SHIVAJI UNIVERSITY, KOLHAPUR
B.Sc. (Part III) Semester -V

Electronics (Paper-XII)

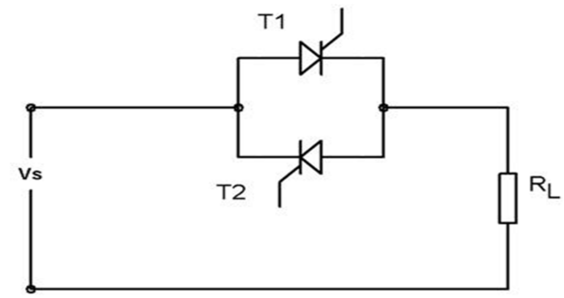
Power Electronic Devices and Applications

Unit 4:- Single phase AC voltage controllers (10 Marks)

AC voltage controller is a thyristor base circuit design to control rms value of AC voltage applied to load.

Principle of ON/OFF control: -

Circuit Diagram:-



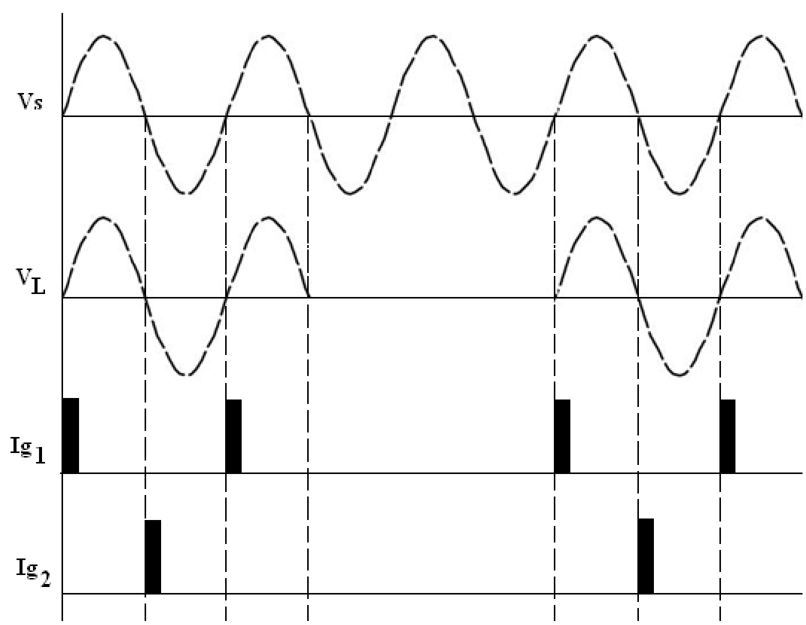
Here load is connected series of pair of thyristors and thyristors are connected in anti-parallel.
In the principle of ON-OFF control, the load is connected to ac source through thyristor for few cycle of ac input then disconnect for another few cycles to ac source. Thus load is alternately connected and disconnected for few cycles to ac source.

If the thyristors are turn ON for an integral number of 'n' cycles and turn OFF for another 'm' cycles then duty cycle is given by,

$$D = \frac{\text{No. of ON cycles}}{\text{No. of ON cycles} + \text{No. of OFF cycles}}$$

$$\mathrm{D} = \frac{\mathrm{n}}{\mathrm{n} + \mathrm{m}}$$

Waveform:-



For above wave form the thyristor is turn on for three cycles and turn OFF for three cycles then its duty cycle is given by,

$$\mathrm{D} = \frac{\mathrm{n}}{\mathrm{n} + \mathrm{m}} \quad => \quad \mathrm{D} = \frac{3}{3 + 3} \quad => \quad \mathrm{D} = \frac{3}{6} \quad => \quad \mathrm{D} = \frac{1}{2}$$

Analysis:-

RMS load voltage:-

$$V_{rms} = \sqrt{\frac{n}{n+m}\frac{1}{2\pi}\int_0^{2\pi} V_S^2 \; d\omega t}$$

$$V_{rms} = \sqrt{\frac{n}{n+m}\frac{1}{2\pi}\int_0^{2\pi} V_m^2 \sin^2 \omega t \; d\omega t}$$

$$V_{rms} = \sqrt{\frac{n}{n+m}\frac{1}{2\pi}\int_0^{2\pi} V_m^2 \sin^2 \omega t \; d\omega t}$$

$$V_{rms} = \sqrt{\frac{n}{n+m}\frac{V_m^2}{2\pi}\int_0^{2\pi} \frac{1-\cos 2\omega t}{2} \; d\omega t}$$

