POWER ELECTRONICS-LAB

PCC-EE-308-G

VI SEMESTER

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Bahal

Power Electronics Laboratory

Class Work: 25
Exam : 25
Total : 50

Course Code	PCC-EE-308		
Category	Engineering Science Course		
Course title	Power Electronics (Laboratory)		
Scheme	L	T	P
	-	-	2

Notes:

At least 10 experiments are to be performed by students in the semester. At least 7 experiments Should be performed from the list, remaining three experiments may either be performed from the above list or designed and set by the concerned institution as per the scope of the syllabus. Group of s Students for practical should be 15 to 20 in number.

List of Experiments

1. Static Characteristics of Power diode &Shottky diode and to study reverse recovery of Power Diode &Shottky diode.
2. Characteristics of IGBT & GTO
3. To study R, RC and UJT firing Circuit with Pulse transformer
4. To study of Firing Circuit based on ICs NE555, 7408 & 3140
5. To Study of Pulse transformer & optocoupler technique
6. To Study of SCR Communication Technique Class A-E.
7. Speed control of small motor using Single Phase Half wave & Full wave fully controlled Converter
8. Speed control of small motor using Single Phase Dual Converter (Continuous and discontinuous Control)
9. Study of Mc Murray - Bed ford Half & Full Bridge Inverter
10. To study Parallel Inverter to drive small AC Induction motor
11. Speed control of a small DC motor using MOSFET based Chopper with output voltage control technique
12. Speed control of small AC induction motor using Single Phase non circulating type bridge by

frequency conversion.

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2	Study of Mc Murray - Bed ford Half & Full Bridge Inverter	
3	To study Parallel Inverter to drive small AC Induction motor	
4	S.C.R Trigger Circuits (Triggering a SCR)	
5	To Study of SCR Communication Technique Class A-E.	
6	To study single phase dual converter (speed - direction control of dc motor)	
7	Single phase Half & Full Wave Converter (speed control of dc motor using converter)	
8	Single Phase Non – Circulating Bridge Cycloconverter (AC induction motor speed control)	
9	To study of firing circuit for thyritor circuits (based upon ICs 555, 3140 & 7408	

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PCC-EE-308 **POWER ELECTRONICS-LAB**

L T P
0 0 2

CLASS WORK :25 Marks
EXAMS : 25 Marks
TOTAL : 50 Marks
DURATION OF EXAM: 3 HRS

LIST OF EXPERIMENTS:

1. Static Characteristics of Power diode & Shottky diode and to study reverse recovery of Power Diode & Shottky diode.
2. Study of Mc Murray - Bed ford Half & Full Bridge Inverter
3. To study Parallel Inverter to drive small AC Induction motor
4. S.C.R Trigger Circuits (Triggering a SCR)
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7. Single phase Half & Full Wave Converter (speed control of dc motor using converter)
8. Single Phase Non – Circulating Bridge Cycloconverter (AC induction motor speed control)
9. To study of firing circuit for thyritor circuits (based upon ICs 555, 3140 & 7408

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EXPERIMENT NO.:-1

Aim:-study of static characteristic & reverse recovery of power & schottky diode

Theory :-A diode is a two terminal p - n junction device and normally formed by diffusion, point contact, alloying or epitaxial growth. The modern technology in diffusion and epitaxial process permit to achieve desired effect (characteristics). The diode characteristics : Generally modern diodes (power) are made of silicon wafers, which permit low forward potential (cut - in) and very high reverse breakdown voltage. When a diode's anode terminal is positive with respect to cathode, the diode is said in forward - bias mode (rectifying action). In such case it has a relatively small forward potential (called cut – in voltage) across it. The current in a forward - biased diode is due to the effect of majority and minority carriers. Once a diode is in forward – conduction mode it pass high current through it, and when its forward current is reduced to zero (by applying reverse voltage), the diode continuous to conduct due to minority carriers which remain stored in the (pn) junction and the bulk semiconductor material. The minority carrier require certain time to recombine with opposite charges and to be neutralized. This time is called as 'reverse recovery time' of diode. The reverse recovery time is denoted as 'trr' and measured from the initial zero crossing of diode current to 25% of peak value as 'ta' and to zero value as 'tb'. Thus from the plot the reverse recovery time trr = ta + tb.

Schottky diode : The charge storage problem of a p - n junction diode is minimized in schottky diode. It is accomplished by setting up a barrierpotential with a contact between a metal and semiconductor. The rectifying action (forward - biased) depends upon majority carriers only, and results is,that there are no excess minority carriers to recombine. The reverse recoverysloely depends upon inter - electrode (junction) capacitance.

Exp procedure

***a. To study of diode (rectifying ch) forward characteristics*.**

1. Connect the circuit as given in fig 1. Keep dc supply control at minimum.

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2. Switch on power.
3. Slowly increase the supply in small steps, and note corresponding voltage-current., as V_F and I_F.
4. From observations plot static characteristics upon graph paper. Observe the difference between two diodes. conclude the result : The schottky diodeshas low cut - in potential and offers low dynamic resistance.

b. To study of reverse recovery characteristics of (switching ch) diode.

Other app req : CRO and function generator.

1. Connect the circuit as shown in fig 3. The CRO must be dc coupled.
2. Adjust function gen frequency 40 ~ 60 KHz (50KHz ideal). Adjust input signal, square wave 10Vpp, trigger CRO with this signal.
3. Trace the input - output waveform. (Kept CRO time base in cal mode). If required expend CRO trace by given factor (x5 or x10 as printed upon CRO).
4. From trace measure the trr (reverse recovery time). conclude the result : The schottky diode has low cut - in potential, and negligible trr, where the power diodes has more cut - in potential and large trr in comparison ofschottky diode. The SD has faster response.

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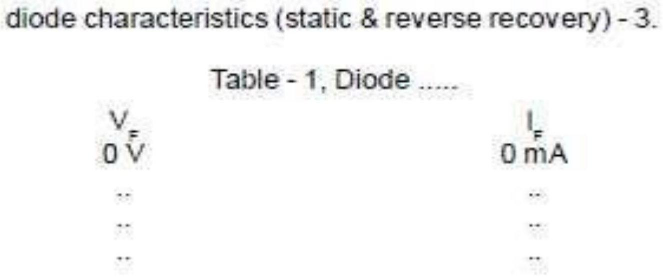
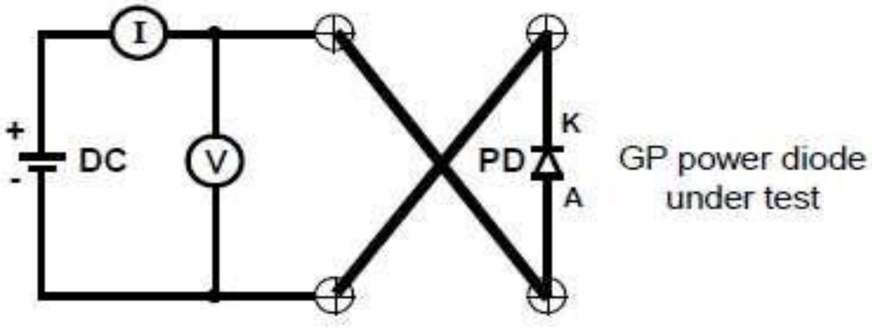
Circuit Diagram:-



diode characteristics (static & reverse recovery) - 3.

Table - 1, Diode .....

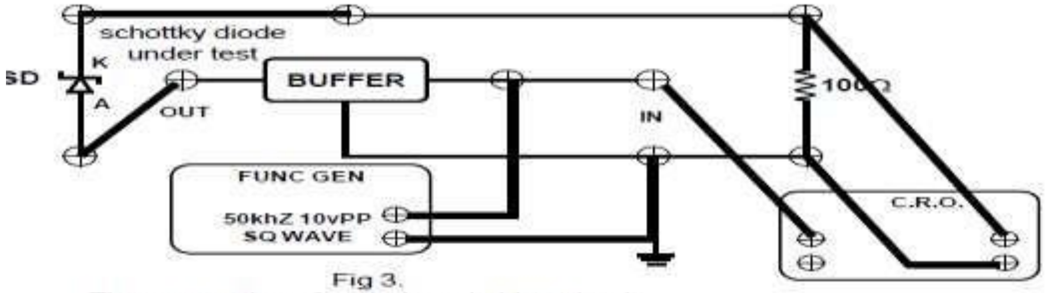
V_F	I_F
0 V	0 mA
..	..
..	..
..	..



The connections to study diode Static ch (rectifying action) circuit.

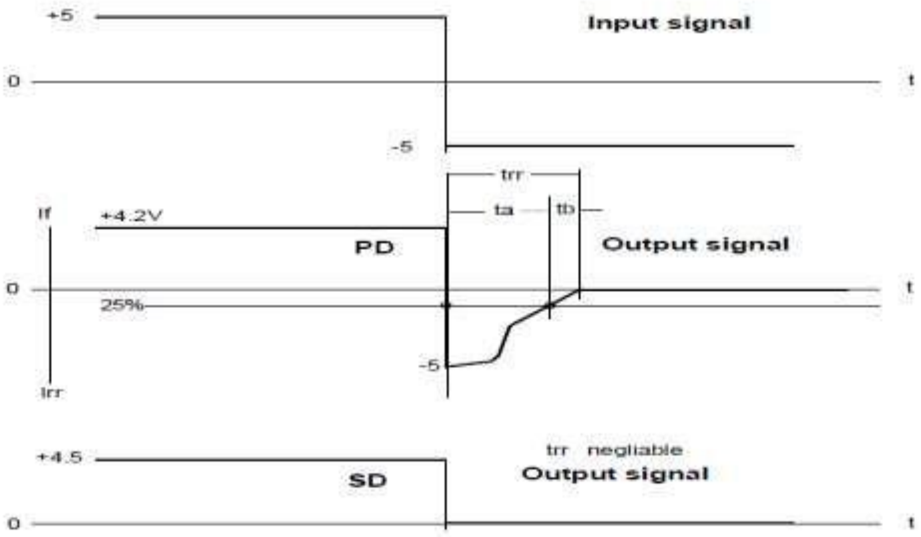
Note : PD is general purpose power diode & SD is schottky diode

diode characteristics (static & reverse recovery) - 4.



schottky diode under test
SD
K
A
OUT
BUFFER
IN
100Ω
FUNC GEN
50khZ 10vPP
SQ WAVE
C.R.O.

Fig 3.
The connections for diode switching circuit.



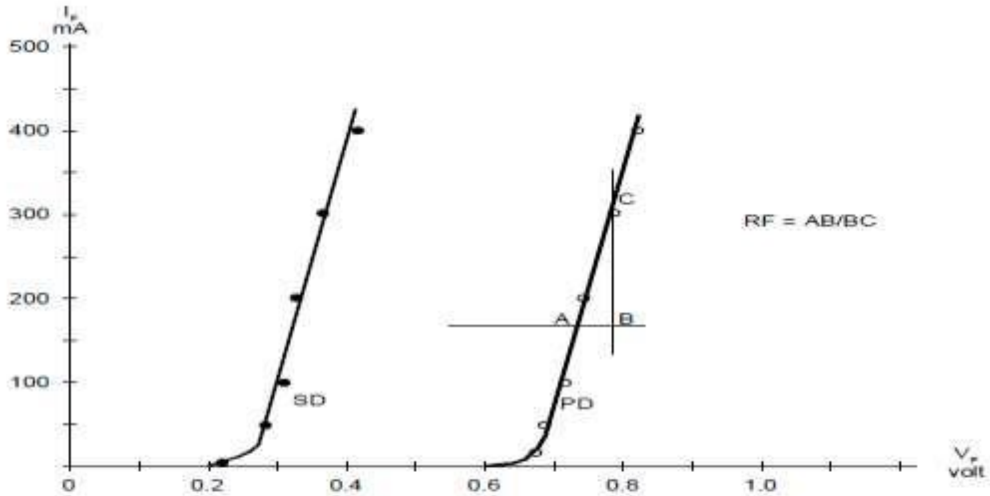


Fig 2.
Typical plot of PD and SD (forward - biased)

Result:-

EXPERIMENT NO.:-2

Aim:- MCMURRAY HALF/FULL BRIDGE INVERTER

Theory of the half bridge inverter circuit :- The inverter circuit is shown in fig 1. The CR1,2 constitute the main load carrying thyristors, while the CR1a,2a constitute the auxiliary thyristors for commutation purpose. The commutation circuitry is built around the L1 - C1 circuit . The working principle is detailed in modes (m). The dc power supply is E1,E2.

m1. The pulse output G1(4), cause to be gating CR1 on. the load current flows from E1,through CR1, RL. +ve part of output waveform shown fig 3(a)is produced here. The load current IL, flows from point P to S (fig 2a). The commutation capacitor C1 has initial charge, Vc = VRL.

m2. Now when pulse output high at G2a(3a), it cause to fire CR2a , while CR1 already in conduction. It cause to flow oscillatory charge current, Ioc, in commutation circuit and C1 charge to, Vc = +2E (approx) value. As the oscillatory current in L1 reverse in direction CR2a commutate (see waveform across L1, C1 in fig 3b & c) Macmurray half / full bridge inveter - 2.

m3. Going pulse G1a(4a) high, cause to trigger CR1a. C1 discharge through CR1, CR1a and L1. The commutation current IC, immediately commutate CR1, and Vc clipped by D1. Now the load current is carried by Vc, shown as decline part in fig 3a. As load current goes to zero CR1a commutate. During the period C charge to, Vc = -VRL with reverse polarity as shown in fig 3b. The capacitor plate at point P side is negative now. IL = 0.

m4. When pulse output G2(3), goes high cause to trigger CR2, through PT, load current flows from E2, RL, CR2 in direction S to P (fig 2d).

m5. Pulse G1a(4a), cause to trigger CR1a, and this bring to charge C1 to a potential equal to -2VRL. CR1a commutate when oscillatory current in L1 reversed.

m6. Going pulse G2a(3a) high, cause to trigger CR2a. C discharge through CR2, CR2a and L1. The commutation current immidiately commutate CR2, and Vc clipped by D2. Now the load current is carried by Vc, shown as part (e) in figure 3a. As load current goes to zero CR2a commutate. During the period C charge to, Vc = +VRL with polarity as shown in fig 3b. The capacitor plate at point P side is positive now. No load current through RL. This complete a cycle across RL. The output waveform is quasi square wave.

