MICROCONTROLLER BASED ZERO VOLTAGE SWITCHING / RESONANT INVERTER

A Project Report
By
M. RAJA
71203415010

In partial fulfillment for the award of the degree

Of

MASTER OF ENGINEERING
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POWER ELECTRONICS AND DRIVES
DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

KUMARAGURU COLLEGE OF TECHNOLOGY
COIMBATORE – 641006

ANNA UNIVERSITY
CHENNAI 600 025

JUNE 2006

BONAFIDE CERTIFICATE

Certified that this project report titled **MICROCONTROLLER BASED ZERO VOLTAGE SWITCHING / RESONANT INVERTER** is the bonafide work of **Mr. M. RAJA** who carried out the research under my supervision. Certified further, that to the best of my knowledge the work reported herein does not form part of any other project report or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

PROJECT GUIDE | **HEAD OF THE DEPARTMENT**

The Candidate with University Register No: 71203415010 was examined by us in the project Viva-Voce examination held on 30.6.06

INTERNAL EXAMINER | **EXTERNAL EXAMINER**

BHARAT HEAVY ELECTRICALS LIMITED
(Govt.of India Undertaking)
High Pressure Boiler Plant, Tiruchirappalli 620 014, India.
MAINTENANCE & SERVICES DEPARTMENT
☎: (0431) 2576623 Fax: 91 (0431) 2521416 *e-mail ssdurai@bheltry.co.in*
AN ISO 9001 COMPANY

CERTIFICATE

This is to certify that

NAME	**REGISTER NO**
M.RAJA	71203415010

Final year M.E student in the branch of Power Electronics and Drives of Kumaraguru college of Technology,Coimbatore-06.

"MICROCONTROLLER BASED ZERO VOLTAGE SWITCHING RESONANT INVERTER"

The above project has done by him in the Maintenance and Service Department of BHEL, Trichy – 14, from 28-12-2004 to 28-03-2005 and found successful in his project work.

During this period he has shown keen interest in bearing various aspects of his project. The out come of this project is benefitable to our organization.

I wish him all success in future endeavors.

5/4/05
EXTERNAL GUIDE
S.SELLADURAI
(DM/M&S/BLDG-5)

S. SELLADURAI
SR. MAINTENANCE ENGINEER
ELECTRICAL / M & S
BHEL / TIRUCHIRAPALLI-14

Regd.Office: BHEL House, Siri Fort, New Delhi - 110 049

ABSTRACT

The objective of the project is to design and develop a lossless three phase zero voltage switching inverter. For this, a sinusoidal AC output with the control of both magnitude and frequency is required. They are many techniques available for the design of inverters. Currently, a PWM technique is used. The PWM technique has many drawbacks like harmonics and high switching losses thereby decreasing the overall efficiency of the inverter.

To realize an improved high performance inverter, a new topology has been proposed where a resonant circuit is introduced to avoid the switching losses in the inverter. The advantages of the resonant DC link inverter are, pure sine wave output, elimination of switching losses and snubbers, low harmonics on AC line side and it has application in adjustable speed AC drives. The resonant link circuit provides zero voltage intervals to eliminate switching loss, and thus permitting the inverter switching at high frequency.

Zero voltage switching of devices provides a number of advantages over the full voltage switching in a regular PWM inverter. The advantages of ZVS resonant DC link inverter are minimal cooling requirements, high efficiency, high reliability, low EMI. The inverter switches are turned ON and OFF at zero voltage i.e., the zero voltage switching concepts is being applied. The addition of one small inductor and one small capacitor to a conventional voltage source inverter has many significant advantages and there by results in a substantial increase in efficiency and the switching frequency of the inverter. Moreover the switching losses are also minimized.

ACKNOWLEDGEMENT

First and foremost, I would like to extend my heart-felt gratitude and thanks to our beloved Principal of Kumaraguru College of Technology, **Dr.K.K.PADMANABHAN** without whom I would not have been studying in this institution.

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I am also indebted to **Dr. T.M.KAMESWARAN,** our Advisor **Mrs. N.KALAIARASI M.E.,** for the helping hand they extended during trying periods while doing the project. I am very much grateful to all other staff members of Electrical & Electronics Engineering Department who extended all kind of cooperation for the completion of this work.

The constant guide and care showered upon me by my **PARENTS** is untold and immeasurable. Finally, it give me a great pleasure to express my sincere thanks to all my **FRIENDS** who have helped me during the course of this work.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF NOMENCLATURE

SYMBOL		EXPANSION
C_{ds}	-	Drain to source capacitance
C_{gd}	-	Gate to drain capacitance
C_{gs}	-	Gate to source capacitance
C_{iss}	-	Input capacitance
E_A	-	Avalanche energy
f_s	-	Switching frequency
g_{fs}	-	Forward transconductance
$I_{d(max)}$	-	Maximum drain current
I_o	-	Initial current
i_L	-	Inductor current
P_d	-	Power dissipation
$R_{ds(on)}$	-	Resistance between source and drain
$t_{D(on)}$	-	Turn on delay time
X_C	-	Capacitive reactance
X_L	-	Inductive reactance
V_{an}, V_{bn}, V_{cn}	-	Single phase output voltage
V_{abc}	-	Three phase output voltage
$V_{gs(th)}$	-	Gate to source threshold voltage
V_c	-	Capacitor voltage
V_{ds}	-	Drain to source voltage
V_{dss}	-	Drain to source breakdown voltage
V_{gd}	-	Gate to drain voltage
V_{gs}	-	Gate to source voltage
V_s	-	Source voltage

CHAPTER I

INTRODUCTION

1.1 EXISTING SYSTEMS

Advances in the semiconductor technology have led to the use of switched mode power supplies in the last two decades. Because of their higher efficiency, small size and weight, relatively low cost and step-up/step-down ability, they are fast replacing the linear mode supplies. PWM converters are widely used for obtaining controllable DC voltage from a fixed DC.

Nowadays, the power converter topology of choice for AC output applications is the 'hard switching' voltage source inverter. The switching devices in converters with a PWM control can be gated to synthesize the desired shape of the output voltage and/or current. The devices are turned "on" and "off" at the load current with a high *di/dt* value.

The switches are subjected to a high voltage stress, and the switching power loss of a device increases linearly with the switching frequency. The turn-on and turn-off loss could be a significant portion of the total power loss. The electromagnetic interference is also produced due to high *di/dt* and *dv/dt* in the converter waveforms. The power density is also an important factor to be considered while selecting an inverter.

1.2 OBJECTIVE

The objective of the system is to design and develop a three phase zero voltage switching inverter. The output of the inverter should be a sinusoidal wave without any switching losses and harmonics. The purpose is to turn on and off the device at zero voltage, which results in the elimination of switching losses. The harmonics is minimized by operating the system at high frequency and the stress on the power electronic devices are also reduced, thereby resulting in higher efficiency, small size, weight, the electromagnetic interference is reduced and the life span of the power devices is also increased.

