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ENERGY EFFICIENT 600Hz POWER SYSTEM FOR INDUSTRIAL AND COMMERCIAL ZONES

A Project Report

Submitted by

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BONAFIDE CERTIFICATE

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ER CONVERSION AND INDUSTRIAL DRIVES",

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ABSTRACT

In this paper, a novel energy efficient three phase 600Hz -power system, suitable for industrial and commercial zones is designed. The system consists of three phase converter, three phase resonant inverter using MOSFET, solid state circuit breaker, amorphous metal core transformer, XLPE cable, TSC compensation and micro controller.

This system has many advantages: efficiency is increased and space, weight are reduced. To increase the system stability, natural energy sources with storage batteries and co-generation system is also added. For compensating line voltage drop and unbalance voltage, Thyristor Switched Capacitors- TSCs are added. XLPE Power cables are used for transmission instead of lines to reduce the inductance drop. An experiment has been conducted on 40 watt, 220V fluorescent tube light with 600Hz and 50Hz supply and found that the 600Hz system has higher efficiency and the choke weight, space, losses, are reduced.

The areas of applications are high-speed induction motors, discharge lamps, dynamic power supply and induction heating. The concept of resonant DC link inverter is proposed to reduce the Switching losses and stresses. The 600Hz power system of transmission line and the experimental results obtained by the simulator are presented.The entire circuit is modeled and simulated using **MATLAB/SIMULINK** and implemented in hardware.

தொகுப்புரை

இந்த ஆய்வில் 600 ஹெர்ட்ஸ் மின் பகிர்மான அமைப்பு நிறுவப்படுகிறது. இது தொழிற்சாலை மற்றும் வீட்டு உபயோகத்திற்கு பயன்யடுத்தப்படுகிறது. இந்த இமைப்பு கன்வர்ட்டர், இன்வர்ட்டர், சர்க்யூட் பிரேக்கர், அமார்பஸ் மெட்டல் கோர் ட்ரான்பார்மர், எக்ஸ். எல். பி. கேபிள், டி.எஸ்.சி. ஆகியவற்றை உள்ளடக்கியது.

இந்த அமைப்பினால் அதிக நன்மைகள் உள்ளன. அதாவது பயனுறுதிறன் அதிகமாகிறது, எடை, இடம் குறைவாகிறது. இந்த அமைப்பில் சோலார் போன்ற இயற்கை சக்திகளையும் பயன்படுத்தலாம். மேலும் அசம நிலையில் உள்ள வோலடேஜை டி.எஸ்.சி. மூலம் சமநிலைக்கு கொண்டு வரலாம். எக்ஸ். எல். பி. கேபிள்கள் லைன் இன்டக்டன்ஸை குறைக்கப்பயன்படுகிறது. இந்த அமைப்பு 40 வாட்ஸ், 600 ஹெர்ட்ஸ், 220 வோல்டில் சோதனை சேய்யப்பட்டுள்ளது. இந்த சோதனை மூலம் 600 ஹெர்ட்ஸ் மின் பகிர்மான நிலையம் அதிக பயனுடையது.

இது இன்டக்சன் ஹீட்டிங், அதிக வேகமுடைய இன்டக்சன் மோட்டார்கள், டிஸ்சார்ஜ் லேம்ப்ஸ் ஆகியவற்றில் பயன்படுத்தப்படுகிறது.

இந்த முழு அமைப்பும் மேட்லேப் என்ற சிமுலேசன் சாப்ட்வேர் மூலம் பரிசோதிக்கப்பட்டுள்ளது. மற்றும் இந்த முழு அமைப்பும் ஹார்ட்வேர் மூலம் பரிசோதிக்கப்பட்டுள்ளது. இந்த சிமுலேசன் தீர்வும், ஹார்ட்வேர் தீர்வும் சமமாக உள்ளது.

ACKNOWLEDGEMENT

I submit our humble gratitude to feet of the divine spirit for having made this project a tremendous success.

I proudly thank our affectionate, eminent and friendly internal project guide **Prof. K. RAJAN**, M.E., (Ph.D) Asst.Professor, Department of Electrical and Electronics Engineering for his invaluable guidance and suggestions.

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I am blessed to be the student of Kumaraguru College of Technology. I am thankful to Principal **Dr. K. K. Padmanaban** B.Sc. (Engg), M.Tech., Ph.D., from his able leadership; I was able to acquire good knowledge and experience from this great institution.

I also thank our faculty members and non- teaching staffs for their Cooperation and great help. Special thanks to all those who helped me to complete this project successfully.

Last but not the least, I thank my parents for their blessings and their guidance and support they gave me for making this project a successful one.

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LIST OF SYMBOLS / ABBREVIATIONS

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 1

1 INTRODUCTION

1.1 EXISTING SYSTEM

Advances in the semiconductor technology have led to the use of many different frequency power supplies, namely static frequency changers, have increasingly being employed in most industry, and recently in offices and homes. Especially high frequency power can be found widespread applications in such as motor drives, induction heating, fluorescent lighting. Most of them are employing forced commutation inverters such as GTO's or transistors. This however is not economical, and becomes difficult and impractical when so large capacity as above 100MW is required because of their technical problems and lack of reliability. It is apparent that a centralized high frequency power contribution system based on a naturally commutated power converter supplying for particular areas can provide economical advantages and result in decrease of cost and saving space by replacing those numerous inverters used in dispersed manners.

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.

1.2PROJECT OBJECTIVES

The objective of the system is to design and implement a 600Hz power system for small industrial and commercial zones. The output of the inverter should be a pure sinusoidal wave without any switching losses and harmonics. The main objective 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. The unbalance voltage is compensated by using TSC.

1.3 PROPOSED SYSTEM

In aircraft and space vehicle 400 Hz supply is used because of lesser weight and smaller size of the electric equipments . The needs for high frequency power supply for industries, commercial and domestic utilities are also increasing. With the development of modern power semiconductor devices like GTO, BJT, IGBT and MOSFET many different frequency power supplies have increasingly being employed in most of the industries, offices and domestic applications. The 600Hz centralized high frequency power system found major attention as an alternate to the conventional 50/60 Hz supply for industrial and commercial zones. The 600Hz power system is able to provide many advantages over 50/60 Hz power as follows:

1) Less iron losses due to large reduction of iron materials.
2) Lesser copper loss due to large reduction in size of the equipments.
3) Large reduction in size and weight of the equipment.
4) Small value inductors and capacitors are used because of high frequency.
5) Quick response DC power supply.

The presence of leakage inductance and junction capacitance in the semiconductor devices cause the power devices to inductively turn off and capacitively turn on. Most switching converters owing to rapid switching of voltage and current produce EMI. Using resonance technique can solve the above problems.

1 ORGANIZATION OF THE REPORT

Chapter 1

It gives a brief introduction to the existing systems and the proposal to the new system.

Chapter 2

It gives the method in which we are going to design and develop the project has been explained. The details of the system block diagram, its description and the simulated output waveforms has also been explained in **chapter 2**.

Chapter 3

It describes the hardware implementation of the resonant inverter, TSC and characteristics of the components.

Chapter 4

It consists of the scope for the future developments that can be made on the project and conclusion of the project.

CHAPTER 2

PROJECT DESCRIPTION AND METHODOLOGIES

2.1 PROPOSED SYSTEM

Fig 2.1 shows the proposed 600 Hz power systems in block schematic form. A power converter composed of a converter and inverter, is used to generate the 600Hz power supply. Amorphous metal core transformers that have higher efficiency, reduced size and lesser weight than silicon steel ones, can be effectively employed. It is important to note that DC natural energy Resource and energy sources unit can be used easily for the energy source of the system, besides the 50 /60 Hz commercial power system. In particular 600 Hz power can be obtained directly from cogeneration systems, which have been increasingly employed. DC natural energy resources and Co generation system make the power system more reliable.

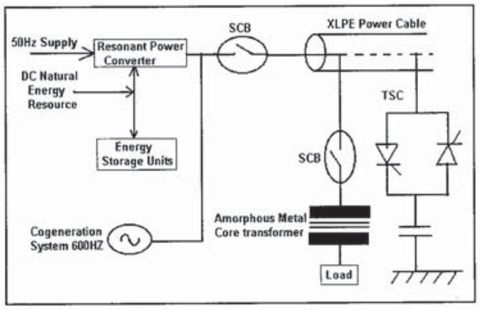
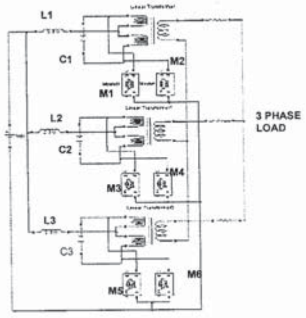


FIG 2.1.A 600Hz POWER SYSTEM

2.2. RESONANT INVERTER

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.

The Resonant inverters are classified into parallel resonant inverter and dc-link inverter. The basic version of 3 Phase resonant parallel inverter is shown in fig.2.2.In this circuit 3 single phase parallel inverters are formed in parallel to get 3 phase parallel resonant inverter. Inductor *L1* acts as a current source and capacitor *C1* is the resonating element. A constant current is switched alternatively into the resonant circuit by MOSFETs *M1* and *M2*. The same operation is done in the remaining two parallel inverters. The output of 3 phase parallel resonant inverter is shown in fig 2.2.1.



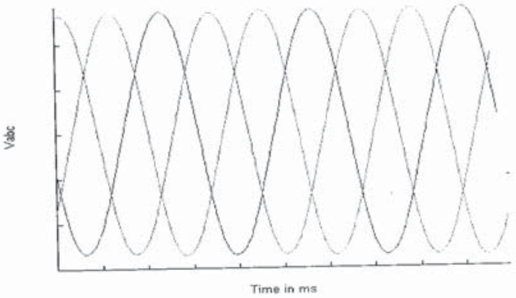


FIG 2.2.1. 3 PHASE OUTPUT OF PARALLEL RESONANT INVERTER

The basic version of the resonant DC link ZVS inverter is shown in fig 2.2.2. It consists of six MOSFETS connected in 3 Phase bridge form. The corresponding waveform of the circuit is also given in the Fig 2.2.3. The MOSFET used is the IRF840. 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.

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.

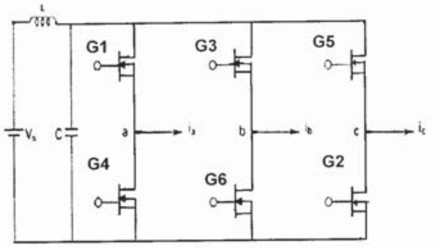
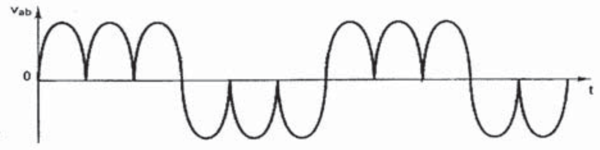


FIG.2.2.2 DC- LINK RESONANT INVERTER



2.2.3. OUTPUT OF RESONANT DC-LINK INVERTER

2.3 CONVERTER

Diode converters are usually employed with voltage source inverters. It consists of 3 Phase diode bridge. It gives DC Power to the inverter.

