POWER CONTROL USING SOLID STATE DEVICES

A
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OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE
(ENGINEERING) IN ELECTRICAL ENGINEERING.

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FEBRUARY, 1974.

CERTIFICATE

THIS IS TO CERTIFY THAT THIS WORK WAS DONE BY ME AND IT HAS NOT BEEN SUBMITTED ELSWHERE FOR THE AWARD OF ANY DEGREE OR DIPLOMA.

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ABSTRACT

Power control circuits using SCR for feeding DC and AC, inductive and resistive loads are designed and contructed. Oscillograms of voltage waveforms across the load and the SCR are obtained for various triggering angle and smooth and efficient control for variable power to load is obtained. A detail study of incandescent lamp load is made.

The design and construction of dimmer circuits for the control of light intensity of fluorescent lamp loads is also described. Dimming of the fluorescent lamps with starter switch is found to be unstable in operation. The conventional fluorescent lamp circuit is modified and it is found that the fluorescent lamps can also be dimmed smoothly using SCR controlled switching circuits.

A comprehensive survey is also carried out on SCR controlled DC chopper circuits for DC to DC conversion for speed control of DC traction motor. Theo operating principles of some efficient DC choppers ared described with their special features and the voltage and current waveforms of the choppers are also shown.

CHAPTER - I

THE DEVICE - SCR

1.1 . INTRODUCTION:

The Silicon controlled rectifier (SCR) is a semoconductor device of enormous potential. It forms the basis of modern electro technology. SCR was first made in 1957 by General Electric Company. SCR has grown rapidly. The curosity of yesterday has become the basic and efficient control and conversion element of electrical powem today. The device SCR is a successor to its fellow transistor. Just as transistor is replacing the valve, SCR is now-a-days replacing thyratron, mercury arc rectifier etc. It is a more efficient and economical design element. The advantages gained by using SCR are, faster switching times, lower switching losses, higher efficiency of operation, little weight, small size, requires modest heat sink, little maintenance cost etc.

SCR can be used as the power handling device of today in all most every kind of application, in industry, military, aerospace, commercial, consumer goods etc. SCR can be used in speed control of both AC and DC motors in control and regulation of light and temperature, in convertion for high voltage direct current transmission, in choppers and inverter circuits etc.

The objectof the research work was to study the device SCR in detail, its characteristics, operation, various gate control circuite, various switching power circuits and design and construction of practical power control circuits, feeding resistive and inductive, DC and AC loads, using SCR's and other components available in Bangladesh. Special emphasis was given to the design and construction of SCR control of incandescent lamp loads and fluoresdent lamp loads takinginto account their peculier and different load conditions and trigger control requirements.

In the begining theory and operations of SCR are described in detail. Then varioue gate control circuits are described. A simple but very efficient trigger pulse generator for gate control is designed and constructed and oscillogram of the control pulse wave form is shown.

Next various types of SCR controlled resistive DC and AC circuits are designed, constructed and described and oscillograms of voltage wave forms for different power level are shown. Variations of power for different conduction angle for various circuit configurations are shown graphically. Incandescent lamp load is used as an example of resistive load taking into account the non-linear characteristic of the filament which permits the high current surges when the lamp is turned on. A detail study of incandescent lamp load is carried out.

For SCR control of inductive load special trigger requirements are described and various circuits for control of DC and AC loads are designed and constructed and the oscillograms of voltage wave forms for different power level are shown.

As an example of inductive AC load fluorescent lamp was chosen. Dimming of conventional fluorescent lamps with switch start was found unstable in operation. The problem is solved by using starterless circuit with permanently heated cathodes. A comprehensive analysis of the circuit components for dimming of fluorescent lamps is carried out taking into account the protection techniques. It was found that fluorescent light can be dimmed smoothly by using electronic circuits.

Lastly some SCR controlled DC chopper circuits are described. Due to high efficiency and low switching time of SCR, it is used as chopper for DC to DC conversion. A comprehensive survey is carried out about the SCR controlled chopper circuits for speed control of DC traction motors and a few useful circuits for control of DC series motors for traction are described in brief and the associated voltage and current wave forms are shown.

1.2 WHAT IS SCR ?

SCR is abbreviation of Silicon Control Rectifier. It is a PNPN device and is semiconductor equivalent of thyratron with a normal blocking characteristic. It is an ON-OF switch. It finds application in high power switching and control circuits. SCR is replacing thyratron, hot-cathode gas triode, controlled mercury pool rectifier, ignitron etc. as it has greater advantages over them. SCR's current carring capacity vary from half ampere to thousands of amperes and it can withstand thousands of volts.

The SCR uses the symbol shown in the fig. 1.1a. Its symbol looks like that of a normal rectifier but it has an extra terminal known as gate.

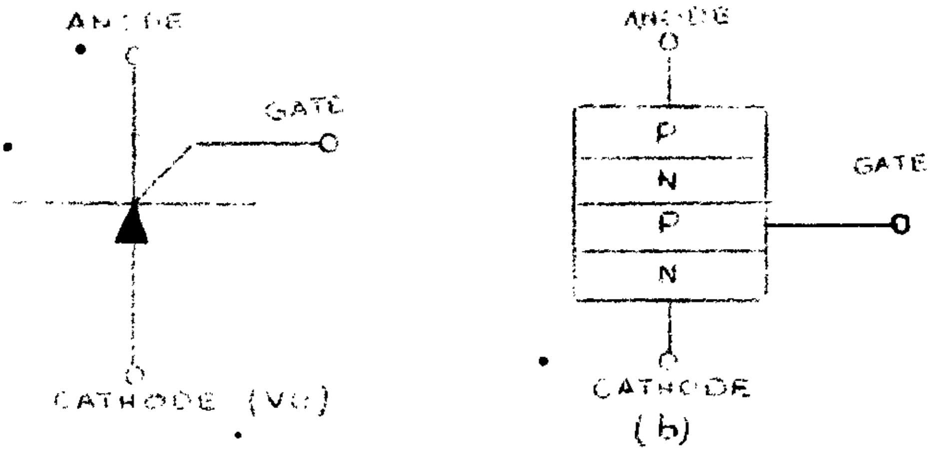


Fig. 1.1

(a) Symbol for SCR.

(b) Simplified diagram of SCR semiconductor structure.

The basic characteristics of SCR are :

(1) The SCR is a semiconductor a rectifier, a stative latching switch which is capable of operating in micro sedonds and a sensitive amplifier. It has no moving parts to wear out or are and silent in operation. It is not adversely affected by severe mechanical vibation, shock or high g forces. SCR is compact, static and capable of being hermetically sealed.

(2) Normally SCR is "blocked" with no bias applied to the gate, i.e., with no gate current and acts between the anode and cathode like an open circuit switch, passing negligible

current in either direction.

(3) It can be turned "ON" by application of small control current to the gate (by applying a positive pulse for a fraction of micro-second to the gate). When SCR latches in to conduction it acts like a normal rectifier and conducts in the forward direction between anode and cathode but blocks in the reverse direction. It has an advantage when the load requires DC, for here SCR serves both to control and rectify.

(4) Once the SCR is turned "ON" the gate loses control and the SCR stays "ON" even though gate bias is removed.

(5) Once the SCR is triggred into conduction it latches, it can be turned off either by opening the anode-cathode circuit or by reducing the anode-cathode current below the holding current. The characteristics then revert to the blocking condition and gate regains control. In AC circuits turn off occurs automatically on the negative half of each cycle. The SCR can not be turned off via gate. SCR is an ON-OFF switch. It can be turned on in one micro-second and off in 10 to 20 micro-second.

(6) Only a few-micro-watts of control signal is required to trigger a SCR into conduction. SCR enables to switch hundreds of killo-watts of load power with high efficiency. A great advantage of SCR is that it offers a high power gain between the gate and external load. Thishhigh control gain permits the use of inexpensive devices such as thermistors, cadmium sulphide light sensitive resistor's etc. which create low level signal in control circuits.

(7) The efficiency of SCR is very high because voltage drop across it is negligible when conducting.

1.3 ADVANTAGES OF SCR:

Some advantages of using equipments with SCR switches are mentioned below :

(1) High operating efficiency and high power gain:

The operating efficiency in SCR controlled equipment is very high due to the fact that a negligible voltage (1 to 2 volts) is developed across SCR when conducting in comparison to the arc drop of thyratron, mercury arc rectifier and twin losses in motor-generator set. The efficiency curves for a 6,000 kw, 750 V, 800 A load controlled by SCR, mercury arc rectifier are shown in fig. 1.2. The SCR controlled unit has highest efficiency. A major advantage of SCR is that it offers a high power gain betwemn gate and external load.

(2) High switching efficiency:

Switching from "OF" state to "ON" state and vice-versa in SCR is very fast. This high rate of response is very useful where high rate of acceleration or accurate automatic setting are required.

(3) Easy maintenance:

As the SCR unit has no moving parts to wear out or no arc formation, or no heater supply the maintenance is easy and less costly.

(4) Insensitive to temperature change:

The SCR can operate in temperature range from - 30°C to + 30°C efficiently without changing the control characteristics.

(5) Requires no-heater supply:

(6) Highly reliable performance:

(7) Long life:

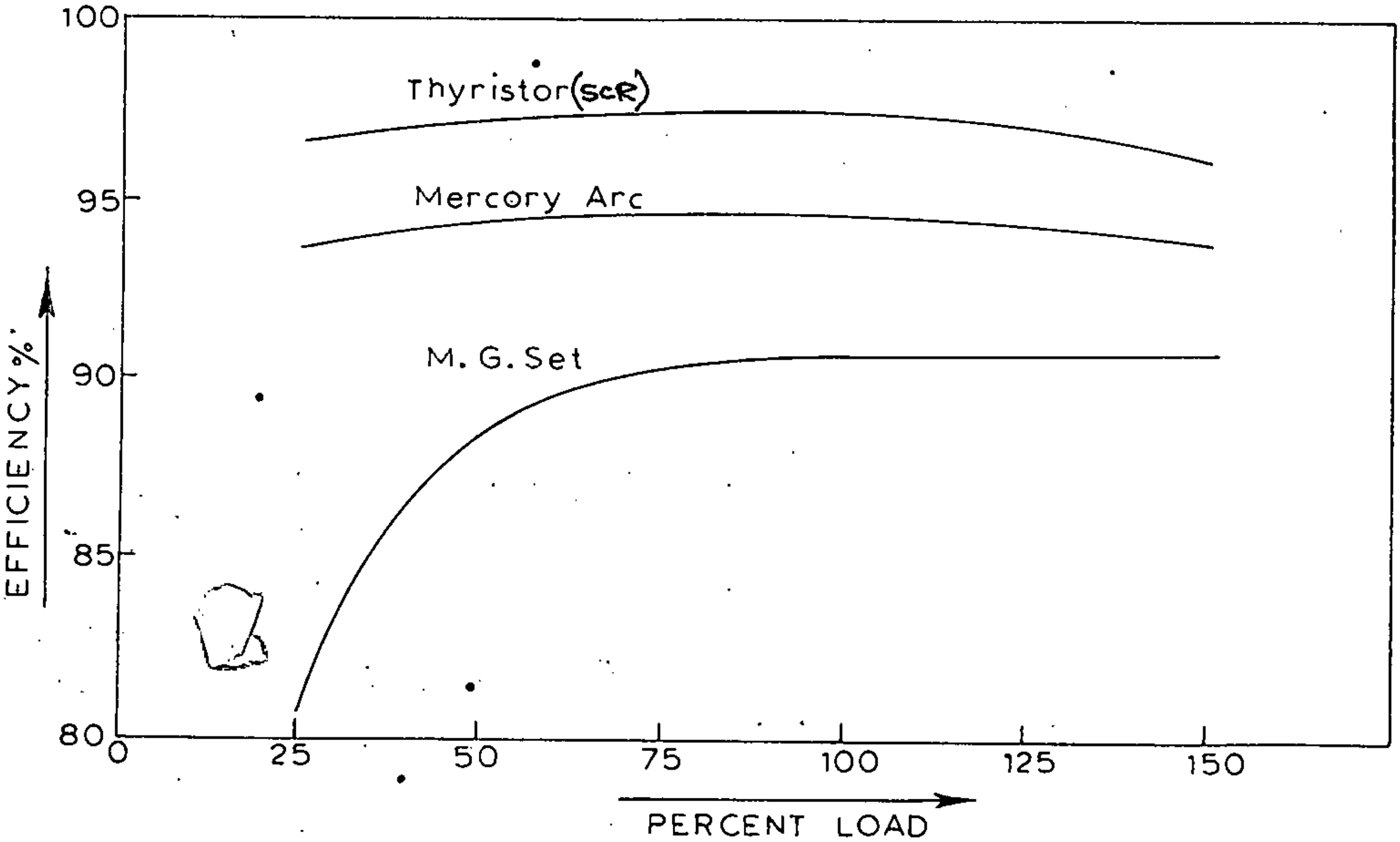
(8) Small size:

(9) Low cost:

(10) Light weight:

(11) Modest cooling requirement:

(12) Silence operation; etc.



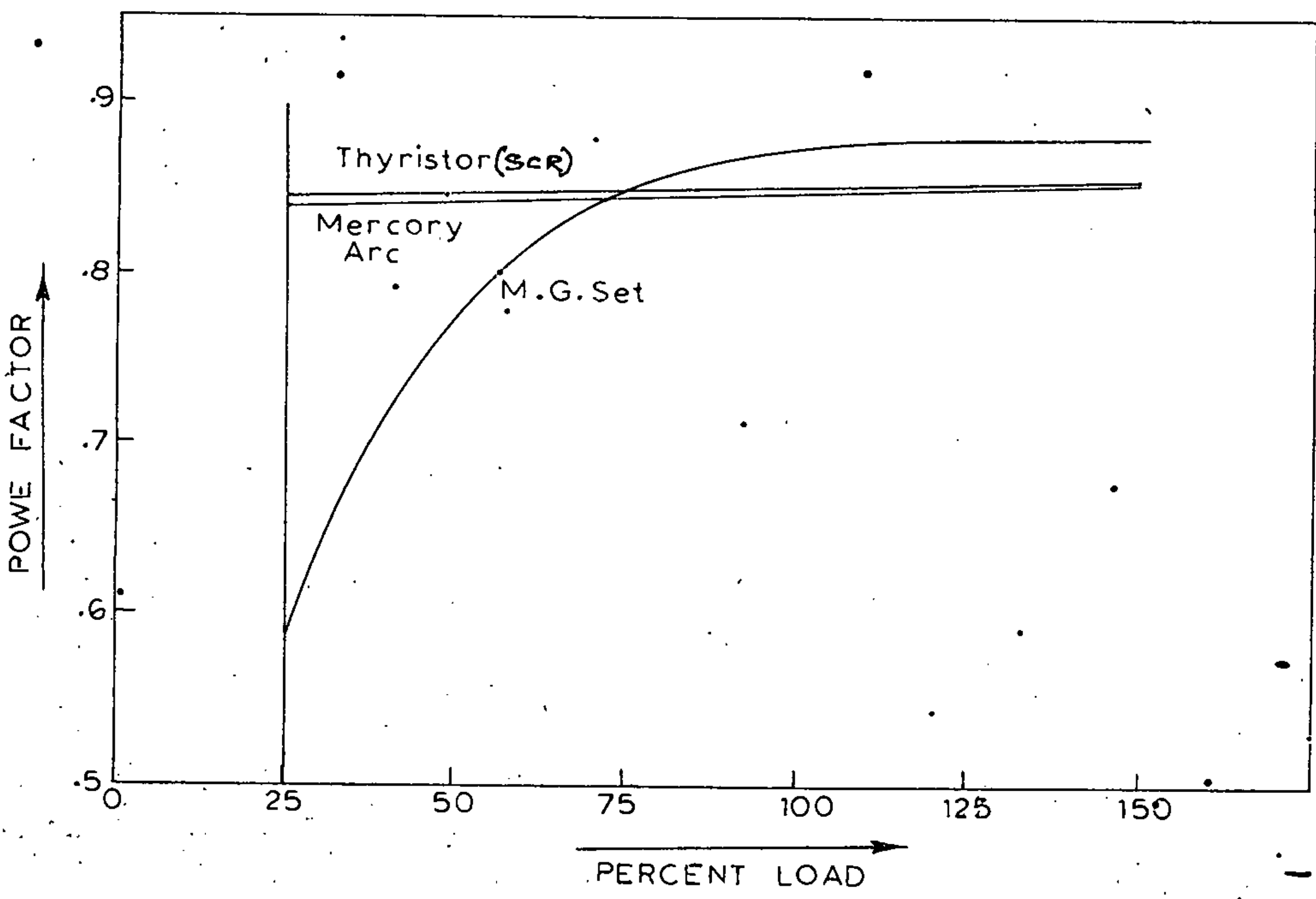


Fig. 1.2 Efficiency And Power Factor Curves For ScR, Mercury Arc Rectifiers And M.G. Set

1.4 APPLICATIONS OF SCR:

SCR's are used more and more now-a-days in almost every kind of applications. The SCR AC regulators find extensible application where distortion of wave form is not important. Although distortion of wave form limits the use of SCR in some cases, yet there are large number of specific application in which distortion has little or no effect such as in resistive load for incandescent lamp for lighting, heating and inductive load of fluorescent lamp and in many other cases, ranging in power from few watts to several hundred kilo-watts.

Now-a-days as the SCR characteristics is greatly improved, they are replacing almost all conventional control elements. The names of few are :

(1) Thyratrons
(2) Relays
(3) M-G-sets
(4) Ignitrons
(5) Magnetic amplifiers
(6) Transformers
(7) Motor starter's
(8) Rheostats
(9) Mercury arc rectifier
(10) Saturable reactors
(11) Timers
(12) Variable auto-transformer
(13) Thermostats
(14) Mechanical speed changers
(15) Fuses
(16) Power transistors

Some important applications of SCR are grouped as follows:

(1) Lighting control in auditorium, cinema hall, theatre, studios etc., for dimming of :

(a) Incandescent lamps,

(b) Fluorescent lamps.

(2) Heating control:

(a) Resistance furnaces and ovens,

(b) Special purpose heaters for metallurgical specimen,

(c) Induction heating generators.

(3) Speed control of specific AC supplied motors:

(a) Universal motors in powertools, domestic machinery such as mixtures, food blenders, hand drill etc.

(b) Small induction motors such as in pumps, fans etc.

(4) Special purpose control for electromagnetic vibrators.

(5) Regulation of rectifier sets to obtain variable or stabilised DC.

(6) High voltage high power SCR's are used:

(a) As converter for DC motor drive in steel mill, speed control of locomotive, antenna drive etc.

(b) As converter for high voltage DC transmission.

(c) As AC switch for primary control of welder.

(7) DC to AC invertion for ultrasonic generators, sonar transmitters, variable speed AC motors.

(8) DC to DC convertion or chopper for controlling the speed of DC series motors for traction.

SCR's also find application in servo systems for precision control of speed, position, light, temperature, etc. SCR's offer a unique combination of efficiency, power handling capacity and convenience of operation, maintenance and installation.

CHAPTER - II

THEORY OF SCR OPERATION

2.1 TWO TRANSISTOR ANALOGY OF SCR: OPERATION:

The SCR is a four layer PNPN device which can be visualised as consisting of two transistors a PNP and a NPN connected as shown in the fig. 2.1b. In fig. 2.1c R_1 and R_2 represents the semiconductor resistances between gate and cathode. Fig. 2.1d shows a stud type of SCR.

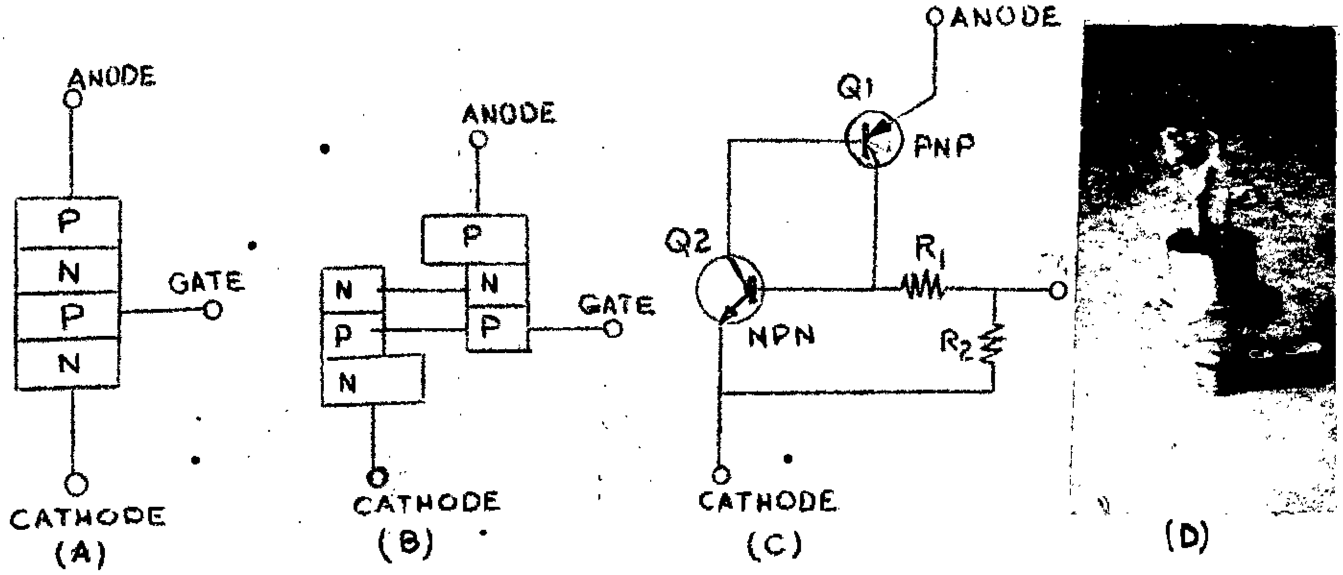


Fig. 2.1 TWO TRANSISTOR ANALOGY OF SCR.

When proper bias is applied to the SCR i.e., anode is made positive with respect to cathode, and zero bias is applied to the gate, i.e., gate current is zero, Q_2 will be in cut off condition as its base current is zero and hence its collector current will be zero. The collector current of Q_2 is the base current of Q_1, therefore Q_1 will also be in cut off condition and no current will flow between anode and cathode.

Now as a positive pulse is applied to the gate, Q_2 is driven on from cut off state. The resulting collector current of Q_2 feeds directly into the base of Q_1 and this transistor is also driven on.

Again the collector current of the transistor Q_1 feeds back into the base of Q_2. Hence a feed back loop is completed and regenerative action takes place driving both transistor in the saturation region. As a result anode and cathod will appear to be short circuited as voltage drop across the SCR will drop to negligible amount and heavy current will flow between anode and cathode. This anode current is limited only by the external circuit load.

As soon as a positive bias is applied to the gate, regeneration starts and once regeneration starts, it will continue and each transistor drives its mate into saturation, gate current will have no effect on the SCR. Once in saturation all junctions of the SCR assume a forward bias and the SCR can only be turned off again by breaking the supply connection or by reducing the anode current below the holding current. SCR cannot be turned off by shorting gate to cathode, as Q_2 base will not be shorted to cathode due to presence of R_1 and Q_2 base will be receiving Q_1 collector current continuously.

The SCR structure may also be analysed in terms of its component transistor "alphas". From the fig. 2.2 it is evident that PNP P

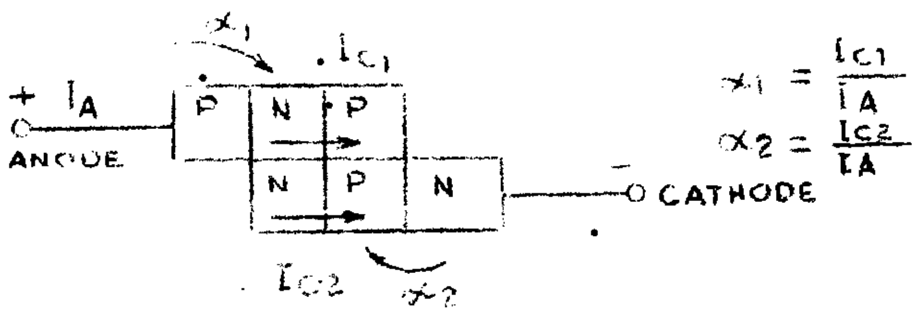


Fig. 2.2.

section of the silicon palet has an alpha α_1 which defines the fraction of hole current travelling from the emitter towards the base into the collector. So the hole current from the P emitter is $I_{c1} = \alpha_1 I_A$. Similarly the NPN section has an "alpha" α_2 which which defines the fraction of electron current travelling from the emitter toward the base into collector. So the electron current from N emitter is $I_{c2} = \alpha_2 I_A$.

The total anode current consists of three components : (1) hole current from the P emitter, (2) electron current from N emitter, (3) leakage current of centre junction I_{co}.

$$I_A = I_{c1} + I_{c2} + I_{co} = \alpha_1 I_A + \alpha_2 I_A + I_{co}$$

$$I_A = \frac{I_{co}}{1 - (\alpha_1 + \alpha_2)}$$

Now if $(\alpha_1 + \alpha_2)$ is considerably less than unity, then $I_A \rightarrow I_{co}$. Since I_{co} in silicon junction is very small the anode current is also small. This situation is "OFF" or "blocking" condition. When $(\alpha_1 + \alpha_2)$ is near unity the anode current I_A becomes very large, being limited by the external load. This situation is "ON" or "conducting" state of the SCR. So by controlling α the SCR can be triggered from "OFF" to "ON" state.

There are a number of methods of increasing α in a transistor. The most important of these are :

(1) Transistor action.

(2) Increase of anode-cathode voltage.

(3) Rate of change of voltage.

(4) Radiant energy using light, etc.

2.2 ANODE-CATHODE V-I CHARACTERISTICS OF SCR:

The volt-ampere characteristics of a typical gate controlled SCR is shown in the fig. 2.3. In the forward blocking region (0 - 2) the middle junction of PNPN device is reversed biased and increasing forward voltage does not increase the current until the point is reached where avalence multiplication begins to take place (1 - 2). Here, the energy of the carriers arriving at the PN junction is sufficient to dislodge additional carriers causing an avalanche break down. Past this point the current increases

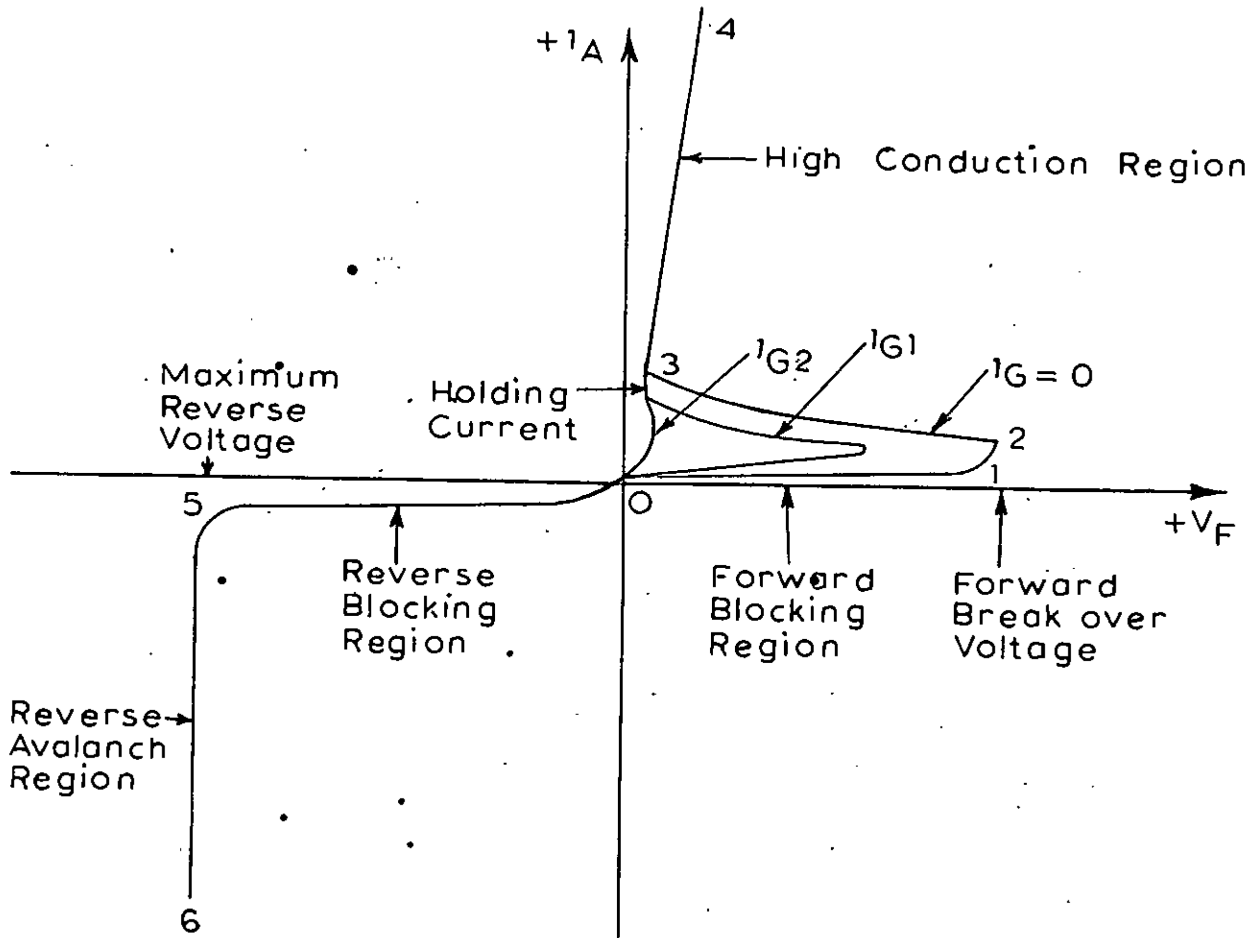


Fig.2.3 V-1 Characteristics of ScR

rapidly until the total current is sufficient to maintain the sum of α's to be equal to or greater than 1. At this point SCR triggers through the unstable negative resistance region (2 - 3) into high conduction region (3 - 4) with high forward current and low voltage drop across SCR. Now if the current through the SCR is brought down below the minimum value called the holding current, the SCR will revert to the forward blocking state. This characteristic of SCR is shown by the $I_g = 0$ curve.