$$V_{rms} = \sqrt{\frac{n}{n+m}\frac{V_m^2}{4\pi}\int_0^{2\pi} 1-\cos 2\omega t \; d\omega t}$$

$$V_{rms} = \sqrt{\frac{n}{n+m}\frac{V_m^2}{4\pi}\left(\int_0^{2\pi} 1 \, d\omega t - \int_0^{2\pi} \cos 2\omega t \, d\omega t\right)}$$

$$V_{rms} = \sqrt{\frac{n}{n+m}\frac{V_m^2}{4\pi}\left([\omega t]_0^{2\pi} - \left[\frac{\sin 2\omega t}{2}\right]_0^{2\pi}\right)}$$

$$V_{rms} = \sqrt{\frac{n}{n+m}\frac{V_m^2}{4\pi}\left([2\pi - 0] - \left[\frac{\sin 4\pi}{2} - \frac{\sin 0}{2}\right]\right)}$$

$$V_{rms} = \sqrt{\frac{n}{n+m}\frac{V_m^2}{4\pi}\left([2\pi - 0] - [0 - 0]\right)}$$

$$V_{rms} = \sqrt{\frac{n}{n+m}\frac{V_m^2}{4\pi}(2\pi)}$$

$$V_{rms} = \sqrt{\frac{n}{n+m}\frac{V_m^2}{2}}$$

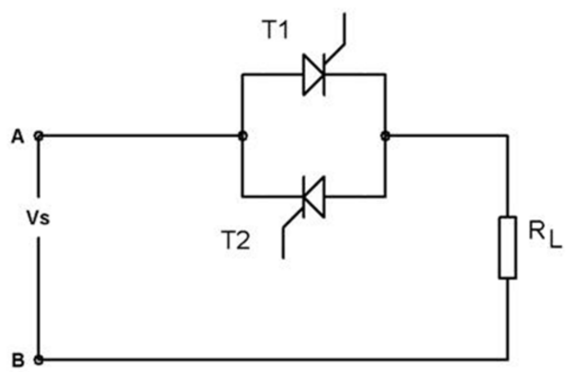
$$V_{rms} = \sqrt{\frac{n}{n+m}}\frac{V_m}{\sqrt{2}}$$

$$V_{rms} = \sqrt{K}\, V_s$$

Where, $K = \frac{n}{n+m}$, $V_s = \frac{V_m}{\sqrt{2}}$

Single- phase bidirectional controller with resistive load (R): -

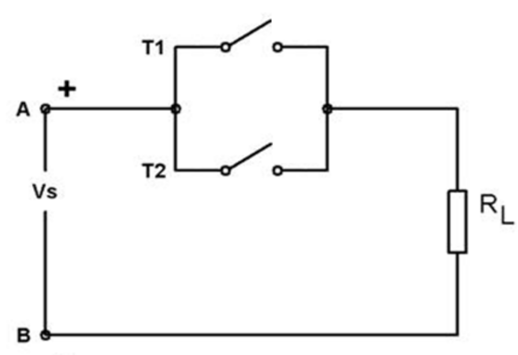
Circuit Diagram:-



In figure load is connected series through thyristor T_1 and T_2. The thyristor T_1 and T_2 are connected in anti-parallel form.

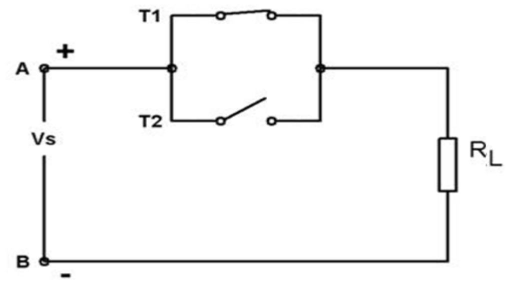
1. 0< ωt < α: -

During this period point A is positive and point B is negative. Therefore thyristor T_1 and is forward biased. But thyristor T_1 is in OFF state therefore it is not conducting any current. Therefore no current flows through the load and output becomes zero.