1.3 PROPOSED SYSTEM

The power density can be improved by increasing the switching frequency. A key factor in reducing the size of reactive components used for filtering and energy storage, improving transient performance and meeting stringent harmonic specifications is the switching frequency of the inverter. Although switching rapidly occurs, switching losses occur during device turn-on and turn-off due to the transient existence of both voltage across, and current in the device. These stresses require significant device dreading for switching frequencies in excess of 5-6 kHz, thus increasing system cost. So at higher frequencies, conventional PWM switched mode converters unsuitable because of high switching losses, high switching stresses, reduced reliability, Electromagnetic Interference (EMI) and acoustic noise. The presence of leakage inductance and junction capacitance in the semiconductor devices causes the power devices to inductively turn- off and capacitively turn-on. When a semiconductor devices switches off an inductive load, voltage spikes induced by sharp di/dt across leakage inductance produce increased voltage stress and noise. Most switching converters owing to the rapid switching of voltage and current produce EMI. The proposed system out come this effect by operating the device at zero voltage.

1.4 SWITCHING TECHNIQUES

To improve switching conditions for semiconductor devices in power processing circuits, two resonant techniques were proposed. They are

- Zero current switching and
- Zero voltage switching.

The first is the zero current switching technique. By incorporating an LC circuit, the current waveform of the switching device is forced to oscillate in a quasi-sinusoidal manner, creating zero current switching conditions during both turn-on and turn-off. By simply replacing the power switches in PWM converters with the resonant switch, family of zero current switched (ZCS) resonant dc link inverters are derived. This new family of circuits can be viewed as a hybrid of PWM and resonant converters. However an LC tank circuit is always present near the power switch and is used not only to shape the current and voltage waveforms of the power switch, but also to store and transfer energy from the input to the out put in a manner similar to conventional resonant inverters.

The second resonant technique is zero voltage technique. By using an LC resonant network, the voltage waveform of the switching device can be shaped into a quasi-sine wave, such that zero voltage condition is created for the switch to turn-on and turn-off without incurring switching loss. This technique eliminates the turn on loss associated with the parasitic output capacitance of the power switch.

The recent advances in modern power semiconductor device technologies have led to high utilization of power converters in a large number of applications. The most visible gain in industrial and commercial products is occurring in the area of power inverters, which convert a DC voltage into a single or polyphase ac voltage at a desired amplitude and frequency. Technology advances in these areas have arisen primarily from improvements in semiconductor power devices.

High frequency power can be found widespread applications in such as high speed motor drives, induction heating, HDL lighting, quick response DC power supplies as shown in FIG 1.1. By operating the power system at high frequency, the system can be made compact because of the large reduction in size and weight of the transformers, reactors, capacitors and circuit breakers. Use of high frequency also speeds the system response and offers high quality power. Moreover newly developed materials such as amorphous metal and low dielectric loss materials can be used much effectively than in the conventional 50/60 Hz power system.

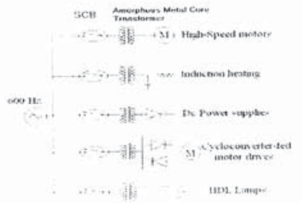

FIG 1.1 APPLICATION OF 600Hz POWER SYSTEM

1.5 ORGANIZATION OF THE REPORT

Chapter: 1

Chapter 1 gives an brief introduction to the existing systems, objectives of the project and a proposal for developing a new system.

Chapter: 2

In chapter 2, the design and development of the proposed system is explained. The details of the system block diagram, its description, the characteristics of the devices used and the simulated output waveforms are also described.

Chapter: 3

The chapter 3 explains the development of a prototype

Chapter: 4

The simulation methodology and simulation results are analyzed in chapter 4.

Chapter: 5

The chapter 5 provides the conclusion of the project and some suggestion for future work are listed

CHAPTER 2

PROJECT DESCRIPTION AND METHODOLIGES

To avoid the switching loss in the inverter a new topology has been proposed, where a resonant circuit is introduced in-between the DC input voltage and the inverter. It has been realized with the addition of only one small inductor and capacitor to a conventional voltage source inverter circuit. The resonance converter is capable of switching at the high frequency. It is extremely important to realize that if the switching environment could be modified to ensure zero switching losses. Zero switching losses could be obtained by holding the DC bus voltage at zero volts for the duration of the switching transient. An elegant method of attaining the desired objective is to make the DC bus oscillatory, ensuring that the voltage remains at zero for sufficient time to allow lossless switching, to take place.

2.1 RESONANT DC LINK ZVS INVERTER

The basic version of the resonant DC link ZVS inverter is shown in FIG 2.1 . It consists of six MOSFETS connected in the sequence. The MOSFET used is the IRF840. It is used along with a protection diode BY399. A gate source voltage of 6V is usually sufficient to turn a standard MOSFET fully on. However further increases in gate to source voltage are usually employed to reduce the MOSFETs on-resistance. Therefore for switching times of about 1.66ms, applying a 10V gate drive voltage to a MOSFET with a 2nF gate source capacitance would require the drive circuit to sink and source peak currents of about 0.5A

The inverter configuration is achieved using a three phase MOSFET Bridge. The MOSFETs used are N-channel power MOSFETs. Here 120 degree phase conduction method is employed. Each MOSFET conduct for 120 degrees, the conduction sequence of MOSFETs is (6,1),(1,2),(2,3),(3,4),(4,5),(5,6),(6,1).

There are three modes of operation in one half cycle. During (0-60^0), the MOSFETs 6,1 conduct. During (60^0-120^0), the MOSFETs 1,2 conduct. During (120^0-180^0), the MOSFETs 2,3 conduct. Like this the MOSFETs gets turned on as said in the above sequence in the remaining half cycle. The basic version of the resonant DC link ZVS inverter is shown in FIG 2.1.

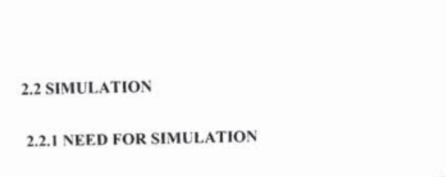

FIG2.1 RESONANNT ZVS DC LINK INVERTER

2.2 SIMULATION

2.2.1 NEED FOR SIMULATION

New designs of power electronics systems are the norm due to new applications and the lack of standardization in specifications is because of varying customer demands. Accurate simulation is necessary to minimize costly repetitions of designs and bread boarding and hence, reduce the overall cost and the concept-to-production time.

