

Dept. of Electronics and Instrumentation Engineering

B.E.-VI semester

Power Electronics Lab

LIST OF EXPERIMENTS

1. SWITCHING CHARACTERISTICS OF
 - a) Power MOSFET
 - b) IGBT
2. MOSFET BASED SINGLE QUADRANT DC CHOPPER
3. SINGLE PHASE CYCLOCONVERTER WITH RESISTIVE LOAD
4. SINGLE PHASE SERIES INVERTER USING SCR
5. SINGLE PHASE FULLY CONTROLLED BRIDGE RECTIFIER WITH R AND R-L LOAD
6. SINGLE PHASE AC VOLTAGE CONTROLLER WITH R AND R-L LOAD
7. VOLTAGE COMMUTATION CIRCUIT FOR SCR
8. SIMULATION OF SINGLE QUADRANT DC CHOPPER AND SINGLE PHASE AC VOLTAGE CONTROLLER USING ORCAD SOFTWARE

P.E. Lab. ECE-VEEAT-A.U

Ex.No.:

DATE:

SWITCHING CHARACTERISTICS OF a) POWER MOSFET AND b) IGBT

a) METAL-OXIDE SEMICONDUCTOR FIELD EFFECT TRANSISTOR (MOSFET)

AIM

To study the switching characteristics of a MOSFET and to determine the timing parameters.

APPARATUS REQUIRED

1. MOSFET module
2. CRO

THEORY

Bipolar Junction Transistor (BJT) is a current controlled device. In this device, the flow of collector current is controlled by base current and hence, current gain is highly dependent on the junction temperature.

However, a power MOSFET is a voltage controlled device, which requires only a small input current. The switching times of these devices are of the order of nanoseconds. Power MOSFETs are finding increasing applications in low-power, high frequency converters. MOSFETs do not have the problems of second breakdown phenomena as do in BJTs. However, MOSFETs have the problem of electrostatic discharge and requires special care in handling. In addition, it is relatively difficult to protect them under short-circuited fault condition.

MOSFETs are generally classified into two types: Depletion MOSFETs and Enhancement MOSFETs. The three terminals of MOSFET are named as gate (G), drain (D) and source (S) as shown in Fig.1. In case of MOSFET, the gate voltage controls the flow of current from drain to source. From the output characteristics, drain current (I_D) is a function of drain-to-source voltage V_{DS} with gate-to-source voltage at constant V_{GS} as shown in Fig.2(a) for an n-channel MOSFET. The output characteristics for p-channel device are the same except, that the current and voltage polarities are reversed and hence the characteristics for the p-channel device would appear in the third quadrant of the I_D - V_{DS} plane.

In power electronics applications, the MOSFET is used as a switch to control the flow of power to the load. In these applications, the MOSFET traverses the I_D - V_{DS} characteristics from cutoff region to ohmic region through active region as the device turns ON, back again when it turns OFF. The cutoff, ohmic and active regions of the characteristics are shown in Fig.2(a). The MOSFET is in cutoff, when $V_{GS} < V_{GS(th)}$, then the device will act as an open circuit and also the drain-source breakdown voltage (BV_{DSS}) must be larger than the applied V_{DS} to avoid breakdown due to avalanche effect.

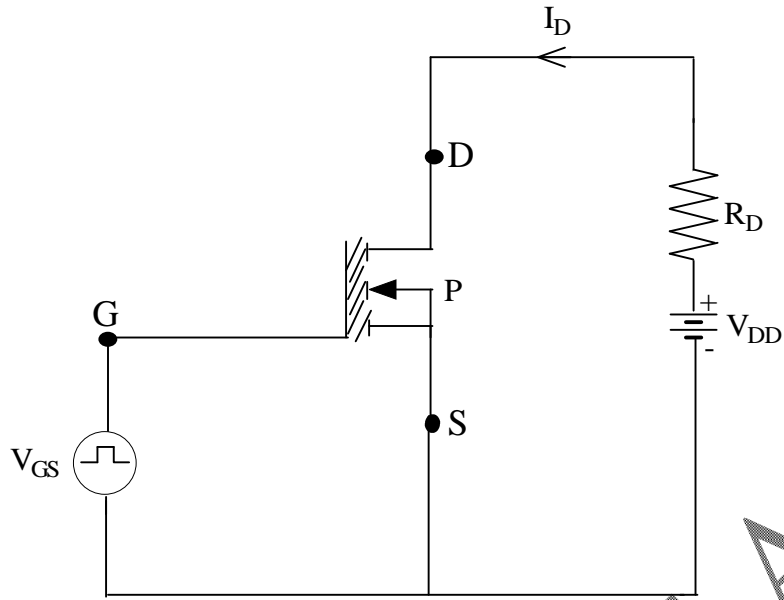


Fig.1. Schematic diagram of n-channel Power MOSFET.

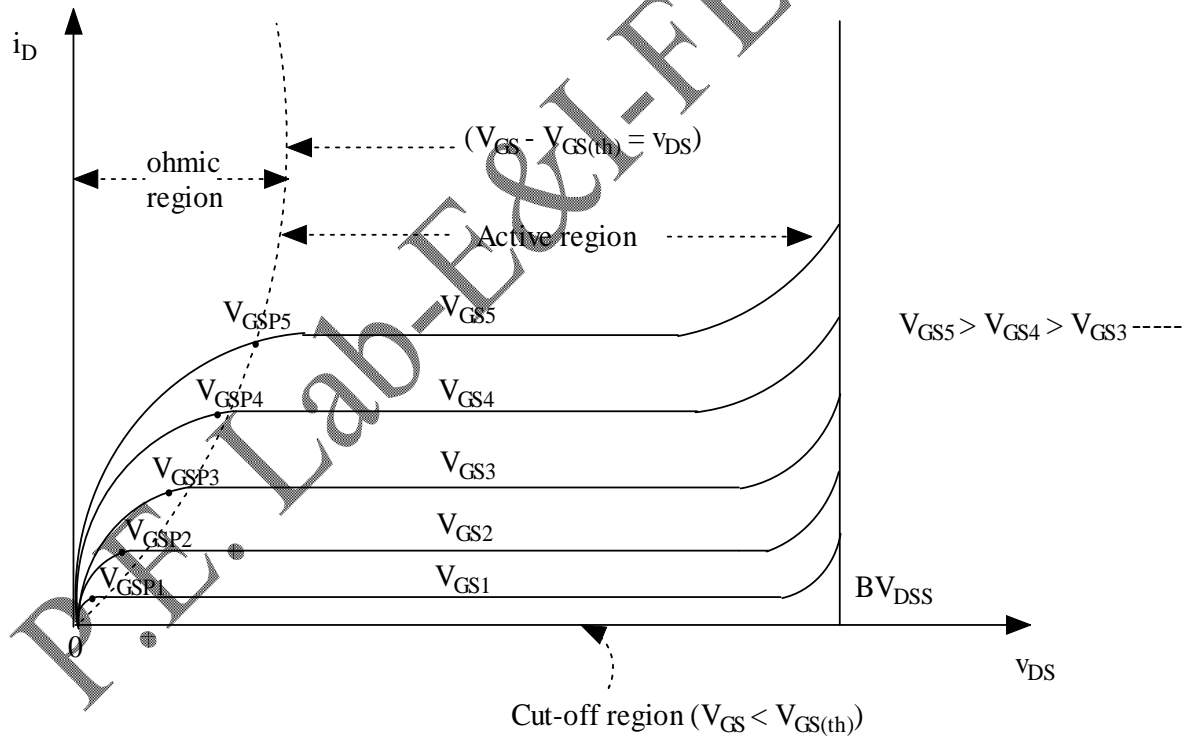


Fig.2(a). Drain characteristics of n-channel E-MOSFET.

When the device is driven by a large V_{GS} , it is driven into the ohmic region, where the voltage $V_{DS(on)}$ is small that is

$$\left(V_{GS} - V_{GS(th)} \right) > v_{DS} > 0$$

In the active region, the current I_D is independent of the drain-source voltage and depends only on gate-source voltage. The current is sometime said to have saturated, and consequently this regions is sometimes called the saturation region or pentode region.

$$i_D = K \left(V_{GS} - V_{GS(th)} \right)^2$$

In this experiment, a gate pulse V_{Gate} is applied to the n-channel MOSFET, the drain current I_D is noted down for the given V_{GS} (as shown in Fig.2 (b) and 2(c)). The parameters like t_{dn} , t_r , t_{df} , and t_f are represented in Fig.3.

DEFINITIONS

From the graphical representation shown in Fig.3, the following parameters are defined:

Turn on delay time (t_{dn})

It is the time in which, input capacitance of MOSFET charges to gate threshold voltage $V_{GS(th)}$.

Rise time (t_r)

It is the time in which, drain current ' I_D ' rises to steady state value when the gate voltage rises from $V_{GS(th)}$ to V_{GSP} .

Turn-on time (t_{on})

It is the summation of the delay time ' t_{dn} ' and rise time ' t_r '.

$$t_{on} = t_{dn} + t_r$$

Turn off delay time (t_{df})

It is the time in which, the drain current does not change while reducing the input signal. During t_{df} , input capacitance discharges from V_1 to V_{GSP} .

Fall Time (t_f)

It is the time in which, the drain current falls from I_D to zero and input capacitance falls from V_{GSP} to $V_{GS(th)}$.

Turn off time (t_{off})

It is the summation of turn off delay time and fall time

$$t_{off} = t_{df} + t_f$$

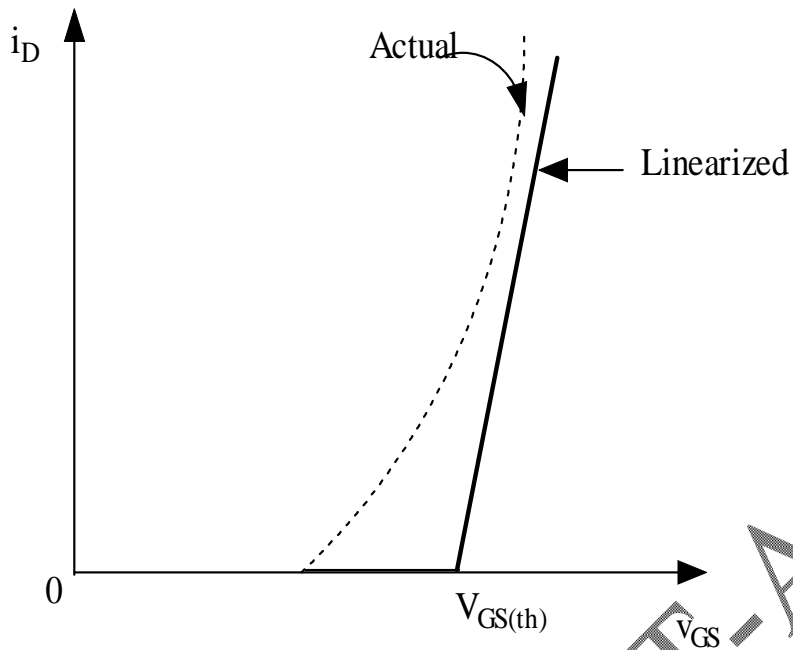


Fig.2(b). Transfer characteristics of n-channel E-MOSFET.

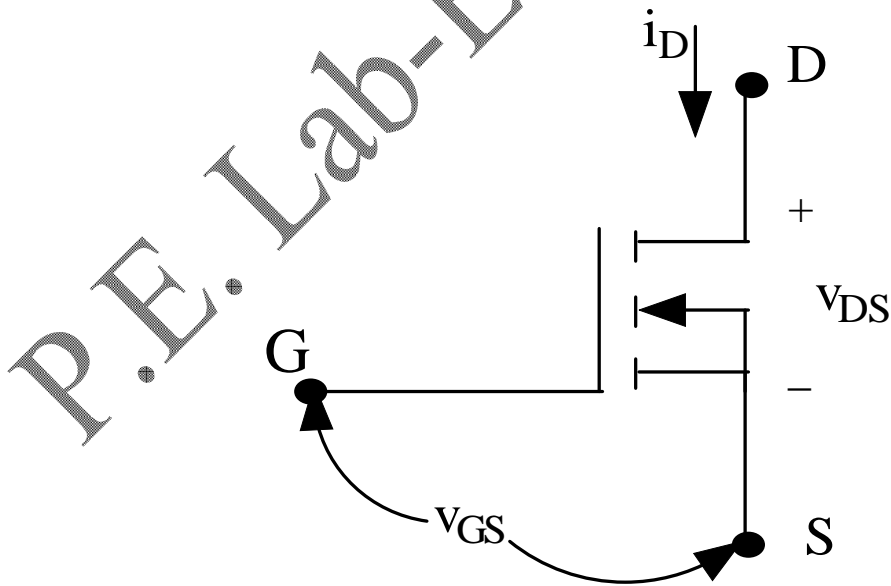


Fig.2(c). Symbolic representation of n-channel E-MOSFET.

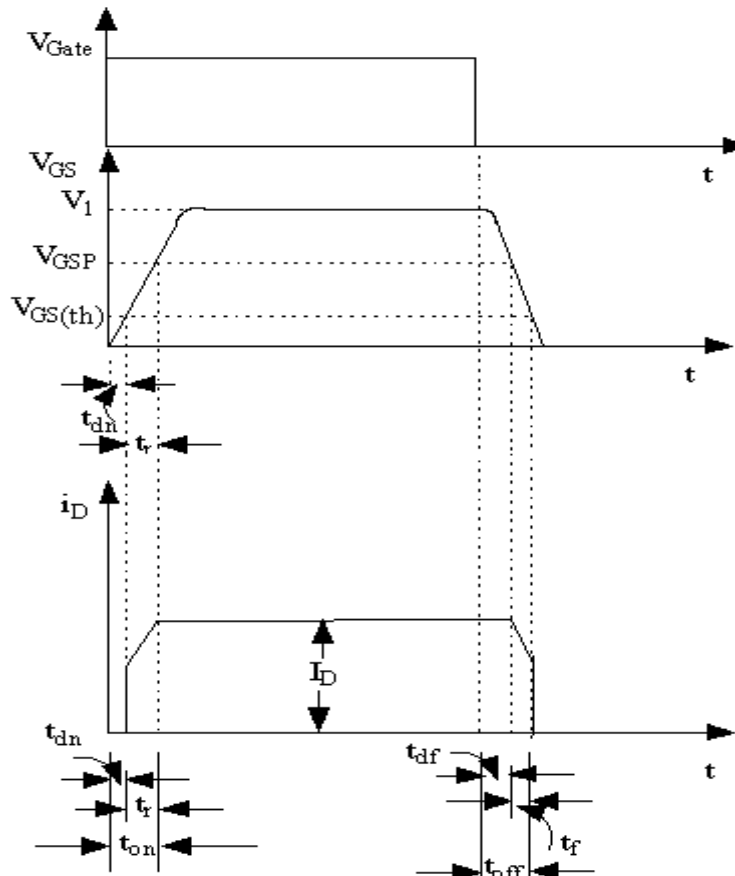


Fig.3. Switching characteristics of E-MOSFET.

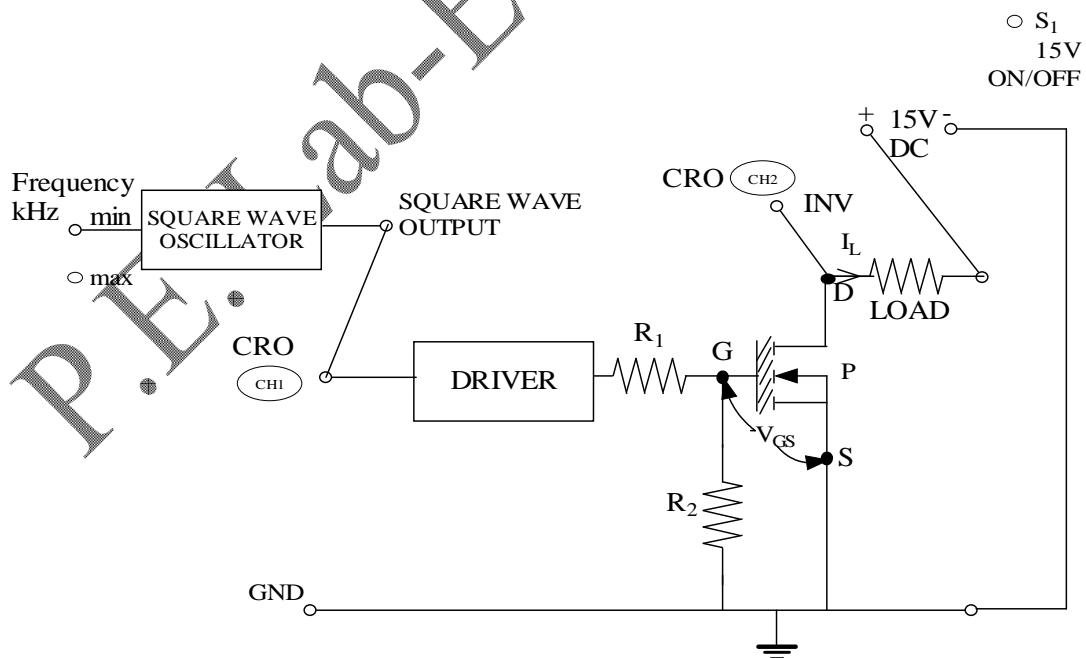


Fig.4. Schematic diagram of E-MOSFET.

PRECAUTIONS

- 1) Keep the oscillator switch in maximum frequency position.
- 2) Before giving connections, check whether all the switches are in OFF position.

PROCEDURE

1. Give connections as per the circuit diagram shown in Fig.4.
2. Switch ON the CRO and fix with x10 magnifying mode.
3. Turn ON the trainer power switch.
4. Turn ON the 15V DC selector switch.
5. To observe the device voltage (V_{DS}), connect the channel 2 of CRO to drain of MOSFET with respect to ground. The load voltage is the inversion of the device voltage, so the channel-2 is in invert mode. Since the load is R, the measure of the load voltage is proportional to the load current I_L and hence I_D .
6. To observe the trigger pulse (V_{GS}) applied to the gate through the driver, connect the channel 1 of CRO at the input of the driver with respect to ground.
7. Compare the above two signals. Determine the parameters t_{dn} , t_r , t_{df} , and t_f and tabulate the values in Table 1.

Table 1. Switching parameters of n-channel E-MOSFET for gating signal frequency 1.8kHz.

Turn ON time (ms)			Turn OFF time (ms)		
t_{dn}	t_r	t_{on}	t_{df}	t_f	t_{off}

b) INSULATED GATE BIPOLAR TRANSISTOR (IGBT)

AIM

To study the switching characteristics of IGBT and to determine the timing parameters.

APPARATUS REQUIRED

1. IGBT module
2. CRO

THEORY

IGBT combines the advantages of BJT and MOSFET. It has high impedance gate like MOSFET and low on-state conduction losses like BJT. Also there is no second breakdown problem like BJT. It is a voltage controlled device, similar to the power MOSFET and has lower switching and conduction losses. IGBT is inherently faster than BJT. However, the switching speed of IGBT is inferior to that of MOSFET. IGBTs are used in medium power applications such as DC and AC motor drives, power supplies, solid-state relays and contactors. The I-V characteristics, transfer characteristics and symbol of an n-channel IGBT are shown in Figs.5(a), (b) and (c) respectively.

In the forward direction, they appear qualitatively similar to those of a logic-level BJT except that the controlling parameter is an input voltage, the gate-source voltage, rather than an input base current. The transfer characteristics I_D - V_{GS} is shown in Fig.5(b) is identical to that of E-MOSFET. The curve is reasonably linear over most of the drain current range and becomes nonlinear only at low drain currents, where the gate-source voltage is approaching the threshold. If $V_{GS} < V_{GS(th)}$, then the IGBT is in OFF state. The maximum voltage that should be applied to the gate-source (V_{GS}) terminal is usually limited by the maximum drain current (I_D) that is permitted to flow in the IGBT. It is basically a BJT with a MOSFET gate input and thus the modified BJT for the n-channel IGBT as shown in Fig.5(a). The schematic diagram of an IGBT is shown in Fig.6.

In this experiment, a gate pulse V_{Gate} is applied to the IGBT, the collector current I_C is noted down for the given V_{GE} . The parameters like t_{dn} , t_r , t_{df} , t_{f1} and t_{f2} are noted down as represented in Fig.7.