2.4. POWER TRANSMISSION LINE

One of the most pronounced differences between 50/60 Hz and the 600Hz power system is in transmission lines. At the higher frequency, line impedance increase due to the higher inductive inductance and AC effective resistance. Therefore power cables are used for the transmission line because they have lower inductance than overhead lines. The XLPE

2.5 TSC- SYSTEM VOLTAGE COMPENSATOR

With the significant voltage drops of the transmission line at 600Hz, some line voltage drop compensation techniques are necessary to improve the system voltage regulation. It can be accomplished by controlling the system reactive power just like that employed in the commercial power systems. TSC is utilizing and provides good performance, which is discussed later. TSC can be also used to compensate for unbalanced voltage due to unbalanced loading.

2.6. EXPERIMENTAL SYSTEM

The experimental system composed of 3 phase converters, 3 phase resonant inverter, two TSC'S, a 3-phase high frequency power transmission line simulator for a 2 km power cable and loads.

Fig.2.6 shows the overall system configuration using naturally commutated MOSFET resonant inverter. A graetz bridge thyristor rectifier and a MOSFET bridge voltage source resonance inverter employing load commutation techniques construct the power converter. Passive filters of 5th, 7 th, and 13 th are used to improve the output voltage waveforms. TSC is connected to the transmission line .TSC is used to compensate for unbalance voltage due to asymmetrical current components of the loads.

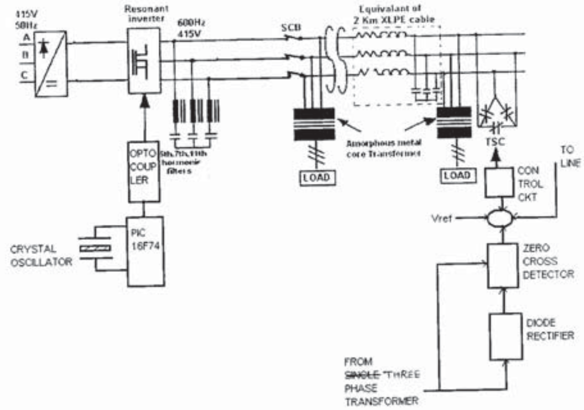


FIG.2.6.AN EXPERIMENTAL SYSTEM

2.6.1 SYSTEM VOLTAGE REGULATION

The system voltage regulation is achieved by Controlling the reactive power of the TSC's and directly adjusting the dc link current of the power converter by means of phase control for the thyristor rectifier. Since the dc link current cannot be changed so quickly because of the dc link reactor, the phase control method by rectifiers suits to suppress large variation with slow response. In the other hand, the capacitors in the TSC can be switched on or off in one cycle at least. Therefore TSC can dynamically compensate for the rapid voltage fluctuation. However its compensation ability is limited by the number of the capacitor banks and their capacitance. By combining the two methods, it can be accomplished good voltage compensation characteristic either in steady state or in the transient state.

2.6.2. TSC PRINCIPLE

The most – significant week point of the power system used a current source iverter is that the line voltage depends on the load connected on the line and thereby nbalance loading results in serious unbalance in the system voltages. It is necessary to ompensate for unbalance voltage because many single-phase loads may exit in the power ystem. This is achieved by asymmetrically controlling the TSC's so as to absorb the egative phase sequence current created by the unbalance load. It is shown in fig.2.6.2.1

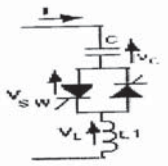


FIG.2.62.1. TSC

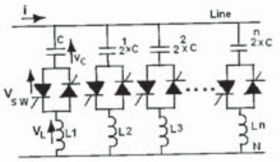


FIG.2.6.2.2.TSC'S

Thyristor switched Capacitors TSCs are fixed at regular intervals in the transmission systems to supply reactive power to increase the transmission power, to minimize the line over voltage under light load conditions , and maintain voltage levels under heavy load conditions. Fig 2.6.2.2. Shows the circuit diagram of the Thyristor Switched capacitors. It consists of capacitors, bi-directional thyristors, and a small surge current limiting reactor. This reactor is needed primarily to limit the surge current in the thyristor under abnormal conditions; it also used to avoid resonances with the ac systems impedance at particular frequencies.

Advantages of TSC:

1. Smooth control
2. No transients
3. No harmonics
4. Redundancy and flexibility
5. Low losses

2.6.3 MICROCONTROLLER BASED CONTROL CIRCUIT

The control circuit is implemented by using pic microcontroller, one is for phase control of the inverter, and the other is for the TSC as shown in fig 2.6. Consequently it makes the hardware very simple and compact. Optocoupler MCT2E is used for the driving purposes and isolation to the circuits. Crystal oscillator 4MHZ is used for the frequency generation

The microcontroller pic 16F72 is used for phase control of the inverter; BJT Triggering ckt is used for the phase control of TSC.

2.6.4. XLPE- CROSS LINKED POLYETHLENE CABLES

XLPE Cross linked polyethylene Cables power cables are used to transmit the power instead of transmission lines. The use of polyethylene has been limited by an upper operational temperature of about 70° C. due to its thermo plasticity. To increase the continuous operation at 90°C, polymers such as polyethylene and polypropylene used in XLPE cables. Nowadays XLPE cables are manufactured with BS specifications to meet international standard and the ratings are available from 1.5 to3000 mm^2 , up to 400KV, in single, 2, 3, 4 core aluminum and copper conductors. These cables have higher operating temperature and over load capacity.

The major difference between the 50 60 Hz and 600 Hz power systems is in the transmission line. At higher frequency, XLPE power cables are used for the transmission

6.5. POWER TRANSMISSION LINE SIMULATOR

As stated earlier, to reduce the line inductance power cables should be utilized for ie transmission line. In order to design the simulator, it is necessary to determine the arameters of the cable. The line inductance *Lo* and the capacitance *Co* of the every 1km able are generally given by

Lo=0.2{ln (2b/a) +0.25} (mH /Km)
Co=0.0556 epsilon r/ ln (b/a) (micro F/Km)
Ro=1+y/KCSo Ohm/m.
Where C=conductance
So=normal cross sectional area (mm2)
Y=lay ratio ratio coefficient of conductors
K=conductivity
A and b are the inner and outer radii of the dielectric
Er is the relative permittivity of the dielectric.

2.6.5. POWER TRANSMISSION LINE SIMULATOR

D. C. RESISTANCE

The d.c. resistance of the cable is dependent on temperature as given by [17]

$$R_t = R_{20}[1+\alpha_{20}(t-20)] \quad \text{-----(1)}$$

Where

R_t = ***conductor resistance at*** $t^{\circ}c(\Omega)$

R_{20} = ***conductor resistance at 20°***$c(\Omega)$

ture coefficient of resistance of the conductor material at 20°c

t = **conductor temperature** $(^{\circ}c)$

n XLPE cable of cross section 150 mm^2 is selected to transfer a power of 260Kw, 415V, 00Hz for a feeder of length 5km, inside an industrial complex. The D.C.resistance is alculated by using the Eqn (1), the D.C. resistance value for the of 150 mm^2 plain copper able at 20°c is 0.124 Ω/km. The temperature coefficient per degree Celsius at 20°C(α_{20}) or copper is 0.00393 [17].

$$\textit{The D.C. resistance } R_t = 0.124[1+0.00393(35-20)]$$

$$R_t = 0.131\,\Omega/km$$

.C. RESISTANCE

A.C. Resistance R' is the D.C. resistance modified by skin effect factor and Proximity factor.

SKIN EFFECT

If a conductor is considered to be composed of a large number of concentric circular elements, those at the centre of the conductor will be enveloped by a greater magnetic flux than those on the outside. Consequently the self- induced back e.m.f will be greater towards the centre of the conductor, thus causing the current density to be less at the centre than at the conductor surface. This extra concentration at the surface is the skin effect and it result in an increase in the effective resistance of the conductor.

ROXIMITY EFFECT

Proximity effects are due to mutual effects between the main cable conductors themselves plus inductive currents in any metallic sheath and eddy currents in both metallic sheath and armour.The A.C. resistance of the cable is very less for the conductor having cross section less than cable 150$_{sq}$ mm. Hence A.C. resistance is neglected and D.C. resistance is considered.

ABLE CAPACITANCE

The cable capacitance per meter length is given by

$$C_t = \frac{q}{V}$$

$$= \frac{\varepsilon_r}{18\log_e(D/d)}(\mu F/km) \qquad -- (2)$$

Where D = diameter over the insulation (m)

d = diameter over the conductor (m)

ε_r = relative permittivity

The cable capacitance for the 150_{sq} mm cable as per BS5467:1989 is

$C \quad = 0.42 \quad (\mu F/Km)$

CABLE INDUCTANCE

The inductance L per core of a 3 – core cable, the self- inductance and mutual inductance is given by

$$L = k + 0.2\log_e \frac{2S}{d} \quad (mH/Km) \qquad -- (3)$$

Where k = a constant relating to the conductor formation as in the table 2

S = axial spacing between conductors within cable (mm), or

= axial spacing between conductors of a trefoil group of single – core cables (mm), or

= 1.26 x phasing for the a flat formation of three single – core cables (mm)

d = conductor diameter

Table 2.6.5

Sl.No	Number of wires in conductor	k
1.	3	0.0778
2.	7	0.0642
3.	19	0.0554

BS5467:1989 is 0.245mH (mH/Km)

$L_t = 0.245mH(mH/Km)$. The cable parameter is as follows:

he D.C. resistance: $R_t = 0.131$ (Ω/km)

he inductance : **$L_t = 0.245mH$** (mH/Km)

[he capacitance : $C_t \;= 0.42\;(\mu F/Km)$

n viewing the skin and proximity effect, the total factor 1.91 for the resistance and 0.90 for he inductance are given as follows.

The D.C. resistance: $R_c = 0.131 \times 1.90 = 0.245$ (Ω/km)

The inductance : **$L_c = 0.245 \times 0.9 = 0.2205$** (mH/Km)

2.6.6. AMORPHOUS METAL CORE AND ITS MAGNETIC PROPERTIES

Fig 2.6.6.2 Shows the B-H loop of amorphous $Fe_{80}B_{11}Si_9$ and grain – oriented silicon steel. The narrowness of the B-H loop for the amorphous metal, the high permeability (B/H), and the low hysteresis component of magnetic losses measured by the area within the B-H loop indicate the relative ease of magnetization. The eddy current component of magnetic losses is also minimized in amorphous metals. The atomic disorder and high solute content of amorphous metals limit the mean – free path of electronics, resulting in electrical resistivity two to three times those of grain oriented silicon steels. The thin gauge of amorphous metals, typically 25 μm compared to 350 μm for grain oriented silicon further increase the total electrical resistance.