In practical applications , the SCR has an applied voltage below the avalence voltage and it is turned on by injecting current through its gate. At anode-cathode voltage less than the break over voltage the SCR can be placed into high conduction region by supplying a gate current I_{g1} as shown in the characteristic curves. This occurs because the gate current increases α and break over takes earlier. For a higher gate current I_{g2} the break over occurs at a still lower voltage. For sufficiently high gate current the entire forward blocking region is removed and the V-I characteristics essentially becomes similar to those of a PN junction diode.

SCR is used to control large amount of power by very small amount of trigger power. This is the advantage of SCR. Typically 15 ma can turn "ON" a 16 amp. SCR. SCR can be triggered into conduction by applying a pulse to its gate. Usually a 10 to 50 μs gate pulse will trigger a SCR in about one micro-second. Once the SCR is triggered into conduction , the gate loses control.

The SCR is in the reverse blocking region (0 - 5), when reverse potential is applied to the device. In the reverse direction, the SCR has two back-biased PN junction in series and its characteristic in the reverse direction is like that of a back-bias silicon diode. Generally in all SCR's peak-reverse voltage is equal in magnitude to the minimum forward break over voltage. If the reverse voltage exceeds the peak reverse voltage rating of SCR than it will be damaged permanently.

The forward break over voltage is quite temperature sensitive as the leakage current through the SCR increases with temperature.

which in turn increases α value. At a high temperature above the maximum rated temperature, the device loses completely to block the forward voltage and its characteristic becomes essentially like that of a PN junction diode.

2.3 GATE-CATHODE V-I CHARACTERISTICS OF SCR:

The gate-cathode V-I characteristics of SCR is essentially like that of a PN junction diode. The gate trigger current is a function of leakage current and the gate current necessary to fire the SCR decreases as the junction temperature rises. In practical operation of SCR, gate potential required to trigger it into conduction varies from 1 to 3 volts with current varying from 1 ma to 300 ma depending on the size of SCR. So very small gate power is required to trigger quite large current from high voltage source to load. SCR possesses large power turn on gain in the order of 10^5 to 10^6.

CHAPTER - III

TRIGGER CIRCUITS FOR SCR

3.1. SCR ON/OFF CIRCUITS:

Basic DC ON/OFF circuits:

Fig. 3.1a shows a basic DC ON/OFF circuit. In this fig. with S_1 open if S_2 is closed the SCR will not trigger into conduction as the current through the gate is zero. Now if S_1 is closed SCR will be turned on and it will latch. The SCR can also be turned on by applying pulse to the SCR gate. The SCR is turned off by momenterily opening the switch S_2 or by reducing the anode current below the holding current. It cannot be turned off via gate. SCR can also be turned off by shorting anode and cathode by the switch S_2 as shown in the fig. 3.1b, when SCR current current will be reduced to zero.

Basic AC ON/OFF circuits:

The fig. 3.2a shows a basic AC (half wave) ON/OFF circuit. When an alternating voltage is applied to the circuit, the SCR will be triggered into conduction in the each positive half cycle if the switch S_1 remains closed. The SCR turns off automatically in the negative half cycle as the anode voltage reverses. The diode D prevents the SCR gate to become negative with respect to cathode.

The fig. 3.2b shows a full wave on/off circuit. Here a diode bridge rectifier is used for full wave rectification and the out put is applied across the SCR and the SCR anode remains positive in each half cycle. With the switch S_1 closed the SCR will conduct in each half cycle. The circuit is not self latching as SCR voltage reduces to zero once in each half cycle. If resistor R_1 is variable, than limited range half wave phase control operation results in fig. 3.2a, and limited range full wave phase control operation results in fig. 3.2b. Since the SCR will trigger and latch into conduction the first time gate current is reached

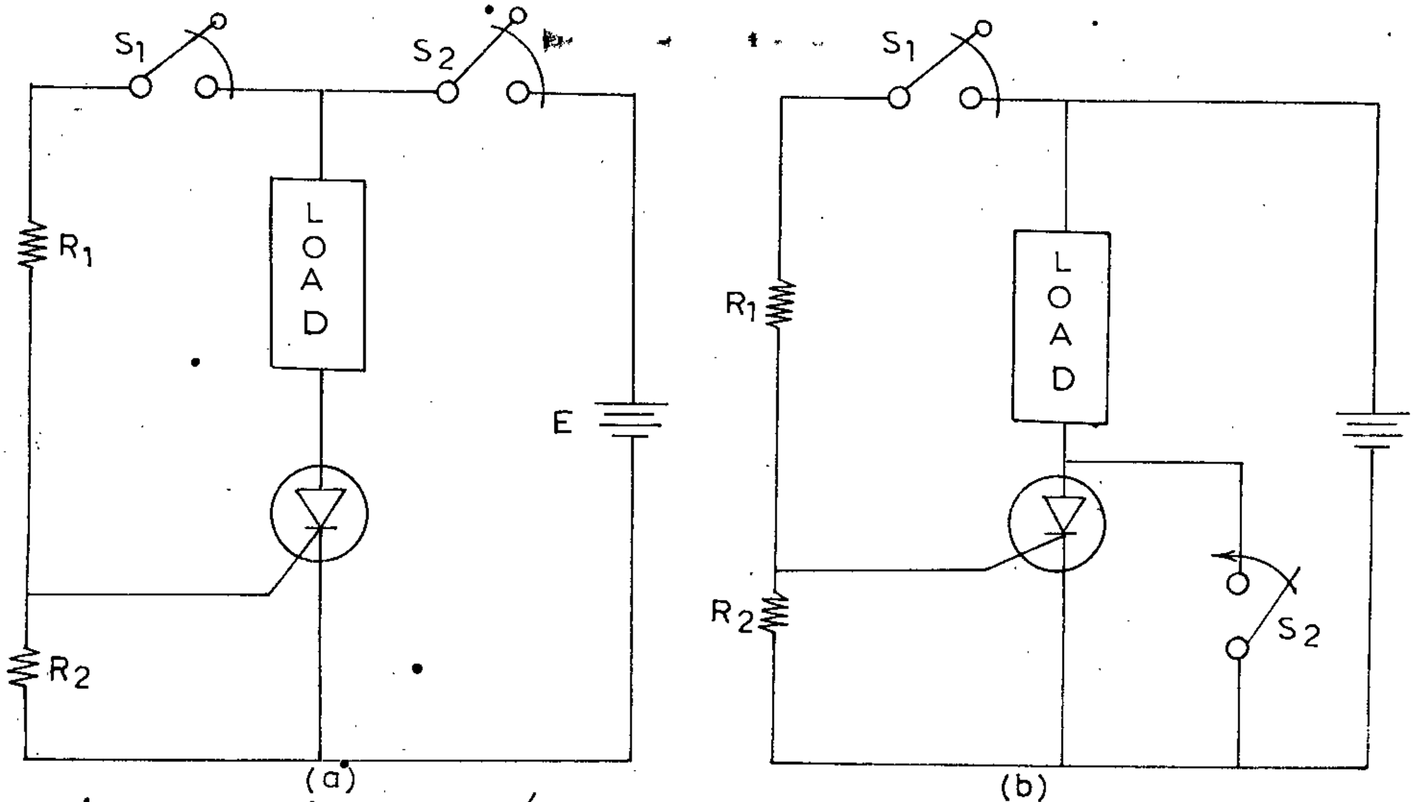


Fig. 3.1 Basic DC ON/OFF Circuits

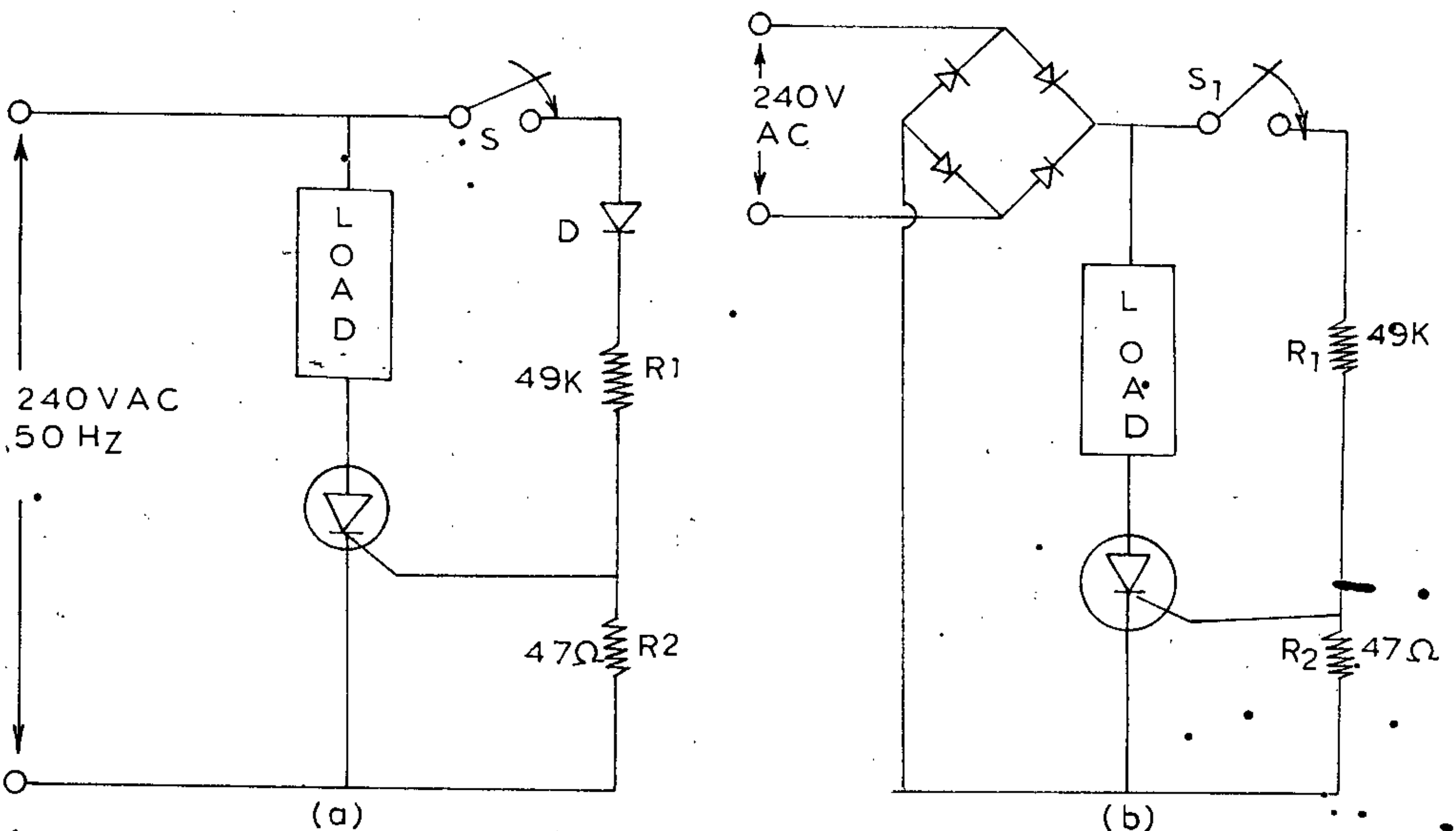


Fig. 3.2 Basic AC ON/OFF Circuits

its conduction can not be delayed more than 90 electrical degrees with so simple a trigger circuit.

3.2 RC TRIGGER CIRCUITS:

Fig. 3.3a shows a RC diode trigger circuit which allows full half cycle control. When the SCR anode voltage swings positive, the capacitor C will charge from the peak of the negative line voltage to the trigger point of SCR in a time determined by the RC time constant and then the SCR triggers into conduction. Here R is the control element. When the SCR anode swings negative, the top plate of the capacitor charges to the peak of the negative voltage through diode CR_2 , thus it is ready for the next cycle. The diode CR_1 protects the gate from reverse voltage when the anode of SCR is negative.

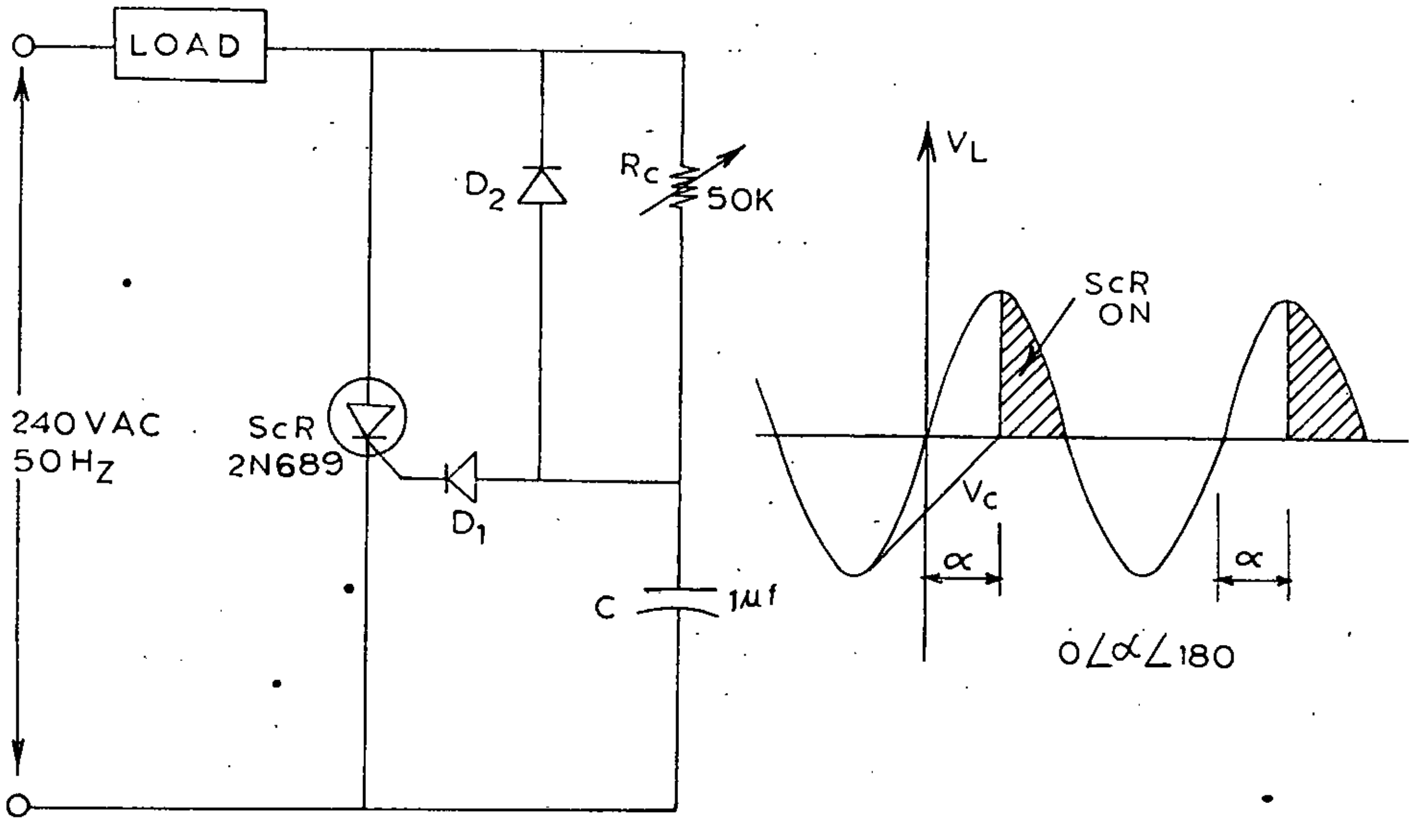
Fig. 3.3b shows a RC trigger circuit which allows full wave phase control.

3.3 UNIJUNCTION TRANSISTOR TRIGGER PULSE GENERATOR:

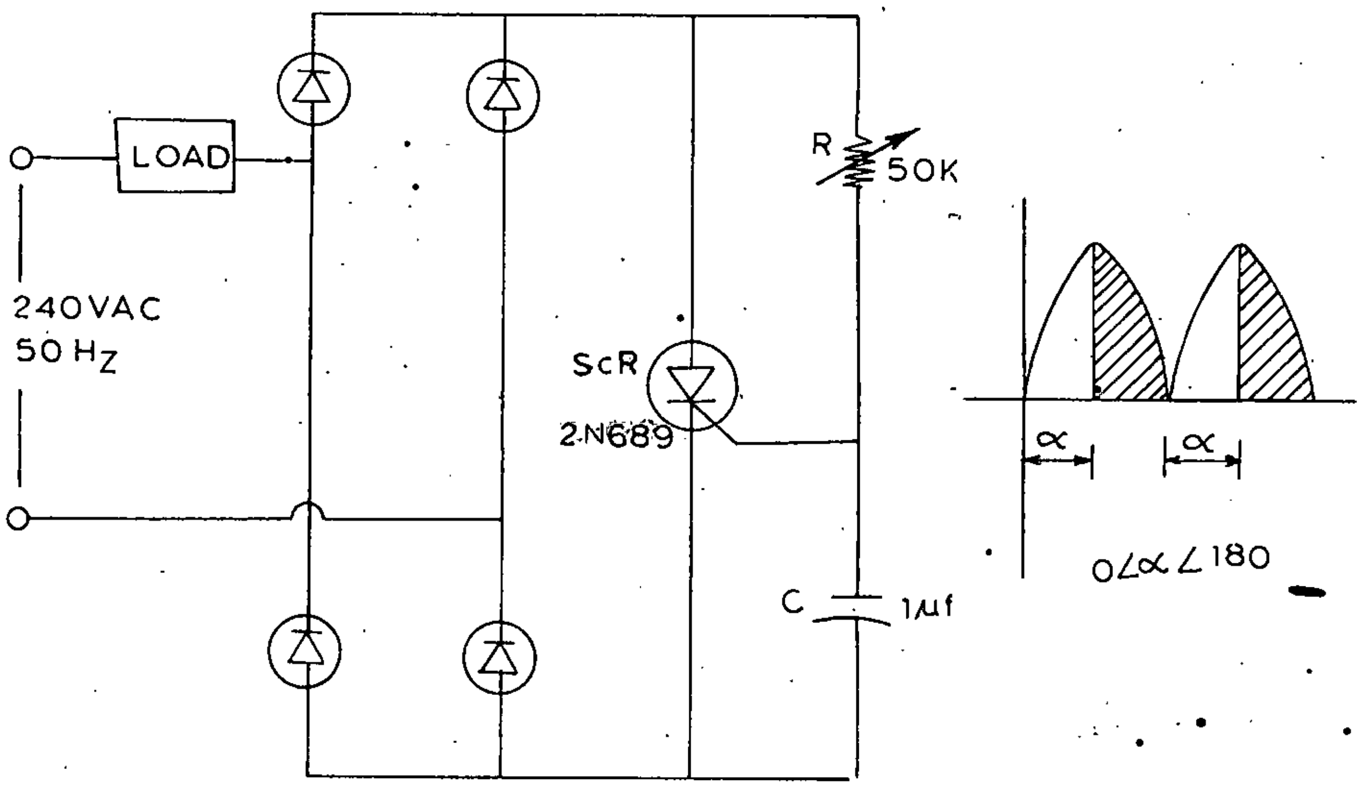
The unijunction transistor is an unique specialised but simple three terminal semiconductor device which has negative resistance characteristic. It can be effectively used to generate pulses to trigger SCR. The symbol of UJT, its constructional form and equivalent circuit are shown in the fig. 3.4.

The device is made of a bar of high resistivity N-type silicon material with two non-rectifying ohomic contacts base one B_1 and base two B_2 at the opposite ends. An aluminium called the emitter E is alloyed to the base to form a PN rectifying junction. The device is named unijunction as it has only one rectifying junction. Between B_1 and B_2 the unijunction has the characteristics of an ordinary resistance. This resistance is known as inter base resistance R_{BB}. Its value varies from 4 kΩ to 11 kΩ .

The normal biasing condition of a typical UJT is shown in the equivalent circuit fig. 3.4c. r_{B1} and r_{B2} represent the resistance of the silicon bar and diode D represents the junction .

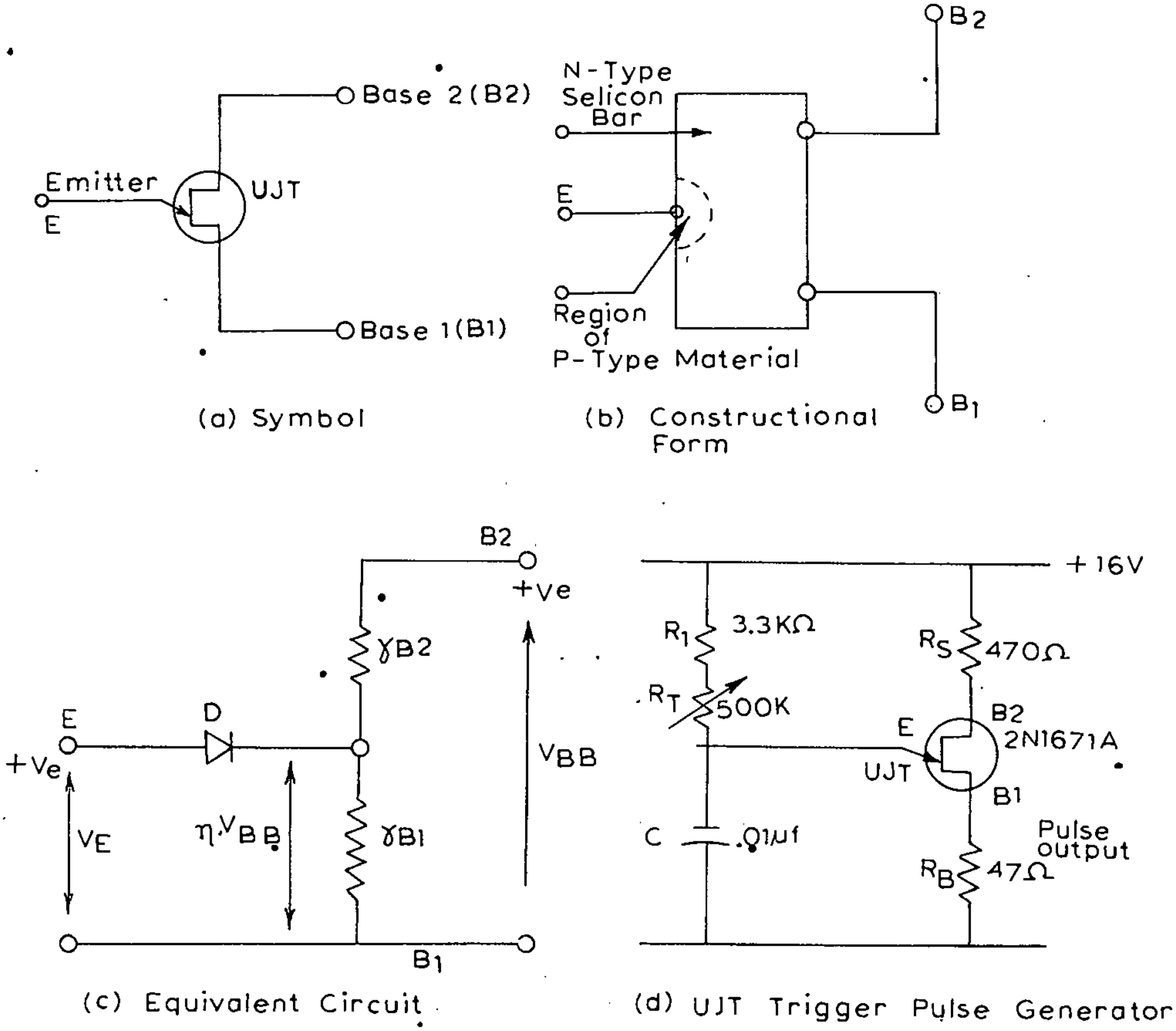


(a)



(b)

Fig. 3.3 RC - TRIGGER CIRCUITS



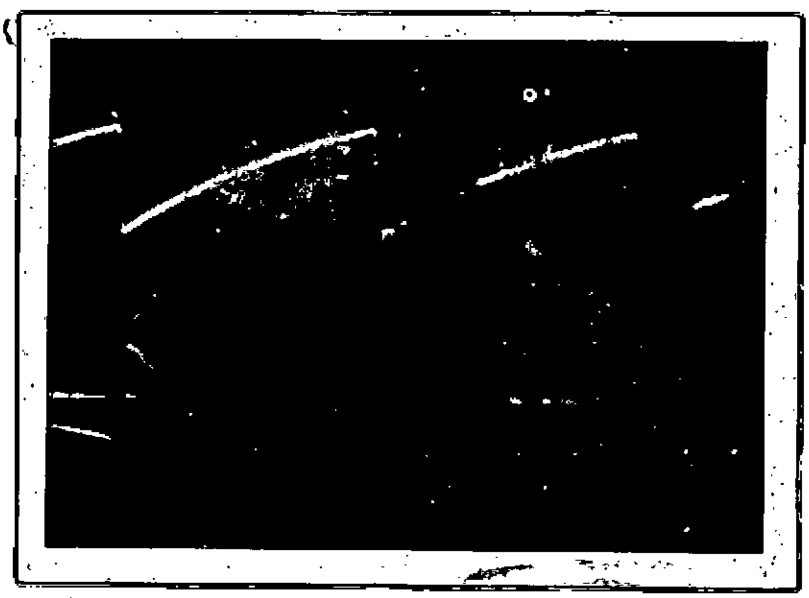


Fig. 3.4 Unijunction Transistor Pulse Generator And The Pulse Wave Forms

formed between the emitter and the bar. When an external voltage V_{BB} is applied between B_2 and B_1 with the polarities shown a voltage of nV_{BB} appears across r_{B1}, where n is called the intrinsic stand off ratio and usually has a value between 0.51 and 0.82. Now if a voltage V_E is applied between emitter E and B_1 which is less than the peak point voltage given by $V_p = nV_{BB} + V_D$. Where V_D is the emitter diode voltage, and the diode D becomes reverse biased and only a small leakage current will flow. Now if V_E is increased to V_p, diode D becomes forward biased and the current starts to flow from emitter to base one, injecting minority carriers into the silicon bar causing a decrease in effective resistance r_{B1}, and D becomes more heavily forward biased as cathode voltage of D decreases due to decrease in r_{B1}. In this way a semi-regenerative action takes place and the emitter input impedance falls sharply to about 20 ohm. When it shows high emitter impedance, it is then called "OFF" state and when very low input impedance it is said to be in "ON" state.

The trigger pulse generator:

The UJT pulse generators can be effectively used for triggering SCR's. The basic temperature stabilised UJT relaxation oscillator trigger pulse generator with the wave forms is shown in the fig. 3.4d. When the circuit is energised the capacitor C charges exponentially through R and R_T toward the supply voltage V until the emitter reaches V_p, the peak point voltage. When UJT fires i.e. turns "ON" and the capacitor C discharges instantly into the low impedance of emitter and ground terminal and a positive output pulse is generated across R_B and a negative pulse at B_2. When the capacitor discharges current falls to a "valley point" I_p, the UJT turns "OFF" and capacitor starts charging and the cycle is repeated. A saw tooth charging waveform is generated between emitter and ground. The oscillagram of saw tooth waveform and the trigger pulse is shown in the fig. 3.4.

