4040410- INDUSTRIAL ELECTRONICS

UNIT I

POWER DEVICES AND TRIGGER CIRCUITS

POWER DEVICES Introduction

Power electronics is one of the important branches of electronics and electrical engineering. It deals with conversion and control of electric energy. Figure 1.1 shows the basic functioning of power electronic system. For example, the input may be AC and the output can be DC. The power electronic system thus performs conversion of electric energy. It also controls the amount of electric energy to be given to the output. **Fig 1.1 Basic inputs / outputs of power electronic systems** Many applications are coming up every day in power electronics. Some of them are

- Speed control of motors.
- Uninterruptible power supplies and stand- by power supplies.(UPS)
- Power control in resistance welding, induction heating, electrolysis, process industry, etc.,
- Power conversion for HVDC and HVAC transmission system.
- High voltage supplies for electrostatic precipitators, and x-ray generators, etc.
- Power supplies for communication systems, telephone exchanges, satellite systems, etc

1.1 IGBT - INSULATED GATE BIPOLAR TRANSISTOR IGBT is the latest device in the field of power electronics. It is made by combining BJT and MOSFET

BJT

MOSFET

BJT has lower ON state losses. Drive requirement of BJT is complicated. MOSFET has high ON state losses Drive requirement of MOSFET is simple.

1.02 The merit of BJT and MOSFET is utilized in forming the new device. i.e the IGBT. The gate circuit of MOSFET and Collector–Emitter circuits of BJT are combined together to form a new device.

Fig 1.2 Symbol of IGBT The IGBT has three terminals: Gate (G), Collector (C) and emitter (E). Current flows from collector to emitter whenever a voltage between gate and emitter is applied. The IGBT is said to be 'on'. When gate emitter voltage is removed, IGBT turns-off. Thus gate has full control over the conduction of IGBT. IGBT is also known as Metal Oxide Insulated Gate Transistor (MOSIGT), Conductively Modulated Field Effect Transistor (COMFET) or Gain Modulated FET (GEMFET). It was also initially called Insulated Gate Transistor (IGT). **Basic structure Fig 1.3 Basic structure of IGBT** Fig 1.3 illustrates the basic structure of an IGBT. It is constructed in the same manner as a power MOSFET. There is, however a major difference in the substrate. The **n+ 1.03** layer substrate at the drain in a power MOSFET is now substituted in the IGBT by a **p+** layer substrate collector. Like a power MOSFET, an IGBT has also thousands of basic structure cells connected appropriately on a single chip of silicon

Working of IGBT

Fig 1.3 (a) IGBT basic structure, with transistor formation (b) IGBT equivalent circuit When gate is positive with respect to emitter and with gate-emitter voltage more than the threshold voltage of IGBT, an n-channel is formed in the p-regions (as in a power MOSFET). This n-channel short circuits the **n-** region with **n+** emitter regions. An electron movement in the n-channel, in turn, causes substantial whole injection from **p+** substrate layer into the epitaxial **n-** layer. Hence, a forward current is established as in figure 1.2. The three layer **p+, n-** and p constitute a pnp transistor with **p+** as emitter, **n-** as base and p as collector. Also **n-**, p and **n+** layers constitute npn transistor as shown in fig 1.3(a). **n-** serves as base for pnp transistor and also as collector for npn transistor. Further, p serves as collector for pnp device and also as base for npn transistor. The two pnp and npn transistors can, therefore, be connected as shown in fig 1.3(b). to give the equivalent circuit of an IGBT.

1.04 IGBT characteristics

Fig. 1.4 (a) IGBT circuit diagram (b) static V I characteristics (c) transfer characteristics Static V-I or output characteristics of an IGBT (n-channel type) show the plot of collector current **IC** versus collector-emitter voltage VCE for various values of the gate emitter voltages. These characteristics are shown in fig 1.4 (b). In the forward direction, the shape of the output characteristics is similar to that of BJT. But here the controlling parameter is gate-emitter voltage VGE because IGBT is a voltage-controlled device. The transfer characteristic of an IGBT is plot of collector current **IC** versus gate-emitter voltage VGE as shown in fig 1.4 (c). This characteristic is identical to that of power MOSFET. When VGE is less than the threshold voltage VGET, IGBT is in the off-state. When the device is off, junction **J2** blocks forward voltage and in case reverse voltage appears across collector and emitter, junction **J1** blocks it.

Merits of IGBT

- Popular in medium and high power applications.
- Voltage controlled device . hence drive circuits is very simple.
- On – state losses are reduced.
- IGBT is free from second break down problem present in BJTs.
- Switching frequencies are higher than thyristors.
- No commutation circuits are required. Small size
- Gates have full control over the operation of IGBT.
- IGBTs have approximately flat temperature coefficient.
- Smaller snubber circuit requirements Highly efficient

Demerits of IGBT

i. IGBTs have static charge problems.
ii. IGBTs are costlier than BJTs and MOSFETs.

1.05 Applications of IGBT

i. AC motor drives, i.e. inverters.
ii. DC to DC power supplies, i.e. choppers.
iii. UPS systems.
iv. Harmonic compensators.

Protection circuits for IGBT IGBT can be protected against,

i. Gate over voltage protection
ii. Over current production
iii. Snubber circuits.

1.2 POWER MOSFET Introduction

A Metal Oxide Semiconductor Field Effect Transistor is a recent device developed by combining the areas of field effect concept MOS technology. A power MOSFET has three terminals called drain, source and gate in place of the corresponding three terminals called collector, emitter and base for BJT. The circuit symbol of power MOSFET is as shown in fig 1.5(a). A BJT is a current controlled device where as a power MOSFET is a voltage controlled device. As its operation depends upon the flow of majority carriers only, MOSFET is a unipolar device. The control device, or base current in BJT is much larger than the control signal (or gate current) required in the MOSFET. This is because of the fact that gate circuit impedance in the MOSFET is extremely high, of the order of the 109 ohm. This large impedance permits the MOSFET gate to be driven directly from microelectronic circuits. BJT suffers from second break down voltage where as MOSFET is free from this problem. Power MOSFETs are now finding increasing applications in low power, high frequency converters. **Types of MOSFET** Power MOSFETs are of two types**;** n-channel enhancement MOSFET and p- channel enhancement MOSFET. Out of these two types, n-channel enhancement MOSFET is more common because of higher mobility of electrons. **1.06 Structure Of Power MOSFET**

n-channel p-channel 1.5 (a)symbol of MOSFET

1.5(b) basic structure of a n-channel power MOSFET

The constructional details of high power MOSFET are illustrated in fig 1.5(b). In this figure shown a planar diffused metal oxide semiconductor (DMOS) structure for n-channel which is quite common for power MOSFETs. On **n+** substrate, high resistivity **n-** layer is epitaxial grown. The thickness of **n-** layer determines the voltage blocking capability of the device. On the other side of **n+** substrate, a metal layer is deposited to form the drain terminal. Now **p-** regions are diffused on the epitaxially grown **n-** layer. Further **n+** regions are diffused in **p-** regions as shown. As before, SiO2 layer is added, which is then etched so as to fit metallic source and gate terminals. A power MOSFET actually consists of a parallel connection of thousands of basic MOSFET cells on the same single chip of silicon.

Working Principle Of Power MOSFET When gate circuit voltage is zero, and VDD is present **n- - p-** junctions are reverse biased and no current flows from drain to source. When gate terminal is made positive with respect to source, an electric field is established and electrons from n-channel in the **p-** regions as shown. So a current from drain to source is established as indicated by arrows. With gate voltage increased, current ID also increases as expected. Length of n-channel can be controlled and therefore on resistance can be made low if short length is used for the channel. Power MOSFET conduction is due to majority carriers, therefore, time delays caused by removal or recombination of minority carriers are eliminated. Thus, power MOSFET can work at switching frequencies in the megahertz range.

1.07 MOSFET Characteristics

The static characteristics of power

MOSFET are now described briefly.
The basic circuit diagram for n-channel power MOSFET is shown in fig 1.6 (a). where voltage and currents are as indicated.

a) Transfer Characteristics

This characteristic curve shows the variation of drain current ID as a function of gate source voltage VGS fig 1.6 (b) shows typical transfer characteristics for n-channel power MOSFET. It is seen that there is these hold voltage VGST below which device is off. The magnitude of VGST is of the order of 2 to 3V. **Fig 1.6 (a) n channel power MOSFET circuit diagram 1.6(b) Typical transfer characteristics Output characteristics Fig 1.6 (c) output characteristics of a power MOSFET**

Power MOSFET output characteristics shown in fig 1.6 (c) indicates the variation of drain current ID as a function of drain-source voltage VGS as a parameter. For low values of VDS, the graph between ID – VDS is almost linear; this indicates a constant value of on-resistance RDS =VDS / ID. For given VGS, if VDS is increased, output characteristics is relatively **1.08**
flat indicating that drain current is nearly constant. A load line intersects the output characteristics at A and B. Here A indicates fully on condition and B fully off state. Power MOSFET operates as a switch either at A or at B just like a BJT. **Merits of MOSFETs**

1. MOSFETs are majority carrier devices.
2. MOSFETs have positive temperature coefficient. Hence their paralleling is easy.
3. MOSFETs have very simple drive

circuits.
4. MOSFETs have short turn-on and turn-off times. Hence they operate at high
Frequencies.
5. MOSFETs do not require commutation circuits.
6. Gate has full control over the operation of MOSFET. **Demerits of MOSFETs**
1. On-state losses in MOSFETs are high.
2. MOSFETs are used only for low power applications.
3. MOSFETs suffer from static charge.
Applications of MOSFET
1. High frequency and low power inverters.
2. High frequency SMPS.
3. High frequency inverters and choppers.
4. Low power AC and DC drives.
1.3 GTO - GATE TURN OFF THYRISTOR A gate turn-off thyristor, a **pnpn** device, can be turned on like an ordinary thyristor a pulse of positive gate current. GTO can be easily turned off by a negative gate pulse of appropriate amplitude. GTOs were developed during the 1960s. **1.09 SYMBOLS**
Working The turn-on conditions for the GTO thyristor are similar to the conventional thyristor, but due to the special structure, the latching current is higher. Once the GTO is turned-on, forward gate current must be continued for the whole conduction period to ensure the device remains in conduction. **Gate turn on** The gate turn-on mechanism of a GTO is similar to that of an SCR. A steep rising positive gate pulse turns-on the GTO.

The anode current rise is slow and takes a total turn-on time TON equal to delay time td and rise time **tr** At least upto 90 percent of rated anode current called latching current, the gate pulse is continued. See turn-on characteristics in fig. 1.7 (b). **Fig 1.7 (b) Turn-on curve** To ensure conduction of all cathode segments and a reduction in the on-state voltage, some manufacturers insist on continuous gate pulse during the entire conduction period. GTOs offer faster turn-on times than conventional thyristors because of narrow emitter width. This makes GTOs suitable for high frequency applications. **1.10 Gate turn-off** When a GTO is conducting, the central region of the GTO crystal is filled with electron-hole pairs. When negative gate current is passed through gate, the excess holes in the P-base are removed. Due to this, the anode current path is reduced to a narrow filament under each cathode segment. These thin filaments of current cannot last longer and collapse. Finally, there is a small but slowly decaying anode current tail due to residual charges in the remote regions of the GTO crystal structure. **Fig 1.7 (c) GTO Turn - off characteristics V I Characteristics of GTO Fig 1.7 (d) V-I characteristics of GTO 1.11 Advantages**

 Higher voltage blocking capability.
 Gate has full control over the operation of GTO.
 Low on-state loss.
 High ratio of peak surge current to average current.
 High on-state gain.
 GTO has faster switching.
 It has more di/dt rating to turn-ON.

- It has lower size and weight.
- It has higher efficiency.
- Low cost.
- Requires less negative gate current to turn it OFF.

Limitations / Disadvantage

- GTO's are suitable for low power applications.
- Very small reverse voltage blocking capability.
- Switching frequencies are very small.
- Magnitude of latching current and holding current are higher.
- ON state voltage drop and the associated loss are more.
- Gate drive circuit losses are more.
- Require high triggering gate current.

Applications

- Induction heating and low power dc drives with fast recovery time.
- High power AC/DC converters.
- Electric traction.
- Voltage source converters.
- Variable speed motor drives.
- Frequency chargers.
- Static breakers.

1.12 1.4 Comparison of Power Devices The power devices can compared on the basic of switching frequency, gate drive circuit, power handling capacity etc. comparison of SCR, BJT, MOSFET and IGBT as shown below.

Sl.
Parameters
SCR
BJT
MOSFET
IGBT
1
Symbol npn pnp n-channel p-channel
2

Triggered i.e. latching or linear
Triggered or latching device
Linear trigger
Linear trigger
Linear trigger
3
Type of carriers in device
Majority carrier device
Bipolar device
Majority carrier device
Majority carrier device
4
control of gate or base
Gate has no control once turned on
Base has full control
Gate has full control
Gate has full control
5
On-state drop
< 2 volts
< 2 volts
4-6 volts
3.3. volts
6
Switching frequency
500 Hz
10 kHZ
upto 100 kHz
20 kHz
7
Gate drive
Current
Current
Voltage
Voltage
8
Snubber
Un polarized
Polarized
Not essential
Not essential
9
Temperature co-efficient

Negative
Negative
Positive
Approximately flat, but positive at high current
10
Voltage and current ratings
10 kV/4 kA
2 kV/1 kA
1kV/50 A
1.5 kV/400 A
1.13
11
Voltage blocking capability
Symmetric and asymmetric (both)
Asymmetric
Asymmetric
Asymmetric
12
Applications
AC to DC converters. AC voltage controllers, electronic circuit breakers
DC to AC converters, induction motor drives, UPS SMPS, Choppers
DC choppers, low power UPS, SMPS, Brushless DC motor drives
DC to AC converters, AC motor drives, UPS, Choppers, SMPS etc.

1.5 TRIGGER CIRCUITS

Triggering of SCR The SCR can be triggered (turned ON) by any one of the following methods.

- Increasing forward voltage beyond breakdown voltage VBO
- applying a positive voltage to gate with respect to cathode (gate control method) – gate triggering.
- dv/dt triggering .
- Focusing light beam on the junction
- Exceeding internal device temp.

The gate control method is more efficient, reliable and easy to control AC and DC power in loads. This is the most common method of triggering.

1.5.1 Requirements for Gate Triggering Circuits To turn on the SCR, the following conditions must be satisfied

- The SCR should be forward biased.
- Gate should be made positive with respect to cathode.
- The load impedance should not be too high so that if the SCR is turned on, the current in the SCR should reach more than the latching in the SCR should reach more than latching current.
- The applied gate signal should not reverse bias the SCR.

1.14 1.5.2 Gate Triggering methods A signal is applied between the gate and the cathode of the device. Three types of signals can be used for this purpose. They are either dc signals, ac signals or pulse signals. Based on the above, the trigger circuits can be classified as

1. DC gate Triggering 2. AC Gate Triggering 3. Pulse gate Triggering.

1. DC Gate triggering: - In this method, SCR is turned ON by applying a proper magnitude of DC voltage between gate and cathode. **Advantages**

- It is the simplest method of triggering the SCR.
- Well suited for control of large inductive loads.

Disadvantages

- There is no electrical isolation between the power circuit and gate circuit
- The gate power loss is high due to presence of gate signal for entire conduction period.

