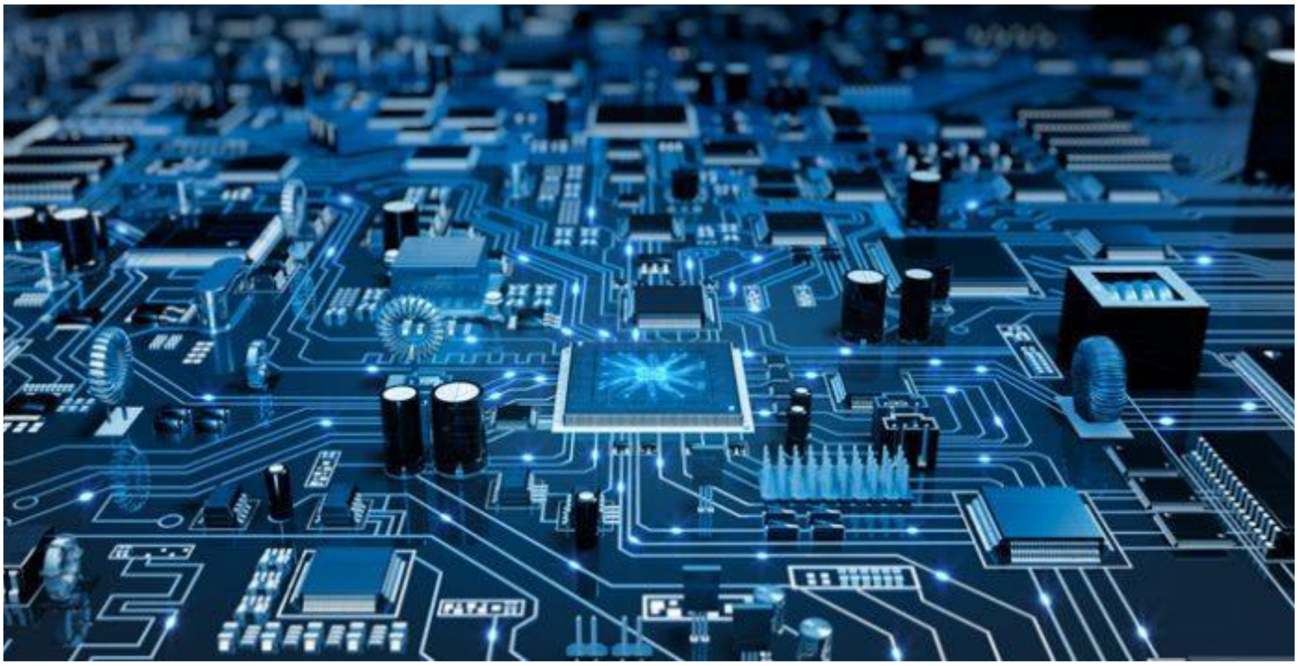
Al-Mustaqbal University
Department of Medical Instrumentation Techniques Engineering
Class: Third
Subject: Medical Communication Systems
Lecturer: Prof. Adnan Ali
Lecture:1

Mode Unit 1

Introduction to Electronic Systems

For
Students of Third Stage
Department of Medical Instrumentation Techniques Engineering



By

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1. Overview:

a. Target population:

For students of third class of Department of Medical Instrumentation Techniques Engineering, Electrical Engineering Technical College, Middle Technical University, Baghdad, Iraq.

b. Rationale:

Electronics systems are the art of converting electrical energy from one form to another in an efficient, clean, compact, and robust manner for convenient utilization.

c. Objectives:

The student will be able after finishing lecture on:

1. Define electronic systems devices.
2. Create an awareness of the general nature of Power electronic equipment.
3. Brief idea about topics of study involved.
4. Choose device for a particular application.
5. Drive and protection of PE devices and equipment common to most varieties.

2. Introduction:

A passenger lift in a modern building equipped with a Variable-Voltage-Variable-Speed induction-machine drive offers a comfortable ride and stops exactly at the floor level. Behind the scene it consumes less power with reduced stresses on the motor and corruption of the utility mains.