The frequency of operation of UJT is approximately given by

$$f = \frac{1}{T} = \frac{1}{2.3RC\log_{10}(1/1-n)}$$

For a typical value of $n = 0.63$, $f = 1/RC$. The frequency is fairly independent of supply voltage and temperature. Rs is a temperature stabilising resistor.

Design consideration:

The supply voltage of UJT pulse generator can be varried from 9 volts to 35 volts. As the amplitude of the output pulse depends on the supply voltage (amplitude is much less than half the supply voltage) the supply voltage is determined by the requirement of the pulse amplitude and allowable power dissipation of UJT. The frequency of operation can be varied by varying both R and C as evident from the expression of frequency. But generally C is kept constant to 0.1 µf and and R is varied, although C can have any value in the range 1000 pf to 1000 µf. The width of the pulse depends on the value of C. So in cases where higher pulse width is required (as in case of trigger SCR in inductive load) high value of C should be taken. The value of resistor R can be varied from about 3 kΩ to 3 MΩ. So via a single variable resistor R, frequency range greater than 1000 : 1 can be obtained. In circuits where output pulse across the R_B is directly coupled to the gates of SCR's, the value of Rs should be low enough to prevent the DC voltage at the gate due to inter base current, from exceeding the maximum voltage that will not trigger the SCR, at the maximum junction temperature at which the SCR's are expected to operate. T

The UJT is a unique device which can trigger SCR's very efficiently. Its advantages are that it maintains a stable triggering voltage and stability in frequency is good with changes of temperature. It requires very low value of trigger current and it has high pulse current capability. It's performance is reliable and it is cheap.

Type 2N1671A UJT is chosen to construct a UJT pulse trigger circuit for triggering SCR's. The values of the components and the supply voltage to trigger a 16A, 600 V SCR are chosen as shown below considering the above design conditions.

V = 16 V	C = 0.1 μf
R_B = 47 Ω	R_1 = 3.3 kΩ
Rs = 470 Ω	R_T =500 kΩ pot.

The characteristics of 2N1671A UJT is shown in the table 1.

TABLE - 1

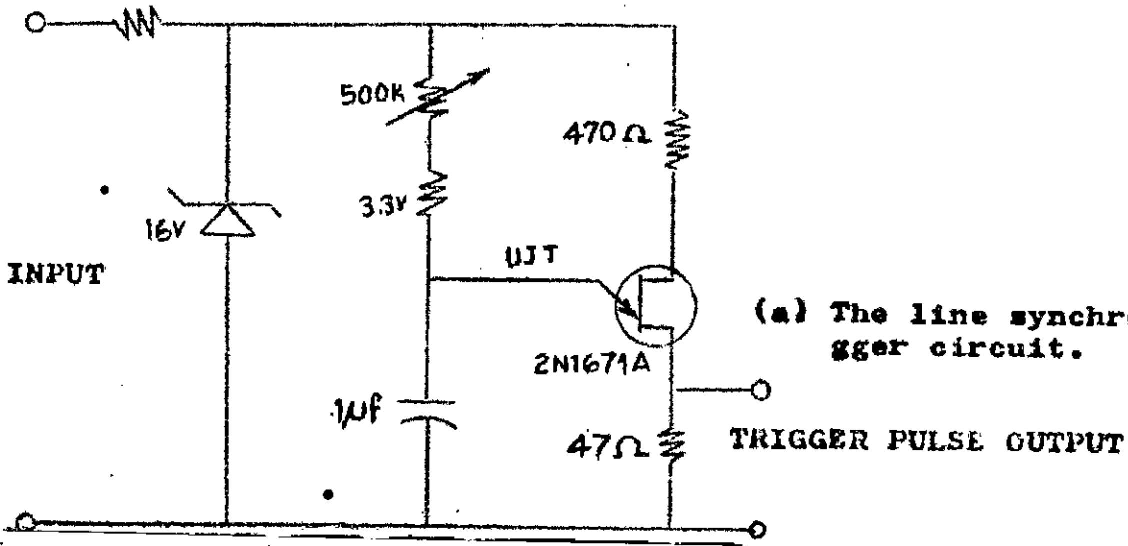
Characteristics of the 2N1671A unijunction transistor

V_{BB} (max.)	= 30 V
Interbase resistance R_{BB}	= 4.7 - 9.1 kΩ
Intrinsic stand-off ratio n	= .47 - .62
Min. valley current I_V	= 8 ma
Max. peak point emitter current I_p	= 25 μa
Min. base one peak pulse voltage	= 3 V

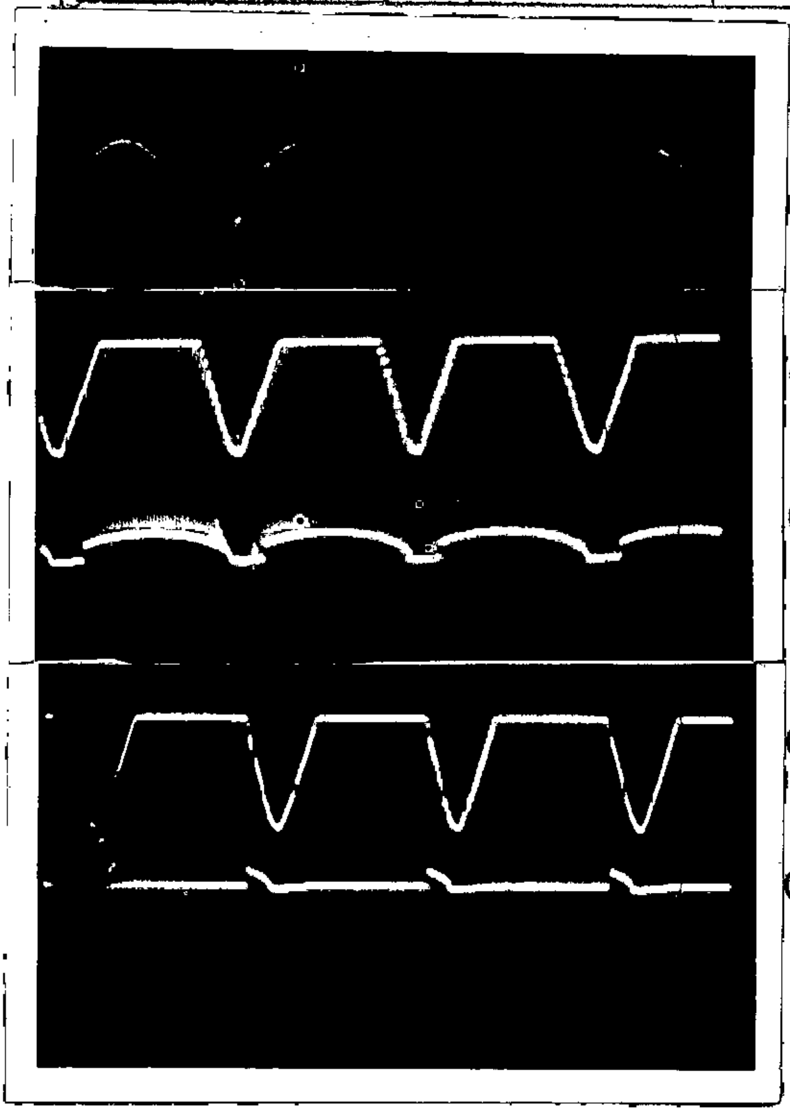
The UJT oscillator was constructed and it was found to operate efficiently and the oscillogram of saw tooth waveform across the emitter and ground, and pulse output across R_B are shown in in the fig. 3.4.

3.4 A LINE SYNCHRONIZED UJT TRIGGER CIRCUIT FOR SCR:

A unique trigger circuit using a UJT useful for triggering the SCR gate for AC line operation is shown in the fig. 3.5a. The trigger circuit is synchronised from the 230 V AC line. The input to the trigger circuit is full wave rectified signal as shown in fig. 3.5b (which can be obtained from the output of a bridge rectifier) which supply both power and synchronising signal to the trigger circuit. A zener diode D is used to clip the peak



(a) The line synchronised trigger circuit.



(b) Full-wave rectified voltage waveform at the input.

(c) Clipped full-wave rectified voltage waveform, across the zener diode.

(d) Trigger pulse produced near the begining of each half cycle.

(e) Clipped full-wave rectified voltage waveform, across the zener diode.

(f) Trigger pulse produced near the end of each half cycle.

Fig. 3.5. The Line Synchronised Trigger Circuit and Voltage Waveforms at Different Instante.

giving the waveform shown in the fig. 3.5c. When the signal is first applied to the circuit, C is uncharged and the emitter is at ground potential. C then charges exponentially through R but as soon as emitter reaches the firing voltage, UJ fires and C discharges rapidly through R_B giving a positive pulse across R_B as shown in fig. 3.5d (only the first one pulse in each half cycle is required to trigger the SCR). At the end of each half cycle, the base two voltage of the UJT drops to zero and C discharges (if C had any charge after first discharge) through the low impedance of the emitter. The capacitor is thus uncharged at the begining of each half cycle and the condition for recharge and triggering in the next half cycle is established. Hence the trigger circuit is synchronised with the line. The instant at which in each half cycle the circuit should trigger (i.e., produce a pulse in the output of UJT to cause the SCR to trigger) is determined by RC time constant. Generally R is varied. If R is small, the triggered pulse will appear near the begining of each half cycle as shown in the fig. 3.5d and if R is large, it will appear near the end of the half cycle as shown in the fig. 3.5e. If R is very large pulse output may not appear at all.

3.5 TRANSISTOR FLIP-FLOP TRIGGER CIRCUIT:

Where SCR must switch high current in a short time and where fast turn on is required such as in inverters pulse modulators etc. the trigger signal must have very short rise time. Again in same cases the pulse width requirement is high to initiate the conduction of SCR as for inductive AC load. The transistor flip-flop circuit as shown in the fig. 3.6a can meet the above requirements. The square waves generated have short rise time and of enough duration to trigger inductive AC load. Transistors Q_2 and Q_3 form a bistable multivibrator and the UJT relaxation oscillator Q_1 drives it, to change state alternately. Two cycles of UJT trigger circuit complete one cycle of the flip-flop and the flip-flop frequency is half of the UJT relaxation oscillator frequency as shown in the fig. 3.6b. The gating signals are taken from the secondaries of

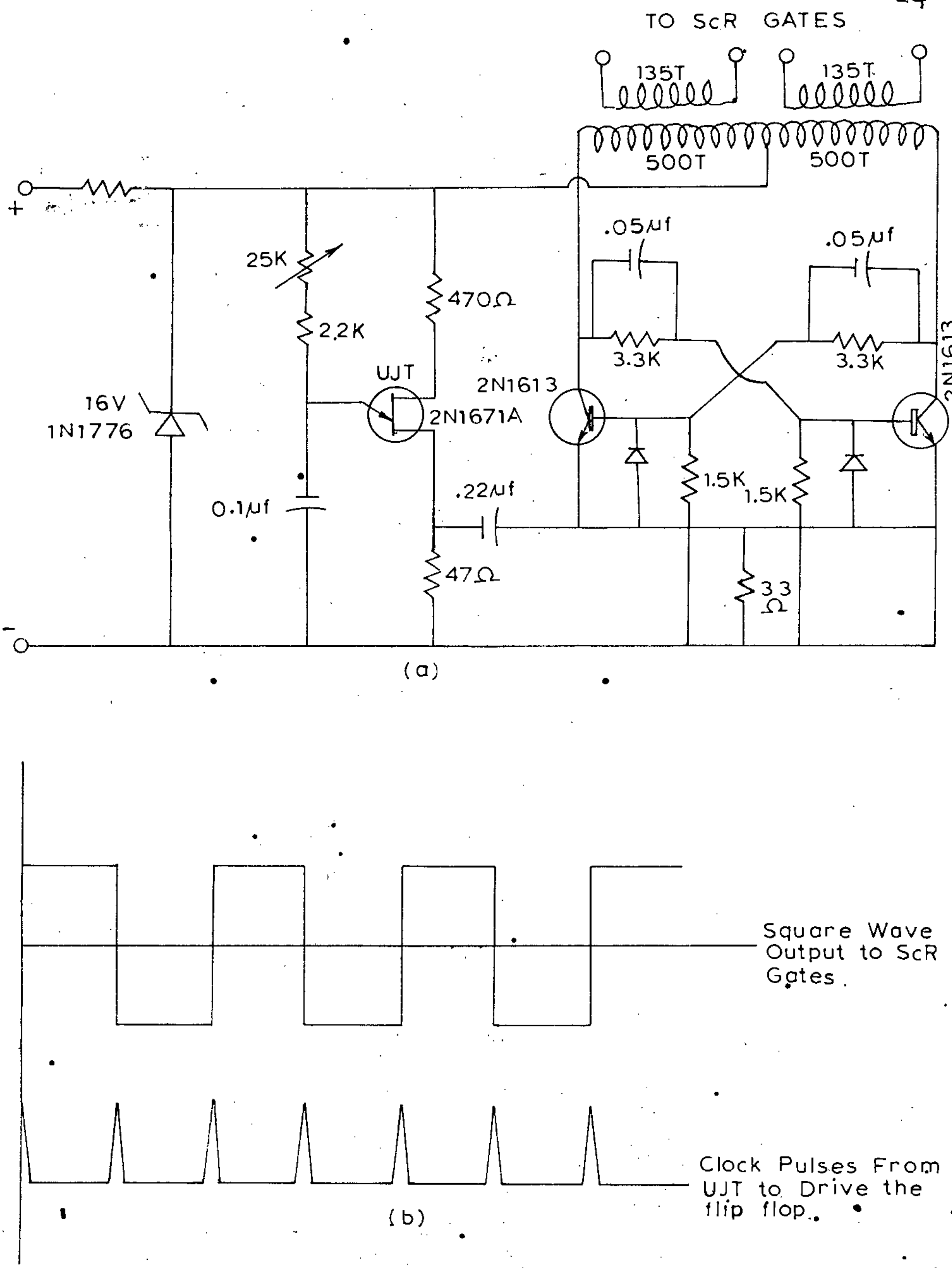


Fig. 3.6 Transistor Flip Flop Trigger Circuit And Square Wave Trigger Waveforms

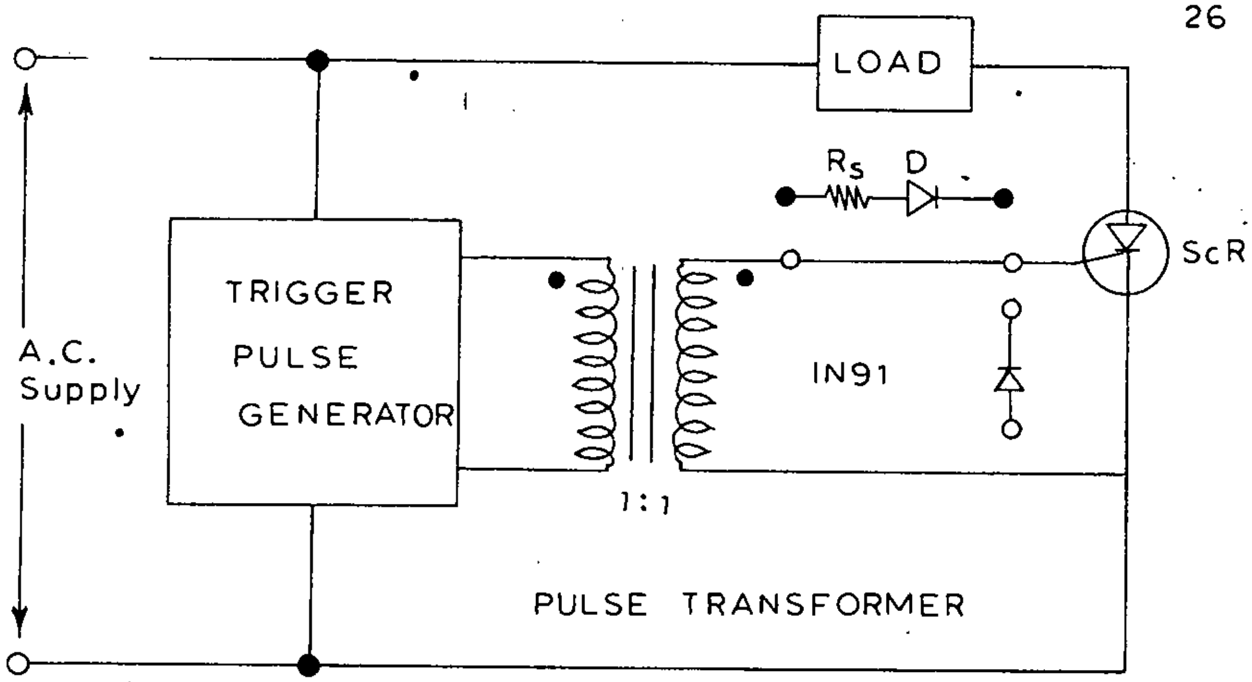
the pulse transformer whereby electrical isolation is obtained between the trigger control circuit and power circuit. The output impedance of this square wave trigger circuit is about 8 ohm. and open circuit voltage is 4 volts peak.

3.6 PULSE TRANSFORMERS IN TRIGGER CIRCUITS:

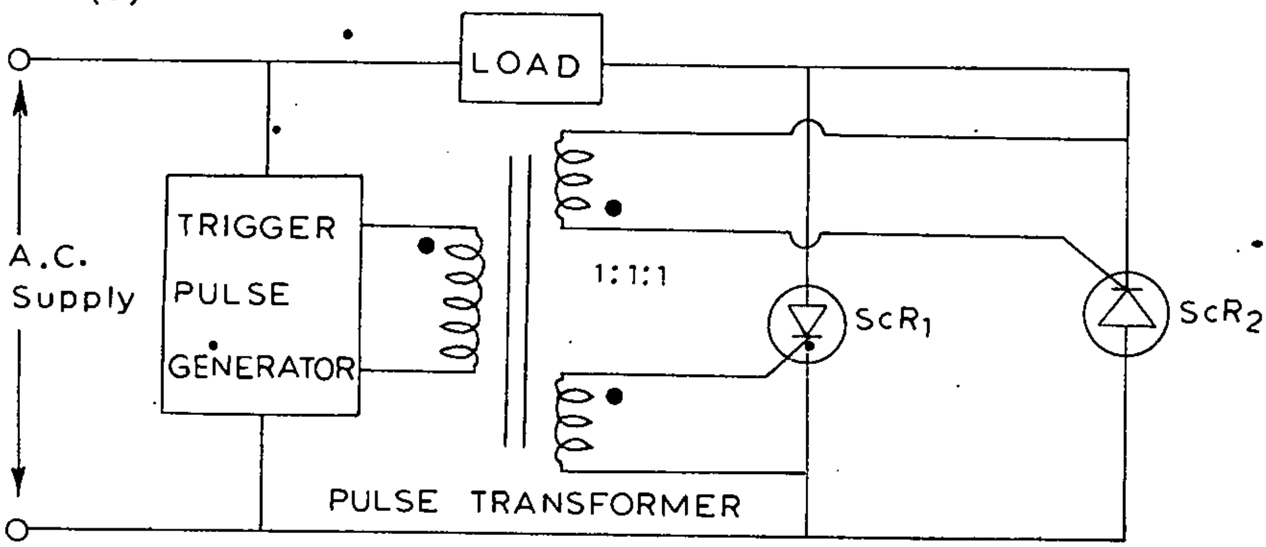
There are a number of methods of coupling the trigger pulse to the gate of a SCR, of which the method of coupling the trigger pulse generator to the SCR gate by pulse transformer is very convenient as it provides electrical isolation between the two circuits and one pulse generator unit can be used to trigger a number of SCR's.

There are a number of methods of connecting pulse transformer for triggering of SCR's. The fig. 3.7a shows a two winding, 1 : 1 transformer for triggering a single SCR. The secondary of the transformer may be connected directly between gate and cathode or there may be a resistor Rs and diode D in series in the secondary. The purpose of the resistor is to keep the gate current within the specification of SCR or to balance the gate currents in a three winding transformer connected to two SCR's . The function of the diode is to block the gate current in the reverse direction (i.e. from cathode to gate) in case of reversal of the pulse transformer output voltage. The oscillogram in the fig. 3.7 shows a typical pulse transformer output pulse. Sometimes the diode D is connected in parallel with gate and cathode to attenuate the negative gate to cathode pulse by the low impedance of diode D, to protect the SCR. The diode 1N91 is generally prefered here as it provides very low impedance in forward direction in comparison to cathode gate impedance. It is sometimes becomes necessary to load the secondary of the transformer with a resistor to prevent false triggering if high noise levels are present.

The fig. 3.7b shows a method of connecting three winding, 1 : 1 : 1 transformer to trigger an inverse-parallel pair of SCR's. Here complete isolation of pulse generator and SCR's is provided by the three winding transformer.



(a)



(b)

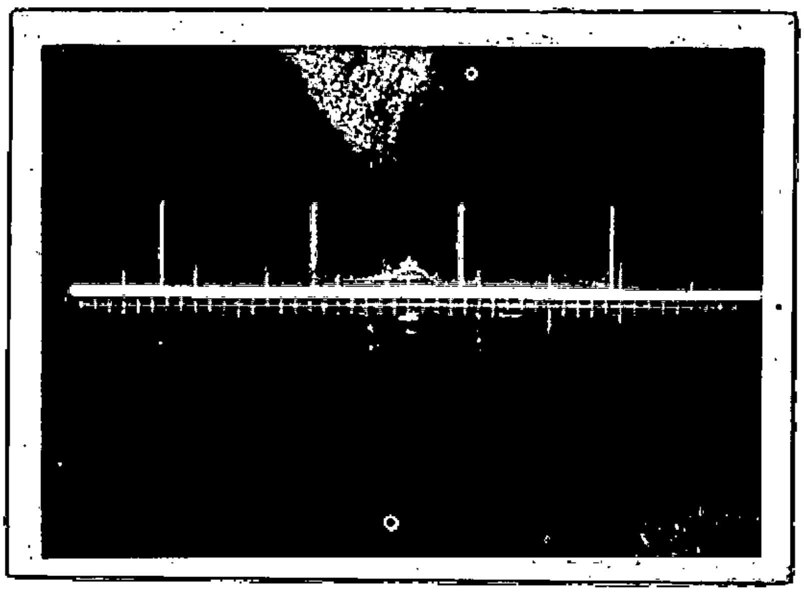


Fig. 3.7 Pulse Transformer Connection For ScRs And The Oscillogram of Trigger Pulse

When one pulse generator is used to trigger two SCR's, it must furnish sufficient energy to trigger both the SCR's and the pulse transformer must supply sufficient gate current to both SCR's under worst-case condition of unbalanced gate impedances. In each half cycle of line frequency, both the SCR's will receive gate trigger pulse but only one SCR will be triggered into conduction (whose anode is positive with respect to cathode) in each half cycle. These precaution taken for single SCR triggering in the fig. 3.7a are also valid for the inverse parallel pair of SCR's.

The design of pulse trigger transformer should be such that it will give high-efficiency so that low power pulses produced by the generator cân trigger the SCR's effectively. In designing pulse transformer the following points are taken into account.

(1) The magnetising inductance of the primary winding should be high enough so that magnetising current is low, in comparison with pulse current during the pulse time.

(2) Core-saturation must be avoided.

(3) Core-should be of high permeability material.

(4) For single SCR control, the coupling between the primary and secondary should be tight and for multiple SCR control there may have some leakage reactance for balancing trigger currents.

(5) Insulation between windings must be adequate to provide isolation of windings even in case of sever transients.

(6) Inter-winding capacitance should be low to minimise the spurious signal effect at high frequencies.

A pulse transformer is designed and constructed with turn ratio 1 : 1 : 1 for coupling trigger pulses to inverse parallel SCR's. The number of turns in each winding is 100. The pulse transformer is found to operate excellently. The oscillogram of pulse waveforms in the secondary is shown in the fig. 3.7 .

CHAPTER - IV

SCR CONTROL OF INCANDESCENT LAMPS

4.1 INTRODUCTION:

SCR's can be very efficiently used for controlling the intensity of light of the incandescent lighting banks. Cenema halls, theatres, television studios, advertising displays and in many other places gradual control of light intensity is required. There are many methods for controlling the light intensity but control of light by use of SCR switching devices provide best performance in all respects, as it will be evident by considering the advantages and disadvantages of various types of control.

Various types of control:

The incandescent lamps are controlled either by varying the current by use of a variable impedance in series with the load or by use of variable voltage source applied to the load. The advantages and disadvantages of various types of control of incandescent lamps are listed below :

Serial No.	Type	Advantage	Disadvantage
1.	Resistance	Low cost	Higher power dissipation, low efficiency
2.	Saturable reactor	Good efficiency	High cost, load sensitive.
3.	Variable Auto-transformer	Good efficiency, not load sensitive	High cost, large size and heavy
4.	Magnetic amplifier	Flexible, not load sensitive	High cost, large size and heavy. Noise level high.

Serial No.	Type	Advantage	Disadvantage
5.	Thyratron	Flexible, not load sensitive	Tube maintenance, separate filament supply and low efficiency.
6.	SCR	High efficiency, small size, flexible, ragged. Not load sensitive, min. maintenance and low cost.	Low over current capacity.

4.2 SOME DESIGN CONSIDERATIONS:

The incandescent lamp:

The volt-ampere characteristics of the incandescent lamps are non-linear, i.e., the cold resistance is must lower than the hot resistance and inrush surge current may be ten to twenty times the normal operating current for heavy load. In rush current decays in ten to twenty cycles at 50 Hz line frequency. The inrush surge current is an important factor in design consideration of the circuit.

The light output, efficiency and life of incandescant lamps depend on the voltage applied to the load. Since SCR controls the amount of voltage applied to the load, it is important to know the effect of applied voltage change on the lamp characteristics. The fig. 4.1 shows the lamp characteristics as function of applied voltage.

Lamp burn out:

When the tungsten filament of incandescent lamp burns out, a field of plasma is created across the burned terminals which creates a serious situation as a short circuit occurs inside the bulb. The SCR current limited only by the SCR and line impedance becomes exceedingly high and itmay damage the device permanently, though —

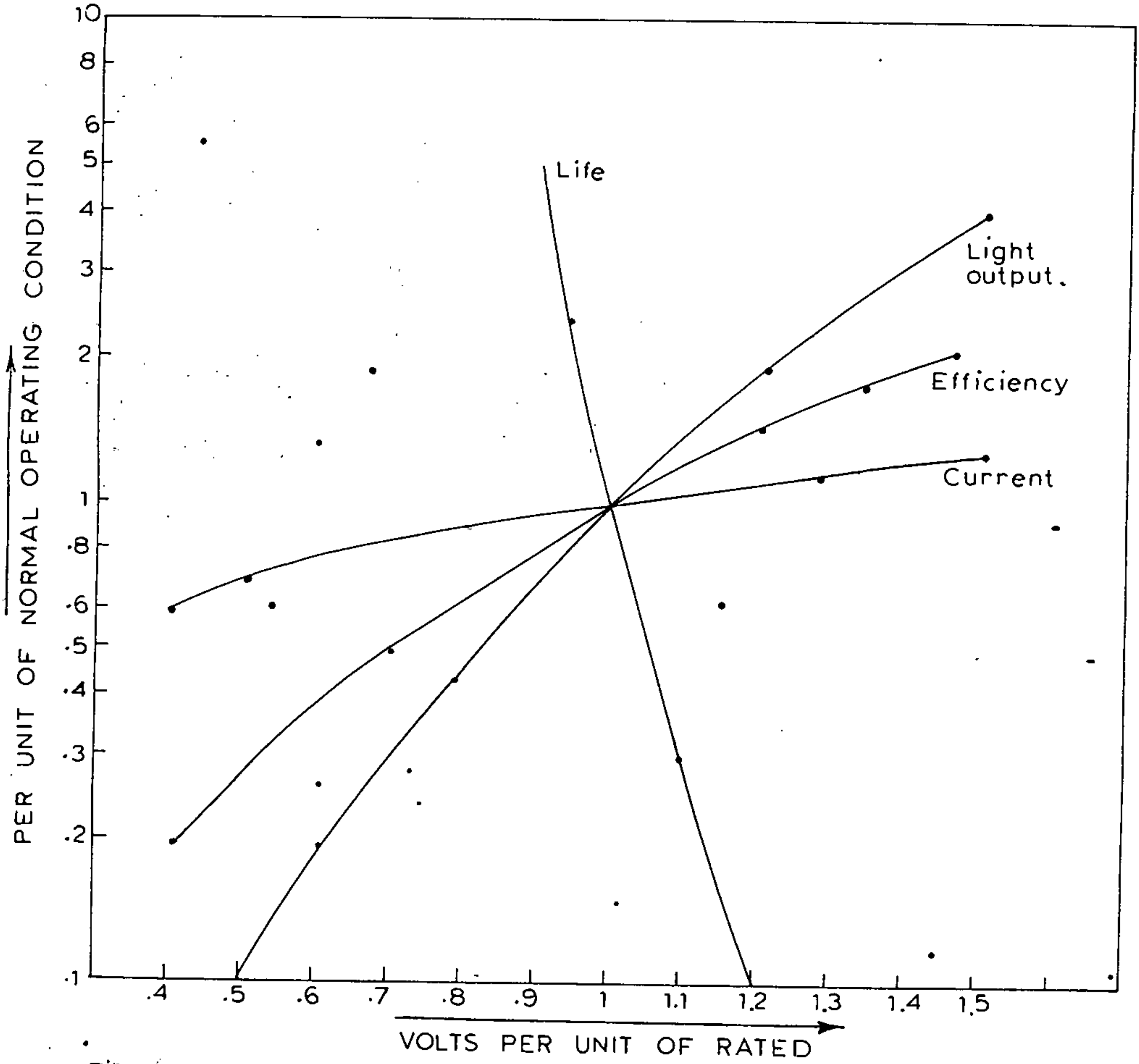


Fig. 4.1 Lamp Characteristics As Function of Applied Voltage

the fault current remains only for the rest of the half cycle. The device SCR can be protected by using proper fuse or series impedance. The I^2t rating of the fuse must be less than I^2t rating of the device SCR. When a series impedance is used its value should be such that it can keep the surge current within the maximum surge current capability of the device.