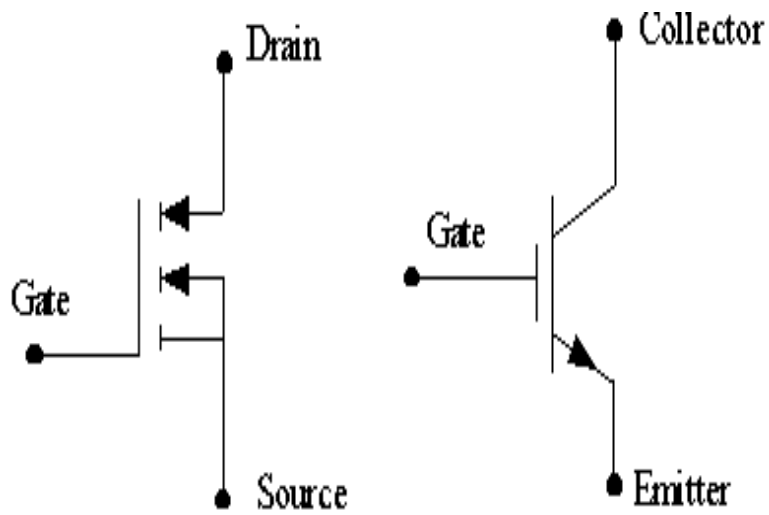


Fig.5(a). Symbolic representation of IGBT and its analogy to E-MOSFET.

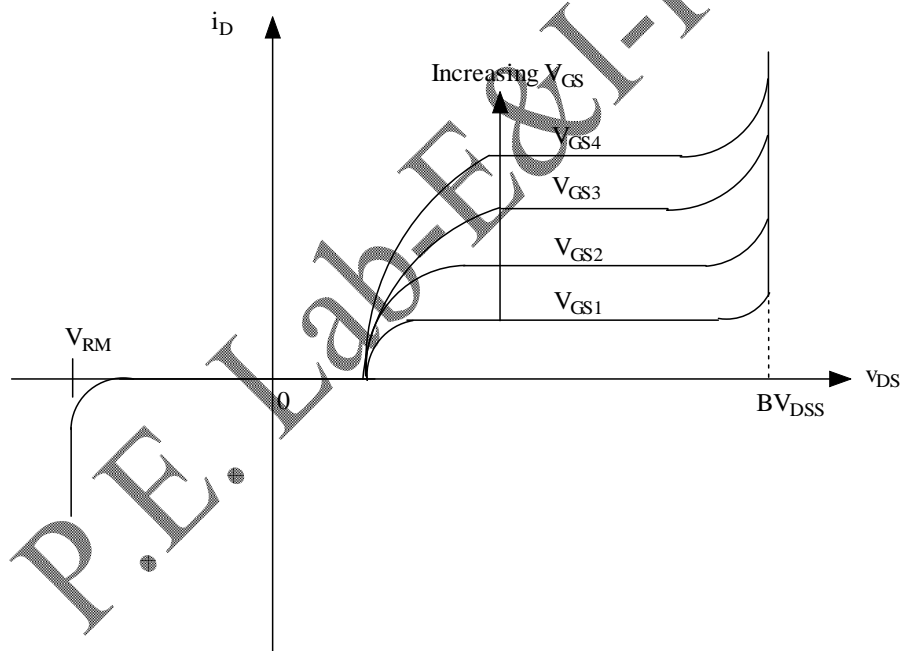


Fig.5(b). The IGBT I_D - V_{DS} characteristics.

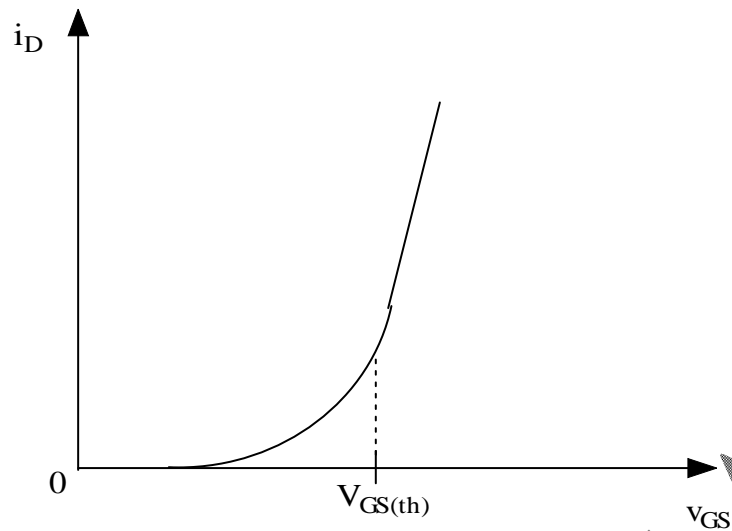


Fig.5(c). Transfer characteristics of IGBT.

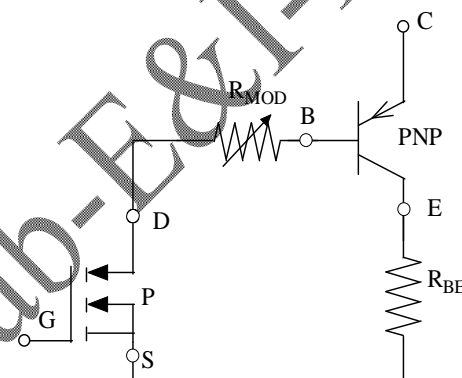


Fig. 6. Schematic diagram of IGBT.

DEFINITIONS

Form the graphical representation shown in Fig.7, the switching parameters are defined as follows:

Delay time (t_{dn})

It is the time in which, the collector current rises from collector-emitter leakage current (I_{CEO}) to 10% of collector current.

Rise time (t_r)

It is the time in which, the collector current rises from 10% of I_C to steady state collector current (I_C).

Turn-on time (t_{on})

It is the summation of the delay time and rise time.

$$t_{on} = t_{dn} + t_r$$

Delay time (t_{df})

It is the time in which, the collector current falls from 100% to 90%.

Initial fall time (t_{f1})

It is the time in which the collector current falls from 90% to 20%.

Final fall time (t_{f2})

It is the time in which the collector current falls from 20% to 10%.

Turn off time (t_{off})

It is the summation of delay time, initial fall time and final fall time.

$$t_{off} = t_{df} + t_{f1} + t_{f2}$$

PRECAUTIONS

- 1) Keep the oscillator switch in maximum frequency position.
- 2) Before giving connections, check whether all the switches are in OFF position.

PROCEDURE

1. Give connections as per the circuit diagram shown in Fig.8.
2. Switch ON the CRO and fix with x10 magnifying mode.
3. Turn ON the trainer power switch.
4. Turn ON the 15V DC selector switch.
5. To observe the device voltage (V_{CE}), connect the channel 2 of CRO to collector of IGBT with respect to ground. Since the load voltage is the inversion of the device voltage, so the channel-2 is in invert mode. Since the load is R, the measure of the load voltage is proportional to the load current I_L and hence i_C .
6. To observe the trigger pulse ($V_{GE} = V_{GS}$) applied to the base, connect the channel 1 of CRO at the input of the driver, with respect to ground.
7. Compare the above two signals. Determine the parameters t_{dn} , t_r , t_{df} , and t_f and tabulate the values in Table 2.

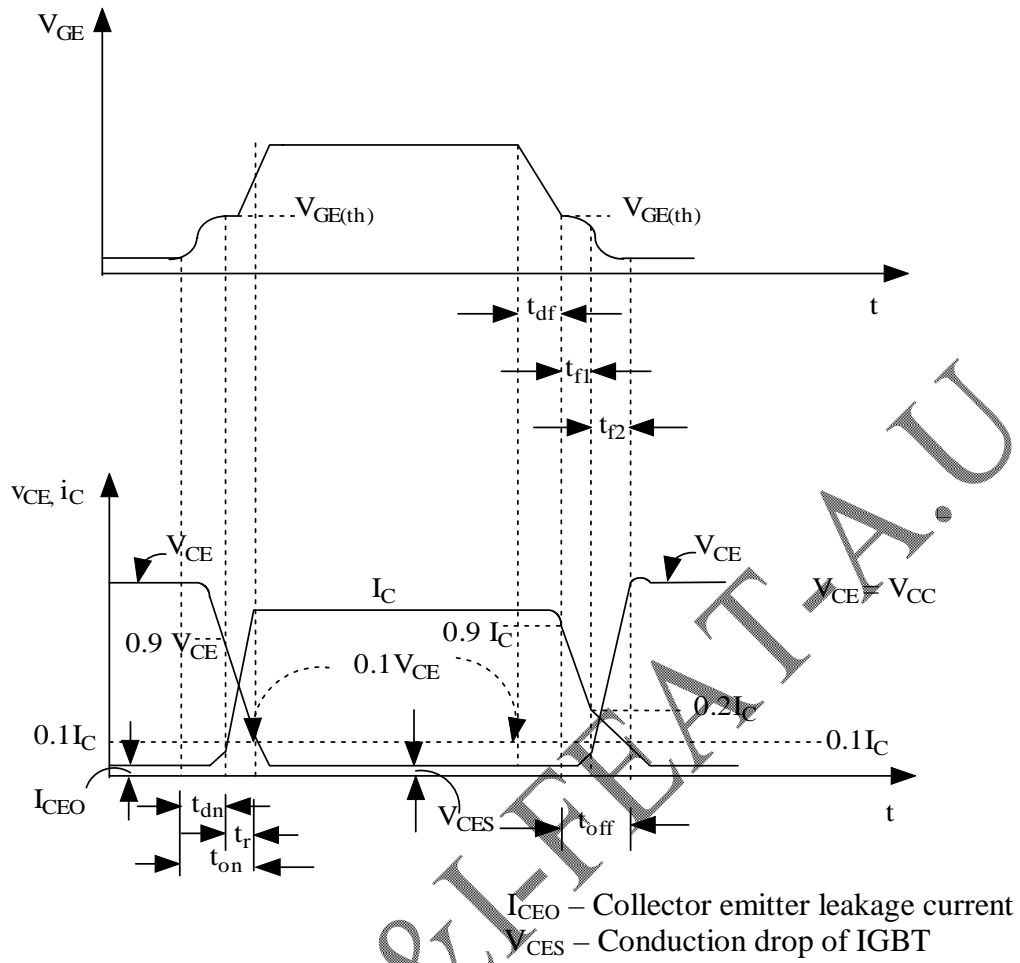


Fig.7. Switching characteristics of IGBT

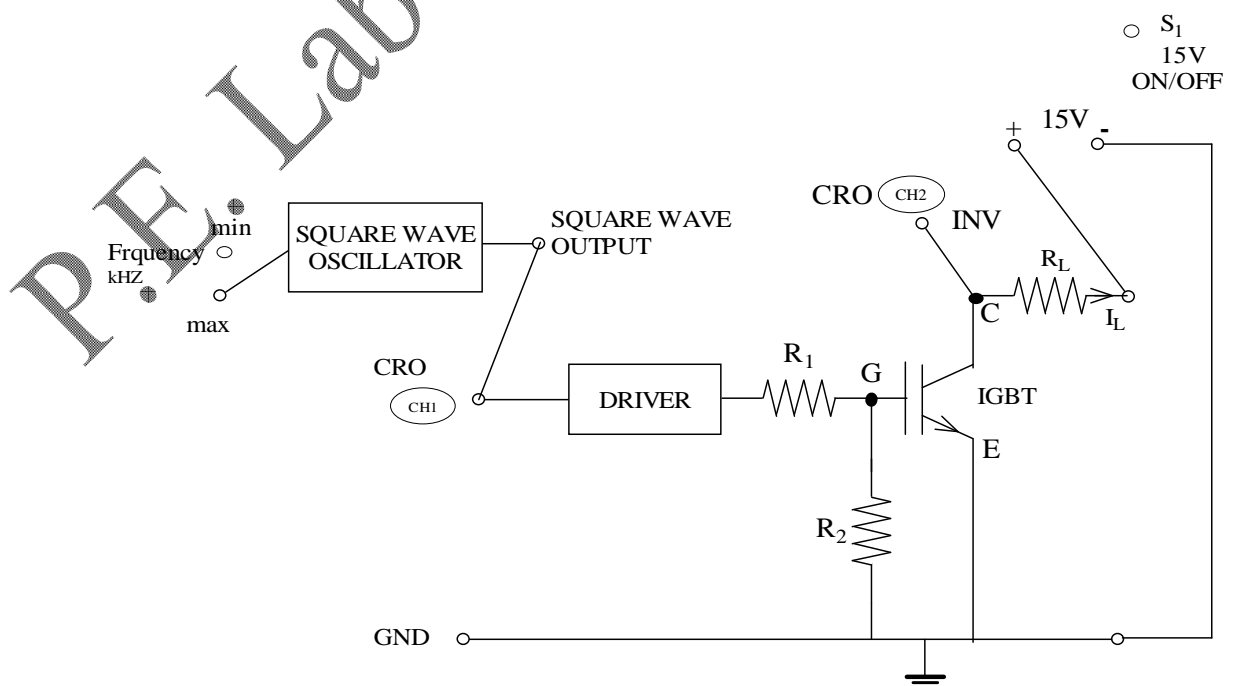


Fig.8. Connection diagram of IGBT.

Table 2. Switching parameters of IGBT for gating signal frequency 10kHz.

Turn ON time (ms)			Turn OFF time (ms)			
t_{dn}	t_r	t_{on}	t_{df}	t_{f1}	t_{f2}	t_{off}

RESULT

Switching characteristics of E-MOSFET and IGBT were studied and the parameters were determined and tabulated.

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MOSFET BASED SINGLE QUADRANT DC CHOPPER

AIM

1. To study the operation of a single quadrant step-down DC chopper.
2. To obtain the output voltage waveforms.

APPARATUS REQUIRED

1. VPET-208 module: DC Chopper Control Circuit.
2. DMM
3. CRO

THEORY

In a.c. circuits, the transformer converts electric power efficiently from one voltage level to another voltage level. DC-to-DC converters do a similar job in DC circuits are called choppers. The operation of transformer is based on an alternating magnetic field. But in choppers, the voltage conversion is achieved using high frequency power semiconductor switches, which operate either in fully ON or fully OFF state.

Choppers are widely used for DC motor control, electric vehicles, trolley cars, lamp loads, heater loads and in DC voltage regulators. DC choppers provide smooth acceleration control, high efficiency and fast dynamic response in electric vehicles. They are classified as:

1. Buck converter i.e. $V_o \leq V_{in}$ (step down)
2. Boost converter i.e. $V_o \geq V_{in}$ (step up)
3. Buck Boost converter (combination of both)

The circuit configuration of a chopper can be designed either to step down or step up the input voltage level. In this experiment, the operation of step down chopper circuit is studied. The two modes of operation of step down chopper are explained as follows:

TWO MODES OF OPERATION OF CHOPPER

Mode 1: $0 \leq t \leq T_{ON}$

When the switch (S) is ON by applying a gating pulse V_G as shown in Fig.1(a), the device voltage V_d (drop across the switch) becomes zero and the load voltage $V_o = V_{in}$. Hence

$$V_o = V_{in} = I_o * R$$

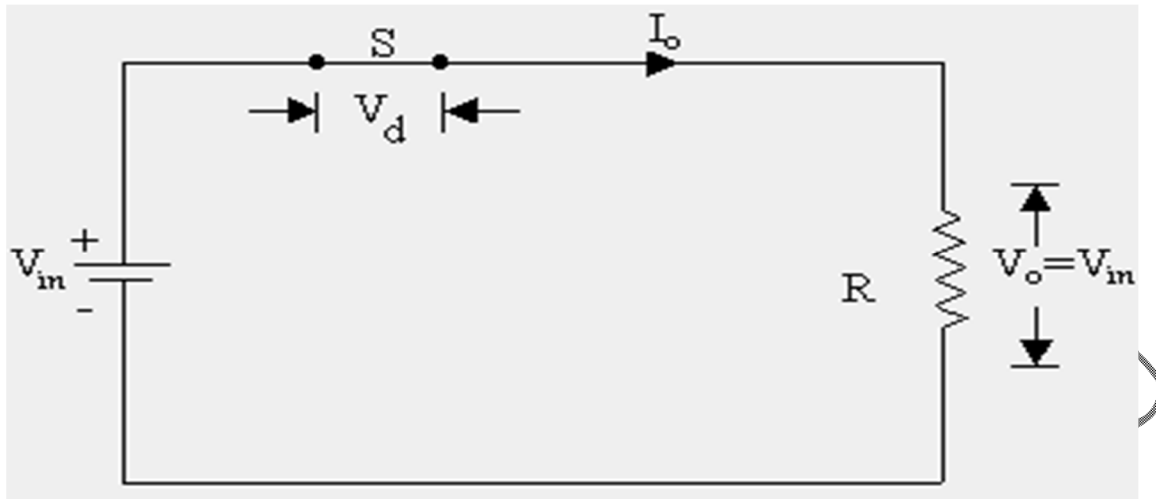


Fig.1(a). Mode 1: Circuit diagram of step-down DC chopper

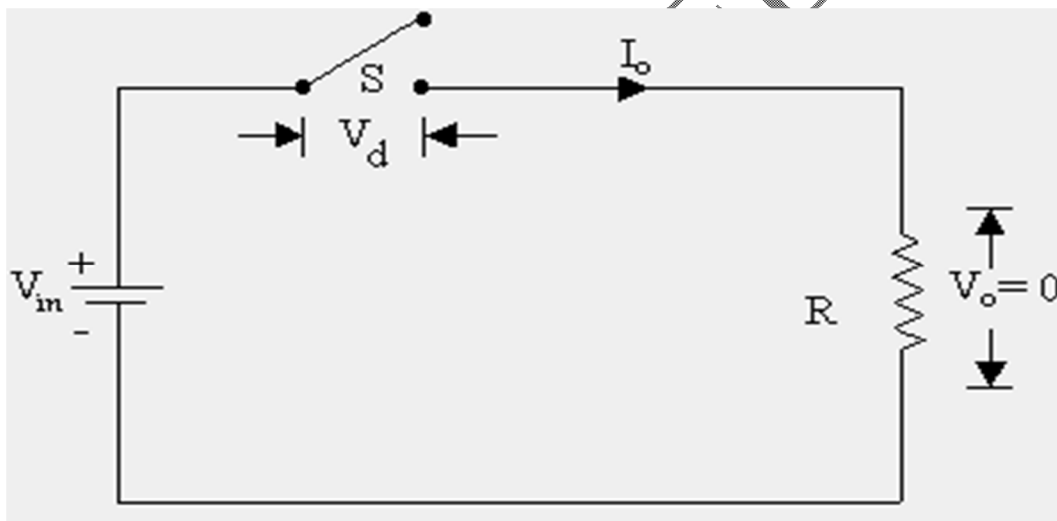


Fig.1(b). Mode 2: Circuit diagram of step-down DC chopper

Therefore the load current

$$I_o = \frac{V_{in}}{R}$$

Mode 2: $T_{ON} \leq t \leq T$

When the switch (S) is OFF ($V_G=0$) as shown in Fig.1(b), the device voltage (V_d) becomes V_{in} and the output voltage $V_o = 0$ and the load current $I_o = 0$. Hence, the power dissipation in the switch (P_d) is zero.

Combining Mode 1(M_1) and Mode 2 (M_2)

Theoretical waveforms for input voltage (V_{in}), gating pulse (V_G), output voltage (V_o) and the device voltage (V_d) are shown in Fig.2. Referring the waveforms, it is clear that

1. The switch closes for T_{ON} seconds in M_1 and for this period, the input voltage appears across the load.
2. The switch opens for T_{OFF} seconds in M_2 and for this period, the load voltage becomes zero.
3. The sum of T_{ON} and T_{OFF} is called chopping period, T and chopping frequency is equal to $1/T$.

STEP DOWN CHOPPER

A chopper which gives an output voltage less than or equal to the input voltage is called a step down chopper. Neglecting, the voltage drop across the switch, the average output voltage $V_{o,avg}$ is given by

$$V_{o,avg} = \frac{1}{\text{period}} \int_0^{\text{period}} V_o(t) dt \quad (1)$$

Where $V_o(t) = V_{in}; 0 \leq t < T_{ON}$

And $V_o(t) = 0; T_{ON} \leq t < T$

$$\text{Period } T = T_{ON} + T_{OFF}$$

Therefore the equation (1) becomes

$$\begin{aligned} V_{o,avg} &= \frac{1}{T} \int_0^T V_o(t) dt \\ &= \frac{1}{T} \left[\int_0^{T_{ON}} V_o(t) dt + \int_{T_{ON}}^T V_o(t) dt \right] \end{aligned}$$

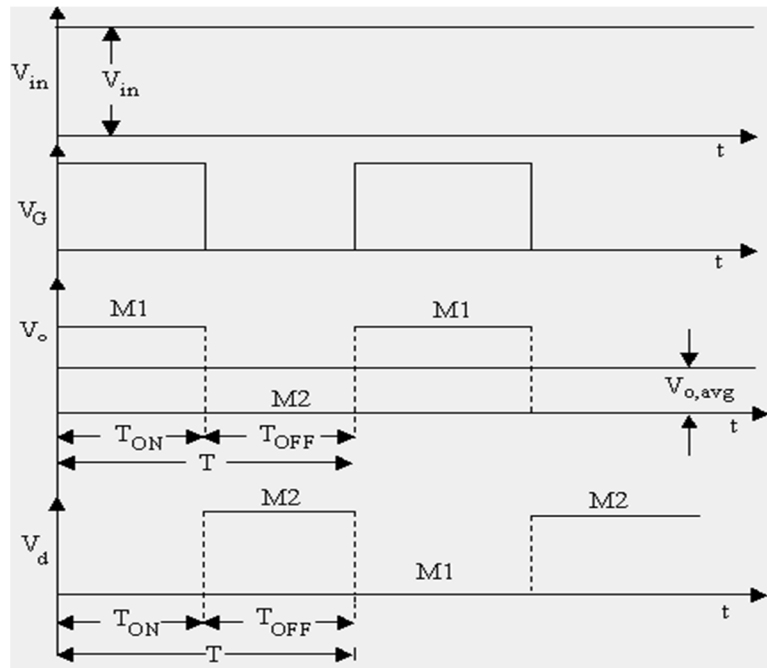


Fig.2. Waveforms of step-down DC chopper.