There are many benefits of simulation in the design process, some of which are listed here

- Simulation is well suited for educational purposes. It is an efficient way for designer to learn- how a circuit and its control work.
- Simulation may give a comprehensive and an impressive documentation of system performance that gives a competitive edge to a company using the simulation.
- It is normally much cheaper to do a thorough analysis than to build the actual circuit in which component stresses are measured. A simulation can discover possible problems and determine optimal parameters, increasing the possibility of getting the prototype "right the first time". Simulation can be used to optimize the performance objective by letting the simulation search over a large number of variables.
- New circuit concepts and parameter variations (including tolerances on components) are easily tested. Changes in the circuit topology are implemented at no cost. There is no need for components to be available on short notice.
- In the initial phase of a study, parasitic effects such as stray capacitances and leakage inductances are best omitted. They are important and must be considered, but they often cause confusion until the fundamental principles of a concept are understood. In a physical circuit, it is not possible to remove the stray capacitance and leakage inductances in order to get down to the fundamental behavior of the system.
- Simulated waveforms at different places in the circuit are easily monitored with out the hindrance of measurement noise (and other noise sources). As switching frequencies increases, the problem of laboratory measurements becomes increasingly difficult. Hence simulation is essential.
- Destructive tests that cannot be done in the laboratory, either because of safety or because of the costs involved, can easily be simulated. Responses to faults and abnormal conditions can also be thoroughly analyzed.
- Specifications of components voltage and current ratings are difficult before the working principles of the circuit and the current and voltage waveforms are fully determined. In a simulation, component ratings are not needed.

- It is possible to simplify parts of circuits in order to focus on a specific portion of the circuit. This may not be possible in a laboratory setup.
- There may be a need to predict the interaction between several converters connected to the same distribution network. This will be almost impossible and certainly very expensive to do without simulation.

2.2.2 REQUIREMENTS FOR A SIMULATION

Simulation of power electronics and motion control systems posses many challenges to the simulation program and its user. These are discussed in the following subsections.

User friendly interface: A simulation program must have an easy to use interface for data entry and for output data processing.

Multilevel modeling capability: In simulating the motor drive example of the power electronics converters are described in the interconnection of circuit element models. On the other hand, the electrical machine and the load are best described by differential equations formulated in terms of state variables. Finally, the continuous and sampled data control systems are often represented in their functional form by transfer functions and/or logic statements that describe the behavior properties between their inputs and outputs. A good simulation program should allow these various locks to be easily implemented.

Accurate models: For a detailed analysis, a simulation program needs accurate models of all circuit elements, including transformers and transmission lines for utility related applications. Even if accurate models are available, if it is difficult to know their parameter values. Parasitic inductances and capacitances are often difficult to estimate.

Robust switching operations: Switching actions due to solid state switches (diodes, thyristors and transistors) must be appropriately handled. Depending on how the switches are modeled, their on-off transitions either represent an extreme nonlinearity or lead to a time-varying structure of the network.

Execution time: The simulation may need to cover a sufficiently large time span to observe the effect of slowly changing variables with large time constants. At the same time, the simulation often needs to proceed with a small time step in order to accurately represent rapidly changing variables with small time constants. A small time step is also required to represent switching times with good resolution in the presence of high switching frequencies. In such simulation, this leads to a large number of time steps. To keep the execution time within reasonable limits, an efficient equation solver with variables time steps is normally required.

Initial conditions: Unlike small-signal electronics, where the steady-state operating conditions are established by a DC bias analysis, there is no easy way to establish the steady-state operating conditions in a power electronics system. Often, an initial estimate of various state variables is provided by the user, and the time required to bring the system to its steady state may be substantial, depending on the accuracy of the initial estimates. Therefore, simulation programs for power electronics must allow user to set initial conditions.

2.2.3 SIMULATION SOFTWARES

The general software packages used to simulate the power electronics circuits are

- PSPICE
- ORCAD
- Labview
- MATLAB
- Multisim

The software tool we have used to simulate the power circuit is MATLAB/SIMULINK 7.0

2.2.4 MATLAB/SIMULINK

If we choose an equation solver, we must ourselves write the differential and algebraic equations to describe various circuit states, the logical expressions, and the controller that determines the circuit state. Then, these differential/algebraic equations are simultaneously solved as a function of time.

In the most basic form, we can solve these equations by programming in any one of the higher level languages such as FORTRAN, C or PASCAL. It is also possible to access libraries in any of these languages which consist of subroutines for specific applications such as to carry out integration or matrix inversion. However, it is far more convenient to use a package such as MATLAB or a host of other packages where many of these convenient features are built in it. Each of these packages uses its own syntax and also excels in certain applications.

The program MATLAB can easily perform array and matrix manipulations, where for example y=a*b results in y, which equals cell by cell multiplication of two arrays a 'and b. Similarly, to invert a matrix, all one needs to specify is y=inv(X). Powerful plotting routines are built in. MATLAB also features various libraries, called toolboxes, which can be used to solve particular class of problems. For example, the neural network toolbox enables the simulation of an unlimited number of layers and interconnections. Neurons can be modeled with sigmoid, linear, limit, or competitive transfer functions. The toolbox contains functions for implementing a number of networks, including back propagation, Hopfield and Widrow-hoff networks.

Simulink is another toolbox for graphical entry and simulation of nonlinear dynamic systems. It consists of a large number of building blocks that enables the simulation of control based systems. Some of the other features include seven integration routines and determination of equilibrium points.

MATLAB is widely used in industry. Also, such programs are used in the teaching of undergraduate courses in control systems and signal processing. Therefore, the students are usually familiar with MATLAB prior to taking power electronics courses. Even if this is not the case, it is possible to learn its use quickly, especially by means of examples.

There are two ways in which a three phase circuit can be obtained. The first method is by paralleling three single phase circuits to obtain a three phase circuit with 120° phase shift with each phase. The second method is by directly obtaining a three phase circuit. Both of them has been implemented using simulation. Both the simulation circuit and their corresponding output's are shown as follow's.

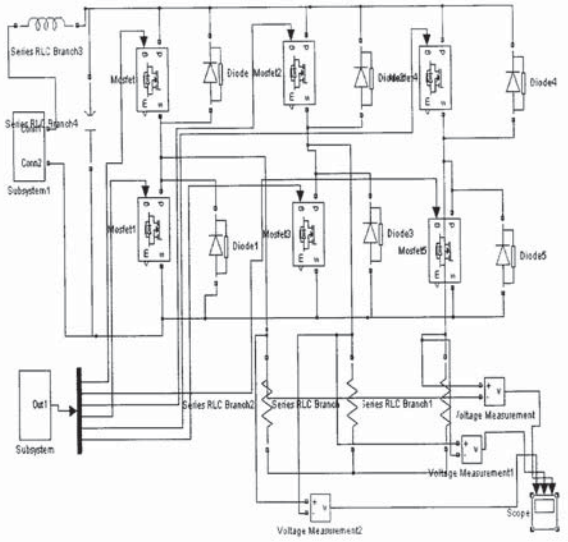

FIG 2.2 DIRECT THREE PHASE SIMULATION CIRCUIT.