Selection of SCR:

The selection of SCR depends on the maximum load demand. It is uneconomic to use a SCR with a current rating about tem times the normal operating current. Generally SCR current rating should be atleast two times the normal operating current of the load when applied to incandescent lighting control and when supplying power to cold tungsten filament, care must be taken to prevent excessive current flowing before the lamps warmup. This is because the resistance of a lamp is determined by the temperature of the filament. This problem is over come by ensuring that full power is not applied to the lamp load instantaneously, but is slowly increased up to full power allowing the filaments to warmup.

4.3 BASIC SCHEMATIC DIAGRAM OF LIGHT DIMMER:

The basic schematic diagram of a SCR controlled light dimmer installation is shown in the fig. 4.2. Dimming of the lamps is ob-

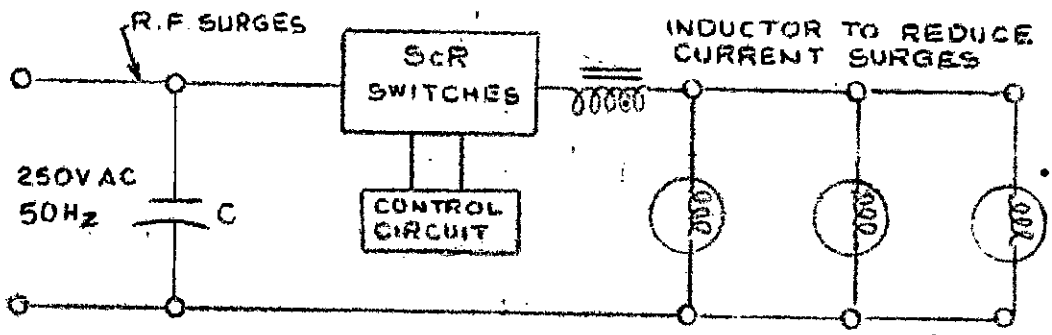


Fig. 4.2 BASIC SCHEMATIC DIAGRAM OF LIGHT DIMMER.

tained by applying variable voltage to the lamp load and the variable voltage is obtained by controlling the phase of SCR conduction.

The leading edge of thecurrent wave is very sharp after the SCR is switched into conduction. This current surge is undesirable both for the SCR and lamp specially when the load demand is high. This may cause the filament of the incandescent lamp to resonate mechanically, which reduce the life of the lamp. An inductor in series with the lamp load will cause the current to rise slowly and thereby protect both the SCR's and lamps. The capacitor C is used to suppress the radio frequency interference, caused by the switching action of SCR's , lightning, supply transients etc.

The SCR switches and the control circuit is generally enclosed in the switch box and the light intensity is controlled by varying a potentiometer.

Chapters V, VI and VII will describe various circuit configurations for control of incandescent lamp load.

CHAPTER - V

HALF WAVE PHASE CONTROLLED VARIABLE POWER CIRCUITS USING SCR

(Resistive Load)

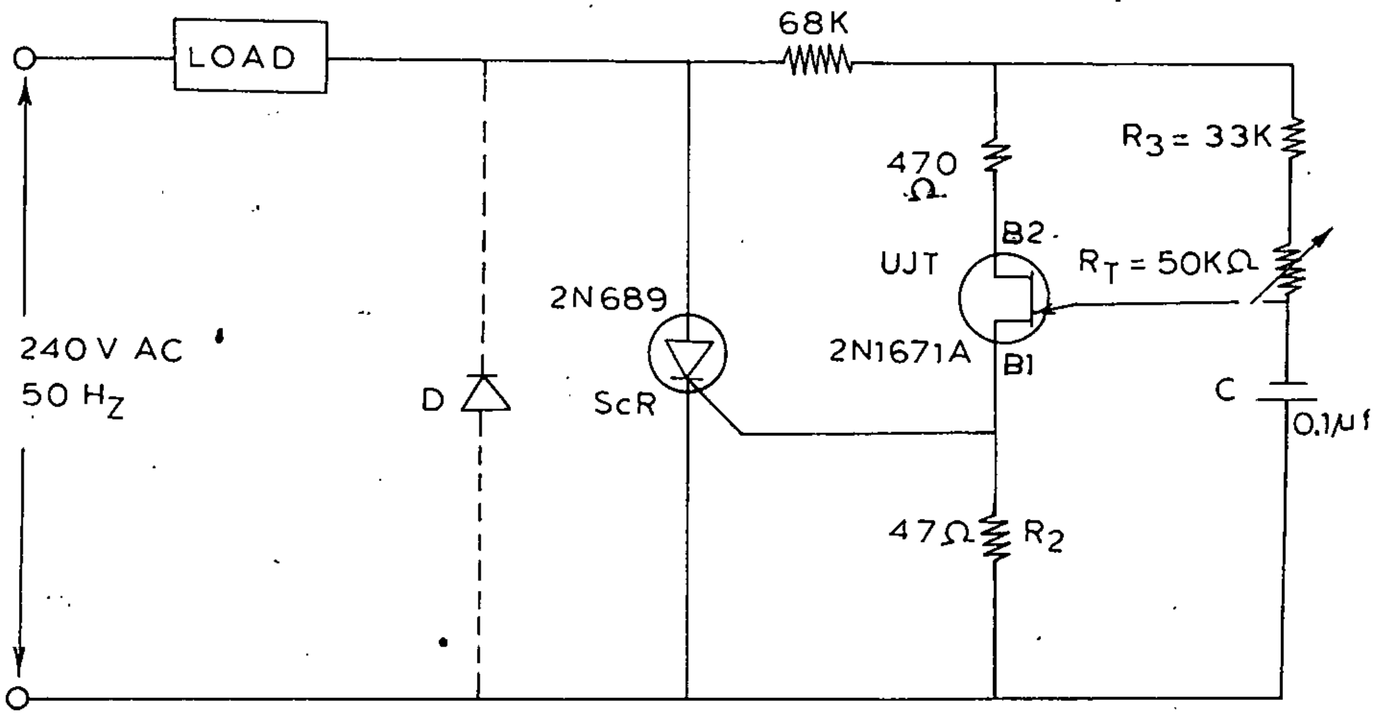
5.1 PRINCIPLE OF PHASE CONTROL:

SCR is controlled rectifier and it can be triggered into conduction at any instant (i.e., at any angle) in a half cycle and "phase control" is the process of controlling the switching of the SCR at any desired instant, when power will be delivered to the load through the SCR. So the average power delivered to the load can be controlled by controlling the instant of switching of the SCR and the SCR will conduct for the rest of that half cycle. If the SCR is triggered near the begining of a half cycle, maximum power will be delivered to the load. Where as if the SCR is triggered near the end of a half cycle minimum power will be delivered to the load.

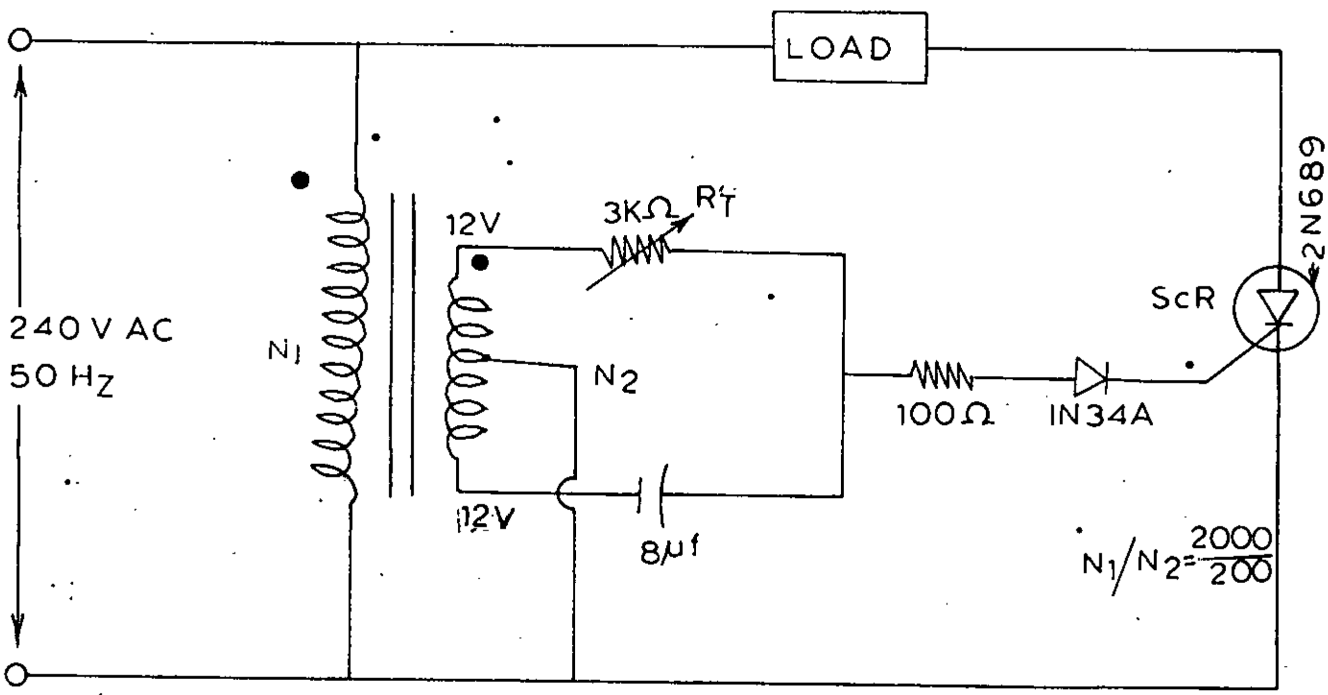
5.2 HALF WAVE PHASE CONTROL USING UJT CIRCUIT FOR TRIGGER CONTROL:

The fig. 5.1a shows a simple phase controlled variable power circuit in which unidirectional current flows through the load. A UJT trigger circuit described in chapter - III is used to gate control. The SCR can conduct only in the positive half cycle and in the positive half cycle conduction period can be varied from nearly zero to 180^o by varying the instant of SCR triggering. The trigger circuit generates pulses in each positive half cycle and the instant is determined by the time constant of the trigger pulse generator, which is dependent on the setting of the controlling potentiometer R_T. In the circuit the resistor R_D is the voltage dropping resistor and its value 68 k-ohm is such that when the input voltage is 240V voltage across the unijunction transistor trigger circuit is 16V which is below its rated specification.

In each positive half cycle, the SCR anode voltage rises with respect to the cathode and the capacitor C_T is charged through R_3 and R_T. When the capacitor voltage reaches the peak point voltage required to trigger the UJT, it generates a positive pulse to the



(a) Phase Control By UJT Trigger Circuit



(b) Phase Control By Phase Shift Bridge

Fig. 5.1 Half Wave Phase Controlled Variable Power Circuits Using ScR gate of the SCR, whereby the SCR is driven into conduction and the load receives power for the remaining duration of the positive half cycle. When the SCR conducts the voltage across it drops to negligible value (1 volt.) and all the voltage appears across the load. As the voltage across the SCR drops to 1 volt when it conducts, the UJT trigger circuit (which gets supply from the line by way of the dropping resistor R_D) voltage falls to near the ground potential and it ceases to generate trigger pulse. At the end of positive half cycle the SCR anode voltage drops to zero and it ceases to conduct. In the negative half cycle neither the SCR can conduct nor the trigger circuit generates pulse. So in the negative half cycle appears across the SCR the full supply voltage.

The amount of power to be supplied to the load is determined by the setting of the potentiometer R_T. For maximum power transfer to the load the potentiometer is set for zero resistance and the capacitor C_T charges to peak point voltage very quickly and the trigger circuit fires the SCR into conduction towards the begining of each positive half cycle. The circuit wave forms across various parts of the circuit for maximum power transfer to the load is shown in the fig. 5.2a.

Now if the potentiometer is set for higher resistance, there will be delay in generating pulses in the trigger circuit. For half maximum power the SCR is triggered in the middle of each positive half cycle and the corresponding circuit wave forms are shown in the fig. 5.2b. For minimum power transfer to the load the potentiometer is set for maximum resistance and so there is maximum delay in firing the SCR and the SCR conducts near the very end of each positive half cycle. The circuit wave forms for minimum powers transfer is shown in the fig. 5.3a . Thus it is found that DC power to the load is fully controllable by the potentiometer R_T.

By use of this circuit power can be controlled very smoothly and efficiently as the several killo-watts of power is being controlled simply by the potentiometer which consumes only milli-watts of power. Moreover the voltage across the SCR when conducting is negligible, whereby the efficiency is greatly increased. The load

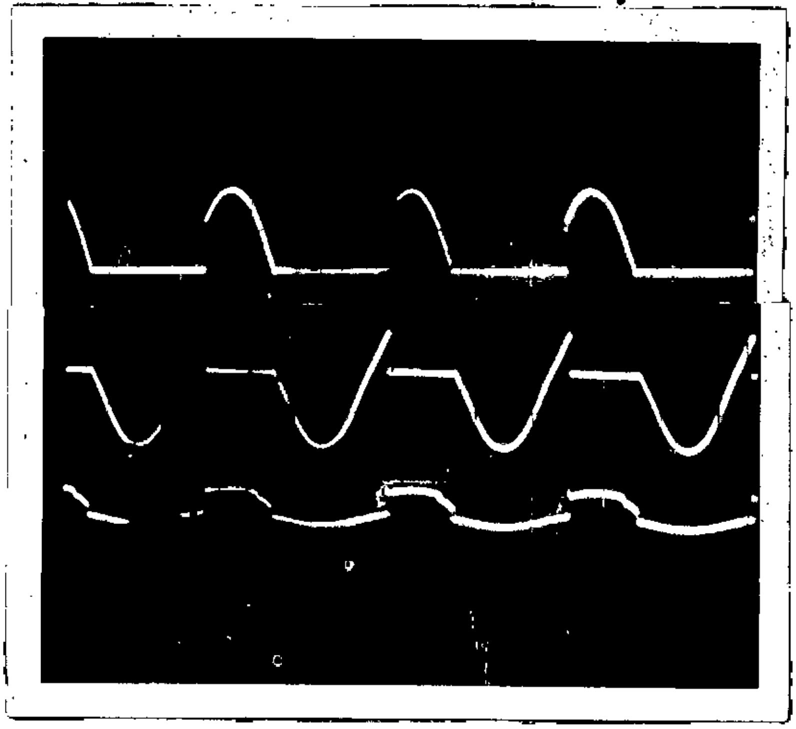


Fig. 5.2a. Voltage Waveforms for Maximum Power Transfer.

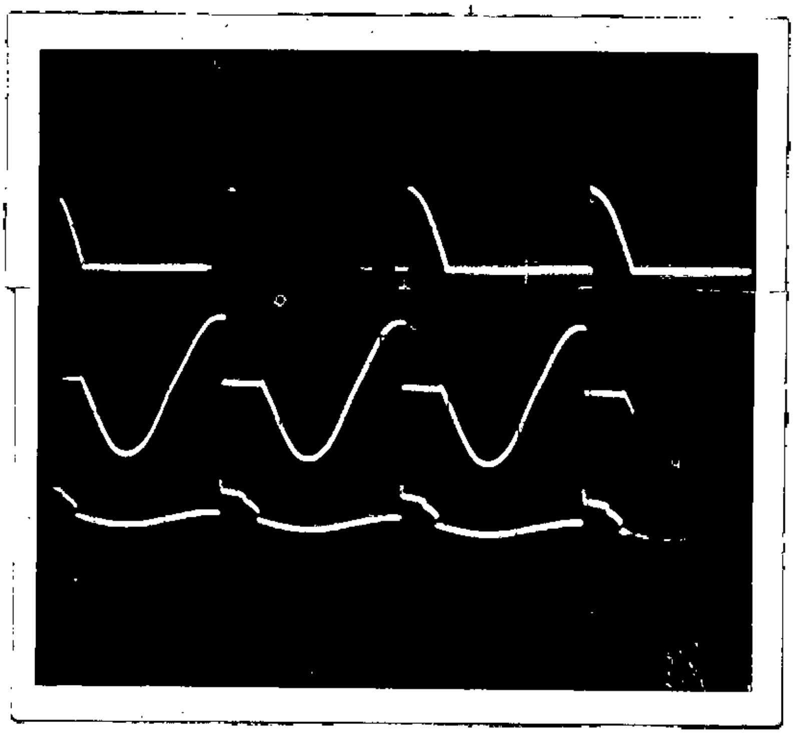


Fig. 5.2b. Voltage Waveforms for Half Power Transfer.

Fig. 5.2. Half Wave Phase Control.

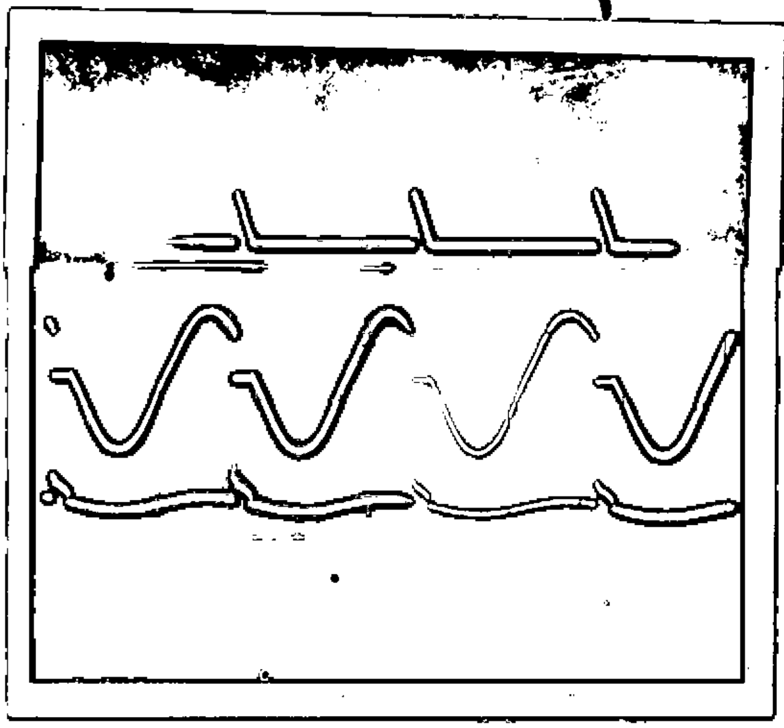


Fig. 5.3a. Voltage Waveforms for Minimum Power Transfer.

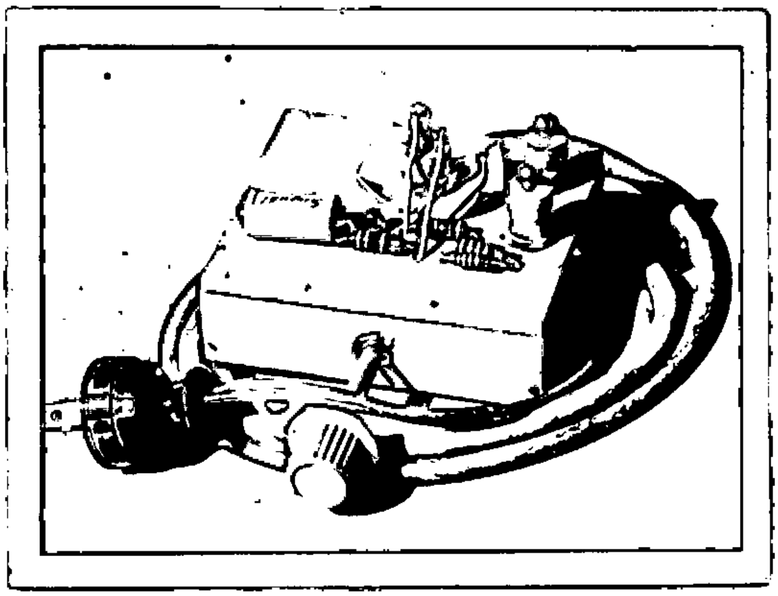


Fig. 5.3b. Photograph of the Circuit Shown in Fig. 5.1a.

receives power only in the positive half cycles and this fluctuation of load current produces noticeable flickering of lamp light, which is undesirable in some systems. The circuit shown in the fig. 5.1a was constructed and the photograph of the circuit is shown in the fig. 5.3b.

<u>Hlalf wave phase control analysis:</u>

For half wave phase control, average load voltage is given by:

$$E_{AVG} = \frac{1}{2\pi}\int_{\alpha}^{\pi} E_p \sin wt \; d(wt) = \frac{E_p}{2\pi}(1 + \cos\alpha)$$

$$\frac{E_{AVG}}{E_p} = \frac{1}{2\pi}(1 + \cos\alpha) \qquad \ldots \qquad \ldots \qquad (1)$$

Again for half wave phase control RMS load voltage is given by :

$$E_{RMS} = \sqrt{\frac{1}{2\pi}\int_{\alpha}^{\pi} E_p^2 \sin^2 wt \; d(wt)} = \frac{E_p}{2\sqrt{\pi}}(\pi - \alpha + \tfrac{1}{2}\sin 2\alpha)^{\frac{1}{2}}$$

$$\frac{E_{RMS}}{E_p} = \frac{1}{2\sqrt{\pi}}(\pi - \alpha + \tfrac{1}{2}\sin 2\alpha)^{\frac{1}{2}} \qquad \ldots \qquad \ldots \qquad (2)$$

The expression of DC load power is given by :

$$P = \frac{E_{AVG}^2}{R_L} = \left[\frac{E_p}{2\pi}(1 + \cos\alpha)\right]^2 \frac{1}{R_L}$$

but $$P_{max} = \left(\frac{E_p}{\pi}\right)^2 \times \frac{1}{R_L}$$

$$\frac{P}{P_{max}} = \frac{1}{4}(1 + \cos\alpha)^2 \qquad \ldots \qquad \ldots \qquad (3)$$

The expressions (1), (2) and (3) are plotted graphically in the fig. 5.4.

If full half-wave voltage is applied to an incanddescent lamp, only 30 % of the full light output is obtained. So this half-wave phase control circuit can control zero to 30% of full light output.

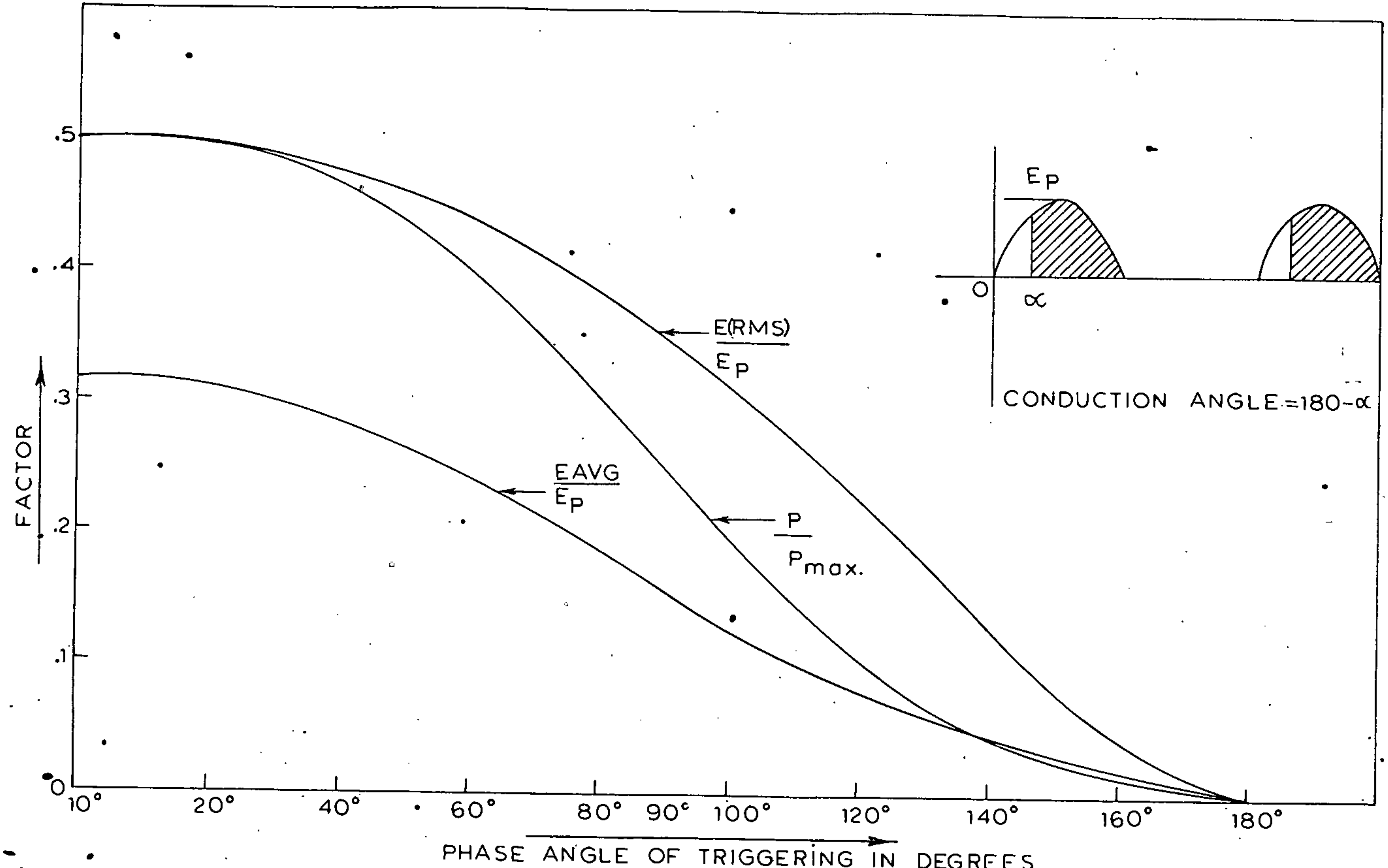


Fig. 5.4 Half Wave Phase Control Analysis

Now if a power diode is connected as shown by the dotted line in the fig. 5.1a, then this circuit will regulate load from half to full power as the load will conduct the full negative half cycle through the power diode D and only the positive half cycle is variable. Consequently the light output from the lamp load can be varied from 30% to 100% of maximum light output.

5.3 HALF WAVE PHASE CONTROL USING A PHASE SHIFT BRIDGE FOR TRIGGER CONTROL:

A simple circuit to demonstrate the use of SCR in a half-wave application using a phase shift bridge for trigger control for variable power output is shown in the fig. 5.1b. The output voltage from the phase shifting network is applied to the SCR gate and this controls the instant in the each positive half cycle at which the SCR should conduct. The phase of the AC gating voltage is variable with respect to SCR anode voltage. The phase of the gating voltage and hence the DC power to the load is variable by the potentiometer R_T. The AC phase shifting network controls precisely the triggering angle and provides smooth control of load current from 0° to 180°.

In this circuit the transformer is used for steping down the 240 V AC in the primary to 25 V AC in the secondary which is centre tapped. The number of turnsin the primary winding is 2,000 and that of secondary winding is 200, so the turn ratio is 10. The mode of winding in the primary and secondary coil is such that voltage at A is always in phase with the anode voltage. The function of the diode D is to prevent the SCR gate from becoming negative . with respecti to cathode.