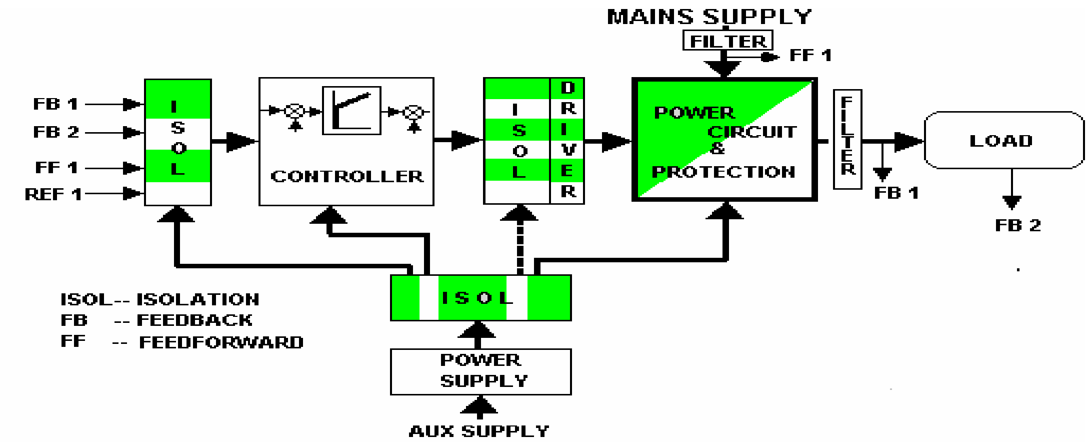

Fig. 1.1 The block diagram of a typical Power Electronic converter

Electronic systems involve the study of

- Semiconductor *devices* - their physics, characteristics, drive requirements and their protection for optimum utilisation of their capacities,
- Power converter *topologies* involving them,
- *Control* strategies of the converters,
- Digital, analogue and micro*electronics* involved,
- Capacitive and magnetic energy storage elements,
- Rotating and static *electrical devices*,
- *Quality* of waveforms generated,
- Electro Magnetic and Radio Frequency *Interference*,
- *Thermal* Management

How is electronic systems distinct from linear electronics?

It is not primarily in their power handling capacities.

While power management IC's in mobile sets working on Power Electronic principles are meant to handle only a few milliwatts, large linear audio amplifiers are rated at a few thousand watts. The utilisation of the Bipolar junction transistor, Fig. 1.2 in the two types of amplifiers best symbolises the difference. In Electronic systems all devices are operated in the switching mode - either 'FULLY-ON' or 'FULLY-OFF' states. The linear amplifier concentrates on fidelity in signal amplification, requiring transistors to operate strictly in the linear (active) zone, Fig 1.3. Saturation and cutoff zones in the V_{CE} - I_C plane are avoided. In a Power electronic switching amplifier, only those areas in the V_{CE} - I_C plane which have been skirted above, are suitable. On-state dissipation is minimum if the device is in saturation (or quasi-saturation for optimising other losses). In the off-state also, losses are minimum if the BJT is reverse biased. A BJT switch will try to traverse the active zone as fast as possible to minimise switching losses.

Fig. 1.2 Typical Bipolar transistor based (a) linear (common emitter) (*voltage*) amplifier stage and (b) switching (*power*) amplifier

Fig 1.3 Operating zones for operating a Bipolar Junction Transistor as a linear and a switching amplifier

An example illustrating the linear and switching solutions to a power supply specification will emphasise the difference.

Fig. 1.4 (a) A Linear regulator and (b) a switching regulator solution of the specification above

The linear solution, Fig. 1.4 (a), to this quite common specification would first step down the supply voltage to 12-0-12 V through a power frequency transformer. The output would be rectified using Power frequency diodes, electrolytic capacitor filter and then series regulated using a chip or a audio power transistor. The tantalum capacitor filter would follow**.** The balance of the voltage between the output of the rectifier and the output drops across the regulator device which also carries the full load current. The power loss is therefore considerable. Also, the step-down iron-core transformer is both heavy, and lossy. However, only twice-line-frequency ripples appear at the output and material cost and technical know-how required is low.

In the switching solution Fig. 1.4 (b) using a MOSFET driven flyback converter, first the line voltage is rectified and then isolated, stepped-down and regulated. A ferrite-core high-frequency (HF) transformer is used. Losses are negligible compared to the first solution and the converter is extremely light. However significant high frequency (related to the switching frequency) noise appear at the output which can only be minimised through the use of costly 'grass' capacitors.

The range of power devices thus developed over the last few decades can be represented as a tree, Fig. 1.5, on the basis of their controllability and other dominant features.