CHAPTER 3

The Prototype model of the system has been developed . the block diagram for the prototype is given in figure 3.1

3.1 BLOCK DIAGRAM

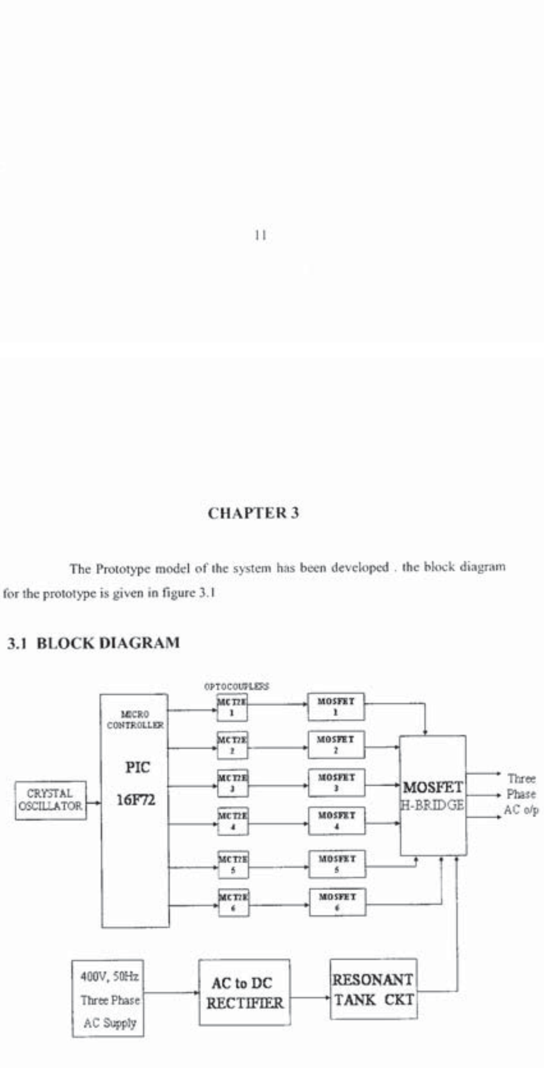

FIG 3.1 BLOCK DIAGRAM

3.1.1 DESCRIPTION

The basic block diagram is shown in 2.8. The input supply to the module is 400v, 50Hz AC supply. This AC supply is rectified by a full wave rectifier DC output is given to the designed resonance components inductor (L) and power capacitor(C). This LC tank circuit is nothing but a parallel resonating circuit whose purpose is not only to shape the current and voltage waveforms of the power switch, but also to store and transfer energy from the input to the output under resonance condition. The MOSFET bridge inverter section is fed from the parallel resonance tank circuit. The MOSFETs used are standard IRF840 series components which are used in the bridge section. The output of the inverter is taken across the mid of the bridge section.

In the MOSFET gate driver circuit, the variable frequency is achieved by means of crystal oscillator. The microcontroller 16F72 is programmed in such a way as to give suitable delay time to the MOSFET switching in order to avoid any "cross conduction".

Safer and complete isolation to the MOSFET Driver circuit from the power inverter module is the most important criteria to be met in a high frequency switching operation. The isolation circuit consists of standard MCT2E optocouplers. The output of the optocoupler is fed as the gate input to the MOSFETs in the bridge circuit. The output of the optocoupler will be from 10-12V, which is sufficient for the MOSFET to get triggered. The three phase output is obtained from the bridge of the inverter section.

3.2 COMPONENT CHARECTERISTICS

3.2.1 POWER MOSFETs

The power MOSFET symbol is as shown in the FIG 3.2

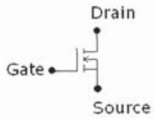

FIG 3.2 MOSFET SYMBOL

The power MOSFET is a voltage controlled device and requires only a small input current. In this device, the control signal is applied to a metal gate electrode that is separated from the semiconductor surface by an inverting insulator, typically silicon dioxide. The control signal required is essentially a bias voltage with no significant steady state current flow in either the on-state or the off-state. Even during the switching of the devices between these states, the gate current is small at typical operating frequencies because it only serves to charge and discharge the input gate capacitance, the high input impedance is the primary feature of the power MOSFET that greatly simplifies the gate drive circuitry and reduces the cost of the power electronic devices.

The power MOSFET is a unipolar device. Current conduction occurs through transport of majority carriers in the drift region without the presence of minority carrier injection required for bipolar transistor operation. In this device, during turn-off, no delays are observed as a result of storage or recombination of minority carriers. Their inherent switching speed is orders of magnitude faster than that for bipolar transistors. This feature is particularly attractive in circuits operating at high frequencies where the switching losses are dominant. The power MOSFETs having operating frequencies are

well above 100 kHz. The power MOSFETs switching time is in order of 50-100 nanoseconds and can generate many kilowatts of power at frequencies up to 500 kHz.

3.2.2 SWITCHING CHARECTERISTICS

The switching characteristics of a power MOSFET are determined largely by various capacitances inherent in its structure. To turn the device on and off the capacitances have to be charged and discharged, the rate at which this can be achieved is dependent on the impedance and the current sinking/sourcing capability of the drive circuit. Since it is the only majority carriers that are involved in the conduction process, MOSFETs do not suffer from the same storage time problems which limit bipolar devices where minority carriers have to be removed during turn-off. For most of the applications therefore the switching times of the power MOSFETs are limited only by the drive circuit and can be very fast. Temperature has only a small effect on device capacitance therefore switching times are independent of temperature. The internal capacitances are shown in FIG 3.3

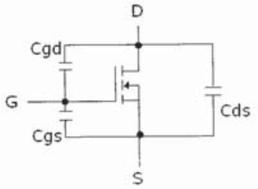

FIG 3.3 INTERNAL CAPACITANCE OF DEPLETION MOSFET

The gate source capacitance needs to be charged up to a threshold voltage up to a threshold voltage of about 3V before the MOSFET begins turn-on. The time constant for this is C_{gs} $(R_{dr}+R_g)$ and the time taken is called the turn-on delay time $[t_{D(ON)}]$. As V_{gs} starts to exceed the threshold voltage the MOSFET begins to turn on and V_{DS} begins to fall. C_{gd} now needs to be discharged as well as C_{gs} being charged so the

time constant is increased and the gradient of V_{gs} is reduced. As V_{ds} becomes less than V_g, the value of C_{gd} increases sharply since it is depletion dependent. A plateau thus occurs in the V_{gs} characteristics as the drive current goes into the charging of C_{gd}.