Typical voltage waveforms at different parts of the circuit are same as shown in the fig. 5.2, 5.3, except the the gate to cathode voltage waveform.

CHAPTER - VI

FULL WAVE (RECTIFIED) PHASE CONTROLLED VARIABLE POWER CIRCUITS USING SCR (Resistive load)

The circuit in the fig. 6.1 shows a full-wave (rectified) phase controlled variable power cifcuit feeding a DC load. Here the load, SCR and the firing circuit are connected to the output side of a single phase rectifier bridge which consists of four power diodes. Rectified full-wave appears across the load and SCR. A single SCR exerts control over the rectified full-wave.

The circuit voltage waveforms across the zener diode, gate and cathode (i.e., the trigger pulse) , the load and the SCR are shown in the fig. 6.2 for maximum power transfer and in the fig. 6.3 for half power transfer.

Due to the action of the bridge rectifier, the zener diode and resistor R_D a rectified and clipped voltage (16V) is applied to the UJT trigger circuit. The resistor R_D is a voltage dropper resistance and 16V zener diode Z_D clips the peak at 16V. The UJT trigger circuit which is used to fire the SCR is synchronised with the power lined frequency as the circuit is automatically connected and disconnected each half cycle.

Power supplied to load is controlled very simply and efficiently by the potentiometer R_T. The voltage wave-form across the zener diode and UJT circuit remains unchanged for all power level as seen in the fig. 6.2 and 6.3d. At the beginingof each new half cycle the UJT circuit starts a timing cycle. The capacitor C is charged through R_T and when it reaches the peak point voltage UJT fires, generating a positive pulse at SCR gate which triggers the SCR into conduction. The time delay of triggering the SCR is determined by the setting of the potentiometer R_T.

When the potentiometer is set for minimum resistance, the SCR will be triggered into conduction in the begining of each half cycle and maximum power will be transfered to the load . This is evident from the oscillogram shown in the fig. 6.2 and conversely

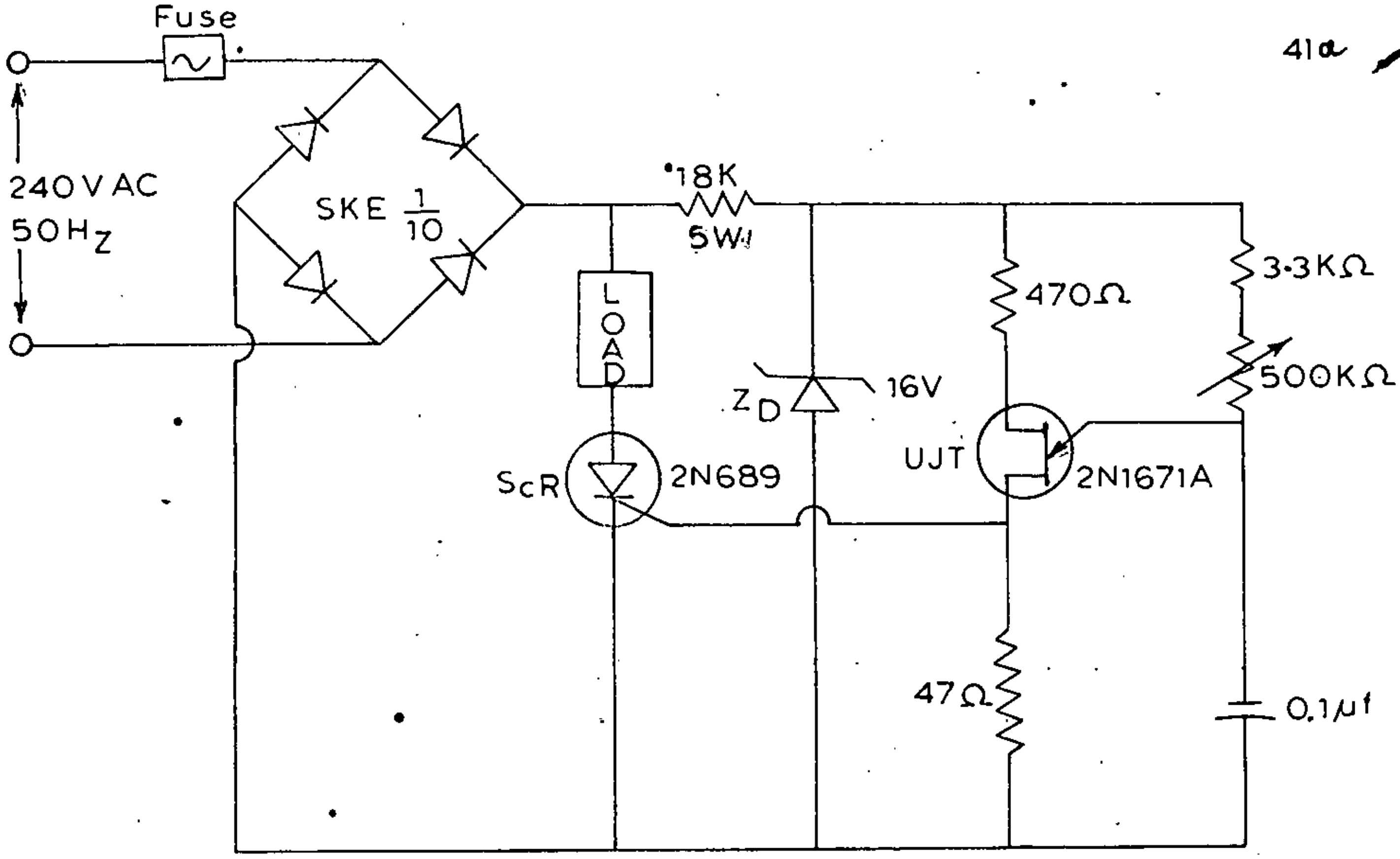


Fig 6.1 Full Wave (Rectified) Phase Controlled Variable Power Circuit Using ScR

for maximum potentiometer resistance minimum power will be transfered to the load.

For half maximum power transfer to the load the SCR is triggered in the middle of each half cycle. The oscillogram for this condition is shown in the fig. 6.3. If this circuits is used for control of a lamp bank then the flickering of light will be eliminated which was present in case of half wave phase control. Although here one SCR, can control the phases of both the half cycles, one power diode bridge is required for full wave rectification. The circuit shown in the fig. 6.1 was controllled and the photograph of the circuit is shown in the fig. 6.3b.

Full-wave phase control analysis:

For full-wave (rectified) phase control the average load voltage is given by :

$$E_{AVG} = \frac{1}{\pi} \int_{\alpha}^{\pi} E_p \sin wt \; d(wt) = \frac{E_p}{\pi} (1 + \cos\alpha)$$

$$E_{AVG}/E_p = \frac{1}{\pi} (1 + \cos\alpha) \qquad \ldots \qquad \ldots \qquad (1^{\circ})$$

and RMS load voltage is given by :

$$E_{RMS} = \sqrt{\frac{1}{\pi} \int_{\alpha}^{\pi} E_p^2 \sin^2 wt \; d(wt)}$$

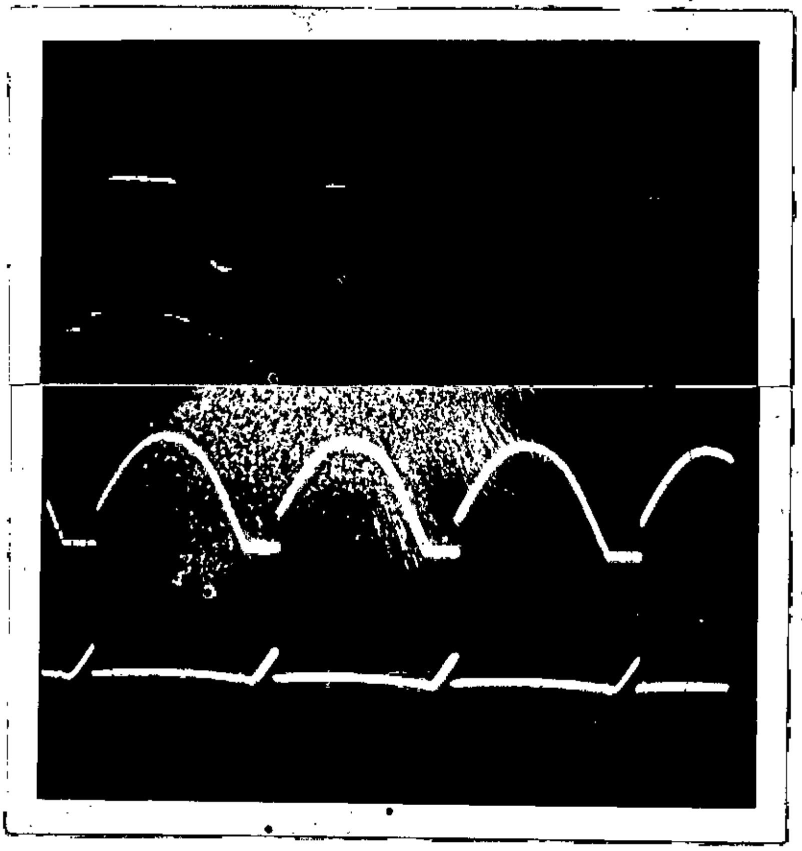
$$= \frac{E_p}{\sqrt{2\pi}} (\pi - \alpha + ½ \sin 2\alpha)^{½}$$

$$\frac{E_{RMS}}{E_p} = \frac{1}{\sqrt{2\pi}} (\pi - \alpha + ½ \sin 2)^{½} \qquad \ldots \qquad (2)$$

The expression of P/P_{max} can be obtained as

$$\frac{P}{P_{max}} = \frac{1}{2} (1 + \cos\alpha)^2 \qquad \ldots \qquad \ldots \qquad (3)$$

The expressions (1), (2) and (3) are plotted graphically in the fig. 6.4.



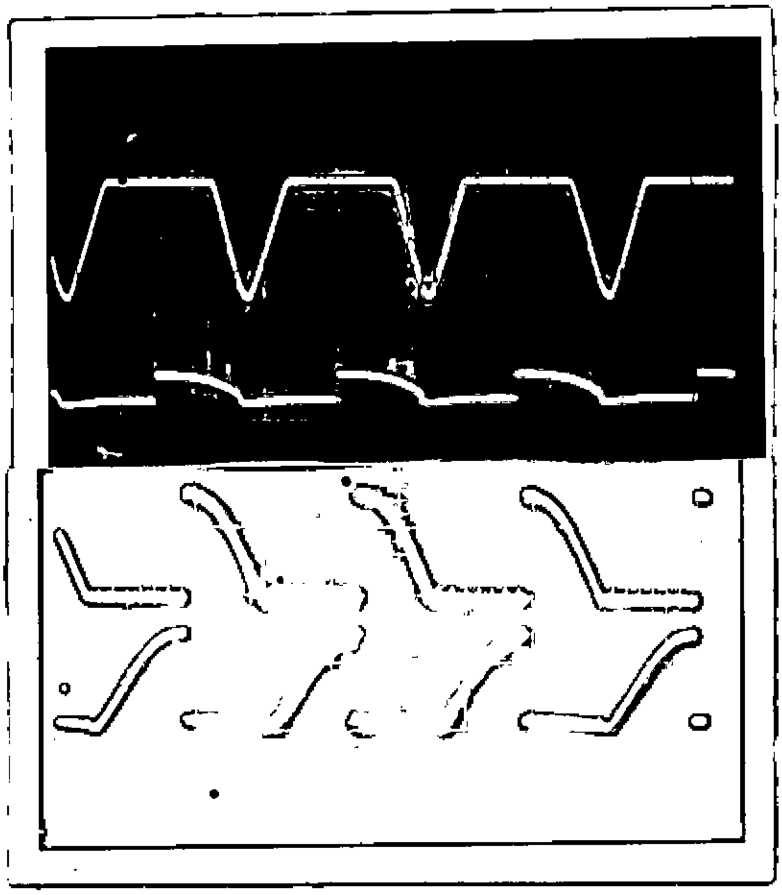
Voltage Across the Zener Diode.

Voltage Between Gate and Cathode.

Voltage Across the Load.

Voltage Across the SCR.

Fig. 6.2. Voltage Waveforms for Maximum Power Transfer in Full Wave (Rectified) Phase Control.



Voltage Across Zener Diode.

Voltage Between the Gate and Cathode.

Voltage Across the Load.

Voltage Across the SCR.

Fig. 6.3a. Voltage Waveforms for Half Power Transfer in

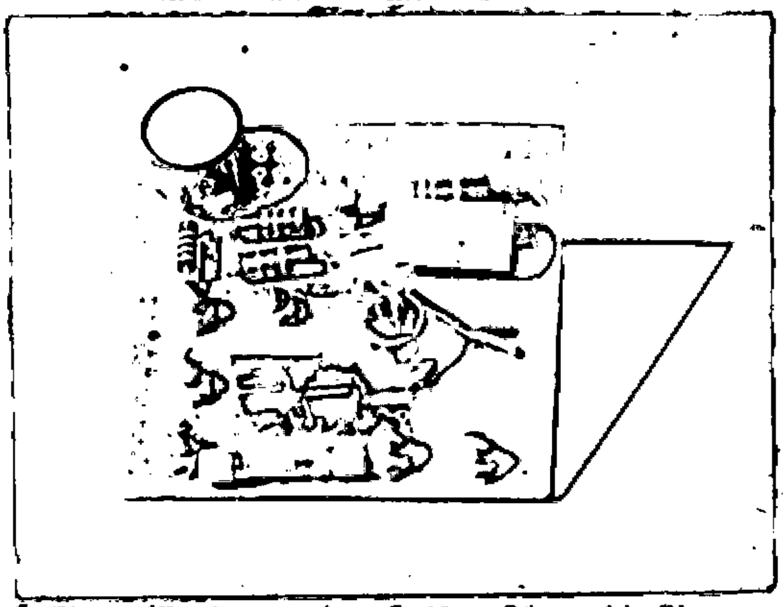


Fig. 6.3b. Photograph of the Circuit Shown in the Fig. 6.1.

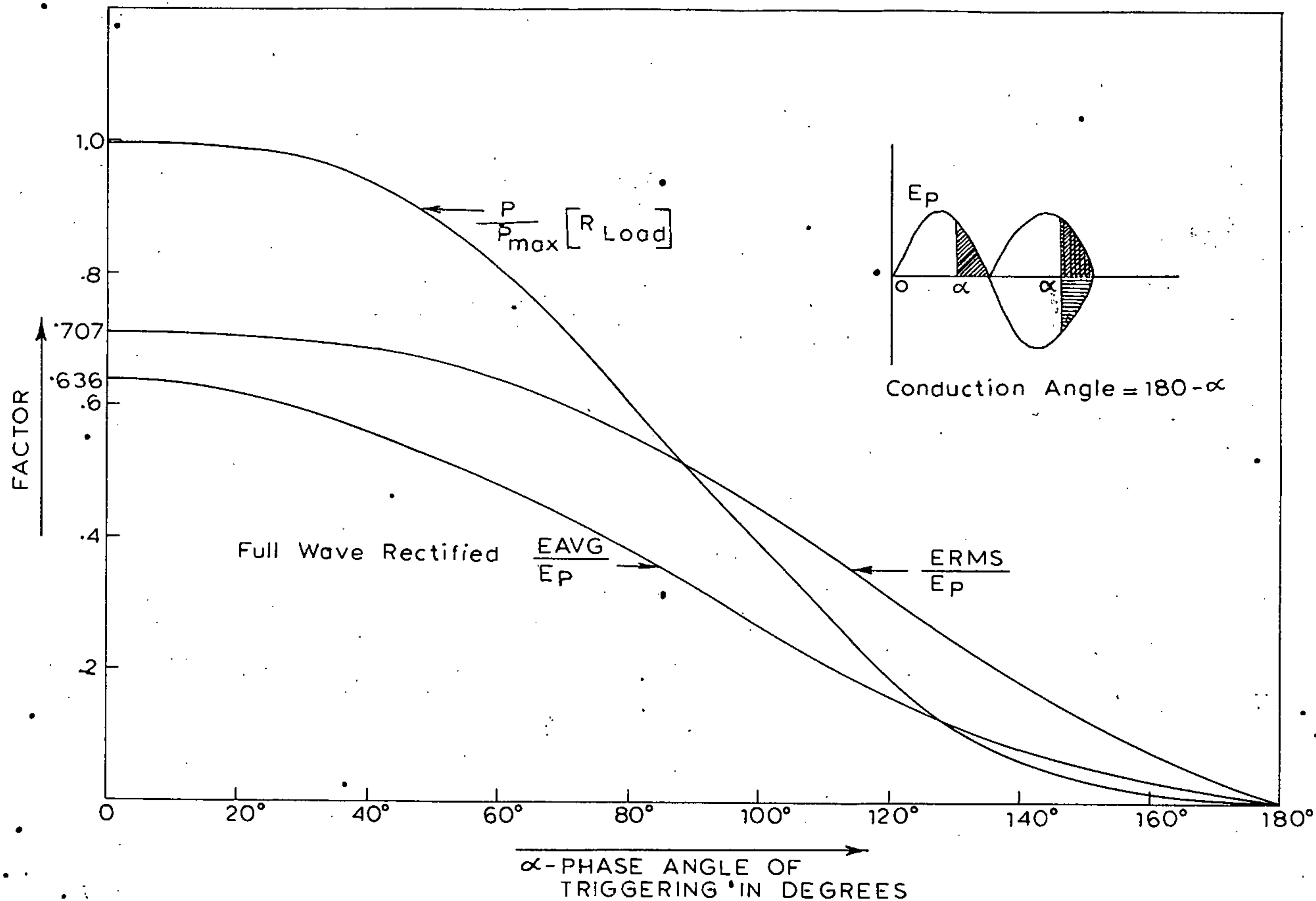


Fig. 6.4 Full Wave (Rectified) Phase Control Analysis

CHAPTER - VII

AC PHASE CONTROLLED VARIABLE POWER CIRCUITS USING SCR
(Resistive load)

7.1 INTRODUCTION:

Two very important single phase, controlled switching circuits using SCR's for feeding variable power to AC loads are discussed in this chapter. These circuits were designed, constructed and were found to operate efficiently. The oscillograms of the voltage wave forms for different power level are obtained to show the phase control. These circuits are suitable for control of incandescent lamp, heating coil etc. In the circuit diagram in the fig. 7.1 two SCR's are connected as inverse parallel pair in which the SCR1 conducts the positive half cycle and in the negative half cycle SCR2 conducts. So AC power is applied to the load. The circuit diagram of fig. 7.1 was constructed as shown in the fig. 7.3b.

7.2 THE TRIGGER CIRCUIT:

The trigger circuit for variable AC power unit is a line synchronised, efficient pulse generator using a unijunction transistor (UJT trigger circuit is describe in chapter - III). In the circuit of the fig. 7.1 , the SCR's are coupled to the pulse generator by a three winding pulse transformer which makes it possible to obtaine electrical isolation between the pulse generator and gates of the SCR's. Another advantage of use of pulse transfermer is that two SCR's are triggered by one trigger pulse generator unit.

7.3 PRINCIPLE OF OPERATION:

The unijunction transistor trigger circuit receives the supply voltage during the non-conductingp period of the SCR's because as soon as the SCR's start conducting the voltage across them drops to 1 volt and the remainingv voltage appears across the load. The resister R_D is a voltage dropper resistance. Its value is such that voltage across the trigger circuiti is writt in the specification of UJT. Because of the action of the bridge diqdes resistor R_D -.

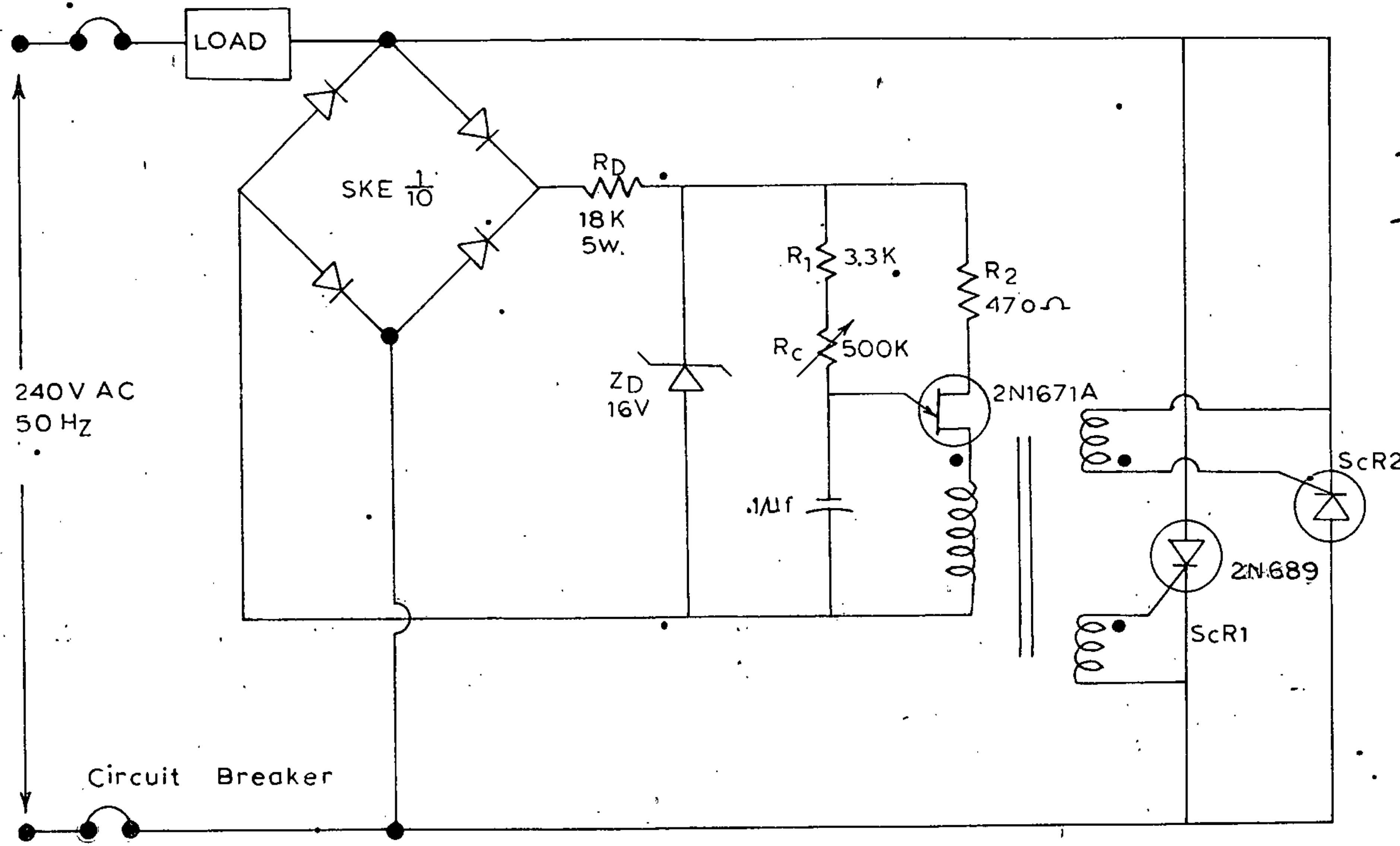


Fig. 7.1 AC Phase Controlled Switching Circuit For Variable Power Supply.

and zener diode Z_D , a rectified voltage clipped at 16 volts is applied to pulse generator. At the start of each new half cycle the trigger circuit starts a timing cycle. The capacitor C is charged through R_1 and R_c to peak point voltage when UJT fires, delivering a positive pulse to the primary of the pulse transformer. By transformer action pulse are transmitted to the gates of the SCR's and the SCR1 which has positive anode voltage during the positive half cycle, triggers into conduction delivering power to the load for that half cycle. When the SCR1 is triggered the voltage across the SCR1 drops to 1 volt, and therefore trigger generator supply voltage drops to near to zero potential. So the capacitor C remains discharged until the line supply voltage reverses (i.e., starts the next half cycle) at which time the sequence of operation starts again for the SCR2.

The firing angle of both SCRs is controlled by the potentiometer R_c . So power to the load can be smoothly varied from near zero to maximum via R_c. The oscillograms of the circuit voltage waveforms across different elements for different power-level are shown in the fig. 7.2(a) and 7.2(b). When R_c is set at maximum resistance, the output power is minimum, because the capacitor C charges near the end of each half cycle and therefore, the SCRs are fired near the end of each half cycle alternately. Since the SCRs conduct for a brief time, the load voltage is approximately 1% to 5% of the full load voltage. When R_c is set at minimum resistance the capacitor C charges near the begining of each half cycle and hence the SCRs are triggered near the begining of each half cycle alternately. So almost the full available power is developed in the load. This is evident from the oscillogram in the fig. 7.2a because almost full cycle appears across the load. The oscillogram 7.2b shows voltage wave-forms for half maximum power transfer to load, because half of each half cycle appears accross the load. Here the potentiometer R_c is set near the middle position.

The fig. 7. shows another form of single phase AC phase controlled switching circuit for feeding variable power to load. This circuit is similar to that of the fig. 6.1 except that here

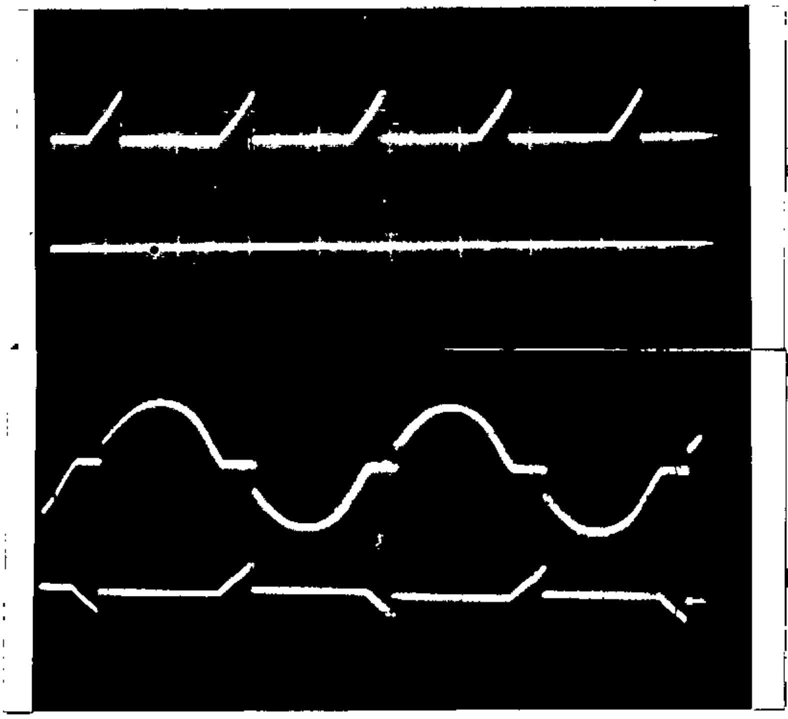


Fig. 7.2a. Voltage Waveforms for Maximum Power Transfer.

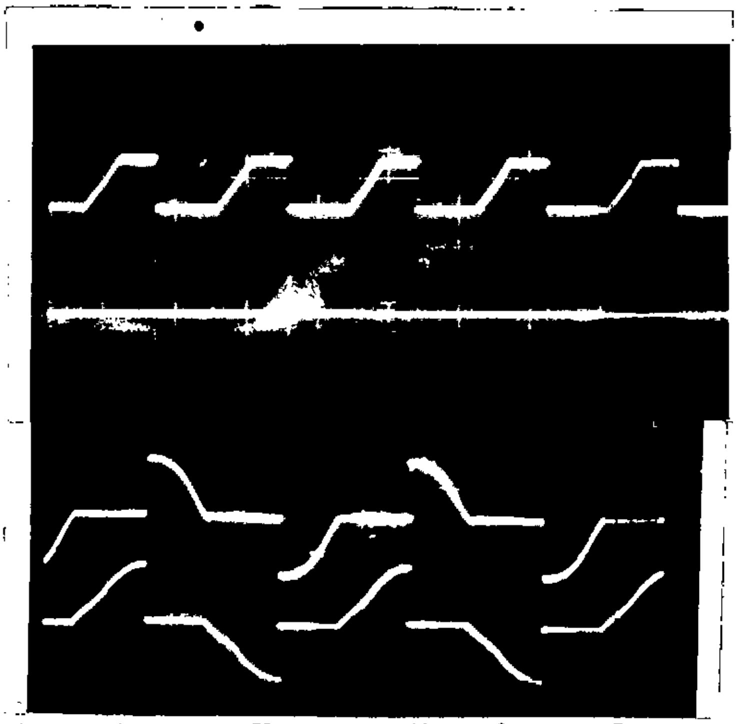


Fig. 7.2b. Voltage Waveforms for Half Power Transfer.