Metal alloys typically posses crystalline atomic structures in which individual atoms are arranged in ordered, repeating patterns. Amorphous – metal alloys differ from their crystalline counter parts in that they consist of atoms arranged in near random configurations devoid of long range order . The discovery of amorphous metals is generally credited to P.Duwez, who in 1960 produced amorphous samples by rapid quenching an $AU_{75}Si_{25}$ alloys from the liquid state. Duwez used a pressurized gas gun to propel small droplets of the molten alloy onto a polished copper plate. On impact, each droplet deformed into a thin film. Intimate contact with the highly conductive copper plate allowed the molten film to cool rapidly and solidify into flake or "splat" form.

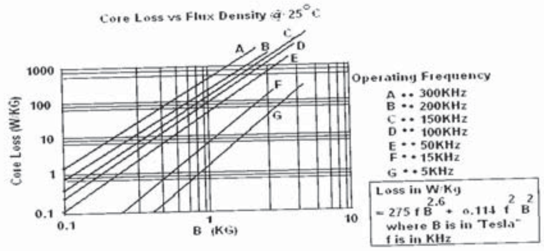


Fig 2.6.6.1 CORE LOSS FOR DIFFERENT FREQUENCY

Infrared analysis indicates that the grain- oriented silicon –steel unit reaches an average emperature of 332 K (59° C). Comparable operation of the most efficient amorphous – metal ore results in a smaller temperature rise to 304 K (31° C).The amorphous metal cores are sed up to 300KHz. Fig 2.6.6.1. Shows the amorphous metal core loss for different frequency.

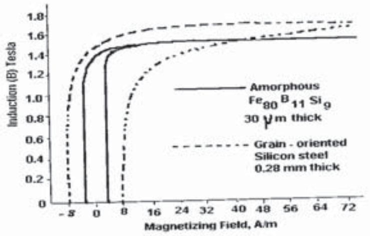


FIG.2.6.6.2.B-H CURVE OF AMORPHOUS AND SILICON STEEL

.7. APPLICATIONS OF 600HZ POWER SYSTEM

Fig 2.7 shows the application of 600Hz power systems. The system will be useful in he following areas

. HDL lamps

!. High-speed induction motors in process and synthetic yarn spinning mills.

3. Induction Heating.

4. DC power supply.

5. Cycloconverter fed motors drives.

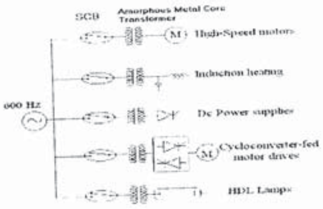


FIG.2.7.APPLICATIONS OF 6OOHz POWER SYSTEM

2.7.1. HIGH SPEED INDUCTION MOTORS

In synthetic yarn manufacturing plants, very high speed 10,000 to 15,000 rpm induction motors are used in take up winding machines. In steel and chemical plants, motors ranging from several thousand kW to 30 MW with 5000rpm motors are used for the application for condensation of ammonia, ethylene, and menthol blowers of gas pipelines and also used in high-pressure compressors. These motors could be run by 600Hz supply.

2.7.2. INDUCTION HEATING

In steel and iron industry, 400Hz -1Kz power supply is used in the induction furnaces for melting of cast steel and alloy. These furnaces are also found use in heat treatment n the conventional frequency power system, high value capacitors are used to improve the ower factor. By using 600Hz power, smaller value capacitors will be used to improve the .F.

.7.3. DC – DC POWER SUPPLY

Quick response DC power supply is obtained by using 600Hz Power supply. This supply will be useful in Computers, where the load is fluctuating nature, like process control unit using PLC. Particularly quick response current control is obtained by employing modern control systems.

2.7.4. CYCLO-CONVERTER FED MOTOR DRIVES

A naturally commutated cycloconverter has high efficiency and reliability. It performs direct AC-to-AC conversion with out any intermediate power stage . In recent days, designing of cycloconverter is easier by using modern power electronics elements with embedded controllers. The cycloconverter reduce the frequency from 600Hz to 0-200Hz.Hence it is possible to run the standard 50/60Hz- induction motors with this system. The cyclo- converter will replace the existing PWM inverter, which has high switching noises and high switching stress on the power devices.

2.8. SIMULATION

2.8.1 NEED FOR SIMULATION

New designs of power electronics systems are the norm due to new applications and

ccurate simulation is necessary to minimize costly repetitions of designs and bread boarding nd 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 ere

- 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. Thus, simulations may become more accurate than measurement.
- 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.

.8.2 REQUIREMENTS FOR A SIMULATION

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

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

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

ccurate models: For a detailed analysis, a simulation program needs accurate models of ll circuit elements, including transformers and transmission lines for utility related pplications. Even if accurate models are available, if it is difficult to know their parameter alues. 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,

apidly changing variables with small time constants. A small time step is also required to epresent switching times with good resolution in the presence of high switching frequencies. n such simulation, this leads to a large number of time steps. To keep the execution time vithin reasonable limits, an efficient equation solver with variables time steps is normally equired.

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.

2.8.3 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.**

2.8.4 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 classes' 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. There are two ways in which a three phase circuit can be obtained. The first method is forming three single phase circuits to obtain a three phase circuit with 180° 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 in following fig

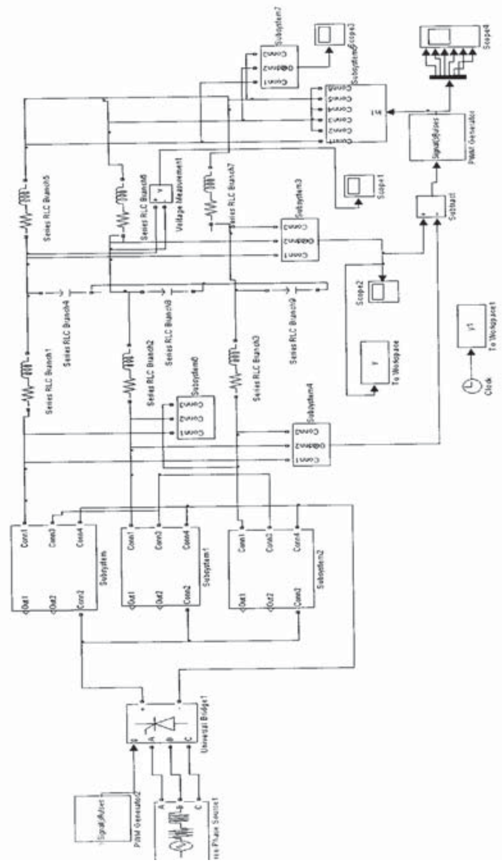


FIG.2.8.4.1. SIMULATION CIRCUIT OF PARALLEL RESONANT INVERTER WITH TSC

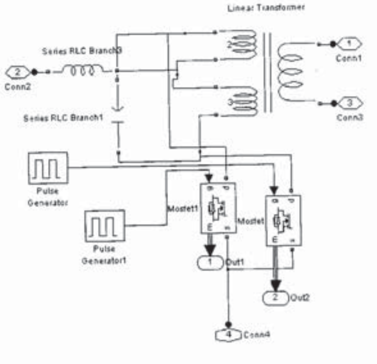


FIG.2.8.4.2. SUB SYSTEM OF PARALLEL RESONANT INVERTER

SINGLE PHASE OUTPUT OF INVERTER

FIG.2.8.4.3.SINGLE PHASE OUTPUT OF RESONANT INVERTER

THREE PHASE OUTPUT OF INVERTER WITH TSC

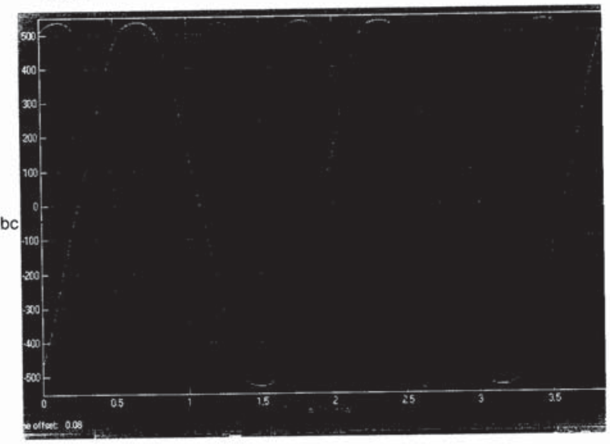


FIG.2.8.4.4.THREE PHASE OUTPUT OF RESONANT INVERTER WITH TSC

UNCOMPENSATED OUTPUT OF INVERTER

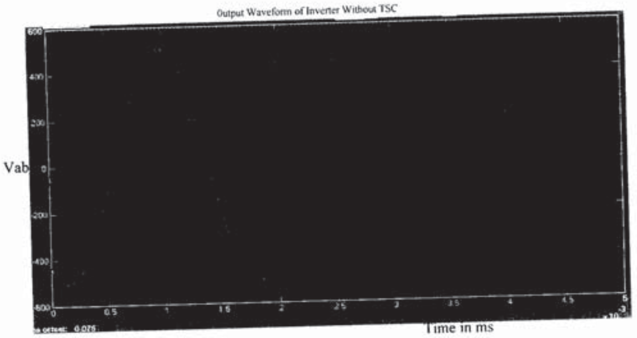


FIG.2.8.4.5.THREE PHASE OUTPUT OF RESONANT INVERTER WITHOUT TSC

The three phase simulations of 600Hz power system are shown in figures 2.8.4.1, 2.8.4.2, 2.8.4.3, 2.8.4.4 and 2.8.4.5.These simulations have been implemented in hardware.

CHAPTER 3

HARDWARE IMPLEMENTATION

3.1 .HARDWARE SECTION OF RESONANT INVERTER

3.1.1 DRIVER MODULE

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

$$PG=QG \cdot VGS \cdot f$$

Where QG 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 ckt should not be so large that there is a possibility of dv/dt turn on. 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.