When V_{ds} has collapsed V_{gs} continues to rise as overdrive is applied. Gate overdrive is necessary to reduce the on-resistance of the MOSFET and thereby keep power loss to a minimum. To turn the MOSFET off the overdrive has to be removed. The charging path for C_{gd} and C_{ds} now contains the load resistor and so the turn off time will be generally longer than the turn-on time.

3.2.3 MOSFET TURN ON CHARACTERISTICS

The turn-on waveforms are shown in FIG 2.11. where the gate drive voltage changes in a step function manner at t=0 from zero to v_{gh} which is well above $v_{gs(th)}$ during the turn-on delay time $t_{d(on)}$ the gate-source voltage v_{gs} rises to $v_{gs(th)}$ because of the currents flowing through c_{gs} and c_{gd} .as is shown FIG 2.10. the rate of rise of vgs in this region is almost liner ,although it is a part of an exponential curve shown in thin line in FIG 3.4.

$I_g = v_{gg} - v_{gs}, i_o / R_g$

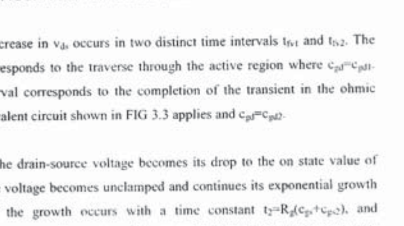

FIG 3.4 TURN ON CHARACTERISTICS OF MOSFET

The decrease in v_{ds} occurs in two distinct time intervals t_{fv1} and t_{fv2}. The first time interval corresponds to the traverse through the active region where $c_{gd}=c_{gd1}$. The second time interval corresponds to the completion of the transient in the ohmic region where the equivalent circuit shown in FIG 3.3 applies and $c_{gd}=c_{gd2}$.

Once the drain-source voltage becomes its drop to the on state value of $i_o r_{ds(on)}$, the gate source voltage becomes unclamped and continues its exponential growth to v_{gg}. This part of the growth occurs with a time constant $t_2=R_g(c_{gs}+c_{gd2})$, and simultaneously the gate current decays towards zero with the same time constant ,as is shown in the waveforms of FIG 3.4.

3.2.4. MOSFET TURN OFF CHARACTERISTICS

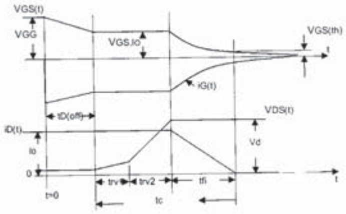

FIG 3.5 TURN OFF CHARACTERISTICS OF MOSFET

The turn-off of the MOSFET involves the inverse sequence of events that occurred during turn on. The turn-off waveforms and associated time interval are shown in FIG 3.5. for an assumed step change in the gate drive voltage at t=0 from v_{gg} t_o zero. The actual values of the switching times will vary depending on whether the gate drive voltage is set to zero or made negative to speed up the transient. Moreover, the value of R_g used during turn off may be different from that used during turn on.

During turn on and turn off, the instantaneous power loss occurs primarily during the crossover time t_c indicated in FIG 3.5. Where p (t)=v_d, i_d is high. Since the MOSFET capacitance do not vary with the junction temperature, the switching power loss in the MOSFET are also independent of the junction temperature. However, the on state resistance does vary with temperature, and thus the conduction loss will vary with junction temperature.

3.2.5. MOSFET PARAMETERS

On resistance, $R_{ds(on)}$.

This is the resistance between the source and drain terminals when the MOSFET is turned fully on.

Maximum drain current, $I_{d(max)}$.

This is the maximum current that the MOSFET can stand pasing from drain to source. It is largely determined by the package and $R_{ds(on)}$.

Power dissipation, P_d.

This is the maximum power handling capability of the MOSFET, which depends largely on the type of package it is in.

Linear derating factor.

This is how much the maximum power dissipation parameter above must be reduced by per °C, as the temperature rises above 25°C

Avalanche energy E_A.

This is how much energy the MOSFET can withstand under avalanche conditions. Avalanche occurs when the maximum drain-to-source voltage is exceeded, and current rushes through the MOSFET. This does not cause permanent damage as long as the energy (power x time) in the avalanche does not exceed the maximum.

Peak diode recovery, dv/dt.

This is how fast the intrinsic diode can go from the off state (reverse biased) to the on state (conducting). It depends on how much voltage was across it before it is turned on. Hence the time taken, t = (reverse voltage / peak diode recovery).

Drain-to-Source Breakdown Voltage, V_{dss}.

This is the maximum voltage that can be placed from drain to source when the MOSFET is turned off.

Gate Threshold Voltage, $V_{GS(th)}$.

This is the minimum voltage required between the gate and source terminals to turn the MOSFET on. It will need more than this to turn it fully on.

Forward transconductance, g_{fs}.

As the gate-source voltage is increased, when the MOSFET is just starting to turn on, it has fairly linear relationship between Vgs and drain current. This parameter is simply (Id / Vgs) in this linear section.

Input capacitance, C_{iss}.

This is the lumped capacitance between the gate terminal and the source and drain terminal. The capacitance to the drain is the most important.

3.2.6. ADVANTAGES

MOSFETs provide much better system reliability.

- Driver circuitry is simple and cheaper.
- MOSFETs fast switching speeds permit much higher switching frequencies and there by the efficiency is increased.
- Overload and peak current handling capacity is high.
- MOSFETs have better temperature stability.
- MOSFETs leakage current is low.
- Drain-source conduction threshold voltage is absent which eliminates electrical noise.
- MOSFETs are able to operate in hazardous radiation environments.

3.2.7. OPTO COUPLERS

An optocoupler is a combination of a light source and a photosensitive detector. In the optocoupler, or photon coupled pair, the coupling is achieved by light being generated on one side of a transparent insulating gap and being detected on the other side of the gap without an electrical connection between the two sides (except for o minor amount of coupling capacitance). In the optocoupler, the light is generated by an infrared light emitting diode, and the photo-detector is a silicon diode which drives an amplifier, e.g., transistor. The sensitivity of the silicon material peaks at the wavelength emitted by the LED, giving maximum signal coupling.