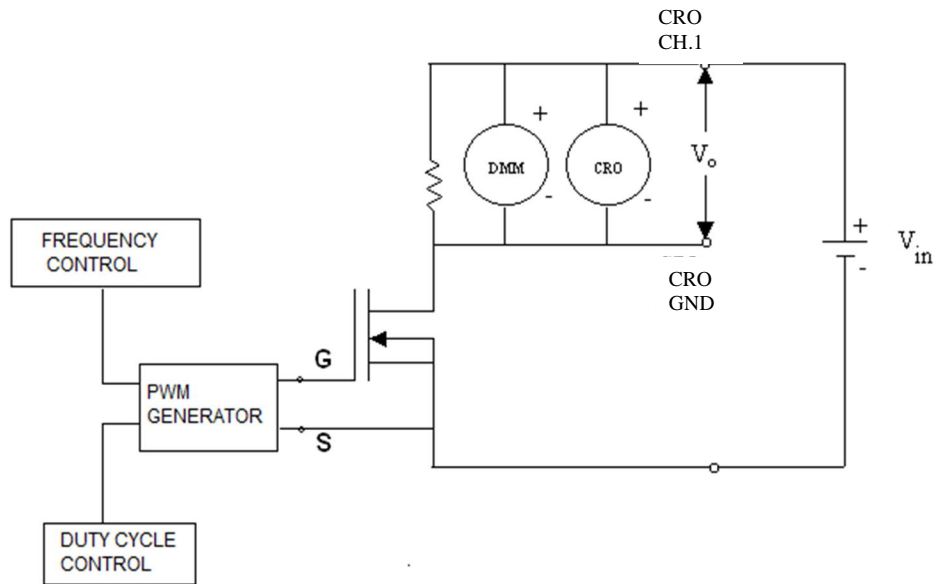


Fig.3(a). Circuit diagram of DC chopper.

$$\begin{aligned}
&= \frac{1}{T} \left[\int_0^{T_{ON}} V_{in} dt + \int_{T_{ON}}^T 0 dt \right] \\
&= \frac{1}{T} [V_{in}] [t]_0^{T_{ON}} \\
&= \frac{V_{in}}{T} * T_{ON} \\
V_{o,avg} &= V_{in} * \frac{T_{ON}}{T} \quad (2)
\end{aligned}$$

where T = Chopping period and

$$\frac{T_{ON}}{T} = \text{Duty cycle ratio}$$

From Eqn. 2, it is clear that the average output voltage $V_{o,avg}$ depends on the T_{ON} and T . It can be varied by varying either the chopping frequency (f) or by varying T_{ON} . Thus the power flow in the circuit can be controlled.

The switch shown in Fig.3, can be any one of the following power semiconductor devices: i) SCR, ii) power transistor (power-BJT), iii) power-MOSFET, iv) IGBT and v) GTO. In this experiment, IGBT [Insulated Gate Bipolar Junction Transistor] is used as a switch.

PRECAUTIONS

1. Ensure the switch is in OFF position while doing circuit connection.
2. Ensure pulse release switch in OFF position whenever power is switched ON.

EXPERIMENTAL PROCEDURE

I) Fixed Frequency Variable Time Ratio Control (FFVTRC)

1. Connect the load and the device as shown in Fig.(3a).
2. Connect channel-1 of CRO and ground across the load (R), to measure the output voltage. Connect Channel-2 of CRO to measure the input voltage (V_{in}) as shown in Fig. (3a).
3. Fix the carrier frequency knob at one position and adjust T_{ON} and T_{OFF} as given in Table 1.

4. Trace the output voltage on CRO for different T_{ON} settings and simultaneously note down the average output voltage using DMM and verify with theoretical value as given below:

$$V_{o,avg} = \frac{T_{ON}}{T} V_{in} \quad (3)$$

- 5.

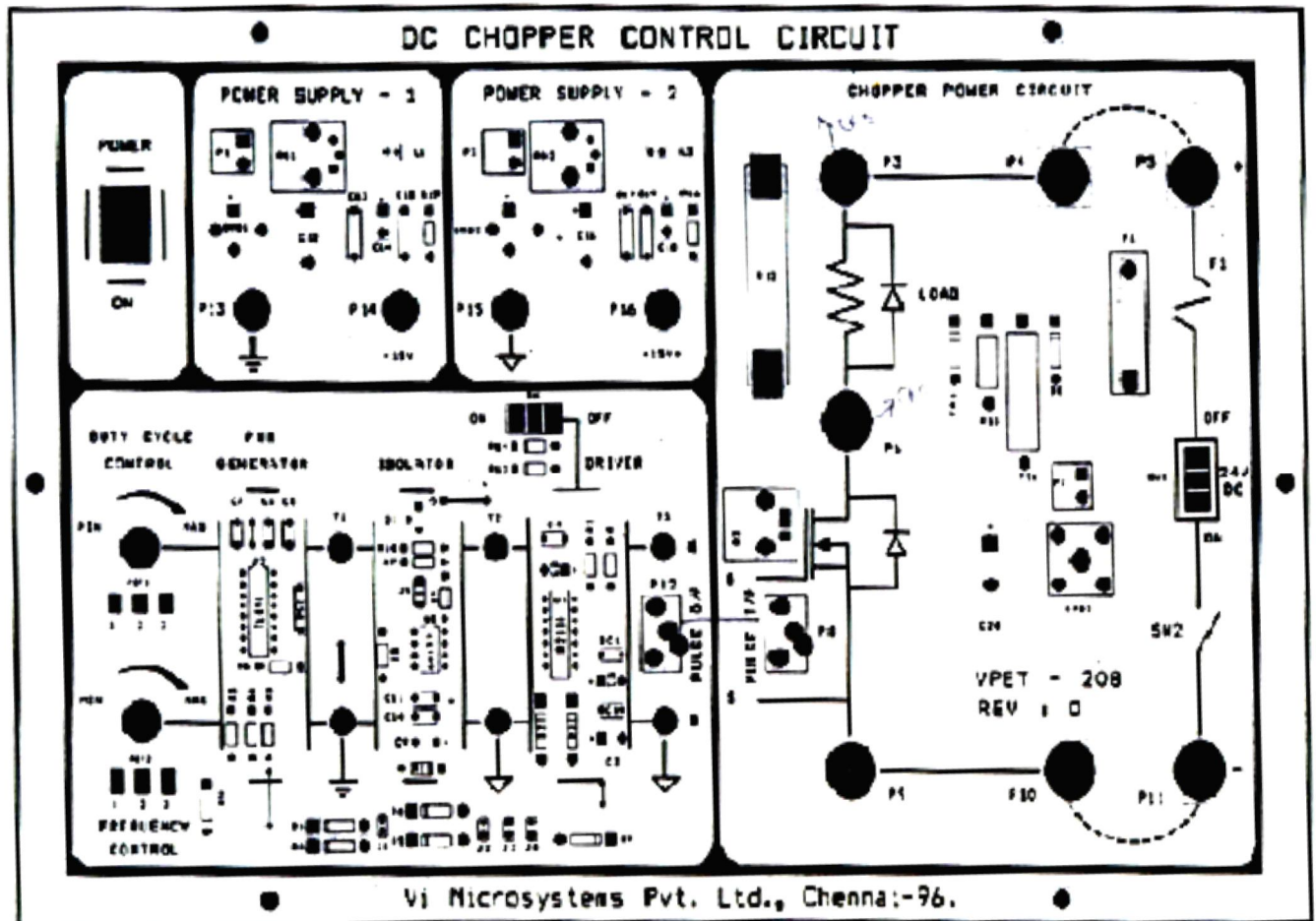


Fig.3(b). Connection diagram of step down DC chopper.

Table 1. Fixed Frequency Variable Time Ratio Control (FFVTRC)

Chopping frequency f_s	Chopping period T	Off period T_{off}	On period T_{on}	Theoretical output voltage V_o (avg) (V)	Practical output voltage V_o (avg) (V)	Input voltage V_{in} (V)

Table 2. Variable Frequency Variable Time Ratio Control (VFVTRC)

Chopping frequency f_s	Chopping period T	Off period T_{off}	On period T_{on}	Theoretical output voltage V_o (avg) (V)	Practical output voltage V_o (avg) (V)

II) Variable Frequency Variable Time Ratio Control (VFVTRC)

1. The connection and procedure are similar to the FFVTRC.
2. Vary both the carrier frequency knob and voltage knob simultaneously to keep T_{ON} fixed and T_{OFF} variable, as given in Table 2.
3. Trace the output voltage for different T_{OFF} settings and simultaneously note down the average output voltage using DMM and verify with theoretical value as given below:

$$V_{o,avg} = \frac{T_{ON}}{T_{ON} + T_{OFF}} V_{in} \quad (4)$$

Result

The operation of a single quadrant step-down DC-DC converter (chopper) with fixed load was studied and output waveforms were obtained.

Ex.No.:
DATE:

SINGLE PHASE CYCLOCONVERTER WITH RESISTIVE LOAD

AIM

1. To study the principle of operation of single phase cycloconverter with resistive load.
2. To obtain the output waveforms with frequency as an integral sub-multiple of the input frequency.

APPARATUS REQUIRED

- 1) Control / firing module
- 2) Cycloconverter module
- 3) Rheostat 220 Ω , 1A
- 4) CRO
- 5) Inductance 125mH
- 6) Transformer (230 / 24-0-24 Volts)

THEORY

Cycloconverter is a device which converts power at one frequency to power at a different frequency with one stage conversion. It is an AC to AC converter. The two types of cycloconverter are:

- i) Step-down cycloconverter.
- ii) Step-up cycloconverter.

In step-down cycloconverter, the output frequency f_o is lower than the input supply frequency f_s ($f_o < f_s$). In step-up cycloconverter, the output frequency f_o is higher than the input supply frequency f_s ($f_o > f_s$). In this experiment, $f_o < f_s$ is considered and operation of the cycloconverter as shown in Fig.1 is explained for $f_o = f_s/2$ (two cycles of AC input signal corresponds to one cycle of AC output). The modes of operation of cycloconverter are shown in Fig.2.

In order to satisfy $f_o = f_s/2$, the output voltage should be positive for first cycle and negative for second cycle of input signal as shown in Fig.3. The principle of operation of single-phase cycloconverter can be explained with the help of Fig.1.

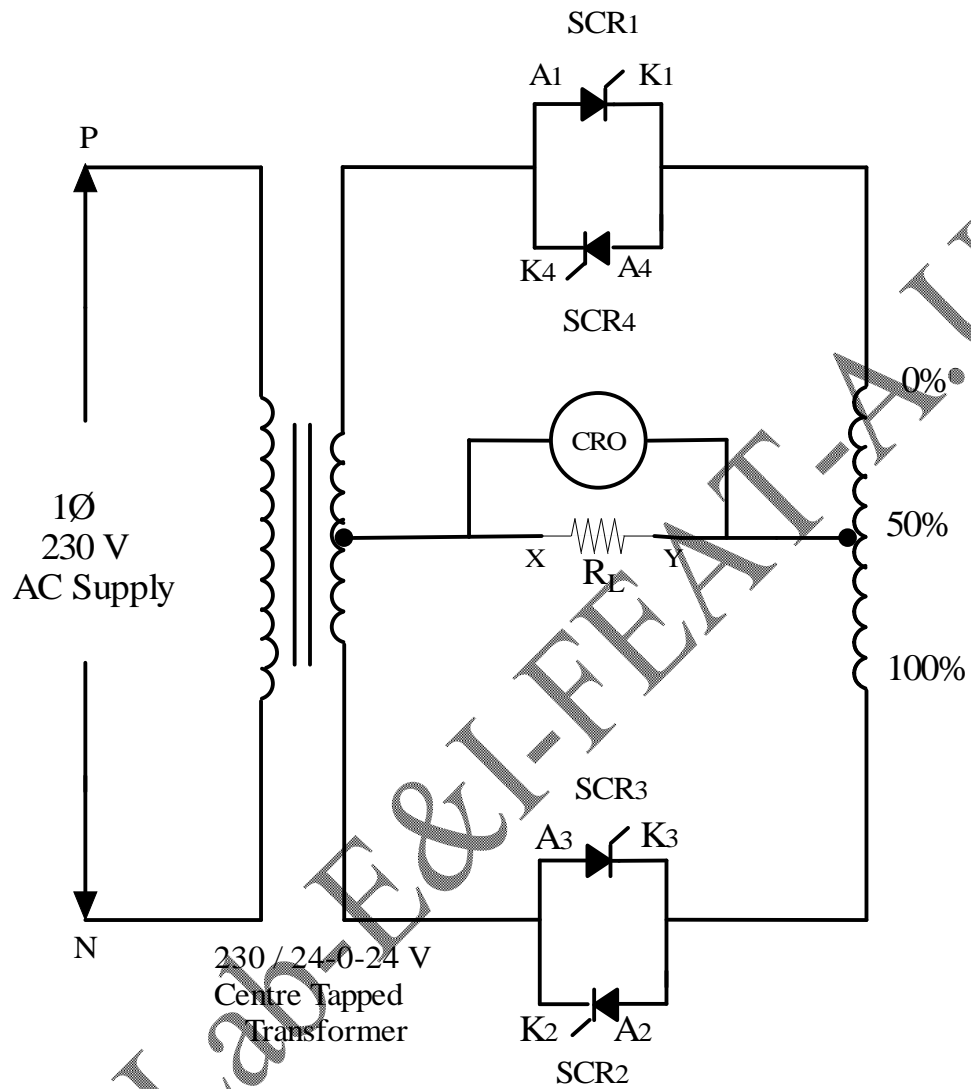


Fig.1. Circuit diagram of single phase cycloconverter with R load.

During the first positive half cycle, point 'a' is positive with respect to point 'b' and point 'c' is positive with respect to point 'd' and hence, SCR₁ and SCR₂ are forward biased. Since positive load voltage is required (load current flows from y → +ve to x → -ve), SCR₁ alone is triggered as shown in Fig.2(a) and SCR₂ is not fired because it will produce negative load voltage. For the first negative half cycle, point 'a' is negative with respect to point 'b' and point 'c' is negative with respect to point 'd' and hence, SCR₃ and SCR₄ are forward biased. Since positive load voltage is required (load current flows from y → +ve to x → -ve), SCR₃ alone is fired as shown in Fig.2(b) and SCR₄ is not fired because it will produce negative load voltage.

During the second positive half cycle, point 'a' is positive with respect to point 'b' and point 'c' is positive with respect to point 'd' and hence, SCR₁ and SCR₂ are forward biased. In this cycle, only negative load voltage is required (load current flows from x → +ve to y → -ve), SCR₂ alone is triggered as shown in Fig.2 (c) and SCR₁ is not fired because it will produce positive load voltage. For the second negative half cycle, point 'a' is negative with respect to point 'b' and point 'c' is negative with respect to point 'd' and hence, SCR₃ and SCR₄ are forward biased. In this cycle, only negative load voltage is required (load current flows from x → +ve to y → -ve), SCR₄ alone is fired as shown in Fig.2(d) and SCR₃ is not fired because it will produce positive load voltage. By changing the firing angle α , the duration of conduction of each SCRs can be varied. The gating sequence of SCRs for $f_o = f_s/2$ are tabulated in Table 1. The SCRs are turned OFF by natural commutation at the end of each half cycle due to resistive load. The waveforms of input voltage, output voltage and gating pulses are shown in Fig. 3.

PRECAUTIONS

1. The load rheostat must be kept at maximum resistance position.
2. Pulse release switch should be in OFF position while main supply is switched ON.
3. The maximum output frequency of cycloconverter should be limited to one-fourth of the input frequency to maintain acceptable waveform with a low harmonic content.

