_{ci}$ (It has been assumed that: V_{c1}=V_{c2}=.....=V_{cn}=V_c. For example to have V_{ab}=V_c, switches S_1 and S_4 are turned on and for V_{ab}=0, switches (S_1,S_3) or (S_2,S_4) are turned on.

Second part of the PET includes the isolation stage. In this part with the aid of isolated half bridges DC/DC converters, magnetic isolation is produced. Here there is a compromise between switching losses and PET size. In fact with increasing the switching frequency, weight and volume reduced but on the other hand the efficiency is degraded. This high frequency pulsating DC input is provided to the transformer primary side. On the secondary side with the help of Diode bridge pulsating DC is converted into pure DC. In the output stage a voltage source inverter converts the resulting low-voltage DC into three-phase regulated AC voltages.

Reference [10] describes a new bi-directional power electronic transformer (PET) for induction heating applications. The proposed PET is made of primary bi-directional cycloconverter switches, high frequency isolation transformer, matching coil and a parallel resonant heating system. Switching routine is applied in such a way that the output voltage regulation is achieved in the full load variations, even at asymmetrical utility conditions. Inverter operating frequency and simulation results are provided to prove the use of PET for induction heating applications.

Chapter 3

Power Electronic Transformer

3.1 Introduction

Transformers are used widely in electrical power distribution/conversion systems to perform many functions, such as isolation, voltage transformation etc. Transformers are one of the heaviest and most expensive parts in an electrical distribution system. The size of transformer is a function of the saturation flux density of core material and maximum allowable core and winding temperature rise. Saturation flux density is inversely proportional to frequency and increasing the frequency allows higher utilization of the steel magnetic core and reduction in transformer size.

The proposed electronic transformer has the following advantages:

1. Identical input/output characteristic as conventional transformer
2. Small size and weight
3. Efficiency compatible with conventional transformer
4. Good voltage regulation

3.2 Design Example

As mentioned earlier transformer size is inversely proportional to the frequency and flux density. Therefore, transformer size can be reduced by increasing the operating frequency. Core loss increases with frequency and depending on the type of core material, reduction in flux density is necessary. However, as described in equation 2.1, transformer size is inversely proportional to frequency assuming flux density is constant.

In order to explore the relative merits of the power electronic transformer concept compared to a conventional transformer, a 1000Hz, 10KVA transformer design is examined with a conventional 60 Hz transformer.

Table 3.1: Comparison Study

PARAMETER	1000Hz	60Hz	Unit
VA rating	10	3.17	KVA
Primary Voltage	679	214.5	V
Maximum flux density	3.03	16	kG
Core loss	77.3	38.6	W
Wire loss	57.4	57.4	W
Temp rise	100	71.1	C
Efficiency	98.6	96.9	%

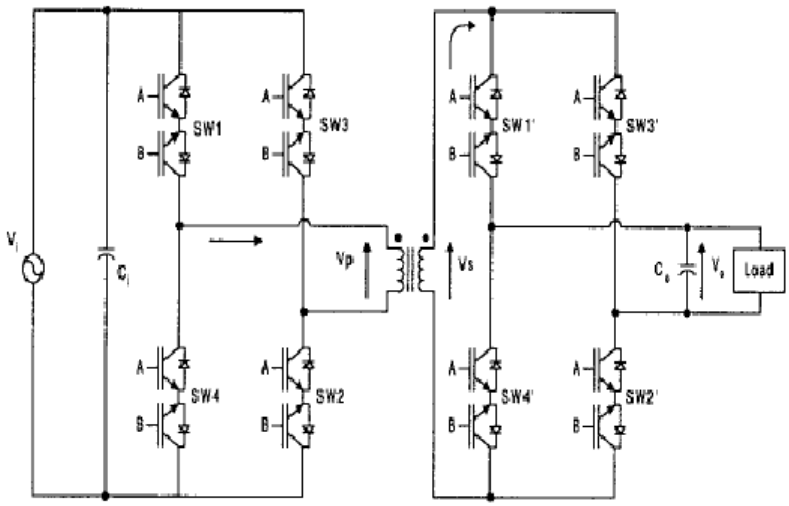


Figure 3.1: Single-phase Power Electronic Transformer

3.3 Power Electronic Transformer Operating Principle

Fig 3.1 shows a single phase electronic transformer topology with a primary/secondary side static converter. Fig 3.2 shows the switching pattern, which is essentially a high frequency square-wave with 50 % duty ratio. Gating signals for switches SW1, SW2; SWl', SW2'; and SW3, SW4; SW3', SW4' form complementary pairs as shown in Fig. 3.2, where θ is the phase shift angle between the two pairs of gating signals.

The switching action generates a high-frequency voltage and current in the transformer primary/secondary windings. The secondary-side static converter then unfolds the transformer secondary voltage into a low-frequency sine wave output voltage. Fig 3.3 shows the input voltage V_i, transformer primary voltage V_p and output voltage V_o respectively.

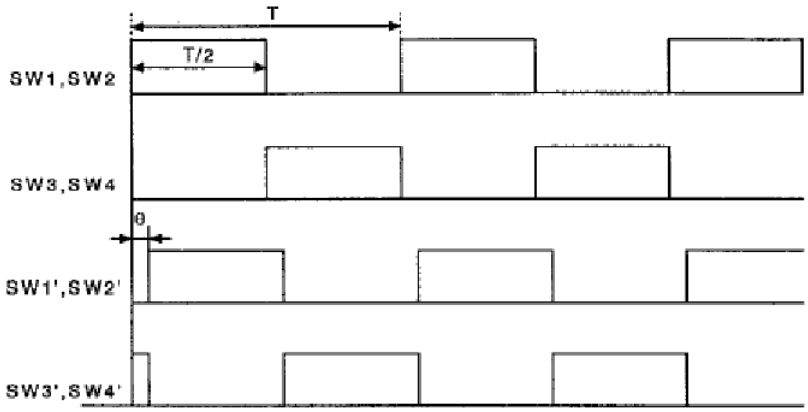


Figure 3.2: Gate Signal of Power Electronic Transformer

3.4 Simulation & Results

Fig. 3.4 shows the simulation model of the Power Electronics Transformer. In this model at the input side high frequency converter is used to convert the fundament frequency in to high frequency and at the output side cycloconverter is used to convert the high frequency back to fundamental frequency. At the input side switches S_1 and S_{41} will conduct together for the positive half cycle & switched $S_2$and S_{31} will conduct for negative half cycle of the supply voltage. On the other hand at output side/secondary side of transformer switches T_1 and T_4 conduct together & switches T_2 and T_3 will conduct together.

For the simulation as shown in Fig 3.5 input sine wave of 150 V AC supply is provided. Fig. 3.6 show the primary side input voltage wave form of the transformer. Fig. 3.7 & 3.8 shows the output waveform of voltage and current respectively. The transformer used here is an ideal transformer. The basic purpose here is to show its working. By changing the transformer turn ration we can use it as either step up or step down transformer.

Fig. 3.9 & 3.10 shows the FFT analysis of output voltage and current of the Electronic Transformer.

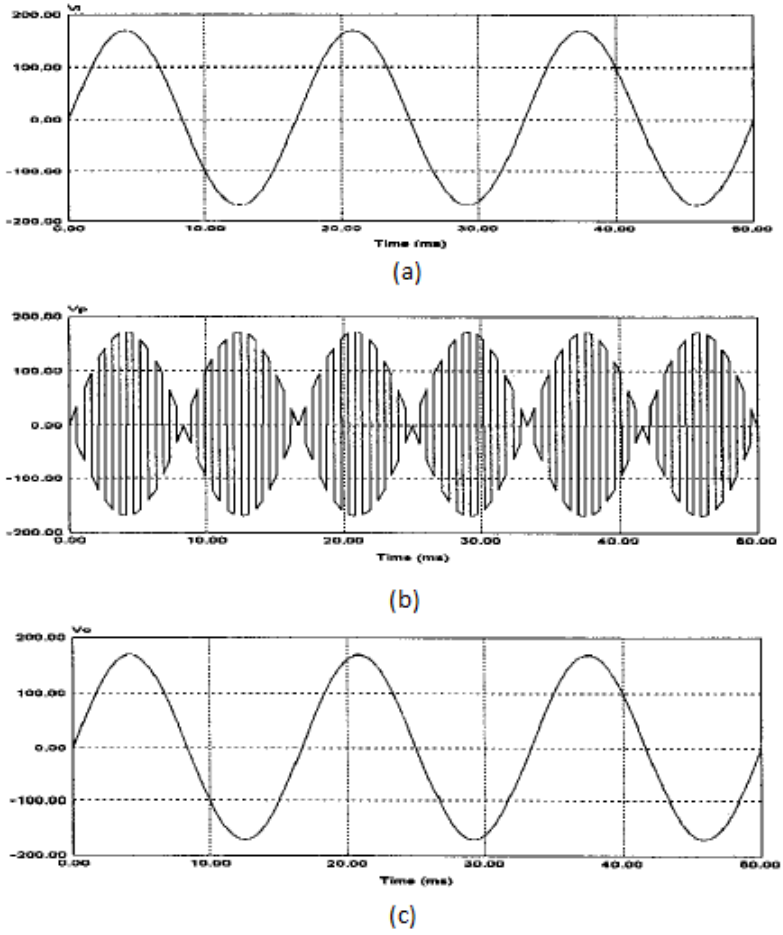


Figure 3.3: (a) Input Voltage V_i (b) Transformer Primary Voltage V_p (c) Output Voltage V_o