Fig. 1.5 Power semiconductor device variety

3. Power Diodes

Fig. 1.6 Typical turn-off dynamics of a soft and a 'snappy' diode'

Silicon Power diodes are the successors of Selenium rectifiers having significantly improved forward characteristics and voltage ratings. They are classified mainly by their turn-off (dynamic) characteristics Fig. 1.6. The minority carriers in the diodes require finite time - t_{rr}

(reverse recovery time) to recombine with opposite charges and neutralise. Large values of Q_{rr}

(= Q_1 + Q_2) - the charge to be dissipated as a negative current when the and diode turns off and t_{rr} (= t_2 - t_0) - the time it takes to regain its blocking features, impose strong current stresses on the controlled device in series. Also a 'snappy' type of recovery of the diode effects high di/dt voltages on all associated power device in the converter because of load or stray inductances present in the network. There are broadly three types of diodes used in Power electronic applications:

Line-frequency diodes: These PIN diodes with general-purpose rectifier type applications, are available at the highest voltage (~5kV) and current ratings (~5kA) and have excellent over-current (surge rating about six times average current rating) and surge-voltage withstand capability. They have relatively large Q_{rr} and t_{rr} specifications.

Fast recovery diodes: Fast recovery diffused diodes and fast recovery epitaxial diodes, FRED's, have significantly lower Q_{rr} and t_{rr} (~ 1.0 _ sec). They are available at high powers and are mainly used in association with fast controlled-devices as free-wheeling or DC-DC choppers and rectifier applications. Fast recovery diodes also find application in induction heating, UPS and traction.

Schottky rectifiers: These are the fastest rectifiers being majority carrier devices without any Q_{rr}.. However, they are available with voltage ratings up to a hundred volts only though current ratings may be high. Their conduction voltages specifications are excellent (~0.2V). The freedom from minority carrier recovery permits reduced snubber requirements. Schottky diodes face no competition in low voltage SPMS applications and in instrumentation.

4. Silicon Controlled Rectifier (SCR)

The Silicon Controlled Rectifier is the most popular of the thyristor family of four layer regenerative devices. It is normally turned on by the application of a gate pulse when a forward bias voltage is present at the main terminals. However, being regenerative or 'latching', it cannot be turned off via the gate terminals specially at the extremely high amplification factor of the gate. There are two main types of SCR's.

Converter grade or Phase Control thyristors These devices are the work horses of the Electronic systems. They are turned off by natural (line) commutation and are reverse biased at least for a few milliseconds subsequent to a conduction period. No fast switching feature is desired of these devices. They are available at voltage ratings in excess of 5 KV starting from about 50 V and current ratings of about 5 KA. The largest converters for HVDC transmission are built with series-parallel combination of these devices. Conduction voltages are device voltage rating dependent and range between 1.5 V (600V) to about 3.0 V (+5 KV). These devices are unsuitable for any 'forced-commutated' circuit requiring unwieldy large commutation components.

The dynamic di/dt and dv/dt capabilities of the SCR have vastly improved over the years borrowing emitter shorting and other techniques adopted for the faster variety. The requirement for hard gate drives and di/dt limting inductors have been eliminated in the process.

Inverter grade thyristors: Turn-off times of these thyristors range from about 5 to 50 μsecs when hard switched. They are thus called fast or 'inverter grade' SCR's. The SCR's are mainly used in circuits that are operated on DC supplies and no alternating voltage is available to turn them off. Commutation networks have to be added to the basic converter only to turn-off the SCR's. The efficiency, size and weight of these networks are directly related to the turn-off time, t_q of the SCR. The commutation circuits utilised resonant networks or charged capacitors. Quite a few commutation networks were designed and some like the McMurray-Bedford became widely accepted.

Asymmetrical, light-activated, reverse conducting SCR's Quite a few varieties of the basic SCR have been proposed for specific applications. The Asymmetrical thyristor is convenient when reactive powers are involved and the light activated SCR assists in paralleling or series operation.

5. MOSFET

The Power MOSFET technology has mostly reached maturity and is the most popular device for SMPS, lighting ballast type of application where high switching frequencies are desired but operating voltages are low. Being a voltage fed, majority carrier device (resistive behaviour) with a typically rectangular Safe Operating Area, it can be conveniently utilized. Utilising shared manufacturing processes, comparative costs of MOSFETs are attractive. For low frequency applications, where the currents drawn by the equivalent capacitances across its terminals are small, it can also be driven directly by integrated circuits. These capacitances are the main hindrance to operating the MOSFETS at speeds of several MHz. The resistive characteristics of its main terminals permit easy paralleling externally also. At high current low voltage applications the MOSFET offers best conduction voltage specifications as the $R_{DS(ON)}$ specification is current rating dependent. However, the inferior features of the inherent anti-parallel diode and its higher conduction losses at power frequencies and voltage levels restrict its wider application.