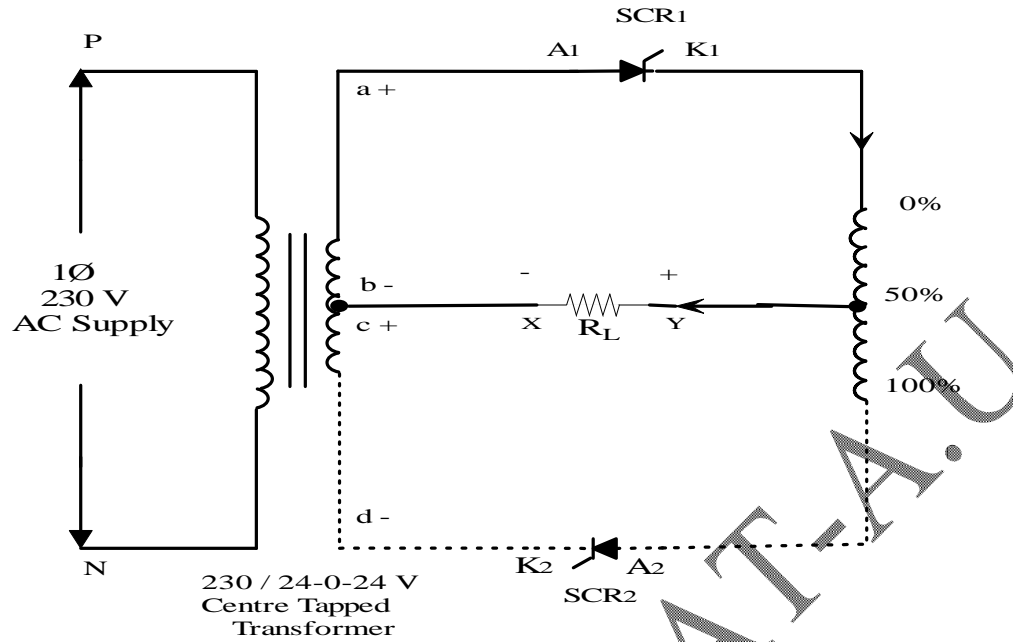


Fig.2(a). Mode diagram of 1st positive half cycle

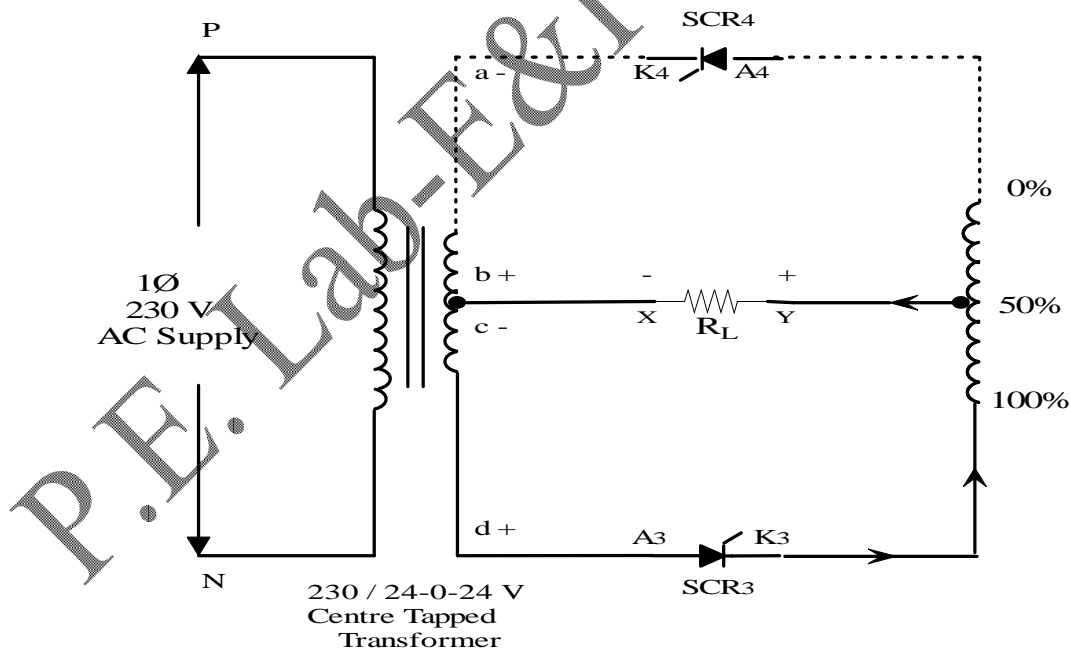


Fig.2(b). Mode diagram of 1st negative half cycle

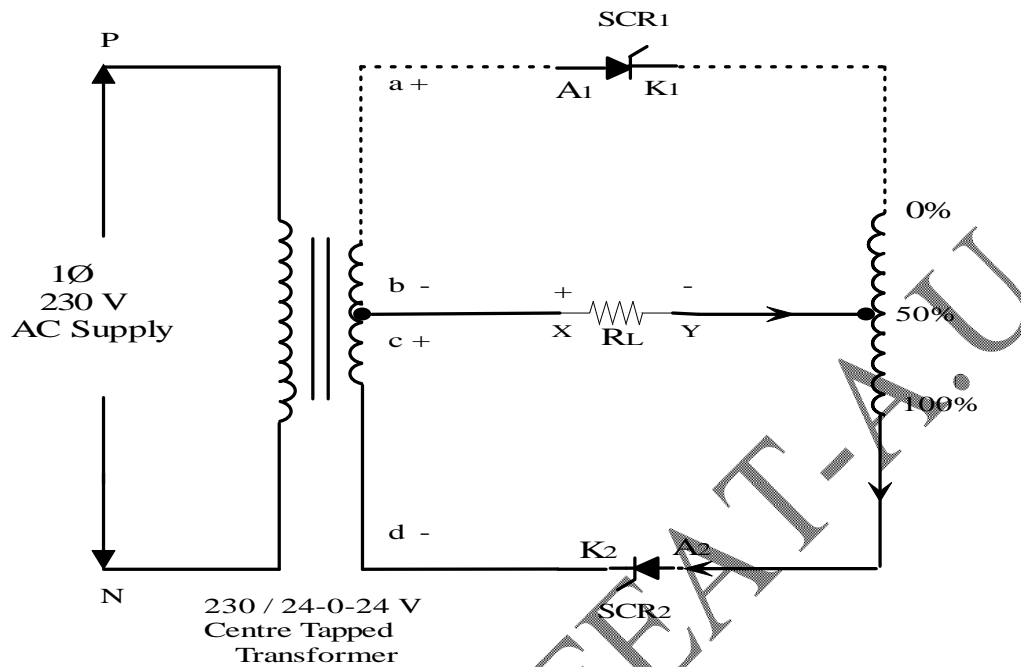


Fig.2(c). Mode diagram of 2nd positive half cycle

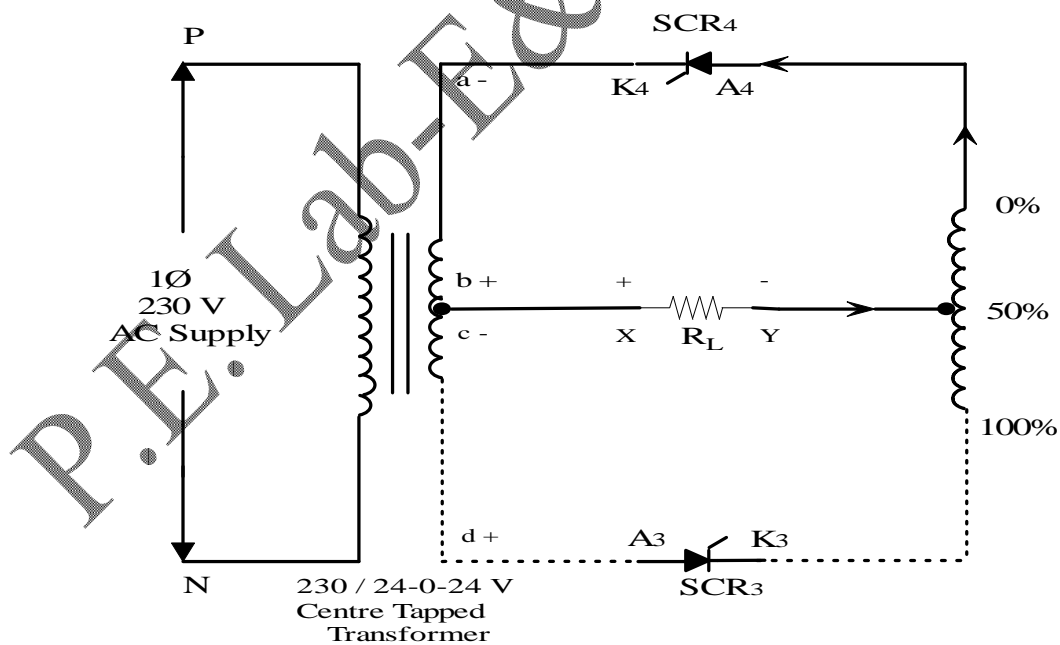


Fig.2(d). Mode diagram of 2nd negative half cycle

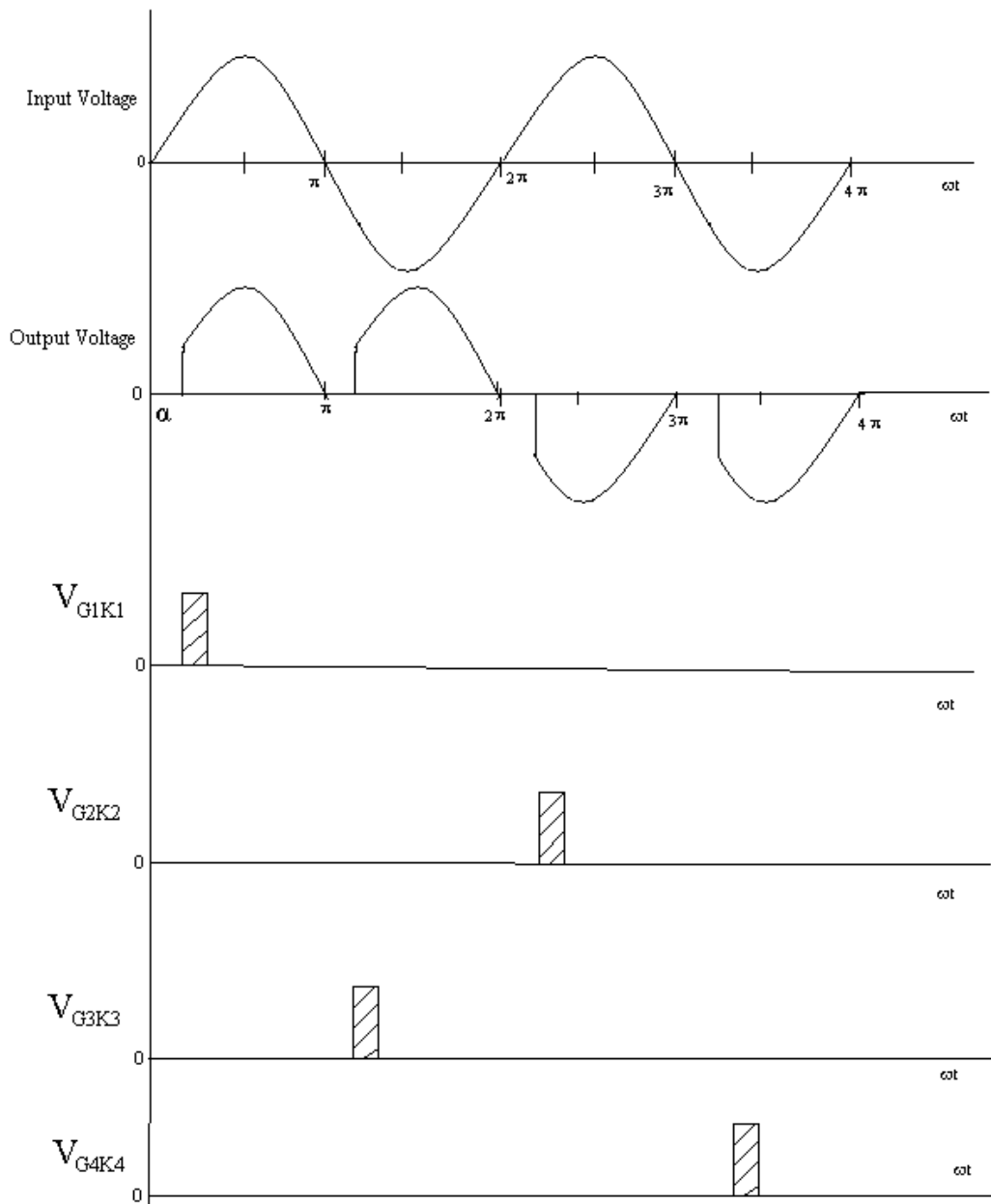


Fig.3. Waveforms of single phase cycloconverter $f_o = f_s/2$

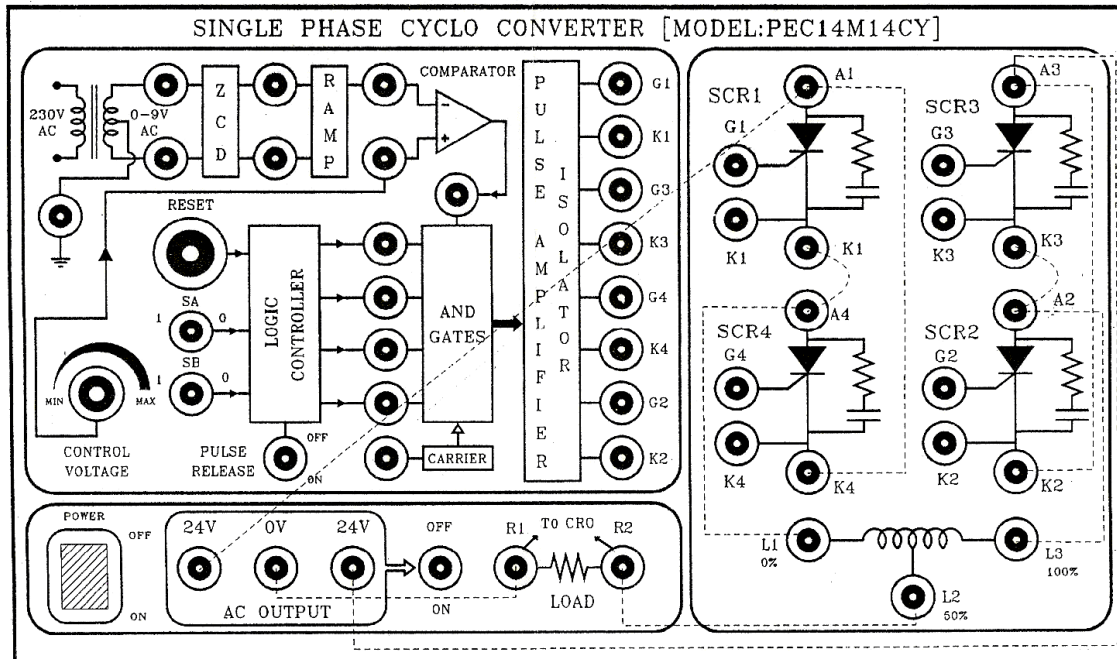


Fig.4. Connection diagram of single phase cycloconverter.

Table 1. Gating sequences of SCRs for $f_0 = f_s/2$

Serial number of half cycle	Nature of half cycle	SCRs forward biased	SCR triggered	Nature of load voltage
1	PHC	1,2	1	y = +ve; x = -ve
2	NHC	3,4	3	y = +ve; x = -ve
3	PHC	1,2	2	y = -ve; x = +ve
4	NHC	3,4	4	y = -ve; x = +ve

PHC → Positive Half Cycle and NHC → Negative Half Cycle

Table 2. Experimental result, $\alpha = \dots\dots$

Switch position		Input frequency f_s (Hz)	Output frequency f_o (Hz)
S_A	S_B		
0	0	50	
1	0	50	
1	1	50	
0	1	50	

Model calculations for firing angle $\alpha = 90^\circ$

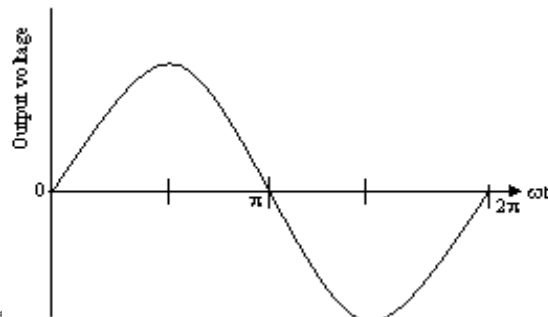


Fig.5. Model calculations for firing angle $\alpha = 90^\circ$.

From Fig.5.

Number of time divisions for one cycle = 4
Therefore 4 divisions = 360°

Hence, the time divisions required to set α at $90^\circ = (4 / 360) * 90 = 1$ div.

PROCEDURE

1. The connections are given as per the circuit diagram as shown in Fig. 4.
2. Connect the firing pulses from cycloconverter firing control module to device module.
3. Switch ON the power supply (230V AC) to the primary of the transformer.
4. Switch ON firing and device module.
5. Connect the CRO across the load.
6. Turn ON the pulse release switch.
7. Observe the output voltage waveform on CRO for the following switch select (S_A , S_B) positions.
 - a) $S_A=0$ and $S_B=0$ → output frequency = input frequency
 - b) $S_A=1$ and $S_B=0$ → output frequency = $1/2$ input frequency
 - c) $S_A=1$ and $S_B=1$ → output frequency = $1/3$ input frequency
 - d) $S_A=0$ and $S_B=1$ → output frequency = $1/4$ input frequency
8. Vary the firing angle α (0 to π) and observe the frequency of the output waveform and tabulate the readings in Table 2.

RESULT

Thus the conversion of single phase AC voltage of particular frequency to single phase of AC voltage of lower frequency was achieved with a cycloconverter and the relevant waveforms were traced.

P.E. Lab-E&I-FEAT-A.U

Ex.No.:

DATE:

SINGLE PHASE SERIES INVERTER USING SCR WITH RESISTIVE LOAD

AIM

To study the operation of single phase series inverter circuit using SCR with resistive load and obtain its output voltage waveform.

APPARATUS REQUIRED

1. SCR series inverter circuit module
2. Resistive load
3. CRO
4. Pulse patch chords
5. Connection patch chords

Features of PEC14M6

- Test points are provided to observe the signals at each stage.
- Heat sinks are provided with SCRs to dissipate the heat at a faster rate.
- Firing circuit and power circuit are isolated.
- The 24 volts DC has short circuit protection.
- SCR is provided with Snubber circuit.
- Output frequency can be controlled from 300Hz to 650Hz.

THEORY

DC to AC converter is known as inverter. The function of an inverter is to change a fixed DC input voltage into a symmetrical AC output voltage of desired magnitude and frequency. For sinusoidal AC output, the magnitude, frequency and phase can be controllable. According to the type of AC output, these topologies can be classified into voltage source inverter (VSI) and current source inverter (CSI). In case of VSI, the independently controlled AC output is a voltage waveform and DC source maintains constant voltage. But in case of CSI, the independently controlled AC output is a current waveform and DC source maintains constant current.

A single phase series inverter circuit using SCR with resistive load is shown in the Fig.1. Initially capacitor C_2 is assumed to be charged to voltage V_c with upper plate negative and lower plate positive. As the capacitors C_1 and C_2 together are connected across the battery, the total voltage across C_1 and C_2 should be equal to V_{DC} . Therefore, C_1 will be charged to $(V_{DC} + V_c)$ value with upper plate positive.

Thyristor T_1 is triggered at instant '0'. with this ,the two current flow through the thyristor T_1 and load R. Current i_1 flows through the path $V_{DC} (+) \rightarrow T_1 \rightarrow L_1 \rightarrow R \rightarrow C_2(+)$,thus charging capacitor C_2 ,which is already charged at this instant will provide the second current i_2 . This discharge current i_2 has the path $C_1 (+) \rightarrow T_1 \rightarrow L_1 \rightarrow R \rightarrow C_1 (-)$.

Since the driving voltage ($V_{DC} + V_c$) , the capacitors C_1 , C_2 and the initial conditions are identical for both these paths, the two currents i_1 and i_2 will always be equal. Hence, 50% of the load current is drawn from the input source and 50% from the discharge of the capacitor.

At the end of the positive half cycle, when the load current becomes zero, SCR T_1 will be turned off and the voltage across the capacitors reversed. In the steady state, capacitor C_2 will be charged to voltage ($V_{DC} + V_c$) in the opposite direction and capacitor C_1 to V_c . When SCR T_2 is triggered, identical load current is obtained from the d.c. input source and the rest 50% from the load current is obtained from the input d.c. supply no more remains intermittent in nature and the ripples are reduced to minimum. The peak forward off-state voltage for the SCRS is V_{DC} and V_c is the peak reverse voltage.

EXPERIMENTAL PROCEDURE

1. Give connections as per the connection diagram shown in Fig.2
2. Switch ON AC power supply
3. Switch ON control circuitry
4. Switch ON 24 volts DC supply.
5. Trace the input, output and capacitor voltage waveforms at desired frequency and observe SCR turn ON and turn OFF times.

CIRCUIT DIAGRAM

The series inverter circuit diagram using SCRs with resistive load is shown in Fig.1

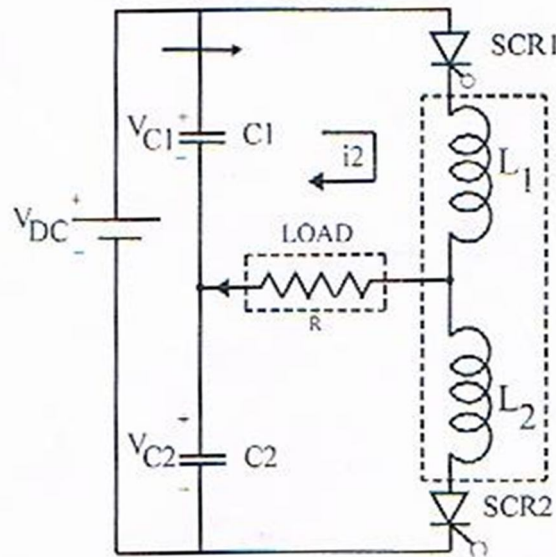


Fig.1 Circuit diagram of series inverter.

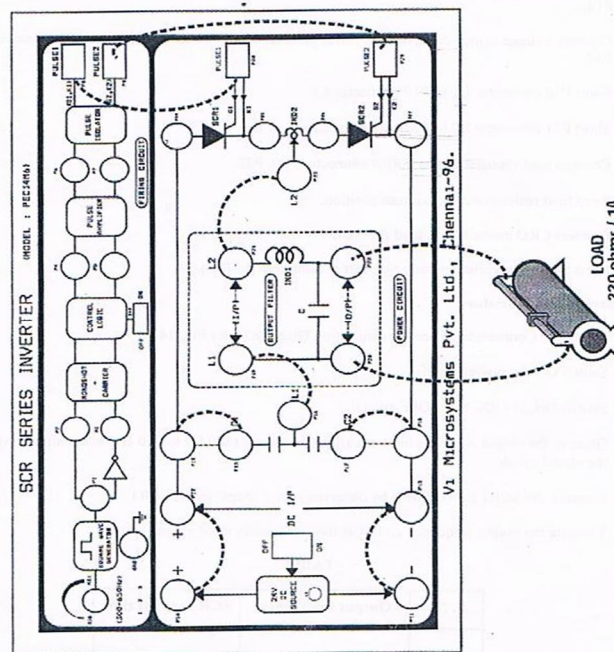


Fig.2 Connection diagram of series inverter.

MODAL OUTPUT WAVEFORMS

Typical waveforms of input voltage, SCR turn ON and turn OFF voltages, and output load voltage are shown in Fig.3 to Fig.5 respectively.

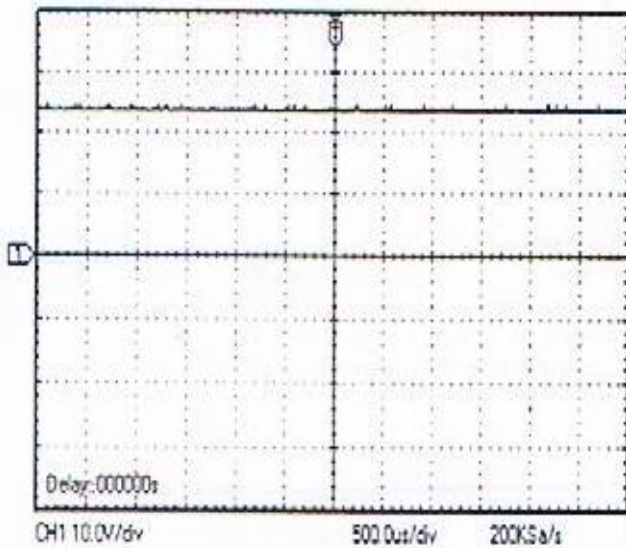


Fig.3 Input DC Voltage

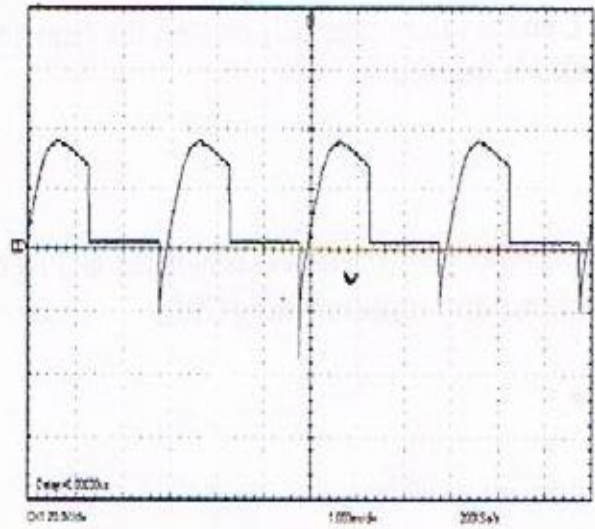


Fig.4 SCR Voltage

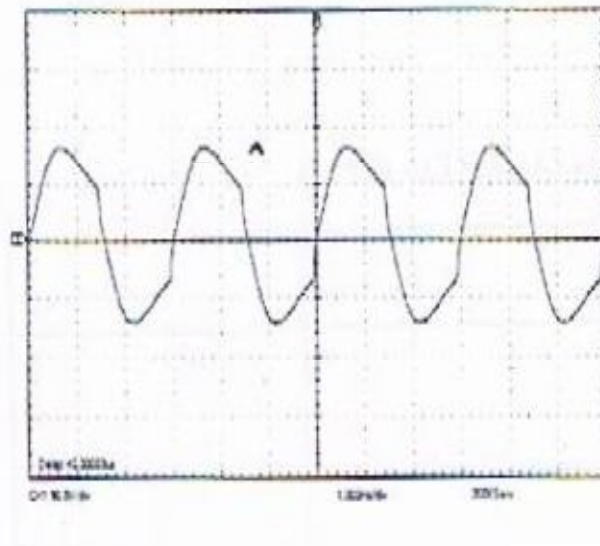


Fig.5 Load Voltage

RESULT

Operation of single phase series inverter using SCR was studied and the output voltage waveform was obtained.