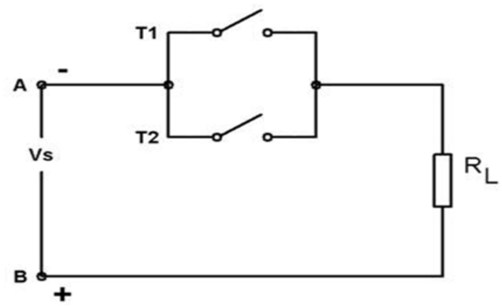
2. $\alpha < \omega t < \pi$: -

At instant $\omega t = \alpha$, the firing pulse is applied to gate of thyristor T_1. As thyristor T_1 is already forward biased, it will be turned ON. As the thyristor is turned on, current start to flows and its path is A→ T_1 → R→ B**.** Thyristor T_1 act as closed switch, therefore load is directly connects to input. The output becomes equals to input voltage.



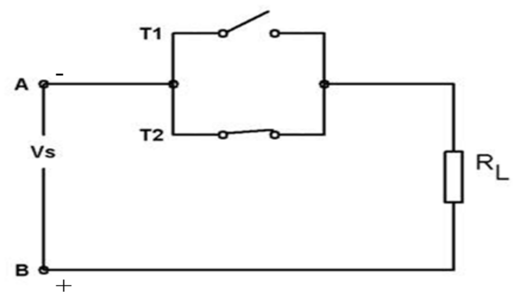
3. $\pi < \omega t < \alpha + \pi$: -

During this time period, point A is negative and point B is positive. Therefore thyristor T_1 is reverse biased. So the current flowing through it becomes zero. The thyristor T_2 is forward biased during this time period. But thyristor T_2 is in OFF state therefore it is not conducting any current. Therefore no current flows through the load and output becomes zero.

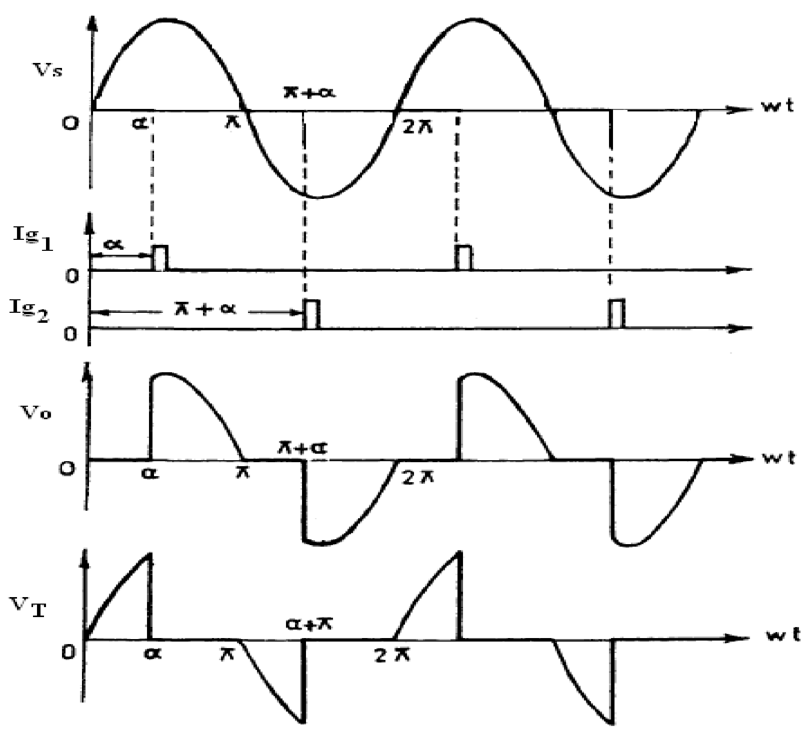


4. $\alpha + \pi < \omega t < 2\pi$: -

At instant $\omega t = \alpha + \pi$, the firing pulse is applied to gate of thyristor T_2. As thyristor T_2 is already forward biased, it will be turned ON. As the thyristor is turned on, current start to flows and its path is B→ T_2 → R →A**.** Thyristor T_2 act as closed switch, therefore load is directly connects to input. The output becomes equals to input voltage.



Waveform:-



Analysis:-

RMS load voltage:-

$$V_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} V_s^2 dt}$$

$$V_{rms} = \sqrt{\frac{1}{2\pi}\left[\int_0^{\alpha} V_s^2 dt + \int_{\alpha}^{\pi} V_s^2 dt + \int_{\pi}^{\alpha+\pi} V_s^2 dt + \int_{\alpha+\pi}^{2\pi} V_s^2 dt\right]}$$

$$V_{rms} = \sqrt{\frac{1}{2\pi}\left[0 + \int_{\alpha}^{\pi} V_s^2 dt + \int_{\pi}^{\alpha+\pi} V_s^2 dt + 0\right]}$$