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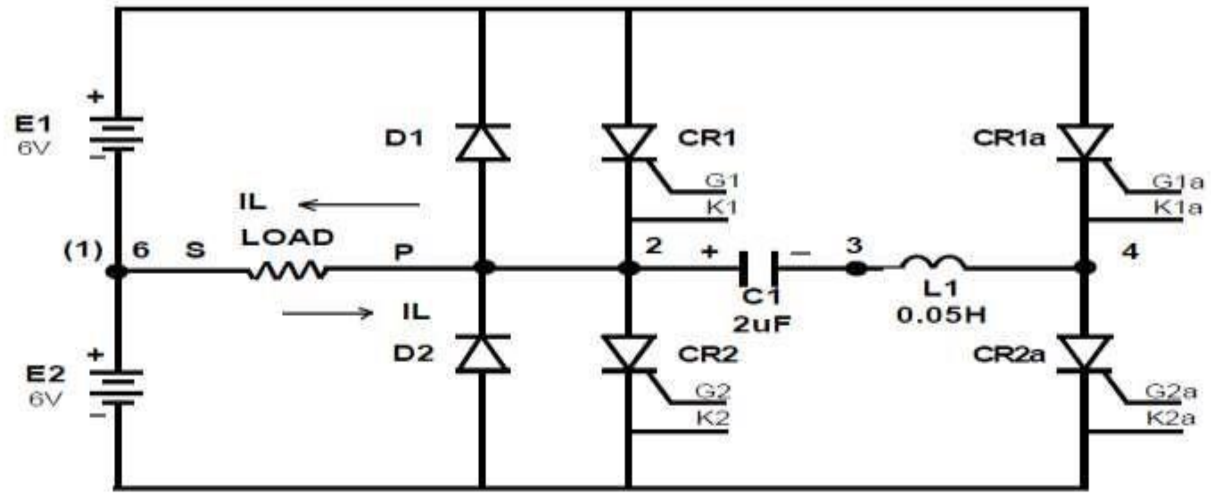
E1
6V
E2
6V
D1
D2
CR1
G1
K1
CR2
G2
K2
CR1a
G1a
K1a
CR2a
G2a
K2a
IL
LOAD
IL
(1)
6
S
P
2
3
4
C1
2uF
L1
0.05H
+
–

Fig 1. The Mcmurray half bridge inverter circuit.

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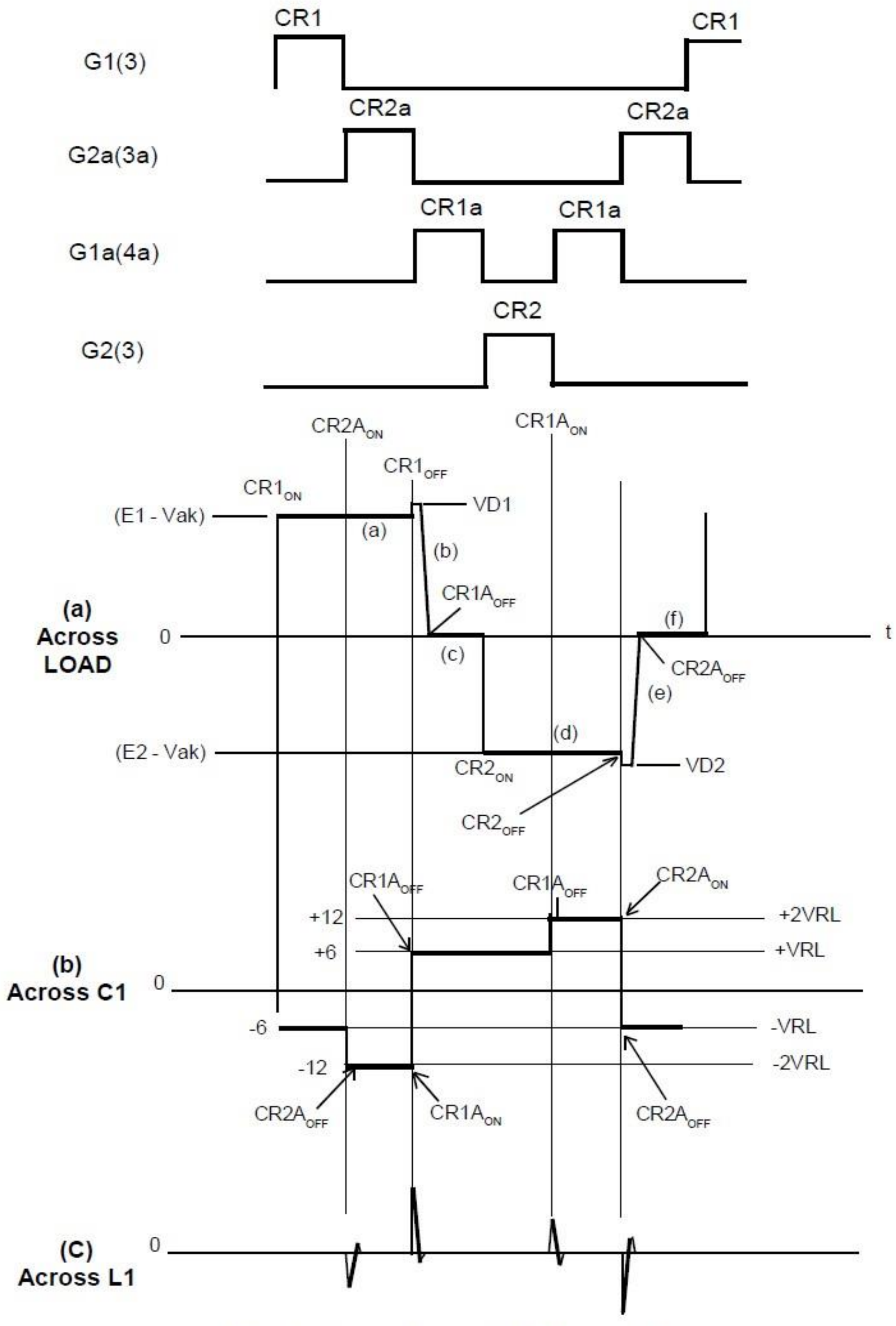
CR1
CR1
G1(3)
CR2a
CR2a
G2a(3a)
CR1a
CR1a
G1a(4a)
CR2
G2(3)
CR2A_ON
CR1A_ON
CR1_OFF
CR1_ON
VD1
(E1 - Vak)
(a)
(b)
CR1A_OFF
(a) Across LOAD
0
t
(f)
(c)
CR2A_OFF
(e)
(d)
(E2 - Vak)
CR2_ON
VD2
CR2_OFF
CR1A_OFF
CR1A_OFF
CR2A_ON
+12
+2VRL
+6
+VRL
(b) Across C1
0
-6
-VRL
-12
-2VRL
CR2A_OFF
CR1A_ON
CR2A_OFF
(C) Across L1
0

Fig 3. The waveforms of McMurray H.B. Inverter.

The full wave bridge inverter :-Its principle of operation is similar to half bridge mode, except this time RL is connected between the both half bridge outputs. The supply voltage is E = E1 + E2. Let its function described in m terms as previous.

m1. The pulse output G1(4), cause to be gating CR1 and CR4 on. the load current flows from E+,through CR1, RL, CR4, -VE. (U) part of output waveform shown fig 4(a)is produced here. The load current IL, flows from point 2 to 6 (fig 4). The commutation capacitors C1,C2 has initial charge, Vc = VRL as shown in fig 4b.

m2. Now when pulse output high at G2a(3a), it cause to fire CR2a,3a , while CR1 & 4, already in conduction. It cause to flow oscillatory charge current, Ioc, in both commutation circuits and C1,C2 charge to, Vc = +2E (approx) value. As the oscillatory current in L1,L2 reverse in direction CR2a,3a commutate (see waveform across C1,C2 in fig 4b)

m3. Going pulse G1a(4a) high, cause to trigger CR1a,4a. C1and C2 discharge through CR1, CR1a, L1 and CR4,4a,L2 respectively. The commutation current IC,immidiately commutate CR1,4, and Vc clipped by D1. Now the load current is carried by Vc, shown as decline part in fig 4a. As load current goes to zero CR1a,4a commutated. During the period C1,C2 charge to, Vc = -VRL & +VRL with reverse polarity as shown in fig 4b. The capacitor plate at point P side is negative now (refer to fig 2f. IL = 0).

m4. When pulse output G2(3), goes high cause to trigger CR2,3, the load current flows from E, RL, CR2,3 in reverse direction, -ve part shown in fig 4a.

m5. Pulse G1a(4a), cause to trigger CR1a,3a and this bring to charge C1,C2 to a potential equal to -2VRL. CR1a,4a commutate when oscillatory current in L1,L2 reversed. **m6**. Going pulse G2a(3a) high, cause to trigger CR2a,3a. C1,C2 discharge through CR2, CR2a, L1 and CR3, CR3a, L2 respectively. The commutation current immediately commutate CR2,CR3 and Vc clipped by D2. Now the load current is carried by Vc, shown as leading part in figure 4a waveform. As load current goes to zero CR2a,3a commutate. During the period C1,C2 charge to, Vc = +VRL, -VRL with polarity as shown in fig 4b. The capacitor plate at point (6) side is positive now. No load current through RL. This complete a cycle across RL. The output waveform is quasi square wave, with amplitude double then half bridge configuration.

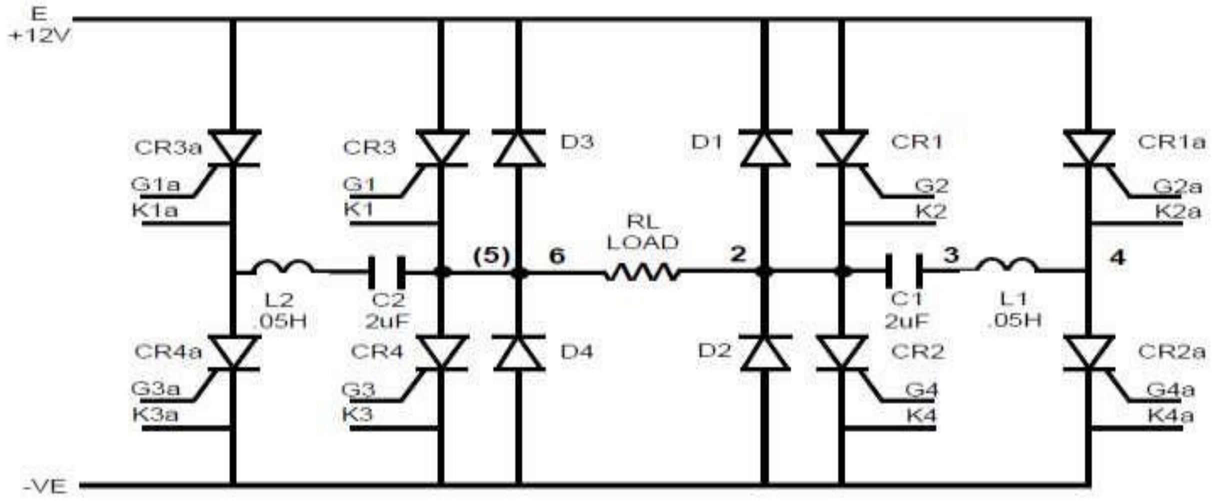

Fig 4. The MacMurray full bridge inverter circuit.

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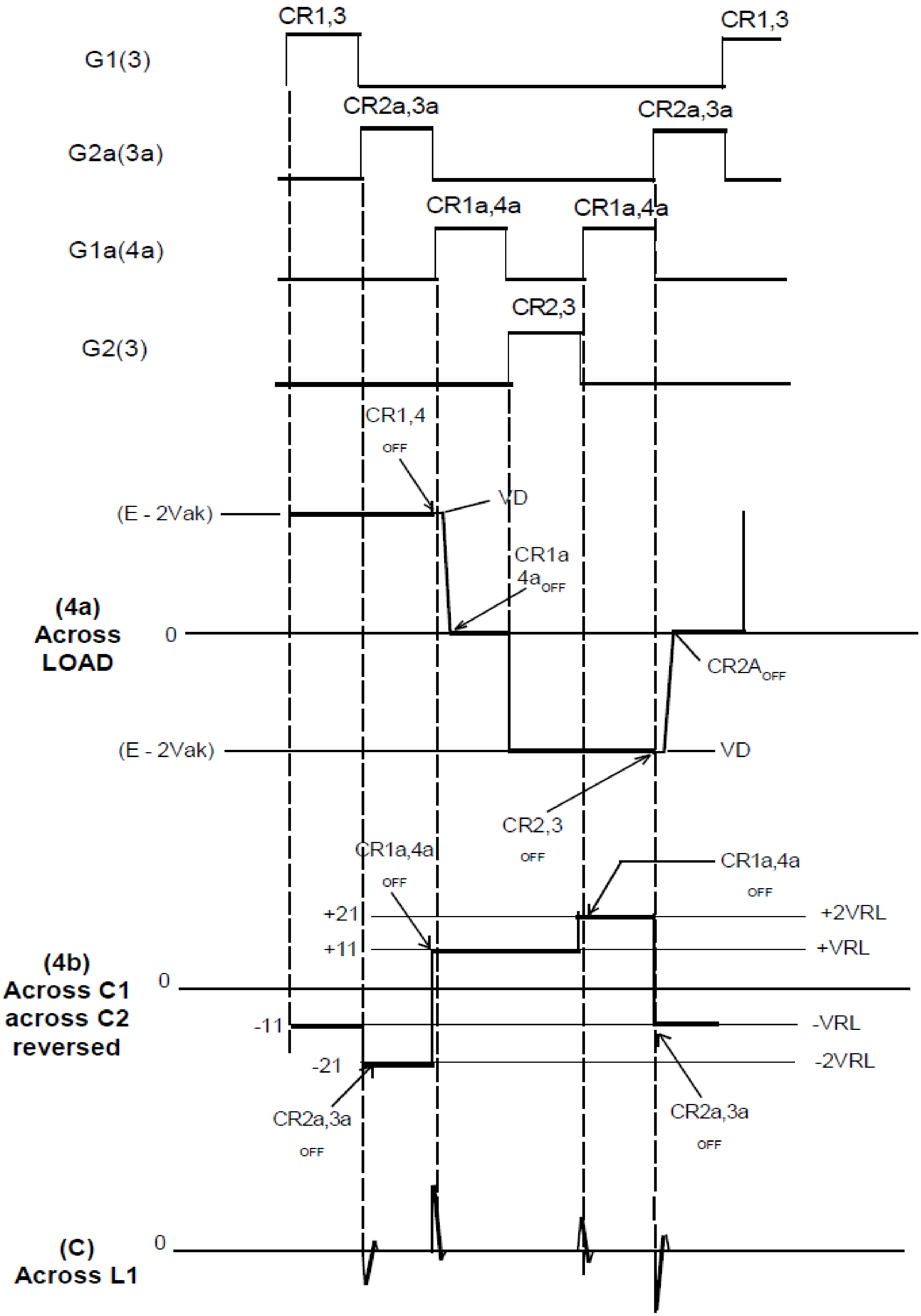
CR1,3
CR1,3
G1(3)
CR2a,3a
CR2a,3a
G2a(3a)
CR1a,4a
CR1a,4a
G1a(4a)
CR2,3
G2(3)
CR1,4
OFF
(E - 2Vak)
VD
CR1a
4a OFF
(4a)
Across
LOAD
0
CR2A OFF
(E - 2Vak)
VD
CR2,3
OFF
CR1a,4a
OFF
CR1a,4a
OFF
+21
+2VRL
+11
+VRL
(4b)
Across C1
across C2
reversed
0
-11
-VRL
-21
-2VRL
CR2a,3a
OFF
CR2a,3a
OFF
(C)
Across L1
0

The waveforms of McMurray F.B. Inverter.