Ex.No.:
DATE:

SINGLE PHASE FULLY CONTROLLED BRIDGE RECTIFIER

AIM

To study the characteristics of single phase fully controlled bridge rectifier.

APPARATUS REQUIRED

- 1) Single phase SCR bridge rectifier module
- 2) Voltmeter 0 – 30V MC
- 3) CRO

THEORY

The circuit diagram of single phase fully controlled bridge rectifier consists of four SCRs is shown in Fig.1. The two modes of operation of bridge rectifier are explained as follows:

Mode 1: Operation with resistive load

In mode 1, bridge rectifier is operated with resistive load. During positive half cycle of AC input voltage, point 'a' is positive with respect to point 'b'. Hence, SCR1 and SCR2 are forward biased as shown in Fig.2. They are fired simultaneously at a firing angle of α . The supply voltage appears across the load R_L ($V_L = V_{in}$). Now the load current flows from supply through SCR1, load and SCR2. The current waveform is in phase with the voltage waveform due to resistive load. At the end of positive half cycle ($\omega t = \pi$), the load current falls to zero and SCR1 and SCR2 turns OFF by natural commutation. During negative half cycle of AC input voltage, point 'b' is positive with respect to point 'a'. Hence, SCR3 and SCR4 are forward biased as shown in Fig.3. They are fired simultaneously at a firing angle of $\pi + \alpha$. The load voltage is zero from π to $\pi + \alpha$. Hence, the supply voltage appears across the load R_L ($V_L = V_{in}$). The load current flows from supply through SCR3, load and SCR4. The direction of current through the load is same in both positive and negative half cycles of AC input voltage and hence, a positive average output voltage V_o is obtained. The waveforms of load current, load voltage and gating pulses are shown in Fig.4.

The connection diagram for mode 1 is shown in Fig.5 and the procedure is as follows:

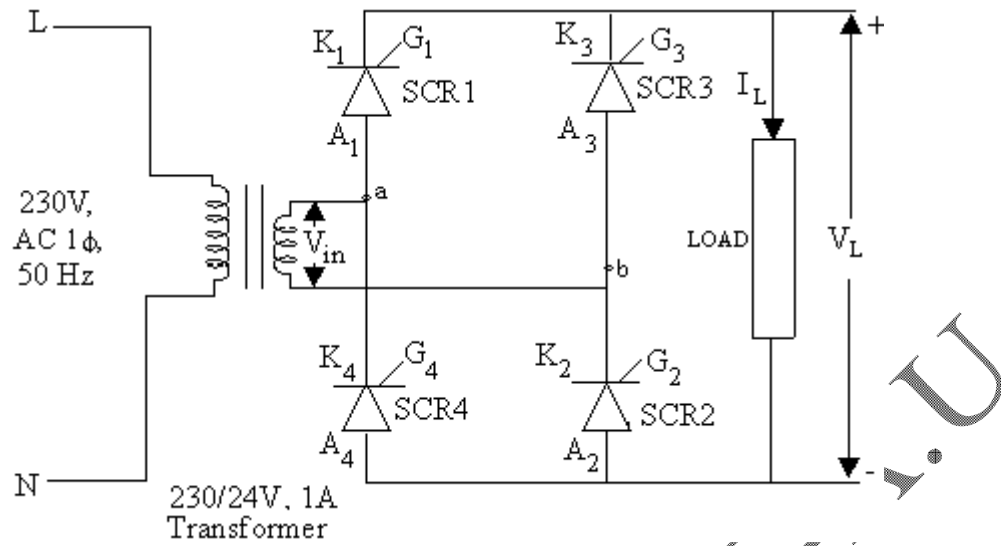


Fig.1. Circuit diagram of a single phase fully controlled bridge rectifier.

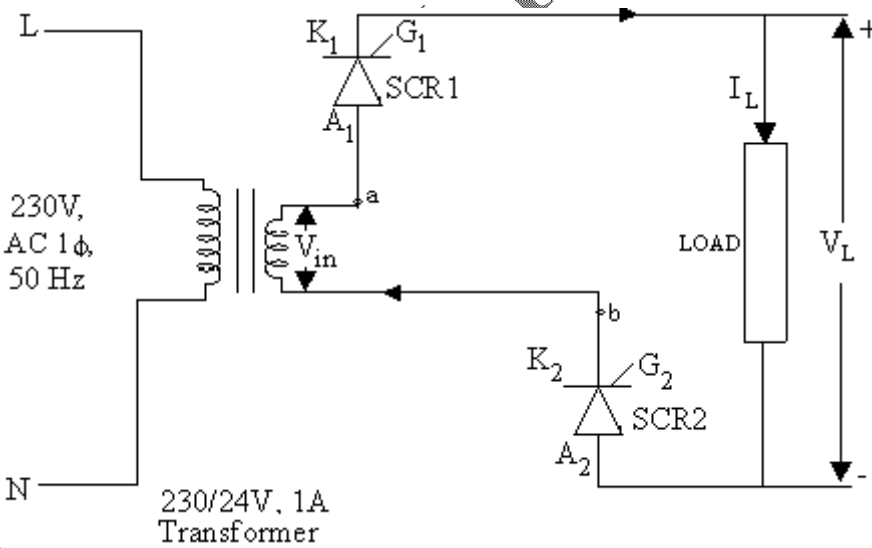


Fig.2. Current conduction during positive half cycle (Mode 1).

PROCEDURE FOR MODE1

- (i) Give connections as per the circuit diagram shown in Fig.5 and Fig.6.
- (ii) Provide the switch SW2 in “INT” mode.
- (iii) Keep the firing knob in minimum position.
- (iv) Switch ON the trainer power module.
- (v) Switch ON the power circuit switch SW4.
- (vi) Release the pulse through pulse release (PR) switch SW3.
- (vii) Vary the control voltage (firing angle) from 0 to 180 degrees in steps of 30.
- (viii) Note down the DC average output voltage for each step using DMM.
- (ix) Trace the output voltage waveform from CRO.
- (x) Calculate the firing angle from the waveform obtained.

Compare the theoretical and practical values of V_o obtained for various α and tabulate in Table1.

Formula for obtaining average dc output voltage with resistive load

$$\text{Average DC output voltage } V_o = \frac{\sqrt{2} * V_{in} * [1 + \cos\alpha]}{\pi}$$

where

V_{in} = RMS value of AC input voltage = 24 volts.

α = Firing angle in degrees (0° to 180°) = $(180 * t) / T$

t = triggering time

T = total time for one half cycle.

Specimen calculation for output voltage

For $\alpha = 45^\circ$

$$V_o = \frac{\sqrt{2} * 24 [1 + \cos 45^\circ]}{3.14}$$

$$= 18.45 \text{ V}$$

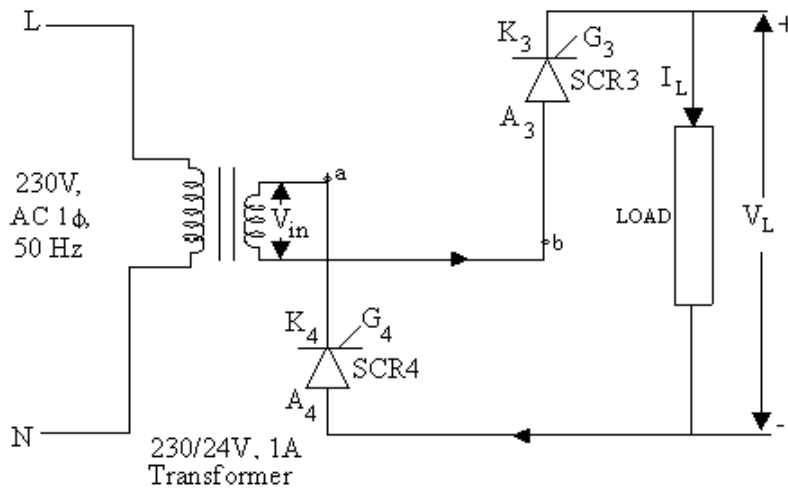


Fig.3. Current conduction during negative half cycle. (Mode 2)

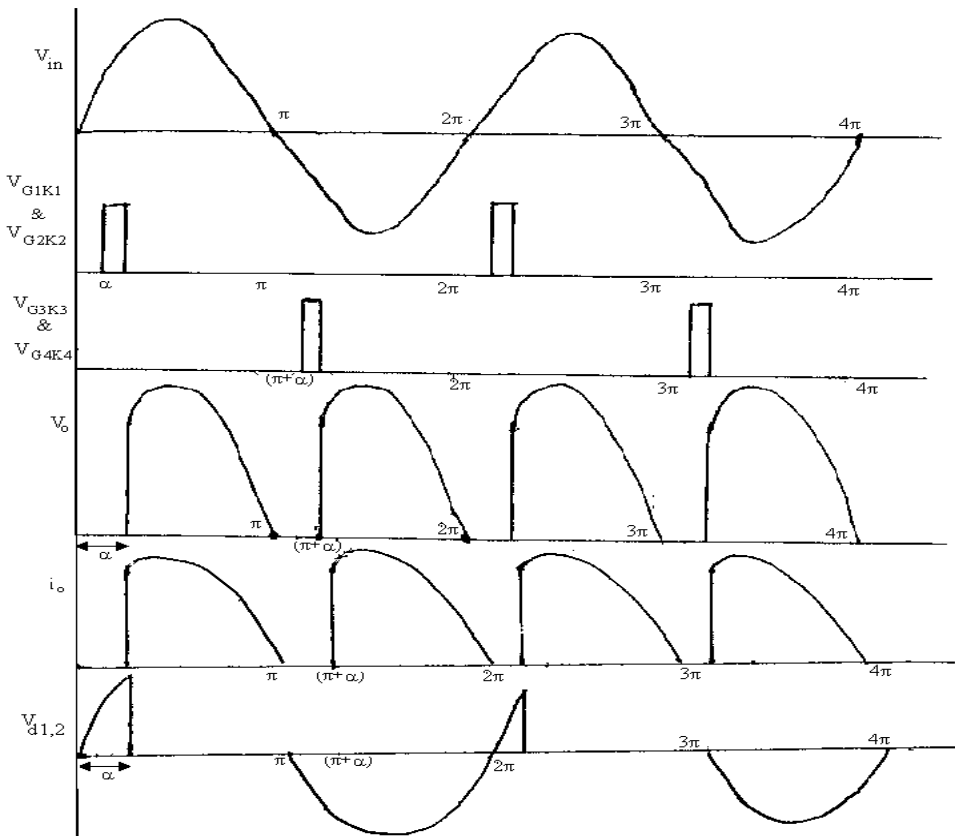


Fig.4. Waveforms of fully controlled bridge rectifier for R load.

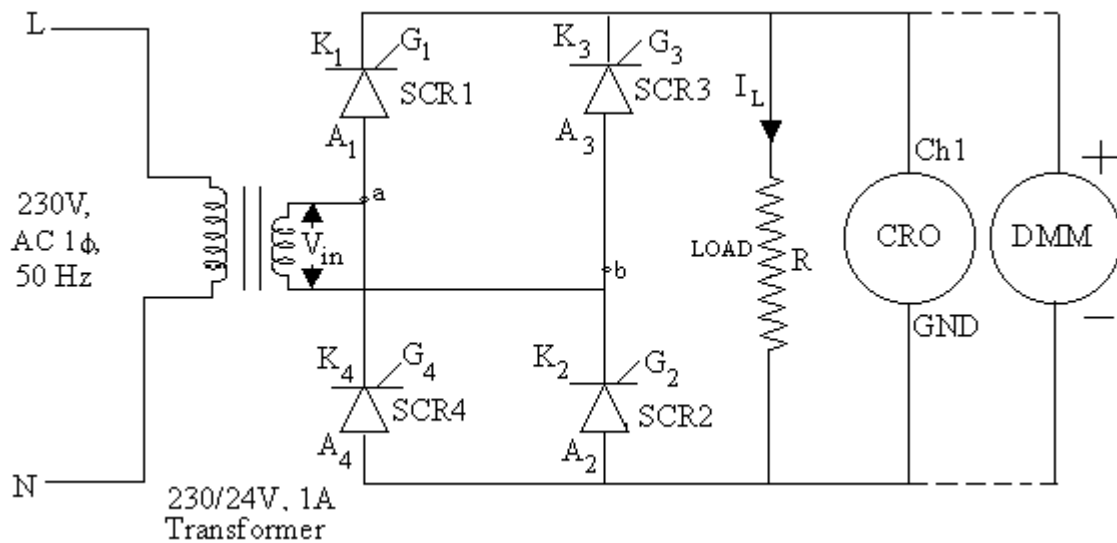


Fig.5. Connection diagram of a single phase fully controlled bridge rectifier with resistive load.

Table1. Parameters obtained with resistive load

Sl. No.	Firing angle (α)		Calculated average output voltage V_o (V)	Measured average output voltage V_o (V)
	Divisions	Degrees		

P

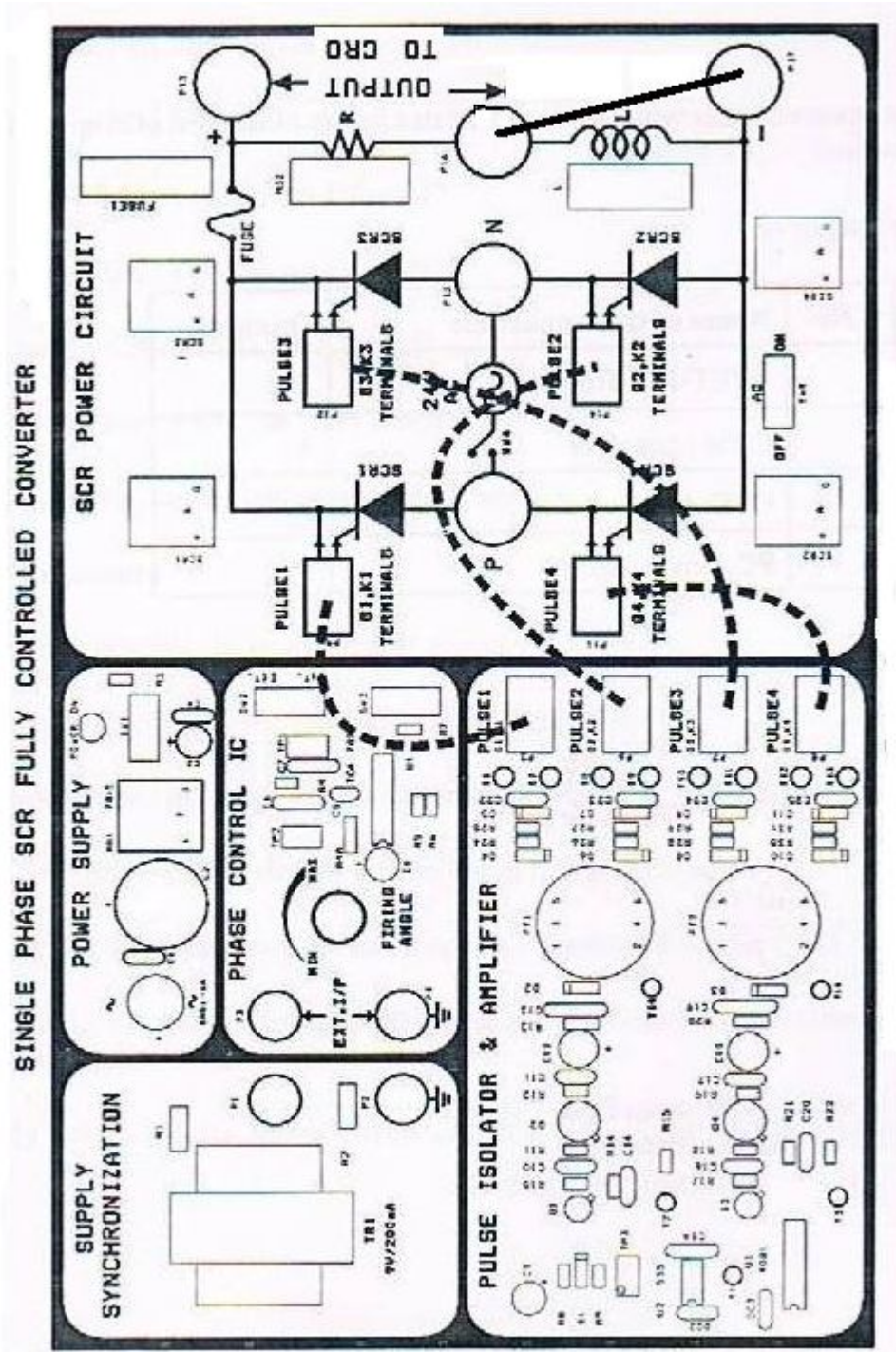


Fig.6. Front panel diagram of bridge converter module for R-load.

Mode 2: Operation with resistive and inductive loads

Bridge rectifier operated with resistive and inductive loads is shown in Fig.7. Working principle is same as explained in mode1 except that during positive half cycle of AC input voltage SCR1 and SCR2 will continue to conduct beyond $\omega t = \pi$ due to inductive load even though the supply voltage reverse its polarity in the negative half cycle. Due to this, the load current will reach zero only at $\pi + \beta$ where β is known as extinction angle. SCR1 and SCR2 turn OFF by current commutation. Similarly during negative half cycle of AC input voltage, SCR3 and SCR4 will continue to conduct beyond $\omega t = 2\pi$ due to inductive load even though the supply voltage reverse its polarity in the positive half cycle. The load current will reach zero only at $2\pi + \beta$. SCR3 and SCR4 turns OFF by current commutation as before. Hence, the cycles repeat. The waveforms of load current, load voltage and gating pulses are shown in Fig.8. The front panel connection diagram for mode 2 is shown in Fig.9 and the procedure is as follows:

PROCEDURE FOR MODE2

- (i) Give the connections as per Figs.7 and 9.
- (ii) Repeat the mode1 procedure from steps (ii) to (x).
- (iii) Calculate the extinction angle (β) from the waveform obtained.
- (iv) Comparison of the theoretical and practical values of V_o are tabulated in Table. 2.

Formula for obtaining average dc output voltage with resistive and inductive loads

$$\text{Average DC output voltage } V_o = \frac{\sqrt{2} * V_{in} * [\cos\alpha - \cos\beta]}{\pi}$$

where

$$V_{in} = \text{RMS value of AC input voltage} = 24 \text{ V.}$$

$$\alpha = \text{Firing angle in degrees } (0^\circ \text{ to } 180^\circ)$$

$$\beta = \text{Extinction angle in degrees } (0^\circ \text{ to } 180^\circ)$$

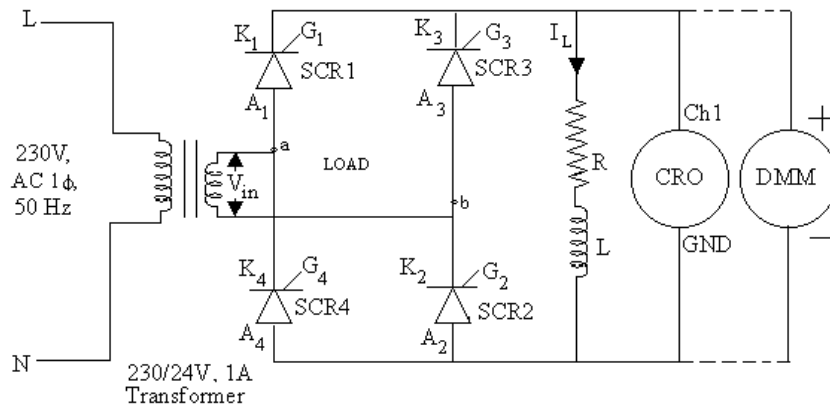


Fig.7. Circuit diagram of a single phase fully controlled bridge rectifier with R-L load.