3.3 OPTOCOUPLER MCT2E

These high speed optocouplers are designed for use in analog or digital interface applications that require high-voltage isolation between the input and output. Applications include line receivers that require high common mode transient immunity and analog or logic circuits that require input-to-output electrical isolation. The MCT2E each consists of light emitting diode and an integrated photon detector composed of a photodiode and an open-collector output transistor. Separate connections are provided for the photodiode bias and the transistor collector output. This feature reduces the transistor base to collector capacitance, result in speed up to one hundred times that of a conventional phototransistor optocoupler. The MCT2E is designed for wide-band analog applications. The optocoupler schematic diagram is as shown in the FIG 3.6

FIG 3.6 SCHEMATIC DIAGRAM OF MCT2E

The optocoupler PIN Details is also shown in the FIG 3.7

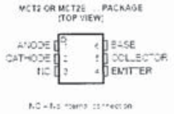

FIG 3.7. PIN DETAILS OF MCT2E

3.4 DRIVER MODULE

3.4.1. REQUIREMENTS

The switching of a MOSFET involves the charging and discharging of the capacitance between the gate and source terminals. This capacitance is related to the size of the MOSFET chip used typically about 1-2 nF. A gate source voltage of 6V is usually sufficient to turn a standard MOSFET fully on. However further increases in gate to source voltage are usually employed to reduce the MOSFETs on-resistance. Therefore for switching times of about 1.66ms, applying a 10V gate drive voltage to a MOSFET with a 2nF gate source capacitance would require the drive circuit to sink and source peak currents of about 0.5A. However it is only necessary to carry this current during the switching intervals. The gate drive power requirements are given in equation

$$P_G=Q_G \cdot V_{GS} \cdot f$$

Where Q_G is the peak gate charge. V_{GS} is the peak gate source voltage and f is the switching frequency. In circuits which use a bridge configuration, the gate terminals of the MOSFETs in the circuit need to float relative to each other. The gate drive circuitry then needs to incorporate some isolation. The impedance of the gate drive circuit should not be so large that there is a possibility of dv/dt turn on. The dv/dt turn on can be caused by rapid changes of drain to source voltage. The charging current for the gate drain capacitance C_{GD} flows through the gate drive circuit. This charging current can

cause a voltage drop across the gate drive impedance large enough to turn the MOSFET on. The driver circuit is shown in the FIG 3.8.

3.4.2 DRIVER CIRCUIT

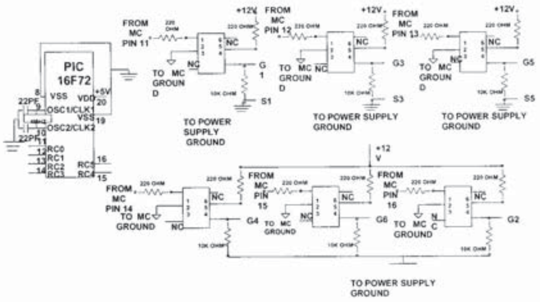

FIG 3.8 BLOCK DIAGRAM OF DRIVER CIRCUIT

3.5 CRYSTAL OSCILLATOR

The 4MHz crystal oscillator produces a square wave output of frequency 600Hz which is used as the switching frequency f_s. Thus the switching frequency is variable and can be adjusted to produce desired switching frequency. The oscillator input is given between 9th and 10th pin of the micro controller. The capacitor connections are done in respective pins.

3.5.1. PULSE GENERATING CIRCUIT

The micro controller is a programmable logic device, designed with resistors, flip-flops and timing elements. The microcontroller has a set of instructions designed internally to manipulate data and communicate with the peripherals. This process of data manipulation and communication is designed by the logic design of the microcontroller. The prime use of microcontroller is to control the operation of a fixed program that is stored in ROM and that does not change the time of the system.

The pulse generation program is developed in a PIC 16F72 microcontroller IC. The control program is stored in EPROM. The heart of the 16F72 is to generate the clock pulses, by which all internal operations are synchronized. Typically a crystal oscillator and capacitors are employed. The crystal frequency is the internal clock frequency of the microcontroller. The crystal oscillator used here is having frequency of 4MHz.

The port C is initialize as the output port. The outputs are taken from Rco,Rc1,Rc2,Rc3,Rc4,Rc5. The signals from these ports are used as gate pulses which are necessary to drive the MOSFETs.

The microcontroller is isolated from the power devices by using MCT2E optoisolators. The purpose of using optoisolators is to provide excellent isolation between the low control voltage and high voltage bridge circuit.

The inverter configuration is achieved by using a three phase MOSFET bridge. The MOSFETs used are standard N-channel power MOSFETs. The MOSFETs are provided with separate floating grounds from separate sources to avoid "cross conduction". BY399 diodes are used as protection diodes across the MOSFETs.

3.5.2. ADVANTAGES

The advantages of RESONANT inverter are,

- Minimum number of power devices
- Elimination of switching losses
- Elimination of switching stresses
- Elimination of snubbers
- High switching frequency
- Low harmonics on AC line side
- Minimal cooling requirements
- High reliability
- Low Electromagnetic interference (EMI)

3.6 MODULE CLASSIFICATION

High frequency resonant inverter consists of the following basic segments

- AC-DC Converter
- Resonant tank section
- Inverter section

3.7AC-DC CONVERTER

The 230V, 50Hz Ac signal is rectified by the full wave bridge rectifier which consists of four IN4007 diodes connected in bridge configuration. The voltage regulators 7812 is used which provides regulated voltage level. The output filtering capacitors of 1000μF/25V and 0.1μF are used suitably to smooth the rectified output of the rectifier.

3.8 RESONANT TANK CIRCUIT

The inductance and capacitance forms the resonant tank circuit. The resonant tank circuit is used to achieve the soft switching. The rectified power signal is made to oscillate by using the resonant tank circuit. The switching of the MOSFETs is done in the zero crossing of the output of the resonant tank circuit.

Resonant Tank Circuit Design

The LC tank circuit shown in FIG 3.9 below is of parallel resonant tank configuration.

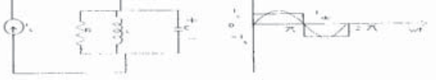

FIG 3.9 PARALLEL RESONANT TANK CIRCUIT AND WAVEFORM

A condition of resonance will be experienced in a tank circuit when the reactances of the capacitor and inductor are equal to each other. Because inductive reactance increases with increasing frequency and capacitive reactance decreases with increasing frequency, there will only be one frequency where these two reactance will be equal.

In the above circuit, we have a 1μF capacitor and a 70mH inductor. Since we know the equations for determining the reactance of each at a given frequency, we are looking for that point where the two reactances are equal to each other, we can set the two reactance formulae equal to each other and solve for frequencies algebraically.

$$X_l = 2\Pi fL$$

$$X_C = 1/2\Pi fC$$

Setting the two equal to each other represents a condition of equal reactance.

$$\Pi fL = 1/2\Pi fC$$

Multiplying both sides f eliminates the f term in the denominator of the fraction

$$2\Pi f^2L = 1/2\Pi C$$

Dividing both sides by $2\Pi L$ leaves f^2 by itself on the left-hand side of the equation

$$f^2 = 1/2\Pi 2\Pi LC$$

Taking the square root on both sides of the equation leaves f by itself on the left side

$$f = \sqrt{1} / \sqrt{(2\Pi 2\Pi LC)}$$

Simplifying,

$$f = 1/2\Pi\sqrt{(LC)}$$

This formula gives the resonant frequency of a tank circuit, given the values of inductance (L) in Henrys and capacitance (C) in Farads. Plugging in the values of L and C in our example circuit, we arrive at a resonant frequency of 600Hz.