Experiment procedure

Object 1: To study of Mcmurray half bridge inverter, (refer to fig 5)

Other app req : CRO.

1. Keep frequency control to maximum. Connect CRO ch A with the G1,(4) output and ground. Switch on power.
2. Adjust CRO time base to appear two ractangular waveforms upon screen. The waveform show the trigger pulse applied to CR1and (4).
3. Now connect CRO ch B with G2a(3a) output. Observe the pulse time appear just under trailing of G1(4) pulse (see fig 3 or 4a).
4. Connect CRO ch B, with given trigger signals and trace it upon paper to verify the trigger sequence of thyristors (see fig 3 or 4a for refrence).
5. Switch off power. Disconnect CRO ch B, from pulse amplifier circuit and connect it with inverter circuit across output (shown in dashed line).
6. Switch on power. Adjust frequency control to appear one cycle trace upon screen. Trace it upon paper with voltage magnitude as shown in fig 3.
7. Connect CRO ch B , across C1 (3 = + and 2 = gnd, +ve lead to L1 side) and trace the waveform with its magnitudes as shown in fig 3a.
8. Connect CRO ch B, with L1 (4 = +ve and 3 = gnd, +ve lead with CR1a cathode) and trace waveform (it look like spike). From the waveforms verify the Mcmurray half bridge operation.

Note : Only one channel of CRO should be connected with bridge ckt. In case of commutation failure switch off power for a minute.

Experiment procedure

Object 1: To study of Mcmurray full bridge inverter, (refer to fig 6)

Other app req : CRO.

1. Keep frequency control to maximum. Connect CRO ch A with the G1,4 output and ground. Switch on power.
2. Adjust CRO time base to appear two ractangular waveforms upon screen. The waveform show the trigger pulse applied to CR1and CR4.
3. Now connect CRO ch B with G2a,3a output. Observe the pulse time appear just under trailing of G1,4 pulse (see fig 3 or 4a).
4. Connect CRO ch B, with given trigger signals and trace it upon paper to verify the trigger sequence of thyristors (see fig 3 or 4a for refrence).
5. Switch off power. Disconnect CRO ch B, from pulse amplifier circuit and connect it with inverter circuit across output (shown in dashed line).
6. Switch on power. Adjust frequency control to appear one cycle trace upon screen. Trace it upon paper with voltage magnitude as shown in fig 4a.
7. Connect CRO ch B , across C1 (3 = + and 2 = gnd, +ve lead to L1 side) and trace the waveform with its magnitudes as shown in fig 3a.
8. Connect CRO ch B, with L1 (4 = +ve and 3 = gnd, +ve lead with CR1a cathode) and trace waveform (it look like spike). From the waveforms verify the Mcmurray full bridge operation.

Note : Only one channel of CRO should be connected with bridge ckt. In case of commutation failure switch off power for a minute.

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Connection Diagram:-

Fig 5.

Connections for half bridge configuration.

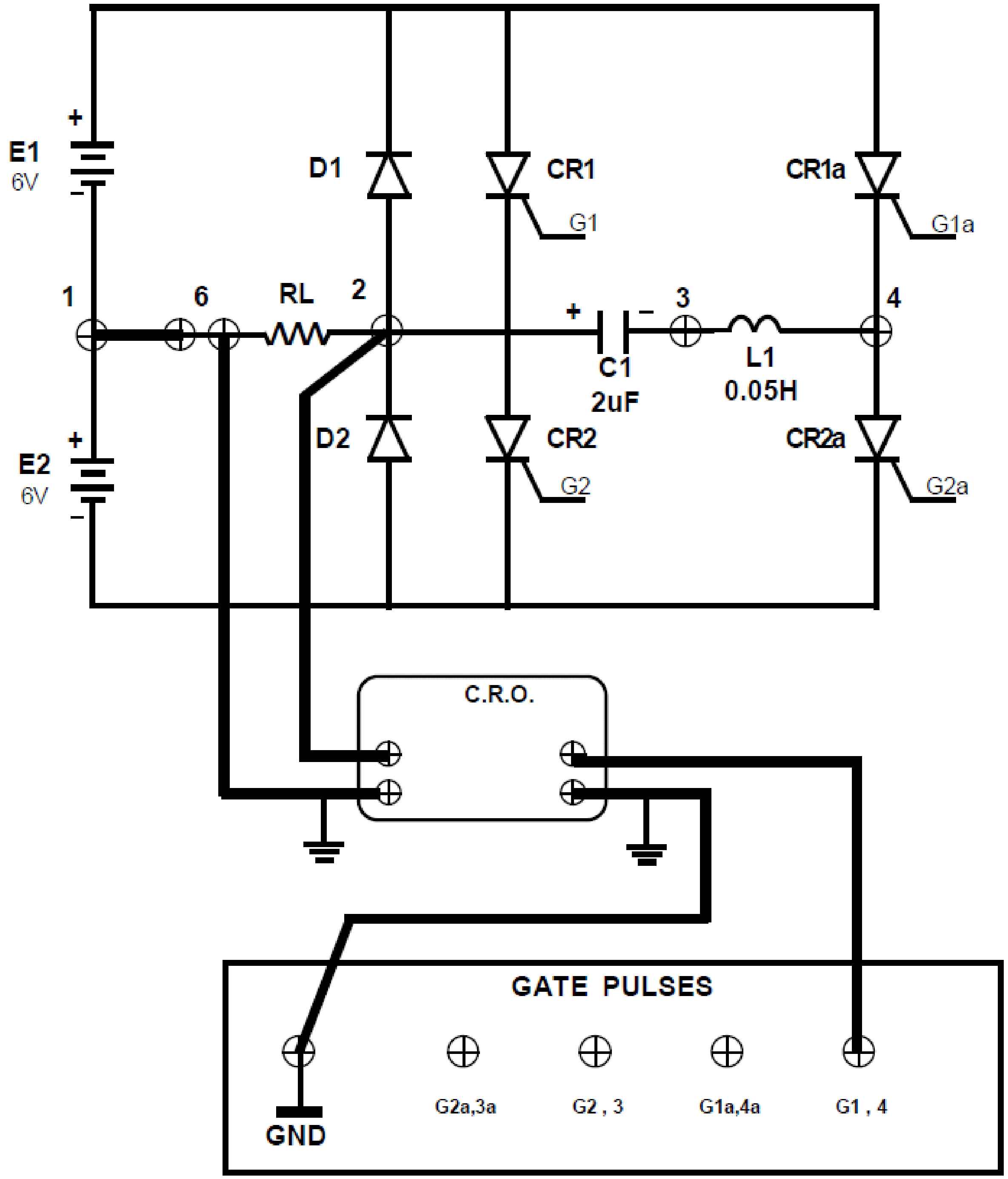
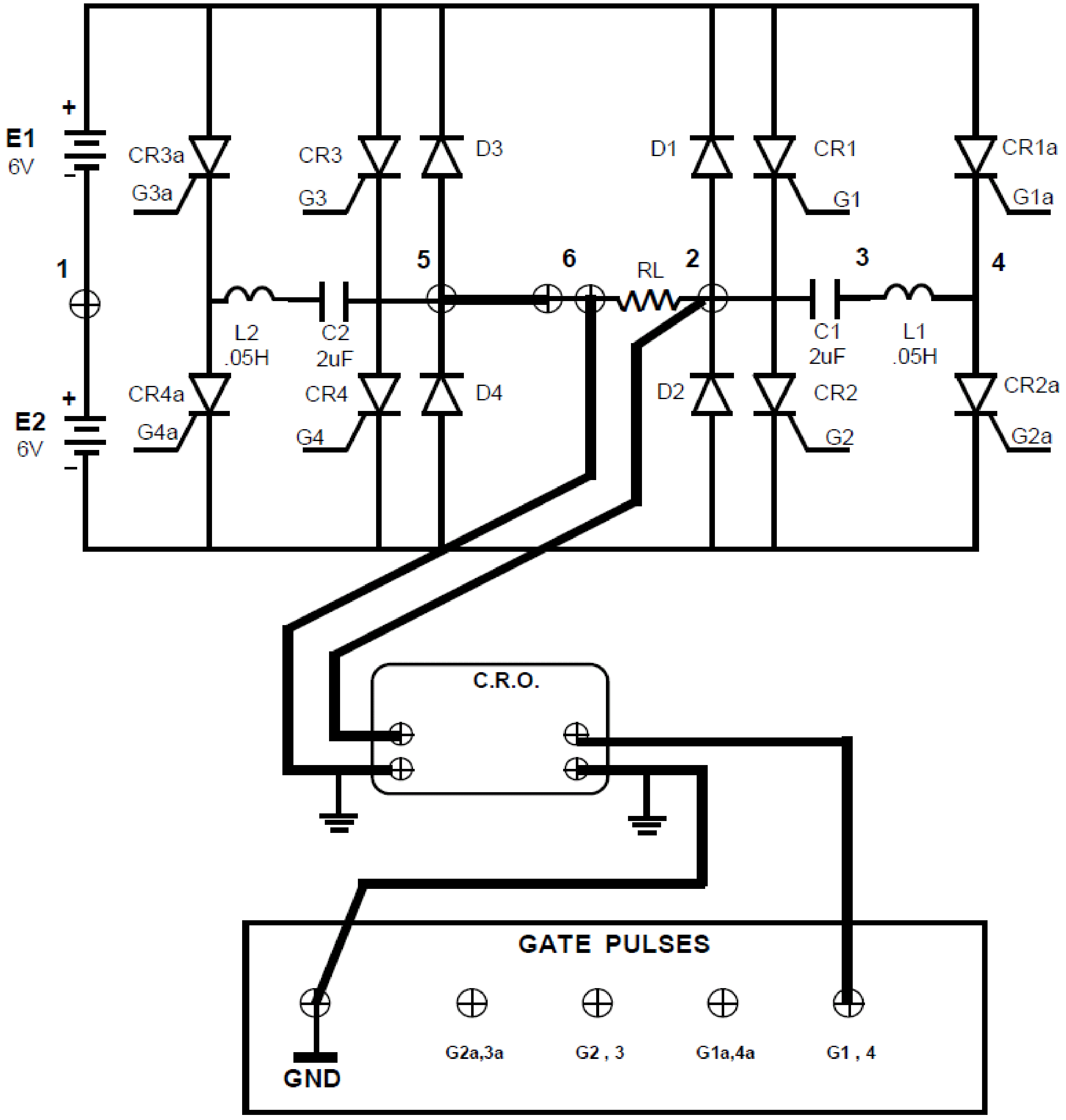

E1
6V
+
-
D1
CR1
G1
CR1a
G1a
1
6
RL
2
+
-
3
4
C1
2uF
L1
0.05H
D2
CR2
G2
CR2a
G2a
E2
6V
+
-
C.R.O.
GATE PULSES
GND
G2a,3a
G2 , 3
G1a,4a
G1 , 4

Fig 6.

Connections for full bridge configuration.


E1
6V
E2
6V
+
–
+
–
1
CR3a
G3a
CR4a
G4a
CR3
G3
CR4
G4
D3
D4
L2
.05H
C2
2uF
5
6
RL
2
3
4
D1
D2
CR1
G1
CR2
G2
C1
2uF
L1
.05H
CR1a
G1a
CR2a
G2a
C.R.O.
GATE PULSES
GND
G2a,3a
G2 , 3
G1a,4a
G1 , 4

Result:-

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EXPERIMENT NO.:-3

AIM :- TO STUDY PARALLEL INVERTER (study of inverter fed ac motor drive)

Theory:- The kit is designed to study SCR parallel inverter driven small ac induction motor. The kit consists inverter transformer, 2 SCRs, one inductor, one commutation capacitor, one small ac induction motor, trigger circuit with variable frequency .