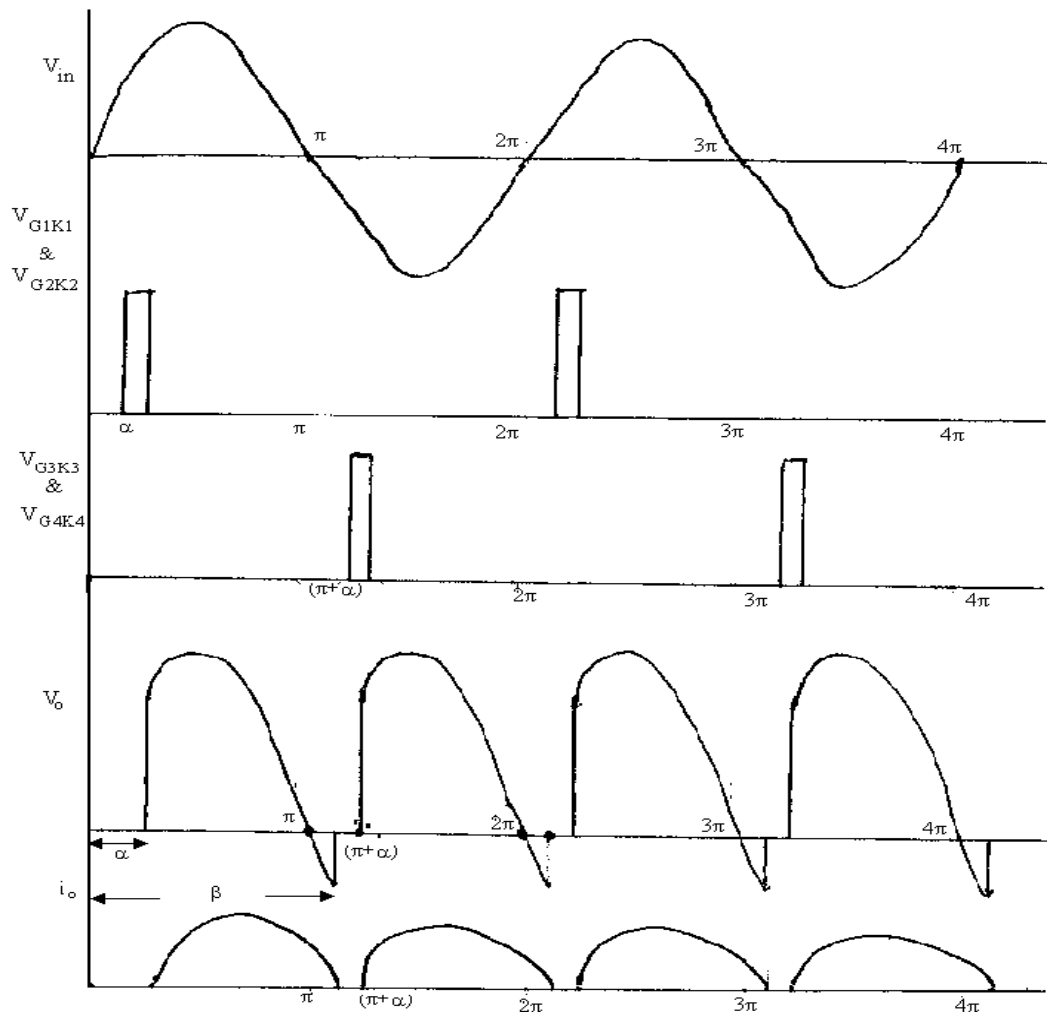


Fig.8. Waveforms of fully controlled bridge rectifier for R-L load.

P

SINGLE PHASE SCR FULLY CONTROLLED CONVERTER

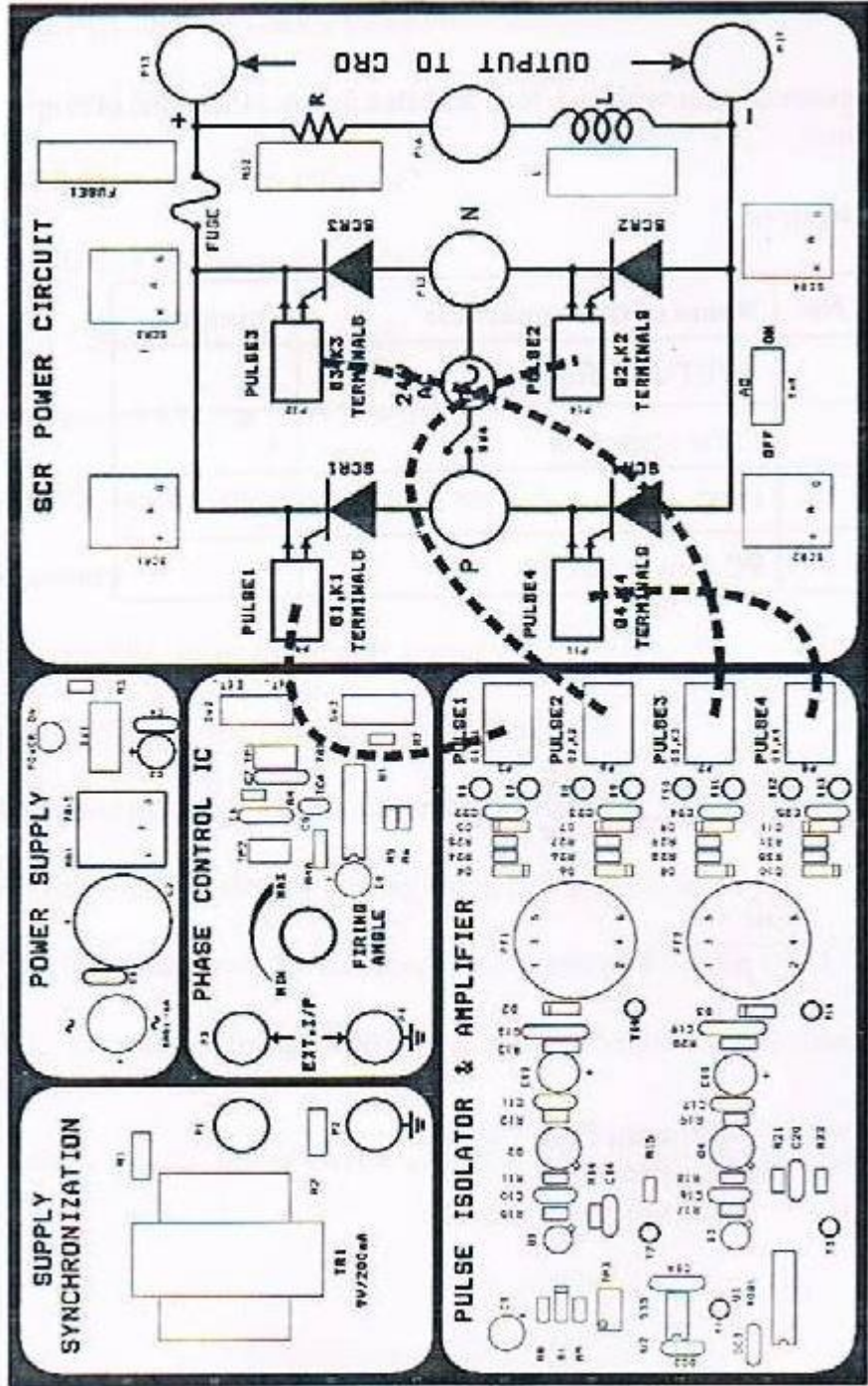


Fig.9. Front panel diagram of bridge converter module for R-L load.

Table2. Parameters obtained with resistive and inductive loads.

Sl. No.	Firing angle (α)		Extinction angle (β)		Calculated DC average output voltage V_o (V)	Measured DC average output voltage V_o (V)
	Divisions	Degrees	Divisions	Degrees		

RESULT

The characteristics of single phase fully controlled bridge rectifier was studied and the parameters were tabulated.

Ex.No.:
DATE:

SINGLE PHASE AC VOLTAGE CONTROLLER WITH R AND R-L LOAD

AIM

1. To study the principle of operation of single phase AC voltage controller.
2. To obtain the output voltage across R and R-L loads for various firing angles by conducting suitable experiment.

APPARATUS REQUIRED

1. Single phase AC voltage controller module.
2. DMM or AC Voltmeter (0-30V) MI.
3. CRO.

SPECIFICATIONS

SCR

- SCR = TYN612.
- Maximum anode to cathode voltage (V_{ak}) = 600V.
- Maximum anode current (I_a) = 12 A.
- Maximum gate to anode voltage (V_{ga}) = 18V.

Snubber circuit

- Snubber resistance - 500 Ω , 5 W.
- Snubber capacitance - 0.1 μ F, 1200V.

Load components

- Load resistance (R) = 225 Ω , 5 W
- Load inductance (L) = 48.5mH.

THEORY

AC voltage controllers are thyristor based devices, which converts fixed alternating voltage to variable alternating voltage without a change in the frequency. Some of the main applications of AC voltage controllers are domestic and industrial heating, transformer tap changing, lighting control and speed control of single phase and three phase ac drives and starting of induction motors. Earlier, the devices used for these applications were autotransformers, tap changing transformers, magnetic amplifiers, saturable reactors, etc. But these devices are now replaced by thyristor based ac voltage controllers because of their high efficiency, flexibility in control, compact size and less maintenance. AC voltage controllers are also adaptable for closed loop control systems.

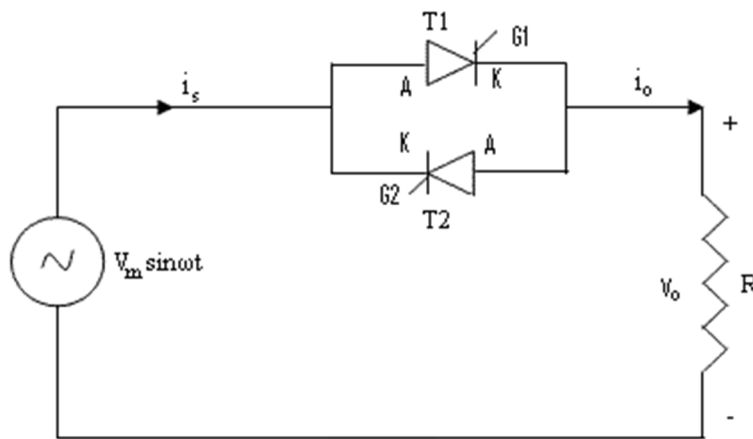


Fig.1. Circuit diagram of single phase AC voltage controller with R load.

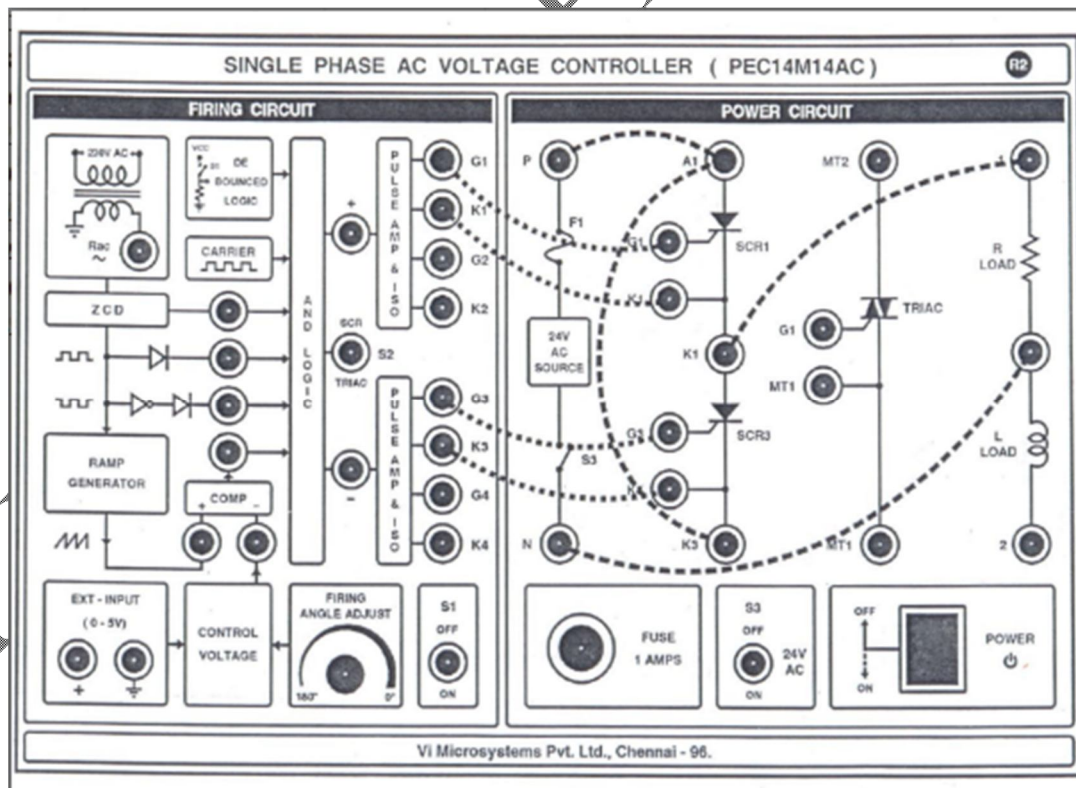


Fig.2. Connection diagram of single phase AC voltage controller module with R load.

Since the ac voltage is phase controlled devices, thyristors and triacs are line commutated and as such no complex commutation circuitry is required. The main disadvantage of ac voltage controllers is the introduction of objectionable harmonics in the supply current and load voltage waveforms, particularly at reduced output voltage levels.

There are two types of control normally used for AC voltage controllers namely

- 1) On-off control
- 2) Phase-angle control

In on-off control, thyristor switches connect the load to the AC source for few cycles of input voltage and disconnect it for another few cycles of input voltage. In phase control, thyristor switches connect the load to the AC source for a portion of each half cycle of input voltage. In this experiment, phase control method is used.

The AC voltage controllers can be classified into two types:

- 1) Single-phase controllers.
- 2) Three-phase controllers.

The objective of this experiment is to study the principle of single phase AC voltage controller and to obtain the output voltage for R and R-L loads with various firing angles. The single-phase AC voltage controller with R load in which, the thyristors are connected in anti-parallel fashion is shown in Fig.1. If an anti-parallel combination of thyristors is connected between AC supply and load, the power flow to the load can be controlled by varying the firing angle of SCRs and hence, the RMS value of AC voltage to the load is changed.

(i) Operation of single-phase AC voltage controller with R load

The operation of single phase AC voltage controller with R load is explained by referring Fig.1. Thyristors T1 and T2 are forward biased during positive and negative half cycles of the input sine signals, respectively. During positive half cycle, T1 is triggered at a firing angle of value α and hence it starts conducting. The source voltage appears across the load for the value of ωt from α to π . At π , both load voltage V_o and load current i_o falls to zero and after π , T1 is subjected to reverse bias, it is therefore commutated. During negative half cycle, T2 is triggered at $(\pi + \alpha)$ and it starts conducting from $(\pi + \alpha)$ to 2π . Soon after 2π , T2 is subjected to reverse bias, it is therefore commutated. This cycle repeats. By changing the firing angle α , the duration of conduction of each SCR can be varied thereby varying the load voltage. Each conducting SCR turns-off by natural commutation at the end of each half cycle due to resistive load.

Connection diagram of single phase AC voltage controller module with R load is shown in Fig. 2. The theoretical waveforms of input voltage (v_s), output voltage (V_o), gate currents (i_{g1} and i_{g2}) and device voltages (v_{T1} and v_{T2}) of the single phase AC voltage controller with 'R' load are shown in Fig.3.

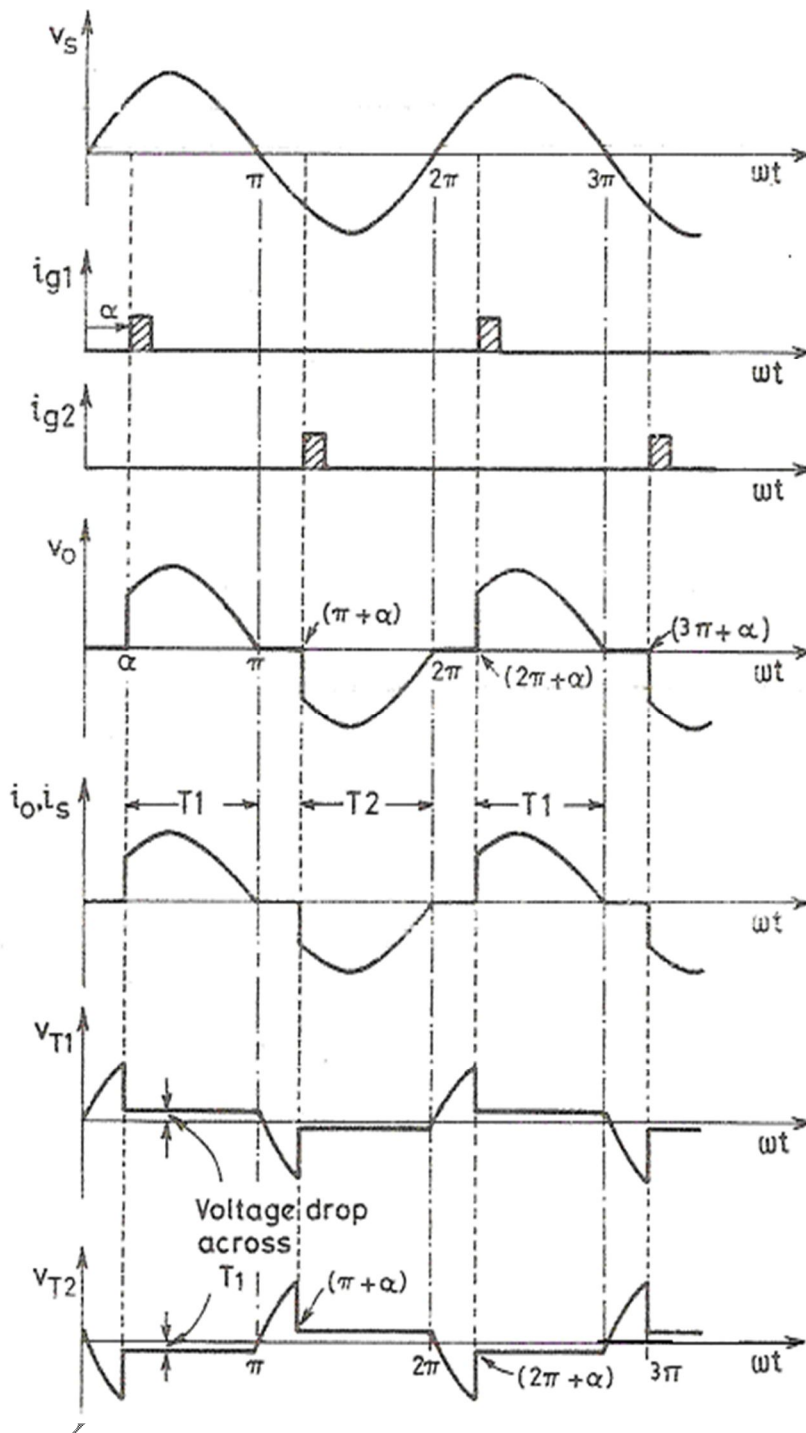


Fig.3. Waveforms of single phase AC voltage controller with R load.

(ii) Operation of single-phase AC voltage controller with R – L load

The operation of single phase AC voltage controller with R-L load is explained by referring Fig.4. Thyristor T1 is fired during the positive half cycle and carries the load current. Due to the inductance in the circuit, the current of thyristor T1 would not fall to zero at $\omega t = \pi$, when the input voltage starts to be negative. Thyristor T1 continues to conduct until its current falls to zero at $\omega t = \beta$. The conduction angle of thyristor T1 is

given by

$$\gamma = \beta - \alpha$$

where the angle β is known as extinction angle.

Connection diagram of single phase AC voltage controller module with R-L load is shown in Fig.5. The theoretical waveforms of input voltage (v_s), output voltage (V_o), gate currents (i_{g1} and i_{g2}) and device voltages (v_{T1} and v_{T2}) of the single phase AC voltage controller with R-L load are shown in Fig.6.