2. AC Gate Triggering

In most of the application, an ac voltage can be used as the gate signal. By using this method, the firing angle control is obtained by changing the phase angle of the gate signal. However, the gate supply is maintained for one half cycle after the devices is turned ON and a reverse voltage is applied between the gate and the cathode during negative half cycle. There are two types of circuits generally employed for AC triggering. They are 1. Resistance Triggering (or) Firing Circuit 2. Resistance – Capacitance triggering circuit **3. Pulsed Gate Triggering: -** This is the most popular method for triggering the SCR. In this method, the gate circuit can produce a single pulse appearing periodically or a sequence of high frequency pulses. This is known as carrier frequency gating. A pulse transformer is used for isolation. **1.15 Types** 1. Single pulse triggering 2. Pulse train triggering. In single pulse triggering, a single pulse of moderate duration is used. The duration is shorter for resistive loads and broader for inductive loads. Sometimes due to the inductive nature of loads and due to the presence of aback emf in case of motors, single pulse may not be successful in triggering the SCR. In that case two successive pulses may be used.

Advantages

- Requires a smaller size pulse transformer.
- Trigger circuit is simple.

Disadvantages

- Only suitable for resistive loads
- One pulse is not sufficient for inductive loads.
- Get loss is more.

(b) Pulse train triggering In this method, a number of short duration

pulses of equal magnitude and duration are used. These pulses are applied to gate cathode circuit to trigger a forward biased SCR. Once the SCR conducts current there is no need for any pulse at gate until the end of the conduction in the particular half cycle. **Advantages of pulse train triggering** Low gate dissipation at higher gate current. Small gate isolating pulse transformer Low dissipation in reverse biased condition is possible. So simple trigger circuits
are possible in some cases. When the first trigger pulse fails to trigger the SCR, the following pulses can succeed in latching SCR. This is important while triggering inductive circuits and circuits having back emfs. **1.16 1.5.3 PULSE TRANSFORMER IN TRIGGER CIRCUITS** The pulse transformers have one primary winding and can have one or more secondary windings. The turn ratio is either 1: 1 or 1:1:1 or 2:1:1. These transformers are designed to have low winding resistance, low leakage reactance and low inter-winding capacitance.
A square pulse at the primary terminals of a pulse transformer may be transmitted at secondary terminals faithfully as a square wave or it may be transmitted as a derivative the input waveform. The series resistor R reduces the SCR holding current. The function of the diode is to allow the flow of current after the pulse period (i.e when the transformer is
off) so that energy stored in the primary pulse transformer is dissipated. The transistor is acting simply as a switch, turning on when the pulse applied its base is at its high level, there by

connecting the dc bias VB to the transformer primary. The general layout of the trigger using a pulse transformer is shown in Fig 1.8 . The function of the diode is to allow the flow of current after the pulse period (that is when the transistor is off) so that the energy stored in the primary of pulse transformer is dissipated. In the fig 1.8 (a) the transistor is acting simply as a switch, turning on when the pulse apply to its base is at its high level, there by connecting the dc bias VB to the transformer primary. **Fig. 1.8 Pulse transformer trigger circuit Merits**

1. It provides an electrical isolation between low voltage gate cathode circuit and the high voltage anode cathode circuit

2. The triggering of two or more devices from the same trigger source.

3. The gate loss is minimized since the duration of the output pulse is small.

4. Pulse transformer does not need external power for its operation

5. It is very simple to use

1.17 Demerits

1. Pulse transformer saturates at low frequencies. Hence it can be used only for high
frequencies.

2. Due to magnetic coupling, the signal is distorted.

1.5.4 ISOLATION OF GATE AND BASE DRIVES Necessity Of Isolation

Generally driver circuits operate at very low power levels. The signal levels are 3 to 12 V. Sometimes digital circuits and microprocessors are also used in the triggering
circuits. The gate and base drives are connected to power devices which

operate at high power levels. This will damage the trigger circuits. Therefore there must be some electric isolation between control and power circuit.

Isolation using op-to couplers In SCR, the electrical isolation between gate control circuit and anode to cathode (Power) circuit is obtained by using opt couplers or opto isolators. These devices use light energy to couple the control signal to the gate of the SCR. An opto isolator consists of light source and light sensitive device. The light source may be an LED or IR LED (infra Red a Emitting Diode) and another light sensor may be a photo diode, photo transistor, photo thyristor, LASCR etc. Optocoupler consists of a pair of infrared LED and phototransistor fig 1.9 (a) shows the symbol of optocoupler. **Fig. 1.9 (a) Symbol of Opto-coupler 1.18 Fig1..9 (b) Triggering circuit using opto coupler**

`T1 turns-on. Therefore the voltage VCC is applied to gate of the MOSFET. Hence MOSFET turns-on. When Vg=0, the LED turns-off, therefore phototransistor also turn-off. Therefore base drive of T1 goes to VCC and it turn-off. When T1 turns off, MOSFET gate voltage becomes zero. Therefore MOSFET turns-off. Thus gate drive circuit using optocoupler works **Advantages**

 Very good response at low frequencies

 Compact and cheaper optocoupler devices are available

Disadvantages

 Optocoupler need, external biasing voltage for their operation

 High frequency response is poor

Applications

- Inverters, SMPS, Choppers, AC motor drives use opto couplers. **Fig 1.9(c) opto couplers 1.19** Some of the available op-to couplers are shown in the fig 1.9 (c). in each case, the devices inside the dotted lines are integrated into a single light tight package with input terminals of a and b, and output terminals of x and y, accessible to the user. The input circuit is simply an IRED which emits IR radiation when it is sufficiently forward biased. This radiation is focused on a light sensitive device so that it switches 'ON' whenever sufficient current flows through the IRED. An op-to coupler used to isolate the low power control circuitry from a high power load. **1.5.5 FEATURES OF FIRING CIRCUITS**

The triggering circuits are called firing circuits. The following features or requirements must be fulfilled by the firing circuit.

Fig 1.10.(a) Main blocks of firing circuit

- The firing circuit should produce the triggering pulses for every thyristor at appropriate instants.
- The triggering pulses generated by the control need to be amplified and passed
through the isolation circuit. The firing circuit operates at low voltage levels (5 to
20 Volts). And the thyristor operates at high voltage levels (greater than 250 volts).
Hence there must be electrical isolation between firing circuit and thyristor.
This isolation is provided by the pulse transformer or optocouplers

1.5.5.3 R-FIRING CIRCUIT

A simple method of varying the trigger angle (firing angle) and thereby controlling power control is shown in fig1.10 (b). The gate does not receive any pulse from outside; it gets the gate current from the a.c source itself. A resistor Rmin, a potentiometer RV and a diode D are used in the circuit to provide the necessary gate current for turning on the SCR. **1.20 Fig 1.10 (b) R firing circuit diagram Fig 1.10 (c) waveform**

The operation of the circuit is briefed in the steps below

1. As supply volts eS positive (anode positive) SCR is forward biased. Triggering does not place until gate current touches Ig (min).
2. The positive supply voltage forward biases the diode D also. Gate current starts rising.
3. As eS rises, gate current IG also rises. When gate current is equal to Ig (min) the SCR turns-on and load voltage eL becomes approximately equal to supply volts eS and follows the wave.
4. SCR continues in on state until es reduces to a point where load current is less than holding current. This can be safely assumed to happen when eS = 0.
5. SCR turns off during es = 0 and during supply voltage negative.

The purpose of the diode in gate circuit is to prevent the gate cathode reverse bias from exceeding peak reverse gate voltage during negative half cycle of supply. The diode is chosen with a peak reverse voltage higher than the maximum value of supply volts so that at any point of reverse volts diode does not get forward biased. **1.21**

1.5.5.4 RC FIRING CIRCUIT AND WAVE FORM Fig 1.10 (d) RC firing circuit diagram

Fig1.10 (e) RC half wave firing circuit with high R- value Figure 1.10 (d) shows the circuit diagram of RC – Firing Circuit. In the negative half cycle, the capacitor charges through diode D2 to negative supply voltage. The capacitor charges to – Vm (i.e negative peak) of the supply. This is shown in waveforms of figure. 1.10(e) Firing angle can be varied from 0 to 180 degrees. In the negative half-cycle, the capacitor C charges to a peak potential Emax with bottom plate positive. This state continues until supply voltage reaches zero and starts positive. As supply voltage makes the thyristor anode positive, the capacitor negative voltage drops and tents towards positive value. When the capacitor voltage just reaches the gate trigger voltage Vgt (= Vg(min) +VD1), the SCR is triggered into conduction. After this, the capacitor is held at some positive potential until it equals the supply voltage. During negative half-cycle, diode D1 prevents the breakdown of the gate-cathode junction. Diode D2 helps capacitor to get charged to negative peak supply voltage (as said initially). **1.22**

1.6 Synchronized UJT triggering (or Ramp triggering)

Fig. 1.11 (a) UJT Triggering Circuit

A synchronized UJT trigger circuit using an UJT is shown in Fig 1.11 (a). Diodes D1 – D4 rectify ac to dc. Resistor R1 lowers Vdc to a suitable value for the zener diode and UJT.

Zener diode Z functions to clip the rectified voltage to a standard level Vz, which remains constant except near the Vdc zero, Fig. 1.11 (a). This voltage Vz is applied to the charging circuit RC. Current i1 charges capacitor C at a rate determined by R. voltage across capacitor is markded by vc in Figs. 1.11 (a) and 1.11 (b). When voltage vc reaches the uni junction threshold voltage ηVz, the E – B1 junction of UJT breaks down and the capacitor C discharges through primary of pulse transformer sending a current i2 as shown Fig 1.11 (a). **1.11 (b) Generation of output waveforms of UJR triggering circuit** As the current i2 is in the form of pulse, windings of the transformer have pulse voltages at their secondary terminals. Pulses at the two secondary windings feed the same in-phase pulse to two SCSRs **1.23** of a full wave circuit. SCR with positive anode voltage would turn on. As soon as the capacitor discharges, it starts to recharge as shown. Rate of rise of capacitor voltage can be controlled by varying R. the firing angle can be controlled up to about 150˚. This method of controlling the output power by varying charging resistor R is called ramp control, open – loop control or manual control. As the zener diode voltage Vz goes to zero at the end of each half cycle, synchronization of the trigger circuit with the supply voltage across SCRs is achieved. Thus the time t, equal to α / ω. **Review questions Part A**

1. Define the term Power electronics.
2. Define the term IGBT.
3. Draw the symbol of IGBT and MOSFET

4. Give an applications of MOSFET.
5. What are the types of trigger circuits?
6. Give advantages of pulse trigger circuit.
7. What are the requirements of pulse trigger circuit.
8. What is the necessity of isolation circuit.
9. Give advantages and disadvantages of opto coupler
10. Give applications of opto coupler.

Part – B

1. Give applications of power electronics.
2. Write short notes on MOSFET.
3. Explain the VI characteristics of MOSFET.
4. Explain the merits and demerits of MOSFET.
5. Explain DC gate triggering.
6. Explain AC gate triggering.
7. Explain Pulse gate triggering.
8. How to turn on firing circuits?
9. Explain the features of firing circuits.

Part –C

1. Explain the working principle of IGBT.
2. Compare power devices.
3. Explain the pulse transformer triggering circuit.
4. Explain the working principle of optocoupler.
5. Draw and explain R- firing circuit.
6. Draw and explain RC- firing circuit.
7. Draw and explain UJT firing circuit.

2.01 UNIT – II CONVERTERS AND CHOPPERS CONVERTERS INTRODUCTION AC to DC using diodes – converter or rectifier - Fixed output voltage. AC to DC using SCRs – controlled converter.

- Variable output voltage

- Possible by varying the firing angle α
- It known as phase control

Types of (phase controlled) converters

Semi converter = 1Φ half controlled bridge converter 3 configurations – 1. Common cathode - popular – symmetrical 2. Common anode – symmetrical 3. SCRs in the same arm - Asymmetrical configuration. An SCR can be triggered on at any angle 'α' (firing angle) with respect to the applied voltage, and it is known as 'phase control'. Using SCRs in various configurations, one can build half-controlled bridge rectifiers or converters, fully controlled converters in both single phase and three phase operation. The loads can be purely resistive load or inductive. **2.02 2.1 CONVERTERS (controlled Rectifier) Definition Fig.2.1 Principle of operation of a controlled rectifier**

 Controlled rectifiers are basically AC to DC converters. The power transferred to the load is controlled by controlling triggering angle of the devices. Figure shows this operation.

 The triggering angle 'α' of the devices is controlled by the control circuit. The input to the controlled rectifier is normally AC mains. The output of the controlled rectifier is adjustable DC voltage. Hence the power transferred across the load is regulated.

 The controlled rectifier is used in battery chargers, DC drives, DC power supplies etc.

2.1.1 Types of (Power Electronic) converters The power electronic circuits are classified into five broad categories depending upon the input, output and the function they perform.

1. AC to DC converters

- Fig. 2.2 shows the inputs and outputs of AC to DC converters. The input is single phase or three phase AC supply normally available from, the mains. The output is the controlled DC voltage and current.

Fig.2.2 AC to DC converters 2.03

- The AC to DC converters includes diode rectifiers as well as controlled rectifiers. The controlled rectifiers mainly use SCRs. SCRs turned off by natural commutation. Hence external commutation are not required. Hence AC to DC converters are also called as line (supply) commutated converters.
- These converters are used for DC drives, UPS and HVDC system.

2. DC to AC converters (Inverters)

- Fig. 2.3 shows the inputs and outputs of DC to AC converters. These converters are commonly called inverters. The input to the inverters is fixed DC voltage. Normally this DC voltage is obtained from the batteries. The output of the inverter is the fixed or variable frequency AC voltage. The AC voltage magnitude is also variable.

Fig.2.3 DC to AC converters

- Inverters are mainly used whenever mains is not available. For example UPS use inverters inside to generate AC output from batteries. Inverters are also used for speed control of induction motors. The voltage, frequency or both are varied by inverter to control the speed of induction motors. Inverters are also used in standby and emergency power supplies.

3. DC to Dc converters (choppers)

- Fig.2.4 shows the inputs and outputs of DC to DC converters or choppers.

The choppers take input from fixed voltage DC supply such as battery or output of uncontrolled rectifier. The output of the chopper is fixed or variable DC voltage.

Fig.2.4 Inputs and outputs of the DC to DC converter or chopper

- The choppers are normally used in DC drives. The speed of the motor can be controlled in forward and reverse directions. The choppers are also used in switched mode power supplies (SMPS).

2.04

4. AC to AC converters (Cyclo converters)

Fig.2.5 shows the inputs and outputs of cyclo converters. The input to the cyclo converters is normally 1Φ or 3Φ AC mains supply. It is fixed voltage and fixed frequency. The cyclo converters provide the output which has variable voltage and variable frequency. The output frequency is lower than the input frequency. **Fig.2.5 inputs and outputs of cyclo converters**

- The cyclo converters are used mainly for AC traction drives.

5. AC Regulators

- Fig.2.6 shows the inputs and outputs of AC regulator. The input to the AC regulator is fixed voltage AC mains. The output is variable AC voltage which is suitable for load. Here note the output frequency is same as input frequency. Thus Ac regulators does not change the frequency. Whereas cyclo converters change the frequency also. This is the difference between AC regulators and cyclo converters. **Fig.2.6 inputs and outputs of Ac regulators** The Ac regulators are used for the speed control of large fans and pumps.