Inverter circuit *:* In fig 1, the inverter circuit is shown. T1 is a power transformer having biflar wound primary and isolated secondary in step up ratio. SCR (cr) 1 and 2 is connected between the both ends of primary and –Ve supply rail. The tap of primary is connected with +Ve rail through an inductor L. A commutation capacitor C4, is connected across the both anode. Diodes D1,D2 and R5,C3 forms feedback circuit, which fed back, stored enrgy in primary of transformer T and C4 to +ve supply.

m1 : When pulse A, goes high at 1st instant, at t1, gate current supplied to CR1 via pulse differentiators ckt, compromising R1,C1 and R3. The +ve voltage at anode of CR1 becomes to Von (Vak = 1V approx) state. The dc voltage E (24V) appears across the half of primary of T, which means the total primary voltage is [(24 -1) + 24 = 47V] 2Edc approx. The C4 charges to this potential as it is connected between two ends of T.

m2 : This mode starts when gate pulse B goes high. This supply gate current to CR2, via differentiator ckt compromising R2,C2 and R4. This turn on CR2. The commutating capacitor (C4) applies a voltage -2Edc, to anode of CR1 (as it is in on state earlier, and CR2 VAK is assumed to 0). This turn off CR1 due to reversep polarity of commutating voltage. Now the 2Edc appears across T primary and C4 again charge to this voltage, in reverse order. The extra energy is fed back to supply through feedback circuit.

m3 : In next cycle the CR1, again turn on, and C4 voltage apeear across it and CR2. Since the end connected with CR2 is -ve 2E, this commutate CR2 as in mode 2 earlier. The alternating primary voltages mutually transferred to secondary of T, which is connected with load (ac induction motor). The speed of induction motor depends upon number of poles and frequency. Since poles are constant, therefore the speed is controlled by varying frequency of inverter.

Note : In this kit the dc input is unregulated thus a ripple can encountered at waveforms.

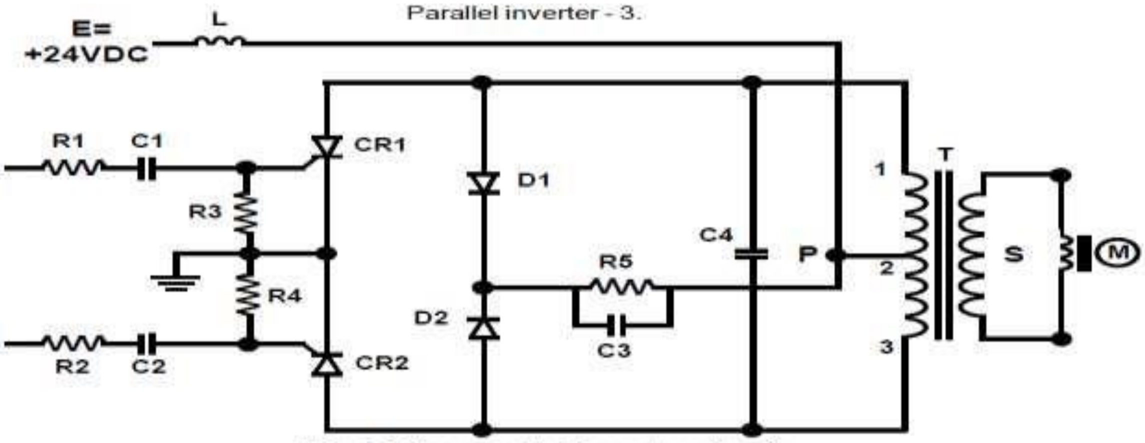
Parallel inverter - 3.
E=
+24VDC
L
A
R1
C1
R3
R4
B
R2
C2
CR1
CR2
D1
D2
R5
C3
C4
P
1
2
3
T
S
M

Fig 1. The parallel inverter circuit.

Waveforms:-

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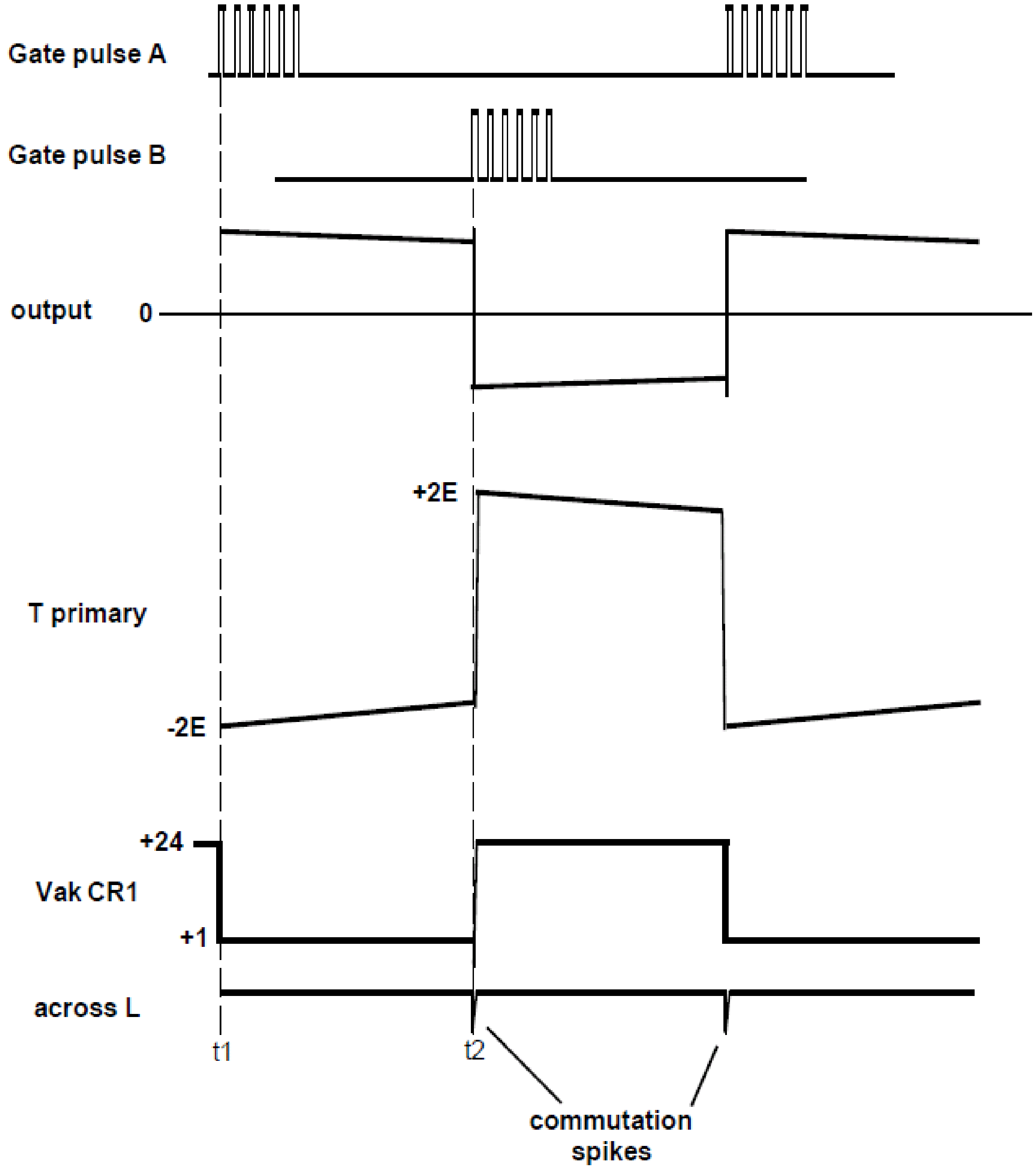

Gate pulse A
Gate pulse B
output
0
+2E
T primary
-2E
+24
Vak CR1
+1
across L
t1
t2
commutation spikes

Experiment procedure

Object : To study of parallel inverter and to drive ac induction motor.

Other app req : CRO with 1 : 10 probe.

1. Keep frequency control to centrel position. Connect CRO ch A with the A pulse output and ground. Switch on power.

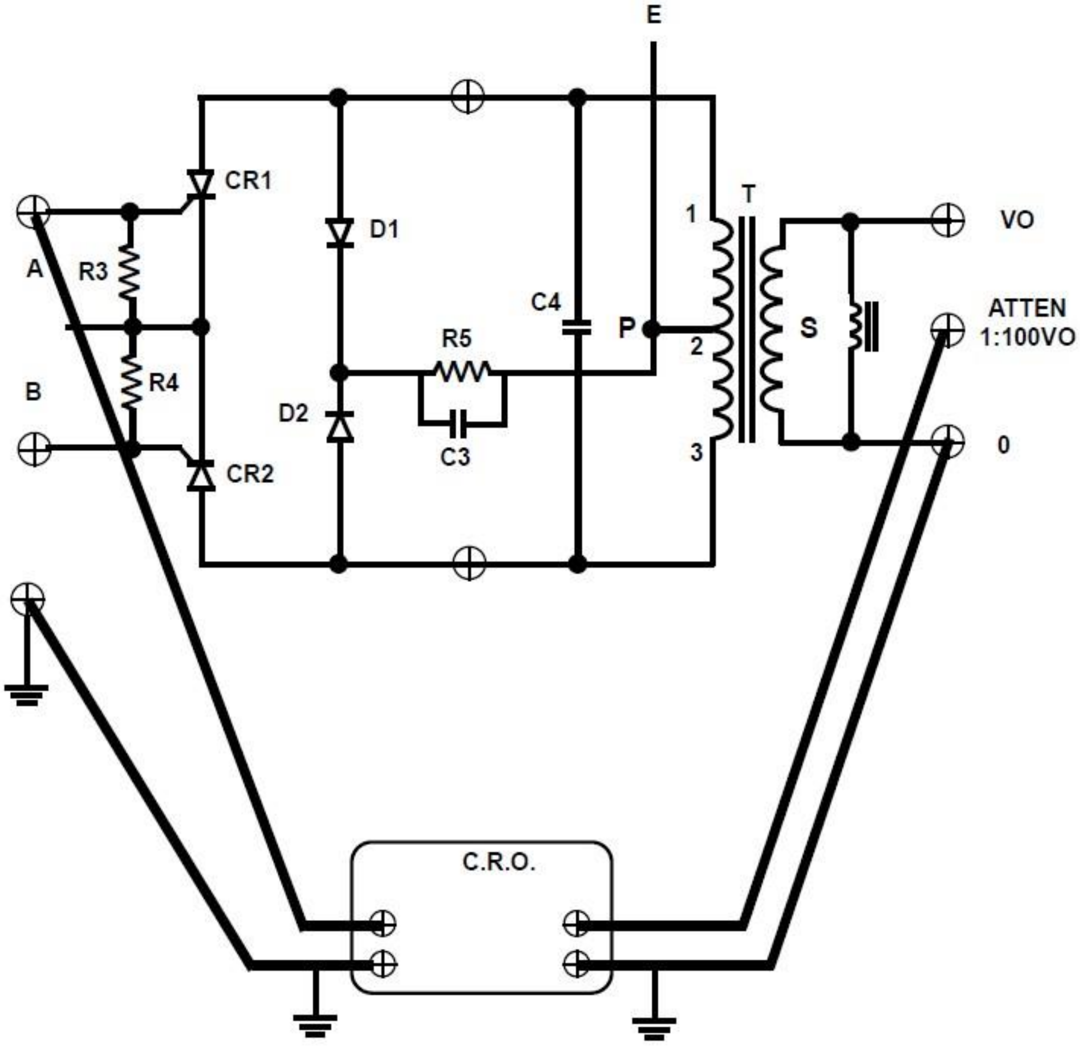
2. Adjust CRO time base to appear two trigger pulse waveforms upon screen. The waveform show the trigger pulse applied to CR1. Connect ch B with pulse B and see that both waveforms are identical, and 1800 apart.

3. Now connect CRO ch B with attenuated output. Observe the output waveform. It is square wave.

4. Change the frequency and observe its effect upon output and speed of motor. The motor speed is proportional to frequency of inverter.

5. To observe other waveforms connect CRO with socket w.r.t. GND with an attenuation of 1 : 10. conclude the result from observations.

Connection Diagram:-



Result:-

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EXPERIMENT NO:-4

Aim:- S.C.R TRIGGER CIRCUITS (Triggering a SCR)

Theory:- Switching a thyristor on, is called its triggering or firing. As we know that current flows in a SCR when it is in ON state. There are many methods by which a SCR can be triggered, but the most widely used is 'gate trigger method'. The gate triggering is most common in practice. In lab practical's we trigger the SCR at different gate current magnitudes to obtain forward break over voltage earlier than its VBo. In SCR a positive polarity signal is applied between its gate - cathode junction to force it on at specified break over voltage. In view of practical application (the phase control) the firing angle α is controlled by varying the gate signal or current magnitude.

In present board three methods are given as
a. The dc control with superimposed ac.
b. The R and R - C phase shift triggering.
c. The pulse triggering by a relaxation oscillator.
The board has inbuilt step down transformer, fixed value load resistor, one dc voltmeter to monitor average load voltage and associated independent circuits for triggering method. The procedure of experiment with the connection diagram is given one by one.

A. The R and R - C phase shift method :
In trigger method a, we observe that firing angle can't be adjusted more than 600. To obtain much wide firing angle the in phase resistive triggering is used as shown in fig 3. In this way the magnitude of gate current is adjusted by varying R(P1). But it is not possible to bring α > 900, since the falling slope of ac half cycle occurs. To obtain the goal an ac trigger circuit has use phase lag method in which the gate signal is delayed by a low pass filter which exhibit phase delay. In fig 4, this trigger circuit is shown.