3.1.2. DRIVER CIRCUIT OF RESONANT PARALLEL INVERTER

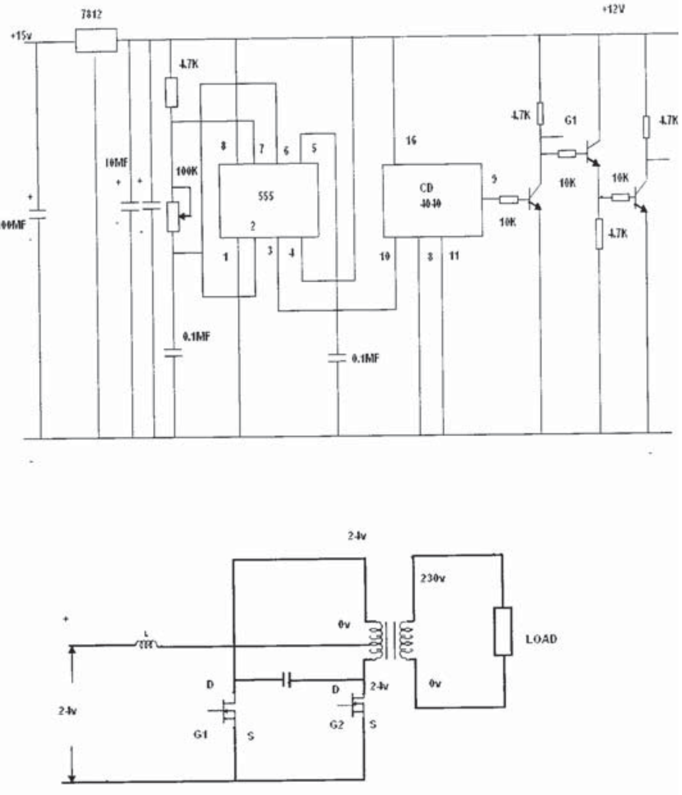


FIG.3.1.2.DRIVER CIRCUIT OF RESONANT PARALLEL INVERTER

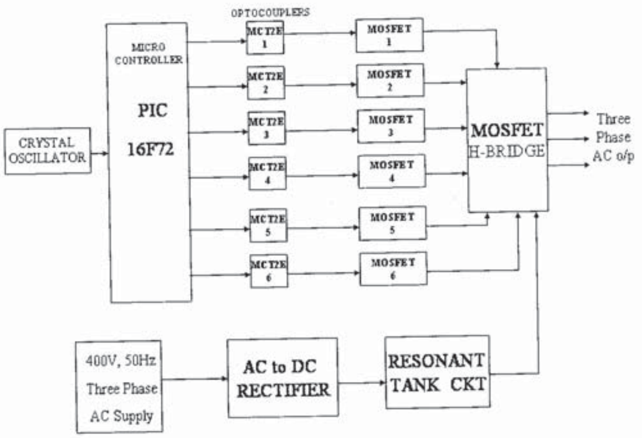
The experimental setup shows the resonant capacitor C1, MOSFETs are mounted on the heatsink. MOSFET gate signal generating clock circuit is assembled in the bread-board. The inductance placed near the auto transformer is acts as current source. The toroital transformer T1 is placed near the capacitorC1 and the MOSFETTs Q1&Q2, functioning as resonant inductor and isolation transformer. The choke is designed with amorphous metal core METGLAS.

In the driver circuit 600Hz frequency is obtained by adjusting the POT. Here 15v input supply is given to the 555 timer to set the time period for 600Hz.The output pin of 555 timer is given to the 12 pin CD 4040 Ripple counter.

The output pin of CD 4040 Ripple counter is given to the corresponding gates through 10k resistors. The MOSFETs used are IRF 840.

From the experiment, it is found that in 600Hz supply, the choke weight is reduced .The core loss, copper loss and size of the ballast is reduced in the 600Hz-power supply. The minimum operating voltage is 125V where as the 50Hz ballast requires minimum 140V . There is saving 16 Watt in each tube light. In heavy Industry, there will be more than 1000 Nos of tube lights are available. By using this supply there will be a huge power saving.

3.2. HARDWARE SECTION OF RESONANT DC-LINK INVERTER



3.2.1 BLOCK DIAGRAM

3.2.1 DESCRIPTION

The basic block diagram is shown in fig.3.2.1. 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 MOSFET bridge inverter section is fed

---

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.

3.2.2 COMPONENT CHARECTERISTICS

3.2.2.1 POWER MOSFETs

The power MOSFET symbol is as shown in the figure 3.2.2.1

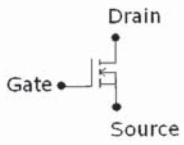


FIG.3.2.2.1.MOSFET SYMBOL

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 ... typically silicon dioxide. The control signal

---

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 to 500 kHz.

3.2.3 SWITCHING CHARECTERISTICS

The switching characteristics of a power MOSFET are determined largely by various capacitances inherent in its structure. These are shown in Fig. 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.3.2.3

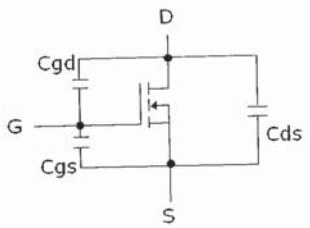


FIG.3.2.3. INTERNAL CAPACITANCES OF DEPLETION MOSFET

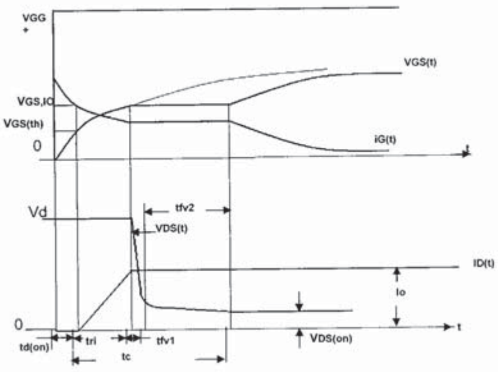
The gate source capacitance needs to be charged up to a threshold voltage up to a threshold voltage of about 3V before the MOSFET begins turn-on. The time constant for this is C_{gs} (R_{dr}+R_g) and the time taken is called the turn-on delay time [$t_{D\,(ON)}$]. As V_{gs} starts to exceed the threshold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

3.2.4. ADVANTAGES

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

3.2.5.1 MOSFET TURN ON CHARACTERISTICS



3.2.5.1. MOSFET TURN ON CHARACTERISTICS

The turn-on behavior of the MOSFET is shown in Fig.3.2.5.1.As shown in this figure, the gate drive voltage changes in step function manner from 0 to *VGG* which is above the threshold voltage *VGS (th).* During the turn on delay time td(on) the gate-source voltage Vgs rises from 0 to *VGS(th)* in fashion similar to an RC circuit .This is due to the resistance in the current path in addition to the equivalent input MOSFET capacitance (*Cgs* and *Cgd*).The rise time constant is given by *t1=RG(Cgs+Cgd1)*.Beyond *VGS(th)*. *Vgs* keeps rising as before and *Ids* starts increasing. Once the MOSFET is carrying the full load current *I0*, the gate-source

through *Cgd* only. As a result, the drain-source voltage starts decreasing until it reaches the drop due to the on-state resistance. At this point, the gate-source voltage becomes unclamped and rises again to *VGG* with a time constant of *t2=RG (Cgs + Cgd2)*.Note here that there are two values of *Cgd* due to the nonlinear nature of this capacitance.

3.2.5.2. MOSFET TURN-OFF CHARACTERISTICS

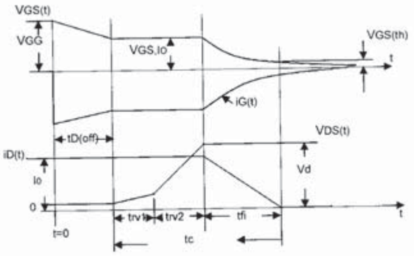


FIG.3.2.5.2.TURN-OFF CHARACTERISTICS OF MOSFET

The turn-off of the MOSFET involves the inverse sequence of events that occurred during turn-on. This is shown in Fig.3.2.5.2.The turn-off process is initiated by applying a step gate voltage of-*VGG*.

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 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.

OPTO COUPLER 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

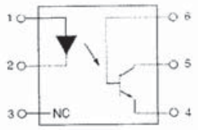
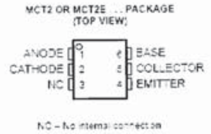
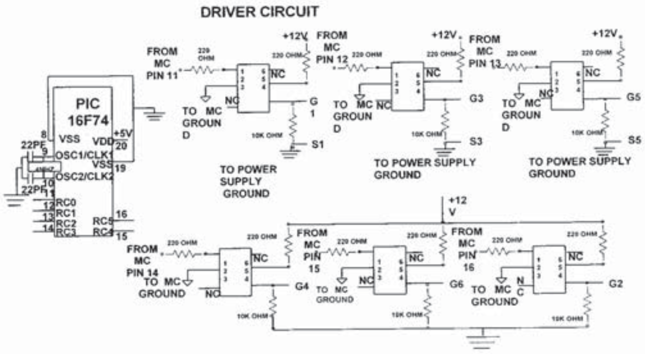


FIG.3.2.6 OPTOCOUPLER PIN DETAILS



3.2.7. DRIVER MODULE



3.2.7.1 CRYSTAL OSCILLATOR

The driver circuit of resonant DC-link inverter is shown in fig.3.2.7. 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.

3.2.7.2 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, and 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 protection for the controller from the high voltages developed in the inverter stage.

The inverter configuration is achieved by using a MOSFET H-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.

3.3 MODULE CLASSIFICATION

High frequency resonant inverter consists of the following basic segments

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

3.3.1 AC-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.

3.3.2 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

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 reactances 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.

$X_L = 2\Pi fL$ $\qquad$ $X_C = 1/2\Pi fC$

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

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,

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

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 $1\mu F$ capacitor and the 70mH inductor and work through the parallel impedance formula to demonstrate this mathematically:

$$X_L = 2\Pi fL$$

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

$$X_L = 265.25\ O$$

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

$$X_C = \quad 1/(2)(\Pi)(600\ Hz)(\ 1\mu F)$$

$$X_C = = 265.25\ O$$

Thus

$$\boxed{X_L = X_C}$$

Hence the resonance condition is achieved.

3.3.3 INVERTER SECTION

The inverter configuration is achieved using a MOSFET H-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 $(0\text{-}60^0)$, the MOSFETs 6,1 conduct. During $(60^0\text{-}120^0)$, the MOSFETs 1,2 conduct. During $(120^0\text{-}180^0)$, the MOSFETs 2,3 conduct. Like this the MOSFETs gets turned on as said in the above sequence.

3.4 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.

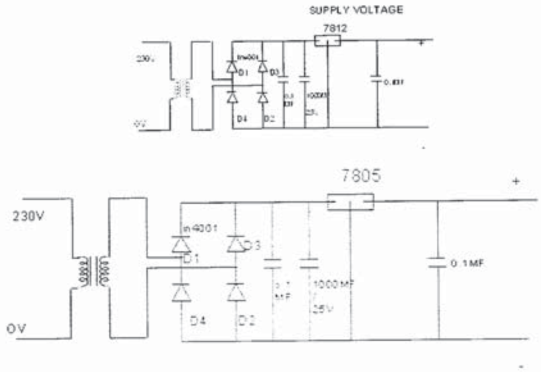


FIG.3.4.POWER SUPPLIES

The ac voltage, typically 120V RMS, is connected to a transformer, which steps that ac

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.

3.4.1 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.

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 milli amperes to tens of amperes, corresponding to power ratings from milli watts to tens of watts.

3.4.2 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).

3.4.3 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.