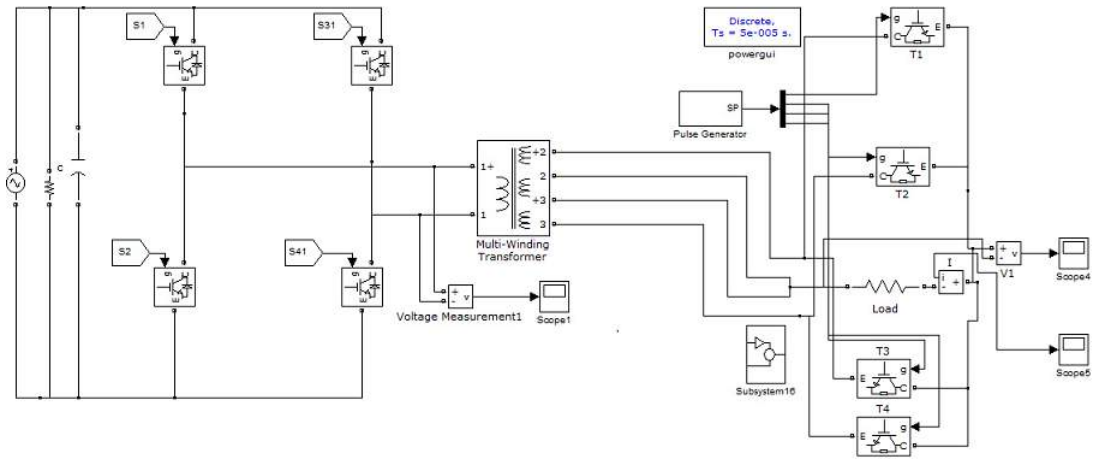


Figure 3.4: Single-phase Electronic Transformer

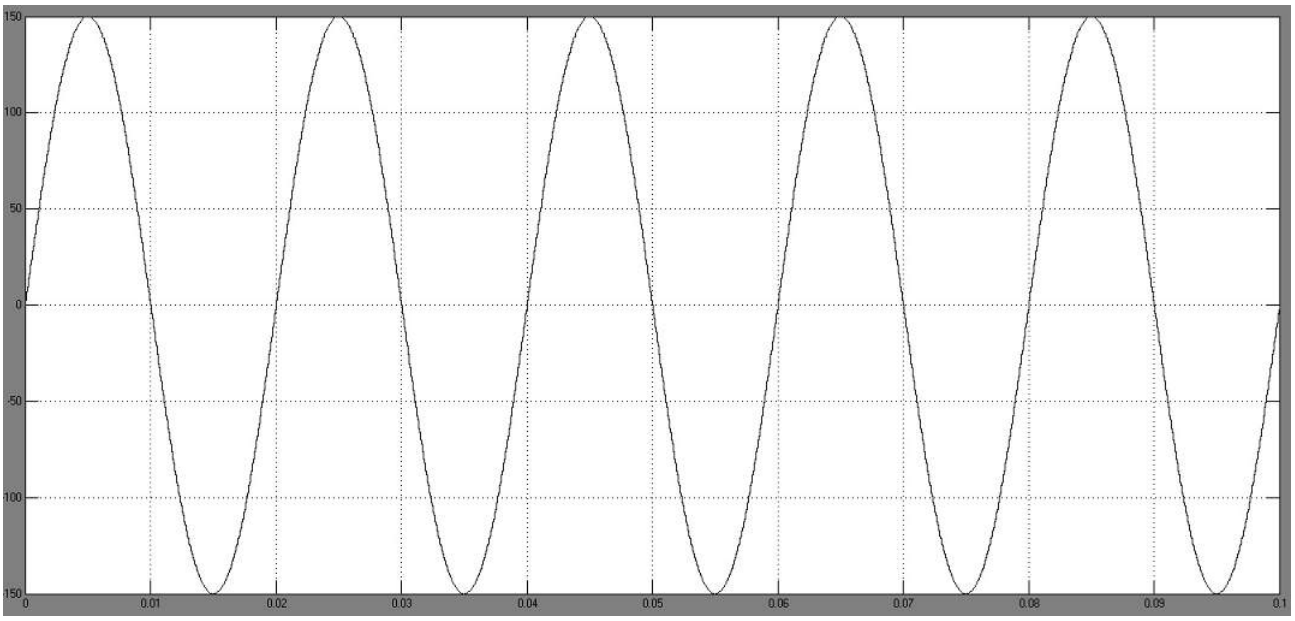


Figure 3.5: Input Waveform

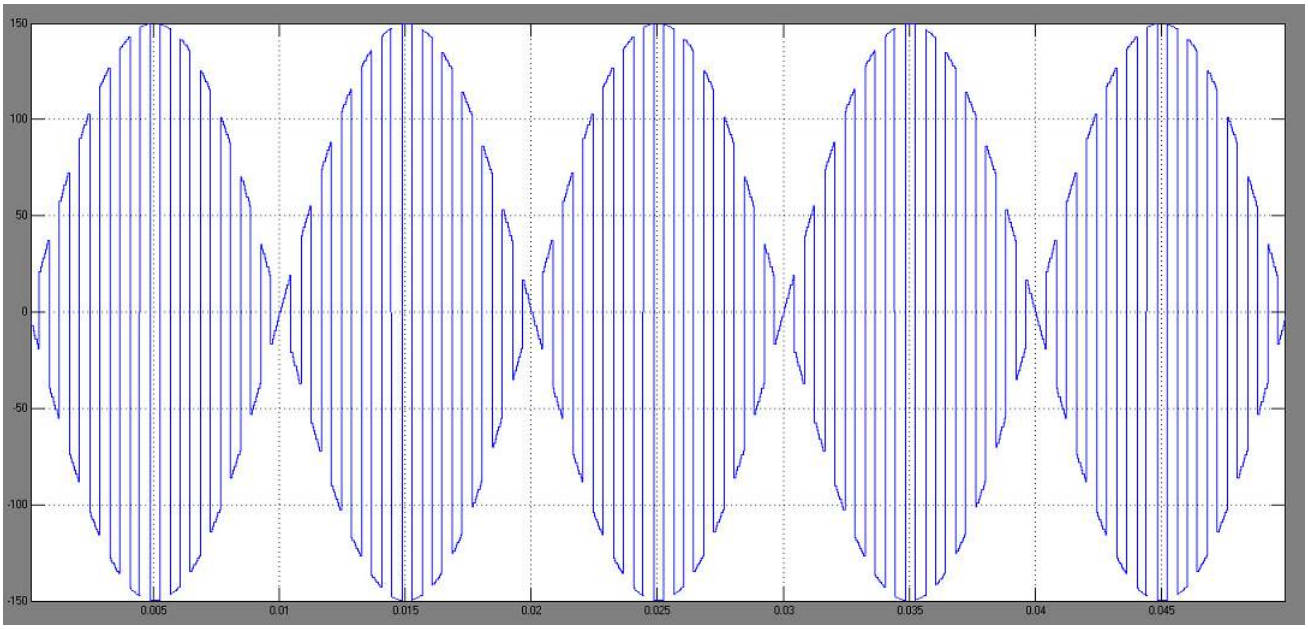


Figure 3.6: Primary Side Voltage of Transformer

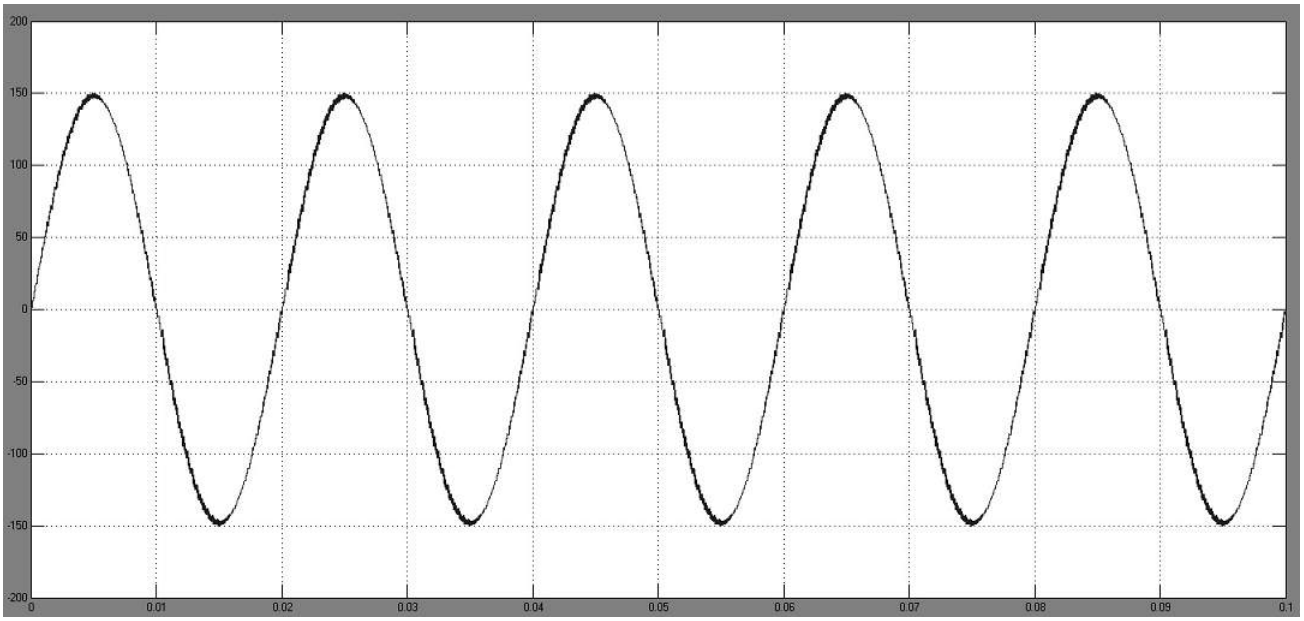


Figure 3.7: Output Voltage

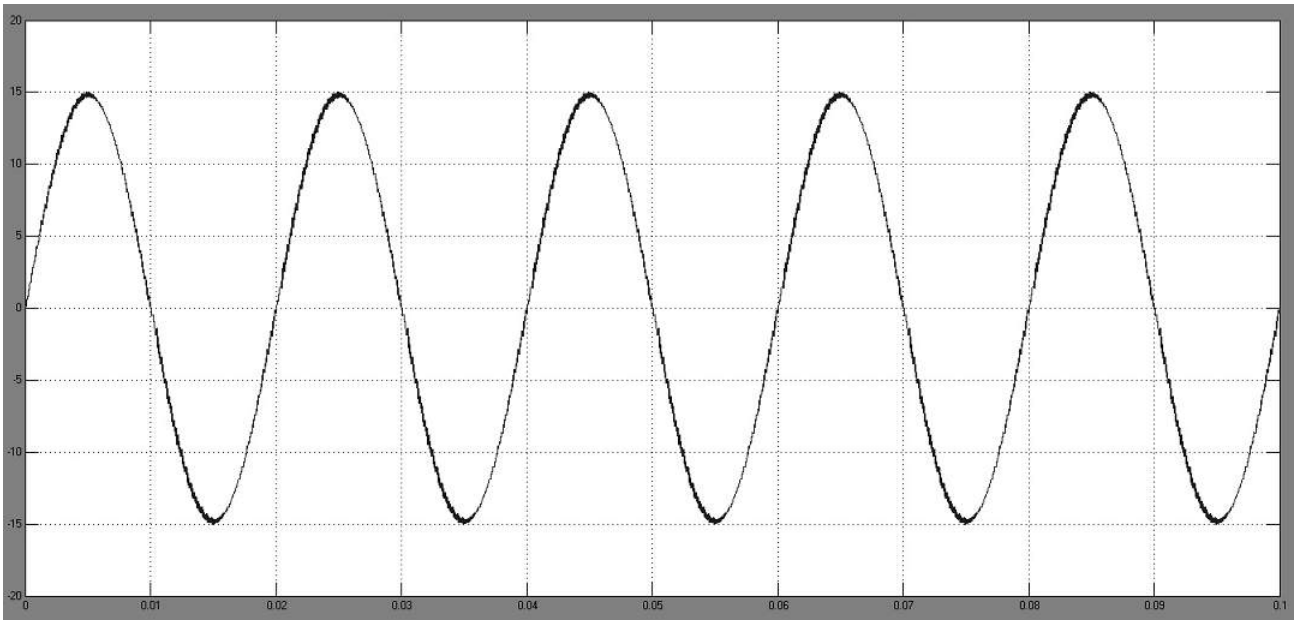


Figure 3.8: Output Current

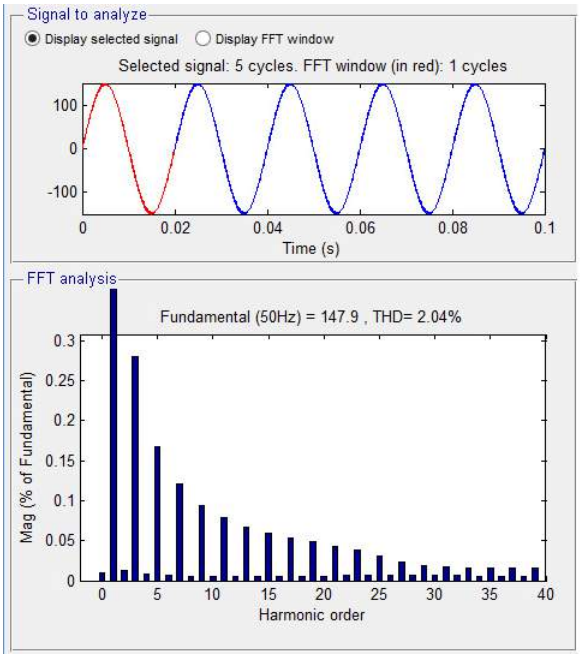


Figure 3.9: FFT Analysis of Output Voltage

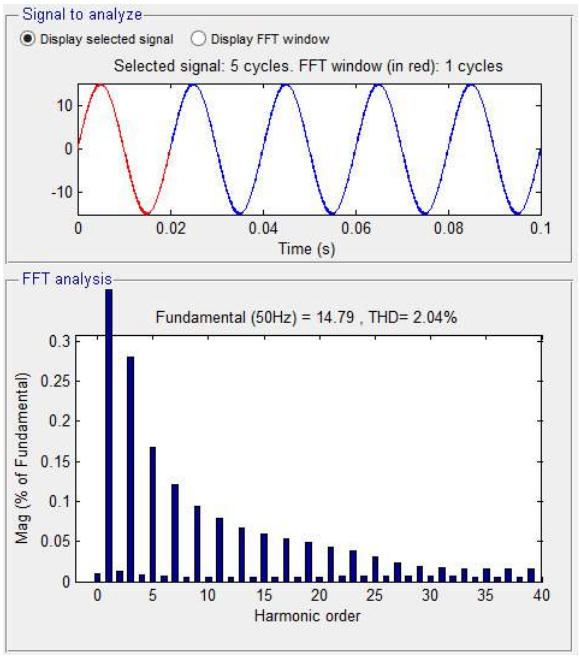


Figure 3.10: FFT Analysis of Output Current

Chapter 4

Flexible Power Electronic Transformer

Power Electronic Transformers (PETs) are developed to replace conventional transformers. PET consists of power electronic devices to perform voltage regulation, power quality improvement and power exchange between generation and consumption by electrical conversion using power electronic. The previous researches show that PETs have a great capacity to receive much more attention due to their merits such as high-frequency link transformation and flexible regulation of the voltage and power. Although many studies have been conducted on application and control of PET in power system [1]- [8], less attention is paid to the area of the circuit topologies [20] and [21]. The topology of PET can be implemented in a different way to achieve multiport electrical system that can be used to achieve multiple applications.

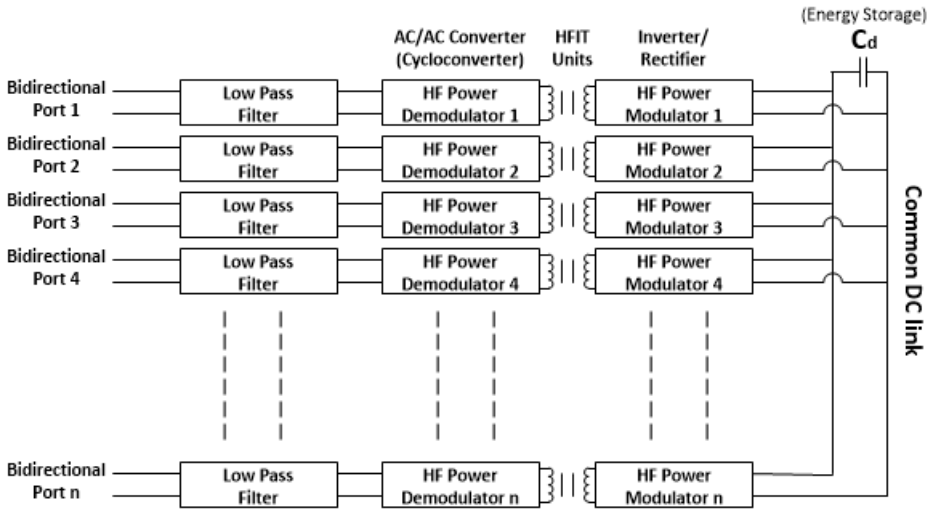


Figure 4.1: Main Concept of Proposed FPET

New advance Power Electronic Transformer(PET) called as Flexible Power Electronic Transformer is constructed based on modules/sections and a common dc link

as shown in Fig. 4.1, which is used for energy transfer between ports, sections and to isolate all ports from each other. This will help in maintaining constant voltage level among the ports. Due to bidirectional topology input and output ports/modules can be varied according to the system requirement. Each module consists of three main parts, including modulator (inverter/rectifier), demodulator (cycloconverter), and high frequency isolation transformer (HFIT). The modulator is a dc-ac converter and the demodulator is an ac-ac converter; both having bidirectional power flow capability. Independent operation of the ports are possible and hence better voltage regulation can be obtained. This topology can be used for many different characteristics such as different voltage level, high/low frequency, change in phase angle, and shape of the waveform. As a result, FPET can be used for almost any kind of application to meet future needs of electricity networks. This advance technology can overcome many drawbacks of the present electrical technology of conventional iron and copper based transformer.

4.1 Proposed Power Circuit of FPET

The proposed circuit is shown in Fig 4.2. As mentioned earlier the proposed topology of FPET can be expended according to system requirement by connecting modules in series or in parallel to obtain higher voltage or current ratings, for three phase applications star/delta connections are also possible. Such variation and different connections are only possible with FPET.

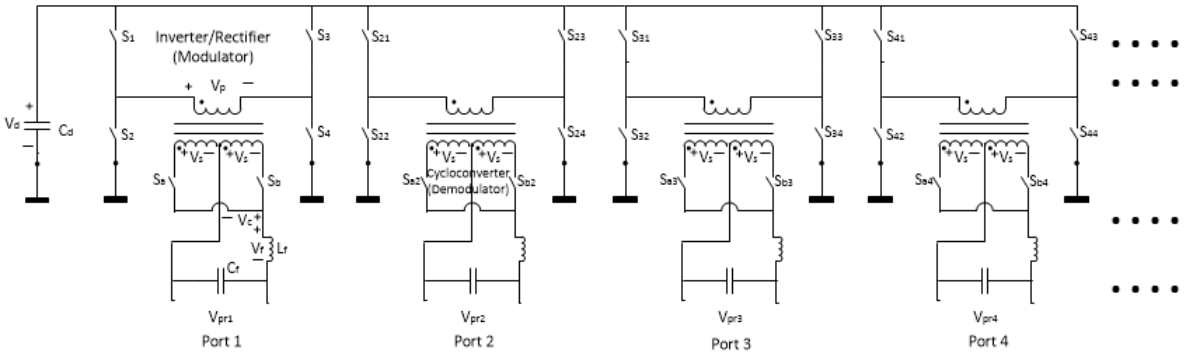


Figure 4.2: Switching Topology of Proposed FPET

As shown in Fig. 4.2, each port is composed of four switches(full-bridge system) connected with the DC-link in order to invert the DC supply hence it is also called as Full-bridge dc-link Inverter(FBDCI), High Frequency Insulation Transformer(HFIT), and a cycloconverter. Here, all the modules are similar and works independently. Independent operation of the modules will help at the time of maintenance or fault in a particular module. By just replacing that particular module the system can be operated without any interruption. Here, analysis of one port is sufficient to introduce whole topology. The FBDCI (modulator) can operate as an inverter as well as rectifier at a particular situation. It can operate as an active inverter when supply voltage

is dropped and dc-link voltage is inverted at HFIT side. And it can operate as an active rectifier when due to sudden increase in load dc-link voltage is dropped and to maintain constant dc-link voltage AC voltage of HFIT is rectified to charge dc-link. Adjustable pulse width can also obtained with the help of FBDCI. In order to reduce harmonics number of switches in the system can be reduced and simpler circuit can be obtained as shown in Fig. 4.3. By reducing number of switches the switching operation can be made simple and the problems of harmonics is also reduced. In this type of circuit one of the half-bridge (two switches) circuits is considered as the reference or master leg and other are considered as slave legs. In the beginning gate pulse is provided to the master leg and according to the system requirement phase shift is provided to the other legs by taking reference of the master leg. By using this kind of topology the number of switches can be reduced to half compared to the previous topology.

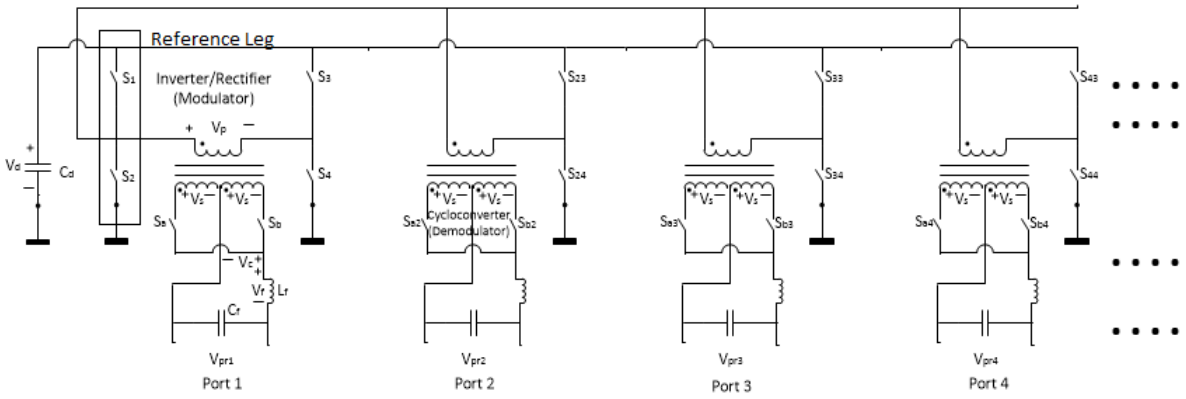


Figure 4.3: Reduced Switch topology of Proposed FPET

The specifications of modulator are as follows:

1. Power flow capability in both the directions;
2. Adjustable switching frequency according to system requirement; and
3. Energy storage capability in dc-link (if the modulator is in active rectifier mode).

Here, demodulator operates with two bidirectional switches. Two switches are used to generally to get the full wave of the supply voltage. The demodulator converts high frequency voltage to low frequency voltage (i.e., V_{pr1}) and vice versa.

The specifications of the demodulator are listed as follows:

1. Power flow capability in both the directions; and
2. Provides zero voltage switching by turning the switches of cycloconverter ON/OFF, when voltage of HFIT reaches to zero.

Table 4.1: Definition of Parameters

Symbol	Definition
G_i	gate driving signal of $S_i where i = 1 to 5$
$G_a and G_b$	gate driving signal of $S_a and S_b$
T_s	switching period
T_{on}	turn-on duration time in $T_s/2$
T_{cd}	cycloconverter switching delay time
V_c	output voltage of the cycloconverter
N	transformer winding ratio N_s/N_p

4.2 Modulator and Demodulator Operation Principles

Phase modulation (PM) is a method of impressing data onto an alternating-current (AC) waveform by varying the instantaneous phase of the wave. This scheme can be used with analog or digital data.

In analog PM, the phase of the AC signal wave, also called the carrier, varies in a continuous manner. Thus, there are infinitely many possible carrier phase states. When the instantaneous data input waveform has positive polarity, the carrier phase shifts in one direction; when the instantaneous data input waveform has negative polarity, the carrier phase shifts in the opposite direction. At every instant in time, the extent of carrier-phase shift (the phase angle) is directly proportional to the extent to which the signal amplitude is positive or negative.

In order to utilize the Phase modulation method more effectively with the reduced switching topology Phase Shift Modulation (PSM) method is used to operate the modulator and demodulator. FBDCI uses PSM method to perform voltage regulation. By using sign function the required polarity (positive/negative) is generated. This polarity is used by the cycloconverter to generate the output pulse. In Fig 4.4 the cycloconverter provides positive output voltage polarity as an example. The switches of cycloconverter turn ON/OFF with a time delay (T_{cd}) respect to those of FBDCI, and according to that other ports are also get the time delay. Small overlap time is also provided to avoid high stresses at the time of switching on and off.

4.3 PSM controller

In Phase shift Modulation, the timing of the carrier wave is modified to encode data. Once a phase shift has occurred, the carrier wave continues to oscillate but jumps to a new point in the wave cycle. Modulation of the phase of the carrier signal is also referred to as Phase-Shift Keying(PSK).

Phase Shift Modulation controller is responsible to provide gate pulses to the cyclocnverter and the inverter/rectifier switches. The implementation of the controller is shown Fig. 4.5. Here four input data lines are used for the operation of the controller. The first one is output voltage polarity with the help of $sign_i$ function.

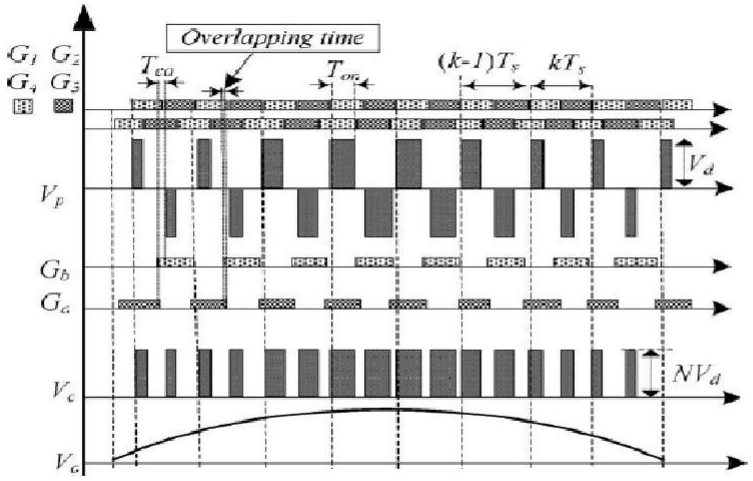


Figure 4.4: Principle of PSM method

The second one is switch-enable of cycloconverter ($Enable_{Ci}$). The third one is switch-enable of dc link ($Enable_{Si}$). The fourth one provides the duty cycle of the port. Where $sign_i$ function helps the cycloconverter to choose the polarity of the waveform. Switch-enable of cycloconverter ($Enable_{Ci}$) gives switchng pulse to cycloconverter and switch-enable of dc link ($Enable_{Si}$) provides switching pulse to FBDCI switches.

Based on the above discussion the duty cycle is defined as follows:

$$D(kT_s) = \frac{2T_{on}(kT_s)}{T_s}, k = 1, 2, 3, ... \tag{4.1}$$

The modulated voltage at the secondary side for one duty cycle is expressed by (4.2)

$$V_s = NV_p \tag{4.2}$$

Secondary side voltage of the transformer is N times the primary side voltage.

The voltage at the output of cycloconverter (V_c) is determined as follows:

$$V_c(t) = sign(t)|NV_p(t)| = sign(t)NV_d(t), \tag{4.3}$$

In order to get positive as well as negative output voltage and to get the full sine wave at the output side of the cycloconverter sign function is used as shown in equation (4.3)

$$sign(t) = 1 or -1, (k-1)T_s < t < kT_s, k = 1, 2, 3, ... \tag{4.4}$$

$$sign(t) = 1 for G_a(t) = G_1(t - T_{cd}) and G_b = G_2(t - T_{cd}) \tag{4.5}$$

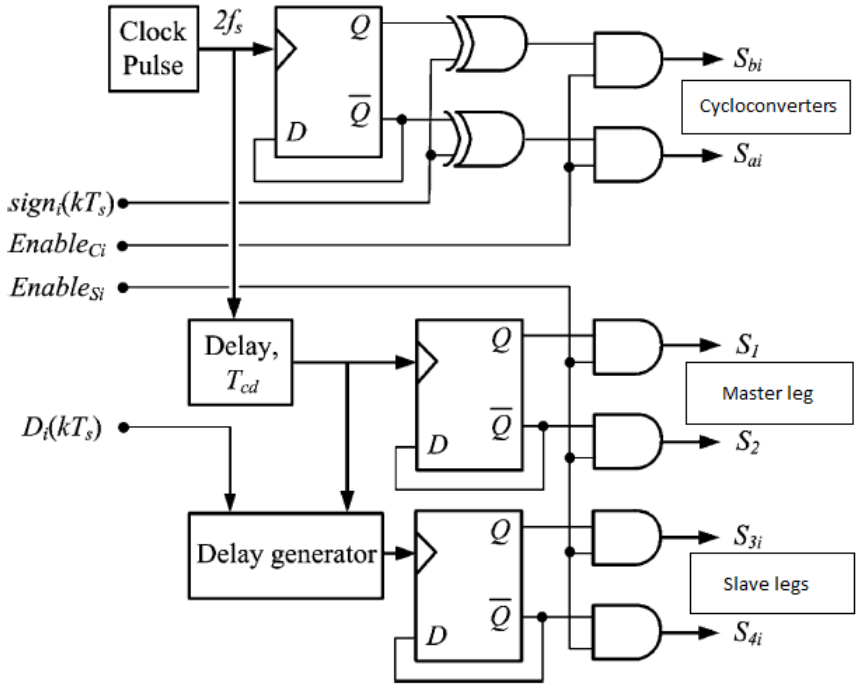


Figure 4.5: Schematic Presentation of PSM controller

$$sign(t) = -1 for G_b(t) = G_1(t - T_{cd}) and G_a = G_2(t - T_{cd}) \tag{4.6}$$

4.4 Use of Ports as a Voltage Source

To get constant and controllable voltage at the output of cycloconvertera port is designed to operate as a voltage source. This port provides a constant voltage regardless of the active or reactive power that is exchange between the port and the grid. So, a controllable voltage at the output of cycloconverter can be obtained and it is given by,

$$v_c = v_{Ref}(t) \tag{4.7}$$

where $v_{Ref}(t)$ is the reference voltage.