$$V_{rms} = \sqrt{\frac{2}{2\pi}\left[\int_{\alpha}^{\pi} V_s^2 dt\right]}$$

$$V_{rms} = \sqrt{\frac{1}{\pi}\left[\int_{\alpha}^{\pi} V_m^2 \sin^2 dt\right]}$$

$$V_{rms} = \sqrt{\frac{V_m^2}{\pi}\left[\int_{\alpha}^{\pi} \sin^2 dt\right]}$$

$$V_{rms} = \sqrt{\frac{V_m^2}{\pi}\int_{\alpha}^{\pi} \frac{1-\cos\ 2\omega t}{2} dt}$$

$$V_{rms} = \sqrt{\frac{V_m^2}{2\pi}\int_{\alpha}^{\pi} (1-\cos 2\omega t)\ dt}$$

$$V_{rms} = \sqrt{\frac{V_m^2}{2\pi}\left(\int_{\alpha}^{\pi} 1\ dt - \int_{\alpha}^{\pi} \cos 2\omega t\, dt\right)}$$

$$V_{rms} = \sqrt{\frac{V_m^2}{2\pi}\left([\ t\ ]_{\alpha}^{\pi} - \left[\frac{\sin 2\omega t}{2}\right]_{\alpha}^{\pi}\right)}$$

$$V_{rms} = \sqrt{\frac{V_m^2}{2\pi}\left([\pi-\alpha] - \frac{1}{2}\ [\ \sin 2\pi - \sin 2\alpha\ ]\right)}$$

$$V_{rms} = \sqrt{\frac{V_m^2}{2\pi}\left([\pi-\alpha] - \frac{1}{2}\ [0 - \sin 2\alpha\ ]\right)}$$

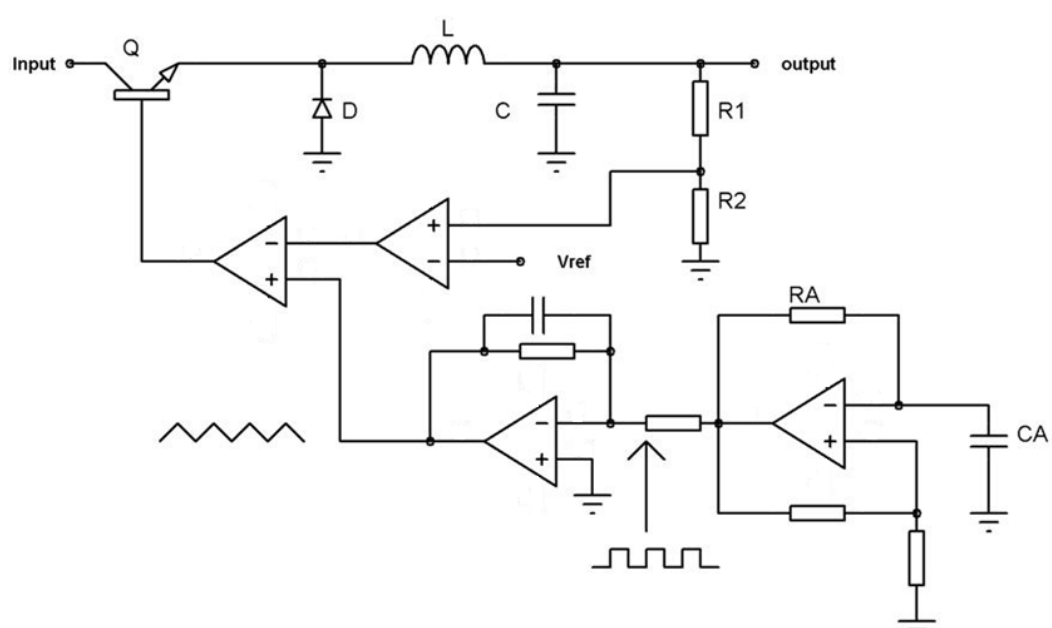
$$V_{rms} = \frac{V_m}{\sqrt{2}}\sqrt{\frac{1}{\pi}\left(\pi - \alpha + \frac{\sin 2\alpha}{2}\right)}$$

Applications of Power Electronics

SMPS (Switch Mode Power Supply): -

- In this power supply series pass element act as a switch having only two states, Cut off and saturation at high frequency.
- It produces square wave output which is filtered to obtain average voltage.
- By switching action efficiency is highest and nearly 95%.