Fig. 7.2. AC Variable Phase Control.

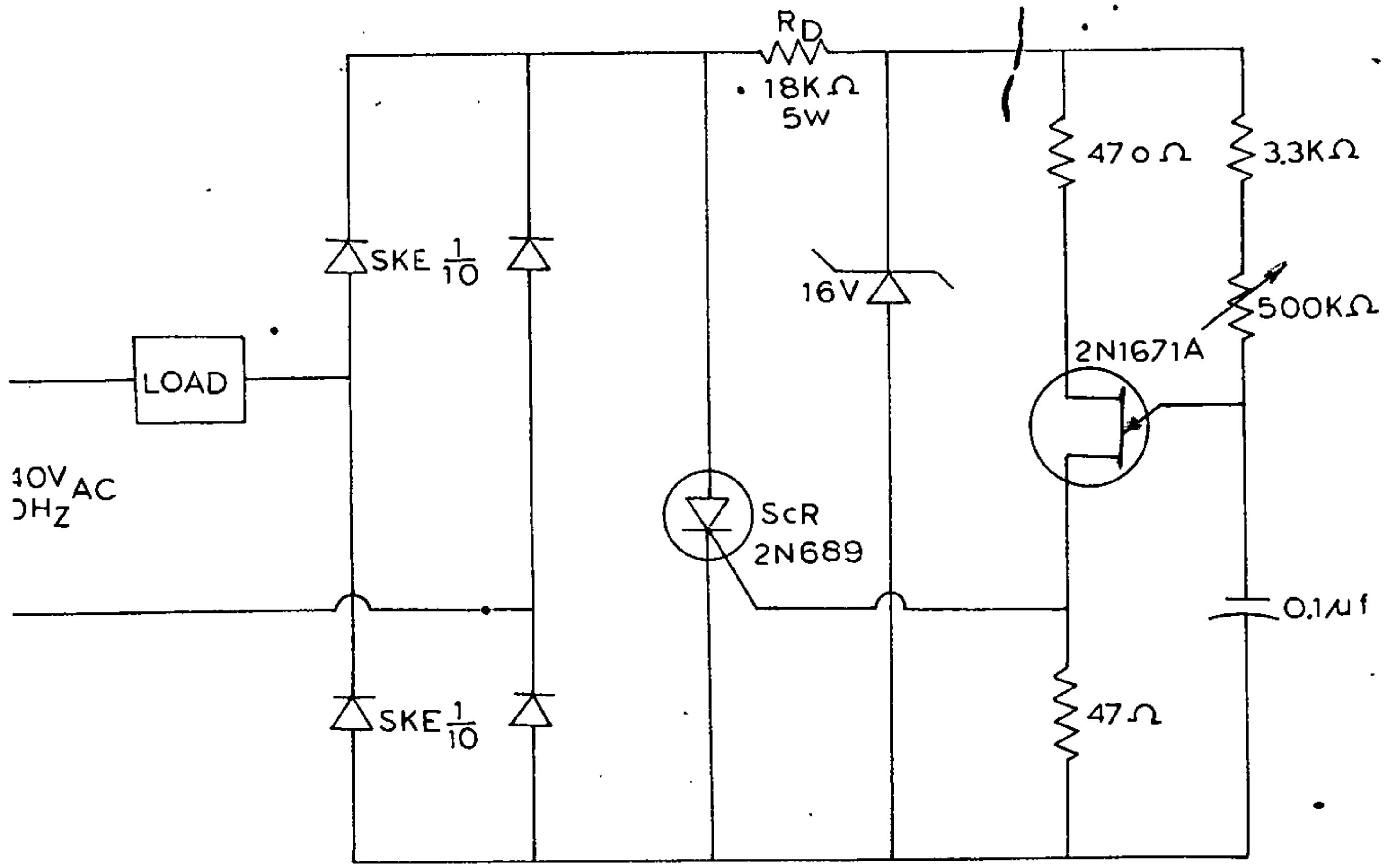


Fig. 7.3a An Alternative Form of AC Phase Controlled Switching Circuit For Variable Power Supply

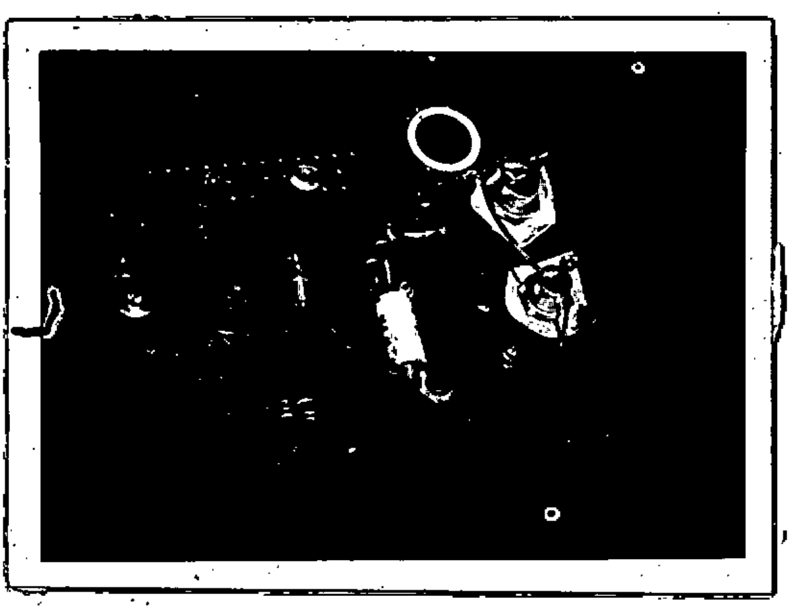


Fig. 7.3b Photograph of the Circuit shown in Fig. 7.1a

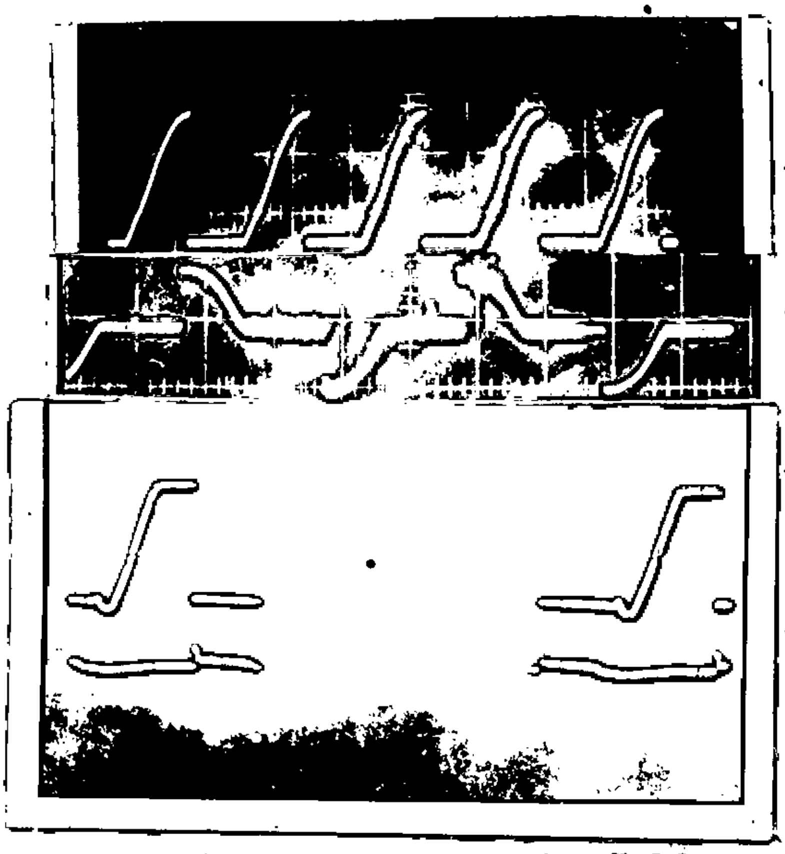


Fig. 7.4a. Oscillogram for Half Power Transfer.

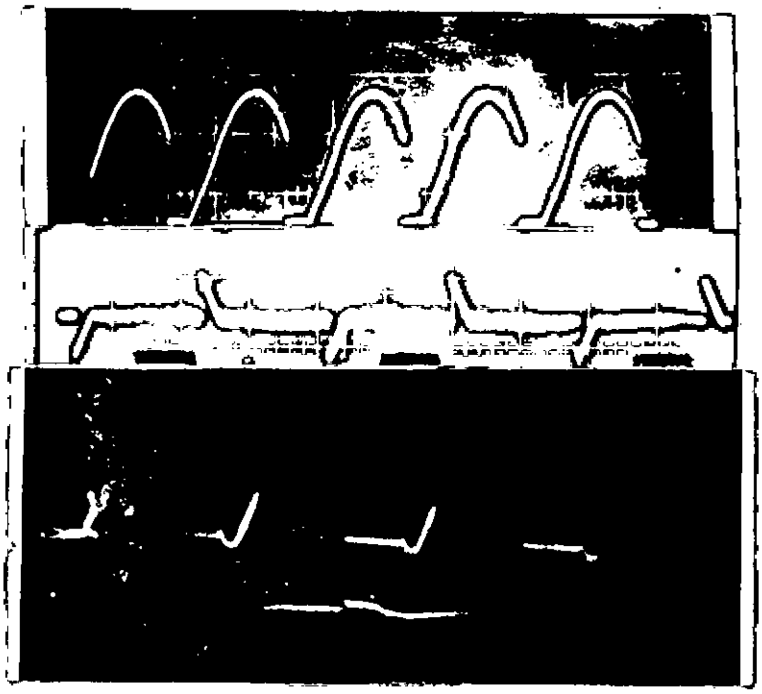


Fig. 7.4b. Oscillogram for Minimum Power Transfer.

Fig. 7.4. AC Variable Phase Control.

the load is in the input side of the bridge rectifier. In this circuit only one SCR is used to control the instant of firing in the both half cycles. This is possible due to the action of the bridge rectifier. The output of the bridge rectifier is a full wave rectified voltage which is applied across the SCR. So the SCR conducts in both the half cycles. This circuit was constructed and the oscillograms of the output voltage waveforms for various firing angle are shown in the fig. 7.4 (a) and 7.4 (b) for lamp load. The oscillograms of 7.4 (a) are for half maximum power transfer to load, because only half of each half cycle appears across the load. The oscillogram of fig. 7.4 (b) are for minimum power transfer to load, because only a small portion of half cycle appears across the load. There is no noticeable flickering from the lamp, but that was present in the half wave application. The maximum current that the load can take from this circuiti is limited by the diodes and the SCR.

7.4 CONCLUSION:

The SCRs find tremendous application in modern technology for control of power. The two circuits described can be efficiently used in many purposes, such as in light dimming of incandescent and fluorescent lamps, temperature control, speed control of motors etc. The oscillograms of the circuit waveforms are taken with resistive incandescent lamp load. The circuit of the fig. 7.1a, by use of two 6 A, 400 V SCRs can control upto maximum 1.5 kilo-watts. of load power. Higher loads such as 4 to 10 kilo-watts. as demanded by theatre, cinema hall, lighting installation etc. can be controlled by use of high power SCRs. When high power SCRs are used for control purposes, special arrangement must be made for cooling. Though the circuit of the fig. 7.3a uses one SCR for control of AC load power it has a disadvantage in that, it uses a bridge rectifier which conducts the load current . So generally this circuit is prefered for low power application.

Though power can be controlled by use of potentiometers, variacs and thyratrons, highest efficiency can only be obtained by use of SCR.

CHAPTER - VIII

SCR CONTROL OF INDUCTIVE DC LOAD

8.1 HALF WAVE PHASE CONTROL:

A circuit for half wave phase control ofi inductive DC load by use of SCR is shown in the fig. 8.1a. A simple UJT trigger circuit described in chapter - III was used for gate control. As current through inductive load can not change instantaneously, so just after triggering the SCR in the positive half cycle, current through the inductive load will rise slowly (instead of step rise) to peak value and then gradually decrease to zero. The inductive nature of the load causes the current to continue to flow beyond the point where line voltage reverses. Hence the voltage applied to the load includes positive and negative components of load voltage during the conduction period of the SCR. The fig. 8.1b shows the load voltage and current waveforms (without the free wheel diode D): The SCR is fired at an angle $\Theta = 60^{\circ}$ in the positive half cycle and it conducts upto $\Theta = 230^{\circ}$ i.e., current continues to flow in the same direction even when, the load voltage reverses. As the current through inductive load starts to cecrease, the voltage across the load reverses, because the sign of L di/dt reverses. The SCR will not turn off until the current decreases below the hold-on value.

In half wave phase control by addition of a choke in series with resistive load, the mean output power may be improved and ripple percentage reduced. If the load is inductive or if inductance is connected in series with resistive load, a free wheel diode must be added across the load as shown in the fig. 8.1a by dotted line and diode D. This diode will than carry the current setup by the discharge of the energy stored in inductance, because as the load current starts to decrease the voltage across the load reverses which makes the anode of diode D positive with respect to cathode and D conducts. The diode acts as a low resistance path for the discharge of energy of the inductor, and current in the load continues to flow for some or most part of the negative half cycle. The

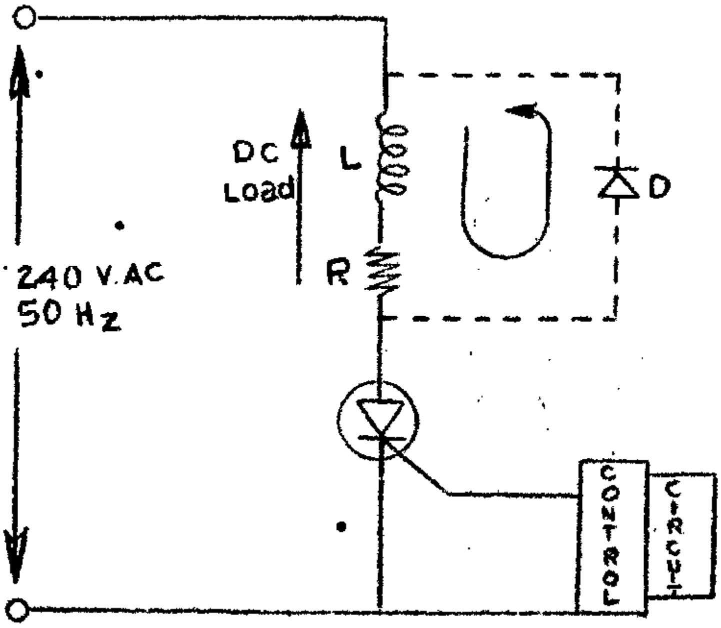
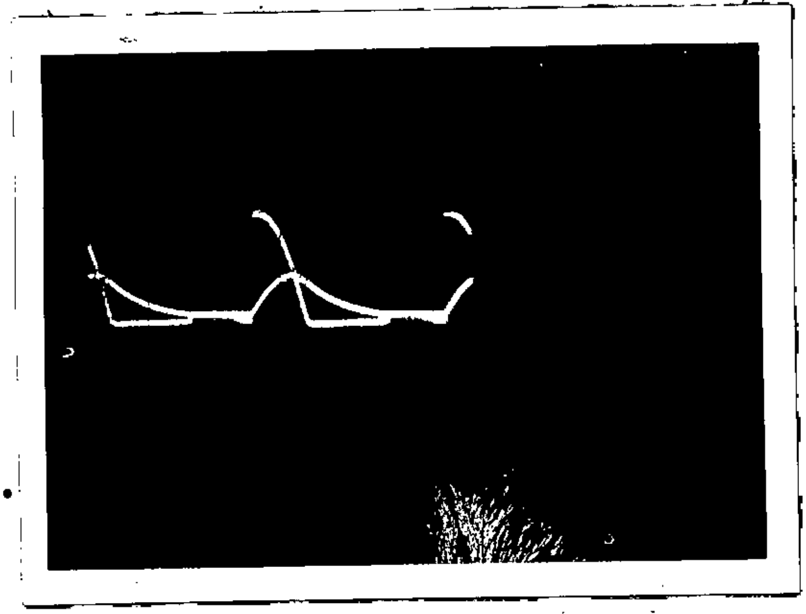


Fig. 8.1a. Half Wave Phase Controlled Inductive Load Circuit.

(1) Load Voltage.

(2) Load Current.

Fig. 8.1b. Inductive Load Voltage and Current Waveforms in Half Wave Phase Control. (Without the Free-Wheel Diode).



(1) Load Voltage.

(2) Load Current.

Fig. 8.1c. Inductive Load Voltage and Current Waveforms in Half Wave Phase Control (With the Free-Wheel Diode Connected).

fig. 8.1c shows the inductive load voltage and current waveforms with free wheel diode connected across the load. The SCR is triggered at $\theta = 80^\circ$ and current continues to flow upto $\theta = 360^\circ$. The earlier the SCR triggers in each positive half cycle, the greater is the stored energy with greater current in the load during the period the SCR is off and the current may be continuous, through the load.

On the other hand if the triggering of the SCR is delayed there will be a period of zero current. The average current rating of the free wheel diode should be not less than the maximum average load current.

CHAPTER - IX

SCR CONTROL OF INDUCTIVE AC LOAD

9.1 INTRODUCTION:

SCRs not only control resistive loads efficiently but these can also be advantageously used to control inductive AC loads. There is no doubt that inductive loads present some difficulties which do not appears when operating SCRs into resistive load yet with some added precautions, reliable performance of the inductive loads can be obtained. SCRs can be used in controlling motors, fluorescent lighting banks, transformer coupled loads etc. and SCRs can be used to replace saturable reactors, adjustable transformer, motor generator sets etc.

9.2 TRIGGER REQUIREMENTS FOR SCR'S TO CONTROL INDUCTIVE LOADS:

Operation of SCRs directly into inductive load is rather more complex than the resistive load, because :

(1) inductive load current does not change instantaneously i.e., SCR anode current rises slowly (instead of step rise as in case of resistive load).

(2) severe dissymmetry between the psotive and negative half cycles of load voltage may result due to magnetic saturation and thereby SCRs may be permanently damaged.

(3) inductive loads set up back electro-magnetic force.

(4) inductive loads present dv/dt, di/dt and other transient problems.

These difficulties can be over come by using suitable trigger circuits and adopting some protective measures. Two basic requirements for proper control of inductive AC load are :

(i) the width of the trigger pulse should be comparatively large.

(ii) the synchronisation voltage trigger circuit must be obtain from the supply terminals rather than the SCR voltage.

The SCRs are generally triggered into conduction by applying trigger pulses to the gate terminals and out put voltage is controlled by phase shifting of the trigger pulses. When a pulse type of trigger is used for triggering SCRs with inductive load, there is a possibility of system instability if the trigger pulses are of short duration. Since the load inductance cause a slow rise in SCR anode current, if the anode current does not at least reach the latching current by the time (the pulse width) the pulse ends the SCR will cease to conduct once the firing pulse has passed and SCR will revert to its blocking state. This type of instability is more likely in early and late part of each half cycle,when the magnitude of AC line voltage is low and therefore the load current rise is slow. This type of instability in early and late part in each half cycle is absolutely undesirable, moreover this type of failure may lead to core saturation due to dissymmetry of the positive and negative half cycles and thereby destroy the SCRs. This problem can be solved by use of variable phase square wave instead of a pulse for triggering. The system stability can be obtained even by use of pulse trigger circuit with some extra connection in the system and it will be described in the next section.

9.3 TRIGGER CIRCUITS FOR INDUCTIVE AC LOADS:

There are a number oft trigger circuits which meet the basic requirements for proper control of inductive AC loads. The following two trigger circuits were designed and constructed and these had been found to operate satisfactorily.

(i) UJT trigger circuit:

The basic unijunction transistor trigger circuit for gating two " inverse parallel " connected SCRs for controlling the inductive load of fluorescent lamps is shown in the fig. 10.3. The gating pulses generated by the UJT trigger circuit may be of so short duration that instability and dissymmetry may arise but the trouble of pulse triggering is virtually eliminated by connecting a bleeder resistor in parallel with the inductive load, to assist the SCRs to latch on reliably after the application of gate pulse. The value of the resistor is such that when the SCR is triggered, sufficient current will flow through the anode to latch the SCR into conduction, regardless of the triggering angle. Fortunately the latching current of SCRs is only (10 ma to 40 ma for most SCRs) a fraction of normal load current and hence a high value of resistance can be used and thereby power dissipation can be reduced and actual load remains unaffected. This resistor also helps in limiting the dv/dt problem that arises across the SCR pair, when one SCR turns off.

This UJT trigger circuit receives synchronisation voltage for phase control from across the AC line, thus meeting all the necessary requirements for triggering inductive AC loads.

(ii) Transistor flip-flop trigger circuit:

Transistor flip-flop trigger circuit which produces square waves in the output meets the trigger requirements for inductive AC loads. A flip-flop circuit is described in chapter - III.

CHAPTER - X

SCR CONTROL CIRCUITS FOR FLUORESCENT LAMP DIMMING

10.1 INTRODUCTION:

The SCR can be efficiently used for dimming the fluorescent lamps. Cinema halls, theatres, etc. use fluorescent lighting banks of sevoral killo-watts, which can be continuously controlled smoothly by electronic circuits by use of SCR. Now-a-days thyratrons are used for the control. SCR equipments have greater advantagos over the thyratron version.

SCR control of fluorescent light is somwwhat more complex than the incandescent light control as :

(i) the fluorescent lighting load is inductive in nature, caused by thebballast choke.

(ii) the fluorescent tube developes a back EMF.

(iii) the fluorescent tube needs adequate striking voltage at all levels of illumination.

(iv) soparate heater transformer is required for pre-heating the electrodes.

The special load characteristics created by the fluorescent lighting tubes do not create any difficulty in operation by the use of SCR.

10.2 CONVENTIONAL FLUORESCENT LAMP CIRCUIT AND ITS OPERATION:

(i) Circuit with starter:

The fluorescent lamp is essentially a lamp for AC operation. The fig. 10.1a shows a general circuit of a fluorescent lamp unit for AC operation which incorporates a ballast choke L and a starter glow switch S and a capacitor C for power factor correction. This kind of circuit isused widely in industry, cinema hall, audotorium, domestic installations etc.

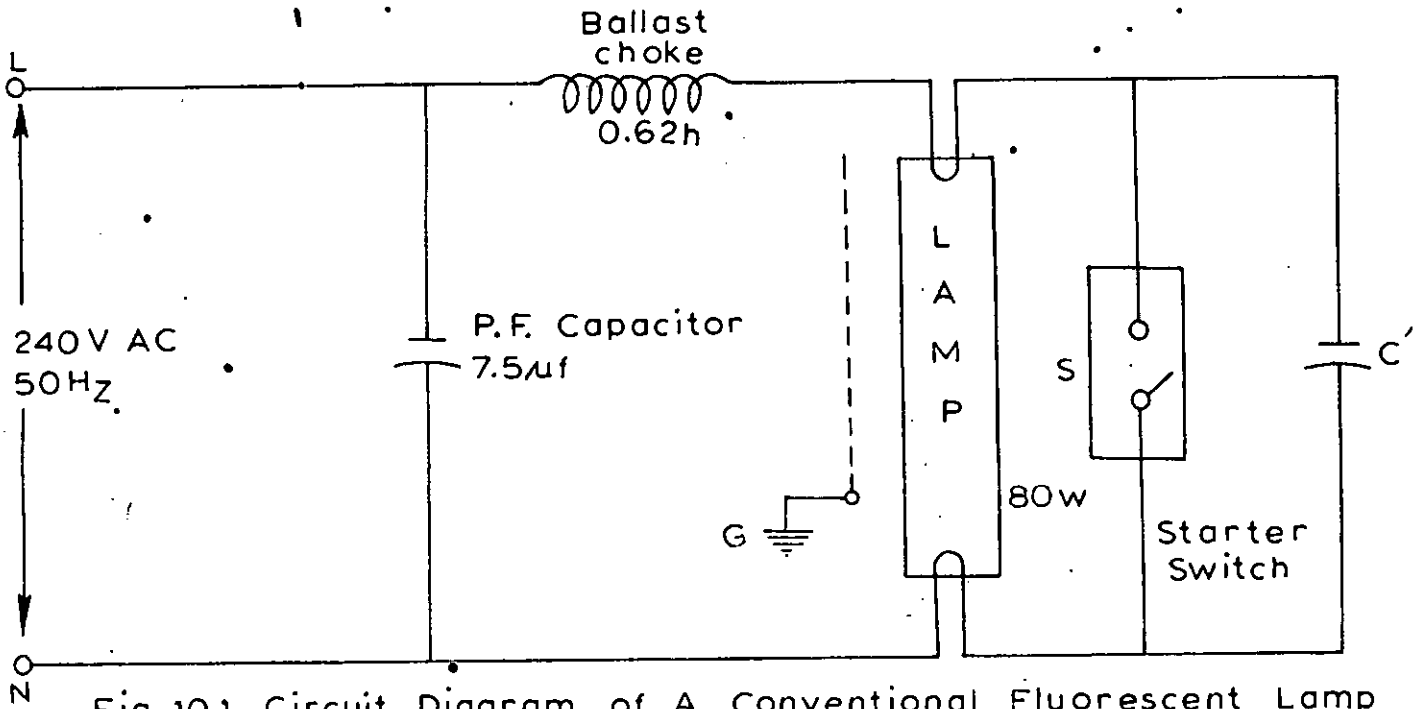


Fig. 10.1 Circuit Diagram of A Conventional Fluorescent Lamp Unit For AC Operation.

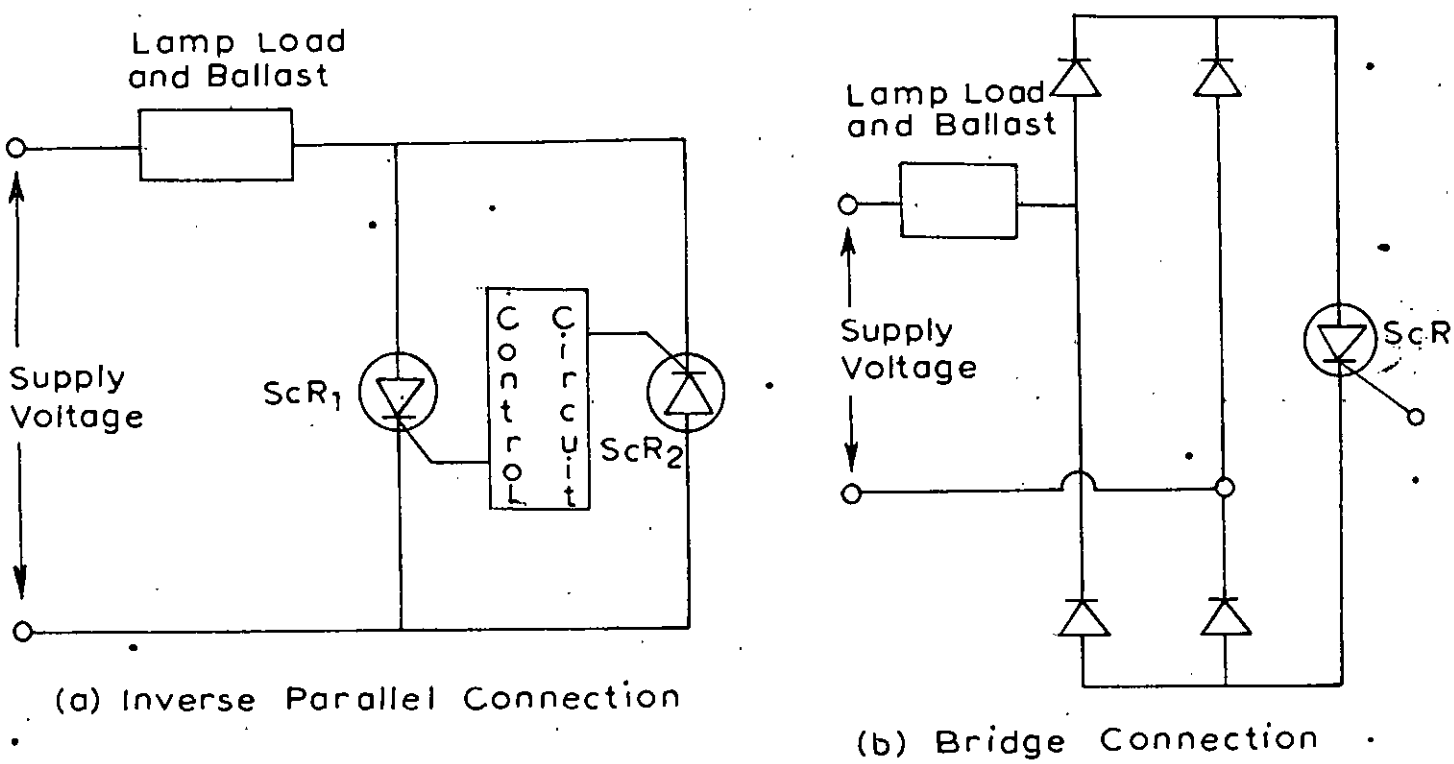


Fig. 10.2 Basic ScR Power Circuits

The function of the starter glow switch:

As soon as 240 V AC supply is applied to the circuit a glow discharge occurs inside the glow switch which contains rare gases. The heat generated causes the bimetallic strip to deflect and close the contacts, when the circuit is completed and the lamp electrodes are heated. When the contacts are closed the glow discharge ceases to exist in the starter switch and the bi-metallic strip temperature falls and ultimately opens the contacts. This sudden interruption of flow of current through the choke causes a voltage surge to appear across the lamp, which ignites the lamp.