FORMULAE USED

For R load

$$v_{o,RMS} = v_s \left[\frac{1}{\pi} \left\{ (\pi - \alpha) + \left(\frac{\sin(2\alpha)}{2} \right) \right\} \right]^{\frac{1}{2}} \quad (1)$$

For R-L load

$$v_{o,RMS} = v_s \left[\frac{1}{\pi} \left\{ (\beta - \alpha) + \left(\frac{1}{2} \sin 2\alpha \right) - \left(\frac{1}{2} \sin 2\beta \right) \right\} \right]^{\frac{1}{2}} \quad (2)$$

where

V_s = Input RMS voltage (V)

α = Triggering angle (rad)

β = Extinction angle (rad)

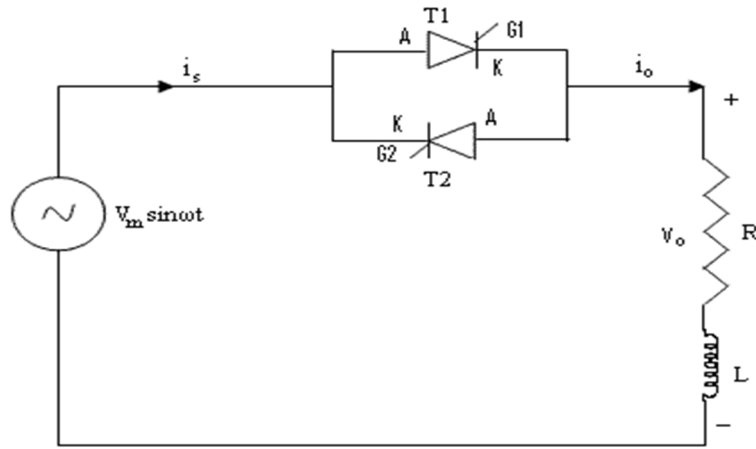


Fig.4. Circuit diagram of single phase AC voltage controller with R-L load.

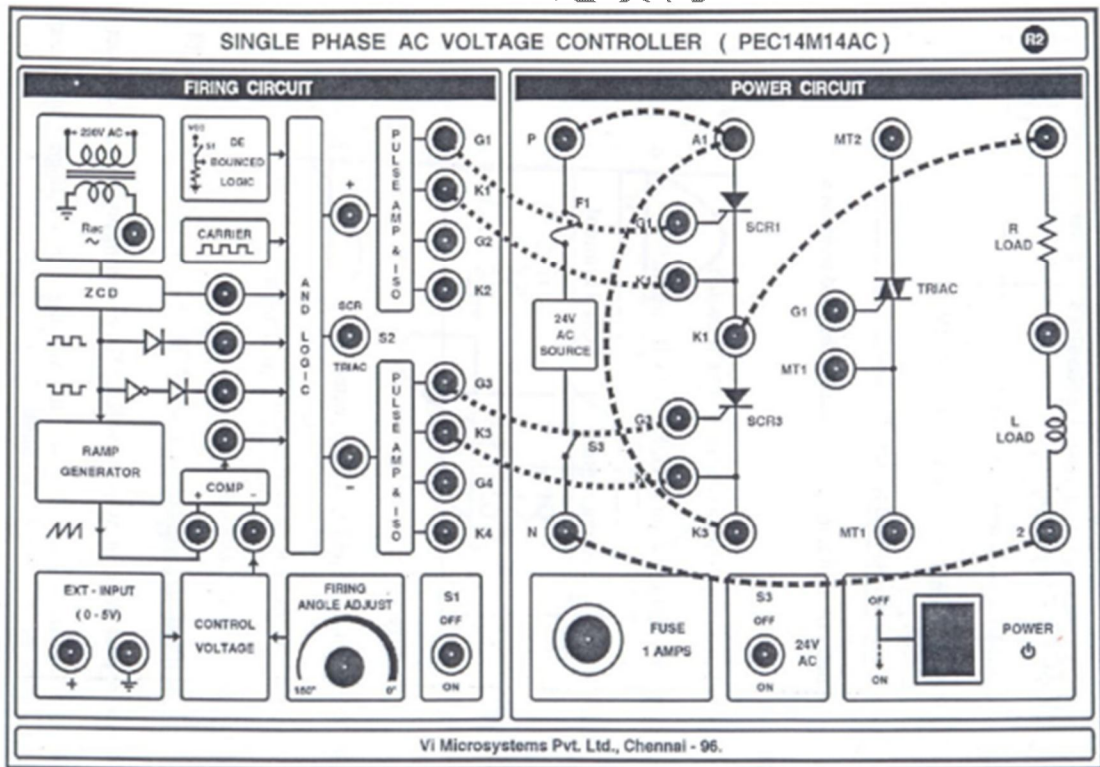


Fig.5. Connection diagram of single phase AC voltage controller module with R-L load.

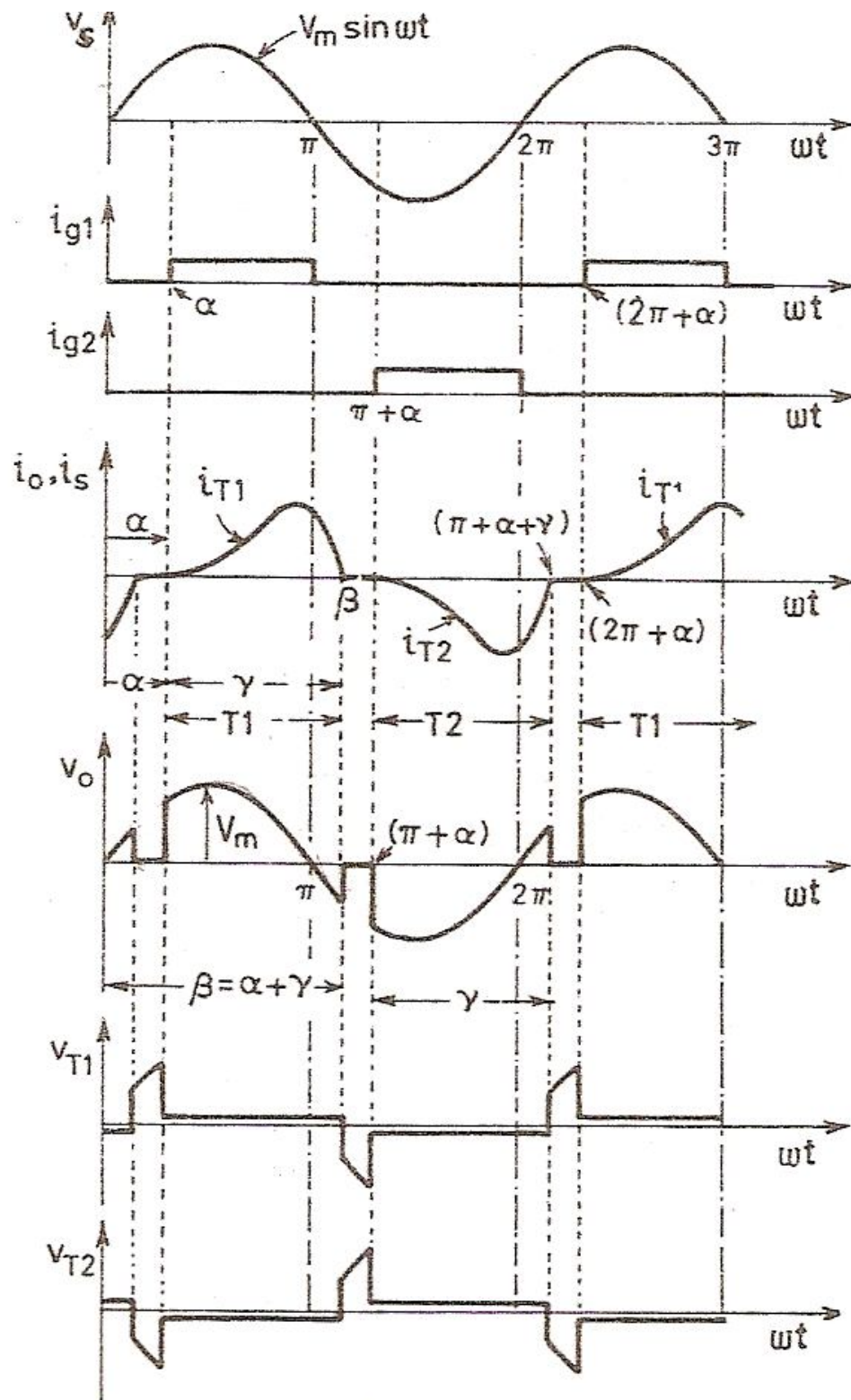


Fig.6. Waveforms of single phase AC voltage controller with R-L load.

Table 1. Experimental results for R load

Sl. No.	Firing angle (α)			Theoretical output voltage $V_{o,RMS}$ (V)	Practical output voltage $V_{o,RMS}$ (V)
	Div.	Deg.	Rad.		
1					
2					
3					
4					
5					
6					

Table 2. Experimental results for R-L load

Sl. No.	Firing angle (α)			Extinction angle (β)			Theoretical output voltage $V_{o,RMS}$ (V)	Practical output voltage $V_{o,RMS}$ (V)
	Div.	Deg.	Rad.	Div.	Deg.	Rad.		
1								
2								
3								
4								
5								
6								

PRECAUTION

Before giving connections, ensure all the switches are in OFF position.

PROCEDURE

- 1) Turn ON the trainer module.
- 2) Turn ON the 24V AC supply.
- 3) Switch ON the debounce logic switch.
- 4) Vary the control voltage knob to fix the firing angle α , from 0 to 180° (π rad) in steps of 30° .
- 5) For each α value, note down the output voltage for R load and tabulate the values in Table 1. Also trace the output waveforms for each firing angle.
- 6) For each α value, note down the output voltage and extinction angle (β) for R-L load and tabulate the values in Table 2. Also trace the output waveforms for each firing angle.
- 7) Compare the measured output voltage with the theoretically calculated output voltage as given in equations (1) and (2).

RESULT

Thus, the operation of single phase AC voltage controller was studied and the output voltage for R and R-L loads with different firing angles were obtained.

Ex.No.:
DATE:

SIMULATION OF SINGLE QUADRANT DC CHOPPER AND SINGLE PHASE AC VOLTAGE CONTROLLER USING ORCAD SOFTWARE

AIM

1. To simulate the circuit diagram of single quadrant step down DC chopper and single phase AC voltage controller with 'R' load using ORCAD software and to obtain their load voltage .

APPARATUS REQUIRED

PC loaded with ORCAD software.

THEORY FOR SINGLE QUADRANT STEP-DOWN DC-DC CHOPPER

DC chopper which converts, the fixed dc input voltage into pulsating dc output voltage. The circuit configuration of a chopper can be designed either to step down or to step up the input voltage level. In this experiment, the operation of step down chopper circuit is studied. The step down chopper is one which gives an output voltage less than or equal to the input voltage and the two modes of operations are explained as below:

TWO MODES OF OPERATION OF STEP DOWN CHOPPER

Mode 1: $0 \leq t \leq T_{ON}$

When the switch (S) is ON as shown in Fig.1, the device voltage V_d (drop across the switch) becomes zero and the load voltage $V_0 = V_{in}$. Hence $V_0 = V_{in} = I_0.R$.

Therefore the load current $I_0 = \frac{V_{in}}{R}$

Mode 2: $T_{ON} \leq t \leq T$

When the switch (S) is OFF as shown in Fig.2, the device voltage (V_d) becomes V_{in} and the output voltage $V_0 = 0$ and the load current $I_0 = 0$. Hence, the power dissipation in the switch (P_d) is zero.

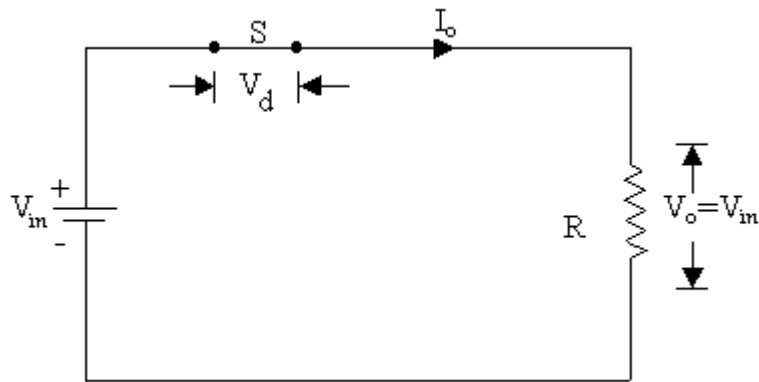


Fig.1. Circuit Diagram of chopper for Mode 1

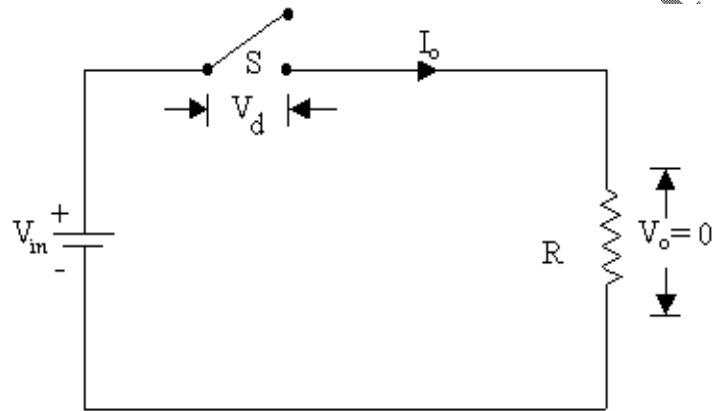


Fig.2. Circuit Diagram of chopper for Mode 2

Combining Mode 1 (M1) and Mode 2 (M2)

1. In mode M1, the switch S closes for T_{ON} seconds. During this period, the input voltage appears across the load.
2. In mode M2, the switch S opens for T_{OFF} seconds. For this period, the output voltage becomes zero.
3. The sum of T_{ON} and T_{OFF} is called chopping period, T and chopping frequency is equal to $\frac{1}{T}$.

STEP DOWN CHOPPER

Neglecting, the voltage drop across the switch, the average output voltage $V_{O,avg}$ is given by

$$V_{O,avg} = \frac{1}{\text{period}} \int_0^{\text{period}} V_O(t) dt \quad (1)$$

where $V_O(t) = V_{in}$; $0 \leq t < T_{ON}$ and

$$V_O(t) = 0 ; T_{ON} \leq t < T$$

$$\text{Period } T = T_{ON} + T_{OFF}$$

Therefore the equation (1) becomes

$$\begin{aligned} V_{O,avg} &= \frac{1}{T} \int_0^T V_O(t) dt \\ &= \frac{1}{T} \left[\int_0^{T_{ON}} V_O(t) dt + \int_{T_{ON}}^T V_O(t) dt \right] \\ &= \frac{1}{T} \left[\int_0^{T_{ON}} V_{in} dt + \int_{T_{ON}}^T 0 dt \right] \\ &= \frac{1}{T} [V_{in}] [t]_0^{T_{ON}} \\ &= \frac{V_{in}}{T} * T_{ON} \end{aligned}$$

$$V_{O,avg} = V_{in} * \frac{T_{ON}}{T} \quad (2)$$

where T = Chopping period and

$$\frac{T_{ON}}{T} = \text{Duty cycle ratio}$$

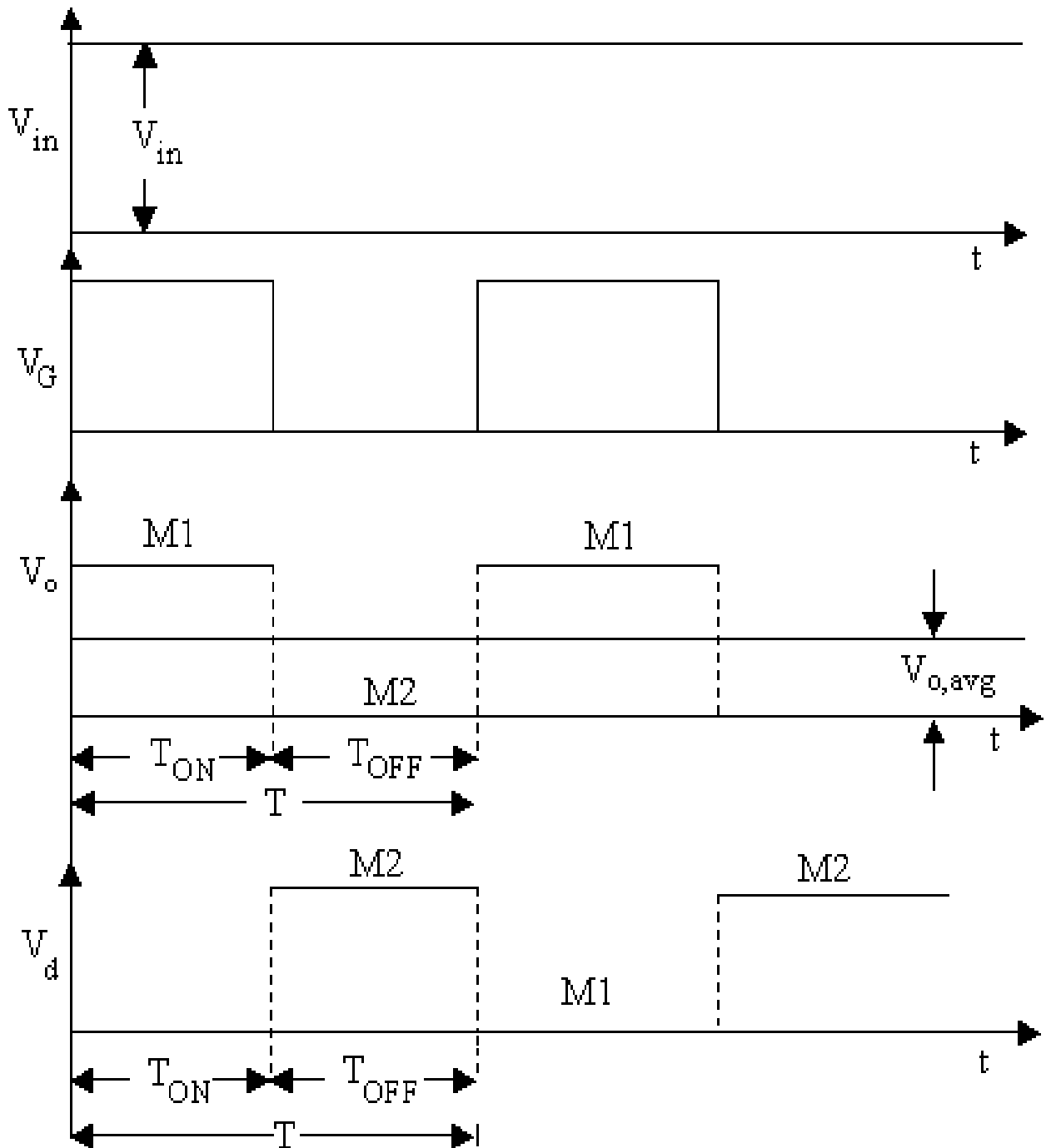


Fig.3. Waveforms of step down DC chopper.

From Eqn.2, it is clear that the average output voltage $V_{o,avg}$ depends on T_{ON} and T . It can be varied by varying either the chopping frequency (f) or by varying T_{ON} . Thus the power flow in the circuit can be controlled. In this experiment, MOSFET is used as a switch.

The model waveforms of input voltage V_{in} , the load voltage V_o , gating pulse V_G and the device voltage V_d are shown in Fig.3.

The schematic diagram of the step down DC chopper circuit drawn using ORCAD software is shown in Fig.4. The various blocks used for this circuit are listed below and the various parameters of the gating pulse are shown in Fig.5.

VARIOUS BLOCKS OF CHOPPER CIRCUIT SIMULATED IN ORCAD

V1 (Component name is VPULSE): This is the voltage pulse block to apply gating pulse with the required specifications of our interest. The following are the specifications of this block:

- V1 - Initial voltage of the pulse (0V)
- V2 - Final voltage of the pulse (10V)
- TD - Delay time (Firing angle of the pulse, here it is 0°)
- TR - Rise time (1n; m-milli, u-micro & n-nano)
- TF - Fall time (1n)
- PW - Pulse width in milli seconds (ON period of the pulse, $T_{ON} = 2m$)
- PER - Time period of the pulse (Time period of the pulse, $T = 20m$)

V2 (Component name is VDC): This is the DC voltage source block (5V).