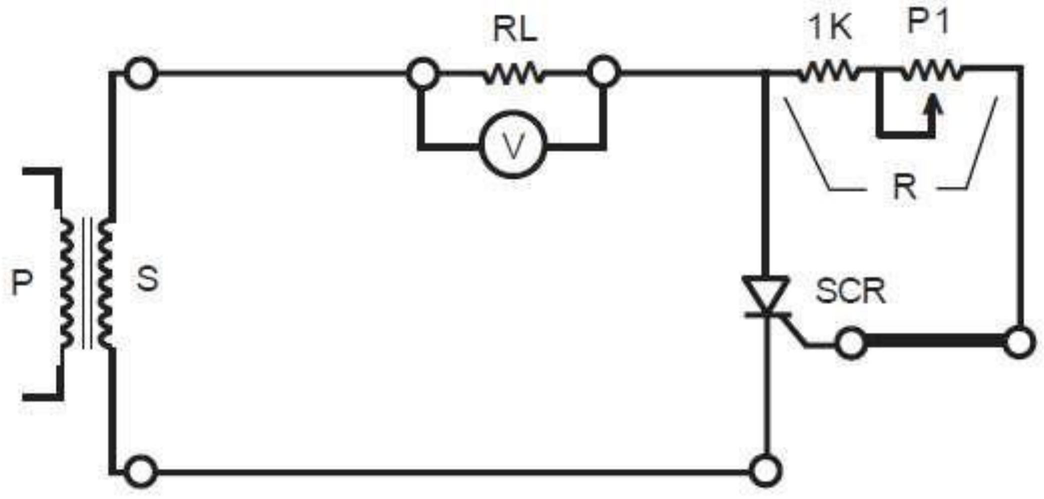

Fig 3.
The dc voltage trigger with in phase R - trigger circuit.

variable resistor P2 with R (1K) and capacitor C forms a low pass filter. As we know that such R - C leg exhibit a phase lag of 600 (900 maximum if C has low ESR and R is non - inductive) with the input. When P2 is introduced in the circuit the signal across C approach to peak level later due to charge current. It is fed into the gate - cathode circuit for trigger purpose the firing angle can be achieved well within (90 + 60 = 1500) more than 1500 since the delayed angle of +ve leading waveform across C has same magnitude (require to trigger) later since charge rate is low because of R introduced by P2. Making P1 zero the faster charge rate obtained and SCR trigger earlier. During -ve half cycle the C charges to - ve peak value and a diode(shown in dotted lines) must be introduced in series with gate and trigger signal if applied voltages are larger. This type of circuits are in common practice in speed control of small dc motors and intensity of lamps. The close loop operation of such circuits is difficult and generally not used for the regulation purpose.

Circuit Diagram:-

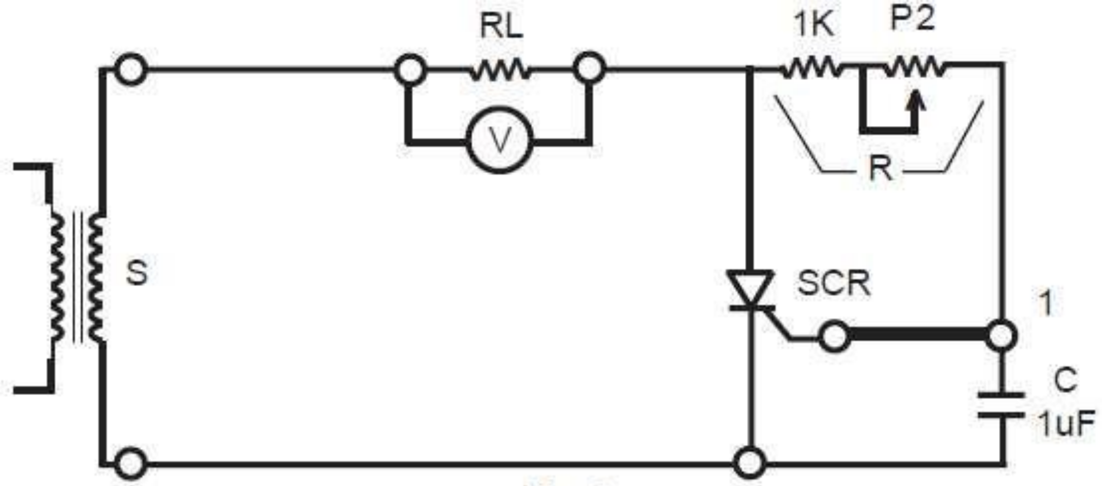

Fig 4.
The R - C phase delay trigger circuit..

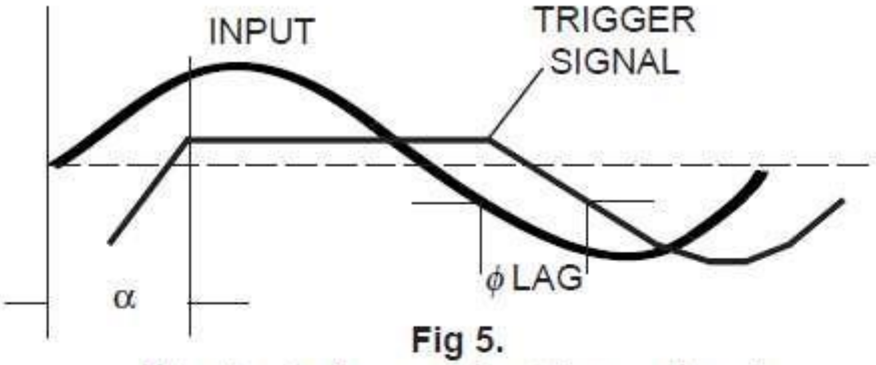

Fig 5.
The R - C phase delay trigger signal.

SCR trigger circuits 506 - 5.

Experiment Procedure :-
Other apparatus required : A dual trace CRO.
Observe the circuit printed upon the panel. Identify the different trigger circuits and their controls
Trigger by R circuit.
1. Connect the circuit as shown in fig 8. The SCR gate with socket marked (2) will complete the circuit. CRO channel 2 with AC sockets.
2. Connect CRO 1st channel with the gate cathode as previous experiment. Select CRO for obtain one ac complete cycle upon screen.
3. Keep pot P1 to fully clockwise to introduce maximum resistance in the circuit. Observe the voltmeter output and gate trigger signal.
4. Now gradually decrease R by mean of pot P1 and observe the effect upon the output at voltmeter and gate signal. Note the firing angle can't be adjusted beyond 900.

Waveforms:-

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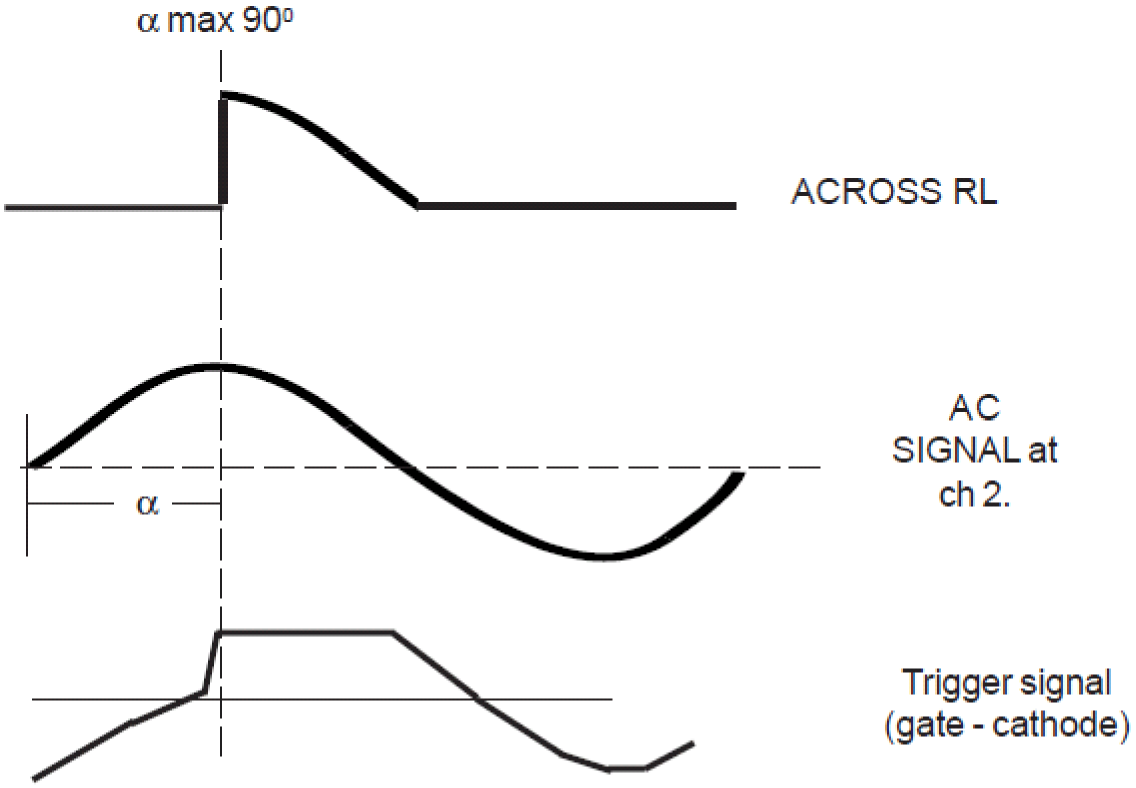

α max 90⁰
ACROSS RL
AC
SIGNAL at
ch 2.
α
Trigger signal
(gate - cathode)

BRCM

Connection Diagram:-

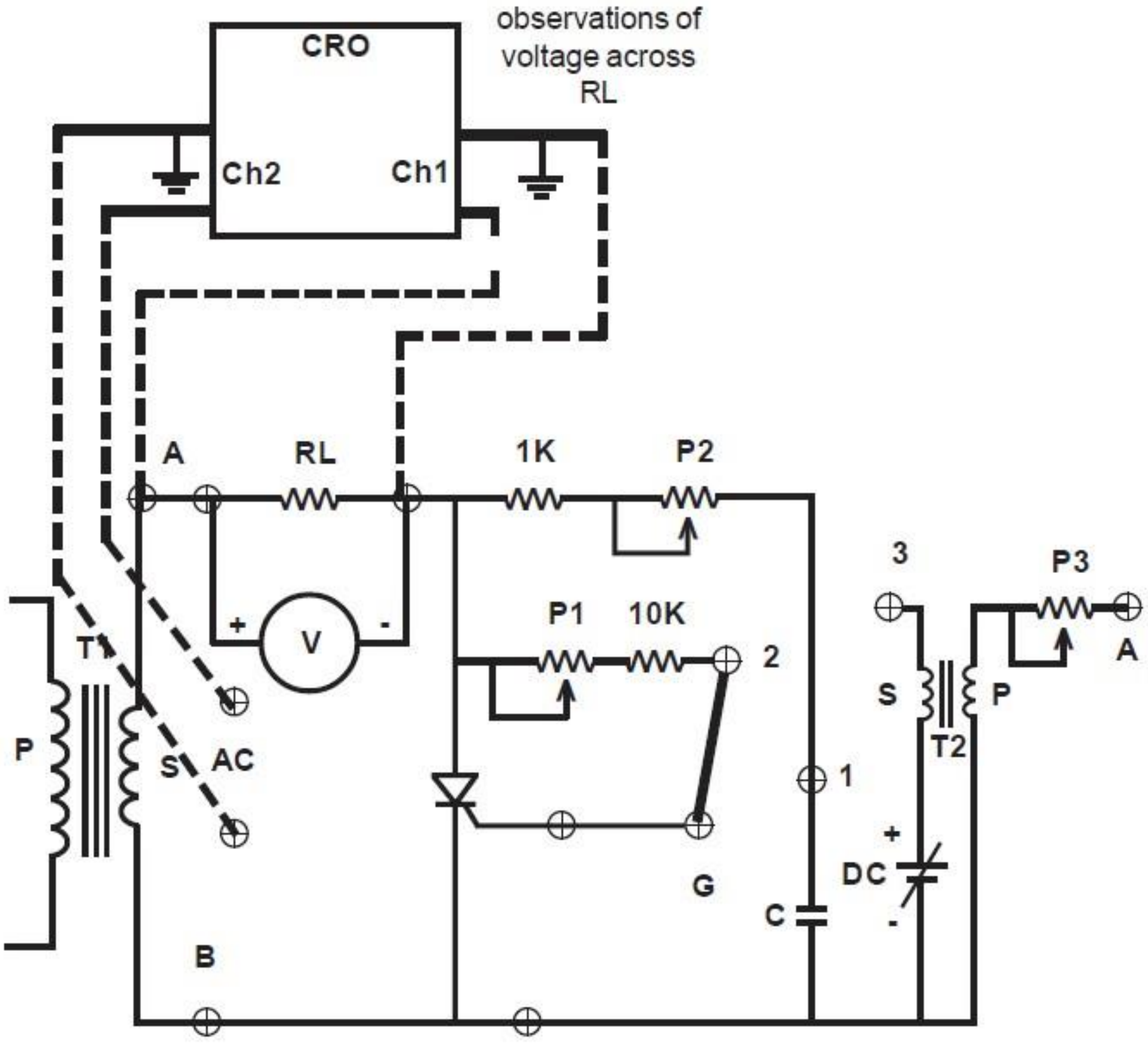
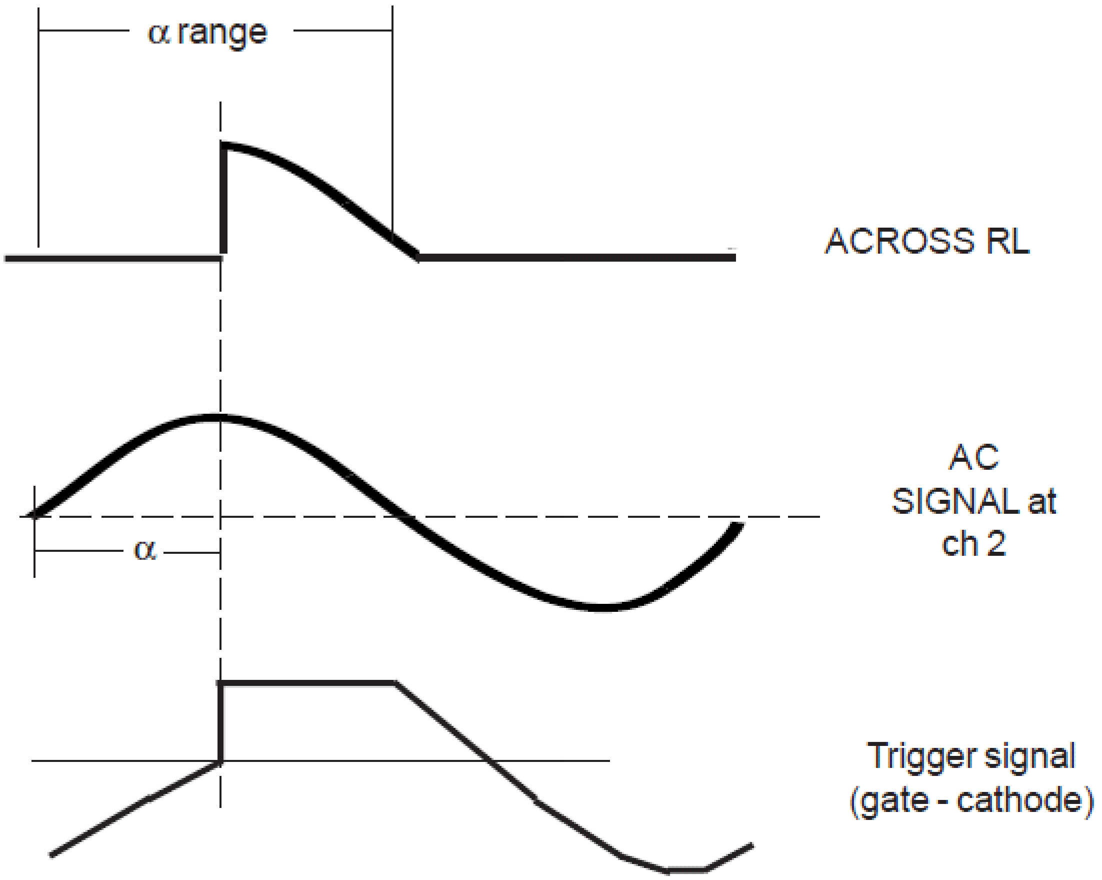

observations of
voltage across
RL
CRO
Ch2
Ch1
A
RL
1K
P2
P1
10K
2
T1
P
S
AC
+
V
-
3
P3
S
P
A
T2
1
+
DC
-
G
C
B

Fig 8.
Connection diagram for R - trigger circuit b.