2.2 SINGLE PHASE HALF CONTROLLED BRIDGE CONVERTER WITH RESISTIVE LOAD

The working of a HC bridge is explained with a common cathode configuration with a transformer in supply side. Input is 230V, 50 Hz AC. Output is DC (across RL). **2.05 Figure 2.7 Circuit Diagram of 1Φ half controlled bridge converter** When supply end A is positive, thyristor T1 is triggered into conduction. Load current flows through thyristor T1, load resistor RL diode D2 and back to supply. During other half cycle, supply end B becomes positive. Now SCR T2 is fired. T2 along with diode D1 conduct the load current in the same direction as before to supply d.c power to the load. Each set conducts for a period from ‘α’ degrees to 180 degrees (π radian). **Figure 2.8 Wave form of 1Φ half controlled bridge converter** Here the output voltage is given by When firing angle is increased, the d.c output voltage is lower and vice-versa.

2.2.1 Single phase Half-controlled bridge rectifier with inductive R-L load

common cathode arrangement of two SCRs and two diodes is used. The load is a combination of resistance (R) and inductance (L). **2.06 Figure 2.9 Circuit Diagram of 1Φ half controlled bridge converter** When supply end ’A’ is positive, the SCR T1 is triggered into conduction. Current flows through thyristor T1, load impedance R and L, diode D2 and back to supply. During the other half cycle, supply end B becomes positive. Hence thyristor T2 is fired. Current flows through thyristor T2, load, diodeD1, and returns to supply. The average D.C voltage Edc is given by a relation.

Figure 2.10 Circuit Diagram of 1Φ half controlled bridge converter

Single firing angle ‘α’ can be varied, the average d.c. output also varies. The circuit works as a controlled rectifier. Unlink the pure resistive load circuit, here the load current does not stop when voltage becomes zero. The current is maintained in the load by the inductance of the load. The thyristor that has been conducting say, thyristor T1 – continues to conduct, but current transfers from diode D2 to diode D1, so that the inductive back emf of the load drives current through the bridge. The load current decays or reduces exponentially. When the next thyristor T2 is fired, thyristor. T1 is reverse biased by the **2.07** supply voltage and turns off. Now current flows from supply through thyristor T2 and diode D1 into the load and extends upto some degrees in the next half cycle and so on. The load current can be controlled by adjusting the firing angle ‘α’ and in most cause the circuit operates satisfactorily. When the trigger pulses are not applies properly or when trigger pulses are removed immediately after firing, the conducting SCR will continue to conduct in the next half cycle also. It will refuse to be turn off. This is a situation where the trigger circuit loses its control over the load. This drawback is overcome in most causes by providing a flywheel across the load. The flywheel or freewheel diode helps in bypassing the load current when the conducting SCR has to stop; the act of stopping a conducting SCR when it is due; and allowing another SCR to take over conduction is called communication. A free wheel diode is shunted across an inductive load to ensure successful communication. **2.3 IMPORTANCE / EFFECT OF FREEWHEEL DIODE** This diode is variously described as a commutating diode, flywheel diode or by-pass diode. This diode is commonly described as a commutating diode as its function is to commutate or transfer load current away from the rectifier whenever the load-voltage goes into a reverse state.

This diode serves two main functions

1. It prevents reversal of load voltage expect for small diode voltage-drop.
2. It transfer the load current away from the main rectifier, thereby allowing all of its thyrisitors to regain their blocking states.

Figure 2.11 Position of Commutating Diode DF Figure 2.12 shows a half-wave controlled rectifier with a freewheel diode DF connected across R-L load. The load-voltage and current waveforms are also shown in fig.2.13With diode Df, thyristor will not be able to contact beyond 1800.

2.08 Figure 2.12 Half wave rectifier with a free wheeling Diode During the positive half-cycle, voltage is inducted in the inductance. Now, this induced voltage in inductance will change its polarity as the di/dt changes its sign and diode **Df** will start conducting as soon as the induced voltage is of sufficient magnitude, thereby enabling the inductance to discharge its stored energy into the resistance.

Hence, after 1800 , the load current will freewheel through the diode and a reverse-voltage will appear across the thyristor. The power flow from the input takes place only when the thyristor is conducting. If there is no freewheeling diode, during the negative portion of the supply voltage, thyristors returns the energy stored in the load inductance to the supply line. With diode Df, the freewheeling action takes place and no power will be returned to the source. Hence the ratio of the reactive power flow from the input to the total power consumed in the load is less for the phase-control circuit with a freewheeling diode. i.e The freewheeling diode improves the input power-factor. **Figure 2.13 Wave form of Half wave rectifier with a free wheeling Diode** Hence the freewheeling diode helps in the improvement of power-factor of the system. **2.09 2.4 SINGLE – PHASE FULLY CONTROLLED BRIDGE CONVERTER WITH RESISTIVE LOAD** When a bridge type converter is built with 4 – thyristors to take care of phase control during positive and negative half – cycles, it becomes a 'Fully – controlled bridge'. The behavior of such a FC bridge with a resistive load is explained. **Figure 2.14 Single – phase Fully controlled bridge converter with resistive Load** Four thyristor T1 to T4 are connected in the bridge configuration as shown. A.C. input points A and B may be connected to a transformer secondary according to voltage requirements and PIV rating of the thyristors. When supply end 'A' is positive, thyristors T1 and T4 are fired simultaneously. Current flows through T2, load resistor

RL, thyristor T4 and back to supply lead B. in the reverse half – cycle supply end B is positive. Now thyristor T2 and T3 are triggered simultaneously. This action applies forward volts to T2 and T3 which readily conduct. At the same reverse voltage is applied to the first set thyristor T1 and T4 which are hence commutated or turned-off. With pure resistance as load, the load voltage truly follows the supply volts from the moment of triggering. Load power factor being unity, the load current also follows the shape of the load voltage. When the thyristors undergo commutation, the load current also stops without any extension of time. The average d.c. output voltage is a function of firing angle α and the characteristics for this FC bridge are identical with that of half – controlled bridge. In the wave forms drawn below for FC bridge, a discontinuous operation is seen from the time of one conducting SCR turns-off and the next SCR is trigger after α degrees in the next half-cycle. **2.10 Figure 2.15 Wave form of Single – phase Fully controlled bridge converter with resistive Load** As firing angle ‘α’ is increased, the load d.c. voltage is lowered. **2.5 FULLY – CONTROLLED BRIDGE WITH INDUCTIVE (R – L) LOAD** A single phase fully controlled bridge rectifier can be built using four thyristors T1 to T4 as shown figure 2.16. The load is assumed to be partly inductive. **Figure 2.16 Fully – controlled Bridge with inductive (R – L) Load** When supply terminal A is positive, thyristors 1 and 4 are triggered at one and the same time. Current flows through thyristor T1, load impedance, thyristor T4 and back to source at B. in the reverse half-cycle thyristors T2 and T3 are fired simultaneously for conduction while thyristors T1 and T4 are turned – off due to reverse bias voltage across them. The load receives d.c. power With load being highly inductive, current does not become zero when load voltage eL reaches zero. But it extends till the next pair of SCRs are triggered into conduction. In this case the current is continuous. When the load is only slightly inductive, the current stops offer extending to a small degree and there is no current through the load for a few degrees **2.11** until the next pair of thyristors are fired. This gives discontinuous current operation. With continuous current, the load voltage is given by the equation.

Figure 2.17 Wave form of Fully – controlled Bridge with inductive (R – L) Load

When load voltage extends to negative half cycle, it means negative power delivery to load or pumping of a small energy back to supply lines. This process is known as regeneration. From the above equation for average d.c. output voltage it is clear that when firing angle α is more than 90 degrees, the output d.c. voltage is negative and the average power involved will flow from load to supply lines. The unit is said to work as inversion (d.c. to a.c. conversion) to take place, a d.c. supply equal to average rectifier output shall be reverse connected in place of load.

2.6 COMMUTATION Definition

Commutation is the process of turning

OFF SCR. Commutation requirements

1. Current through SCR is reduced below the holding current.
2. The voltage across the SCR is reversed.

2.12 Types of commutation techniques Natural Commutation/ line commutation Figure 2.18 Circuit diagram of Natural commutation

Figure2.18 shows the circuit using natural commutation. It is basically half wave rectifier. The mains AC supply is applied to the input. The SCR is triggered in the positive half cycle at α. Since the SCR is forward biased, it starts conducting and load current *io* starts flowing. Since the load is resistive

$$io = \frac{vo}{R}$$

The natural commutation does not need any external components. It uses supply (mains) voltage for turning off the SCR. Hence it is also called as line commutation. It is also called as class F commutation. **2.13**

2.6.1 Forced Commutation Figure 2.19 Circuit diagram of forced Commutation Forced commutation is used when the supply is DC. A commutation circuit is connected across the SCR as shown in figure 2.19. The commutation circuit is normally LC circuit. The LC circuit stores energy when the SCR is on. This energy is used to turn – off the SCR. The LC circuit imposes reverse bias across the SCR due to stored energy. Hence forward current of SCR is dropped below holding current and the SCR turns – off. There are different types of forced commutation circuits depending upon the way they are connected. **2.6.2 Classification of Forced Commutation**

Class A

Self Commutation by resonating load and I.C. circuit

Class B

Auxiliary current commutation (resonant pulse commutation)

Class C

Complementary commutation

Class D

Auxiliary voltage commutation (impulse commutation)

Class E

External pulse commutation

2.7 CHOPPER Definition The DC choppers convert the input DC voltage into fixed or variable DC output. Hence DC chopper is also called as DC to DC converter. **Fig 2.20 Basic block diagram of the chopper. 2.14** The chopper as fixed or variable DC input, Vs and the output V0 is also fixed or variable. The output V0 can be greater or less than the input. Hence the choppers can be step down or step up type. The dc choppers use switching principle. Hence they have high efficiency. The choppers are also used in dc voltage regulators for high efficiency. **2.7.1 Principle of DC chopper** A chopper is a thyristor, high speed ON/OFF semiconductor switch. **Fig.2.20 (a) Circuit Diagram of DC chopper** The above figure 2.20(a) illustrates the principle of a chopper. The chopper is represented by an SCR inside a dotted square. It is triggered periodically and is kept conducting for a period Ton and is blocked for a period of T off. The chopped load voltage waveform is shown in figure

2.21. During the period Ton, when the chopper is on, the supply terminals are connected to the load, terminals. During the interval T off when the chopper is off, load current flows through the freewheeling diode DF. As a result, load terminals are short circuited by DF, and load voltage is therefore, zero during Toff. In this way, a chopped dc voltage is produced at the load terminals.

Fig.2.21 Output voltage and current waveforms of DC chopper 2.15

The average load-voltage Eo is given by where

= on time of the chopper

= off-time of the chopper

T

= Ton + T off.= chopping period

If □□= Ton / T be the duty cycle, then above equation becomes, E0 = Edc.□ Thus, the load voltage can be controlled by varying the duty cycle of the chopper. **2.8 JONES CHOPPER (Typical chopper circuit) Figure 2.22 Circuit diagram of Jones Chopper**

□ The Jones chopper circuit is another example of Class D commutation. In this circuit SCR T1 is the main thyristor, where SCR T2 capacitor C, D1 and autotransformer (T) forms the commutating circuit for the main thyristor T1.

□ The special feature of this circuit is the tapped autotransformer T through a portion of which the load current flows. Here L1 and L2 are closely coupled so that the capacitor always gets sufficient energy to turn off the main SCR T1.

□ If the main thyristor T1 is on for a long period, then the motor will reach the maximum steady-state speed determined by the battery voltage, the motor and the mechanical load characteristics.

- If thyristor T1 is off, the motor will not rotate. Now, if thyristor T1 is alternatively on and off in a cyclic manner, the motor will rotate at some speed between maximum and zero.

2.16

- Let us assume that initially capacitor C is charge to a voltage Edc with polarity as shown in figure. SCR T1 is triggered at time t=t1, current flows through the path CA-T1-L2-D1-CB and capacitor C charges to opposite polarity, i.e. plate B positive and plate A negative. However diode D1 prevents further oscillation of the resonating L2 C circuit. Hence capacitor C retains its charge until SCR T2 is triggered.
- Now SCR T2 is triggered. Current flow through the path CB-T2-T1-CA. Therefore, discharge of capacitor C reverse-biases SCR T1 and turns it off. The capacitor again charges up with plate A positive and SCR T2 turn off because the current through it falls below the holding current value when capacitor C is recharged. This cycle repeats when SCR T1 is again triggered.

Advantages

- Reliable turn-off of main SCR due to auto transformer.
- The auto transformer becomes the part of load. This provides filtering action.

Disadvantages

- Bulky autotransformer is required. Hence losses are increased.
- Higher operating frequencies are limited due to autotransformer.

Applications of DC Choppers

Choppers are used in the following applications

- DC motor drives when the DC supply is available.
- Battery operated vehicles, Switched mode power supplies.
- Battery charges where uncontrolled rectifier give DC to choppers.
- Traction drives use four quadrant choppers for energy saving.
- Lighting and lamp controls also prefer choppers.

2.9 PRINCIPLE OF WORKING OF 1Φ AC CHOPPERS The AC voltage magnitude can be changed by two methods. The well known first method is by means of step-up and step-down transformer. The second method of changing magnitude of an ac voltage is by means of a solid state switch. In this method, the ac input voltage is switched on and off periodically by **2.17** means of a suitable switch. Voltage changing circuits employing semiconductor devices as a static switch are known as ac choppers.

Fig.2.23 Circuit diagram of 1Φ AC chopper Figure 2.23 shows the commonly used single-phase ac chopper circuit. In this circuit SCR T1 and T2 are the main SCR whereas SCR T3 and T4 are the auxiliary SCRs. C1 and C2 are the commutating capacitors. Diodes D1 and D2 provide the charging path for the capacitors. Thyristors T1 and T3 forms the first pair for producing the positive alternation and T2 and T4 constitute the second pair for producing the negative alternation of the input ac voltage.

Fig.2.24 Waveform of 1Φ ac/chopper Figure 2.24 shows the load voltage waveforms. For the sake of simplicity, circuit operation is described in various operating modes. **2.18**

i. Mode 0 operation: Initially, during the positive half-cycle of the supply voltage, capacitor C2 charges through the path L-C2-D2-R2-M, with polarity shown in figure. Similarity, during the negative half-cycle of the supply voltage, capacitor C1 charges through the path M-R1-D1-C1-L, with the polarity shown in figure. The voltage across these capacitors is used for commutation of main SCRs T1 and T2.

ii. Mode I operation: As shown in figure during the first positive half-cycle of the supply voltage, thyristor T1 is triggered at instance t1 with a firing angle α. The current flows through the path L-SCR T1–Load-M. When the instantaneous voltage reaches the instant T2, auxiliary thyristor T3 is triggered. As soon as thyristor T3 is triggered, capacitor C1 will start discharging through the path CB-T3-T1-CA. When the discharging current of capacitor C1 becomes more than the forward-current of the SCR T1. SCR T1 becomes turned-off. The auxiliary SCR T3 will be automatically turned off at instant t3 because of the zero current at this instant. Hence, SCRs T1 and T3 form the first pair for producing the positive alternation of the input ac voltage.

iii. Mode II operation: For the formation of the negative alternation, second pair of thyristor T2 and T4 are used. The main SCR T2 is triggered at the instant t4 as shown in figure, during the first negative half-cycle of the input voltage. The current flows through the path M-Load-T2-L. When the instantaneous voltage reaches the instant t5, SCR T4 is triggered. As soon as thyristor T4 is triggered, capacitor C2 will starts discharging through the path Cc-T2-T4(A-K)-CD. When this discharging current is more than the load current, SCR T2 becomes turned off. At instant t6, SCR T4 automatically turned off as the current passing through it becomes zero. Again at instant t7, SCR T1 is triggered to produce the next positive alternation. This is a continuous process and repeated again and again to generate an ac voltage across the load.