3.5 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 efficiency
- High reliability
- Low Electromagnetic interference (EMI)

.6 HARDWARE SECTION OF TSC

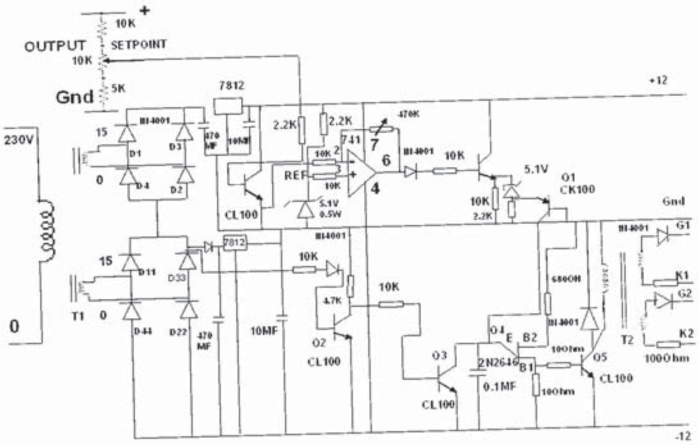


FIG.3.6 DRIVER CIRCUIT OF TSC

The Driver circuit of TSC is given in Fig.3.6.Here drive circuit for gate is implemented by using BJT triggering circuit. In this circuit gate pulse is given by comparing the output voltage of inverter and drop voltage of inverter using comparator, then the compared output is given to the gate as pulses.Here IC 741 is used as a comparator to compare the output voltage of inverter and drop voltage of inverter. In this circuit Q5 CL100 transistor is used for the triggering circuit.Here set point is obtained by using POT. Transformer T1 provides

odes. Here UJT Q4 is used for the generating triggering pulse. The pulse transformerT2 1:1 is used to give the gate signal to the thyristor circuit, the input of pulse transformer is onnected to the transistor Q2 CL100 then the two secondary output is given to the Thyristor ate through IN4001 doides.

7 TESTING

7.1 OUTPUT WAVEFORM OF RESONANT PARALLEL INVERTER

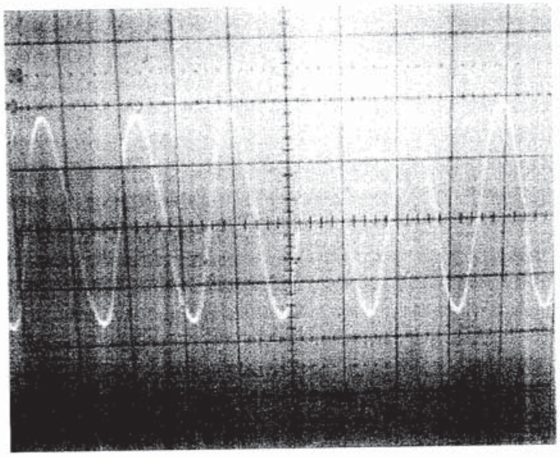


FIG.3.7.1.PARALLEL RESONANT INVERTER WAVEFORM AT 600Hz

The above waveform has been observed in Digital scope Oscilloscope

7.2 OUTPUT WAVEFORM OF RESONANT DC-LINK INVERTER

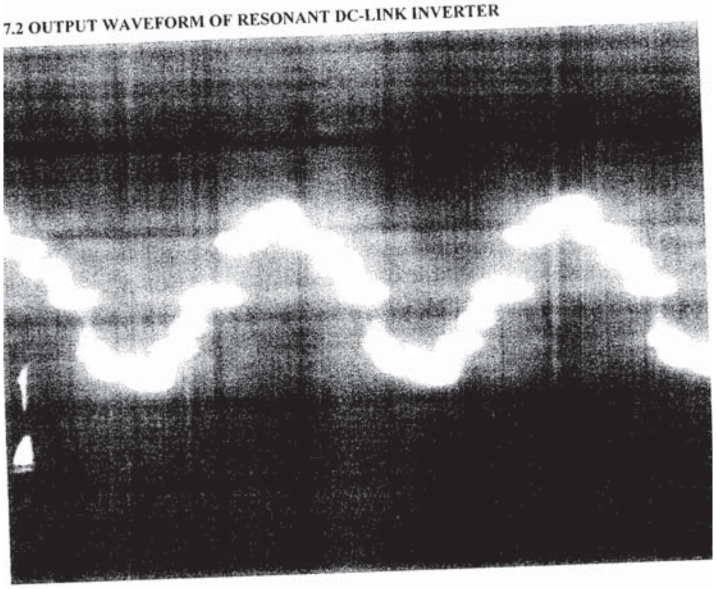


FIG.3.7.2 RESONANT DC-LINK INVERTER WAVEFORM AT 600Hz

The above waveform has been observed in Digital scope Oscilloscope.

8. SYSTEM VALIDATION

The resonant inverter ckt has been simulated in MATLAB/SIMULINK .0 for the parameters considered in the design ckt. In the simulation, the waveforms of the esonant inverter is shown. The hardware has been implemented and the output waveform of e ckt is shown in the digital CRO. The ckt output waveform agrees closely with simulated vaveform.

The ckt output is tested with a compact fluorescent lamp (CFL). The CFL amp is having many advantages working under high frequency resonant conditions ompared 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.
- ❖ 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.

The compared output of 50Hz and 600Hz in **LUX** is given below

Voltage	A	
	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.

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

.1. CONCLUSION

In this project a 600Hz-frequency power system has been developed for supplying ower to specific areas such as Industrial zones, Commercial complex, Intelligent buildings and offices where high efficiency, low weight of the equipments and space saving are required. A 600Hz-power system suitable for a 20Km by 20KM industrial zone or 1KM by 1KM commercial areas is proposed and its application is investigated. A40w fluorescent lamp is tested with 220V, 600Hz amorphous choke and with 220V, 50Hz silicon steel choke. In the experiment, using 600Hz power supply system, the efficiency is increased and losses, space, weight are reduced. The weight of the core is reduced by 83%, iron loss is reduced by 72%, copper loss is reduced by 76%, weight of the copper is reduced by 74%volume of the choke is reduced by 72%, Inductance of the choke is reduced by 91.21%.The 600Hz power system will be useful in HDL lamps, High-speed induction motors in process and synthetic yarn spinning mills, Induction Heating, DC to DC power supply, Cycloconverter fed motors Drives. The Naturally commutated cycloconverter will replace the PWM inverters in many applications offering high efficiency and reliability. The Solid-state circuit breaker, resonant inverter, amorphous metal core transformer can be used effectively in commercial power system. Capacitors can be made much smaller as about 1/12 times with low cost. The system can be economically used to improve the power factor of the loads electric furnace. Distributed natural energy generation and cogeneration systems can be directly used for the energy source of the 600Hz-power system. Stability and efficiency of the fluorescent lamps and mercury lamps can be improved and made compact. Higher frequency power can be used in Steel and Chemical plants for compressors and induction heating. High frequency power can be effectively used in commercial areas and intelligent buildings.

---

2. RECOMMENDATIONS FOR FUTURE ENHANCEMENTS

The 600 Hz Power System using resonant inverter gives pure sine wave, required the following areas.

1. Induction heating
2. High speed induction motors
3. Quick response DC power supplies
4. HDL laps
5. Cyclo-converter fed motors.

At present the project concentrates on applications in such areas as industrial, ommercial zones and intelligent buildings, where the high efficiency less space and small eight of the electric equipments are required. By using amorphous metal core in ansformer, motors and in inductance, the application could be extended to all commercial nd industrial areas.

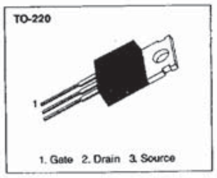
APPENDIX 1-MICROCONTROLLER PROGRAM

```
**********************************************************************
                                        *
  Notes:gate pulse in rc0:rc6           *
                                        *
                                        *
                                        *
                                        *
;*********************************************************************


      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                  :8
              call delay
              movf temp.w
              decfsz counter,f
              goto $-6                     :4
              goto rep
 ;------------------------------------------------------------
 lookup:
              addwf pcl,f
              retlw b'00010001'
              retlw b'00100001'
              retlw b'00100010'
              retlw b'00001010'
              retlw b'00001100'
              retlw b'00010100'
 ;------------------------------------------------------------
```

```
:lay:
        movlw .86           ;x-19
        movwf temp1
        decfsz temp1,f
        goto $-1
        return

---------------------------------------------------------------------
iitio:
        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
```

FEATURES

- Lower $R_{DS(ON)}$
- Improved inductive ruggedness
- Fast switching times
- Rugged polysilicon gate cell structure
- Lower input capacitance
- Extended safe operating area
- Improved high temperature reliability



PRODUCT SUMMARY

Part Number	V_{DS}	$R_{DS(on)}$	I_D
IRF840	500V	0.85Ω	8.0A
IRF841	450V	0.85Ω	8.0A

ABSOLUTE MAXIMUM RATINGS

Characteristic	Symbol	IRF840	IRF841	Unit
Drain-Source Voltage (1)	V_{DSS}	500	450	Vdc
Drain-Gate Voltage (R_{GS}=1.0MΩ)(1)	V_{DGR}	500	450	Vdc
Gate-Source Voltage	V_{GS}	±20		Vdc
Continuous Drain Current Tc=25 °C	I_D	8.0		Adc
Continuous Drain Current Tc=100 °C	I_D	5.0		Adc
Drain Current - Pulsed (3)	I_{DM}	32		Adc
Gate Current - Pulsed	I_{GM}	±1.5		Adc
Single Pulsed Avalanche Energy (4)	E_{AS}	510		mJ
Avalanche Current	I_{AS}	8.0		A
Total Power Dissipation @ Tc=25 °C Derate above 25 °C	P_D	125 1.0		Watts W/ °C
Operating and Storage Junction Temperature Range	T_J, T_{STG}	-55 to +150		°C
Maximum Lead Temp. for Soldering Purposes, 1/8" from case for 5 seconds	T_L	300		°C

Notes : (1) T_J=25°C to 150°C
(2) Pulse test : Pulse width ≤ 300μs, Duty Cycle ≤ 2%
(3) Repetitive rating : Pulse width limited by max. junction temperature
(4) L=1.4mH, V_{dd}=50V, R_G=25Ω , Starting T_J=25°C

ELECTRICAL CHARACTERISTICS (Tc=25°C unless otherwise specified)