B. Trigger by R - C circuit.

1. Connect the circuit as shown in fig 9. The SCR gate with socket marked (1) will complete the circuit. CRO channel 2 with AC sockets.
2. Connect CRO 1st channel with the gate cathode as previous experiment. Select CRO for obtain one ac complete cycle upon screen.
3. Keep pot P2 to fully clockwise to introduce maximum resistance in the circuit. Observe the voltmeter output and gate trigger signal.
4. Now gradually decrease R by mean of pot P2 and observe the effect upon the output at voltmeter and gate signal. Note the firing angle can be adjusted well beyond 900. This circuit is useful to control phase angle in wide range.

Waveforms:-


α range
ACROSS RL
AC
SIGNAL at
ch 2
α
Trigger signal
(gate - cathode)

BR

Connection Diagram:-

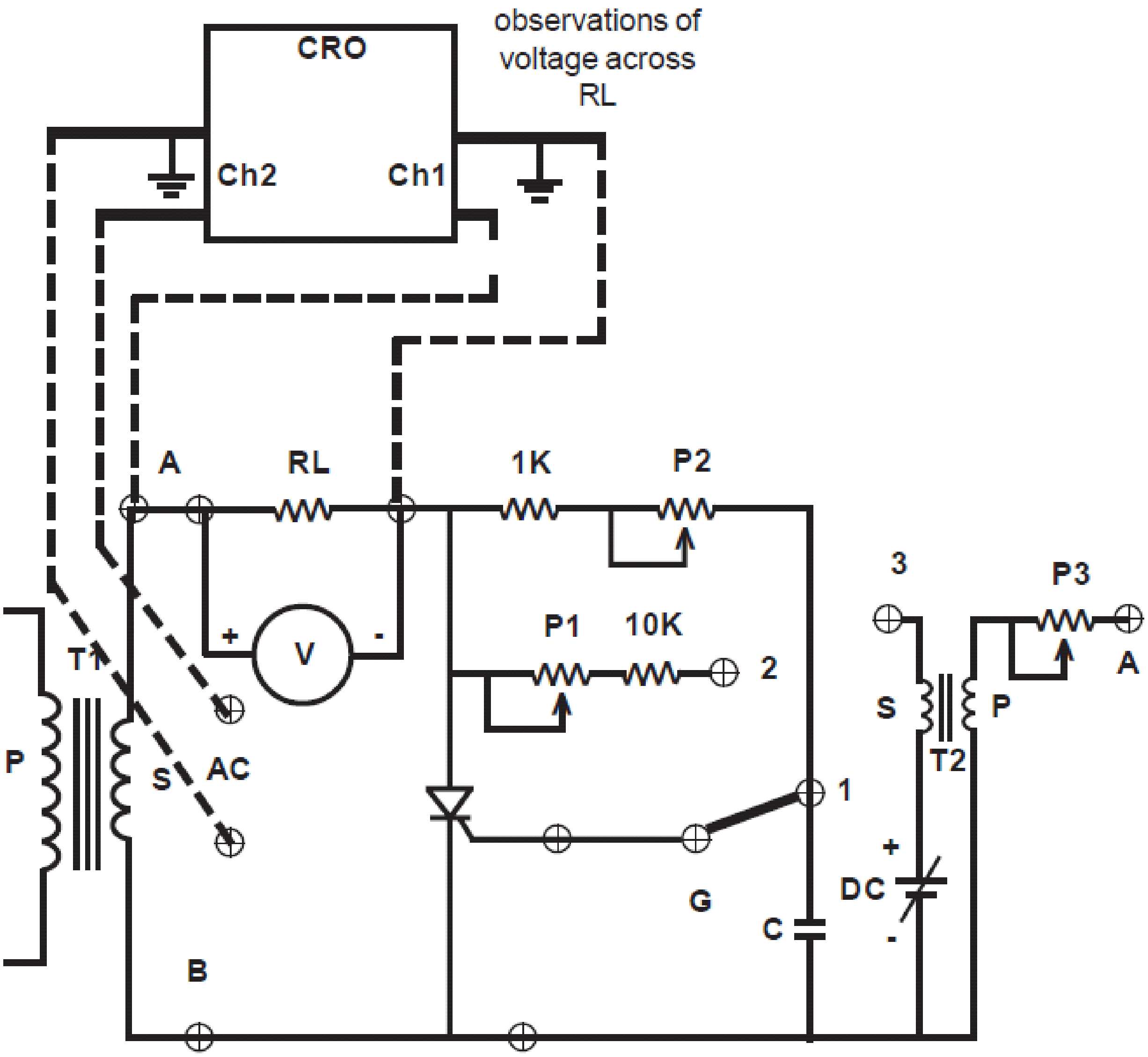

observations of voltage across RL
CRO
Ch2
Ch1
A
RL
1K
P2
P1
10K
2
3
P3
A
+
V
-
T1
P
S
AC
S
P
T2
1
+
DC
-
G
C
B

Fig 9.
Connection diagram for R -C trigger circuit c.

Result:-

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EXPERIMENT NO.:-5

AIM:- TO STUDY SCR COMMUTATION CIRCUITS

THEORY:- In ac circuits the SCR commutate itself when the input line cycle cross zero point which is designated as class F, in commutation circuits. But in dc circuits where the dc does not switchover to such point, a commutation circuit is adopted by mean of which the SCR can be turn off as in inverters and choppers circuits. Except the above said the commutation circuits in regard of dc source classified between A to E depends upon the method adopted. In the given board it is try to make familier these circuits in basic form to the students. The board has independent commutation circuits with the SCRs and has inbuilt trigger source, one fixed value resistive load and 15V dc supply as source. Any of the provided circuit may be connected using few patch cords. To define the circuit working system a graphical representation is required made by some observation on cathode ray oscilloscope. Since the practical involve slow time response it is necessary to observe the cathode ray oscilloscograph very carefully. In all practical it is necessary to use oscilloscope in dc coupled mode and the amp / div should be in calibrated mode. The dc supply as given in the board swings between 14 volt to 12 volt dc depends upon the nature of turn on continuation of circuits. However it is not the matter since these voltage is easily measured by a voltmeter.

1. *Class A commutation* : - The class A commutation circuit is defined as 'in which the commutation is achieved by the load voltage, or in other words in class A commutation the SCR is being commutated by the voltage appear at load'. These circuits use resonant components L - C in which it may be in series with load or C in parallel with load (a series resonant or a parallel resonant in which the load connected across C if it has R >> L r). As shown in fig 1a, the load RL (100 Ohm) is connected across commutation capacitor C (100 uF) with L (400 mH) in series with SCR with respective polarities. When a trigger pulse having a width << the resonant freq fr (1 / T) of L - C, the SCR turn on thus allows to flow current in load resistance RL through L. The voltage across RL is peak value which is due to L in series with the C. The C has charge of this voltage value which is almost 1/3 times more than dc voltage. It force SCR cathode to being more +ve than the anode and current stops through it since it is a reverse bias. The load current is now supplied by the C discharge through load exponentially. The direction of current in L now being reversed and opposite polarity voltage developed across it which goes to zero after a while and load current stops. In these type of commutation the off time depends upon L, C and load value.

2.*Class B commutation* : - It is another L - C resonant commutation circuit in which the commutation is carried out by these components. As shown in fig 2a, the L - C series resonant circuit is connected across the SCR anode cathode termination. When no trigger applied to the gate, C charge through L and RL to a voltage value nearly applied dc,with the polarity as shown in fig 2a. When a trigger pulse applied to the gate SCR conducts and it brought a low ohmic path across its anode – cathode which allow to discharge C through L and itself. The C discharge current through L is more than the load current. This current cause to commutate the SCR, hence it is also called as current commutation. The load voltage value approach to the capacitor peak charge value which is more than the applied dc. The current in L now get reversed and approached to +ve value and goes to again zero as C charge again to nearly applied dc potential. During the time load current is supplied by C which charge exponentially through it. The commutation current flows through load in early cycle. In both commutation circuits the commutation is done by the oscillatory current flow in L - C. To trigger such circuits a narrow width pulse required since the commutation is performed by peak charge of C. If a wider pulse having pulse width > the peak discharge time to approach voltage across RL near to dc potential applied than the SCR can't be turn off .

3.*Class C commutation* : - This class of commutation is defined as complementary voltage commutation method. As shown in fig 3a, two SCRs are used in this circuit. The RL connected with SCR A which is the main SCR carrying the load current and while the SCR B is part of commutation circuit. When no trigger pulse applied to any of the SCRs the commutation capacitor C has no charge upon it since its both ends has same +ve potentials. When the main SCR A is being trigger by applying a pulse upon gate the load current flows through RL and anode - cathode of it. As the SCR on potential is very low the anode of it is nearly ground potential (+1V) which allow to charge C through R1 and it to a voltage value nearly applied dc with such polarity as shown in fig 3b. When a trigger pulse applied to the SCR B gate it conducts and discharge C through itself and through SCR A. The peak discharge current bring anode of SCR A to a -ve potential having magnitude nearly equal to applied dc. These complemented voltage cut - off current flow through SCR A since potential with reverse polarity reverse bias CRA. Hence SCR A commutate and current stops through RL. The C now discharge through load RL and R1, hence RL carries this current observed as sharp peak at
cut - off of CRA.

4.*Class D commutation* : - This class of commutation is also same phenomenon as class C, but there is a difference between these two. Here the commutation capacitor is charged by the load transition and auxiliary SCR is used to discharge it to commutate the main SCR. As shown in fig 4, SCR A is the main load current carrying SCR and SCR B is the auxiliary SCR used to commutate SCR A. When no trigger applied the C has very small charge upon it by leakage current of D which can be shown by indicated polarity. When a trigger pulse applied to the SCR A, it conducts and load current supplied to RL through L'. The load current transition which is sharp +ve pulse through L' is boosted by L and charge C through D. As C has smaller value it charge initially and diode D get reverse biased
as the voltage across C becomes > load voltage (nearly 2 Vdc). The C has now voltage polarities as shown in fig 4 parenthesis. When SCR B is triggered by applying gate pulse it conducts and discharge C through SCR A. The cathode of SCR A is now > dc potential than anode which get it reverse biased and commutate it. The remaining charge of C discharge through RL and SCR B commutate when the discharge current becomes below holding current of it. In this method the on trigger pulses should be such apart from off pulse that C must accumulate the charge prior to apply off trigger pulse.

5.*Class E commutation* : - This method is called as impulse commutation.

As shown in fig 5a, transformer T secondary which has larger turns than primary, is connected between SCR cathode and load RL. A capacitor C does also connected across the +dc rail and RL used to hold the off trigger pulse. The off pulse is applied to transformer primary. When no trigger pulse applied to the circuit, the SCR is off and C charge to shown polarity through RL. When trigger pulse applied to SCR gate it conducts and load current flow through load RL. It brings a path to

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discharge C through secondary of T and SCR. When a off pulse applied to the primary of T, the energy transferred to secondary and C charges. As the SCR is in on state, and the applied pulse at cathode has large +ve amplitude than cathode potential the SCR commutate due to reverse bias. The C again discharge in RL and hold its previous value as at beginning. As the details given in text the first two commutation circuits are referred as self commutation circuits. In these circuits only one trigger pulse is required to turn on the SCR, while turn off is performed by L - C resonant circuits. The other classes are classified as force commutation in which two trigger pulses are required one for turn on and other for turn off.

Experiment procedure

Object : - To study of SCR commutation circuits.

Other apparatus required : - CRO and DMM.

1. **The class A commutation circuit**.

Connect the circuit with given power source, the load and the given trigger source as shown in fig 1a, with bold lines. Draw the circuit upon paper.

Switch on the power. If connections is made as per fig 1a, than the LED (IL), fitted nearby RL will flash at trigger rate (12.5Hz).

Connect CRO across the RL as its ground lead with the -ve rail of RL. Adjust CRO time base and amplitude control to obtain a stable waveform upon CRO screen. The CRO should be DC coupled.

Trace the waveform appearing across RL.

Connect CRO hot lead with cathode of SCR and trace the waveform.

Now connect CRO leads across L, where CRO hot lead should be connect with cathode of SCR. Trace the voltage waveform appearing across the L. From waveforms (1b - 1d) it is observed that due to oscillatory current in L, C charge more than cathode potential cause to commutate SCR. It is voltage commutation.