2.10 MOSFET BASED CHOPPER (Chopper using MOSFET)

The circuit diagram of chopper using MOSFET as shown in the figure 2.25. The circuit converts an input DC voltage to an output DC votage, that is either high or low voltage. The input DC voltge (+Vin) is chopped by a switching circuit. **Fig.2.25 Circuit of chopper using MOSFET 2.19** The circuit diagram of chopper using MOSFET is shown in figure 2. . It converts a fixed input DC voltage to a fixed or variable DC voltage. The input DC voltage (+Vin) is chopped by a switching circuit. The gate signal is a positive going square wave signal with a voltage ranging from 0V to VGS (ON) voltage. The signal alternatively cut-offs and saturates the power MOSFET. Whenever MOSFET switches ON, the input signal Vin is developed across the transformer with the peak voltage of +Vin. By this effect, a square wave signal is developed across the secondary of the transformer. The diode D and the capacitor as filter produce the DC output voltage Vout. By using different turn ratios, we can get a DC output voltage which is lower or higher than the input voltage Vin. For lower ripple, a full wave or bridge rectifier can be used. **Review questions Part -A**

1. Define the term converter.
2. What you mean by commutation? Give their types.
3. Classify the types of forced commutation.
4. Define the term chopper.
5. Give advantages and disadvantages of Jones chopper.

Part –B

1. Give importance of freewheeling diode.
2. Explain natural and forced commutation.
3. Explain the working principle of chopper.
4. Give applications of Jones chopper.
5. Explain MOSFETR based chopper.

Part – C

1. Draw and explain single phase half controlled bridge converter with R load.
2. Draw and explain single phase half controlled bridge converter with RL load.
3. Draw and explain single phase fully controlled bridge converter with R load.
4. Draw and explain single phase fully controlled bridge converter with RL load.
5. Explain with neat diagram of Jones chopper.
6. Explain with neat diagram of AC chopper.

2.20 ANNEXURE FOR UNIT- II 1. **Comparison of half controlled and full controlled bridge rectifiers** Now let us compare the half controlled and fully controlled bridge rectifiers.

S.No.

Half controlled converter

Fully controlled converter

1.

This consists of half number of SCRs and half number of diodes.

This consists of all the SCRs as controlled devices.

2.

This operates in only one quadrant.

This can operate in two quadrants.

3.

Output voltage is always positive.

Output voltage can be negative in case of inductive loads.

4.

Inherent freewheeling action is present.

External freewheeling diode is to be connected for freewheeling.

5.

Power factor is better.

Power factor is poor than that half converter.

6.

Inversion is not possible.

Inversion is possible.

7.

Used for battery charges, lighting and heater control.

Used for DC motor devices

2. Power semiconductor devices: The power semiconductor devices are used as on / off switches in power control circuit. These devices are classified as follows :

Diodes Thyristors Transistors

1. General purpose 1. SCRs 1. BJT
2. High speed 2. GTO 2. MOSFET
3. Schottky 3. RCT 3. IGBT
4. SITH 4. SIT 5. GATT 6. LASCR 7. MCT 8. TRIAC **2.21** In this chapter we will briefly study the characteristics,

power rating and operating frequencies of these devices. **3. Natural commutation Vs forced commutation**

S.No.	Natural commutation	Forced commutation
1.	No external commutation components are required.	External commutation components are required.
2.	Requires AC voltage at the input.	Works on DC voltage at the input.
3.	Used in controlled rectifiers, AC voltage controllers etc.	Used in choppers, inverters etc.
4.	No power loss takes place during commutation.	Power loss takes place in commutating components.
5.	SCR turns off due to negative supply voltage.	SCR can be turned-off due to voltage and current both.
6.	Cost of the commutation circuits is nil.	Cost of the commutation is significant.

4. Types of choppers:

A. According to the input/output voltage levels

- Step-down chopper – the output is less than the input voltage.
- Step-up chopper – the output voltage is greater than the input voltage.

B. According to the directions of output voltage and current

- Class A chopper.
- Class B chopper.
- Class C chopper.

- Class D chopper.
- Class E chopper.

C. According to circuit operation

- One-quadrant chopper.
- Two-quadrant chopper.
- Four-quadrant chopper.

D. According to commutation method

- Voltage – commutated choppers.
- Current – commutated choppers.
- Load – commutated choppers.
- Impulse – commutated choppers.

3.01 UNIT – III INVERTERS AND APPLICATIONS 3.1 INVERTERS

The inverters are DC to AC converters. The input is fixed or variable DC, and the output is variable voltage, variable frequency AC.

- The output voltage waveform of the inverter can be square wave, quasi-square wave or low distorted sine wave.
- The output voltage can be controlled (i.e. adjustable) with the help of drives of the switches.
- The Pulse Width Modulation (PWM) techniques are most commonly used to control the output voltage of inverters. Such inverters are called PWM inverters.
- The inverters can be classified as voltage source inverters or current source inverters.
- Sometimes, the DC input voltage to the inverter is controlled to adjust the output. Such inverters are called variable DC link inverters.
- The inverters can have single phase or three phase output.

3.2 Application of inverters

i) Variable frequency AC motor drives.
ii) Uninterruptible power supplies (UPS).
iii) Standby (emergency) power

supplies.
iv) Induction and dielectric heating.
v) Power supplies used in spaceships and air crafts.
vi) High voltage DC transmission lines.
vii) Various flow control / regulation applications in chemical plants, oil engines, paper manufacturing and textile industries.

3.3 SERIES INVERTERS WITH RESISTIVE LOAD

In the series inverter, the commutating inductance and capacitance are in series with the load. Thus commutation circuit is part of the load. The circuit diagram of the
series inverter is shown in figure 3.1. L and C are commutating components. T1 and T2
carry load current in positive and negative half cycles. Operation of the circuit can be
understood through following modes.

3.02

Vdc

T1

T2

L

C

R

Figure 3.1 Single phase inverter with R load

Mode-I

At the beginning of this mode, capacitor is charged to negative voltage as shown in
waveforms of figure 3.2. At ‘t1’ , SCR T1 is triggered and positive voltage is produced at
the output. The output current starts flowing through T1 and L-C-R circuit as shown in
figure 3.3. Because of the RLC circuit,

the current increase sinusoidal. The current becomes maximum, when capacitor voltage is equal to Vdc. Then the current reduces. At t2, current becomes zero. Hence T1 turns-off. The capacitor charges to the value higher than Vdc. The charge is hold by the capacitor.

Mode – II

This mode begins when SCR T2 is triggered at t3 and negative voltage at the output.

Equivalent circuit-II in figure 3.4 has shown the current path. The current stars flowing in opposite direction. The capacitor starts discharging in the RLC circuit. The current becomes maximum, when capacitor voltage is zero. The current then starts reducing and become zero at ‘t4’. Therefore T2 turns-off at t4. The capacitor is charged to negative

Vo

voltage. This charge is hold by the capacitor. The cycle repeats when T1 is triggered again.

3.03

Figure 3.2 Waveforms of Single phase inverter with R load

t

t

t

t

t

Triggering signal T1

Triggering signal

T2
Triggering
signal T1
Output
current
Capacitor
voltage Vc
Load
voltage Vo
t1 t5
t3
t2
t4

Figure 3.3 Equivalent circuit I 3.04
Figure 3.4 Equivalent circuit II 3.4
SINGLE-PHASE INVERTER WITH RL LOAD Figure 3.5 Single phase inverter with RL load

Figure 3.5 gives the circuit configuration of a single-phase inverter with RL load. For this basic circuit configuration, the triggering circuit and the commutation circuit are

Vdc
T1
T2
L
C
R
Vdc
T1
T2
L
C
R

not shown for simplicity. The gating signals for the thyristors and the resulting output voltage waveform as shown in figure 3.6. As shown in the waveform 3.6, for the interval 0< t≤ T/2, thyristor T1 is conducting and load is subjected to a voltage Edc/2 due to the upper voltage source Edc/2. At instant t=T/2, thyristor T1 is turned off and T2 is turned on. During the interval T/2≤ t ≤ T, thyristor T2 conducts and the load is subjected to a voltage (-Edc/2) due to the lower voltage source Edc/2. So, the Output is AC signal.

3.05 Each thyristor is gated at frequency f = 1/T of the ac supply desired. The gating signals of the two thyristors have a phase single of 180o. From the figure the output is easily seen to be rectangular ac waveform of frequency,

where, T is the triggering period of the thyristor. Frequency of the inverter output voltage can be changed by controlling T. In this circuit, an alternating path is provided by diodes D1 and D2 which is across the SCRs T1 and T2 to avoid the damage of SCR. These diodes are called feedback diodes.

ω=
2π
rad/s
T
Ig1
Ig2
+Edc/2
-Edc/2
0
Load Voltage EL
Triggering Signal
T/2
T
3T/2
1800
t
t
t

Figure 3.6 Wave form of Single phase inverter with RL load 3.5 METHODS OF OBTAING SINE

WAVE OUTPUT FROM AN INVERTER Most of the inverters produce square wave at the output. For faithful operations, AC loads require sinusoidal voltages. **3.06** Generally, the square wave produced by the inverter is sine wave with harmonics. If the harmonics are removed, a sine wave can be obtained. To reduce the harmonics, the following methods can be used.

i) Resonating the Load.
ii) Using proper filters.
iii) Using pulse width modulation.
iv) Using sine wave synthesis.
v) Using poly phase inverter.

i) Resonating the load

By making the load itself resonant at the output frequency, a near about sine wave may be produced. To achieve desired harmonic reduction, the "Q" factor of the load network should be very high.

ii) Using proper filters

Suitable filters can be used for eliminating the harmonics. LC filter is the simplest filter used for harmonics reduction. Simple LC filters are shown in figure 3.7. For higher degree of harmonic reduction, two sections of LC filters are required. **Figure 3.7 LC filters**

3.07

iii) Using pulse width modulation

Figure 3.8 Output waveforms

If the width of the output voltage produced by inverter is reduced, certain harmonics can be reduced. By triggering the SCR multiple times, multiple pulses are
generated per half cycle. As the number of pulses increase, the harmonic content is

reduced. But there is a limit for the number of pulses to reduce switching losses.

iv) Sine wave synthesis

T1

T2

Figure 3.9 Transformer connected in series

Inverter1

Inverter2

Constant Vo

dc voltage

Output with pulse width modulation

modulation

Output without modulation

Voltage

Time

Time

When the square wave outputs of two identical inverters are connected in series through transformers with a phase difference, a quasi square wave signal is produced. The harmonics present in the quasi signal are less than the individual inverter waveforms. **3.08** If the two quasi signals are again added using transformer with a phase difference, the harmonics are further reduced. **3.6 OUTPUT VOLTAGE CONTROL IN INVERTERS** AC loads may require constant or variable voltage at their input terminals. When such loads are fed by inverters, it is essential to control the output voltage of the inverters. The various methods to control the output voltage of the inverter are,

1) External control of AC output voltage.

2) External control of DC input voltage.

3) Internal control of inverter.

1) External control of AC output

voltage
There are two possible methods of external control of AC output voltage obtained from inverter output terminals
a) AC voltage control.
b) Series inverter control.
a) AC voltage control
In this method, an AC voltage controller is inserted between the output terminals of inverter and the load terminals as shown in figure 3.10 .The input voltage to the AC load is regulated through the firing angle control of ac voltage controller. This method is not suitable for low power applications.
Constant Controlled
Dc voltage AC Voltage Figure 3.10 External control of AC output voltage
b) Series inverter control
Inverter
AC Voltage controller
AC Load
In this method two or more inverters are connected in series as shown in figure
3.11. Here, the output voltage of two inverters is summed up with the help of transformers
to obtain the adjustable output voltage. The secondary of two transformers is connected in
series.
3.09
T1
T2
Figure 3.11 Series inverter control of two inverters
2) Internal control of inverter
The output voltage control within the inverter can be done by pulse width modulation technique. In this method, a

fixed dc voltage is given to the inverter and the
controlled output voltage is obtained by varying the ON and OFF periods of the inverter.
This is the most popular method called as pulse width modulation (PWM) control.

3) External control of DC input voltage

If the available voltage source is AC, then the fully controlled rectifier or chopper is
used to control the DC voltage applied to the inverter.

Constant controlled
AC voltage Dc voltage AC voltage

Figure 3.12 External control of DC input voltage

3.7 THE McMURRAY INVERTER (AUXILIARY COMMUTATED INVERTER)

The McMurray Inverter is an impulse commutated inverter which depends on an LC
circuit and an auxiliary thyristor for commutation in the load circuit. The impulse is
derived from the resonating LC circuit and is applied to turn off a thyristor. A single
phase full-bridge McMurray inverter is shown figure 3.13.

Rectifier or
Chopper
Filter Inverter
Inverter1
Inverter2
Constant Vo
dc voltage
3.11

Figure 3.13 Single phase McMurray inverter The circuit consists of the main thyristor T1, T2, T3 and T4, the freewheeling diodes D1,D2,D3 and D4, the auxiliary thyristor TA1,TA2,TA3 and TA4, and the commutating components L and C. When the thyristor pair T1 and T2 conducts, a positive voltage is produced across the load. When thyristor pair T3 and T4 conducts, a negative voltage is produced across the load. Thus, by alternate conduction of pair of thyristors (T1 & T2,T3 &T4) an alternating voltage is produced across the load. The operation of the McMurray inverter may be subdivided into various operating modes as follows: **Mode – 1** This mode begins when the thyristor pair T1, T2 is triggered. When thyristor T1,T2 become turned-on, the supply current flows through the path Edc+-T1-Load-T2-Edc(_) and hence, positive load voltage is obtained. The commutating capacitor C1, C2 are already charged to a voltage Ec with the polarities shown in figure3.13, during the commutation of the previously conducting thyristor T4, T3. **Mode – 2**

This mode begin when thyristor TA1, TA2 are triggered to turn off the main thyristors T1, T2. When thyristor TA1, TA2 have been turned on, capacitor C1,C2 start discharging. Capacitor C1 forms the discharging loop C1 (+)-T1-TA1-L1-C1(-) and capacitor C2 forms the

+

-

-

+

Edc

+

-

discharging loop C2(+)-L2-TA2-T2-C2(-). Voltage drop across T1, T2 reverse-biases D1,D2 .Therefore, current flows only through T1,T2 and not through D1,D2. As load current I*L* is **3.12** constant, an increase in lc causes a corresponding decrease in lT1, lT2 (IT1 or IT2=Ic-IL). At the particular time, the capacitor current Ic rise to I*L* and therefore, current lT1 and lT2 become zero. As a result, main thyristor T1 and T2 become turned off **Mode – 3** When the current Ic exceeds IL, the excessive current circulates through feedback diodes D1,D2. The resonating oscillation continues through the path C1(+)-D1-TA1-L1-C1(-) and C2(+)-L2-TA2-D2-C2(-) respectively. The voltage drop across D1, D2 reverse biases T1,T2 to bring it to forward blocking capability. The commutation current Ic rises to peak value (Icp) when capacitor voltage (Ec) is zero, and then decreases as the capacitor is charged in the reverse direction. Now Ic falls back to the load current IL and diodes D1,D2 stop conducting. **Mode – 4** This mode starts when diode D1and D2 stop conducting. The capacitor starts recharge through the load . This mode ends when the capacitor voltage becomes equal to the dc supply Edc tends to overcharge due to the energy stored in inductor L. **Mode – 5** This mode begins when the capacitor voltage is greater than Edc and diodes D4, D3 become forward-biased. The energy stored in inductor L is transferred to the capacitor, causing it to be overcharged with respect to supply voltage Edc. This mode ends when the capacitor current falls again to zero and the capacitor voltage is reversed to that of original polarity and now the current is ready for the next cycle of operation. During the next half cycle, thyristor pair T3, T4 is triggered and a negative half cycle of voltage is produced across the load. **Advantages**

1. Output voltage is square wave, which is better than series inverter.
2. Simple commutating circuit.
3. Switching frequency is higher.