The block diagram of the control circuit is shown in Fig. 4.6. This controller is used basically to generate sign function outputs and to provide delay to the slave legs. These two blocks are used in the PSM controller as discussed above. In the control circuit block diagram product of V_{ref} with capacitor voltage V_d, math function and some gain is used to get the Delay time with the help of limiter/saturation.

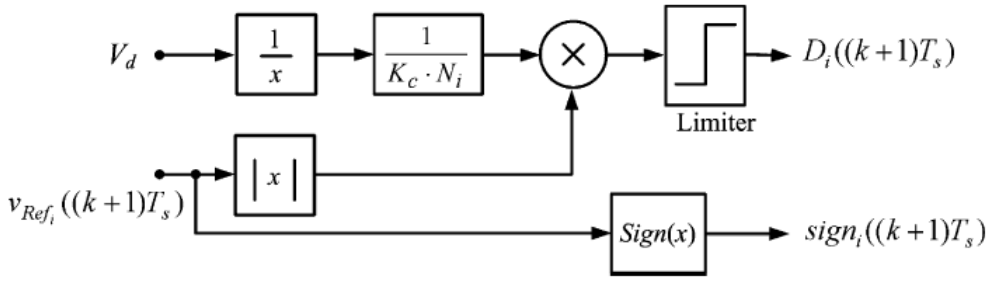


Figure 4.6: Control circuit of a typical port that operate as a voltage source

4.5 Energy balance in the proposed FPET

In every system, there is a balance among losses, input energy and output energy. As discussed earlier the proposed FPET consists of n number of ports and hence the energy balancing is more important in this kind of scheme. It is always important to keep same amount of vaoltage and currant rating in each port to get desired amount of output ratings.

Here in this system there are three kind of energy which is required to be balanced which are input/output energy, stored energy in dc link(capacitor) and various losses in the system.

The energy balance for FPET is as follows:

$$\sum_{i=1}^{n} W_i + W_{C_d} + W_{loss} = 0 \tag{4.8}$$

where W_i, W_{C_d}, W_{loss} are the input/output energy, stored energy of dc link and system losses, respectively. Neglecting the power losses, (4.8) can be approximated by

$$\Delta \sum_{i=1}^{n} P_i \approx -\Delta P_{C_d} \tag{4.9}$$

From (4.9) it is clear that constant power or power equilibrium can be achieved by achieving constant dc-link voltage. To achieve this it is required that some of the ports should inject or absorb the reactive power in the system at the time of unbalance in the load.

Following two methods can be used to charge the dc-link capacitors to the desired value.

1. As the voltage in the dc-link drops down, the dc-link capacitor can be charged using the external dc source. As the desired voltage level is achieved in the dc-link the external dc source should be disconnected.

2. FBDCI can be used as an inverter to charge the dc-link voltage. The cycloconverter can provide a high frequency voltage across HFIT. This high frequency

voltage can be used by the FBDCI switches to convert the ac voltage in to dc voltage and to charge the capacitor up to desired level. The dc voltage can charge the capacitor considering the winding ratio of HFIT.

4.6 Reference Voltage of DC Link and Winding Ratio of HFIT

From practical point of view, lower dc-link voltage results in lower voltage stress of switches. In addition, the decrease of the dc-link voltage increases the current of dc link switches. Consequently, by selecting an appropriate dc link reference voltage ($V_{d,Ref}$) and the maximum ripple voltage, the minimum dc-link voltage ($V_{d,min}$) can be determined. In the worst condition, the lowest dc-link voltage ($V_{d,min}$), maximum duty cycle (D = D_{max}) and the maximum magnitude of desired voltage ($V_{i,max}$) can determine the winding ratio as follows:

$$N_i > \frac{V_{i,max}}{K_c V_{d,min} D_{max}} \tag{4.10}$$

Chapter 5

Simulation Result of FPET

5.1 Proposed FPET

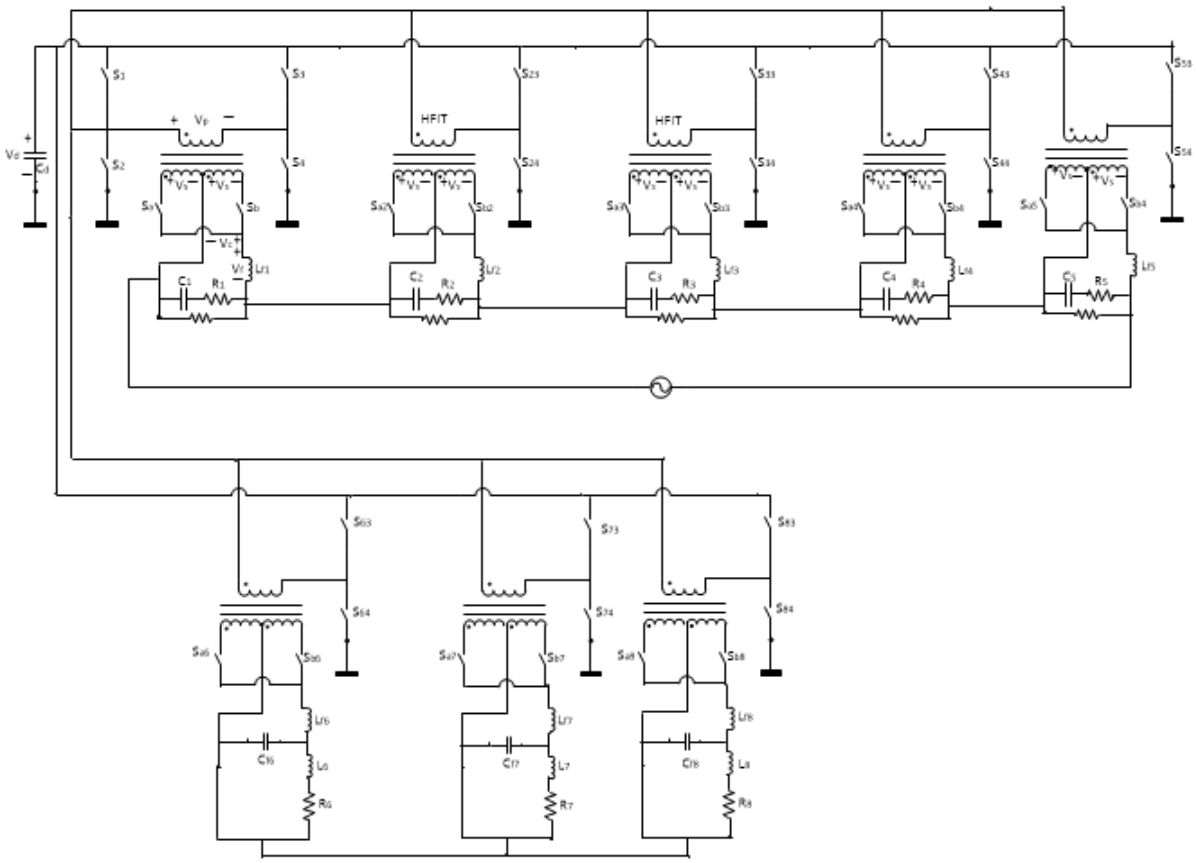


Figure 5.1: Proposed FPET Model

In order to use PET for HV application, the modules of PETs are connected in series as described in [5], [9], and [11]. One more advance cascaded H-bridge multilevel PET has been proposed in [9]. The advantages of this PET are: the low

Table 5.1: Parameters of FPET

Parameter	Definition
f_{HFIT}	2kHZ, frequency of HFIT
$L_{f1,2,3,4,5}$	4mH (total 20mH)
C_d	2200*10^{-6} F
$C_{f6,7,8}$	3*20*10^{-6} F
$L_{f6,7,8}$	3*1.5mH
$LoadPF$	0.8 Load power factor
Load	3 * 10kW, 3 phases
$V_{d,ref}$	600 V
V_1	1900 V rms, 50 Hz, Utility
$N_{1,2,3,4,5}$	1.6, Turn ratio
$N_{6,7,8}$	0.8, Turn ratio

Table 5.2: Parameters Cascaded H-bridge Multilevel PET [2]

Parameter	Definition
No. of Ports	5 Ports, series connected
f_{tr}	2kHZ, MF transformer frequency
L_b	10mH Line inductance
$C_i + C_c$	5*2*560*10^{-6} F+680*10^{-6} F, Units capacitors
C_f	3*100*10^{-6} F, Load filter capacitor
L_f	3*1.5mH, Load filter inductor
$LoadPF$	0.8 Load power factor
Load	3 * 10kW, 3 phases
dc bus Ref.	600 V
V_{in}	1900 V rms, 50 Hz, Utility
n_1/n_2	12/5, Turn ratio

switching frequency, the low input current harmonics, the power factor correction, and the reduction of the input voltage distortion at the output side. In order to get these advantages and many more, proposed FPET is connected in series to achieve high voltage as shown in Fig. 5.1. This proposed scheme should be compared with the PET described in [9] to see how effectively this scheme really works. As shown in fig. five ports, i.e., $P_1, P_2, ..., P_5$ are connected in series to increase the rating of the input voltage. Number of ports can be increased or decreased according to the requirement of the voltage level.

The RC circuit ($R_s and C_s$) is connected to each port to divide high input voltage equally among the ports. The sixth, seventh, and eight ports are connected to a low voltage three-phase load. Here, single phase input voltage is converted in to three phase output voltage. Table I & Table II lists the parameters of both FPET and cascaded H-bridge multilevel PET respectively.

5.2 Circuit Description

Figure 5.2 & 5.3 shows the model of proposed FPET and the PSM controller respectively used for the simulation.

The simulation circuit shown in Fig. 5.2 consists of AC source with 1900 V_{rms} V. By using RC series circuit this voltage is divided in to each port by 380 V_{rms} or 536 V as shown in Fig 5.6 voltage measured at 1^{st} port input. And Fig. 5.7 shows the measured value of current at the same port which is around 30 A. Transformer turns ratio N_s/N_p is 1.6 for the ports from 1 to 5. Here, in the input side of the FPET voltage is stepped up to maintain the desired voltage level.

Dc-link capacitor is used to get constant voltage as shown in Fig. 5.8. At the output side transformer turns ratio N_s/N_p is 0.8 for the ports from 6 to 8. Single phase and three phase output voltage waveforms are shown in Fig. 5.9 and in Fig. 5.10 respectively.

Simulation results presented over here can be compared with the results getting in [9]. After proper observations of both the results it can be said that the proposed circuit of the FPET gives almost the similar results which are presented in [9]. So, from this we can say that the proposed FPET gives many more advantages with similar kind of results presented in PET based on Cascaded H-bridge Multi-level Converter.

5.3 Case Study

We have already done the analysis of FPET at no fault condition. In this case study we will do the analysis of FPET at the time of fault.

In order to study the capacity of FPET at voltage swell and sag, the simulation model is tested by applying Voltage sag and swell by generating faults by sine wave and timer as shown in Fig. 5.11 for time intervals [0 1 1.2] and Amplitude [1 1.3 0.5].

Fig. 5.13, 5.15 and 5.16 shows the input, dc-link and output voltages. This is clear that the output i.e. port 6 remains almost constant during voltage sag and swell, respectively. These simulation shows that the multilevel PET proposed in [9] and FPET have the same capacity of the power factor correction and power quality enhancement. The advantage of multilevel PET over FPET is its lower harmonic components in the input current. On the other hand, FPET has the capability of the bidirectional power flow, while the multilevel PET is unidirectional. It must be mentioned that, FPET has one dc link and one dc capacitor but multilevel PET has two dc link in each module. In addition, the output ports of FPET can be connected in star configuration to provide a three phase four-wire system.

Fig. 5.18 shows the FFT Analysis of the output voltage. THD we are getting is around 2.94