Symbol	Characteristic	Min	Typ	Max	Units	Test Conditions
BV_{DSS}	Drain-Source Breakdown Voltage					
	IRF840	500	-	-	V	V_{GS}=0V, I_D=250μA
	IRF841	450	-	-	V	
$V_{GS(th)}$	Gate Threshold Voltage	2.0	-	4.0	V	V_{DS}=V_{GS}, I_D=250μA
I_{GSS}	Gate-Source Leakage Forward	-	-	100	nA	V_{GS}=20V
I_{GSS}	Gate-Source Leakage Reverse	-	-	-100	nA	V_{GS}=-20V
I_{DSS}	Zero Gate Voltage Drain Current	-	-	250	μA	V_{DS}=Max. Rating, V_{GS}=0V
		-	-	1000	μA	V_{DS}=0.8 Max. Rating, V_{GS}=0V, Tc=125°C
$R_{DS(on)}$	Static Drain-Source On Resistance (2)	-	-	0.85	Ω	V_{GS}=10V, I_D=4.0A
g_{fs}	Forward Transconductance (2)	4.0	6.5	-	℧	V_{DS} ≥ 10V, I_D=4.0A
C_{iss}	Input Capacitance	-	1510	-	pF	V_{GS}=0V, V_{DS}=25V, f=1.0MHz
C_{oss}	Output Capacitance	-	154	-	pF	
C_{rss}	Reverse Transfer Capacitance	-	66	-	pF	
$t_{d(on)}$	Turn-On Delay Time	-	14	21	ns	V_{DD}=0.5 BV_{DSS}, I_D=8.0A, Z_O=9.1Ω (MOSFET switching times are essentially independent of operating temperature)
t_r	Rise Time	-	23	35	ns	
$t_{d(off)}$	Turn-Off Delay Time	-	49	74	ns	
t_f	Fall Time	-	20	30	ns	
Q_g	Total Gate Charge (Gate-Source Plus Gate-Drain)	-	-	74	nC	V_{GS}=10V, I_D=8.0A, V_{DS}=0.8 Max. Rating (Gate charge is essentially independent of operating temperature)
Q_{gs}	Gate-Source Charge	-	9.0	-	nC	
Q_{gd}	Gate-Drain ("Miller") Charge	-	27.0	-	nC	

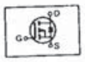
THERMAL RESISTANCE

Symbol	Characteristics		All	Units	Remark
R_{thJC}	Junction-to-Case	MAX	1.0	K/W	
R_{thCS}	Case-to-Sink	TYP	0.5	K/W	Mounting surface flat, smooth, and greased
R_{thJA}	Junction-to-Ambient	MAX	62.5	K/W	Free Air Operation

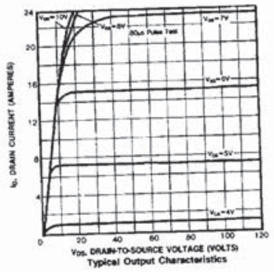
Notes : (1) T_J=25°C to 150°C
(2) Pulse test : Pulse width ≤ 300μs, Duty Cycle ≤ 2%
(3) Repetitive rating : Pulse width limited by max. junction temperature

---

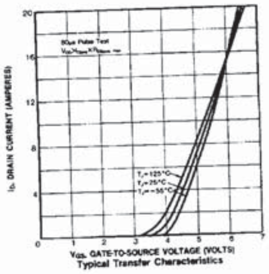
SOURCE-DRAIN DIODE RATINGS AND CHARACTERISTICS

Symbol	Characteristic	Min	Typ	Max	Units	Test Conditions
I_S	Continuous Source Current (Body Diode)	-	-	8.0	A	Modified MOSFET symbol showing the integral reverse P-N junction rectifier 
I_{SM}	Pulse Source Current (Body Diode) (3)	-	-	32	A	
V_{SD}	Diode Forward Voltage (2)	-	-	2.0	V	T_J=25°C, I_S=8.0A, V_{GS}=0V
t_{rr}	Reverse Recovery Time	-	460	970	ns	T_J=25°C, I_F=8.0A, dI_F/dt=100A/μS

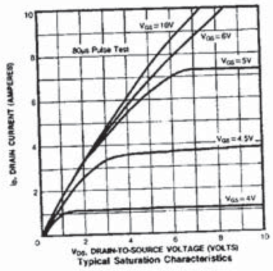
Notes : (1) T_J=25°C to 150°C
(2) Pulse test : Pulse width ≤ 300μs, Duty Cycle ≤ 2%
(3) Repetitive rating : Pulse width limited by max. junction temperature



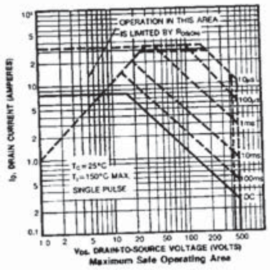
Typical Output Characteristics



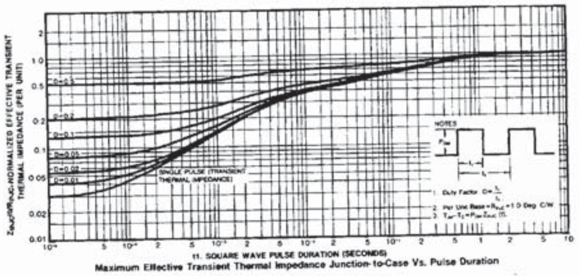
Typical Transfer Characteristics



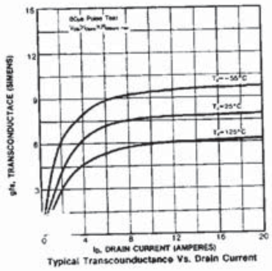
Typical Saturation Characteristics



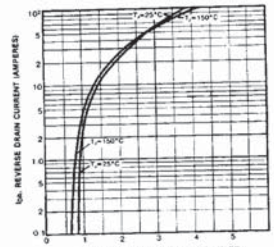
Maximum Safe Operating Area



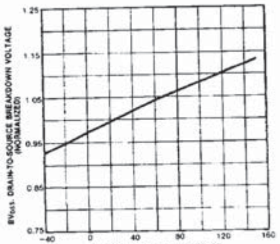
Maximum Effective Transient Thermal Impedance Junction-to-Case Vs. Pulse Duration



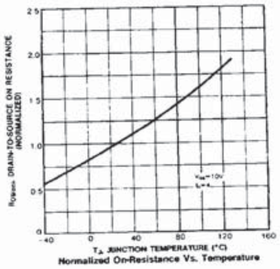
Typical Transcounductance Vs. Drain Current



Typical Source—Drain Diode Forward Voltage



Breakdown Voltage Vs. Temperature



Normalized On-Resistance Vs. Temperature

MICROCHIP

PIC16F72

28-Pin, 8-Bit CMOS FLASH MCU with A/D Converter

Device Included:

- PIC16F72

High Performance RISC CPU:

- Only 35 single word instructions to learn
- All single cycle instructions except for program branches, which are two-cycle
- Operating speed: DC - 20 MHz clock input
  DC - 200 ns instruction cycle
- 2K x 14 words of Program Memory, 128 x 8 bytes of Data Memory (RAM)
- Pinout compatible to PIC16C72/72A and PIC16F872
- Interrupt capability
- Eight-level deep hardware stack
- Direct, Indirect and Relative Addressing modes

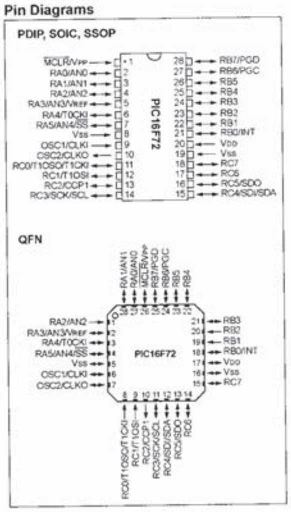
Peripheral Features:

- High Sink/Source Current: 25 mA
- Timer0: 8-bit timer/counter with 8-bit prescaler
- Timer1: 16-bit timer/counter with prescaler, can be incremented during SLEEP via external crystal/clock
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler
- Capture, Compare, PWM (CCP) module
  - Capture is 16-bit, max. resolution is 12.5 ns
  - Compare is 16-bit, max. resolution is 200 ns
  - PWM max. resolution is 10-bit
- 8-bit, 5-channel analog-to-digital converter
- Synchronous Serial Port (SSP) with SPI™ (Master/Slave) and I²C™ (Slave)
- Brown-out detection circuitry for Brown-out Reset (BOR)

CMOS Technology:

- Low power, high speed CMOS FLASH technology
- Fully static design
- Wide operating voltage range: 2.0V to 5.5V
- Industrial temperature range
- Low power consumption:
  - < 0.6 mA typical @ 3V, 4 MHz
  - 20 μA typical @ 3V, 32 kHz
  - < 1 μA typical standby current

Pin Diagrams



Special Microcontroller Features:

- 1,000 erase/write cycle FLASH program memory typical
- Power-on Reset (POR), Power-up Timer (PWRT) and Oscillator Start-up Timer (OST)
- Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation
- Programmable code protection
- Power saving SLEEP mode
- Selectable oscillator options
- In-Circuit Serial Programming™ (ICSP™) via 2 pins
- Processor read access to program memory

Key Reference Manual Features	PIC16F72
Operating Frequency	DC - 20 MHz
RESETS and (Delays)	POR, BOR, (PWRT, OST)
FLASH Program Memory - (14-bit words, 1000 E/W cycles)	2K
Data Memory - RAM (8-bit bytes)	128
Interrupts	8
I/O Ports	PORTA, PORTB, PORTC
Timers	Timer0, Timer1, Timer2
Capture/Compare/PWM Modules	1
Serial Communications	SSP
8-bit A/D Converter	5 channels
Instruction Set (No. of Instructions)	35

1.0 DEVICE OVERVIEW

This document contains device specific information for the operation of the PIC16F72 device. Additional information may be found in the PICmicro™ Mid-Range MCU Reference Manual (DS33023), which may be downloaded from the Microchip website. The Reference Manual should be considered a complementary document to this data sheet, and is highly recommended reading for a better understanding of the device architecture and operation of the peripheral modules.

The PIC16F72 belongs to the Mid-Range family of the PICmicro devices. A block diagram of the device is shown in Figure 1-1.

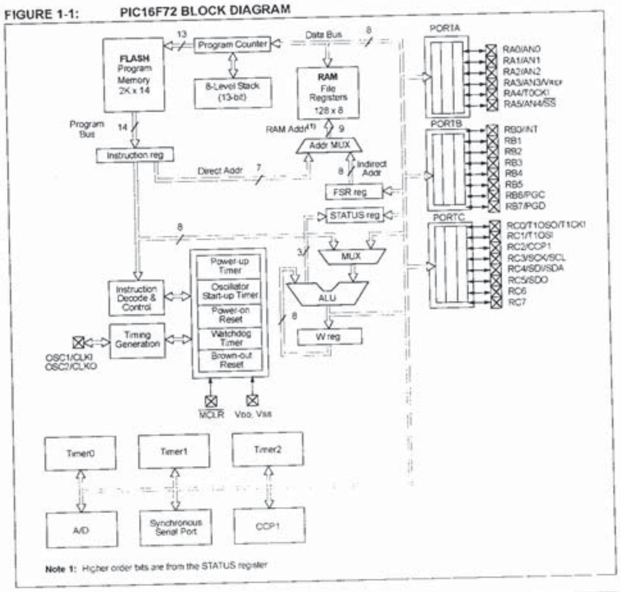
The program memory contains 2K words, which translate to 2048 instructions, since each 14-bit program memory word is the same width as each device instruction. The data memory (RAM) contains 128 bytes.