Disadvantages

1. Large amount of energy in trapped in commutating capacitor. It is to be removed with the help of additional feedback diodes.
2. Heavy transformer is required to carry load current.

3.13 3.8 PARALLEL INVERTER

Figure 3.14 shows the circuit diagram of parallel inverter. T1 and T2 carry the current in positive and negative half cycles. Capacitor 'C' is the commutating capacitor. Capacitor is connected across the transformer primary. Load is connected across the secondary. Capacitor is connected in parallel to the load. Hence this inverter is called parallel inverter. **Figure 3.14 Circuit diagram of Parallel inverter**

Mode-I Thyristor T1 is triggered. The supply voltage Vdc appears across half of the primary winding. Now the load voltage is positive. The voltage of 2Vdc is induced across the primary by auto transformer action. The capacitor is connected across primary. Hence it also charged to voltage 2Vdc. The capacitor remains charged to this level.

Mode-II As soon as T2 is triggered, a capacitor voltage of 2Vdc is applied across T1. Hence T1 immediately turns-off. The load current starts flowing through other half of the primary winding. Now the load voltage becomes negative as shown in the waveforms. **Mode -III** When SCR T1 is turned ON, the fully charged capacitor will turn off the SCR T2. And same process continuous. If trigger pulses are applied periodically to each SCR, an AC voltage is produced at the output**.**

C
T1
3.14
Figure 3.15 Model wave form of Single phase parallel inverter Figure 3.16 Equivalent circuits of Single phase parallel inverter
3.15
Ig1
Ig2
Cap. Voltage Vc
VT1
Load volt Vo
2Vdc
-2Vdc
Vdc
-Vdc
time
time
time
time
time

3.9 SWITCHED MODE POWER SUPPLIES (SMPS) Basic concept of SMPS The dc output of the rectifier or battery is not regulated. It varies according to the load variations**.** Switching mode regulators are used to convert unregulated dc to regulated DC output**.** SMPS is based on the chopper principle. The output dc voltage is controlled by varying the duty cycle of the chopper by PWM or FM technique. Generally PWM technique is used. If power transistors are used, the chopping frequency is limited to 40 KHz. For power MOSFETs, the chopping frequency is up to 200 KHz.

Types of SMPS SMPS are categorized into four different types. They are

1) AC-DC converter
2) DC-DC converter
3) Forward Converter
4) Fly back converter

AC- DC Converter This type of SMPS has an AC input and it is converted into DC by using rectifier & filter. The switching operation is done by using a power MOSFET amplifier and action of switching is controlled by a feedback using the PWM oscillator. **DC-DC converter**

In this power source, a high voltage DC power is directly acquired from a DC power source. The switching-power supply o/p is regulated by using Pulse Width Modulation. **Forward Converter** But, in this type of SMPS a control is connected at the output of the secondary winding of the transformer to control the switch. As compared to the fly back converter, the filtering and rectification circuit is complicated. This is also called as a DC-DC buck converter. **3.16**

Fly back converter In this type of SMPS, output power is very low (less than 100W) . This type of SMPS is very simple circuit compared with other SMPS circuits. This type of SMPS is used for low power applications. **3.9.1 BLOCK DIAGRAM OF SMPS** The switching mode regulators use dc choppers for switching action. . Figure 3.17 shows the block diagram of switching mode regulator. The dc chopper takes the input from some unregulated supply. The chopper may use Transistor, MOSFET, IGBT, SCR or GTO for switching.

High freq switch Output DC
Input AC DC
High volt. Low frequency
Error Amp **Figure 3.17 Block diagram of SMPS Working principle of SMPS**

Input rectifier and filter This block rectifies the input AC voltage into pulsating DC and filters the DC to reduce the ripples. **High frequency switch** MOSFET or Bipolar transistors are used as high frequency switch. It converts the DC voltage into high frequency AC square wave of 20-100 KHZ. **Power transformer** The power transformer isolates the circuits and step up or step down the voltage to a level required by DC the voltage. **3.17**

Rectifier and filter filter
Rectifier and filter filter
O/p Sensor
Isolation
Reference
PWM Oscillator
Step down Transformer

Output rectifier and filter Here again AC voltage will be converted into DC voltage by rectifier .The filters are used to make the output voltage ripple free and smooth. And the output ripple of high frequency (20 – 100 KHz) ripple will be filtered by filter. **Output sensor** It detects the output DC voltage and feedback it to the control circuit

Control circuit

- In the control circuit, the error amplifier compares the reference voltage with output voltage. The reference voltage is set for the particular output voltage.

 The error amplifier generates the error signal depending on the difference between output voltage and reference voltage.
 The error signal acts as the control voltage to drive the high frequency switch(chopper).
 This control voltage varies the width (duty cycle) of the pulse width modulation (PWM) oscillator to adjust the switching speed of high frequency switch.
 To reduce the DC voltage, pulse width will be reduced by control voltage.
 To increase the DC voltage, pulse width will be increased by control voltage. By this technique, a regulated dc output voltage can be obtained.

3.10 Advantages, Disadvantages and Application of SMPS Advantages

i) In linear power supply the series pass transistor operates inactive region. Hence there is high power loss. But in SMPS, devices operate in saturation and cut-off regions. Therefore losses are reduced in SMPS.
ii) Due to reduced power loss, SMPS have efficiencies up to 95% but linear power supplies have very small efficiencies.
iii) SMPS operate at very high frequencies. Therefore filtering components and transformers have very small size. Where as linear power supplies have bulky components.
iv) SMPS have transistors in switching mode. Hence their power handing capacity is more as compared to linear mode.
v) SMPS are more cost effective due to reduced size of transformer and filters.

3.18 Disadvantages

i) Since SMPS operates at high switching frequencies, they generate Radio Frequency Interference (RFI) to neighboring circuits.
ii) Since the devices operate in switched mode, there are switching losses at high frequencies.
iii) The transient response of SMPS is very slow compared to linear power supplies.
iv) SMPS have poor load regulation as compared to linear power supply.

Applications of SMPS

i) Televisions, DVD player.
ii) Computer, printer, monitors.
iii) Battery charges, electronic ballasts.
iv) Video games, toys.

3.11 UNINTERRUPTIBLE POWER SUPPLIES

UPS or battery backup is an electrical apparatus that provides emergency power to a load when the input power source or mains power fails**.** A temporary power failure can cause large economic losses. For such critical it is an important to provide an uninterruptible power supply (UPS) system to maintain the continuity of supply . Static UPS system are of two types; namely off line UPS and on line UPS.. **3.11.1 ON LINE UPS (No-break UPS)** In on line UPS, load gets continuous uninterrupted supply from the power source, even a power failure takes place. The block diagram of OFF line UPS is shown in figure 3.19.

Normally OFF
Power Flow
Static transfer switch
Main AC Supply Normally ON \

Figure 3.19 Block diagram of ON line UPS 3.19

□ n this system, main AC supply is

rectified and the rectifier delivers power to charge the batteries.

- Rectifier also supplies power to inverter continuously which is then given to AC-type load through filter and normally-on switch.

Rectifier Ac- DC
Inverter DC - AC
Batteries
Filter
Critical Load

- In case of main supply failure, batteries supply power to critical load without any interruption. No discontinuity in the illumination is observed in case of on-line UPS.
- In case inverter failure is detected, main ac supply directly applied to the load by turning on the Normally-off static switch and opening the Normally-on static switch.
- The transfer of load from inverter to main AC supply takes 4 to 5 ms by static transfer switch as compared to 40 to 50 ms for a mechanical contactor.
- After inverter fault is cleared, uninterruptible power supply is again restored to the load through the normally on switch.

Advantages of On line Ups

i) Load is protected from transients in the main supply.
ii) Inverter output frequency can be maintained at the desired level.
iii) Inverter can be used to condition the supply delivered to load.

3.11.2 OFF Line UPS (Short break UPS) In off line UPS, the load gets disconnected from the power source for a short duration of the order of 4 to 5 ms, when mains supply fails. The block diagram of OFF line UPS is shown in figure 3.18.

Normally ON Power Flow Static
transfer switch
Main AC Supply Normally OFF

Figure 3.18 Block diagram of OFF line UPS 3.20

- In this system, main AC supply is rectified to DC. This DC output from the rectifier charges the batteries and is also converted to AC by an inverter.

Rectifier Ac- DC
Inverter DC - AC
Batteries
Filter
Critical Load

- Under normal circumstances normally-on contacts are closed and normally-off contacts are open.
- The main supply delivers ac power to the load through Normally On contacts
- At the same time, the rectifier supplies continuous charge to batteries to keep them fully charged.
- In the event of power failure, normally-off switch is turned –on and the batteries deliver ac power to critical load through the inverter and filter.
- A momentary interruption may occur (4 to 5 ms) to the load. It is also called as stand-by power supply.

3.12 COMPARISON OF OFF-LINE UPS AND ON-LINE UPS

S.NO	OFF-LINE UPS	ON-LINE UPS
1.	Inverter is used when AC mains fails	Inverter is always used irrespective of AC mains fails
2.	Unregulated output, when AC main is present	Always regulated, filtered and

continuous output to load
3.
Delay during change over from main to inverter
No delay during change over period
4.
High in efficiency
Low in efficiency
5.
Low cost
High cost

3.13 BATTERY BANKS

A battery bank is the result of joining two or more batteries together for a single application. By connecting batteries, the voltage or amperage can be increased, or both. When we need more power, instead of using massive super tanker of a battery, a battery bank can be constructed. There are 2 ways to successfully connect two or more batteries. The first is Series and the second is parallel. **3.21**

Series Connection

+
-
+
-
- +
6 Volts 10 AH AaAAh
- +
6 Volts 10 AH AaAAh

Double Voltage, same capacity (Ah) 12 Volts, 10 Ah Figure 3.20 Batteries connected in series

Series connection adds the voltage of the two batteries, but keeps the same amperage rating (also known as Amp Hours). For example, these two 6 Volt batteries joined in series and produce 12 Volts, but still have a total capacity of 10 Amps. To connect batteries in a series, use a jumper wire to connect the negative terminal of the first battery to the positive terminal of the second battery. Use another set of cables to connect the open positive and negative terminals to your application. Never cross the remaining open positive and open negative terminals with each other, as this will short circuit the batteries and cause damage or injury. It is best to use the same voltage and capacity rating battery. Otherwise, charging problems, and shortened battery life. **Parallel Connection Same Voltage, Double capacity (Ah) 6 Volts, 20 Ah Figure 3.21 Batteries connected in parallel 3.22** Parallel connections will increase the current rating, but the voltage will be same. In the diagram 3.21, voltage is same as 6 Volts, but the Amps increase to 20. It's important to note that because the amperage of the batteries increased, you may need a heavier duty cable to avoid the cables burning out.

- +

6 Volts 10 AH AaAAh

- +

6 Volts 10 AH AaAAh

To join batteries in parallel, connect both the positive terminals and negative terminals of both batteries to each other. Negative to negative and positive to positive, then connect the load to ONE of the batteries, but both drain equally. It is also possible to connect batteries in a Series/Parallel configuration This may sound confusing, Here, both voltage output and current rating are increased. To do this successfully, at least 4 batteries are required. **Series / Parallel Connection** If two sets of batteries are already connected in parallel, join them together to form a series. In the figure 3.22, we have a bank that produces 12 Volts and has 20 Amp Hours.

Double Voltage, Double capacity (Ah) 12 Volts, 20 Ah Figure 3.22 Batteries connected in series and parallel In theory, we can connect as many batteries together as we want. But when we start to construct a tangled mess of batteries and cables, it can be very confusing, and confusion can be dangerous. Keep in mind the requirements for the application, and stick to them. Also, use batteries of the same capabilities. Avoid mixing and matching battery sizes wherever possible. **3.23 REVIEW QUESTIONS PART – A**

1. What is inverter?
2. Mention the methods to obtain sine wave from an inverter.

- +

6 Volts 10 AH AaAAh

- +

6 Volts 10 AH AaAAh

- +

6 Volts 10 AH AaAAh

- +

6 Volts 10 AH AaAAh

3. Mention the methods to control the output voltage in inverters.
4. Give any three applications of inverter.
5. State any two advantages of Mcmurray inverter.
6. What is SMPS?
7. Give the types of SMPS.
8. Define UPS.
9. Give any two differences between on-line UPS and off-line UPS.
10. Give any two requirements of inverter.

PART – B

1. Explain any three methods to obtain sine wave from an inverter.
2. Draw the circuit diagram of single phase inverter with RL load.
3. Briefly write about the methods to control output voltage in inverters.
4. Compare on-line UPS and off-line UPS.
5. Give the advantages, disadvantages and applications of SMPS.

PART – C

1. With a neat diagram explain single phase inverter with resistive load.
2. Explain single phase series inverter with RL load with neat diagram.
3. Draw and explain the parallel inverter with waveform.
4. Explain the working of SMPS with block diagram.
5. With a diagram explain on-line UPS and off-line UPS.

4.01 UNIT – IV PROGRAMMABLE LOGIC CONTROLLER 4.1 EVOLUTION

The first PLC systems evolved from conventional computers in the late 1960s and early 1970s. These PLCs were first installed in automotive plants. Because, auto plants had to be shut down for up to a month at model changeover time during which revised relay
and control panels were taken place. The PLC keyboard programming replaced the rewiring of a panel with full of wires, relays, timers and other components and reduces the changeover time. In 1972, the introduction of the microprocessor chip made improvement in PLC programming and PLC became more useful. In 1980s the use of PLCs was increased and is still growing. Instead

of computer numerical controls (CNCs), PLCs have been used in machine tool industry. PLCs are also used extensively in building energy and security control systems. **4.2 INTRODUCTION TO PLC** PLC means Programmable Logic Controller. A PLC is an user-friendly, microprocessor based specialized computer that control machines and processes. The PLC can be operated on the input side by digital or discrete input devices (on/off) or by analog (variable) input devices. PLC will operate any system with digital outputs (on/off) and analog outputs (variable).

4.3 ADVANTAGES OF PLC OVER RELAY LOGIC

1. In relay logic, any alterations require more time for rewiring of panels. In PLCs no rewiring is required. So, alterations can be made within minutes by changing the program
2. It is lower cost with increased technology
3. Relays can take more time to actuate. But the operational speed of PLC is very fast.
4. PLC is made of solid-state components. Solid state devices are more reliable than relays and timers.
5. The PLCs are more effective when periodic changes in operation are made.
6. Economical in long term use. 7. Security.