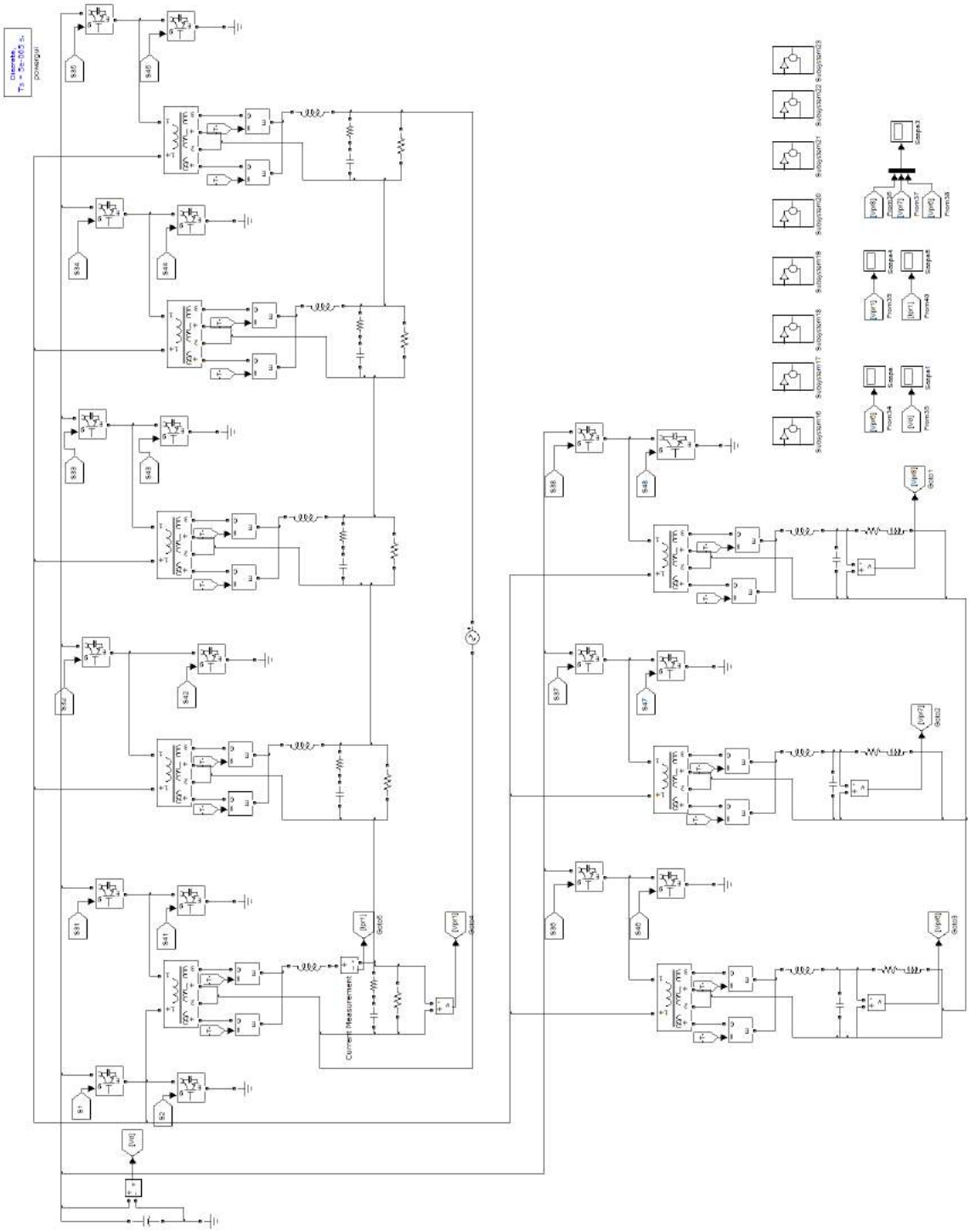


Figure 5.2: Simulation Model of FPET

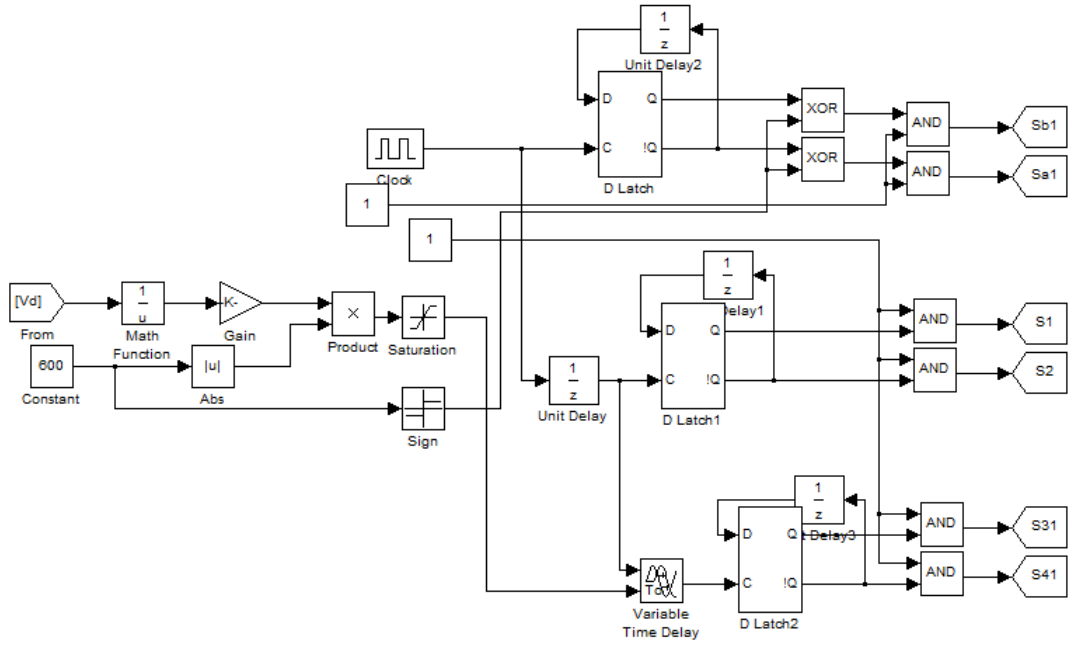


Figure 5.3: PSM Controller

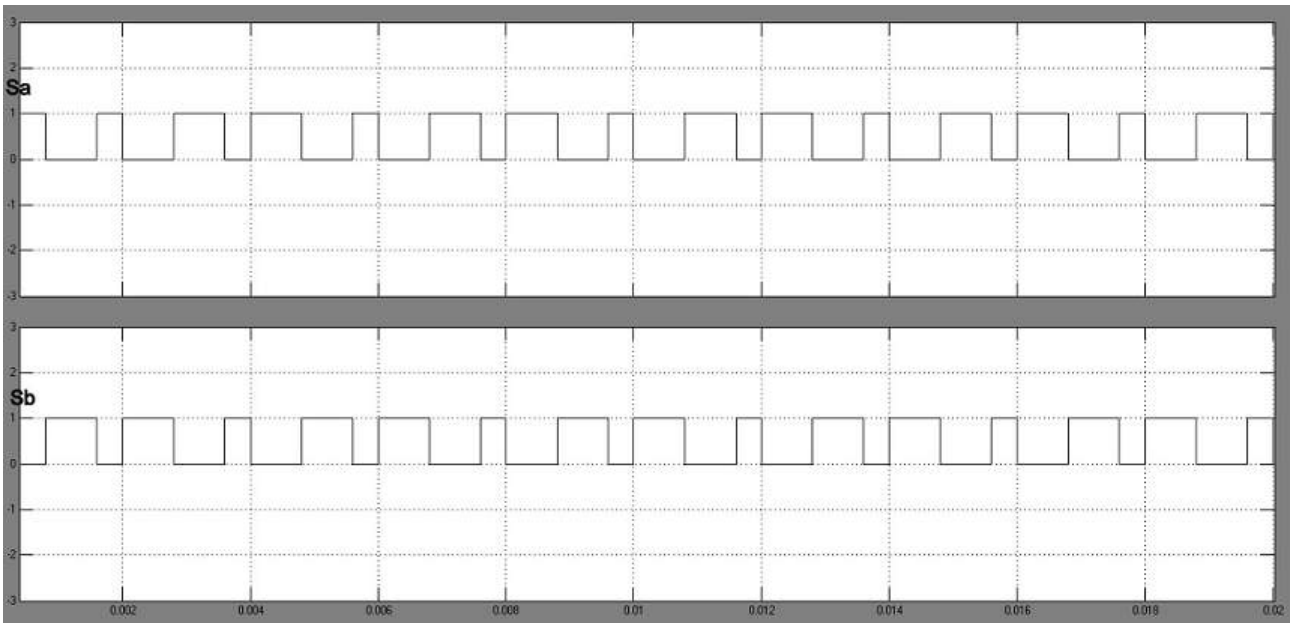


Figure 5.4: Pulses to Demodulator

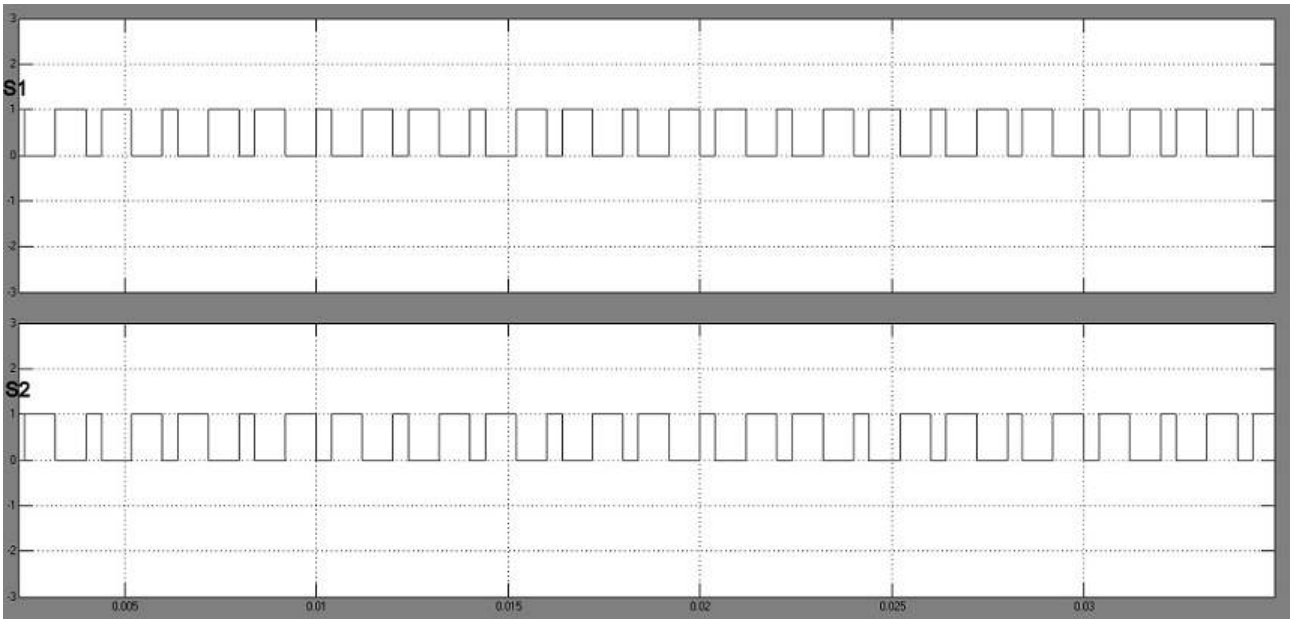


Figure 5.5: Pulses to Modulator

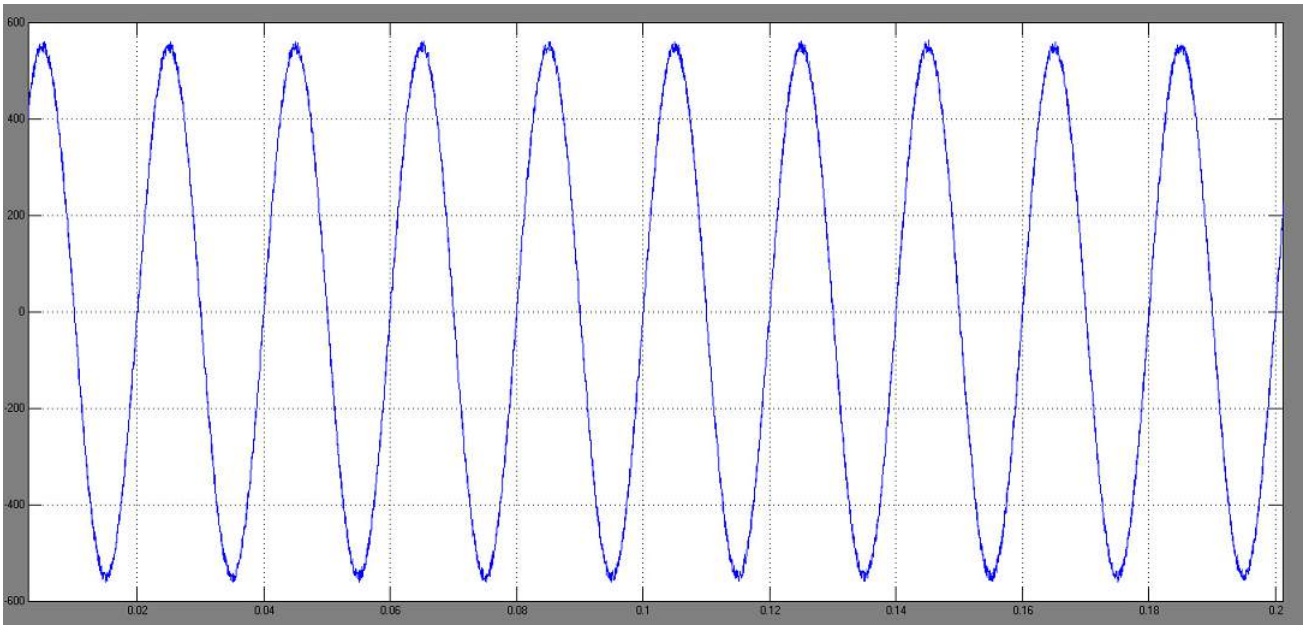


Figure 5.6: V_{rms} Voltage at 1^{st} port

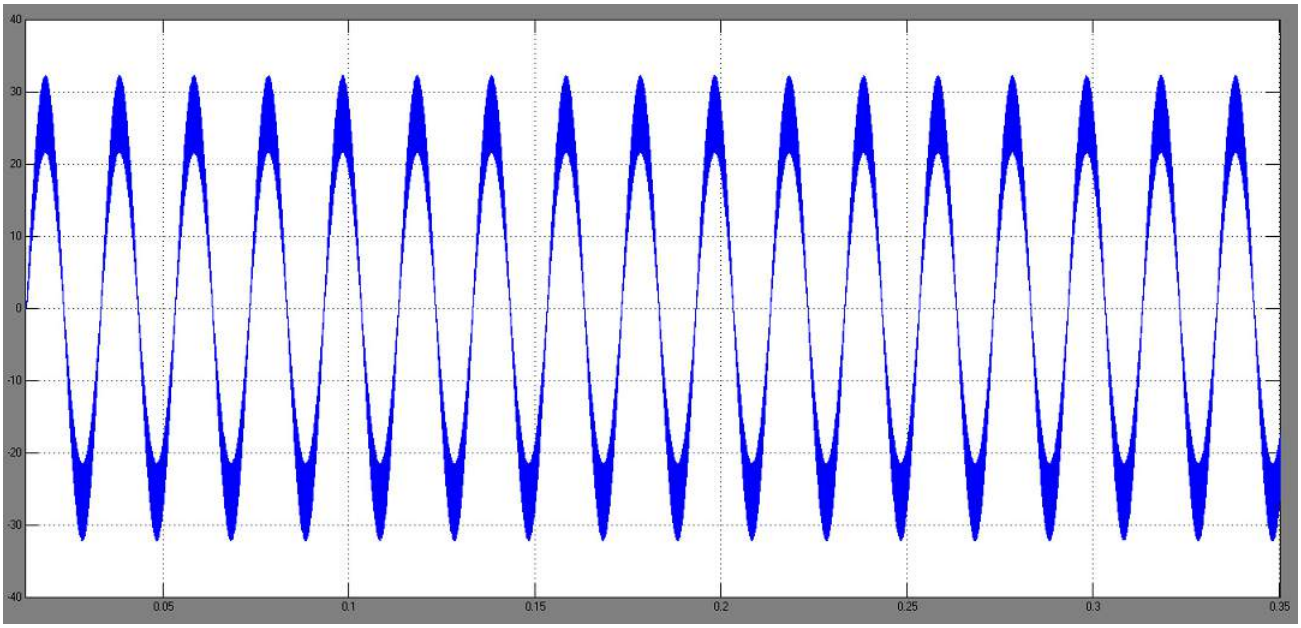


Figure 5.7: I_{rms} Current at 1^{st} port

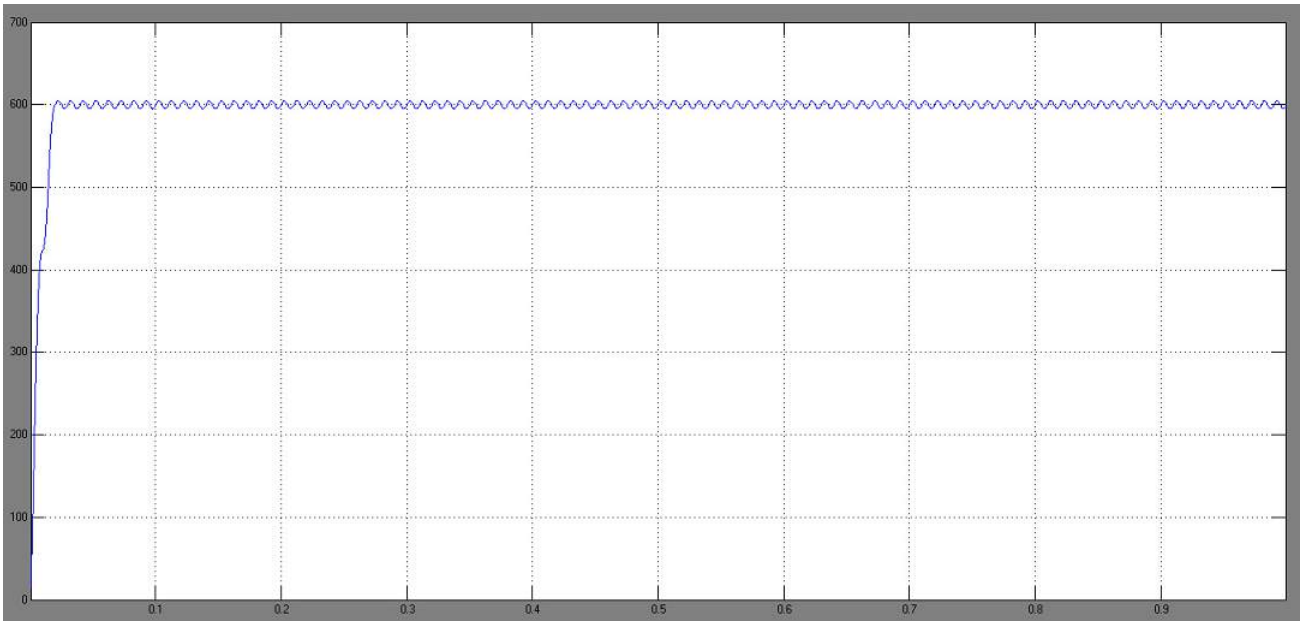


Figure 5.8: DC link Voltage

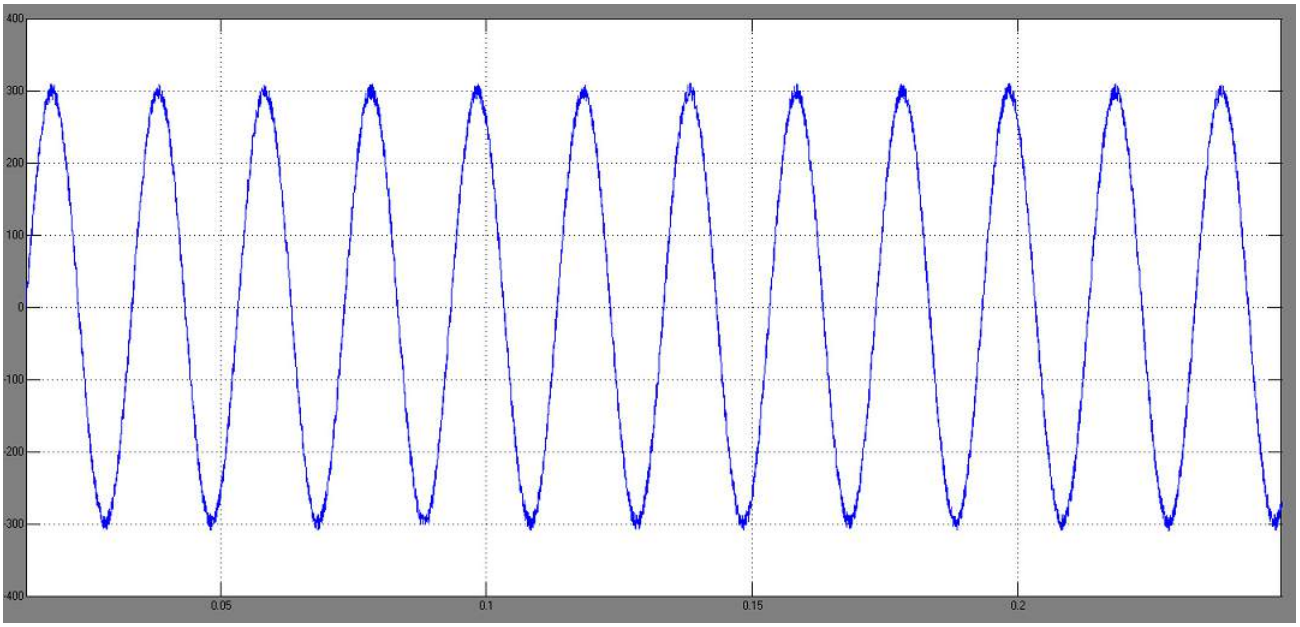


Figure 5.9: Single Phase Output Voltage

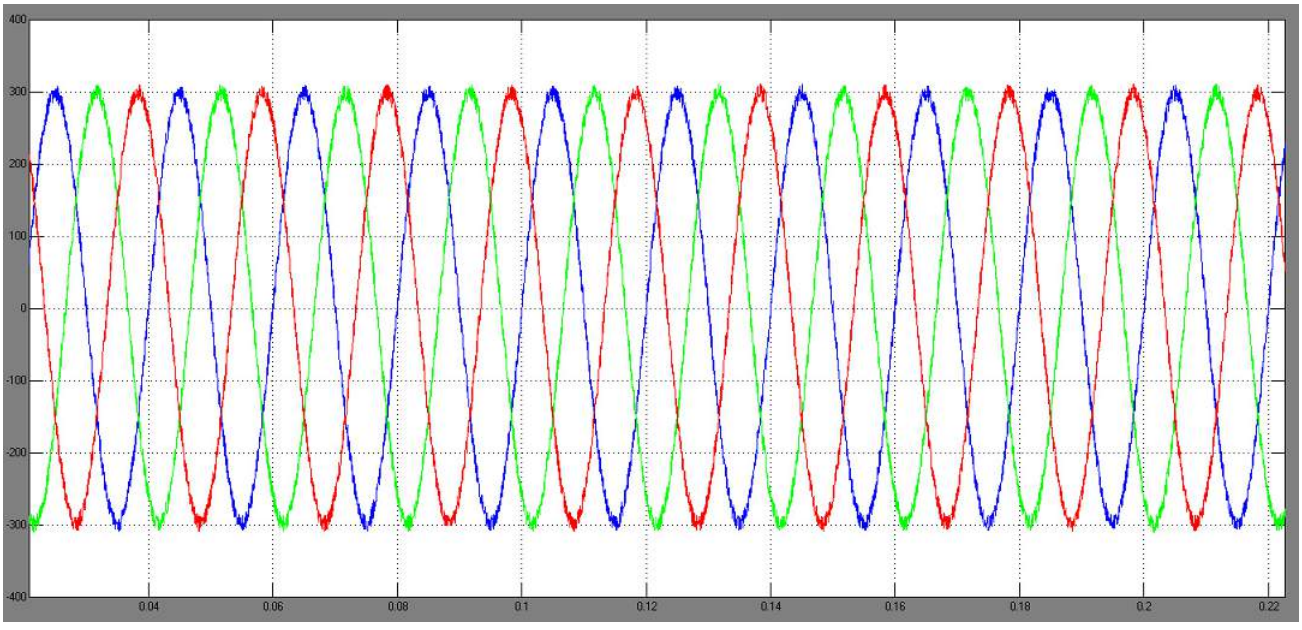


Figure 5.10: Three Phase Output Voltage

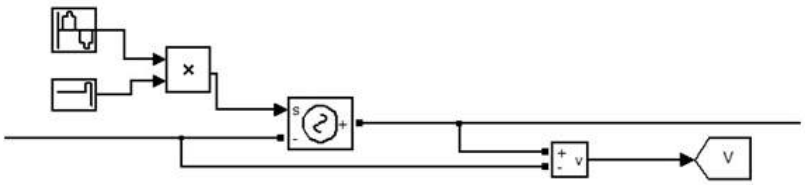


Figure 5.11: Fault Generator

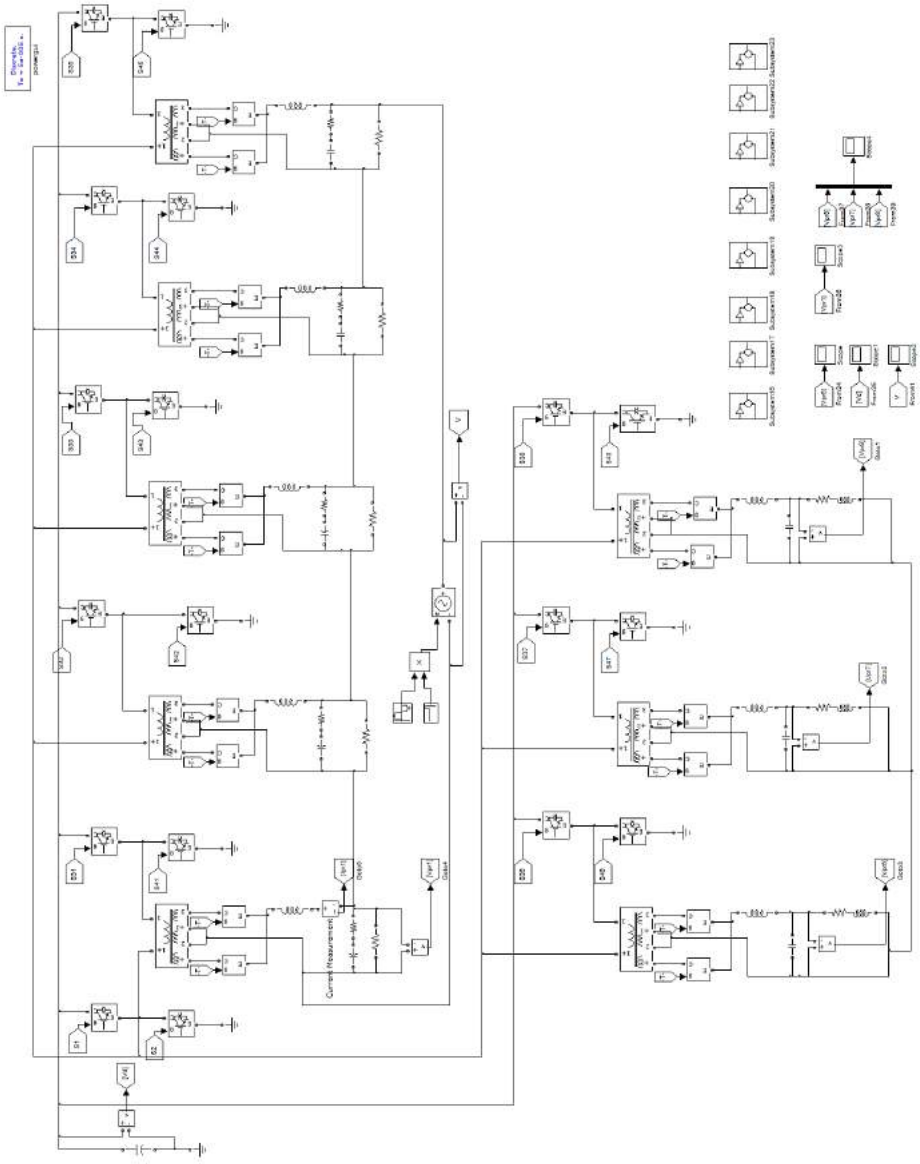


Figure 5.12: Simulation Model of FPET at Faulty Condition

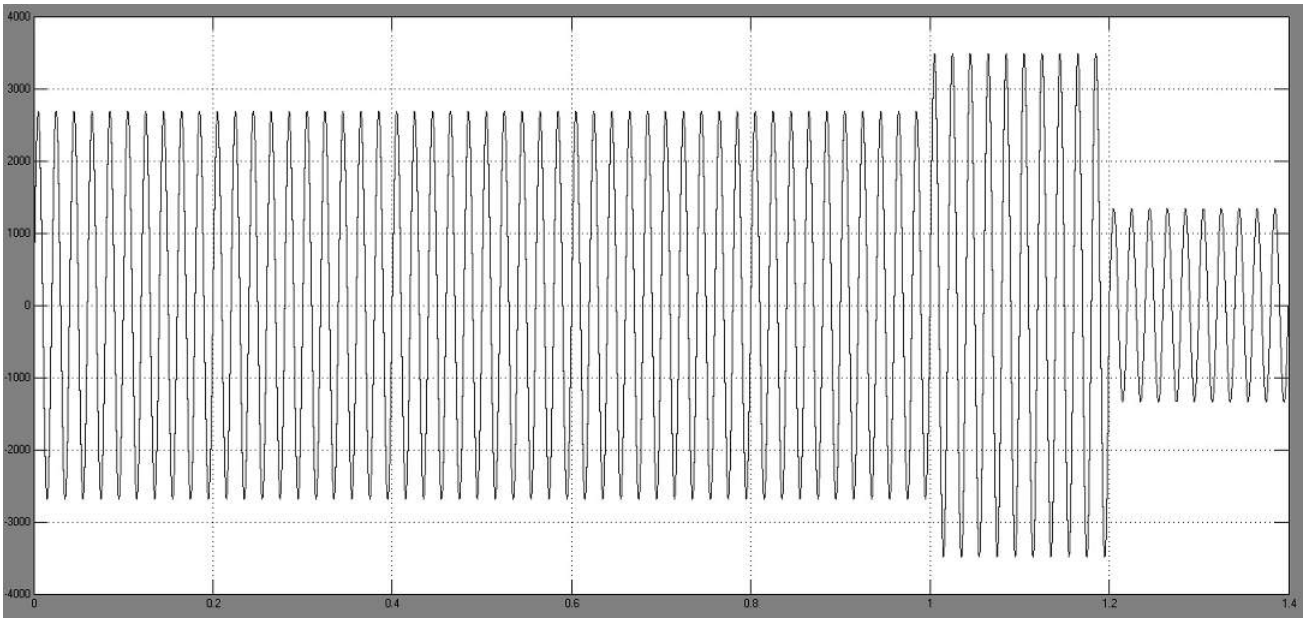


Figure 5.13: Voltage Source in Fault Case

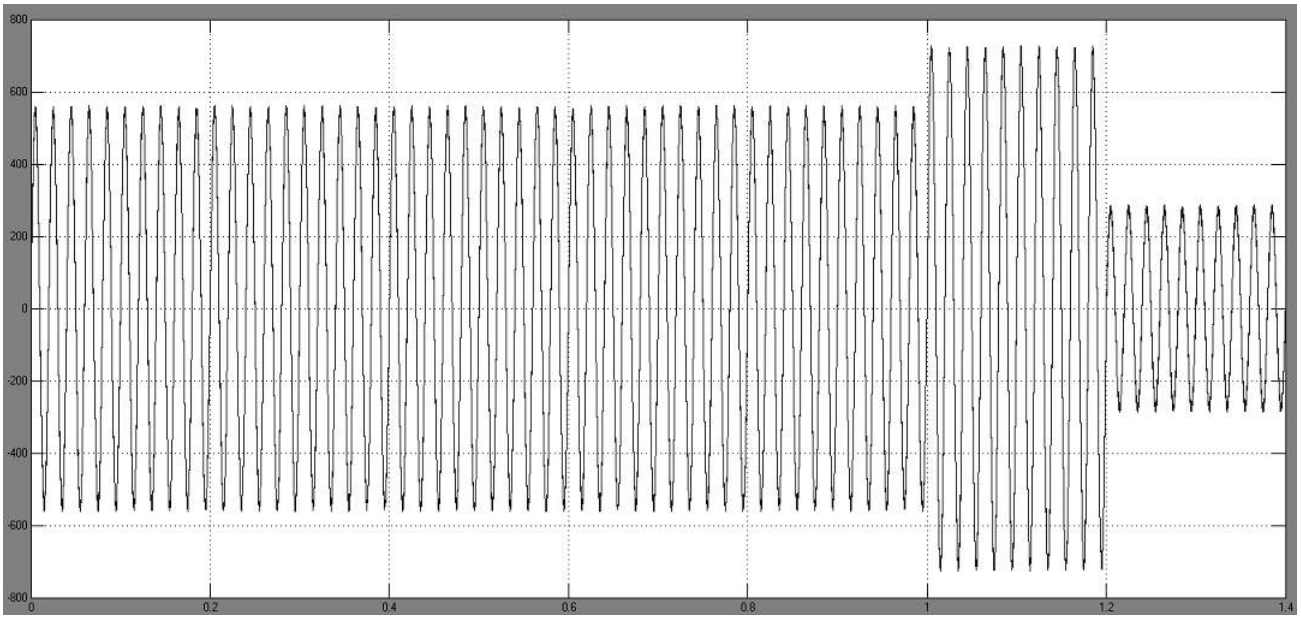


Figure 5.14: V_{rms} Voltage at 1^{st} port

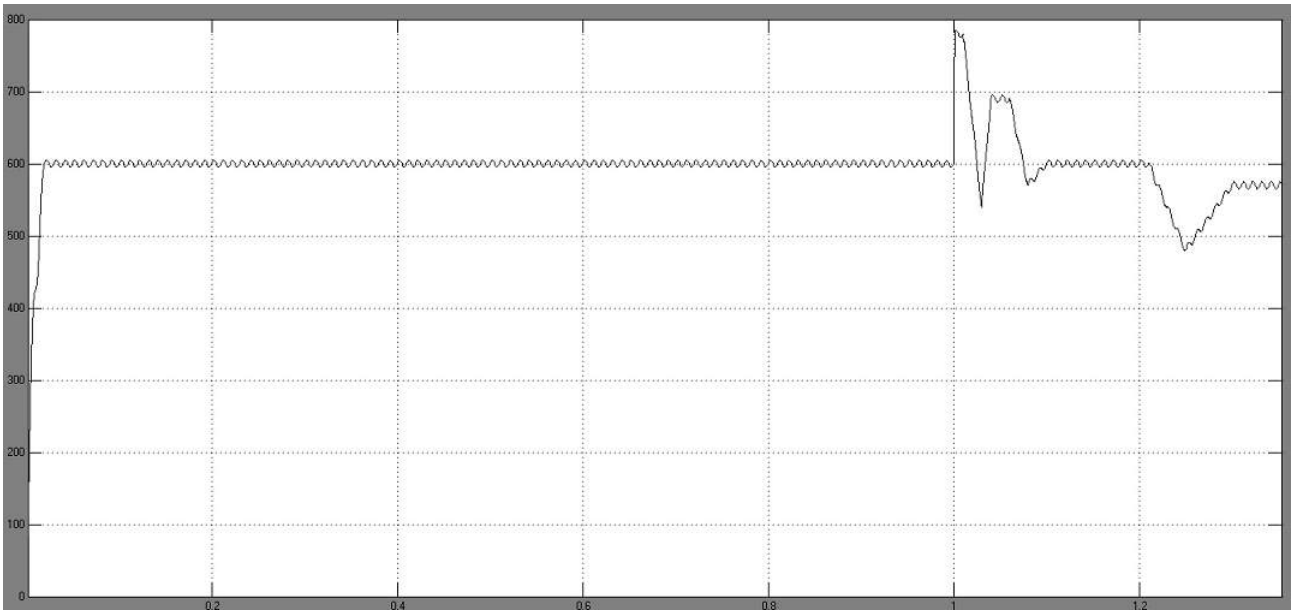


Figure 5.15: DC link Voltage

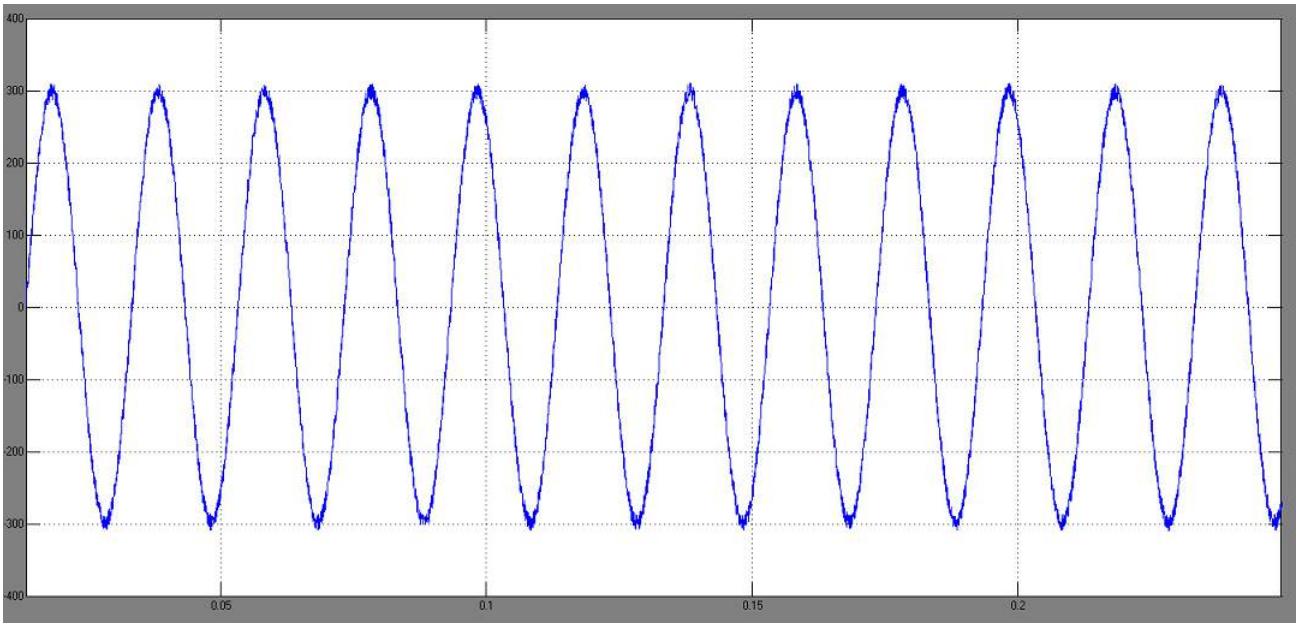


Figure 5.16: Single Phase Output Voltage

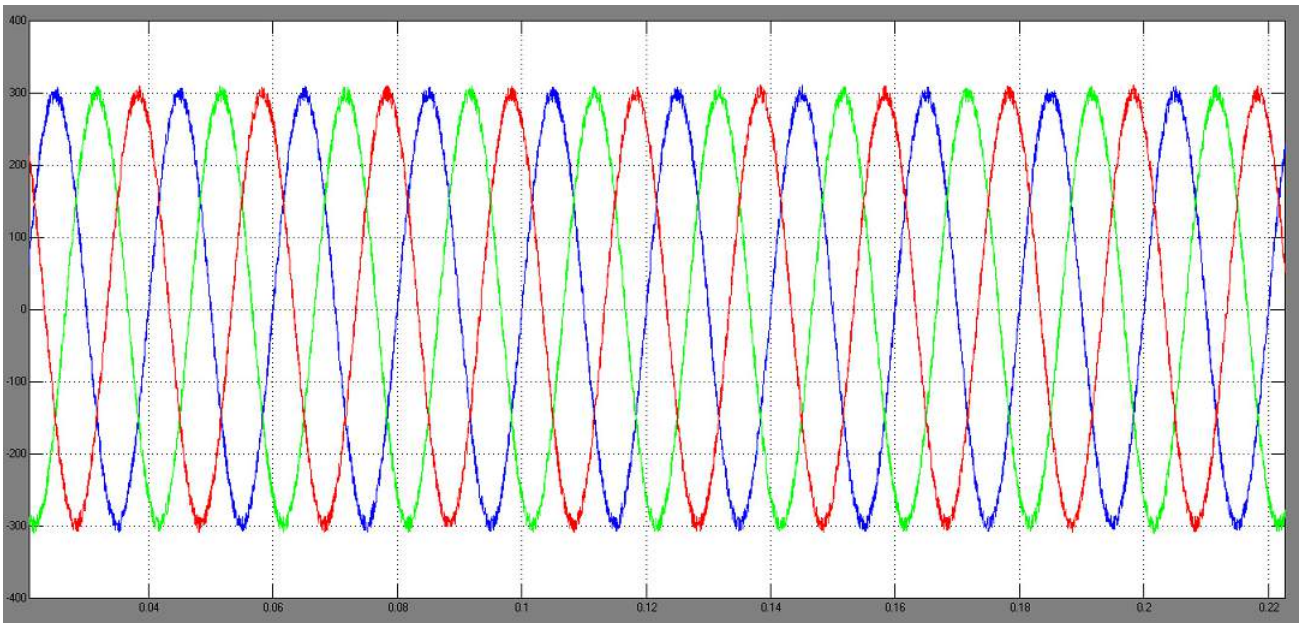


Figure 5.17: Three Phase Output Voltage

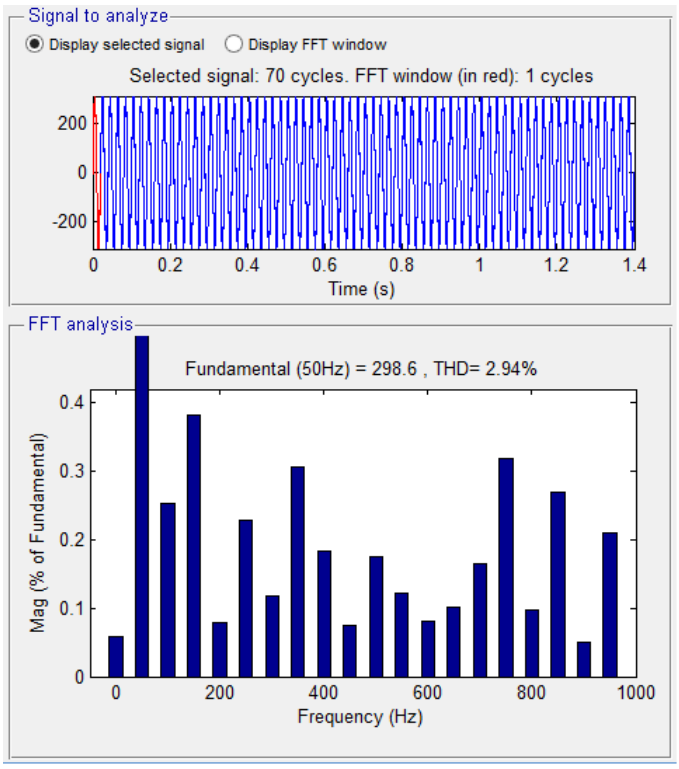


Figure 5.18: FFT Analysis of Output Voltage

Chapter 6

Comparison of HFIT with other PETs

A comparison study is provided to compare the advantages and disadvantages of the FPET with other PETs. A three-phase system, contains six ports, is compared to the similar kind of PETs. Now, some of the advantages and disadvantages of bidirectional FPET in comparison to the unidirectional topologies. In the unidirectional systems, input power factor is not controlled but in bidirectional structures input and even output power factor can be adjusted. Hence we can regulate active as well as reactive power of each port. Also for DG systems wind turbine, bidirectional capability is desirable [13]. A detail comparison study (e.g. cost, efficiency, quality, etc.) is given in Table I to clarify the advantages and disadvantages of FPET and the existing topologies proposed in [7] and [13].

As can be seen from Table I, conversion efficiency of FPET is relatively low in compare to the similar circuits topologies proposed in [7] and [13]. To reduce the size of protection circuits in FPET, a PSM approach is used, so the cycloconverter switches and FBDCI switches can select the PSM pulses automatically and can commutate independently. Therefore, the switches communicate at almost zero voltage.