There are 22 I/O pins that are user configurable on a pin-to-pin basis. Some pins are multiplexed with other device functions. These functions include:

- External interrupt
- Change on PORTB interrupt
- Timer0 clock input
- Timer1 clock/oscillator
- Capture/Compare/PWM
- A/D converter
- SPI/I²C

Table 1-1 details the pinout of the device with descriptions and details for each pin.

FIGURE 1-1: PIC16F72 BLOCK DIAGRAM



Note 1: Higher order bits are from the STATUS register

15.0 DC AND AC CHARACTERISTICS GRAPHS AND TABLES

Note: The graphs and tables provided following this note are a statistical summary based on a limited number of samples and are provided for informational purposes only. The performance characteristics listed herein are not tested or guaranteed. In some graphs or tables, the data presented may be outside the specified operating range (e.g., outside specified power supply range) and therefore, outside the warranted range.

"Typical" represents the mean of the distribution at 25°C. "Maximum" or "minimum" represents (mean + 3σ) or (mean - 3σ) respectively, where σ is a standard deviation, over the whole temperature range.

FIGURE 15-1: TYPICAL IDD vs. FOSC OVER VDD (HS MODE)

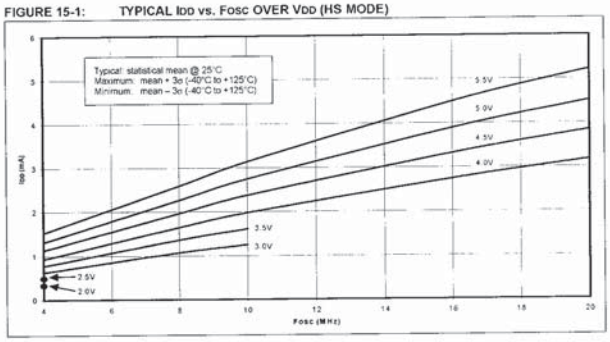
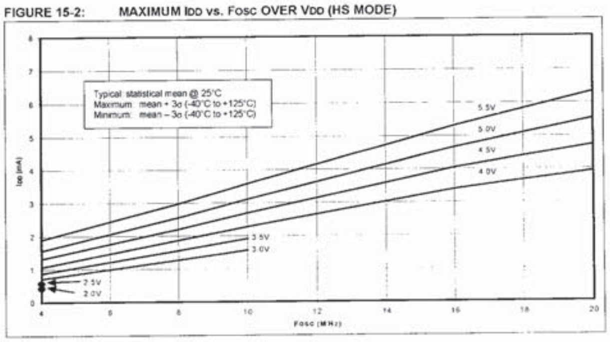


FIGURE 15-2: MAXIMUM IDD vs. FOSC OVER VDD (HS MODE)



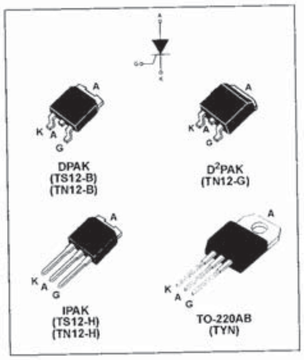
TN12, TS12 and TYNx12 Series

SENSITIVE & STANDARD

12A SCRs

MAIN FEATURES:

Symbol	Value	Unit
$I_{T(RMS)}$	12	A
V_{DRM}/V_{RRM}	600 to 1000	V
I_{GT}	0.2 to 15	mA



DESCRIPTION

Available either in sensitive (TS12) or standard (TYN, TN12...) gate triggering levels, the 12A SCR series is suitable to fit all modes of control found in applications such as overvoltage crowbar protection, motor control circuits in power tools and kitchen aids, in-rush current limiting circuits, capacitive discharge ignition, voltage regulation circuits...
Available in though-hole or surface-mount packages, they provide an optimized performance in a limited space area.

ABSOLUTE RATINGS (limiting values)

Symbol	Parameter			Value		Unit
$I_{T(RMS)}$	RMS on-state current (180° conduction angle)		Tc = 105°C	12		A
$IT_{(AV)}$	Average on-state current (180° conduction angle)		Tc = 105°C	8		A
				DPAK / IPAK	D²PAK / TO-220AB	
I_{TSM}	Non repetitive surge peak on-state current	tp = 8.3 ms	Tj = 25°C	115	146	A
		tp = 10 ms		110	140	
I^2t	I^2t Value for fusing	tp = 10 ms	Tj = 25°C	60	98	A^2s
dI/dt	Critical rate of rise of on-state current $I_G = 2 \times I_{GT}$, tr ≤ 100 ns	F = 60 Hz	Tj = 125°C	50		A/µs
I_{GM}	Peak gate current	tp = 20 µs	Tj = 125°C	4		A
$P_{G(AV)}$	Average gate power dissipation		Tj = 125°C	1		W
T_{stg} Tj	Storage junction temperature range Operating junction temperature range			- 40 to + 150 - 40 to + 125		°C
V_{RGM}	Maximum peak reverse gate voltage (for TN12 & TYN)			5		V

APPENDIX-3-PHOTOGRAPHS

FIG A 3.1. EXPERIMENTAL SETUP OF 600Hz RESONANT INVERTER

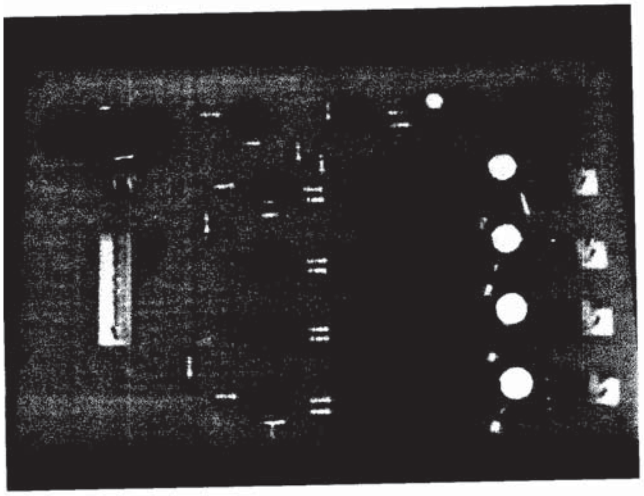


FIG A 3.1. DRIVER SECTION OF RESONANT DC-LINK INVERTER

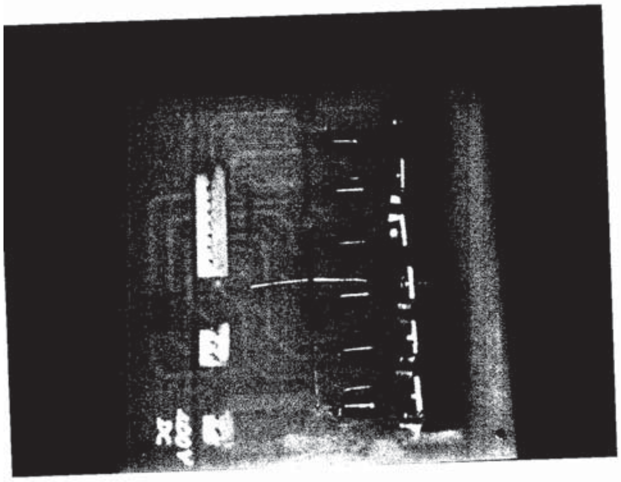


FIG A 3.2. INVERTER BRIDGE SECTION

REFERENCES

1. Steffen Bernet "Recent Developments of High Power Converters for Industry and traction Applications "IEEE Transactions on Power Electronics, Vol 15, No.6, Nov 2000, pp 1102-1117.
2. ie Chang," High – Frequency and Precision Three –Phase Sine/Pwm Controller with Near – Zero Frequency of MPU Intervention – Novel design supporting Distributed AC Drive Systems" IEEE transactions on Industrial Electronics, Vol.52,No.5, OCT 2005
3. L.Takahashi et all. "A 500 Hz Power System – Power converter and Transmission lines" IEEE/IAS Ann. Meet conf.rec., part 1, pp 988-995 1989
4. L.Takahashi et all. " A 500 Hz Power System applications" IEEE/IAS Ann. Meet conf.rec., part 1, pp 966-1002, 1989.
5. T.Nakamura et. all., "A 500 Hz Power System- Microprocessor control of the power converter" Rec. KANSAI – section joint conv og I.E.E. , Japan, Nov., 1988.
6. N.G..Hingorani, " Power Electronics in electric utilities: Role of power Electronics in future power systems," Proc., IEEE, vol. 76, pp 481-482, Apr., 1988.
7. E.Sakoguchi et. all. " A new inverter and control method for induction cooking appliance"Int. power Electronics conference Rec. Tokyo, pp 894-903, 1983.
8. Y.Yokoo et. all. " High frequency induction heating equipment by using static induction transistors". Proc., Power conv. & intelligent motions, pp 101-108, 1988.
9. K.M.N.Murthy, " Economics of power factor Improvement and advantages of improving power factor" proc., of Role of power factor in Electrical power systems, organized by IE (India), session 1, Feb, 1996.
10. G.K.Dubey et all, "Thyrizstorised Power Controllers.
11. Metglas High frequency cores manual from M/s. Honeywell.
12. N.G. Hingorani, "Understanding FACTS"
13. M.H.Rashid, 'Power Electronics"
14. G.F. Moore, "Electric cables Hand Book" –ISBN -0-632-04075-0

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ntersil

CD4020BMS, CD4024BMS, CD4040BMS

CMOS Ripple-Carry Binary Counter/Dividers

er 1996

eatures

- High Voltage Types (20V Rating)
- Medium Speed Operation
- Fully Static Operation
- Buffered Inputs and Outputs
- 100% Tested for Quiescent Current at 20V
- Standardized Symmetrical Output Characteristics
- Common Reset
- 5V, 10V and 15V Parametric Ratings
- Maximum Input Current of 1µa at 18V Over Full Package-Temperature Range;
  - 100nA at 18V and 25°C
- Noise Margin (Over Full Package Temperature Range):
  - 1V at VDD = 5V
  - 2V at VDD = 10V
  - 2.5V at VDD = 15V
- Meets All Requirements of JEDEC Tentative Standard No. 13B, "Standard Specifications For Description Of 'B' Series CMOS Devices"

Applications

- Control Counters
- Timers
- Frequency Dividers
- Time-Delay Circuits

Description

CD4020BMS - 14 Stage

CD4024BMS - 7 Stage

CD4040BMS - 12 Stage

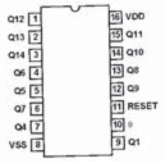
CD4020BMS, CD4024BMS, and CD4040BMS are ripple-carry binary counters. All counter stages are master-slave flip-flops. The state of a counter advances one count on the negative transition of each input pulse; a high level on the RESET line resets the counter to its all zeros state. Schmitt trigger action on the input-pulse line permits unlimited rise and fall times. All inputs and outputs are buffered.