4.02 4.4 RELAYS Relays are the primary protection as well as switching devices in most of the control processes or equipments**.** The relay is an important part of many control systems because it is useful for controlling high voltage and current devices with a low voltage and current control signal.

Relays have NO (Normally open) or NC (Normally close) or combinations of both contacts. **Different Types of Relays**

Depending on the operating principle and structural features relays are of different types such as electromagnetic relays, thermal relays, reed relays power varied relays, multi-dimensional relays, and so on, with varied ratings, sizes and applications. 1. **Electromagnetic Relay** These relays are constructed with electrical, mechanical and magnetic components, and have operating coil and mechanical contacts. Therefore, when the coil gets activated by a supply system, these mechanical contacts gets opened or closed. The type of supply can be AC or DC. **Attraction Type Electromagnetic Relay** These relays can work with both AC and DC supply and attract a metal bar or a piece of metal when power is supplied to the coil. So, an armature being attracted towards the poles of an electromagnet as shown in the figure 4.1 and contacts get closed. In the contact side, load can be used. These relays don't have any time delays so these are used for instantaneous operation. **Figure 4.1 Electromagnetic Relay 4.03 Magnetic Latching Relay** These relays use permanent magnet or parts with a high remittance to remain the armature at the same point when the coil power source is taken away. **2. Solid State Relay (SSR)** Solid State uses solid state components such as Transistors, SCR, TRIAC, and DIAC to perform the switching operation without moving any parts. Since the control energy required is much lower compared with the electromagnetic relay that results the high power gain. These are of different types: reed relay coupled SSR, transformer coupled SSR,

Armature

photo-coupled SSR, and so on. **Fig 4.2 Solid state Relay** In the above figure 4.2, when the DC power supply is applied, LED starts conduction and emits light. Now light activated TRIAC receives the light and gets ON and triggers the TRIAC Q1. So, TRIAC starts conduction by 230 V AC supply and Lamp is ON. Thus, Lamp is ON by triggering the TRIAC without moving any part as normal switch. **3. Hybrid Relay** These relays are composed of electromagnetic relays and electronic components. Usually, the input part contains the electronic circuitry that performs rectification and the other control functions, and the output part include electromagnetic relay. **4. Thermal Relay** These relays are based on the effects of heat, which means that the rise in the ambient temperature from the limit, changes the contacts in switch from one position to other. These are mainly used in motor protection and consist of bimetallic elements **4.04** like temperature sensors as well as control elements. Thermal overload relays are the best examples of these relays. **5. Reed Relay Figure 4.3 Reed relay** Reed Relays consist of a pair of magnetic strips (also called as reed) that is sealed with in a glass tube. This reed acts as both an armature and a contact blade. When the magnetic field applied to the coil which is wrapped around this tube, reeds move towards each one and gets closed contact. So that switching operation is performed. Based on dimensions, relays are differentiated as micro miniature, subminiature and miniature relays. Also, based on the construction, these relays are classified as hermetic, sealed and open type relays. Furthermore, depending on the load operating range, relays are of micro, low, intermediate and high power types. Reed relays are also available with different pin configurations like 3 pin, 4 pin and 5 pin relays given in figure 4.4. The ways in which these relays are operated is shown in the figure. Switching contacts can be SPST, SPDT, DPST and DPDT types. Some of the relays are normally open (NO) type and the other are normally closed (NC) types. **4.05**

Figure 4.4 Pin Configuration of Reed Relay These are some of the different types of relays that are employed in most of the electronic as well as electrical circuits. **4.5 BLOCK DIAGRAM OF PLC** The block diagram of PLC is given in fig. 4.5. The main parts of PLC are central processing unit(CPU), input/output section, power supply , memory and programming device. **Figure 4.5 Block diagram of PLC Central processing unit (CPU)**

- It is the brain of the system.
- It consists of microprocessor and memory. Microprocessor is used to implement logical and mathematical operations.
- The user's application program is stored in memory area.

4.06

- The data required to perform mathematical calculation is stored in data memory.

- The processor reads input data from various sensing devices, and executes the stored program from memory depending on the input. The data and relay ladder logic program is stored in memory area.
- Then processor sends output commands to control output devices. A direct current (dc) power source is required for processor to produce the low-level voltage for computer operations. **Input / Output section**
- The I/O section consists of input modules and output modules.
- Input module is used to interface input devices like push buttons, limit switches with processor. It converts input voltages of 120-240V AC or 0-24V DC from discrete devices to low level DC voltage typically 5V.
- Similarly, output module is used to interface output devices like motors, motor starters, and solenoid valves with processor.
- In digital input module, the input given to processor from input devices will be only 0(off) or 1(ON).
- In analog module, variable input like real time machine temperature sensed by sensor will be given to processor.
- In digital output module, processor only switches ON or OFF the output devices.
- In analog module, processor controls the speed of output devices depending on the input given to processor.

Programming device

- The programming device is used to enter the desired program into the memory of the processor.
- This program is entered using relay ladder logic, statements lists or control system flow charts. Ladder logic which

is the most popular programming language.

 Ladder logic programming language uses graphic symbols for programming.

 Handheld programming devices are sometimes used to program small PLCs because they are inexpensive and easy to use.

4.07

 A personal computer is the most commonly used programming device. The personal computer communicates with the PLC processor via serial or parallel port.

Power Supply

 The power supply provides power to memory system, processor and I/O Modules.

 It converts the higher level AC line Voltage to various DC voltages for processor and internal circuit of input and output modules. It filters and regulates the DC voltages for proper computer operations. **4.6 PLC PROGRAMMING LANGUAGE**

PLC programming language is the method by which user gives information to the PLC to control the function of any process. The three most common language structures are ladder diagram language, Boolean language and function chart.

 Ladder diagram language is the most commonly used PLC language that represents the program by graphical diagram.

 The diagram resembles a ladder with two vertical rails (supply power) and many “rungs” (horizontal lines). So, it is called as ladder diagram.

 Boolean language can also be used to program the original circuit. This statement uses the AND, OR and NOT

logic gate functions.
 Function chart programming was originally developed in Europe and is called GRAFCET. A function chart program is a pictorial representation of sequential control process.
An example for ladder diagram, Boolean language and function chart programming is given in figure 4.6
Start PB1 AND CR1 OR LS1 AND NOT CR2 OUT SOL
(a) Boolean Language
4.08
PB1 CR1 CR2 SOL
LS1 **(b) Ladder Logic program (c) Sequential function chart programming Figure 4.6 PLC programming languages 4.7 ARITHMETIC FUNCTIONS** The arithmetic functions performed by PLCs are addition, subtraction, multiplication and division. **Addition instruction (ADD)** The ADD instruction performs the addition of two values stored in the memory locations. Fig. 4.7 shows an example of the ADD instruction. In this example, the value stored at the source A address N7:0(20) is added to the value stored at the source B address, N7:1(40), and the answer (60) is stored at the destination address, N7:2. **4.09**
ADD ADD Source A N7:0 20
Source B N7:1 40 Destination N7:2 60
Figure 4.7 Example of Addition instruction Subtraction Instruction (SUB) Fig. 4.8 shows an example of the SUB instruction. In this example, the value stored at the source B address N7:1(20) is subtracted from the value stored at the source A address, N7:0(40), and the answer (20) is stored at the destination address, N7:2.

SUB SUBTRACT Source A N7:0 40 Source B N7:1 20 Destination N7:2 20 **Figure 4.8 Example of subtraction instruction Multiplication Instruction (MUL)** Fig. 4.9 shows an example of the MUL instruction. In this example, the value stored at the source A address N7:0(40) is multiplied by the value stored at the source B address, N7:1(20), and the answer(800) is stored at the destination address, N7:2.

MUL MULTIPLY Source A N7:0 40 Source B N7:1 20 Destination N7:2 800 **Figure 4.9 Example of multiplication instruction 4.10 Division Instruction (DIV)**

Fig. 4.10 shows an example of the DIV instruction. In this example, the value stored at the source A address N7:0(40) is divided by the value stored at the source B address, N7:1(20), and the answer(2) is stored at the destination address, N7:2.

DIV DIVIDE Source A N7:0 40 Source B N7:1 20 Destination N7:2 2 **Figure 4.10 Example of division instruction Square root Instruction (SQR)** Fig. 4.11 shows an example of square root (SQR) instruction. The number whose square root value we want to find is placed in the source. SQR instruction calculates the square root and places it in the destination.

SQR SQUARE ROOT Source A N7:101 144 Destination N7:105 12 **Figure 4.11 Example of square root Instruction 4.11 4.8 COMPARISON FUNCTIONS** In general comparison instructions are used to test a pair of values to energize or de-energize a rung. The following is a list of the comparison instructions

□ EQU - Equal □ NEQ - Not Equal □

LES - Less Than LEQ - Less Than or Equal GRT - Greater Than GEQ - Greater or Equal MEQ - Masked Comparison for Equal LIM - Limit Test **EQU - Equal** EQU Equal Source A N7:0 32000< Source B N7:1 0< Test whether two values are equal or not. If source A and Source B are equal, the instruction is logically true. Source A must be an address. Source B can either be a program constant or an address. Negative integers are stored in two's complement. **NEQ - Not Equal** NEQ Not Equal Source A N7:0 32000< Source B N7:1 0< Test whether one value is not equal to a second value. If Source A and Source B are not equal, the instruction is logically true. If the two values are equal, the instruction is logically false. **4.12** Source A must be an address. Source B can be either a program constant or an address. Negative integers are stored in two's complement. **LES - Less Than** LES Less than (A<B) Source A N7:0 32000< Source B N7:1 0< Test whether one value is less than a second value. If Source A is less than the value at source B the instruction is logically true. If the value at source A is greater than or equal to the value at source B, the instruction is logically false. Source A must be an address. Source B can either be a program constant or an address. Negative integers are stored in two's complement. **LEQ - Less Than or Equal** LEQ Less than or Eql (A<=B) Source A N7:0 32000< Source B N7:1 0< Test whether one value is less than or equal to a second value. If value at source A is less than or equal to the value at source B, the instruction

is logically true. If the value at source A is greater than or equal to the value at source B, the instruction is logically false. Source A must be an address. Source B can either be a program constant or an address. Negative integers are stored in two's complement. **GRT - Greater Than** GRT Greater than (A>B) Source A N7:0 32000< Source B N7:1 0< **4.13** Test whether one value is greater than the second value. If the value at source A is greater than the value at source B, the instruction is logically true. If the value at source A is less than or equal to the value at source B, the instruction is logically false. Source A must be an address. Source B can either be a program constant or an address. Negative integers are stored in two's complement. **GEQ - Greater or Equal**
GEQ Greater than or eql (A>=B) Source A *N7*:0 32000< Source B N7:1 0< Test whether one value is greater or equal to a second value. If the value at source A is greater than or equal the value at source B, the instruction is logically true. If the value at source A is less than to the value at source B, the instruction is logically false. Source A must be an address. Source B can either be a program constant or an address. Negative integers are stored in two's complement. **MEQ - Masked Comparison for Equal** MEQ Masked Equal Source N7:0 32000< Mask 00FFh 255< Compare N7:0 32000< **4.14** MEQ instruction is used to compare data at a source address with data at a compare address. By this instruction, portions of the data are

masked by a separate word. Source is the address of the value you want to compare. Mask is the address of the mask through which the instruction moves data. The mask can be a hexadecimal value. Compare is an integer value or the address of the reference. If the 16 bits of data at the source address are equal to the 16 bits of data at the compare address (less masked bits), the instruction is true. The instruction becomes false as soon as it detects a mismatch. Bits in the mask word mask data when reset; they pass data when set.

Example Source N7:1 01010101 01010101 Mask N7:5 11111111 11110000 Compare N7:8 01010101 0101xxxx The masked data of Source N7:1 is compared with the masked data at the compare parameter N7:8. If the data matches, the instruction is true. In the above example, logical instruction is true because both are same except xxxx. **LIM - Limit Test** LIM Limit Test Low Lim N7:0 32000< Test N7:1 0< High Lim N7:2 0< Test whether one value is within the limit range of two other values The Low limit, Test, and High Limit values can be word addresses or constants, restricted to the following combination: If the Test parameter is a program constant, both the Low Limit and High Limit parameters must be word addresses.

4.15 If the Test parameter is a word address, the Low Limit and High Limit parameters can be either a program constant or a word address.

4.9 BASICS OF INPUT AND OUTPUT MODULE The I/O system provides an interface between external devices and CPU. The input module accepts signals from the machine or process devices and converts them into signals that can be used by the controller. Output interface modules convert controller signals into external signals used to control the machine or process. There are two types of I/O modules. They are

i) Digital (or) discrete I/O module

ii) Analog I/O module

4.9.1 Digital or discrete Input module

Digital Input modules interface field input devices of On/Off nature such as selector switches, pushbuttons and limit switches. **Figure 4.12 (a) Input connection diagram of discrete input module**

L1

(120 v ac) Input To

signal Processor

L2 5v dc **Figure 4.12(b) Block diagram of discrete input module**

4.16 The fig. 4.12(b) shows block diagram for one input of a typical alternating current (ac) discrete input module. It consists of two basic sections: the power section and logic section. The power and logic sections are coupled together by an isolator that electrically separates them. **Figure 4.13 Schematic diagram of discrete input module**

Bridge Rectifier

Zener diode Level detection

Isolator or

Logic

PLC

A simplified schematic diagram of ac discrete input module is shown in figure 4.13

 When the switch is closed, 120V AC voltage is applied to the bridge rectifier through resistors R1 and R2.

- Bridge rectifier produces a low level dc voltage, which is applied across the LED of the optical isolator.
- The zener diode regulates the voltage.
- When light from the LED falls on the photo transistor, it starts conduction and low level dc voltage to the processor.
- The optical isolator not only isolates the higher ac voltage from the logic circuits but also prevents damage to the processor due to line voltage transients.

Input modules perform four tasks in the PLC control system

1) Sense when a signal is received from a sensor on the machine
2) Convert the input signal to the correct voltage level
3) Isolate the PLC from fluctuations in the input signal
4) Send a signal to the processor indicating which sensor sends the signal

4.17 4.9.2 Digital or Discrete Output module Figure 4.14 Block diagram of AC discrete output module Fig. 4.14 shows the block diagram of AC discrete output module. Discrete output module consists of two basic sections. They are power section and logic section, coupled by an isolator circuit. The output interface can be a electronic switch to which power is applied to control output devices.

Figure 4.15 Schematic diagram of typical AC output module A simplified schematic diagram for one output of a typical ac output module is shown in figure 4.15. When a voltage 5V dc is applied across LED of the isolator from processor, LED emits light. Now phototransistor receives light and gets into conduction. So, TRIAC switches into conduction and lamp is turned ON .Fuses are also required for the output module for protection. The figure 4.16 shows the output module wiring connection with output devices like lamp, solenoid valve etc. **4.18 Figure 4.16 AC output module connection diagram 4.10 LOGIC FUNCTIONS AND Gate**

The AND gate requires two inputs and has one output. If here 0 is called false , 1 is called true .The gate acts in the same way as the logical AND operator. The output is true when both inputs are true. Otherwise, the output is false.