In addition, Table I shows some of the most noticeable applications of FPET. Dynamic voltage restorer (DVR) [14] and active filter (AF) [15] applications can be satisfied by the FPET, because it can connect to the grid in series or/and in parallel. Desired voltage and current can provide by the flexibility of FPET in providing various waveforms and due to addition and subtraction of number of ports. FPET can provide desired waveform in each phase (or port) independently, so this can be used in Universal Power Quality Conditioner (UPQC) [16]. FPET can transfer active and reactive power from one port or phase to another port or one phase. This in power distribution system is very useful for Interline Power Flow Controller (IPFC) [17]. FPET can play a role in providing useful power from variable low-voltage dc sources due to bi-directional power flow capability. That is suitable for renewable energy applications such as photovoltaic and fuel cell [18].

Design simplicity and expandability (to achieve higher ratings) are other advantageous of FPET.

From Table I we can say that No. of semiconductor switches used and No. of transformers used in FPET are more compare to other PETs but the advantages that we are getting by using FPET are much more compare to these PETs. Cost, design

Table 6.1: Comparison Study of FPET and Those Proposed in [7] and [13]

Definition	FPET (6 port)	[7]	[13]
No. of semiconductor devices	38	34	22
No. of storage capacitors	1	4	0
No. of HF transformer	6	1	1
Bidirectional power flow capability	Yes	Yes	Yes
Cost efficient, regarding the design simplicity, the no. of dc link capacitor and the no. of transformer	Better	Good	The best
Efficiency regarding number of switches	Good	Better	The best
Reliability regarding independent operation capability of phases(ports)	The best	Better	Good
Providing desired voltage and current and connecting in series or parallel to the grid. Suitable for DVR and AF application	Yes	No	No
Independent capability of providing desired waveform and independent capability of active/reactive power adjustment in each phase (UPQC application)	Yes	No	No
Transfer of active/reactive power from one phase to another phase or from one line to another line in power distribution system act as IPFC	Yes	No	No
Management of variable low-voltage dc source suitable for renewable energy application	Yes	No	No
Providing neutral wire at the input or output side	Yes	No	No
Design simplicity	Yes	No	No
Expandability to achieve higher ratings	Yes	No	No

simplicity and efficiency regarding number of switches are less compare to other PETs but the advantages are overcoming the disadvantages of FPET.