The CD4020BMS, CD4024BMS and the CD4040BMS is supplied in these 14 lead outline packages:

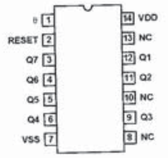
	CD4020B	CD4024B	CD4040B
Braze Seal DIP	H4W	H4Q	H4X
Frit Seal DIP	H1F	H1B	H1F
Ceramic Flatpack	H6W	H3W	H6W

Pinouts

CD4020BMS
TOP VIEW

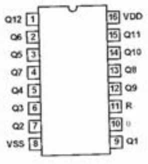


CD4024BMS
TOP VIEW



NC = NO CONNECTION

CD4040BMS
TOP VIEW



Specifications CD4020BMS, CD4024BMS, CD4040BMS

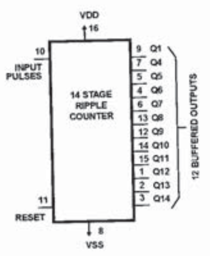
TABLE 8. BURN-IN AND IRRADIATION TEST CONNECTIONS (Continued)

FUNCTION	OPEN	GROUND	VDD	9V ± -0.5V	OSCILLATOR 50kHz	OSCILLATOR 25kHz
Static Burn-In 2 Note 1	3 - 6, 8 - 13	7	1, 2, 14			
Dynamic Burn-In Note 1	8, 10, 13	2, 7	14	3 - 6, 9, 11, 12	1	
Irradiation Note 2	3 - 6, 8 - 13	7	1, 2, 14			
PART NUMBER CD4040BMS						
Static Burn-In 1 Note 1	1 - 7, 9, 12 - 15	8, 10, 11	16			
Static Burn-In 2 Note 1	1 - 7, 9, 12 - 15	8	10, 11, 16			
Dynamic Burn-In Note 1	-	8, 11	16	1 - 7, 9, 12 - 15	10	
Irradiation Note 2	1 - 7, 9, 12 - 15	8	10, 11, 16			

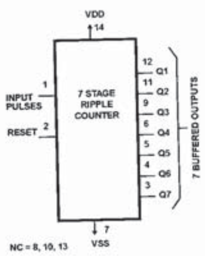
NOTE:

1. Each pin except VDD and GND will have a series resistor of 10K ± 5%, VDD = 18V ± 0.5V
2. Each pin except VDD and GND will have a series resistor of 47K ± 5%; Group E, Subgroup 2, sample size is 4 dice/wafer, 0 failures, VDD = 10V ± 0.5V

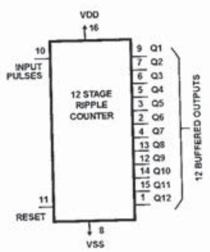
Functional Diagrams



CD4020BMS



CD4024BMS



CD4040BMS

Typical Performance Characteristics

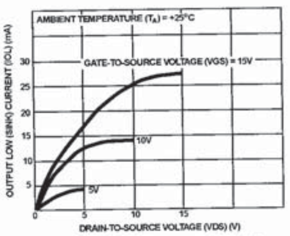


FIGURE 4. TYPICAL OUTPUT LOW (SINK) CURRENT CHARACTERISTICS

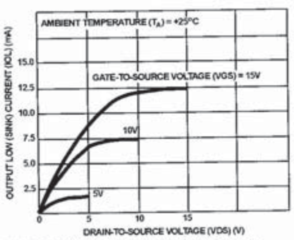


FIGURE 5. MINIMUM OUTPUT LOW (SINK) CURRENT CHARACTERISTICS

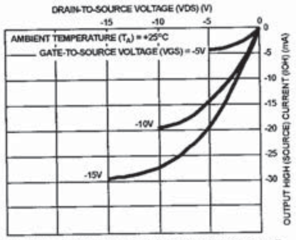


FIGURE 6. TYPICAL OUTPUT HIGH (SOURCE) CURRENT CHARACTERISTICS

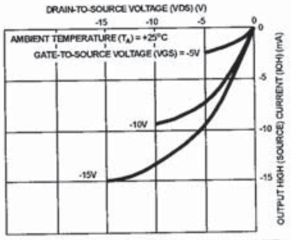


FIGURE 7. MINIMUM OUTPUT HIGH (SOURCE) CURRENT CHARACTERISTICS

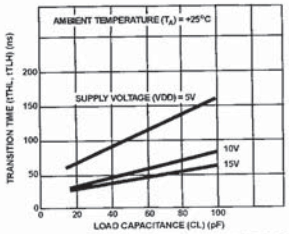


FIGURE 8. TYPICAL TRANSITION TIME AS A FUNCTION OF LOAD CAPACITANCE

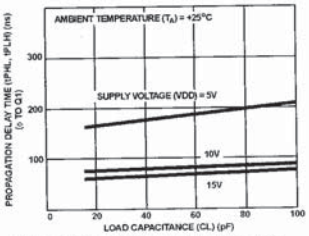


FIGURE 9. TYPICAL PROPAGATION DELAY TIME AS A FUNCTION OF LOAD CAPACITANCE (φ TO Q1)

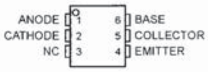
MCT2, MCT2E
OPTOCOUPLERS

SOES023 – MARCH 1983 – REVISED OCTOBER 1995

COMPATIBLE WITH STANDARD TTL INTEGRATED CIRCUITS

- **Gallium Arsenide Diode Infrared Source Optically Coupled to a Silicon npn Phototransistor**
- **High Direct-Current Transfer Ratio**
- **Base Lead Provided for Conventional Transistor Biasing**
- **High-Voltage Electrical Isolation . . . 1.5-kV, or 3.55-kV Rating**
- **Plastic Dual-In-Line Package**
- **High-Speed Switching:**
  t_r = 5 µs, t_f = 5 µs Typical
- **Designed to be Interchangeable with General Instruments MCT2 and MCT2E**

MCT2 OR MCT2E . . . PACKAGE
(TOP VIEW)



NC – No internal connection

absolute maximum ratings at 25°C free-air temperature (unless otherwise noted)†

Input-to-output voltage: MCT2 . . . . . . ± 1.5 kV
MCT2E . . . . . . ± 3.55 kV
Collector-base voltage . . . . . . 70 V
Collector-emitter voltage (see Note 1) . . . . . . 30 V
Emitter-collector voltage . . . . . . 7 V
Emitter-base voltage . . . . . . 7 V
Input-diode reverse voltage . . . . . . 3 V
Input-diode continuous forward current . . . . . . 60 mA
Input-diode peak forward current (t_w ≤ 1 ns, PRF ≤ 300 Hz) . . . . . . 3 A
Continuous power dissipation at (or below) 25°C free-air temperature:
Infrared-emitting diode (see Note 2) . . . . . . 200 mW
Phototransistor (see Note 2) . . . . . . 200 mW
Total, infrared-emitting diode plus phototransistor (see Note 3) . . . . . . 250 mW
Operating free-air temperature range, T_A . . . . . . −55°C to 100°C
Storage temperature range, T_{stg} . . . . . . −55°C to 150°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds . . . . . . 260°C

† Stresses beyond those listed under "absolute maximum ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under "recommended operating conditions" is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTES: 1. This value applies when the base-emitter diode is open-circulated.
2. Derate linearly to 100 °C free-air temperature at the rate of 2.67 mW/°C.
3. Derate linearly to 100 °C free-air temperature at the rate of 3.33 mW/°C.

PN Unijunction Transistors

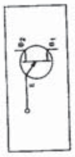
Silicon PN Unijunction Transistors

2N2647

. . . designed for use in pulse and timing circuits, sensing circuits and thyristor trigger circuits. These devices feature:

- Low Peak Point Current — 2 µA (Max)
- Low Emitter Reverse Current — 200 nA (Max)
- Passivated Surface for Reliability and Uniformity

PN UJTs



CASE 22A-01
STYLE 1

*MAXIMUM RATINGS (T_A = 25°C unless otherwise noted.)

Rating	Symbol	Value	Unit
Power Dissipation, Note 1	P_D	300	mW
RMS Emitter Current	$I_{E(RMS)}$	50	mA
Peak Pulse Emitter Current, Note 2	I_E	2	Amps
Emitter Reverse Voltage	V_{B2E}	30	Volts
Interbase Voltage	V_{B2B1}	35	Volts
Operating Junction Temperature Range	T_J	−65 to +125	°C
Storage Temperature Range	T_{stg}	−65 to +150	°C

*Indicates JEDEC Registered Data.

Notes: 1. Derate 3 mW/°C increase in ambient temperature. The total power dissipation (available power to Emitter and Base-Two) must be limited by the external circuitry.
2. Capacitor discharge — 10 µF or less, 30 volts or less.

ıental Device India Limited
O 9002 and IECQ Certified Manufacturer

ISISO 9002
Lic# QSC/L- 000019.2

ìILICON PLANAR TRANSISTORS

CL 100, A, B
CK 100, A, B

TO-39
Metal Can Package

) And CK 100 Are Medium Power Transistors Suitable For Awide Range
dium Voltage And Current Amplifier Applications.

lementary CK100, A, B

LUTE MAXIMUM RATINGS (Ta=25ºC unless specified otherwise)

RIPTION	SYMBOL	VALUE	UNITS
tor -Emitter Voltage	V_{CER}	50	V
tor -Base Voltage	V_{CBO}	60	V
r Base Voltage	V_{EBO}	5	V
tor Current-Continuous	I_{CM}	1	A
Dissipation @ Ta=25ºC	P_D	800	mW
above 25ºC		5.33	mW /°C
levice dissipation @ Tc=25ºC	P_D	3	W
above 25ºC		20	mW /°C
ting And Storage Junction erature Range	T_j, T_{stg}	-55 to +175	°C

TRICAL CHARACTERISTICS (Ta=25ºC unless specified otherwise)

RIPTION	SYMBOL	TEST CONDITION	MIN	TYP	MAX	UNIT
tor Emitter Breakdown Voltage	BV_{CER} *	I_C =10mA, I_B =0	50			V
tor Base Breakdown Voltage	BV_{CBO}	I_C =100µA, I_E =0	60			V
r Base Breakdown Voltage	BV_{EBO}	I_E=100µA, I_C=0	5			V
tor Leakage Current	I_{CBO}	V_{CB}=40V, I_E=0			50	nA
r Leakage Current	I_{EBO}	V_{EB}=4V, I_E=0			1	µA
rrent Gain	h_{FE} *	I_C=150mA,V_{CE}=10V	40		300	
Emitter On Voltage	V_{BE}(on)*	V_{CE}=1V, I_C=150mA,			0.9	V
tor Emitter (Sat) Voltage	V_{CE}(sat)*	I_C=150mA,I_B=15mA			0.6	V

CLASSIFICATION	A	B
HFE	40-120	100-300

: Condition : PW ≤300us, Duty Cycle ≤ 2%