Truth table Figure 4.16 Logic Diagram

Figure 4.17 Ladder Logic Diagram In this logic, output C is ON, if the switches A and B are ON. If any one of the switches is in OFF condition, output C is OFF. **4.19 OR Gate** The output will be true if any of the input is true. **Truth Table**

Figure 4.18 Logic Diagram

Figure 4.19 Ladder Logic Diagram

Inputs
Output
A
B
C
0
0
0
0
1
0
1
0
0
1
1

1
Inputs
Output
A
B
C
0
0
0
0
1
1
1
0
1
1
1
1

In this logic, switches A and B are connected in parallel. Output C is ON, if any one of the switches (A or B) is ON. If both switches are in OFF condition, output C is OFF. **NOR Gate** NOR gates output are invert of OR gate. If both inputs are false then output will be true. **Truth Table**
Figure 4.20 Logic Diagram Figure 4.21 Ladder Logic Diagram 4.20 In this logic, if both the switches A and B are OFF, output C is ON. If anyone is ON or both are ON, output C is ON.
NAND Gate NAND gates output are invert of AND gate. If both inputs are true then output will be false. **Truth Table**
Figure 4.22 Logic Diagram
Figure 4.23 Ladder Logic Diagram
Inputs
Output
A
B
C
0

0
1
0
1
0
1
0
0
1
1
0
Inputs
Output
A
B
C
0
0
1
0
1
1
1
0
1
1
1
0
In this logic, if any one switch or both the switches are off, output C is ON. If both the switches are ON, output C is OFF. **XOR Gate** If only one input is true then the output will be true. **Truth Table**

Figure 4.24 Ladder Diagram 4.21

Figure 4.25 Ladder Diagram The input and output is total opposite. If switch A is ON and B is OFF or switch A is OFF and B is ON, output coil C will be energized (ON). If both are ON or OFF**,** output coil will be de-energized (OFF) **NOT gate Truth Table** A B

Figure 4.26 Logic diagram Figure 4.27 Ladder diagram

Inputs
Output
A
B
C
0
0
0
0
1
1
1
0
1
1
1
0
Input
Output
A
B
0
1
1
0

Here, if switch A is OFF, output coil B is energized else B is deenergized. **4.11 Symbols used in ladder logic diagram**

Instruction
Symbol
Normally open
Normally closed
Output coil
Negated Output

4.22

Latch output coil
L
Unlatch output coil
U
Timer On delay Timer

Timer
Off delay Timer
Counter Up Counter
Counter
Down Counter

Figure 4.28 symbols used in ladder logic diagram

4.12 TIMER

The following is a list of timer instructions in PLC

- TON - Timer On Delay
- TOF - Timer Off Delay
- RTO - Retentive Timer

TON - Timer on Delay

With an on-delay timer, timing begins when voltage is applied. When the time reaches preset time, the contacts close and remain closed until voltage is removed from the coil.

TON
Timer ON delay EN
Timer T4:1
Time Base 1.0 DN
Preset 10.0
Accum 0

- Count time base intervals when the instruction is true.

4.23

- The Timer on Delay instruction begins to count time base intervals when rung conditions become true. As long as rung conditions remain true, the timer increment its accumulated value (ACC) until it reaches the preset value (PRE). The accumulated value is reset when rung conditions go false, regardless of whether the timer has timed out.
- Each Timer on Delay is made of a 3-word element.

o Word 1 is the control word
o Word 2 stores the preset value. (PRE)
o Word 3 stores the accumulated value

(ACC)

 Time Base is the timing update interval, this can vary from 0 - 1 second.

TOF - Timer off Delay

When using an off-delay timer, nothing happens when voltage is applied. When closing the control input (SW), the contacts gets closed. Opening the control input causes timing to begin, and the contacts remain closed. When time reaches preset time, the contacts open.

TOF
Timer OFF Delay
EN
Timer T4:1
Time Base 1.0 DN
Preset 10.0
Accum 0

 Counts time base intervals when the instruction is false.

 The Timer off Delay instruction begins to count time base intervals when the rung makes a true to false transition. As long as rung conditions remain false, the timer increments its accumulated value (ACC each scans until it reaches the preset value (PRE). The accumulated value is reset when rung conditions go true regardless of whether the timer has timed out.

 Each timer address is made of a 3-word element.

 Word 1 is the control word

 Word 2 stores the preset value. (PRE)

 Word 3 stores the accumulated value. (ACC)

 Time Base is the timing update interval, this can vary from 0 - 1 second.

4.24

RTO- Retentive Timer

RTO
Retentive Timer ON
EN
Timer T4:3
Time Base 1.0 DN
Preset 10.0
Accum 0

- Counts time base intervals when the instruction is true and retains the accumulated value when the instruction goes false or when power failure occurs.
- The Retentive Timer instruction is a retentive instruction that begins to count time base intervals when rung conditions become true.
- The Retentive Timer instruction retains its accumulated value when any of the following occurs:
- Rung conditions become false.
- Changing Processor mode from REM run /Test / program mode.
- The processor loses power while battery backup is still maintained and a fault occurs.

4.13 LADDER PROGRAMMING

Ladder programming is a graphical programming language for PLCs. It is very similar to relay control circuit. The relay diagram consists of two vertical lines representing the power rails. Circuits are connected as horizontal lines which are called rungs placed between power rails. Contacts and coils are the basic symbols of the ladder logic diagram instruction set. The main function of ladder logic diagram is to control outputs based on input conditions. In general , a rung consists of set of input conditions , represented by contact instructions, and an output instruction at the end of the rung represented by coil.

The output coil is energized, when any one right-left path contact is closed. A complete closed path is referred as logic continuity. When logic continuity exists, the rung condition is said to be true else false.

The inputs and outputs are addressed by giving digital addresses, depending on the PLC manufacturer. Branch instructions are used to create parallel paths of input condition instructions.

4.25 4.14 LADDER LOGIC DIAGRAM FOR STAR-DELTA STARTER The relay logic diagram of star-Delta starter is shown in fig. 4.29. The operation of the given circuit is as follows **Figure 4.29 Relay logic Diagram of Star-Delta Starter** When the start button is pressed, coil ‘S’ is energized. Auxiliary contacts S4 closes and S5 opens. When S4 is closed, it will energize M coil. Now the main contact closes giving 3ɸ supply to the motor and causes the motor to run in star connection. At the same time Timer T is also energized. It is a ON delay timer. So, the contact T1 will be opened after particular time period. Now the coil S goes to de-energized. When coil S is de-energized, its contacts S4 opens and S5 closes. Now delta contacts get energized and the motor runs in delta connection.

As soon as the delta contactor is energized its inter locking contact D opens, which avoids energization of star contactor. In the running condition contactor M and contactor D remain energized while contactor S and timer T remain de-energized. So, at the beginning 3ɸ motor is run by Star contact. After a particular time period set by the programmer, motor is run by Delta contact till the end.

A) Listing of inputs needed

a. START push button

b. STOP push button

c. Over load Relay(OLR)

4.26

B) Listing of output needed

a. STAR contactor coil(S)

b. DELTA contactor coil(D)

c. MAIN contactor coil(M)

d. ON-DELAY Timer(TON)

Ladder Logic Diagram The ladder logic diagram of Star-Delta starter is shown in the fig.4.30

Figure 4.30 Ladder Logic Diagram of Star-Delta Starter

Execution of Ladder logic diagram

The PLC performs the following functions

1) When START button is pressed, the Star contact gets energized.

2) So, O:0/1 is closed in the Rung 2 and Main contactor (O:0/1) will be energized and motor starts to run by Star contactor.

3) When the Main contactor(O:0/1) is energized, ON delay timer (T4:0) is energized in Rung3 **.**

4) After the particular time set by timer (10 sec), Timer T4:0/DN is energized and it will open the T4:0/DN in rung1. So, Star contactor is de-energized.

4.27

5) Now Delta contactor is energized in Rung4 . So, Main contact is energized by Delta contactor instead of Star contactor. Now motor is run by Delta contactor.

6) When STOP button is pressed, Main contactor gets de-energized and motor

is
Stopped. **4.15 CONVEYOR CONTROL** In sequential control, operations are performed in a specific order. Transporting or moving objects on a conveyor are a simple example of a sequential control system. The process involves the following operation

- o Starting the process
- o Indication for the conveyor movement
- o Indication for the conveyor stoppage
- o Emergency stop
- o Stop the movement when the object has reached the location Motor

Package
Limit switch
Figure 4.31 Schematic diagram of Conveyor Control process The schematic diagram of conveyor process flow is shown in the figure 4.31. The relay ladder diagram for conveyor is shown in fig4.32. The diagram shows all the input switches and output units.
4.28 Figure 4.32 Relay ladder diagram for conveyor control The conveyor process can be written as follows

1. Start button(PB1) is pressed and relay coil ICR is energized
2. Relay coil ICR closes and works as a sealing contact for start button
3. Contact ICR1 opens and red lamp is switched OFF
4. Contact ICR2 closes and green light is Switched ON
5. Contact ICR3 closes, motor winding gets supply. So the conveyor starts moving
6. When the object reaches the location, limit switch LS1 opens and ICR coil is de-energized

7. Coil ICR opens and sealing contact opens
8. Contact ICR1 closes and red light is ON
9. Contact ICR2 opens and green pilot light is OFF
10. Contact ICR3 opens and the motor supply is stopped. Conveyor halts, sequence is over.

The address of input and output contacts are given below. **Input Output** Start - I:0/0 ICR - O:0/0 Stop - I:0/2 Red light -O:0/1 LS1 -I:0/3 Green light(Run) - O:0/2 Motor -O:0/3 The ladder logic diagram of conveyor control is shown in figure 4.33. **4.29**
Figure 4.33 Ladder Logic Diagram of Conveyor belt 4.16 LIFT CONTROL
In the present scenario, buildings are constructed with many numbers of floors. When the number of floors increased, the control mechanism will also become more complex. But programmable logic controllers are used to reduce this problem.
Figure 4.34 Input / Output Connection diagram of Lift Control
An input / output connection diagram for a two floor control system using PLC is shown in figure 4.34 .At the input side, four switches are connected. First two are call floor switches and the remaining two are “sensor floor” switches. At the output side, only two coils are connected, one for motor Hoist up(HU), control and another for motor Hoist down(HD) control. **4.30**
The ladder diagram of two floor lift control system is shown in fig. 4.35
 The first two rungs are used to sense the floor position of the lift car.
 The next two rungs are used to call the floor to go to desired floor.

 The next three rungs are used to hoist the lift car up or down with respect to the floor calling and its current position

The steps for the working of lift car are given below Assume that a lift car moves from the second floor to first floor

 When the call 1st floor button is pressed, 1st called coil gets energized.

 It deactivates the 1st called switch in rung2 and 2nd called coil gets de-energized.

 When 1st called switch is turned ON, Hoist down gets energized in the rung 5 and lift car starts to come down.

 When it reaches the 1st floor, 1st sensed coil gets energized by 1st sensor. So, 1st sensed contact is opened in rung 5 and hoist down coil gets de-energized and lift car stops.

 Now 1st called and 1st sensed are ON and hoist complete coil gets energized in rung6.

 Now the lift car is in the first floor.

 Similarly, when lift moves from 1st floor to 2nd floor, same process takes place in reverse manner .In each floor, to open or close the door, timer can be used.

4.31 Figure 4.35 ladder diagram of Lift Control 4.17 PLC INTERFACING WITH GSM

GSM Modems are playing very important role in every industry and automation industry. GSM modules are largely used in automation industry for providing communication between PLC and other applications like SCADA and HMI's.

4.32 Figure 4.36 PLC interfacing with GSM To communicate Delta PLC with GSM modem the following steps

should be followed **Requirements**
a) Delta PLC with Rs485 or Rs232 port
b) GSM Modem
c) RS232 to RS485 Convertor
d) RS232 to RS485 Convertor
For interfacing between Delta PLC and GSM modem, RS-485 communication port at PLC side and RS232 port at GSM modem side are used . And to connect both these RS-232 to RS-485 convertor have been used as shown in figure 4.25. For this communication, make communication settings in program and then send commands by Serial communication instructions. Commands can be sent to GSM modem with the help of PLC instruction as follows 1. Set M1122. Whenever sending commands to GSM MODULE. M1122 is sending request flags M1122 for COM2. It has to be enabled in advance for obtaining correct operation. 2. for sending commands use following instruction and operands.

RS
S
m
D
n

Use the following operands for instruction **4.33** S: Start device for transmitting data m: Transmitting data group number(m=0-256) D: Start device for receiving data
n: Receiving data group number Now to send AT command from PLC , the instruction can be used as shown in figure 4.37

M0
AT Sending request

Figure 4.37 PLC interfacing with GSM To Set M0 bit, ASCII commands have to be sent. RS instruction will transfer the AT commands to GSM modem. For that write ASCII value of commands in D408 to D410. The ASCII value of command is written in following register,

ASCII CHARACTER	DATA REGISTER	HEX CODE
A	D408	H41
T	D409	H54
	D410	HD

If GSM Modem is working properly, it will respond to AT command. And we get below data in D2200 to DD2206 register.

ASCII CHARACTER	DATA REGISTER	HEX CODE
A	D2200	H41
T	D2201	H54
	D2202	HD
	D2204	HD
O	D2205	H4F
K	D2206	H4B

SET M1122

RS D408 K3 D2200 K6 M1122

4.34 Now, OK will be received from the GSM Modem, then send below commands from PLC. **AT+CMGF=1 AT+CMGR="9900123456"** (Phone number to send SMS) Similarly a message can be sent from PLC and get response from GSM modem. Suppose, if we want to send "Hello". Here we have sent five letters only. It needs to send ctrl+z to send your message. So we have sent five data register for our message and one for ctrl+z. ASCII code for ctrl+z is H1A. If a message contains more letters then write appropriate value in instructions; if message contains 16 letters then use 16 data register for message and plus one data register for ctrl+z; so use total 17 data register including ctrl+z.

REVIEW QUESTIONS PART- A

1. Define PLC.
2. What is relay?
3. What are the different types of relay?
4. State any two advantages of relay.
5. What is input module?
6. Give any two examples for input devices.
7. Give any two examples for output devices
8. Mention the parts of PLC.
9. State the different types of I/O module.
10. Draw any two symbols in ladder diagram.

PART- B

1. Compare PLC circuit and relay logic circuit
2. Write briefly about input module
3. Write briefly about output module
4. Draw the ladder diagram for EX-OR and NAND gate.
5. Draw the symbols used in ladder logic diagram.
6. Draw ladder logic diagram for conveyor control.

4.35 PART – C

1. Draw the block diagram of PLC and explain each block.
2. Explain the digital input module with neat diagrams.
3. Explain the different types of relays.
4. Explain the digital output module with neat diagrams
5. Draw the ladder logic diagram of STAR- DELTA starter and explain it.
6. Explain the various logic functions used in PLC.
7. Draw the ladder diagram of lift control system and explain neatly.
8. Draw the ladder diagram of conveyor control system and explain neatly.