Chapter 7

High Frequency Transformer

7.1 Ferrite Material

Ferrites are dense, homogenous ceramic structures made by mixing iron oxide with oxides or carbonates of one or more metals such as zinc, manganese, nickel or magnesium. They are pressed, then fired in a kiln at 1093 C, and machined as needed to meet various operational requirements. Ferrite parts can be easily and economically molded into many different geometries. Many diverse materials are available, providing many choices of desirable electrical and mechanical properties.

7.2 Ferrite Cores

POT Cores

The pot core shape is a convenient means of adjusting the ferrite structure to meet the specific requirements of an application. Pot cores, when assembled, nearly surround the wound bobbin. This self-shielded geometry isolates the winding from stray magnetic fields or effects from other surrounding circuit elements.

Typical applications for pot cores include; differential inductors, power transformers, power inductors, converter and inverter transformers, filters, both broadband and narrow transformers and telecom inductors.

E Cores

E cores are less expensive than pot cores, and have the advantage of simple bobbin winding plus easy assembly. E cores do not, however, offer self-shielding. Lamination size E cores are available to fit commercially offered bobbins previously designed to fit the strip stampings of standard lamination sizes. E cores can be pressed to different thicknesses, providing a selection of cross-sectional areas. E cores can be mounted in different directions.

Typical applications for E cores include differential, power and telecom inductors, as well as, broadband, power, converter and inverter transformers.

EFD Cores

The industry standard economical flat design of EFD cores offers excellent space utilization for transformers or inductors. The optimized cross-sectional area is ideal for very flat compact transformer applications.

EFD cores are ideal for compact transformers and inductor applications.

EER Cores

EER cores are an economical choice for transformers and inductors. The round centerpost offers the advantage of a shorter winding path length than the winding around a square centerpost of equal area.

Differential inductors and power transformers are typical applications of Magnetics EER cores.

EC Cores

A cross between a pot core and an E core, EC cores have a round center post that provides a wide opening on each side, and therefore, minimum winding resistance. The long legs support low leakage inductance designs.

Magnetics EC cores are typically used in differential inductor and power transformer applications.

U, I, UR Cores

U Shape cores are ideal for higher power operation in tight spaces or unusual form factors. The long legs of a U core support low leakage inductance designs and facilitate superior voltage isolation. U/I combinations facilitate economical assembly.

U cores are ideal for power transformer applications.

ER Cores

ER cores are a cross between E cores and pot cores. The round centerpost of the ER core offers minimal winding resistance. In addition, they offer better space utilization and shielding than with rectangular center leg planar cores. When compared with nonlinear cores, ERs offer minimal height and better thermal performance.

Typical applications of ER cores include differential inductors and power transformers.

PQ Cores

PQ cores are designed specifically for switched mode power supplies. This design provides an optimized ratio of volume to winding area and surface area. As a result, both maximum inductance and winding area are possible with a minimum core size. The cores provide maximum assembled transformer weight and volume. This efficient design provides a more uniform cross-sectional area; thus cores tend to operate with fewer hot spots than with other designs.

Typical applications include power transformers and power inductors.

RS-DS Cores

Slab cores are modified pot cores with the sides removed. The slabs can be paired with one round half of a standard pot core (RS combination) or two slabs can be paired together for a double slab (DS combination). The RS geometry offers all the advantages of port cores for filter applications, plus many additional features for power applications. DS cores accommodate large size wire and assist in removing heat from the assembly.

Typical applications for RS-DS combinations include; low and medium power transformers, switched-mode power supplies, and converter and inverter transformer.

RM Cores

RM cores are square-designed cores that offer all the magnetic and mechanical advantages of port cores, plus the added feature of maximum magnetic performance while minimizing PC board space. Easy to assemble and adaptable to automation, completed units provide at least 40 % savings in mounting area compared to a similar size pot core assembly.

Typical applications include differential inductors, power inductors, filter inductors, telecom inductors and broadband transformers.

ETD Cores 34/17/11 Economical Transformer Design (ETD) cores are an economical choice for transformers or inductors. ETDs offer a round centerpost for minimum winding resistance. Also, dimensions are optimized for power transformer efficiency. The combined cross-sectional area of the two outer limbs equals the cross-sectional area of the center limb allowing an even flux distribution throughout the core. This ensures the absence of localized 'hot spots' that can reduce performance at high frequencies or high flux levels. Their round center limb provides for minimal winding resistance, leakage inductance and copper eddy current losses.

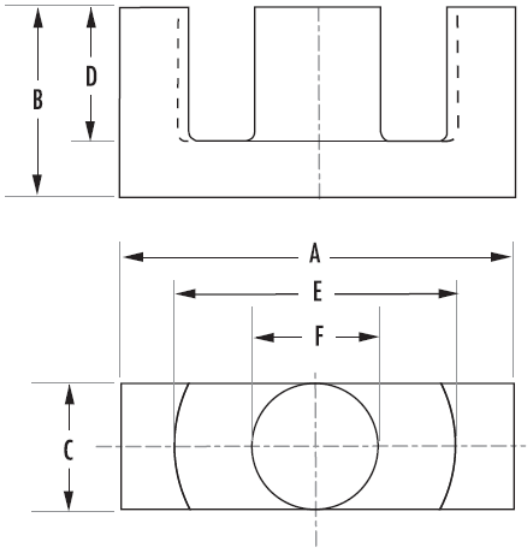


Figure 7.1: ETD Cores

Typical applications of Magnetics ETD cores include differential inductors and power transformers.

Ferrite cores have to meet mechanical requirements during assembling and for a growing number of applications. Since ferrite are ceramic material one has to be aware of the special behavior under mechanical load. As valid for any ceramic material, ferrite cores are brittle and sensitive to any shock, fast changing or tensile load. Especially high cooling rates under ultrasonic cleaning and high static or cyclic loads can cause cracks or failure of the ferrite cores.

Stresses in the core affect not only the mechanical but also the magnetic properties. It is apparent that the initial permeability is dependent on the stress state of the core. The higher the stresses are in the core, the lower is the value for the initial permeability. Ferrites can run hot during operation at higher flux densities and higher frequencies.

Table 7.1: Magnetic characteristics

Symbol	Parameter	Value	Unit
I_e	Effective magnetic path length	76.8	mm
A_e	Effective magnetic cross section	97.1	mm^2
A_{min}	Minimum core cross section	91.6	mm^2
V_e	Effective magnetic volume	7630	mm^3

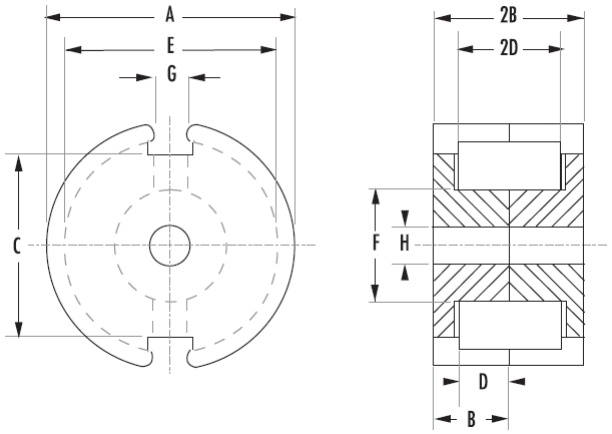


Figure 7.2: POT Cores

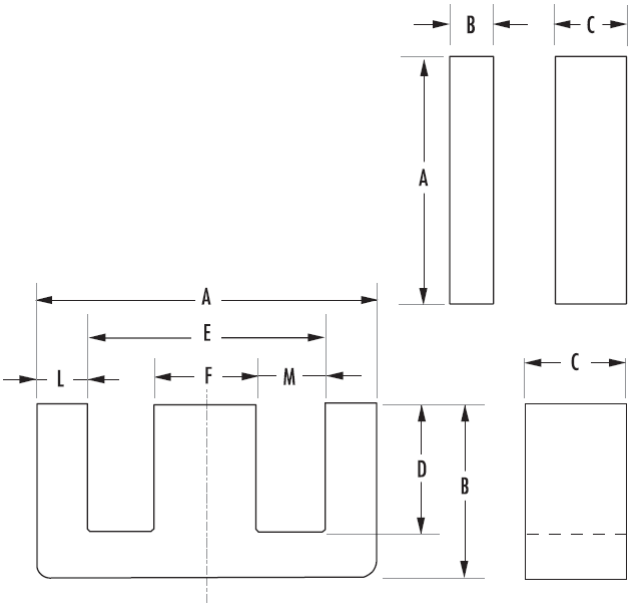


Figure 7.3: E Cores

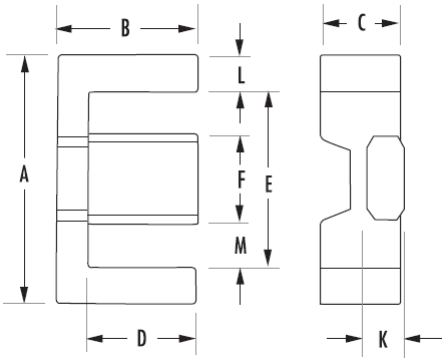


Figure 7.4: EFD Cores

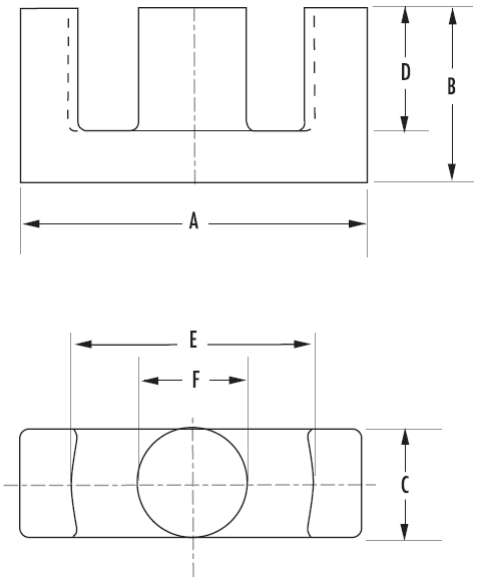


Figure 7.5: EER Cores

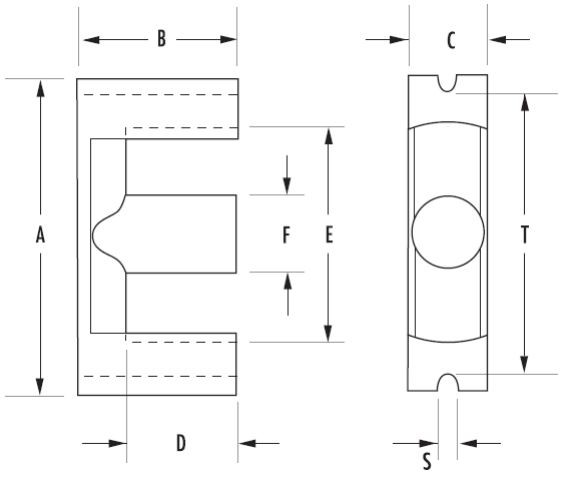


Figure 7.6: EC Cores

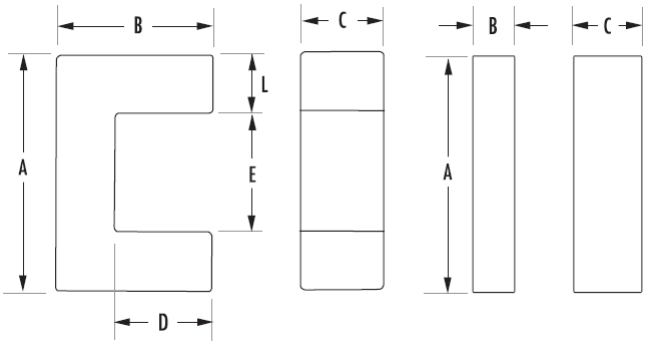


Figure 7.7: U & I Cores

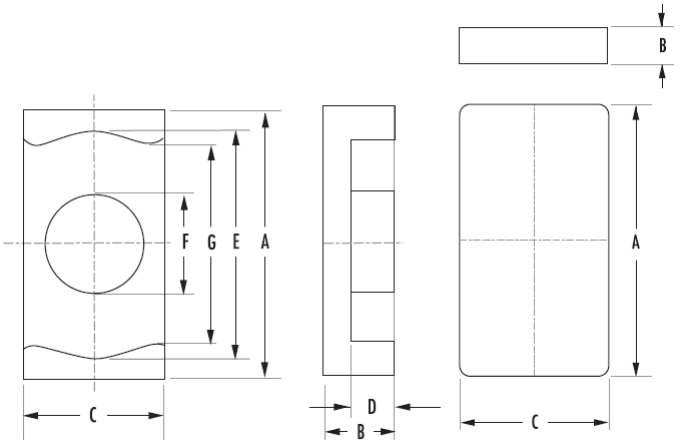


Figure 7.8: ER Cores

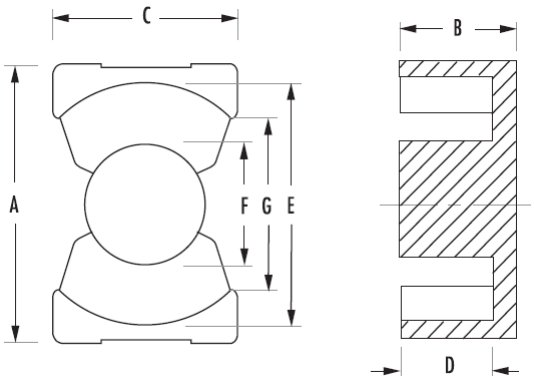


Figure 7.9: PQ Cores

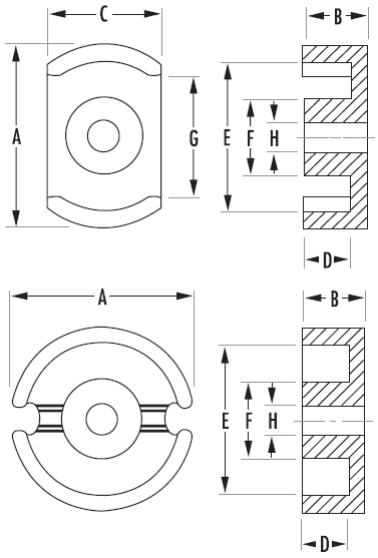


Figure 7.10: RS-DS Cores

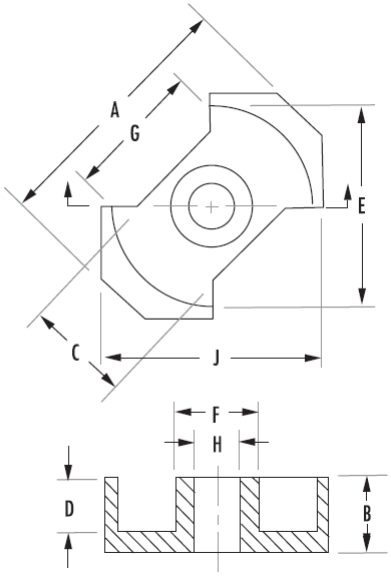


Figure 7.11: RM Cores

Chapter 8

Driver Circuit

Driver circuit is used here to increase or to decrease the value of Frequency. Our aim here is to see how the value of voltage changes with change in the value of frequency. The driver circuit is shown in Fig. 8.1 and the components are described as under.

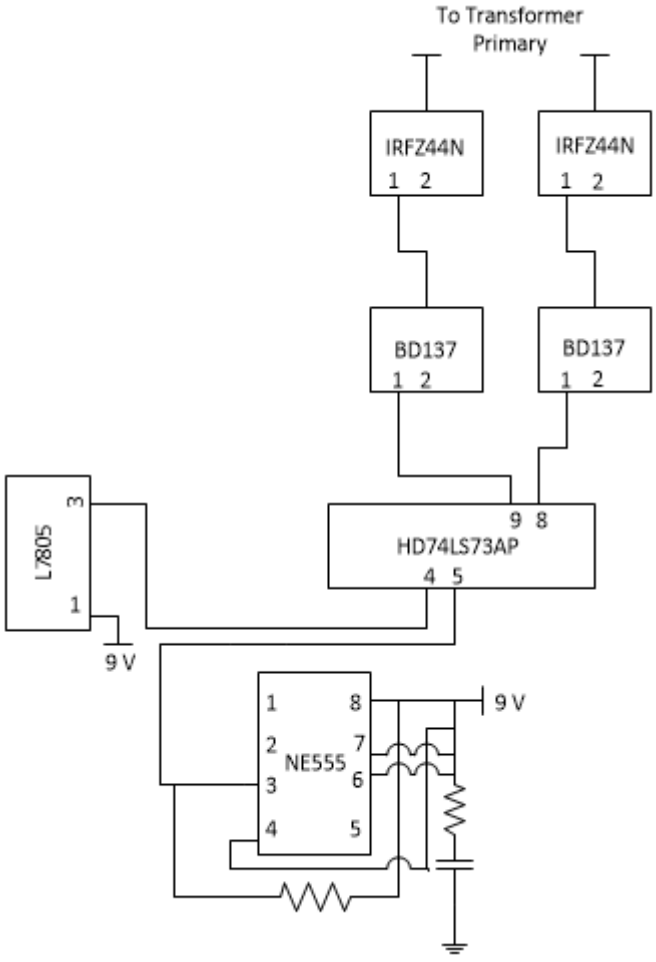


Figure 8.1: Driver Circuit Connection

8.1 Precision Timer(NE555)

Features

1. Timing From Microseconds to Hours
2. Astable or Monostable Operation
3. Adjustable Duty Cycle
4. TTL-Compatible Output Can Sink or Source up to 200mA

Description

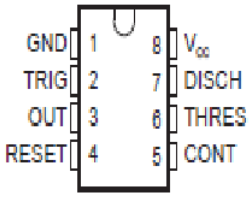


Figure 8.2: Pin Configuration of NE555

These device is precision timing circuit capable of producing accurate time delay or oscillation. In the time-delay or monostable mode of operation, the timed interval is controlled by a single external resistor and capacitor network. In the astable mode of operation, the frequency and duty cycle can be controlled independently with two external resistors and a single external capacitor.

In the monostable mode, the 555 timer acts as a "one-shot" pulse generator. The pulse begins when the 555 timer receives a signal at the trigger input that falls below a third of the voltage supply. The width of the output pulse is determined by the time constant of an RC network, which consists of a capacitor (C) and a resistor (R). The output pulse ends when the voltage on the capacitor equals 2/3 of the supply voltage. The output pulse width can be lengthened or shortened to the need of the specific application by adjusting the values of R and C.

$$t = RCln(3) = 1.1RC \tag{8.1}$$

The threshold and trigger levels normally are two-third and one-third, respectively, of V_{cc}. These levels can be altered by use of the control-voltage terminal. When the trigger input falls below the trigger level, the flip-flop is set, and the output goes high. If the trigger input is above the trigger level and the threshold input is above the threshold level, the flip-flop is reset and the output is low. The reset (RESET) input can override all other inputs and can be used to initiate a new timing cycle. When RESET goes low, the flip-flop is reset, and the output goes low. When the output is low, a low-impedance path is provided between discharge (DISCH) and ground.

Table 8.1: Function Table (NE555)

RESET	TRIGGER VOLTAGE	THRESHOLD VOLTAGE	OUTPUT	DISCHARGE SWITCH
Low	Irrelevant	Irrelevant	Low	On
High	$<1/3\ V_{cc}$	Irrelevant	High	Off
High	$>1/3\ V_{cc}$	$>2/3\ V_{cc}$	Low	On
High	$>1/3\ V_{cc}$	$<2/3\ V_{cc}$	As previously established	

Table 8.2: Recommended Operating Conditions (NE555)

	MIN	MAX	UNIT
V_{cc} Supply voltage	4.5	16	V
V_i Input voltage	V_{cc}		V
I_o Output current	$\pm$ 200		mA
T_A Operating free-air temperature	0	70	C

The output circuit is capable of sinking or sourcing current up to 200 mA. Operation is specified for supplies of 5 V to 15 V. With a 5-V supply, output levels are compatible with TTL inputs.