Block diagram:-



The figure shows detail block diagram of switching regulator. Square wave generator whose frequency is by R_A and C_A is used as relaxation oscillator. This square wave integrated to get a triangular wave which drives the non inverting input. It is triangular to pulse converter box. The pulse train output of this circuit drives base of series pass transistor Q.

The transistor acts like a switch. When base voltage is high transistor is saturated. When base voltage is low transistor is cut off.

The diode is connected from the emitter of transistor to ground. This avoids the distraction of transistor due to inductor kick back and inductor tries to keep current through constant. When transistor cut off, the diode continues to provide path for current through inductor.

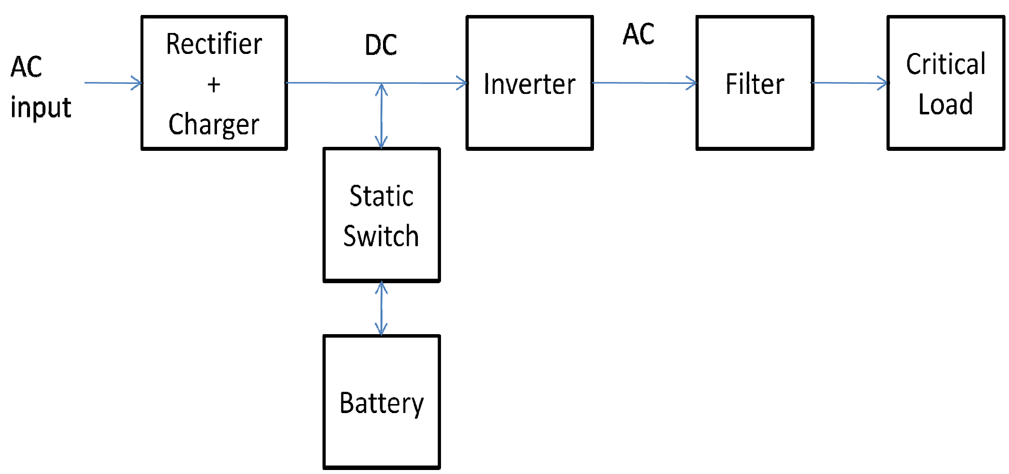
L and C acts as a filter. It control the duty cycle of input voltage. This input voltage varies from 0 to V_{in}. As switching frequency around 20 KHz. R_1 and R_2 provide the voltage of comparator. It is compared then drives the inverting input of signal modifier. The DC output voltage depends upon duty cycle (D).

Advantages of SMPS:-

1. In SMPS transistor acts as higher speed switch, power is used more efficiently.
2. Large and heavy main transformer is not necessary.
3. At the same time two different DC voltages can be obtain.
4. Like series regulators, it is not bulky.

UPS (Uninterrupted Power Supply): -

General Block diagram:-



It consists of rectifier cum charger, battery, inverter, filter and static switch.

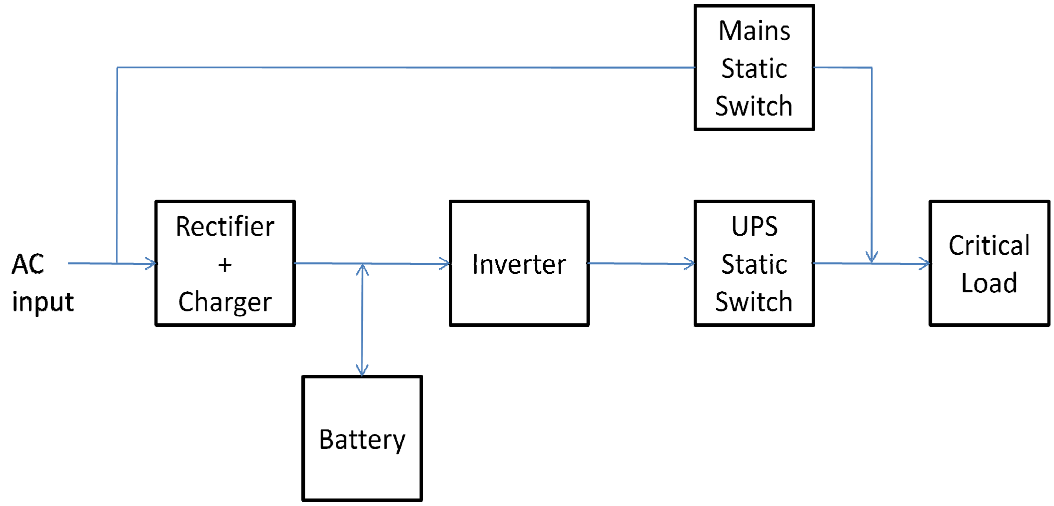
Working:-

Rectifier converts single phase or three phase AC voltage into DC which supplies power to the inverter as well as battery. Inverter gets a DC input voltage from the rectifier when AC mains ON and from the battery when AC mains is OFF. Inverter converts this DC voltage into AC voltage and through a suitable filter applies it to the load. Static switch will connect or disconnect the battery from input of inverter depending on the status of AC mains.