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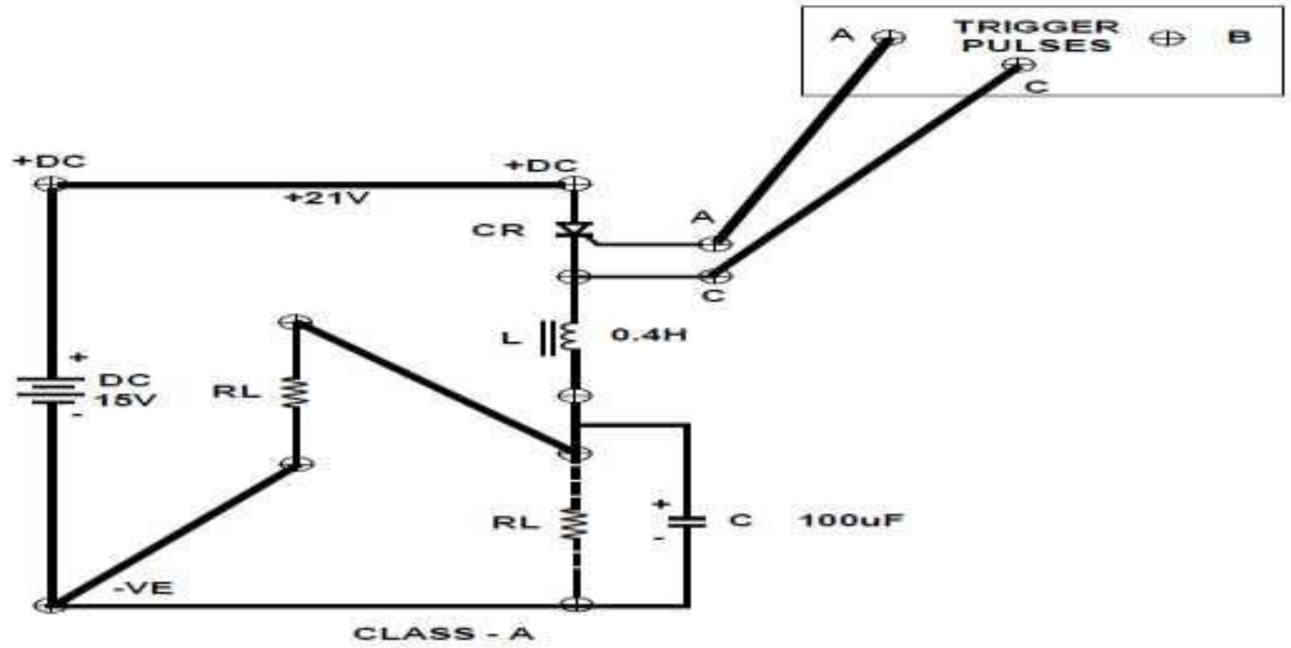
A
TRIGGER PULSES
B
C
+DC
+DC
+21V
CR
A
C
L
0.4H
+
DC 15V
-
RL
RL
+
-
C
100uF
-VE
CLASS - A

FIG 1a.
Connection diagram for class A commutation circuit.
Bold lines are shown for patch cords.

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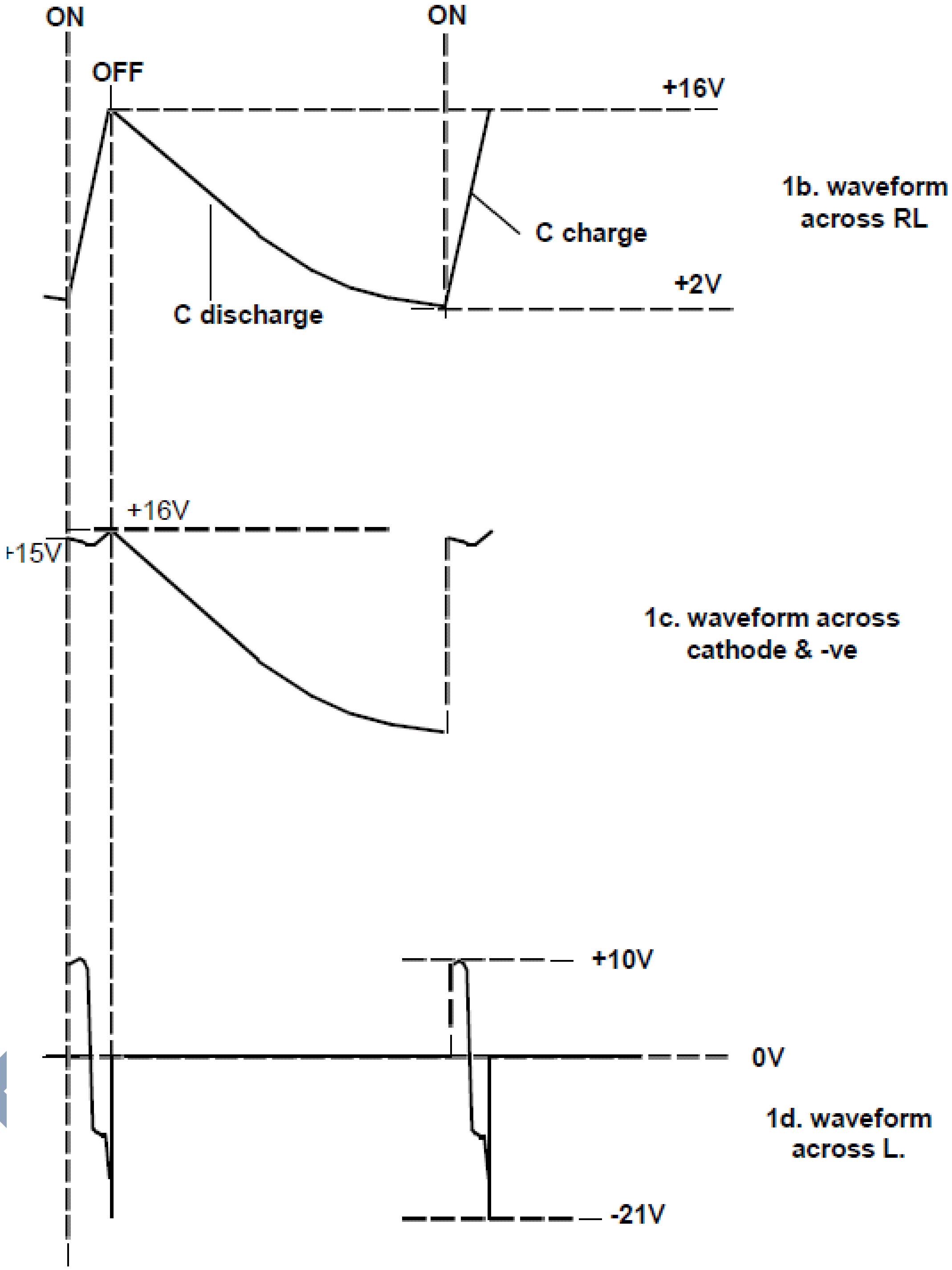

ON
ON
OFF
+16V
1b. waveform across RL
C charge
+2V
C discharge
+16V
+15V
1c. waveform across cathode & -ve
+10V
0V
1d. waveform across L.
-21V

2. The class B commutation circuit.

Connect the circuit with given power source, the load and the given trigger source as shown in fig 2a with bold lines. Draw the circuit upon paper.

Switch on the power. If connections is made as per fig 2a, than the LED fitted nearby RL will flash at trigger rate (12.5 Hz).

Connect CRO across the RL as its ground lead with the -ve rail of RL. Adjust CRO time base and amplitude control to obtain a stable waveform upon CRO screen. The CRO should be DC coupled.

Trace the waveform appearing across RL.

Now connect CRO leads across C, where CRO ground lead shouldbe connected with CR cathode (-ve of C). Trace the waveform.

Now connect CRO leads across L, where its ground lead should be connected with C end. Trace the waveform.

From waveforms (2b - 2d) it is observed that discharge of C through SCR impact large current (observed by large amplitude of discharge curve) which is > IL, cause to commutate SCR.

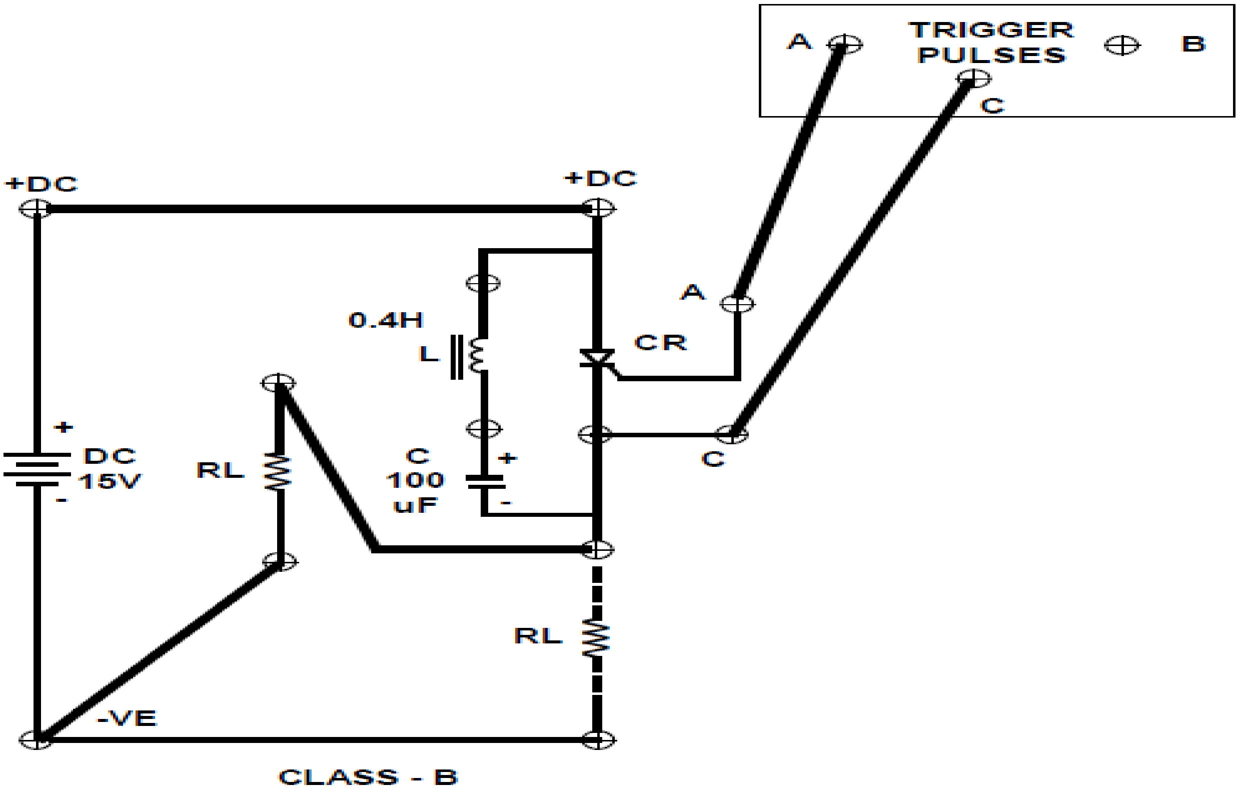
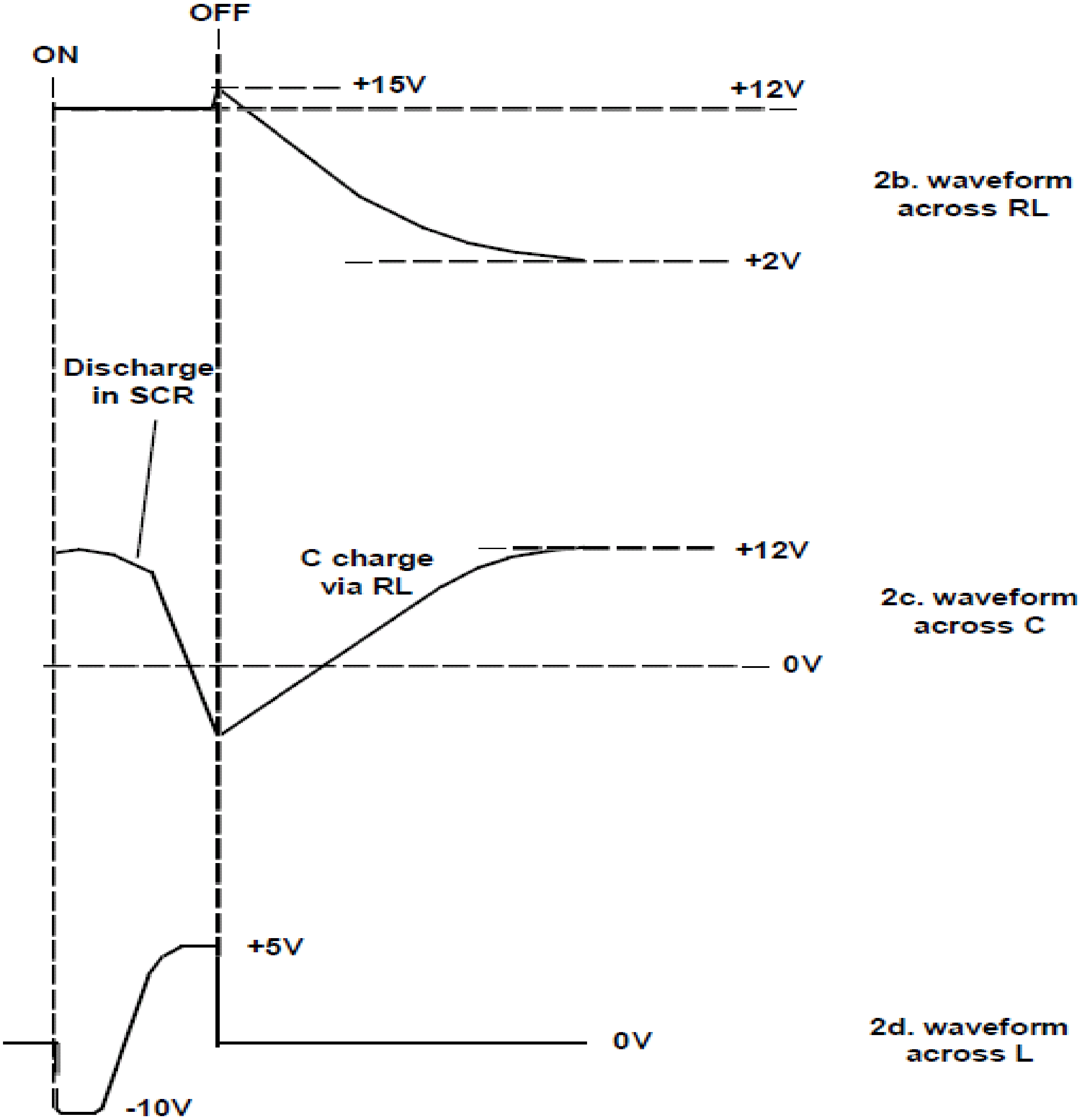


FIG 2a.
Connection diagram for class B commutation circuit.
Bold lines are shown for patch cords.