5.01

UNIT – V DISTRIBUTED CONTROL SYSTEM 5.1 INTRODUCTION In any plant, the purpose of automation is to maintain the product quality, consistency, reduce start-up time, and increase speed of operation with human safety. Control system whether it is a Programmable Logic Controller (PLC) or a Distributed Control System (DCS) is required for the same purpose. **5.2 EVOLUTION OF DISTRIBUTED CONTROL SYSTEM**

<1950s - Early Process Control

- Analog devices
- Wired by hand
- Poor flexibility
- Main cost = the more loops =more space
- Simple loops not automated

1950s - The Pioneering Period

- Computer controlled system
- Supervision, printing instructions, set point control
- Control still analog

- Improved understanding
- Specialized hardware
- Interrupts

1960s - Direct Digital Control

- Direct Digital Control
- Only large systems
- Digital operator panels
- Better flexibility
- DDC(Direct digital Control) languages
- No programming, just configuration
- Only pre-defined control
- Building automation

1970s - Cheaper Computers

- Microcomputers – Cheaper, faster, more reliable

1980s - DCS Emerges

- Analog system replaced with digital
- Distributed Control system introduced
- Redundancy and real-time communication

5.02

1990s - The Field bus Wars

- Communication analog to digital
- No standard communication protocol
- Many organizations and DCS vendors
- Microsoft Windows

Till now

- Modern DCSs also support neural networks and fuzzy application
- DCSs are usually designed with redundant processors to enhance the reliability of the control system

5.3 HYBRID SYSTEM ARCHITECTURE

Hybrid systems are basically networks of interacting digital and analog devices. A computer which acts as a logic decision unit, processes input and provides output in digital form, i.e. 0 and 1. It is also known as a discrete-time system. It is easy to see that a system which processes only continuous-time data is called a continuous-time system, that is, it can be represented by mathematical functions. **The mixture of discrete-time system and continuous-time system is known as hybrid control system.**

A typical hybrid system is represented in the figure 5.1. Almost any hybrid control system can be modeled by this two-layer structured block diagram. The layers called discrete event system and continuous system communicate through the interface. The continuous control layer is the power control part and the logic part is the preset program or logic. The analog to digital converter and digital to analog converter are the interface. As we can see, Figure 5.1 is a highly ordered and hierarchical structure, the logical layer(discrete event system) issues instructions which are converted into continuous input for the continuous layer(continuous system). The continuous layer feeds reference values back to the interface which converts them into discrete form. If the output of a system feeds back to its input, it is called a closed loop system; otherwise it is called an open loop system. Both types of systems are shown in figure 5.2. **5.03**

DISCRETE EVENT SYSTEM Finite State Machine, Fuzzy Logic Rule based Generalized D/A Generalized A/D Converter Converter

Figure 5.1 Hybrid control system architecture

Ea(S)

R(S) + _

Input Output

Open loop(without feedback) Closed loop(with feedback) Figure 5.2 Open loop and Closed loop system

Apart from the continuous control system layer, the logic layer is also an important part of a hybrid system. A hybrid system provides more flexibility than purely continuous **5.04** systems, since the logical unit has decision-making ability and planning capacity, because decision-making and planning are basically discrete processes. For most systems, the logic part and continuous part are designed independently, and then combined by an interface which is designed for solving the specific problem, or the whole system is analyzed as either purely discrete or continuous entities.

5.4 CENTRALIZED SYSTEM ARCHITECTURE

INTERFACE

Signal / Symbol Translator

CONTINUOUS SYSTEM Differential / Difference Equations

Process

H(s)

G(s)

In a central architecture a PC which deals with all tasks such as I/O connections, PLC, and motion control. However, there is only one CPU means only one such spare part is needed.

Figure 5.3 Centralized control system for a real-time system In a centralized control model, one component is designated as the controller and is responsible for managing the execution of other components. Centralized control models fall into two classes, depending on whether the controlled components execute sequentially or in parallel.

1. Call–return model: This is the familiar top-down subroutine model where control starts at the top of a subroutine hierarchy and, through subroutine calls, passes to lower levels in the tree. The subroutine model is only applicable to sequential systems.

2. Manager model: This is applicable to concurrent systems. One system component is designated as a system manager and controls the starting, stopping, Co-ordination and scheduling of other system processes.

5.05 Figure 5.3 is an illustration of a centralized management model of control for a concurrent system. The central controller manages the execution of a set of processes associated with sensors and actuators. The building monitoring system uses this model of control.

The system controller decides when processes should be started or stopped depending on system state variables. It checks whether other processes have produced information or to pass information to them for processing. The controller usually checks the status of sensors and other processes for events or state changes. For this reason, this model is sometimes called an event-loop model.

5.5 DISTRIBUTED CONTROL SYSTEM ARCHITECTURE A Distributed Control System (DCS) is a control system for a process or plant, wherein control elements (controllers) are distributed through out the system. This is in contrast to non-distributed systems that use a single controller at a central location.

Production Scheduling
Production Control

Plant
supervisory
Direct control
Field level **Figure 5.4 Distributed Control system Architecture 5.06** A DCS typically uses custom designed processors as controllers and uses either interconnections or standard protocols for communication. Input and output modules form the peripheral components of the system.

The controllers receive information from input modules and command from operator through computer center, coordinating computer and supervisory computer. Then controllers process the information and decide actions to be performed by the output modules. The input modules receive information from input instruments like sensors and the output modules transmit instructions to the actuators in the plant for starting actions mainly via final control elements. The inputs and outputs can either be continuously changing analog signals e.g. 4~20mA dc current or 2 state discrete signals that switch either "on" or "off" e.g. relay contacts. The signals can be transmitted via a communication

Computer Center
Coordinating Computer
Coordinating Computer
Supervisory Computer
Supervisory Computer
Supervisory Computer
Supervisory Computer
Controller
Controller
Controller
Controller
Controller
Controller

Controller
Controller
Plant
Plant

link such as PC Link and other digital communication bus that carries not only input and output signals but also advanced messages such as error diagnostics and status signals. **5.6 COMPARISON OF ARCHITECTURES**

FEATURE
HYBRID ARCHITECTURE
CENTRAL COMPUTER ARCHITECTURE
DISTRIBUTED ARCHITECTURE

1. Scalability and expandability
Good due to modularity
Poor-very limited range of system size
Good due to modularity
2. Control capability
Limited by analog and sequential control hardware
Full digital control capability
Full digital control capability
3. Operator interfacing capability
Limited by panel board instruments
Digital hardware provides significant improvement for large system
Digital hardware provides improvement for full range of system sizes.
4. Integration of system functions
Poor due to variety of products
All functions performed by central computer
Functions integrated in a final products
5. Significance of single point failure
Low due to modularity
High due to modularity
Low due to modularity
6. Installation cost
High due to discrete wiring and large

volume of equipment
Medium- saves control room and equipment room space but uses discrete wiring
Low-savings in both wiring costs and equipment space

5.07

7. Maintainability
Poor-many module types , few diagnostics
Medium requires highly trained computer maintenance personnel
Excellent automatic diagnostics and module replacement

5.7 LOCAL CONTROL UNIT:

The local control unit (LCU) is the smallest collection of hardware in the distributed control system that performs closed loop control. That is, it takes inputs from process measuring device and commands from the operator and computes the control outputs. It is sends the control outputs to the output devices such as actuators, drives, valves, and other mechanical devices that regulate the flows, temperatures, pressures, and other variables in the plant.

Basic Elements of LCU The basic elements of a generalized microprocessor-based LCU is as shown in figure 5.5. The microprocessor along with its associated clock is the central processing unit (CPU) of the controller. Read only memory (ROM) is used for permanent storage of controller programs, and random-access semiconductor memory (RAM) is used for temporary storage of information. Depending on the type of microprocessor used, RAM and ROM can be located on the microprocessor chip or on separate memory chips.

Figure 5.5 Block diagram of Local control unit 5.08 The LCU also must have input / output (I/O) circuitry. So that it can communicate with the external devices by receiving analog and digital data as well as sending similar signals out. Generally, the CPU communicates with the other elements in the LCU through internal bus that transmits address, data, data control, and status information. The control algorithms could be written in assembly language and loaded into ROM. After the controller was turned on, it would read inputs, execute the control algorithms, and generate control in a fixed cycle indefinitely.

1. **Flexibility of changing the control configuration**

In industrial applications the same controller product is used to control different functions. It should have the flexibility of changing the control system without changing the controller hardware

2. **Ability to use the controller without being a computer expert**

CPU
ROM
RAM
I N T E R N A L B U S
Digital input module m m
Digital output module m m
Analog input module m m
Analog output module m m

However, the user is usually not capable of or interested in programming a microprocessor in assembly language. He or she simply wants to be able to implement the selected control algorithms. Therefore, a mechanism for allowing the user to "configure the LCU''s control algorithms in a relatively simple way must be provided.

3. **Ability to bypass the controller**
Shutting down the process is very expensive and undesirable for the control system user. Since all control equipments are in failure condition, the system architecture must allow an operator to run the process by hand until the control hardware is repaired or replaced.

4. **Ability of the LCU to communicate with other LCUs and other elements in the system**
Controllers in an industrial control system must work in conjunction with other controllers, data I/O devices, and human interface devices. **5.8 Operator displays:** The operator is able to monitor and control the whole process only by using these displays, which usually are arranged in a fixed logical structure or hierarchy**.** A typical version of this hierarchy, illustrated in figure 5.6 is composed of displays at four levels. **5.09**

Plant status display
. . . Area Graphics
Alarm Summary
.. . . Batch sequences .
Operator Guides
X- Y Plots Tuning Displays
Plant
Area
Area
Group
Group
Group
Group
Individual Loops or Data Input Points

Figure 5.6 Block diagram of Local control unit

1. **Plant level** – Displays at this level provide information about the entire plant, which (if large enough) can be broken up into several area of interest.
2. **Area level** – Displays at this level provide information about a portion of the plant equipment that is related in some way, e.g. a boiler-turbine-generator set in a power plant.
3. **Group level** – Displays at this level provide information about a single process unit within a plant area, such as a distillation column or a coding tower.
4. **Loop level** – Displays at this level give information about individual control loops, control sequences, and data points.

Plant-level displays This display summarizes the key information of current plant conditions. This example shows the overall production level at which the plant is operating compared to full capacity. It also indicates how well the plant is running. In addition, some of the key problem areas (e.g. equipment outages or resource shortages) are displayed. **5.10** The names of the various areas in the plant serve as a main menu (index) to the next level of displays. At the top of the plant-status display, a status line of information is provided in all operating displays. This line shows the current day of the week, the date, and the time of the day for display labeling purposes. In addition, it provides a summary of process alarms and equipment diagnostic alarms by listing the number of the plant areas in which outstanding alarm exists.

Figure 5.7 Plant level displays Area-level displays In area level displays as shown in figure 5.8, the information about a selected plant area can be obtained. This can be done by means of several types of displays. Figure 5.8 shows a composite of four of these types. The top line of the display is the system date and status line as previous display. The upper left quadrant illustrates an area display type known as deviation overview, which displays in bar graph. If the absolute value of deviation exceeds a predetermined level (e.g. 5 percent of span), the process variable enters a deviation-alarm status condition and the bar graph for that variable changes color. If the process variable is within a small percentage of the set point, the analog pointer for that variable remains hidden behind a green band on the station face. The operator then can determine which loops are upset by simply scanning the row of stations and seeing which pointers **5.11** are outside the green band. The deviation overview display provides same information in a CRT display format.

Figure 5.8 Area level displays The lower left quadrant graph indicates the absolute value of the process variable. It also shows the set point and the high and low limits on the process variable. When one of these limits is exceeded, the bar graph changes color as in the deviation display. In the upper right-hand quadrant, tag numbers of the various loop and process variables are arranged in clusters by group. If a particular tag is not in alarm, its tag number is displayed in a low-key color. If it is in alarm, it changes color and starts flashing to get the attention of the operator. Underlining also can be used under the tag number to see the alarm state clearly. The lower right-hand quadrant shows the current value of the process variable which is displayed in engineering units in addition to their alarm status. **5.12 Group-level displays**

To perform control operations, however, it is necessary to use the displays at the next lower level called as the group level. As in the case of the higher-level displays, many of the display formats are designed to obtain similar functions.

Figure 5.9 Group level displays

Figure 5.9 shows one example of a typical group display. Mimics of manual and automatic stations for continuous control loops occupy the upper left-hand corner of the display. These mimics include all the elements contained in a similar panel board station. Bar graphs showing values of set point, control output, and process variables. Manual, automatic, and cascade mode indicators and high and low alarm levels are used in display.

Loop-level displays The displays at the group level are the operator's primary working displays. The operator uses a few types of displays dealing with single loops or data points for control and analysis purposes. **5.13**

Figure 5.10 Loop level displays

Figure 5.10 shows an example of X-Y operating display. Here one process variable is plotted as a function of another to show the current operating point of this pair of variables. The operator then can compare this operating point against an alarm limit curve or an operating limit curve.

Design considerations for displays

1. Displays should not be cluttered, but

kept as simple as possible. The simple version is used for most operation; the operator presses a detail key to get more information when needed.

2. Displays should not be overly "flashy" or have light-colored backgrounds. Because the operator can get tired and annoyed when he look at them all day while trying to run a plant.

3. As described previously, the top line or two of each display should contain common information of interest to the operator, such as the date and time of day as well as an overview of the alarm status situation. The bottom line or two of each display should be reserved for communication (e.g., prompts of error messages) between the HLOI system and the operator.

5.14

4. Color should be used in a consistent way throughout all displays to minimize operator confusion. The user should be able to select or change colors in both standard and custom displays to meet the needs of the application.

5. Color should not be used to represent the critical functions such as alarming. Instead. Other mechanisms such as blinking or underlining can be used.

5.9 FEATURES OF DCS Handling complex process DCS is preferred for complex control applications with more number of I/Os with dedicated controllers. **System redundancy** DCS facilitates system availability when needed by redundant feature at every level. **More sophisticated HMI** Similar to the SCADA system, DCS can also monitor and control through HMI's (Human Machine Interface) which provides sufficient data to the operator to charge over various processes and it acts as heart of the system. **Scalable platform** Structure of DCS can be scalable based on the number I/O's from small to large server system by adding more number of clients and servers in communication system and also by adding more I/O modules in distributed controllers.

System security: Access to control various processes leads to plant safety. DCS design offers perfect secured system to handle system functions for better factory automation control. **5.10**

ADVANTAGES OF DCS

1. Flexible in system design
2. Expansion of plant is very easy
3. Maintenance of DCS is easy
4. User can start out at a low level of investment
5. Complete loss of the data highway will not cause complete loss of system capability **5.15**

5.11 APPLICATIONS OF DCS

DCS is used in

1. Oil refineries
2. Petrochemicals
3. Nuclear power plants
4. Environmental control systems
5. Water treatment plants
6. Cement production
7. Steel making and paper making.
8. Agro chemical and fertilizer etc.

REVIEW QUESTIONS PART- A

1. What is meant by hybrid system.
2. Define centralized system.
3. Define DCS.
4. State the features of DCS.
5. State the advantages of DCS.
6. State the applications of DCS.
7. What is local control unit ?
8. Mention the types of operator displays used in DCS.

9. Define local control unit.
10. What is plant displays?
11. What is area displays?
12. What is loop level displays?
13. What is group level displays?
14. State the any two features of DCS.
15. State any four advantages of DCS.
16. Give the applications of DCS.

PART – B

1. Compare hybrid system, centralized system and distributed control system architecture.
2. Briefly write about plant level displays.
3. Briefly write about area level displays.
4. Briefly write about group level displays.
5. Briefly write about loop level displays.
6. Write about the features of DCS.

5.16 PART – C

1. With neat diagram explain the hybrid system architecture.
2. Draw the block diagram of centralized system architecture and explain it.
3. With diagram explain about generalized distributed control system.
4. Define LCU and explain the basic elements of LCU.
5. Briefly explain the different operator displays.