The IGBT

It is a voltage controlled four-layer device with the advantages of the MOSFET driver and the Bipolar Main terminal. IGBTs can be classified as punch-through (PT) and non-punch-through (NPT) structures. In the punch-through IGBT, a better trade-off between the forward voltage drop and turn-off time can be achieved. Punch-through IGBTs are available up to about 1200 V. NPT IGBTs of up to about 4 KV have been reported in literature and they are more robust than PT IGBTs particularly under short circuit conditions. However they have a higher forward voltage drop than the PT IGBTs. Its switching times can be controlled by suitably shaping the drive signal. This gives the IGBT a number of advantages: it does not require protective circuits, it can be connected in parallel without difficulty, and series connection is possible without dv/dt snubbers. The IGBT is presently one of the most popular device in view of its wide ratings, switching speed of about 100 KHz a easy voltage drive and a square Safe Operating Area devoid of a Second Breakdown region.

6. The GTO

The GTO is a power switching device that can be turned on by a short pulse of gate current and turned off by a reverse gate pulse. This reverse gate current amplitude is dependent on the anode current to be turned off. Hence there is no need for an external commutation circuit to turn it off. Because turn-off is provided by bypassing carriers directly to the gate circuit, its turn-off time is short, thus giving it more capability for highfrequency operation than thyristors. The GTO symbol and turn-off characteristics are shown in Fig. 30.3. GTOs have the I^2t withstand capability and hence can be protected by semiconductor fuses. For reliable operation of GTOs, the critical aspects are proper design of the gate turn-off circuit and the snubber circuit.

7. Protection of Power devices and converters

Power electronic converters often operate from the utility mains and are exposed to the disturbances associated with it. Even otherwise, the transients associated with switching circuits and faults that occur at the load point stress converters and devices. Consequently, several protection schemes must be incorporated in a converter. It is necessary to protect both the Main Terminals and the control terminals. Some of these techniques are common for all devices and converters. However, differences in essential features of devices call for special protection schemes particular for those devices. The IGBT must be protected against latching, and similarly the GTO's turn-off drive is to be disabled if the Anode current exceeds the maximum permissible turn-off-able current specification. Power semiconductor devices are commonly protected against:

1. Over-current;
2. di/dt;
3. Voltage spike or over-voltage;
4. dv/dt ;
5. Gate-under voltage;
6. Over voltage at gate;
7. Excessive temperature rise;
8. Electro-static discharge;

Semiconductor devices of all types exhibit similar responses to most of the stresses, however there are marked differences. The SCR is the most robust device on practically all counts. That it has an I^2t rating is proof that its internal thermal capacities are excellent. A HRC fuse, suitably selected, and in co-ordination with fast circuit breakers would mostly protect it. This sometimes becomes a curse when the cost of the fuse becomes exorbitant. All transistors, specially the BJT and the IGBT is actively protected (without any operating cost!) by sensing the Main Terminal voltage, as shown in Fig. 1.7. This voltage is related to the current carried by the device. Further, the transistors permit designed gate current waveforms to minimise voltage spikes as a consequence of sharply rising Main terminal currents. Gate resistances have significant effect on turn-on and turn-off times of these devices - permitting optimisation of switching times for the reduction of switching losses and voltage spikes.

8. **Post test**

Qs1: Which is the Power semiconductor device having

a) Highest switching speed;

b) Highest voltage / current ratings;

c) Easy drive features;

d) Can be most effectively paralleled;

e) Can be protected against over-currents with a fuse;

f) Gate-turn off capability with regenerative features;

g) Easy drive and High power handling capability

Qs2: An SCR requires 50 mA gate current to switch it on. It has a resistive load and is supplied from a 100 V DC supply. Specify the Pulse transformer details and the circuit following it, if the driver circuit supply voltage is 10 V and the gate-cathode drop is about 1 V.

9. key answer

Ans Qs1: a) MOSFET; b) SCR; c) MOSFET; d) MOSFET; e) SCR ; (f) GTO; (g) IGBT

Ans Qs2: The most important ratings of the Pulse transformer are its volt-secs rating, the isolation voltage and the turns ratio.

The volt-secs is decided by the product of the primary pulse-voltage multiplied by the period for which the pulse is applied to the winding

If the primary pulse voltage = (Supply voltage – drive transistor drop)

The turn-on time of he SCR may be in the range 50 µsecs for an SCR of this rating. Consequently the volt secs may be in the range of 9 x 50 = 450 µvolt-secs

The Pulse transformer may be chosen as: 1:1, 450 µVs, V_{isol} = 2.5 KV, I_M = 150 mA

The circuit shown in Fig. 1.7 may be used. Diodes 1N4002

Series resistance

= (Supply voltage – drive transistor drop – gate-cathode drop)/100mA

= (10 –1 –1) / 100 E-3

= 80 Ohm

= 49 or 57 Ohm (nearest available lower value)