What happens at resonance is quite interesting. With capacitive and inductive reactances equal to each other, the total impedance increases to infinity, meaning that the tank circuit draws no current from the AC power source. We can calculate the individual impedances of the 1μF capacitor and the 70mH inductor and work through the parallel impedance formula to demonstrate this mathematically:

$$X_L = 2\Pi fL$$

$$X_L = (2)(\Pi)(600\text{ Hz})(70\text{mH})$$

$$X_L = 265.25\ \Omega$$

$$X_C = 1/2\Pi fC$$

$$X_C = 1/(2)(\Pi)(600\text{ Hz})(1\mu\text{F})$$

$$X_C = 265.25\ \Omega$$

Thus

$$X_L = X_C$$

Hence the resonance condition is achieved.

Another method is the resonant DC link inverter. In resonant dc-link inverter,a resonant circuit is connected between the dc input voltage and the PWM inverter, so that the input voltage to the inverter oscillates between zero and a value slightly greater than twice the dc input voltage.

The resonant link inverter shown in FIG 3.10 where i_0 is the current drawn by the inverter. Assuming a lossless circuit and R=0, the link voltage is

$$Vc=V_s(1-\cos\omega_0 t)$$

and the inductor current is,

$$i_l=V_s\sqrt{C/L}\sin\omega_0 t + I_0$$

under lossless condition the oscillation continues and there is no need to turn on switch Q_1. However in practice there is power loss in R,i_l is damped sinusoidal, and Q_1 is turned on to bring the current to the initial level. The value of R is small and the circuit is underdamped. Under this condition, i_l and v_c can be shown.

$$I_l=i_0+e^{-\alpha t}[V_s/\omega L\sin\omega_0 t+(i_{l0}-i_0)\cos\omega_0 t]$$

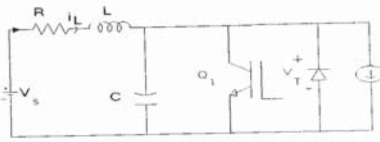

FIG 3.10 RESONANT DC LINK INVERTER CIRCUIT

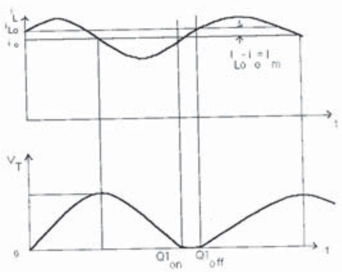

FIG 3.11 THE WAVEFORMS FOR Vc AND i_l

And the capacitor voltage V_c is

$$Vc=V_s+e^{-\alpha t}[\omega_0 L(i_{L0}-i_0)\sin\omega_0 t-Vs\cos\omega_0 t]$$

3.9 INVERTER SECTION

The inverter configuration is achieved using a MOSFET three phase bridge. The MOSFETs used are N-channel power MOSFETs. Here 120 degree phase conduction method is used. Each MOSFETs conduct for 120 degrees, the conduction sequence of MOSFETs is (6,1),(1,2),(2,3),(3,4),(4,5),(5,6),(6,1). There are three modes of operation in one half cycle. During (0-60^{0}), the MOSFETs 6,1 conduct. During (60^{0}-120^{0}), the MOSFETs 1,2 conduct. During (120^{0}-180^{0}), the MOSFETs 2,3 conduct. Like this the MOSFETs gets turned on as said in the above sequence.

3.10 POWER SUPPLIES

Starting with an ac voltage, a steady dc voltage is obtained by rectifying the ac voltage, then filtering to a dc level, and finally, regulating to obtain a desired fixed dc voltage. The regulation is usually obtained from an IC voltage regulator unit, which takes a dc voltage and provides a somewhat lower dc voltage, which remains the same even if the input dc voltage varies, or the output load connected to the dc voltage changes.

SUPPLY VOLTAGE

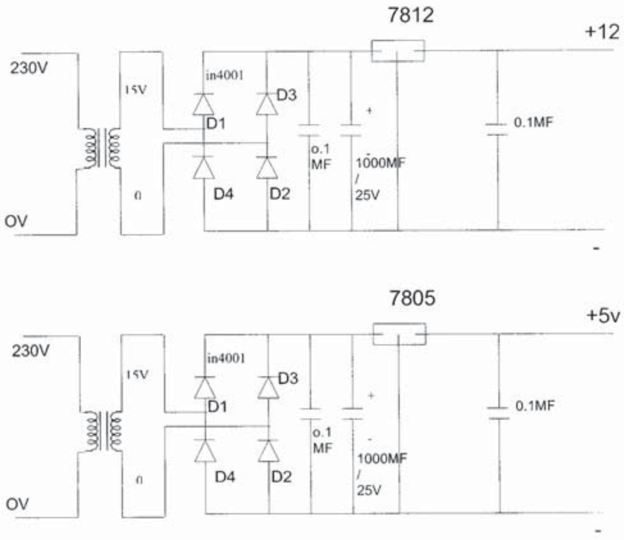

FIG 3.12 +12V AND +5V DC REGULATED SUPPLY CIRCUIT.

The ac voltage, typically 120V RMS, is connected to a transformer, which steps that ac voltage down to the level for the desired ac output. A diode rectifier then provides a full-wave rectified voltage that is initially filtered by a simple capacitor filter to produce a dc voltage. This resulting dc voltage usually has some ripple or ac voltage variation. A regulator circuit can use this dc input to provide a dc voltage that not only has much less ripple voltage but also remains the same dc value even if the input dc voltage varies somewhat, or the load connected to the output dc voltage changes. This voltage regulation is usually obtained using one of a number of popular voltage regulator IC units.

3.11 IC VOLTAGE REGULATOR

Voltage regulators comprise a class of widely used ICs. Regulator IC units contain the circuitry for reference source, comparator amplifier, control device, and overload protection all in a single IC. Although the internal construction of the IC is somewhat different from that described for discrete voltage regulator circuits, the external operation is much the same. IC units provide regulation of either a fixed positive voltage, a fixed negative voltage, or an adjustably set voltage. The setup is shown in FIG 3.12.

A power supply can be built using a transformer connected to the ac supply line to step the ac voltage to desired amplitude, then rectifying that ac voltage, filtering with a capacitor and RC filter, if desired, and finally regulating the dc voltage using an IC regulator. The regulators can be selected for operation with load currents from hundreds of milliamperes to tens of amperes, corresponding to power ratings from milliwatts to tens of watts.