Since the fluorescent lamps have a negative volt-ampere characteristic, the lamp voltage will drop to the arc voltage of the lamp as soon as it is ignited, therefore a impedance is connected in series with the lamp in order to limit the current to the desired value. The great advantage of AC operation is the fact that the current can be limited by use of a choke with relatively small loses. A power factor corrector capacitor C can be connected across the mains supply terminals for economic use of the supply system, when a large number of lamps are used. A small capacitor C' of the order of 0.006 to 0.020 µf is built into the canister of the starter switch. This capacitor suppreses to a great extent the radio-interference which might be generated by the discharge in the tube. An earthed conductor near the lamp aids in starting the lamp at sufficiently low voltage and it eliminates the flickering of the light completly.

(ii) Circuit without starter:

In starterless circuit of fluorescent lamps, a separate starting heater transformer is used for pre-heating the electrodes. Thep primary of the transformer is connected directly to the mains supply and two isolated secondary windings are connected to the electrodes at the two ends of the lamp to provide heating current. When the mains switch is closed the full supply voltage is connected across the primary of the transformer and the cathodes are heated with a current of the same magnitude as in a circuit with starter. The transformer takes the place of the starter-switch in that it provides the cathode heating.

In starterless circuit there is a problem of reaching a sufficiently low striking voltage, therefore some kind of starting aid is necessary. This is simply provided by placing a earthed conductor in the vicinity of the lamp. Generally the reflector of the lamp is earthed. The starterless circuit simplifies the maintenance problem of the lamp, because the starters often give trouble after some hundreds of its operations, when the starters are replaced. This problem is avoided in starterless circuit. Moreover, the lapse of time between switching on and striking of the lamp can be considerably reduced in starterless circuit.

10.3 DIFFERENT SCR CONTROLLED POWER CIRCUITS FOR FLUORESCENT LAMP DIMMING:

A 50 Hz fluorescent lamp dimming system consists mainly of two component circuits.

(i) The power circuit, which includes the lamp, inductive ballast, ballast resistor and the SCRs.

(ii) Trigger or control circuit, which controls the amount of power to transfer to the load.

These two circuits are incorporated into one system.

The fig. 10.2 shows two probable basic SCR power circuits. These two circuits (a) and (b) meet the fundamental requirements for the dimmer. When the SCRs are not triggered into conduction, its impedance will be high and the lamp will be in "OFF" state. And when the triggering pulses are applied to the gate or gates of the SCRs, they will conduct and their impedance will be low and the lamp load will be driven into "ON" state. The SCRs will present a variable and a symmetrical AC impedance and hence the effective voltage across the load will varry whereby the dimming will be obtained. The smooth and continuous transition from the "OFF" to "ON" will be performed by the phase control of the SCRs. Since the load is inductive i.e., it contains an inductive ballast, the SCR circuit of the dimmer must be symmetrical in its mode of operation to eliminate any tendency toward core saturation. This requirements is also meet by the SCR power circuits.

The choise of the basic power circuit depends on a number of factors. Both the circuits have advantages and disadvantages over each other. In the inverse parallel circuit of the fig. 10.2a one SCR conducts the positive half cycle and the other the negative half cycle and phase control in both half cycles is possible. This circuit has greater efficiency as only one SCR is in the circuit at any time for conduction. On the other hand in the "bridge connection"circuit of the fig. 10.2b only one SCR is required for full-wave phase control of AC load but itr requires four power diodes. And two diodes and one SCR are always in the circuit for conduction. The heat sink problem are more severe with the circuit of fig. 10.2b than with that of fig. 10.2a. But for low power outputt the circuit of the fig. 10.2b may be useful. And since the circuit of the fig. 10.2b requires only one SCR, its triggering circuit will be simpler as it is found that less components are required to trigger one SCR than two SCRs.

The selection of proper power circuit will depend on load requirements, cost of SCRs, diodes, lighting application, available control circuit etc. Moreover the selection will have a great effect on the mechanical design of the dimmer circuit. The total performance of the system will depend on the characteristic and effective design of the component circuits and their parts and the extent to which these components match to others.

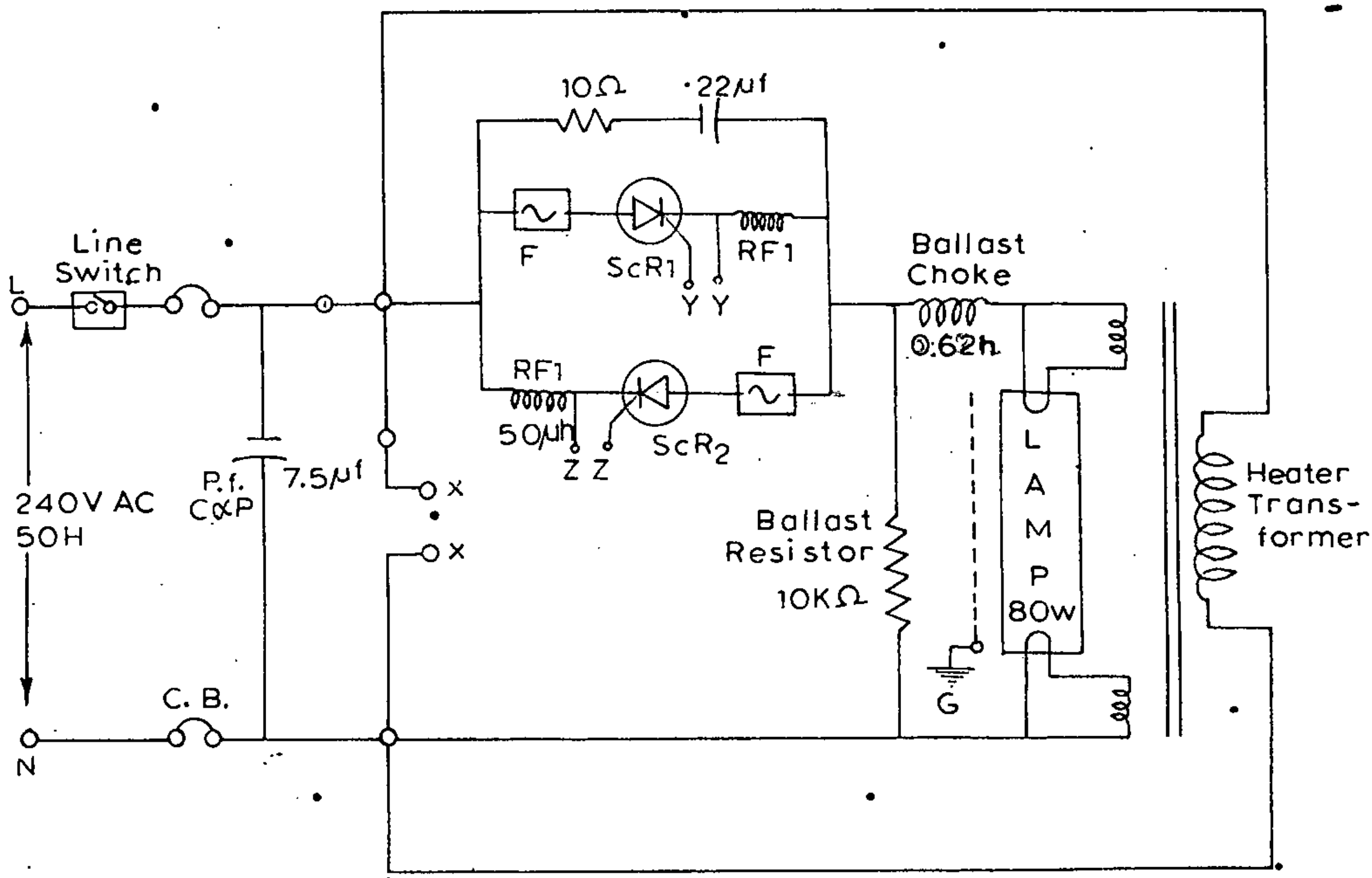
10.4 DIMMING OF FLUORESCENT LAMPS WITH STARTER:

One SCR dimmer circuit with inverse-parallel configuration power circuit as shown in the fig. 10.2a for a fluorescent lamp with starter was constructed. The line synchronised UJT trigger circuit shown in the fig. 3.6a was used for control purpose. It was found that fluorescent lamps with starter can be dimmed but the operation becomes unstable at low currents and flickering results. The minimum starting voltage in the process of setting the control potentiometer of the dimmer, for going from darkness to light is too high and the light obtained is too great and the smooth variation from darkness to light is not obtained. Moreover the starter closes at different voltages at different times. This difficulty is removed by using a starterless circuit with permanantly heated cathodes. Variation of lamp current at constant heating current provides a continuous and smooth regulation of light output.

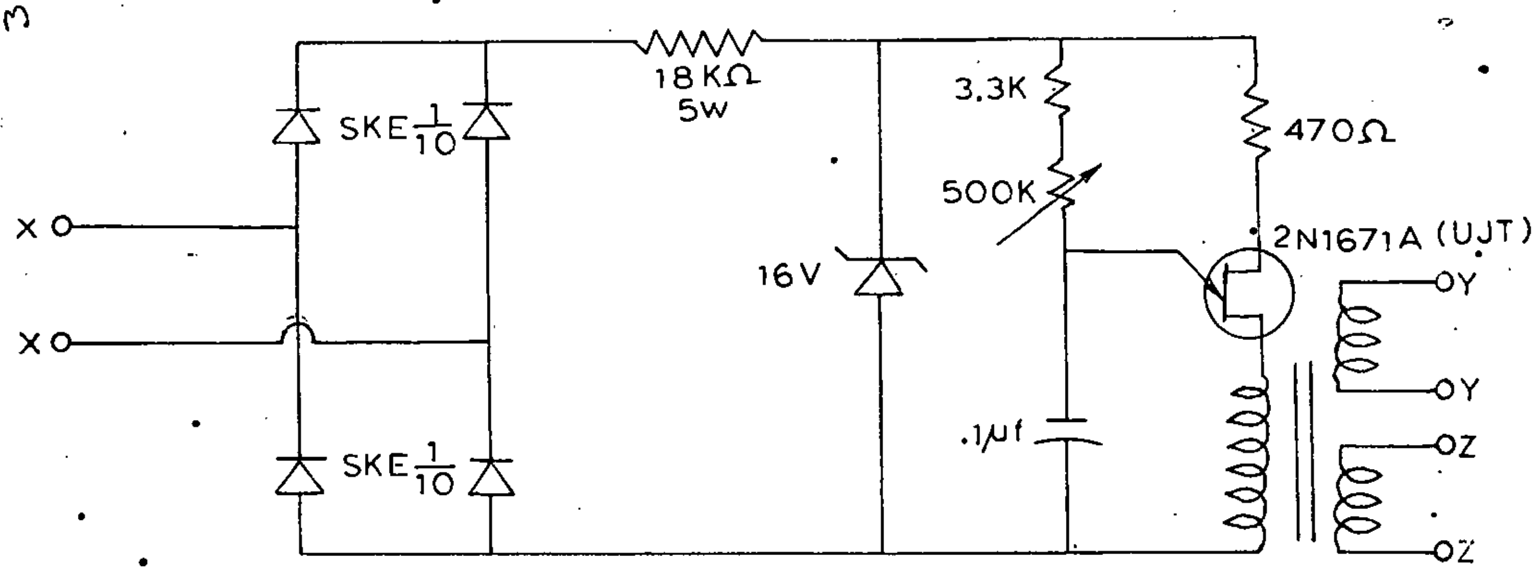
10.5 A PRACTICAL FLUORESCENT LAMP DIMMER CIRCUIT USING SCR:

A practical fluorescent lamp dimmer circuit with permanantly heated cathodes and with SCRs in "inverse parallel" connection is shown in the fig. 10.3 . Here the power circuit and the control circuit are shown separately. In the power circuit 10.3a the SCR1 conducts in the positive half cycle and the SCR2 in the negative half cycle. The triggering pulses are obtained from the secondary of the pulse transformers in the control circuit 10.3b. This fluorescent lamp dimmer circuit was designed and constructed and it was found that the system performance is reliable. The important parts of the system is discussed below.

The lamp: The lamp is instant start fluorescent tube. The fluorescent lamps are highly efficient in radiating light and the light output of a fluorescent lamp is proportional to the current through the lamp. Therefore the dimming can be performed by varying the voltage whereby the current is varied. Another condition for smooth dimming is that adequate striking voltage must be available to start the lamp at the lowest setting of the control potentiometer. The voltage required to start the lamp is reduced by pre-heating the electrodes of the lamps by a heater transformer as shown in the fig. 10.3a, irrespective of the setting of thed dimmer. The starting aid is supplied to the lamp by grounding the metallic planed of the lamp. Where the fluorescent lighting bank is to be controlled a



(a) Power Circuit



(b) Control Circuit

Fig. 10.3 A Practical Fluorescent Lamp Dimmer Circuit With ScRs In "Inverse Parallel" Connection.

number of lamps are to be connected in parallel and the simultaneous dimming of all lamps will be accomplished by the single control circuit.

The ballast choke: The function of the ballast is to limit current through the fluorescent lamp as it has a negative resistance characteristics. Moreover it supplies proper starting voltage and limits di/dt problem. When n lamps are to be operated on one choke, thei inductance of the common choke should be L/n where L is the inductance for a single lamp. All the lamps may have their indivisual chokes.

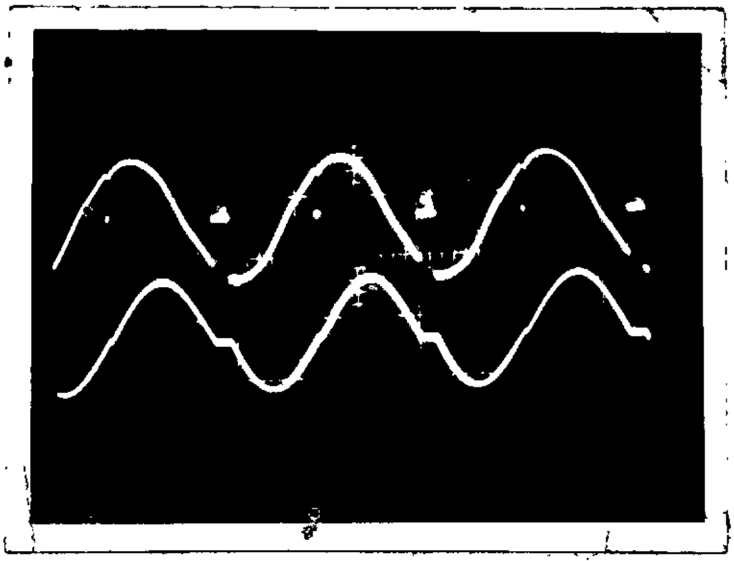
The ballast resistor: It helps the SCR pair to switch into conduction reliably after they are being triggered. Details are described in the control circuit. It also helps to limit the dv/dt problem and thereby prevent premature triggering of the SCR pair. A ballast of 100 watts is satisfactory for 4 killo-watts load.

The heater transformer: The function of the heater transformer as already mentioned is to supply constant pre-heating current to the electrodes of the fluorescent lamp. The primary of the heater transformer is connected directly across the line supply and two isolated secondaries are connect to two lamp filaments, to supply necessary pre-heating current. The two secondaries should be isolated as they are at different potential with respect to neutral. When a number of fluorescent tubes are to be controlled by one dimmer control circuit, if one heating transformer is used for each tube than the total costo of transformer will be exceedingly high. If on the other hand, one common heater transformer is used to supply pre-heating current to all the filaments from its secondaries, the transformer cost will be reduced but this arrangement will need more distribution wires, yet this arrangement will be economic when large number of fluorescent tubes are to be controlled such as in cinema hall, audotorium etc.

The control circuit: The controlc circuit shown in the fig. 10.3b is a line synchronised UJT trigger circuit. The synchronisation voltage for the control circuit is derived from across the AC line rather than from across the SCR. This condition is essential in order to maintain symmetry between the positive and negative half cycles of the load voltage of inductive AC load and thereby to maintain system stability. Other requirements for triggering SCRs connected to inductive load is that the trigger pulse width should be such that inductive load current must have time to reach at least the latching current before the gate pulse terminates, otherwise the SCR will cease to conduct once the trigger pulse has passed and the SCR will revert to blocking state. This problem is effectively eliminated by use of a ballast resistor across the load to assist the SCR to latch on reliably after the application of gate pulse. In a resistive load the triggering angle of a SCR can be varied from 0 to 180^{o} but for the inductive load of fluorescent lamp the triggering range is limited from 60^{o} to 150^{o}. The load voltage and current waveforms at different triggering angle is shown in the oscillograms of fig. 10.4. The oscillogram of fig. 10.4a shows the load voltage and load current waveforms for maximum power transfer i.e., maximum illumination, when triggeringa angle is 60^{o}. The oscillograms of fig. 10.4b shows load voltage and load current waveforms for half power transfer to load, when the triggering angle is 120^{o}. The oscillograms of fig. 10.5a shows voltage waveforms across the load and the SCR pair, when the triggering angle is 80^{o}. Variation of load current with conduction angle is shown in the page number 67.

Power factor correction: When heavy load is to be controlled there must be arrangement for power factor correction for economic use of power supply system. The power factor correction is carried out on the mainss side of the SCR pair, by connecting a capacitor across the mains supply. The value of the capacitance will depend on the number of tubes and their wattage. For each 75 watts tube the value of capacitance should be 7.5 uf. When n lamps are to be operated the value of power factor capacitor should be nC, where C is capacitance for single lamp.

Protection: Adequate protection against over current and over voltage is necessary for satisfactory operation of the SCR circuits, the associated electrical devices and the buswork.

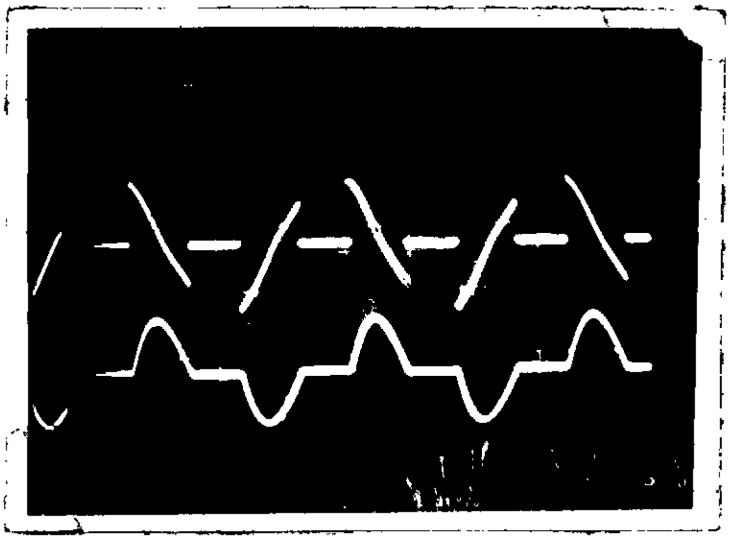


Load Voltage Waveform.

Load Current Waveform.

Triggering Angle = 60°.

Fig. 10.4a. Waveforms for Maximum Power Transfer.



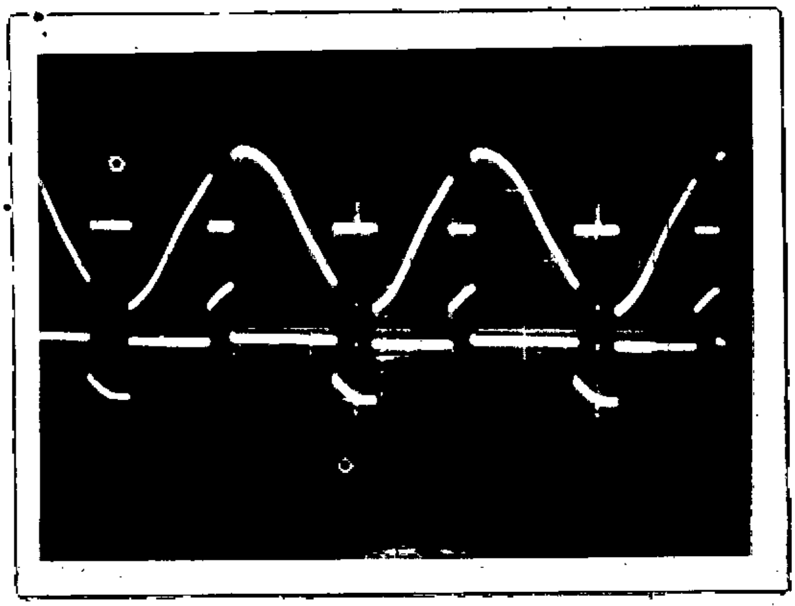
Load Voltage Waveform.

Load Current Waveform.

Triggering Angle = 120°.

Fig. 10.4b. Waveforms for Half Power Transfer.

Fig. 10.4. Fluorescent Lamp Load Voltage and Current Waveforms at Different Triggering Angles.



Load Voltage Waveform.

Voltage Waveform Across the SCR pair
= Triggering Angle =80°

FIG. 10.5a. VOLTAGE WAVEFORMS ACROSS THE LOAD & THE SCR PAIR.

VARIATION OF LOAD CURRENT WITH CONDUCTION ANGLE

Lamp = 80 W
Line Voltage = 240 V

	Mean Current in Ampere	Peak Current in Ampere
60°	0.85	1.42
90°	0.60	0.95
120°	0.15	0.35
150°	0.05	0.07

<u>Protection against over loads and faults</u>: Over current protection of SCR can be obtained by interrupting the current flow and also by introducing elements in circuit which will limit the rate of rise of current flow by virtue of their impedance. Since the SCRs fail by shorting rather than by opening, AC circuit breaker, fast acting current limiting fuse or SCR circuit breaker may be used to protect the power SCRs. The fluorescent lamp dimmer circuit of the fig. 10.3a uses AC circuit breakers across the main lines and each SCR of the "inverse parallel" connection is indivisually provided with fuse to provide adequate protection against heavy fault of duration less than half a cycle. If SCRs used are rated many times the normal load requirements, then the system will survive unusual over current condition. This may be uneconomic. Most practical and economical solution lies in over designing a little the current carrying capability of the SCRs. The rate of rise of current flow may be limited by source impedance, transformer impedance or inductance and resistance in series with the load. In the circuit of fig. 10.3a the ballast choke limits the rate of rise of current.

<u>Protection against transient over-voltage</u>: Voltage transients have profound influence on successful and reliable operation of SCR. Transient voltages may be generated due to load switching, disturbances caused by lightning etc. High voltage transients will switch SCRs harmlessly into conduction in the forward direction. But this is highly undesirable in control of fluorescent lamps. This can be avoided by use of devices with higher voltage ratings but this answer may not be economical. The transient over voltages can be greatly reduced most economically by providing additional energy storage or dissipation means in the circuit. Capacitors placed across the input lines or across the SCR components, ample resistance across the AC input terminals, thyrector surge voltage suppressors connected across the anode-cathode of SCR pair etc. greatly reduce the over voltage transients. In the circuit of the fig. 10.3a pf. capacitor, ballast

resistor and RC network help to reduce the over voltage transient. The resistance is used for damping the ringing of the capacitance current with the load inductance.

Radio frequency interference: In the inductive load such as in fluorescent lamp dimming installation, radio frequency is created by the discharge in the tube itself. VHF services such as Television or FM broadcasting are not generally disturbed by RFI but AM broadcast band receives severe interference if SCR circuits are not properly filtered. In the fluorescent lamp dimmer circuit, choke and pf. capacitor helps to suppress the interference. Two small chokes RFI and RC network connected across the inverse parallel SCR pair as shown in the fig. 10.3a are used to filter the radio-frequency interference.

CONCLUSION: It is found feasible and practical to use phase controlled SCRs for the control of fluorescent lamp dimmer circuit. Smooth dimming ever wide range can be obtained. The circuit shown in the fig. 10.3a can control upto 1 killo-watt of load which is limited by current rating of SCRs (400V, 6A) . By use of higher current rating SCRs load upto 10 killo-watts of power can be controlled. There is much flexibility in the system layout, depending on the performance, reliability, load power, and cost of the system. Instead of manual control, automatic control for constant illumination level by use of photocell, can be employed.

There must be arrangements for adequate cooling of power SCRs for successful operations. For cooling the power SCRs of the fluorescent lamp dimmer circuit, the body of each SCR was screwed into different aluminium heat sinks, for good thermal contact between the SCR and the heat sink.

Since the fluorescent lamp are highly efficient in radiating light and have economic advantages, their application is enormous in many fields.

CHAPTER - XI

DC CHOPPERS WITH SCR FOR CONTROL OF DC TRACTION MOTORS

11.1 INTRODUCTION:

In this chapter some recently developed DC chopper circuits with SCR are described which find potential application for the control of DC traction motors, such as DC electric locomotives and battery driven DC series motors. These choppers can control the speed continuously between zero and maximum value very smoothly. The advantages of DC choppers with SCR over the present form of resistance control are improved efficiency negligible starting loss, continuous running at any speed without resistance loss, elimination of mechanical contactors, moving parts and the associated maintenance problems etc.

The speed of DC series traction motors can be controlled by the following three methods:

(i) By varying a rheostat connected in series with the motor, which will vary the voltage to and hence the speed of the motor. This method is smooth but uneconomic as much power is wasted in the rheostat.

(ii) By switching the battery cells (in case of battery driven motor) in series or parallel combination. This method is lossless but the action is jerky.

(iii) By use of a rapid acting switch called a chopper, in series with the traction motor.

Since SCR has very high operating efficiency, high switching efficiency and high power gain, it can be conveniently used as chopper switch to convert direct current from a given DC input voltage to direct current at a lower voltage, to control the speed of DC series traction motors.