Depending on the arrangement of the basic block of the UPS they can be classified into following configuration:

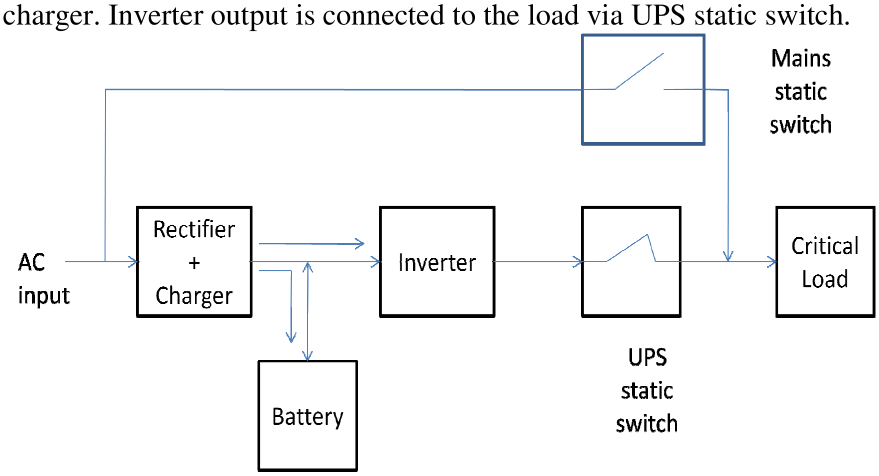
1. ON line or Inverter preferred UPS
2. OFF line or Line preferred UPS system
3. Line interactive UPS

1. ON line UPS:-

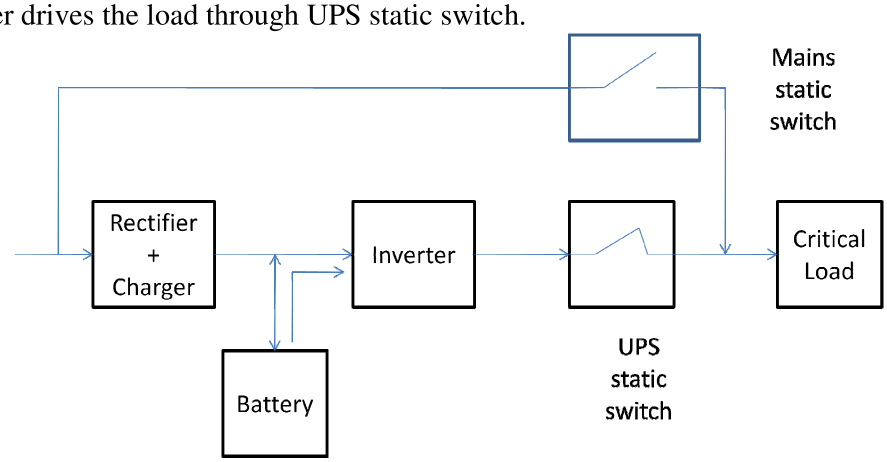


- In the ON line UPS system the load is always connected to the inverter through UPS static switch.
- The UPS static switch "Normally ON: switch. It turns off only when UPS system fails.
- In that case the "Mains static switch" is turned on to connect AC directly to the load.
- The operation can be divided into three modes:

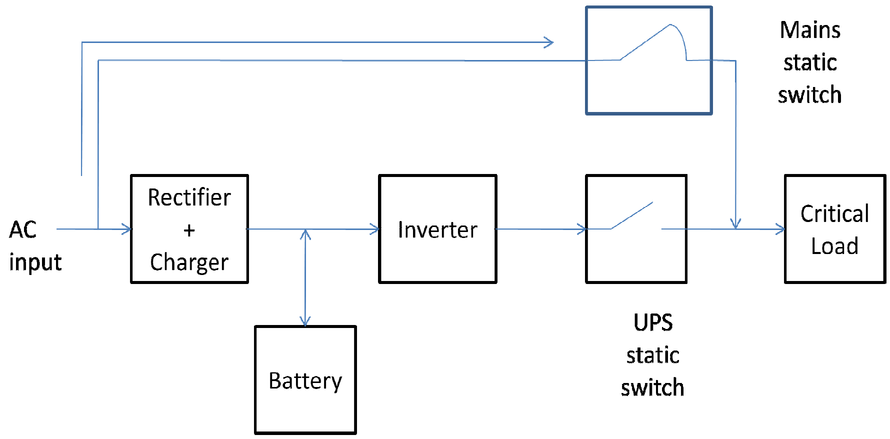
1. Mode I (mains ON):-
   When mains is on, the rectifier circuit will supply the power to the inverter as well as battery. So it acts as rectifier cum charger. Inverter output is connected to the load via UPS static switch.