3.11.1. THREE-TERMINAL VOLTAGE REGULATORS

The fixed voltage regulator has an unregulated dc input voltage, Vi, applied to one input terminal, a regulated output dc voltage, Vo, from a second terminal, with the third terminal connected to ground. For a selected regulator, IC device specifications list a voltage range over which the input voltage can vary to maintain a regulated output over a range of load current. The specifications also list the amount of output voltage change resulting from a change in load current (load regulation) or in input voltage (line regulation). The +12v supply is given to the collector terminal and the +5v supply is given to the PIC 16F72 microcontroller IC.

3.11.2. FIXED POSITIVE VOLTAGE REGULATORS

The series 78 regulators provide fixed regulated voltages from 5 to 24V. A 7812 IC is used to provide voltage regulation with an output of +12V dc. An unregulated input voltage Vi is filtered by capacitor C1 and connected to the IC's IN terminal. The IC's OUT terminal provides a regulated +12V which is filtered by capacitor C2 (mostly for any high frequency noise). The third IC terminal is connected to ground (GND). While the input voltage may vary over some permissible voltage range, and the output load may vary over some acceptable range, the output voltage remains constant within specified voltage variation limits. These limitations are spelled out in the manufacturer's specification sheets.

CHAPTER 4

The resonant inverter circuit has been simulated in MATLAB/SIMULINK 7.0 for the parameters considered in the design circuit. In the simulation, the waveforms of the resonant inverter are shown in FIG 2.4, 2.5, 2.7. The hardware has been implemented and the output waveform of the circuit is shown in the Fig 4.1. an o/p of the CRO. The circuit output waveform agrees closely with simulated waveform.

The circuit output is tested with a compact fluourrescent lamp (CFL). The CFL lamp is having many advantages working under high frequency resonant conditions compared to conventional 50/60Hz system.

They are :

- The illumination of the CFL is obtained at minimum operating voltages and flicker less operation is also obtained. The compared output of 50Hz and 600Hz in **LUX** is given below.
- Since diode reverse recovery current is high at high frequency operation, the CFL glows for the voltages below the normal operating voltage and hence quick, dynamic response is obtained
- The harmonics in the bridge rectifier circuit of the CFL is reduced at high frequency operation.

Table 4.1 Comparison of the Intensity of Light at 50 Hz and 600 Hz

Voltage	Light intensity	
	50Hz	600Hz
150	150	210
165	210	290
182	230	320
194	260	370
206	290	410
220	350	490
230	400	560

The values are measured at a distance of approximately 12 inches from the CFL lamp.

4.1 OUTPUT WAVEFORM

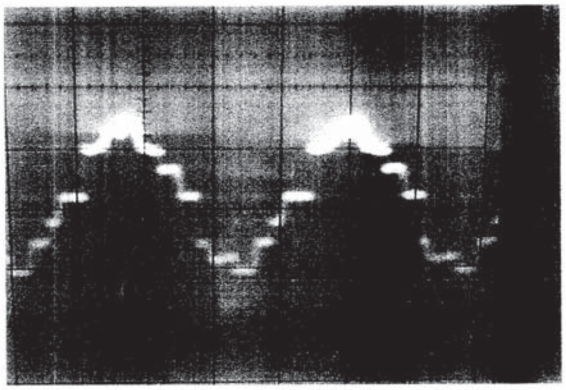

FIG 4.1 OUTPUT SINE WAVE AT 600Hz

CHAPTER 5

CONCLUSION AND FUTURE ENHANCEMENTS

Conclusion from this project:

A lossless three phase zero voltage switching inverter for modern industrial drives has been designed and developed. This project has been simulated using MATLAB. The simulation has been verified by hardware implementation. Using this hardware module, sinusoidal wave has been generated.

The unique aspect of this project is that high frequency up to 600Hz has been generated and tested successfully. One of the important benefits from the use of zero voltage switching inverter circuit is the low dv/dt that a capacitive snubber yields.

The conclusion drawn is that the high frequency power system module is able to provide many advantages like low EMI, higher efficiency, minimum switching losses, minimum stress on power devices, large reduction in size and weight of the transformers, reactors, capacitors and circuit breakers. At high frequencies by using amorphous metal core the core thickness can be reduced to 25 µm compared to 200 µm for grain oriented silicon core, which results in smaller size of the core. These are some of the advantages over the conventional 50/60Hz power system.

Future Enhancements:

This project can be enhanced using various techniques. The project can be further extended to 600Hz power system by using the TSC. If there is any unbalanced output voltage due to unbalanced loading, we can solve the above said problem by using the TSC. Also we can correct the power factor using TSC.

Energy and space saving, high performance by the use of the higher frequency to fluorescent lighting systems, amorphous metal cored transformers, DC power supplies and naturally commutated cycloconverters can be experimentally demonstrated.

In the future, more than 20 kHz, high power resonant inverters can be implemented depending on the requirement of the industry. Irrespective of the applications where size and space play an important role, the system can be upgraded and modifications can be incorporated in a flexible manner so as to reflect the new requirement.

The high frequency power can find many applications both in industrial and commercial utilization such as high speed induction motors in synthetic spinning yawn making machines, induction furnaces, high discharge lamps and also in quick response DC power supplies.

APPENDIX 1- MICROCONTROLLER PROGRAM

```
        list      p=16f72              ; list directive to define processor
        #include  <p16f72.inc>         ; processor specific variable definitions

;******VARIABLE DEFINITIONS******************************
temp            EQU     0x20
temp1           EQU     0x21
counter         EQU     0x22

;**************************************************************


start:
                call initio
rep:            movlw 0x06
                movwf counter
                clrw
                movwf temp
                incf temp,f
                call lookup
                movwf portc
                call delay
                movf temp,w
```

```
                decfsz counter,f
                goto $-6
                goto rep
;-------------------------------------------------------------------------
lookup:
                addwf pcl,f
                retlw b'00010001'
                retlw b'00100001'
                retlw b'00100010'
                retlw b'00001010'
                retlw b'00001100'
                retlw b'00010100'
;-------------------------------------------------------------------------

delay:
                movlw .86
                movwf temp1
                decfsz temp1,f
                goto $-1
                return

;-------------------------------------------------------------------------


initio:
                bcf status,7
                bcf status,5
                bcf status,6                    ;selecting bank0
```

```
                clrf porta              ;clearing data
                clrf portb
                clrf portc
                bsf status,5            ;selecting bank1
                movlw b'00000110'       ;to make portA digital i/p
                movwf adcon1
                movlw b'11111111'
                movwf porta
                movwf portb             ;defining data direction
                movlw b'10000000'
                movwf portc
                bcf status,5
                return
;-------------------------------------------------------------------------
                end
```

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