11.2 PRINCIPLE OF OPERATION OF DC CHOPPERS:

The fig. 11.1 illustrates the principle of chopping with a switch as power control element. The load voltage and hence the speed is regulated by varying the repetition rate of the switch

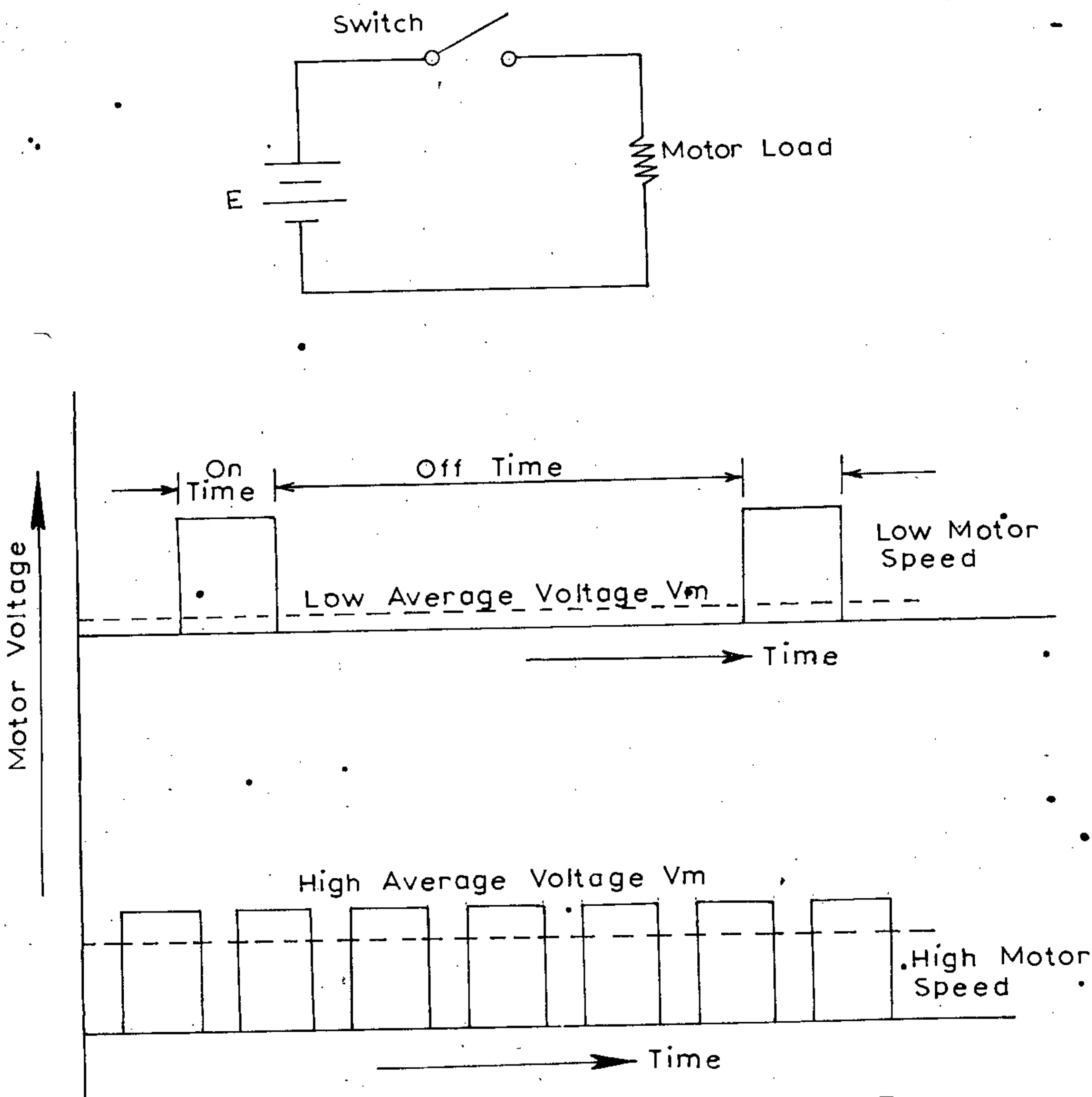


Fig. 11.1 Basic Chopper and The Wave Forms

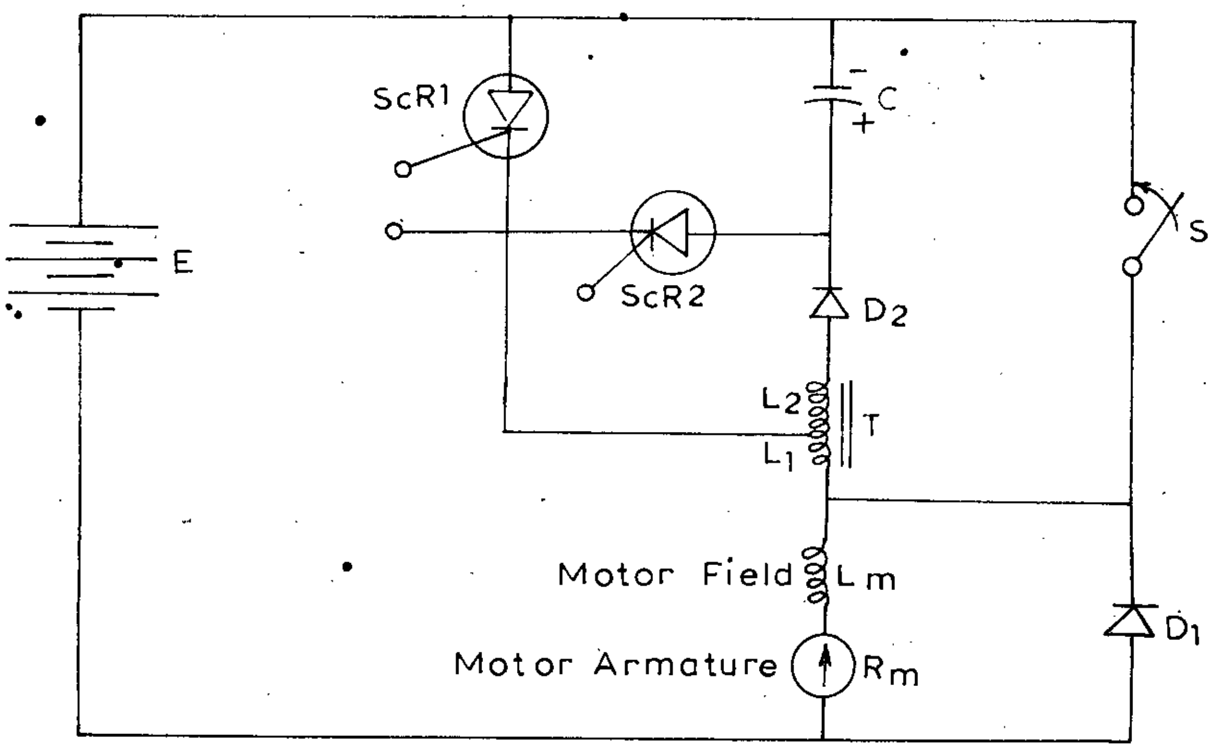
closing. At low repetition rate "ON" time is much less than "OFF" time so the average voltage supplied to the motor is low and hence its speed will be low. At high repetition rate average voltage increases and hence the speed increases. In this mode of operation, pulse width is kept constant and frequencyi is variable. In an alternative mode of operation frequency is kept constant and the pulse width is varied.

11.3 DC CHOPPLR CIRCUITS WITH SCR:

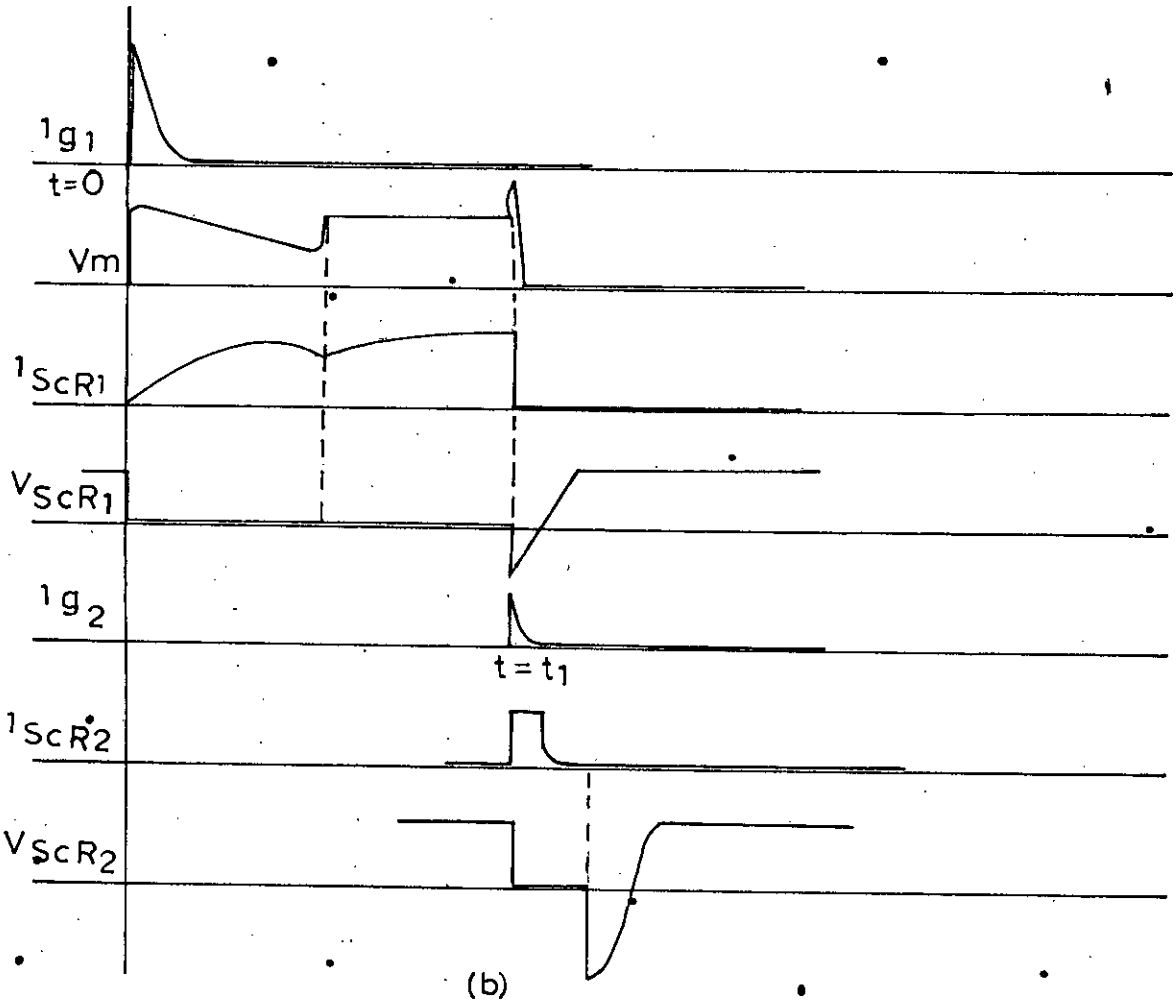
SCR can perform the chopping function in many circuit configurations. In this chapter few circuits will be described, which operate with high efficiency.

THE "JONES" CHOPPER CIRCUIT:

The fig. 11.2a shows the Jones chopper circuit. The switching of SCRs can be performed by two UJT pulse trigger circuits described in chapter - III. The SCR1 is power SCR as it carries the load current of the motor. When SCR1 is triggerdd (at t = 0) the current flows from the battery to the motor via the bottom winding L_1 of the auto-transformer T. A voltage is induced in the winding L_2 by auto-transformer action which charges the capacitor C through D_2, so that bottom plate of C becomes positive with respect to its top plate. Once charged, the diode D_2 maintains this voltage on C. When the SCR2 is triggered at(at $t = t_1$) the voltage of capacitor C appears directly across SCR1 whereby it is reverse biased and it is turned off, thus removing the voltage from the motor load. Inductive load current of the motor is discharged through the diode D_1, and thus it prevents high voltage appearing across the motor. The SCR2 is of much lower rating than SCR1 and it handles only the commutating energy. Typical circuit waveformsare shown in the fig. 11.2b. When the chopper is operating at low speed about 20% of the line voltage is applied to the motor (the minimum allowable repetition rate is determined by the length of time the capacitor C can maintain the commutating voltage before it leakes off). As the load of the motor is increased about 80% of the line voltage can be applied to the motor through



(a) The Jones Chopper Circuit



(b)

Fig. 11.2 The Jones Chopper and The Wave Forms the SCR chopper. Full voltage can be applied to the motor by closing the switch S, to supply maximum torque.

Due to the action of auto-transformer, increased load develop a higher commutating voltage on C, particularly when starting the chopper. This load compensation action is a great advantage of Jones chopper.

THE MORGAN CHOPPER CIRCUIT:

The Morgan circuit shown in the fig. 11.3a is a little modified version of Jones chopper. Here a saturable current transformer T function both as a load sensitive auto-transformer and a commutating switch. Hence the SCR2 and D_2 of Jones chopper are not required here. The Morgan circuit has efficiency over 90% and a load voltage range of 10 : 1 is possible.

The principle of operation of the Morgan circuit is interesting. When the SCR is not triggered the capacitor C charges upto the battery voltage E, through the reactor and load. Now as the SCR is triggered into conduction by a suitable trigger circuit, the full voltage on C appears across the top winding N_s through the SCR and the reactor is saturated in the negative direction after a short time and the charge on C is reversed resonantly, i.e., now the lower plate of C becomes positive with respect to the upper plate. The current flowing through the load via the lower winding N_p charges the capacitor to a still higher voltage by auto-transformer action. Again after some time the upper winding N_s is saturated in positive direction i.e., the cathode of the SCR is made positive with respect to anode and it is turned off. The voltage on the motor load can be varied by varying the trigger frequency.

THE JAUQUET, GOUTHIERE AND HOLOGNE CHOPPER CIRCUIT:

This chopper circuit is shown in the fig. 11.3b. Here SCR1 is the load current carrying or power SCR. AS SCR1 is switched on by a control circuit, the supply voltage V appears across the motor load and due to absence of back EMF in armature, motor current will rise rapidly to the value determined by circuit resistance and at a

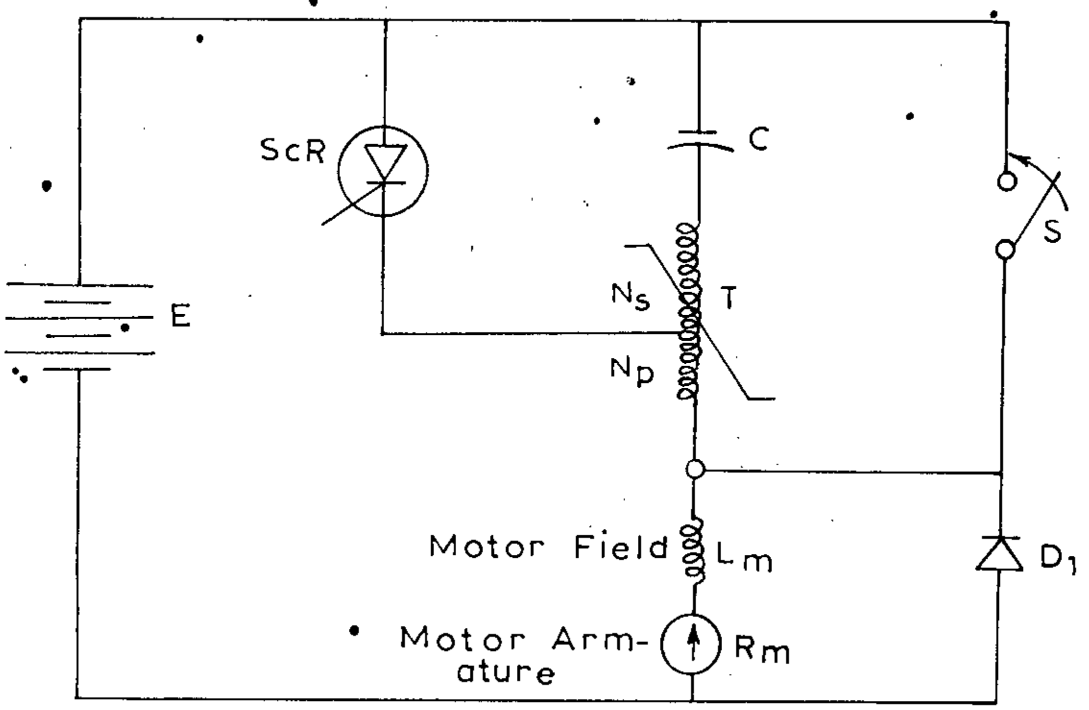


Fig. 11.3a The Morgan Chopper Circuit

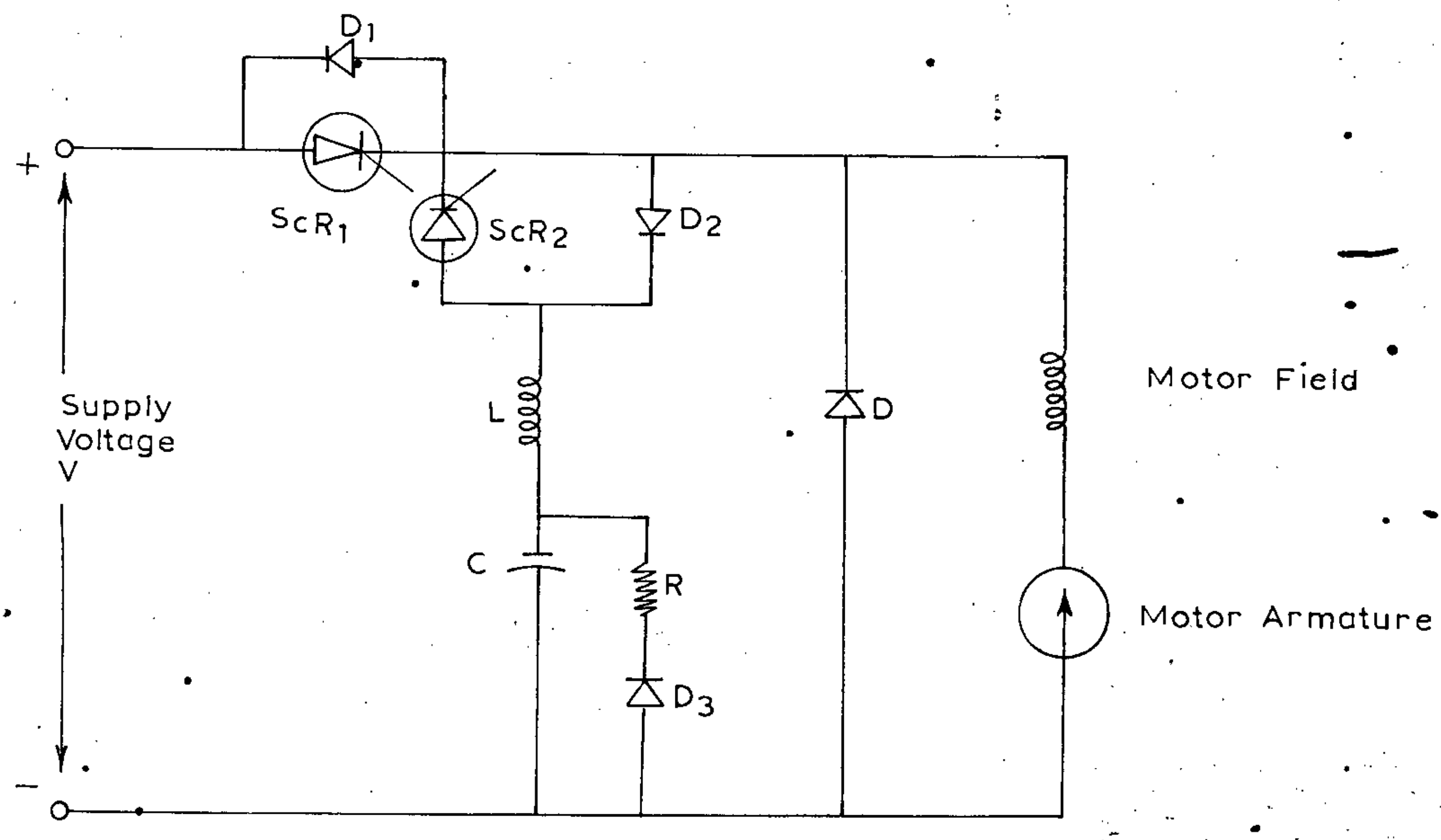


Fig. 11. 3b The Jauquet Gouthiere and Hologne Chopper Circuit

rate determined by the inductance of the motor. Also after sometime (determine by L and C) the capacitor C will be charged to 2V, twice the supply voltage resonantly through L and D_2 with top plate positive with reepect to the bottom plate. The capacitor C will remain the charge until SCR2 is fired as the diode D_2 is now reversed biased.

Now as the SCR2 is fired, a current starts to flow from the capacitor C (which was charged to 2V potential) through L, SCR2 and D_1 to supply, and the SCR1 cathode rises to the positive supply potential and it is turned off. Current from the capacitor C continues to flow and after sometimes the capacitor will be charged in the reverse direction. As soon as the SCR2 current falls below the holding value, it will be turned off and the dapacitor C discharges through D_3 and R. The voltage across C thereby drops to zero. And now it becomes ready for the next switching of SCR1. When SCR1 was turned off by the auxiliary circuit, the inductive energy of the motor load flowed a discharging current through the free wheel diode. If the time constant L/R of the load is great enough in comparison with the period the load current will never fall to zero.

THE BEASLEY AND WHITE CHOPPER CIRCUIT:

This circuit shown in fig. 11.4a finds potential application for control of DC traction motors from high voltage DC line supply. The principle of operation of this circuit is as follows.

The SCR1 is the power or load current carrying SCR. At the begining the SCR2 is triggered into conduction whereby the capacitor C is charged to supply potential through motor field and armatature, with the left hand plate positive with respect to the right hand plate. As soon as C is charged up, the current drops to zero and the SCR2 is turned off. Now as SCR1 is fired line voltage appears across the motor load and the right hand plate of C_1 reaches the supply positive potential V so the left hand plate becomes 2V potential with respect to ground. So the capacitor C drivés a current through L_1, D_2 and SCR1 and after as short time the capacitor C is charged to potential V resonantly in the reverse direc-

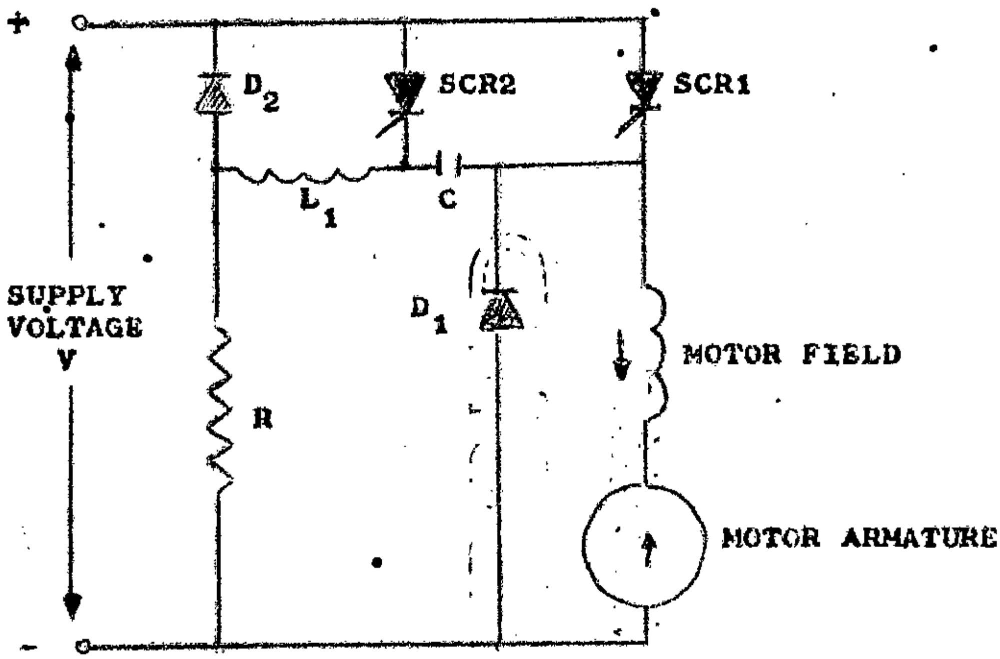


FIG. 11.4a. THE BEASLEY AND WHITE CHOPPER CIRCUIT

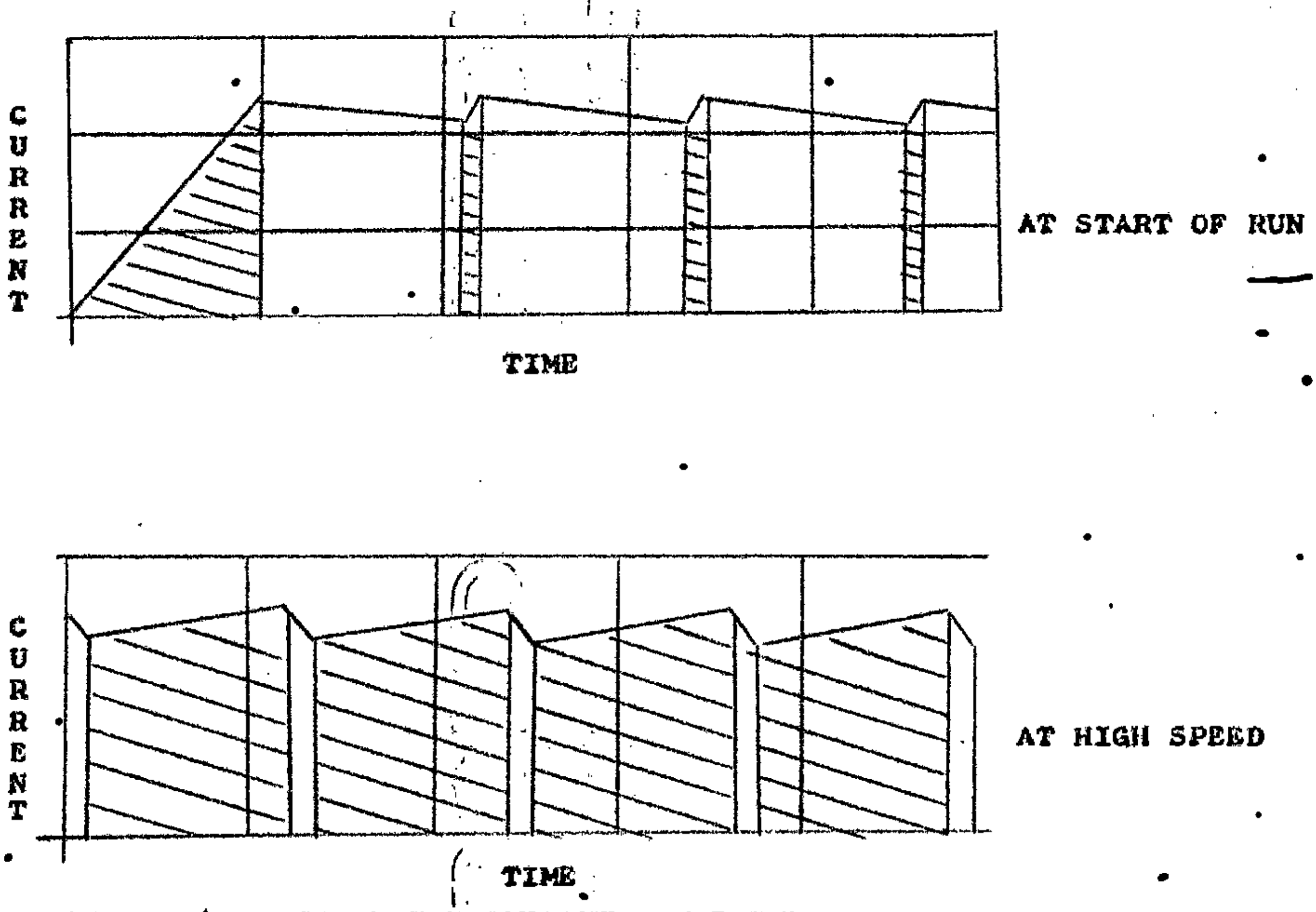


FIG. 11.4b. THE MOTOR CURRENT WAVEFORMS

tion i.e., now the right hand plate becomes positive and the diode D_2 holds on this voltage on C. A small bleeding path is provided through R for the leakage current through D_2 and SCR2, so that the potential on the lefth hand side of C remains all most unchanged, SCR2 and the L_1C resonant circuit is used to turn off the power SCR2. Now as SCR2 is triggered the charged capacitor C appears across the SCR1, which is then reverse biased and is turned off. The capacitor C discharges into motor load and is recharged to the supply voltage V with the left hand plate positive with respect to right hand plate. After the capacitor is charged, current through SCR2 drops to zero and it is turned off again. The inductive energy of the motor is discharged through the free wheel diode D_1. The circuit is now ready for the next cycle.

Motor current waveforms are shown in fig. 11.4b, at start of run and at high speed. On starting, current rises rapidly due to absence of back EMF and decays slowly, but at high speed, back EMF is developed and current rises slowly and decays rapidly.

11.4 SOME PRACTICAL ASPECTS:

The chopper circuits described are suitable for speed control of DC series traction motors. For the control of high voltage DC locomotive traction motors, a series string of SCRs and diodes are used. In this case adequate DC voltage sharing is obtained by non-linear resistors connected across each SCR and diode. The transient voltages developed across the SCR during switching is limited by using conventional RC networks. To protect the SCRs from the damaging effect of high rate of rise of current, saturating chokes are generally connected in series with SCRs. The trigger circuits for switching the SCR are not shown in the basic chopper circuits. Trigger circuits for SCR control of load are described in chapter - III.

Since closed loop systems provide better regulation, a control loop is generally provided in the chopper circuit for accurate speed control of DC motors.

11.5 CONCLUSION:

The chopper circuits described above are most modern and reliable. These circuits are used inpractiee and are found to operate successfully for the control of DC traction motors, smoothly and efficiently. These circuits are replacing the conventional equipments for control of DC traction motors.

CONCLUSION

SCR is found to be efficient power handling device for control of both resistive and inductive load. It is shown that incandescent lamps can be dimmed smoothly using SCR though incandescent lamps create problems in the design of SCR controlled circuits due to high inrush of current during starting. The fluorescent lamp dimming is found to be practical and the circuitsefficient in light control as the flickering of light is eliminated by using permanently heated cathodes.

The dimmer circuits designed and constructed may be used for light control in cinema halls, theatres andotoriums, factories etc. These circuits may also be used for speed control of DC and induction motors, temperature control of liquids etc.

The operation principle of DC chopper for speed control of traction motors are found to be simple and the circuits are efficient and reliable as SCRs are used for switching purpose.

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