2. Mode II(mains OFF):-
   Under the condition of mains off, rectifier output is zero. So battery now supplies power to the inverter, then the inverter drives the load through UPS static switch.



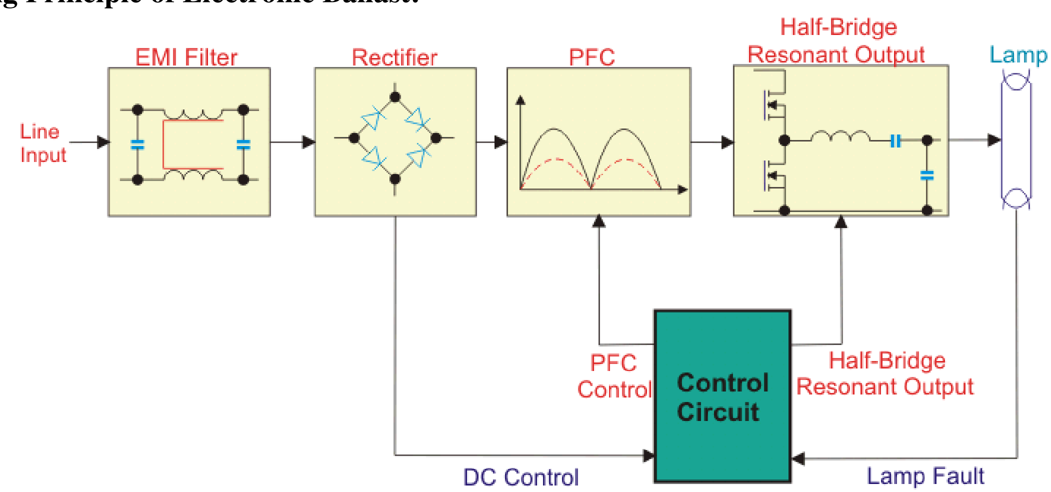
3. Mode III (UPS fails):-
   Due to some reason, if UPS fails, then the normally off mains static switch is turned on to connect the mains to the load by passing UPS system. The UPS static switch automatically turns off and disconnects



Electronic Ballast: -

Electronic ballast is a device that converts power frequency to very high frequency to initialize gas discharge process in Fluorescent Lamp by controlling voltage across the lamp and current through the lamp.

Working Principle of Electronic Ballast:-



Electronic ballast takes supply at 50 – 60 Hz. It first converts AC voltage into DC voltage. After that, filtration of this DC voltage is done by using capacitor configuration. Now filtered DC voltage is fed to the high frequency oscillation stage where oscillation is typically square wave and frequency range is from 20 kHz to 80 kHz. Hence output current is with very high frequency. A small amount of inductance is provided to be associated with high rate of change of current on high frequency to generate high valued $L\frac{di}{dt}$. Generally more than 400 V is required to strike the gas discharge process in fluorescent tube light. When switch is ON, initial voltage across the lamp becomes 1000 V around due to high valued $L\frac{di}{dt}$, hence gas discharge takes place instantaneously.

Once the discharge process is started, the voltage across lamp is decreased below 230V up to 125V and then this electronic ballast allows limited current to flow through this lamp. This control of voltage and current is done by control unit of the electronic ballast. In running condition of fluorescent lamp electronic ballast acts as a dimmer to limit current and voltage.