R1 (Component name is R): This is the resistor block (1k; k-kilo, m-mega)

M1 (Component name is IRL150): This is the power MOSFET block

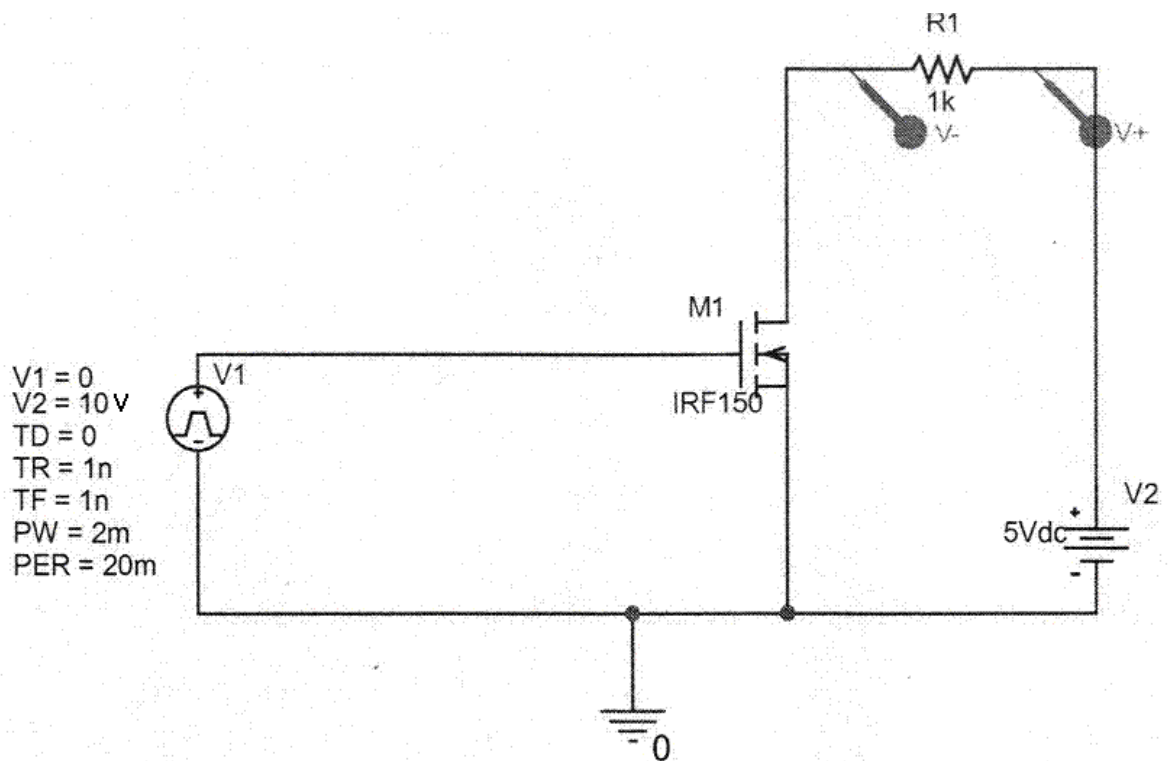


Fig.4. Simulated diagram of step down DC chopper using ORCAD software.

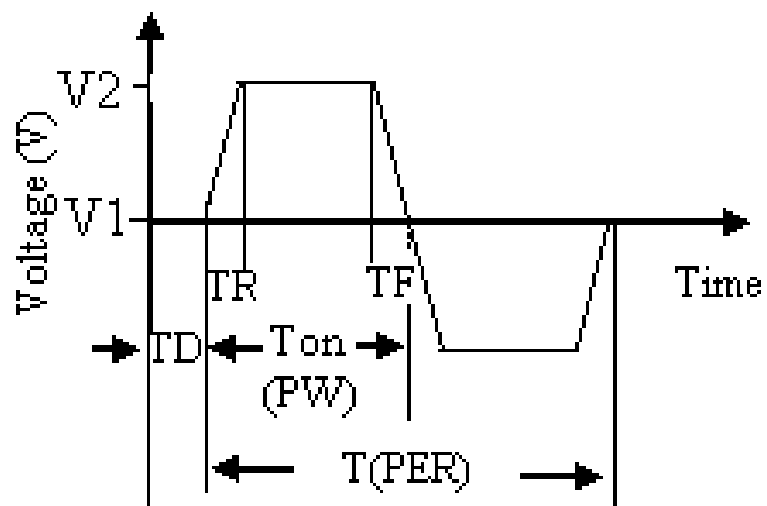


Fig.5. Parameters of gating pulse

SIMULATION PROCEDURE

1. Go to **Programs** in **Start menu**, select **Cadence License Manager** and minimize it.
2. Again go to **Programs** in **Start menu** and select **Orcad Family Release9 - Capture**.
3. Go to **File**; select **New – Project**, a window will appear. Here type your Filename and select **Analog or Mixed A/D**.
4. Another window will appear, in that select **Create Blank Project** and press Enter key to now Schematic Page is opened.
5. Select **Second icon** from the top of the right side screen or go to **Place** in Main menu bar and select **Part** in the pull-down menu or press **Shift+P** to select the components. For ground, select **Ninth icon** from the top of the right side screen and select **0/SOURCE**.
6. To change the parameters of the blocks, double click either the block or the parameters itself.
7. Select the necessary components from the components library and place those in the schematic page.
8. Select **Third icon** from the top of the right side screen or go to **Place** in Main menu bar and select **Wire** in the pull-down menu to wire the components.
9. To simulate the circuit, go to **PSpice** in **Main menu**, select **New Simulation profile**, give a filename and click **Create**.
10. A window will appear on which, enter the run-to-time usually 4 to 5 times the period.
11. Select the necessary Probes (current probe, voltage probe, differential voltage probe etc.) from the toolbar and place them in the required positions in the circuit.
12. Go to **PSpice** and select **Run**, to simulate the chopper circuit. Trace the output waveform as shown in Fig.6.

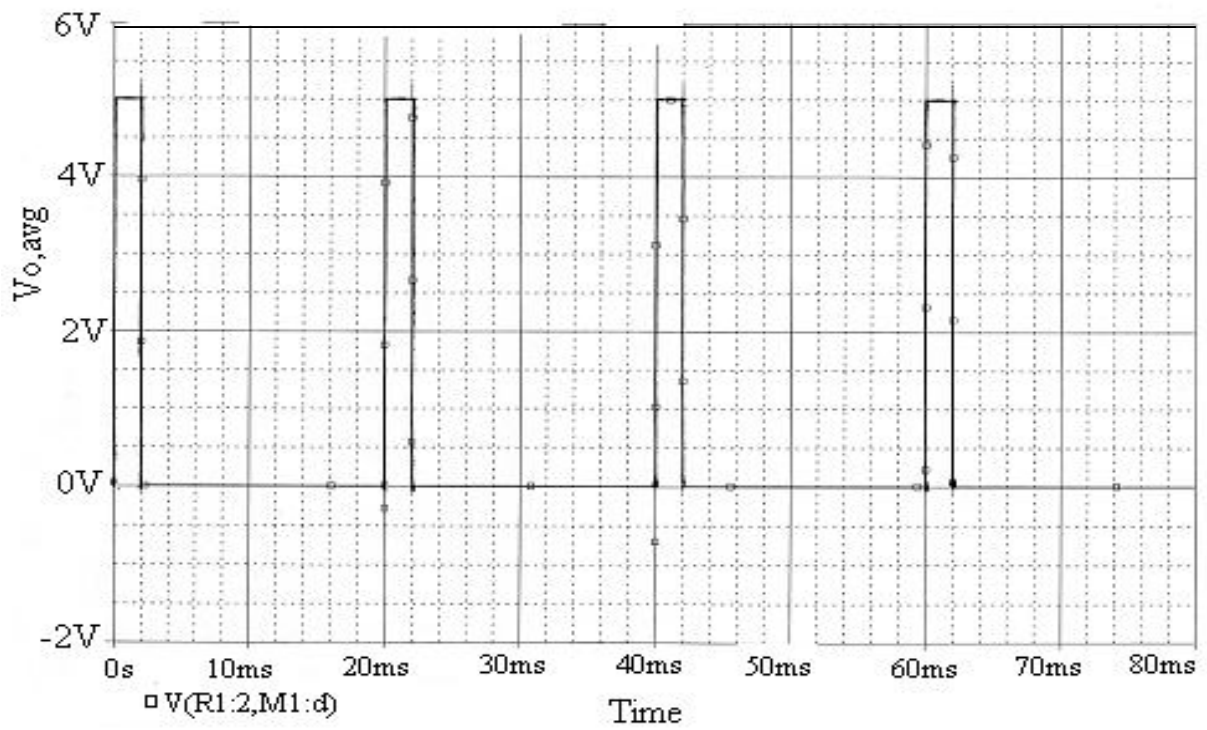


Fig.6. Simulated output response of the step down DC chopper using ORCAD software.

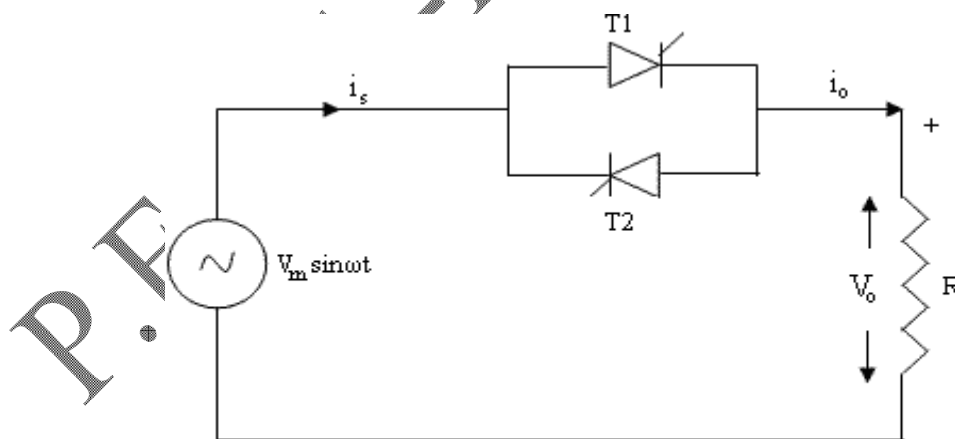


Fig.7. Circuit diagram single phase AC voltage controller with R load

EXPERIMENTAL PROCEDURE

By varying the parameters PW and PER of the VPULSE block in the circuit, the FFVTRC (Fixed Frequency Variable Time Ratio Control) and VFVTRC (Variable Frequency Variable Time Ratio Control) can be performed and the responses can be obtained as shown in Fig. 6 for various duty cycles.

CALCULATION OF 'PW' AND 'PER'

For FFVTRC, the time period (T) remains unchanged and the on time (T_{ON}) is changed i.e. $D = \frac{T_{ON}}{T}$. For VFVTRC, the time period (T) is changed and the on time (T_{ON}) remains unchanged i.e. $D = \frac{T_{ON}}{T}$. When the chopping frequency is 50Hz (FFVTRC) and the duty cycle is 10% as shown in Fig.6. The calculation of 'PER' and 'PW' is done as follows:

$$PER = T = \frac{1}{50\text{Hz}} = 20\text{ms}$$

$$PW = T_{on} = \frac{10}{100} 20\text{ms} = 2\text{ms}$$

THEORY FOR SINGLE PHASE AC VOLTAGE CONTROLLER

The single phase AC voltage controller is one, in which the thyristors are connected in anti-parallel fashion as shown in Fig.7. AC voltage controllers are thyristor based devices which convert fixed alternating voltage directly to variable alternating voltage without altering the frequency. If an anti-parallel combination of thyristors is connected between AC supply and load, the power flow to the load can be controlled by varying the firing angle of SCRs and hence the Root Mean Square value of AC voltage appeared across the load is changed.

FORMULA USED FOR 'R' LOAD

$$V_{o,RMS} = V_s \left[\frac{1}{\pi} \left\{ (\pi - \alpha) + \left(\frac{\sin(2\alpha)}{2} \right) \right\} \right]^{\frac{1}{2}} \quad (3)$$

where V_s = Input RMS voltage (V)
 α = Triggering angle in radians (0 to 2π) and
 β = Extinction angle in radians.

From Eqn.3, it is clear that the RMS output voltage $V_{o,RMS}$ depends on the firing angle of thyristors, T1 and T2. If the firing angle of the thyristor T1 is ' α ' radians, then the firing angle of the thyristor T2 is ' $\pi + \alpha$ ' radians always.

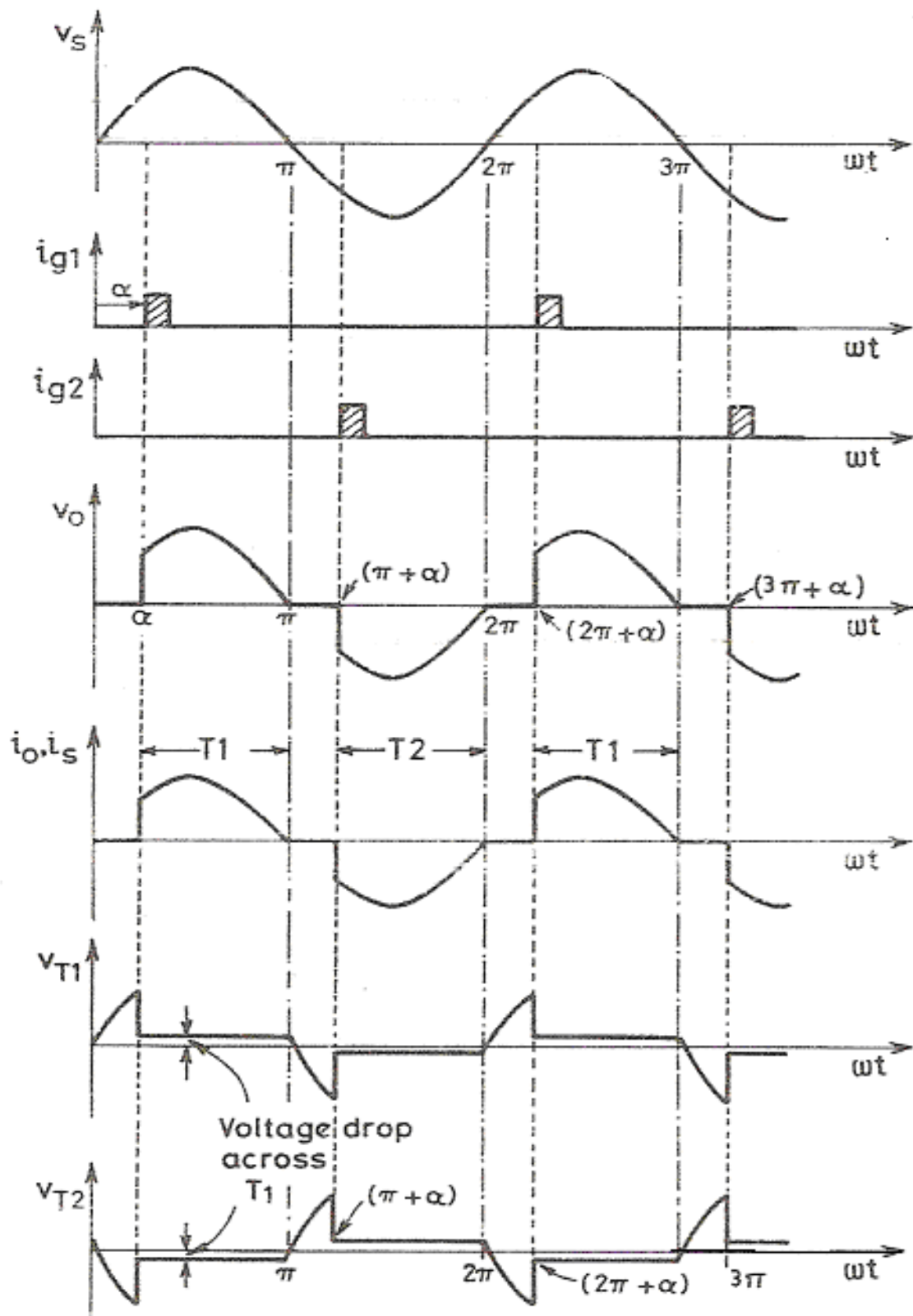


Fig.8. Waveforms of single phase AC voltage controller with 'R' load.

The model waveforms of input voltage V_s , the load voltage V_o , gating pulses i_{g1} and i_{g2} and the device voltages v_{T1} and v_{T2} are shown in Fig.8. The schematic diagram of the single-phase ac voltage controller drawn using ORCAD software is shown in Fig.9. The various blocks used for this circuit is listed below and the various parameters of the gating pulse are same as shown in Fig.5.

VARIOUS BLOCKS IN THE AC VOLTAGE CONTROLLER CIRCUIT SIMULATED IN ORCAD

V1 (Component name is VSIN) : This is the sinusoidal ac voltage source block (offset voltage, $V_{OFF} = 0V$, voltage amplitude, $V_{AMPL} = 24V$ and frequency, $FREQ = 50Hz$).

X1 (Component name is 2N1595) : This is the thyristor, T1.

X2 (Component name is 2N1595) : This is the thyristor, T2.

V2 (Component name is VPULSE): This is the voltage pulse block to apply gating pulse for the thyristor, T1 with the required specifications of our interest. The following are the specifications of this block:

- V1 - Initial voltage of the pulse (0V)
- V2 - Final voltage of the pulse (10V)
- TD - Delay time (Firing angle of the pulse, $\alpha = 90^\circ$ i.e. 5ms)
- TR - Rise time (1n; m-milli, u-micro & n-nano)
- TF - Fall time (1n)
- PW - Pulse width (ON period of the pulse, $T_{ON} = 1m$)
- PER - Time period of the pulse (Time period of the pulse, $T=20m$)

V3 (Component name is VPULSE): This is the voltage pulse block to apply gating pulse for the thyristor, T2 with the required specifications of our interest. The following are the specifications of this block,

- V1 - Initial voltage of the pulse (0V)
- V2 - Final voltage of the pulse (10V)
- TD - Delay time (Firing angle of the pulse, $\pi + \alpha = 270^\circ$ i.e. 15ms)
- TR - Rise time (1n; m-milli, u-micro & n-nano)
- TF - Fall time (1n)
- PW - Pulse width (ON period of the pulse, $T_{ON} = 1m$)
- PER - Time period of the pulse (Time period of the pulse, $2\pi = T = 20m$)

R1 (Component name is R): This is the resistor block (1k; k-kilo, m-mega)

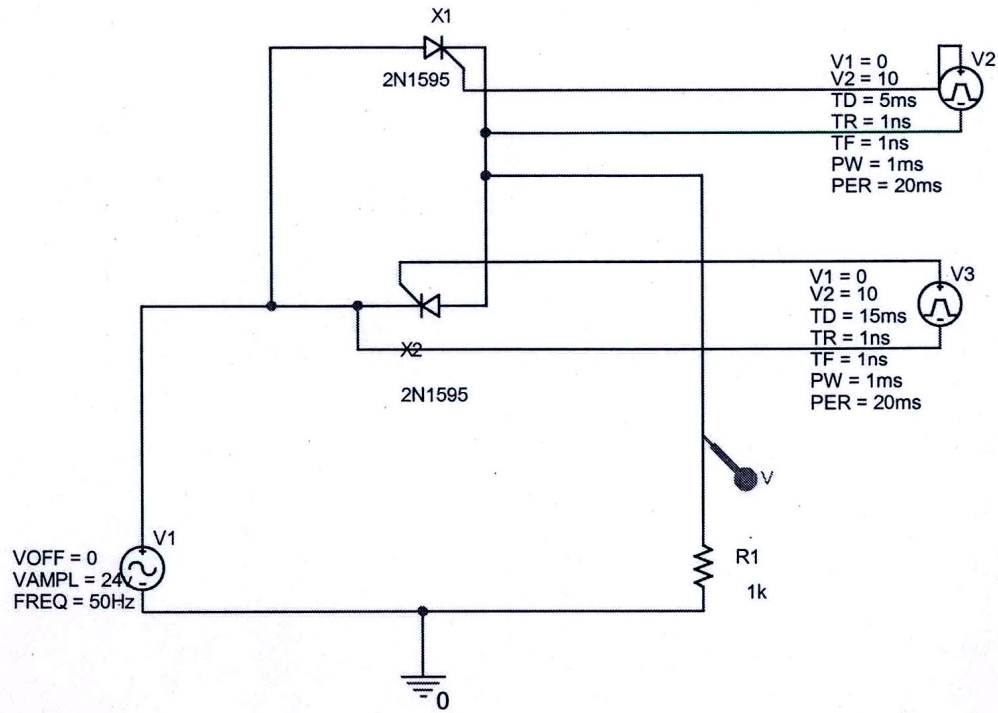


Fig.9 Simulated diagram of single phase AC voltage controller using ORCAD software.



Fig.10. Simulated response of single phase AC voltage controller using ORCAD software.

SIMULATION PROCEDURE

This is same as that of the procedure given for step-down DC-DC chopper from steps 1 to 12. After those steps are carried out, Go to **PSPICE** and select **Run** to simulate the circuit. Trace the output waveform of single-phase ac voltage controller as shown in Fig.10.

EXPERIMENTAL PROCEDURE

By varying the parameter TD of the VPULSE blocks V2 and V3 in the circuit, the output response can be obtained as shown in Fig.10 for various firing angles.

CALCULATION OF 'TD'

When the supply frequency is 50Hz and the firing angle is 90° as shown in Fig.10, the calculation of firing angle, TD is done as follows.

$$\text{The firing angle for thyristor T1 is, TD} = \frac{\left(\frac{1}{50\text{Hz}}\right)}{\left(\frac{360^\circ}{90^\circ}\right)} = 5\text{ms i.e. } \alpha = 5\text{ms.}$$

And hence, the firing angle for thyristor T2 is, TD = 15ms, i.e. $\pi + \alpha = 15\text{ms}$

RESULT

The operation of single quadrant step down DC-DC chopper and single phase AC voltage controller with 'R' load were simulated and waveforms were obtained.