8.2 Positive Voltage Regulator(L7805)

Features

1. Output current up to 1.5 A
2. Output voltages of 5; 6; 8; 8.5; 9; 12; 15; 18; 24 V
3. Thermal overload protection
4. Short circuit protection
5. Output transition SOA protection

Description

The L78xx series of three-terminal positive regulators is available in TO-220, TO-220FP, TO-3 and DPAK packages and several fixed output voltages, making it useful in a wide range of applications. These regulators can provide local on-card regulation, eliminating the distribution problems associated with single point regulation. Each type employs internal current limiting, thermal shut-down and safe area protection, thermal shut-down and safe area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1 A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltage and currents.

Advantage:

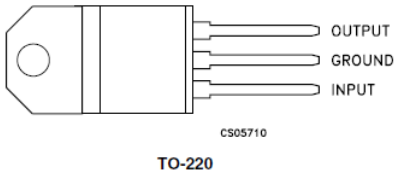


Figure 8.3: Pin Configuration of L7805

1. 78xx series ICs do not require additional components to provide a constant, regulated source of power, making them easy to use, as well as economical and efficient uses of space. Other voltage regulators may require additional components to set the output voltage level, or to assist in the regulation process. Some other designs (such as a switched-mode power supply) may need substantial engineering expertise to implement.

2. 78xx series ICs have built-in protection against a circuit drawing too much power. They have protection against overheating and short-circuits, making them quite robust in most applications. In some cases, the current-limiting features of the 78xx devices can provide protection not only for the 78xx itself, but also for other parts of the circuit.

Disadvantage:

1. The input voltage must always be higher than the output voltage by some minimum amount (typically 2 volts). This can make these devices unsuitable for powering some devices from certain types of power sources (for example, powering a circuit that requires 5 volts using 6-volt batteries will not work using a 7805).

2. As they are based on a linear regulator design, the input current required is always the same as the output current. As the input voltage must always be higher than the output voltage, this means that the total power (voltage multiplied by current) going into the 78xx will be more than the output power provided. The extra input power is dissipated as heat. This means both that for some applications an adequate heatsink must be provided, and also that a (often substantial) portion of the input power is wasted during the process, rendering them less efficient than some other types of power supplies. When the input voltage is significantly higher than the regulated output voltage (for example, powering a 7805 using a 24 volt power source), this inefficiency can be a significant issue.

8.3 Dual J-K Flip-Flops(HD74LS73AP)

Pin Arrangement

Table 8.3: Recommended Operating Conditions (L7805)

Symbol	Parameter	Value	Unit
V_I	DC input voltage for V_o= 5 to 18 V	35	V
I_o	Output current	Internally limited	
P_D	Power dissipation	Internally limited	
T_{STG}	Storage temperature range	-65 to 150	C
T_{OP}	Operating junction temperature range	-55 to 150	C

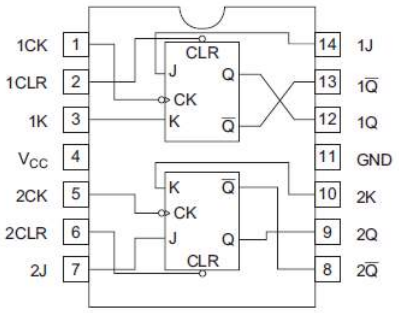


Figure 8.4: Pin Arrangement of HD74LS73AP

where, H = high level; L = low level; × = irrelevant; ↓ = transition from high to low level; Q_o = level of Q before the indicated steady-state input conditions were established; $\overline{Q_o}$ = level of Q before the indicated steady-state input conditions were established; Toggle = each output changes to the complement of its previous level on each active transition indicated by ↓.

Table 8.4: Function Table (HD74LS73AP)

Inputs				Outputs	
Clear	Clock	J	K	Q	$\overline{Q}$
L	×	×	×	L	H
H	↓	L	L	Q_o	$\overline{Q_o}$
H	↓	H	L	H	L
H	↓	L	H	L	H
H	↓	H	H	Toggle	
H	H	×	×	Q_o	$\overline{Q_o}$

Table 8.5: Absolute Maximum Ratings (HD74LS73AP)

Item	Symbol	Ratings	Units
Supply voltage	V_{cc}	7	V
Input voltage	V_{IN}	7	V
Power dissipation	P_T	400	mW
Storage temperature	T_{stg}	-65 to 150	C

Table 8.6: Recommended Operating Conditions (HD74LS73AP)

Item	Symbol	Min	Typ	Max	Unit
Supply voltage	V_{cc}	4.75	5.00	5.25	V
Output current	I_{OH}	-	-	-400	A
	I_{OL}	-	-	8	mA
Operating temperature	T_{opr}	-20	25	75	C
Clock frequency	f_{clock}	0	-	30	MHz
Pulse width	$t_{w(ClockHigh)}$	20	-	-	ns
	$t_{w(ClearLow)}$	25	-	-	ns
Setup time	$t_{su(HData)}$	20↓	-	-	ns
	$t_{su(LData)}$	20↓	-	-	ns
Hold time	t_h	0↓	-	-	ns

Table 8.7: Absolute Maximum Ratings (BD 139)

Symbol	Parameter	Value	Units
V_{CBO}	Collector-base voltage ($I_E = 0$)	80	V
V_{CEO}	Collector-emitter voltage ($I_B = 0$)	80	V
V_{EBO}	Emitter-base voltage ($I_C = 0$)	5	V
I_C	Collector current	1.5	A
I_{CM}	Collector peak current	3	A
I_B	Base current	0.5	A
P_{TOT}	Total dissipation at $T_c \leq 25$ C	12.5	W
P_{TOT}	Total dissipation at $T_{amb} \leq 25$ C	1.25	W
T_{stg}	Storage temperature	-65 to 150	C
T_j	Max. operating junction temperature	150	C

Table 8.8: Thermal data (BD 139)

Symbol	Parameter	Max Value	Units
$R_{thj-case}$	Thermal resistance junction-case	10	C/W
$R_{thj-amb}$	Thermal resistance junction-ambient	100	C/W

8.4 MOSFET Driver (BD 139)

These epitaxial planar transistors are mounted in the SOT-32 plastic package. They are designed for audio amplifiers and drivers utilizing complementary or quasi complementary circuits. The NPN types are the BD 135 and BD 139, and the complementary PNP types are the BD 136 and BD 140.

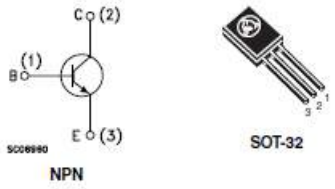


Figure 8.5: Pin Arrangement of BD 139

8.5 MOSFET(IRFZ44N)

N-channel enhancement mode standard level field-effect power transistor in a plastic envelope using 'trench' technology. The device features very low on-state resistance

Table 8.9: Reference data (IRFZ44N)

Symbol	Parameter	Max.	Unit
V_{DS}	Drain-source voltage	55	V
I_D	Drain current	49	A
P_{tot}	Total power dissipation	110	W
T_j	Junction temperature	175	C
$R_{DS(ON)}$	Drain-source on-state resistance	22	mΩ

and has integral zener diodes giving ESD protection up to 2kV. It is intended for use in switched mode power supplies and general purpose switching applications. In the Pin Configuration Pin no. 1,2 and 3 will work as gate, drain and source respectively.

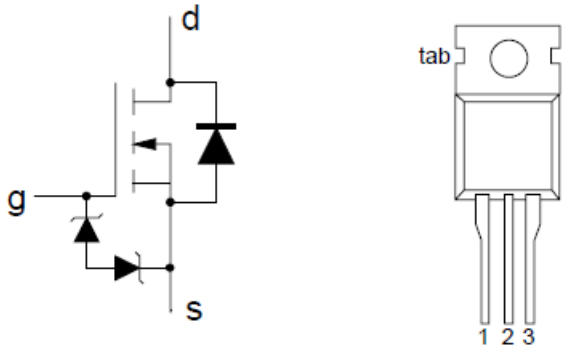


Figure 8.6: Pin Arrangement of IRFZ44N

8.6 PCB Implementation

To generate square pulse in the PCB implementation one Timer NE555, One Voltage Regulator L7805, and to divide the timer output in to two equal half's Dual J-K Flip Flop HD74LS73AP is used. The two outputs of the J-K Flip Flops are given to two MOSFET Driver BD139 which will drive two MOSFET IRFZ44N.

Fig. 8.7 shows the driver PCB. NE555 timer output is shown in Fig. 8.8. From Fig. 8.9 it can be seen that the value of one MOSFET cycle is half compared to one NE555 cycle. So NE555 output is devided equally between two MOSFETS. And Fig. 8.10 shows two opposite MOSFET switching pulses.

Table 8.10: Limiting Values (IRFZ44N)

Symbol	Parameter	Condition	Value	Units
V_{DS}	Drain-source voltage	-	55	V
V_{DGR}	Drain-gate voltage	R_{GS}= 20 kΩ	55	V
± V_{GS}	Gate-source voltage	-	20	V
I_D	Drain current	T_{mb}= 25 C	49	A
I_D	Drain current	T_{mb}= 100 C	35	A
I_{DM}	Drain current(pulse peak value)	T_{mb}= 25 C	160	A
P_{TOT}	Total power dissipation	T_{mb} = 25 C	110	W
T_{stg}, T_j	Storage & operating temperature	-	-55 to 175	C

Table 8.11: ESD Limiting Value (IRFZ44N)

Symbol	Parameter	Condition	Value	Units
V_C	Electrostatic discharge capacitor voltage	Human body model	2	kV

Table 8.12: Thermal Resistances (IRFZ44N)

Symbol	Parameter	Condition	Typ.	Max.	Unit
R_{thj-mb}	Thermal resistance junction to mounting base	-	-	14	K/W
R_{thj-a}	Thermal resistance junction to ambient	in free air	60	-	K/W

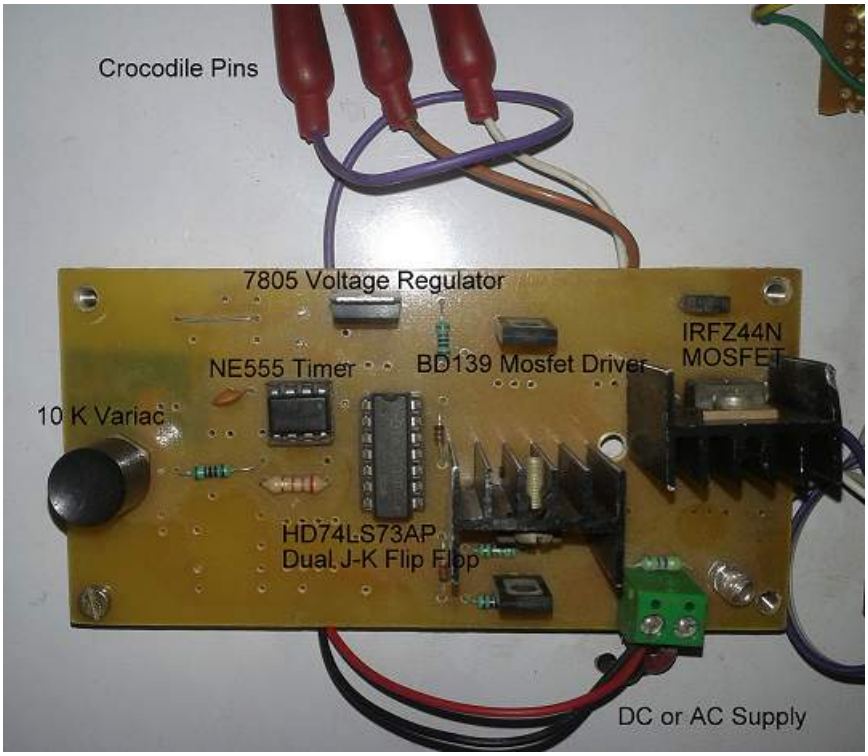


Figure 8.7: PCB Implementation

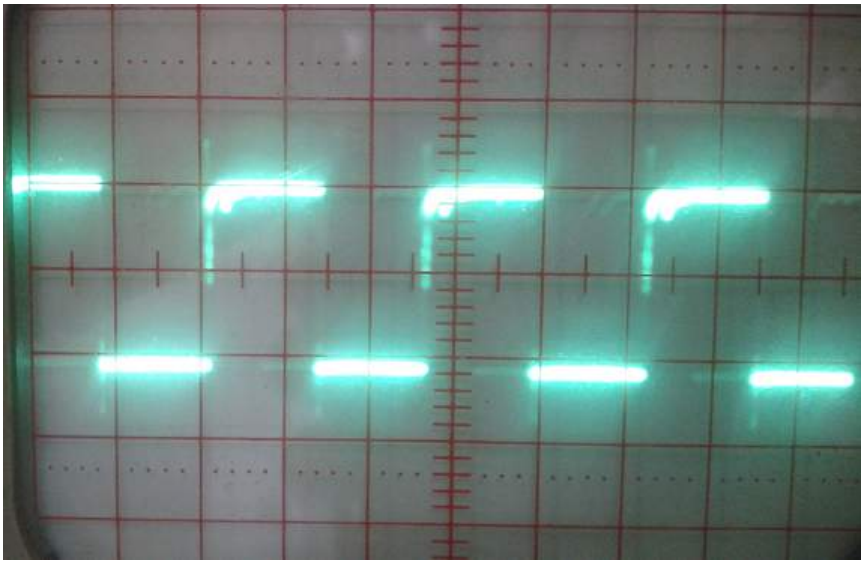


Figure 8.8: Timer NE555 Output

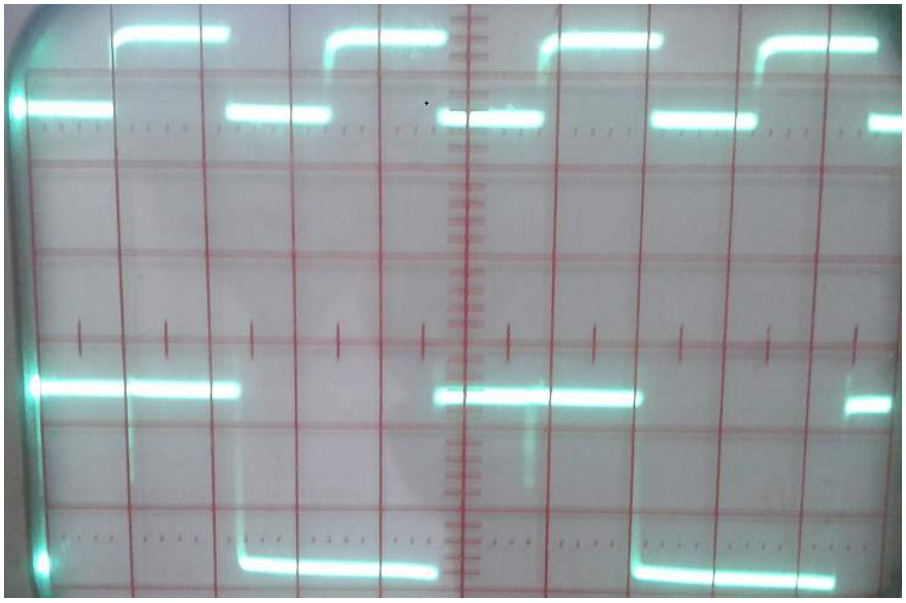


Figure 8.9: Timer NE555 with One J-K Flip Flop Output

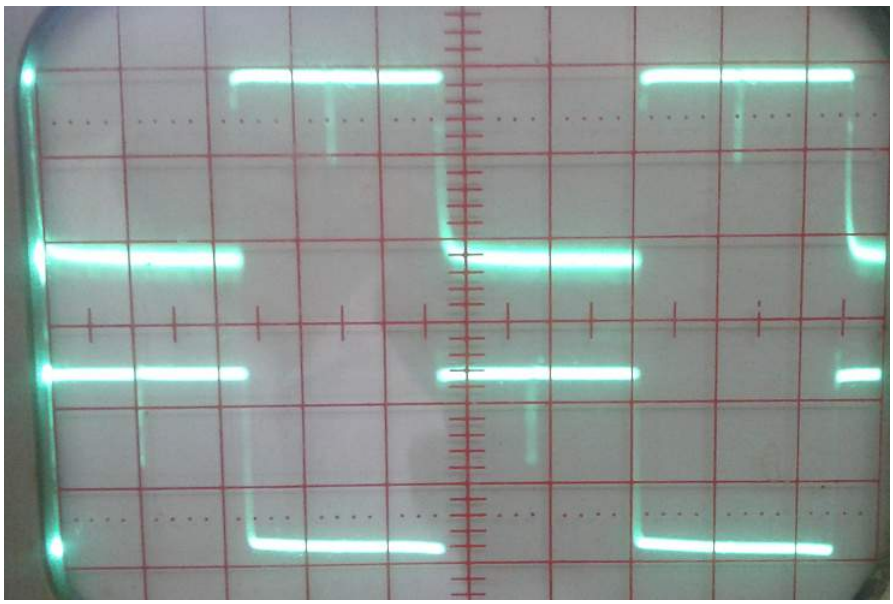


Figure 8.10: Switching Pulses for MOSFET

Chapter 9

LCD Interfacting

To see the amount of variation done in frequency LCD display is provided. With the help of LCD display it is easy to see how the value of voltage is changing with change in frequency.

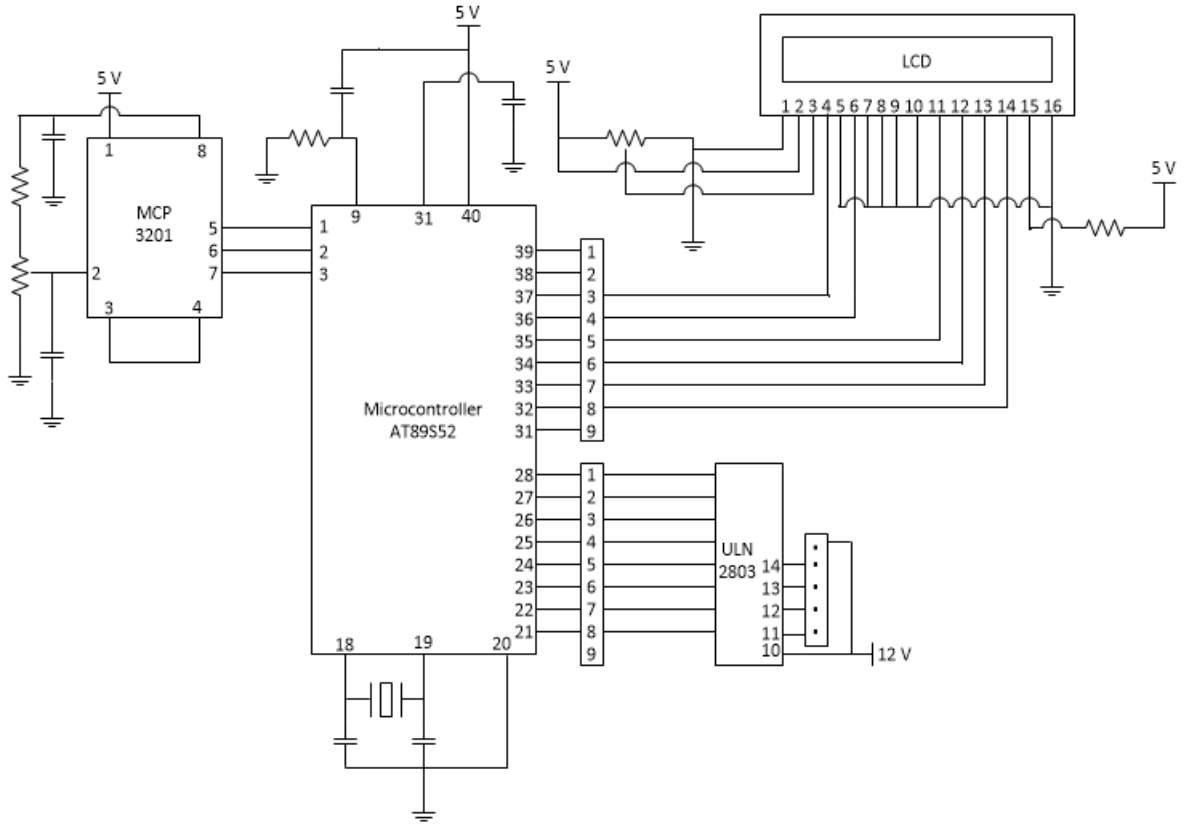


Figure 9.1: Microcontroller Circuit Diagram

As show in Fig. 9.1 the input voltage supply required for MCP3201 which is a 12-bit A/D converter is taken from the secondary side of the transformer. So, whatever change occurs in the voltage can be seen at the LCD display. Driver ULN2803 requires 12 V supply and hence step down transformer is used to convert 230 V in to 12 V

AC. Diode rectifier circuit is used as shown in Fig. 9.2 to convert this AC supply in to DC supply. Here L7812CV and L7805CV both the voltage regulators are used to get 12 v supply for ULN2803 driver and 5 V supply for other components.