Power factor correction: -

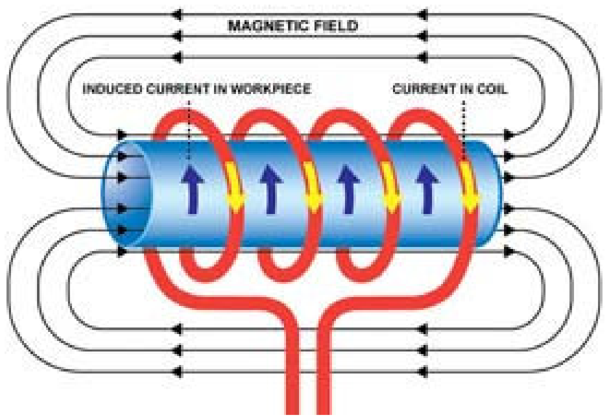
POWER FACTOR is the ratio between the useful (true) power (KW) to the total (apparent) power (KVA) consumed by an item of A. C. electrical equipment or a complete electrical installation. It is a measure of how efficiently electrical power is converted into useful work output. The ideal power factor is unity, or one. Anything less than one means that extra power is required to achieve the actual task at hand.

Power factor correction is the term given to a technology that has been used to restore the power factor to as close to unity as is economically viable. This is normally achieved by the addition of capacitors to the electrical network which compensate for the reactive power demand of the inductive load and thus reduce the burden on the supply. There should be no effect on the operation of the equipment.

Principle of induction and dielectric heating: -

Induction heating: -

When conducting object (metal object) is subject to changing magnetic field according to Faraday's low, emf is induced in the object. The metal object, being a conductor offers many short circuited paths, so induced emf causes current to flow through these paths. The current in the form of eddies (circular in nature); hence they are called as eddy current. The eddy currents flowing through resistive path in metal object causes power loss (I^2R loss) and heat is produced, which are induced due to induction. This heating is called as Induction heating.



The power loss caused by eddy currents is given by,

$$\mathbf{P_e = K_e * f^2 * B_m^{-2} * V}$$

Form above equation it is seen that, power loss is directly proportional to:

1. Square of supply frequency (f)
2. Square of maximum flux density (B_m)
3. Volume (V) of the object

If frequency of supply current that produces changing magnetic field is increased, the heating is improved. Hence high frequency AC source is used for this heating. Therefore this heating is normally called as High frequency heating or Radio frequency heating.

Advantages:

1. Heating in a special atmosphere, such as vacuum tube, inert gas etc is possible, hence oxidation can be totally eliminated during heating and quality heating is ensured.
2. Automatic control of temperature is easily possible.
3. Very high heating rate is possible.
4. Heating process is pollution free; hence quality of product is maintained.
5. Due to automatic control, unskilled labor can handles the operation.

Disadvantages:-

1. A high frequency power source is required, which is costly and complex. Thus initial cost required more.
2. A running cost or cost of operation is high.
3. Due to conversion of regular AC supply (50Hz) into high frequency and low efficiency of induction coil. This heating process is not efficient. The overall efficiency is poor, less than 50% in many cases.

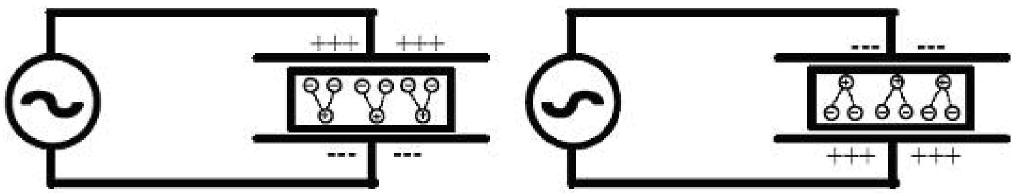
Applications:-

Welding, drying of paint, bonding of clutch facing, sterilizing surgical instruments, melting of materials, surface hardening of steel, brazing.

Dielectric heating: -

Whenever the non conducting materials (Dielectric material) are subjected to an alternating electric field, some power loss takes place in them and heat is generated. This power loss is called as dielectric loss. The process in which the heating takes place due to dielectric loss is known as dielectric heating.

When dielectric material is subjected to an alternating electric field, the rapid reversal of this field distorts and agitates the molecular structure of the material. The internal molecular friction generates heat uniformly throughout all parts of materials.



Reversal of polarity causes the material to heat

Application:-

1. Food processing:-
   I. Pasteurizing milk and bear insides the bottles and containers.
   II. Cooking food without removing outer shell.
   III. Dehydration fruits, vegetables etc
   IV. Sterilizing food while sealed in their final container.
2. Plastic processing.
3. Wood processing.
4. Electronic sewing.
5. Drying and heat treatment of textiles such as nylon.
6. Processing of chemicals during manufacturing, rubber and synthetic materials, semiconductor devices
7. Producing artificial fever in human body for medical treatment.