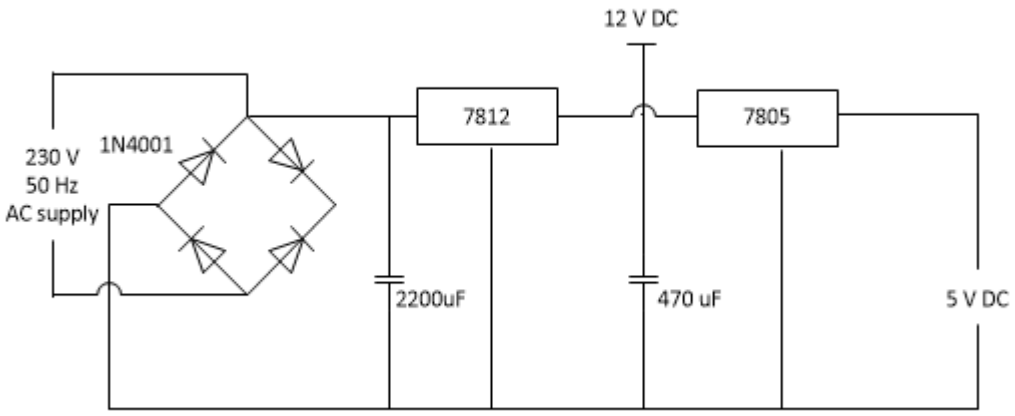


Figure 9.2: Diode Rectifier Circuit

9.1 12-bit A/D Converter(MCP3201)

Description

The Microchip Technology Inc. MCP3201 is a successive approximation 12-bit Analog-to-Digital (A/D) Converter with on-board sample and hold circuitry. Communication with the device is done using a simple serial interface compatible with the SPI protocol. The Serial Peripheral Interface or SPI bus is a synchronous serial data link, that operates in full duplex mode. It is used for short distance, single master communication, for example in embedded systems, sensors, and SD cards. A full-duplex (FDX) system, or sometimes called double-duplex, allows communication in both directions, and, unlike half-duplex, allows this to happen simultaneously.

Features

1. 12-bit resolution
2. On-chip sample and hold
3. SPI serial interface
4. Single supply operation: 2.7 V - 5.5 V
5. Low power CMOS technology

Applications

1. Sensor Interface

Table 9.1: Pin Function Table with Maximum Ratings

Name	Function	Max. Ratings
V_{DD}	Supply voltage	2.7 V to 7 V
V_{SS}	Ground	
IN+	Positive Analog Input	
IN-	Negative Analog Input	
CLK	Serial Clock	
D_{OUT}	Serial Data Out	
V_{REF}	Reference Voltage Input	
All inputs and outputs w.r.t		V_{SS} -0.6 V to $V_{DD} + 0.6V$
Storage temperature		-65 C to +150 C

2. Process Control
3. Data Acquisition
4. Battery Operated Systems

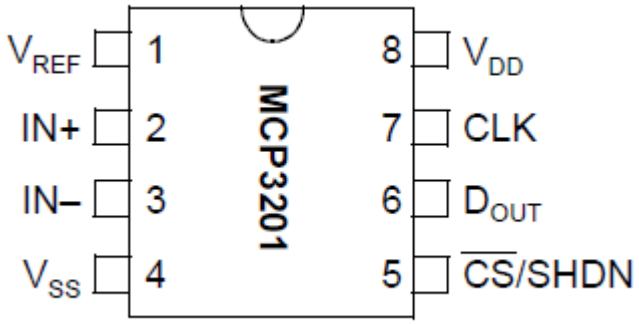


Figure 9.3: Pin Configuration of MCP3201

9.2 8-bit Microcontroller (AT89S52)

Description

The AT89S52 is a low-power, high-performance CMOS 8-bit microcontroller with 8K bytes of in-system programmable Flash memory. The on-chip Flash allows the program memory to be reprogrammed in-system or by a conventional nonvolatile memory programmer. By combining a versatile 8-bit CPU with in-system programmable Flash on a monolithic chip, the Atmel AT89S52 is a powerful microcontroller which provides a highly-flexible and cost-effective solution to many embedded control applications.

Features

1. Compatible with MCS-51(8051) Products
2. 8K Bytes of In-System Programmable (ISP) Flash Memory
3. Fully Static Operation : 0 Hz to 33 MHz
4. Three-level Program Memory Lock
5. 256 × 8-bit Internal RAM
6. 32 Programmable I/O Lines
7. low-power Idle and Power-down Modes
8. Interrupt Recovery from Power-down Mode
9. Watchdog Timer - A watchdog time is an electronic timer that is used to detect and recover from computer malfunctions.

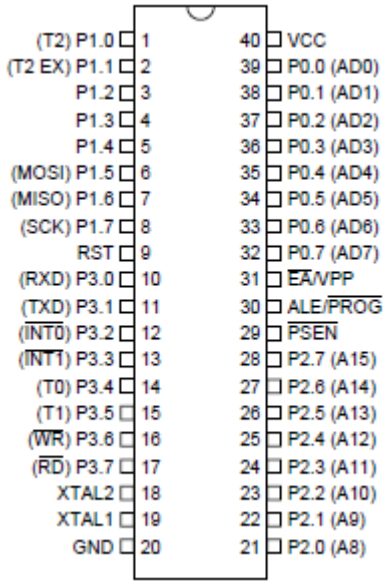


Figure 9.4: Pin Configuration of AT89S52

9.3 Driver(ULN2803)

Description

The ULN2803A device is a high-voltage, high-current Darlington transistor array. The device consists of eight npn Darlington pairs that feature high-voltage outputs

with common-cathode clamp diodes for switching inductive loads. The collector-current rating of each Darlington pair is 500 mA. The Darlington pairs may be connected in parallel for higher current Types of Logic capability.

Applications include relay drivers, hammer drivers, lamp drivers, display drivers (LED and gas discharge), line drivers, and logic buffers. The ULN2803A device has a 2.7-k series base resistor for each Darlington pair for operation directly with TTL or 5-V CMOS devices.

Features

1. Output current (single output) 500 mA (Max.)
2. High sustaining voltage output 50 V (Min.)
3. Output clamp diodes
4. Inputs compatible with various types of logic

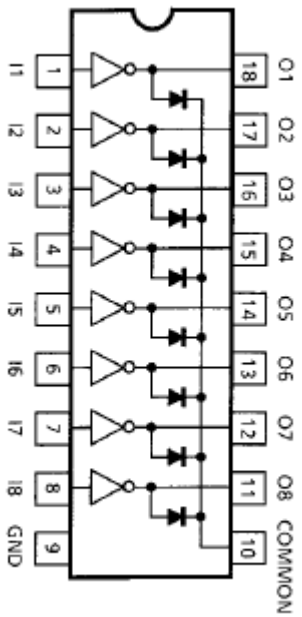


Figure 9.5: Pin Configuration of ULN2803

9.4 16 × 2 Character LCD

Features

1. 5 × 8 dots with cursor
2. +5 V Power supply

Table 9.2: Maximum Ratings

Characteristic	Symbol	Ratings	Unit
Output Sustaining Voltage	$V_{CE(SUS)}$	-0.5 to 50	V
Output Current	I_{OUT}	500	mA/ch
Input Voltage	V_{IN}	-0.5 to 30	V
Clamp Diode Reverse Voltage	V_R	50	V
Clamp Diode Forward Current	I_F	500	mA
Operating Temperature	T_{opr}	-40 to 85	C
Storage Temperature	T_{stg}	-55 to 150	C

Table 9.3: Mechanical Data

Item	Standard Value	Unit
Module Dimension	80 × 36	mm
Viewing Area	66 × 16	mm
Dot Size	0.56 × 0.66	mm
Character Size	2.96 × 5.56	mm

3. 1/16 duty cycle
4. B/L to be driven by pin 1, pin 2 or pin 15
5. N.V. optional for +3 V power supply

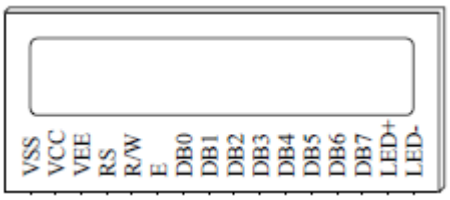


Figure 9.6: Character LCD

9.5 PCB Implementation

Circuits shown in Fig. 9.1 & 9.2 are implemented on PCB. Details regarding the inputs and connections are mentioned earlier. PCB implementation is shown in Fig. 9.9.

Table 9.4: Electrical Specifications

Characteristic	Symbol	Ratings	Unit
Input Voltage	VDD	Min. 4.7 & Max. 5.3	V
Supply Current	IDD	Typ. 1.2 & Max. 3.0	mA
LED Forward Voltage	VF	Typ. 4.2 & Max. 4.6	V
LED Forward Current	IF	Typ. 130 & Max. 260	mA

Table 9.5: 16 × 2 Character LCD

Pin Number	Symbol	Function
1	V_{ss}	GND
2	V_{dd}	+3 V to +5 V
3	V_o	Contrast Adjustment
4	RS	H/L Register Select Signal
5	R/W	H/L Read/Write Signal
6	E	H to L Enable Signal
7	DB0	H/L Data Bus Line
8	DB1	H/L Data Bus Line
9	DB2	H/L Data Bus Line
10	DB3	H/L Data Bus Line
11	DB4	H/L Data Bus Line
12	DB5	H/L Data Bus Line
13	DB6	H/L Data Bus Line
14	DB7	H/L Data Bus Line
15	A/V_{ee}	+4.2 V for LED/Negative Voltage Output
16	K	Power Supply for B/L (OV)

Table 9.6: Maximum Ratings

Characteristic	Symbol	Ratings	Unit
Maximum Recurrent Peak Reverse Voltage	V_{RRM}	50	V
Maximum RMS Voltage	V_{RMS}	35	V
Maximum DC Blocking Voltage	V_{DC}	50	V
Max. Avg. Forward Rectified Current	I_O	1	A
Typical Junction Capacitance	C_J	15	pF
Operating & StorageTemperature	T_{OPR}, T_{STG}	-65 to 175	C

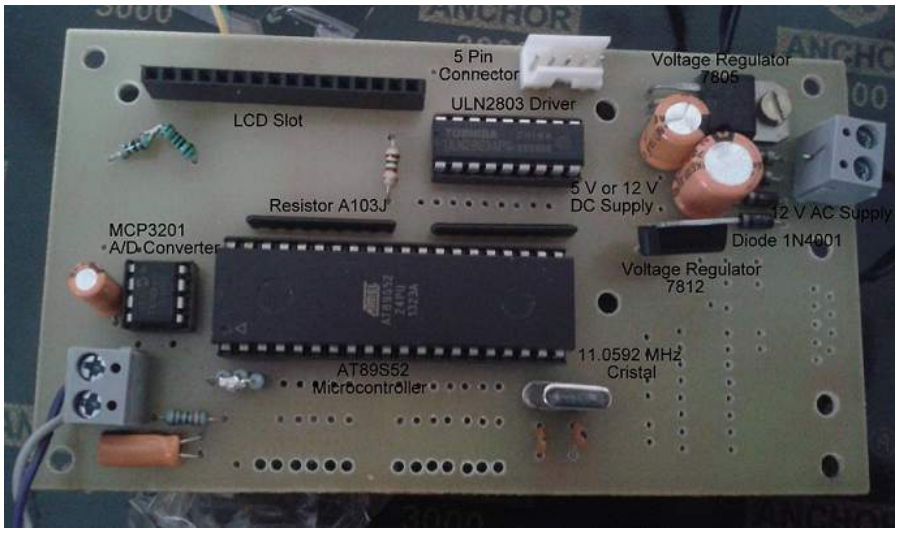


Figure 9.7: PCB Implementation

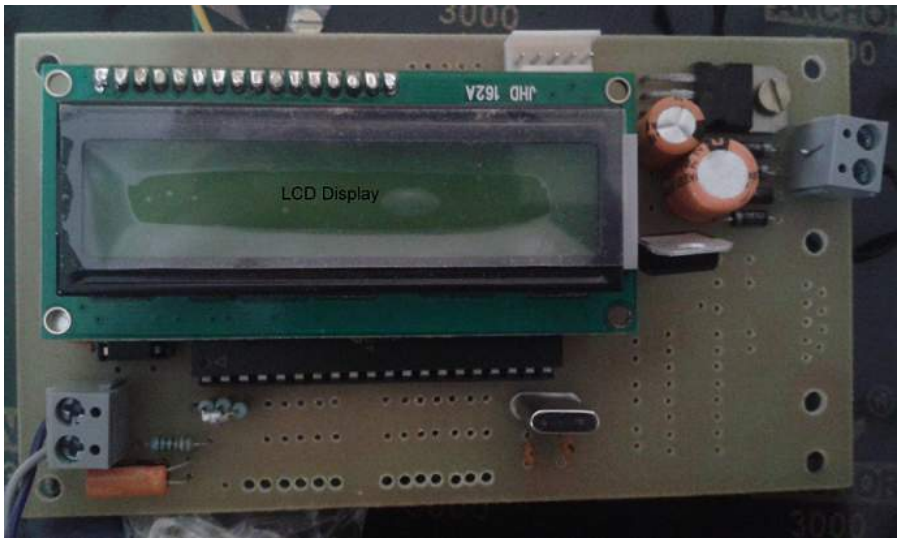


Figure 9.8: LCD Display

Chapter 10

Prototype Model

To prepare the Prototype model of the FPET, three main parts High frequency transformer, Driver circuit and LCD display circuit are connected together. Number of components used to prepare this model and output ratings of the transformer are given below.

In the driver circuit we can change the time of the timer NE555 by varying the value of 10K ohm resistor. The combination of R and C gives various kinds of time variations according to the equation 10.1

$$t = RCln(3) = 1.1RC \tag{10.1}$$

With change in time switching frequency of the MOSFETs also changes and according to that variation in the voltage level can be observed.

Observation table of the transformer is presented below to see how the voltage level changes with change in frequency.

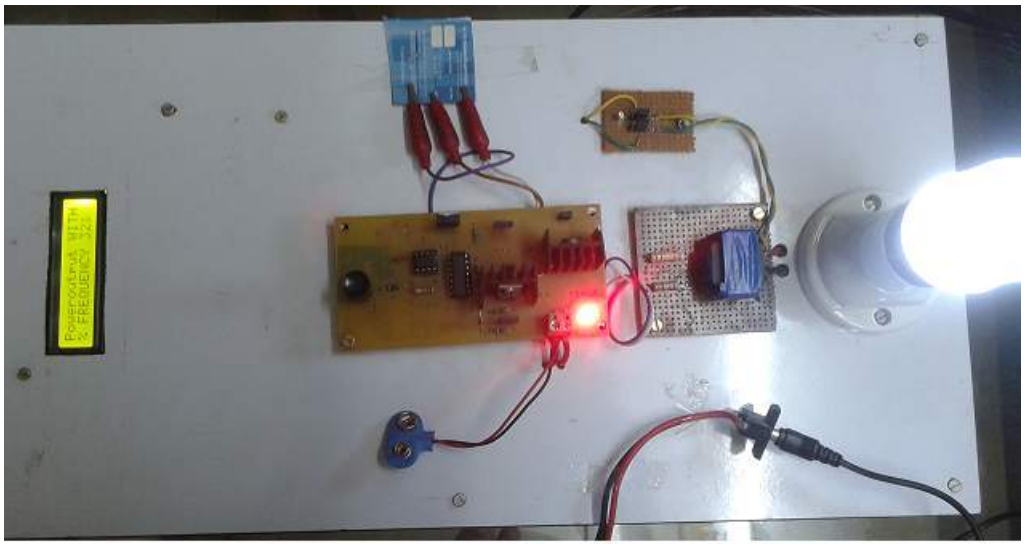


Figure 10.1: Prototype Model

From the observation table it is clear that as the switching time decreases the value of voltage increases. With decrease in the switching time frequency increases.

Table 10.1: No. of Components used for Driver Circuit

Component	Nos.
1K ohm resistor	4
300 ohm resistor	1
10K ohm variable resistor	1
0.01 uF Capacitor	1
L7805CV Voltage Regulator IC	1
NE555 Timer IC	1
BD139 Mosfet Driver IC	2
IRFZ44N Mosfet	2
Heat Sink	2
HD74LS73AP Dual J-K Flip-Flop IC	1
Red Color LED	1
9 V Battery	1

Table 10.2: No. of Transformers Used

Transformer	Nos.
High Frequency Ferrite Core	1
Conventional Step Down	1

Table 10.3: No. of Components used for LCD Display Circuit

Component	Nos.
10 uF Capacitor	2
1K ohm resistor	1
10K resistor	1
A103J resistor	2
MCP3201 A/D Converter IC	1
22pF Capacitor	2
IRFZ44N Mosfet	2
11.0592 MHz Cristal	1
AT89S52 Microcontroller IC	1
ULN2803 Driver IC	1
L7812CV Voltage Regulator IC	1
L7805CV Voltage Regulator IC	1
220uF Capacitor	1
470uF Capacitor	1
5 Pin Connector	1
16 $\times$ 2 LCD	1
1N4001 Diode	4

Table 10.4: Observation Table for Transformer

R in Kohm	C in uF	t in seconds	V_p in V	V_s in V
7.96	0.01	0.00008756	14.6	33.50
7.48	0.01	0.00008228	17.1	39.20
7.00	0.01	0.000077	21.2	48.50
6.48	0.01	0.00007128	22.3	51.20
5.67	0.01	0.00006237	23.5	54.00

Hence it is clear that as frequency increases voltage also increases and the size of the transformer decreases.

Chapter 11

Conclusion and Future Scope

11.1 Conclusion

To overcome the drawbacks of the conventional transformer a Flexible Power Electronic Transformer is designed to facilitate many requirements that are expected in electrical and distribution systems.

From the simulation results and the case study presented, it is clear that the proposed circuit gives similar kind of result even in the fault condition and since the topology is flexible we can expand it for high voltage and high current applications. The proposed topology is flexible enough to provide bidirectional power flow and can have as many ports as required. The dc link plays a significant role to provide energy balance, power management in the circuit and independent operation of ports. With the help of comparison study we can say that the results getting from the proposed topology are almost similar presented in [9].

Prototype model presented here gives a brief idea about the working of the FPET. Although the results getting from the model are not much accurate as desired and many assumptions are taken while preparing the model but still it gives a proper relation between the frequency and voltage.

11.2 Future Scope

As mentioned above the prototype model presented is not accurate & also not capable enough to fulfill all the applications and advantage discussed earlier. Much improvement can be made in the model by using different kind of control schemes for various applications. It is possible to prepare much improved and high rating model using appropriate components.

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