OFF
ON
+15V
+12V
2b. waveform
across RL
+2V
Discharge
in SCR
C charge
via RL
+12V
2c. waveform
across C
0V
+5V
0V
2d. waveform
across L
-10V

3. The class C commutation circuit.

Connect the circuit with given power source, the RL, and trigger source as shown in fig 3a bold lines. Draw the circuit upon paper.

In this circuit the gate trigger require two pulses, as trigeer ON and trigger OFF.

Switch on the power. If connections is made as per fig 3a, than the LED fitted nearby RL will glow at trigger rate (12.5 Hz).

Connect CRO across the RL as its ground lead connected to SCR A anode. The CRO should be DC coupled.

Observe/trace the waveform across RL. Observe peak +ve pulse appear at RL when C discharge through it.

Connect CRO across SCR A such its ground lead with cathode.

Connect other channel with SCR B anode. Observe the waveforms.

Observe that negative polarity pulse appear at CRA anode as soonas CRB triggered on. The C discharge through RL as CRA cut - off.

Observe the charge of C is exponenetial since R1 is large than RL.

From fig 3b, waveforms it is observed that load carrying SCR (A) is commutated by reverse polarity (complemented) voltage across it.

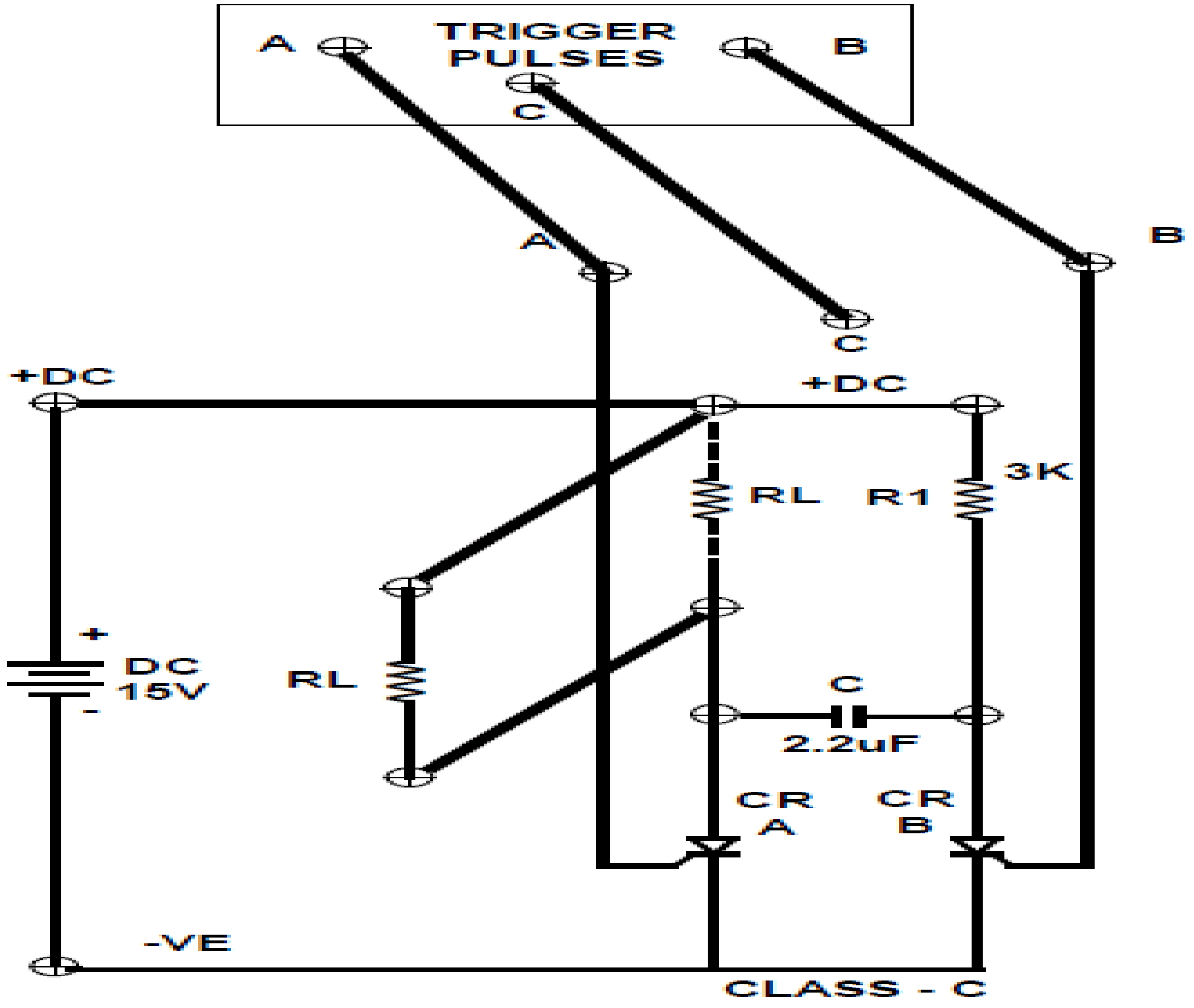

A
TRIGGER
PULSES
B
C
A
B
C
+DC
+DC
RL
R1
3K
+
DC
15V
-
RL
C
2.2uF
CR
A
CR
B
-VE
CLASS - C

FIG 3a.
Connection diagram for class C commutation circuit.
Bold lines are shown for patch cords.

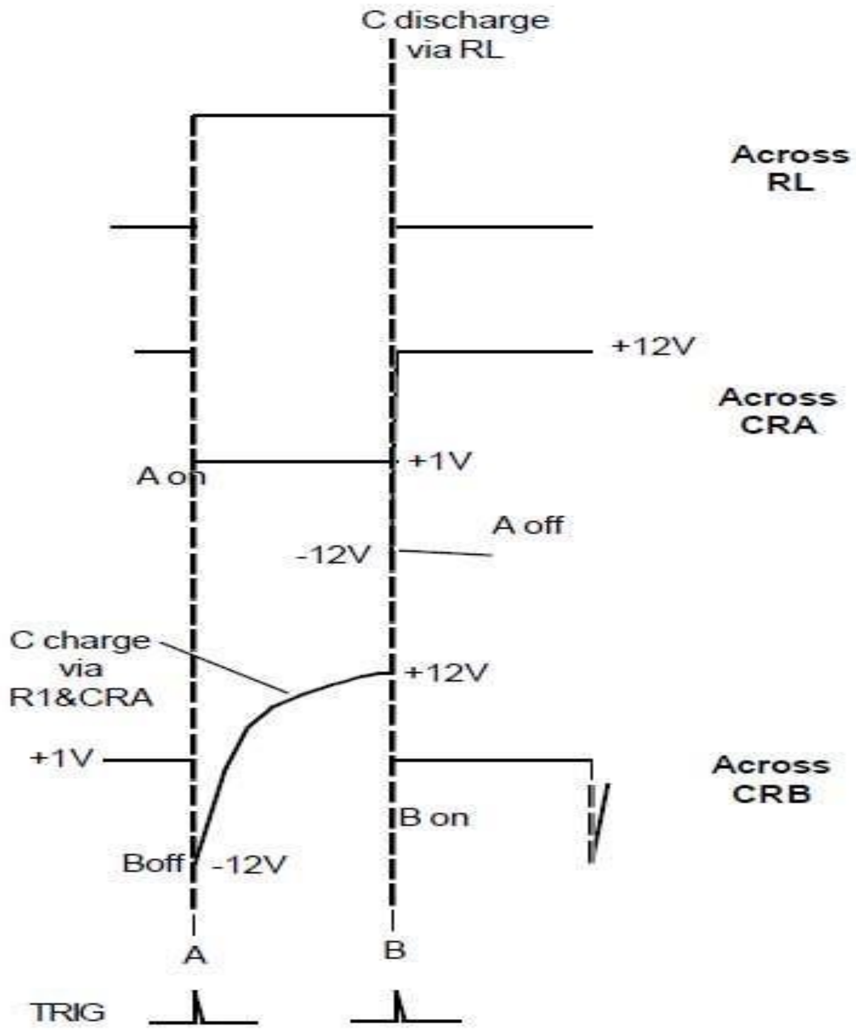

C discharge
via RL
Across
RL
+12V
Across
CRA
A on
+1V
A off
-12V
C charge
via
R1&CRA
+12V
+1V
Across
CRB
B on
Boff
-12V
A
B
TRIG

FIG 3b.
waveforms of fig 3a.

4. The class D commutation circuit.

Connect the circuit with given power source, the RL, and trigger source as shown in fig 4a bold lines. Draw the circuit upon paper. In this circuit the gate trigger require two pulses, as trigeer ON and trigger OFF.

Switch on the power. If connections is made as per fig 4a, than the LED fitted nearby RL will glow at trigger rate (12.5 Hz).

Connect CRO across the RL as its ground lead connected to -ve supply. The CRO should be DC coupled.

Observe/trace the waveform across RL. Observe small peak +ve pulse appear at RL when CRB get triggered.

Connect CRO hot lead with SCR B anode and its ground lead with -ve.

Observe that charge appears upon capacitor and discharge of it via CRB.

From waveforms in fig 4b, it is observed that CRB anode is more +ve than cathode of CRA. When triggered these voltage appears across CRA cause to reverse bias it, hence commutation performed by triggering auxillary SCR B.

SCR commutation circuits - 17.

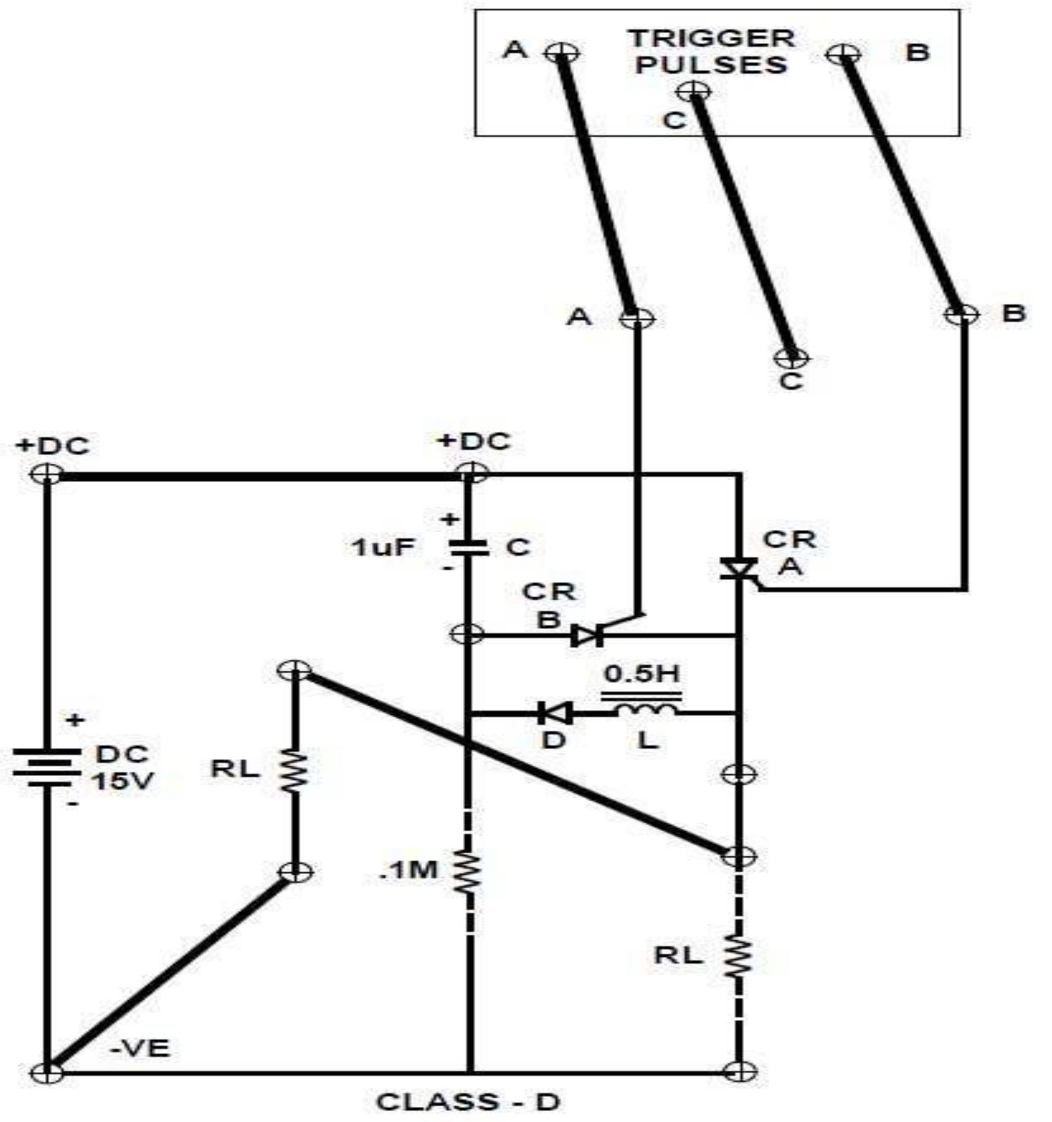

A
TRIGGER PULSES
C
B
A
C
B
+DC
+DC
+
1uF
-
C
CR A
CR B
0.5H
D
L
+
DC 15V
-
RL
.1M
RL
-VE
CLASS - D

FIG 4a.
Connection diagram for class D commutation circuit.
Bold lines are shown for patch cords.

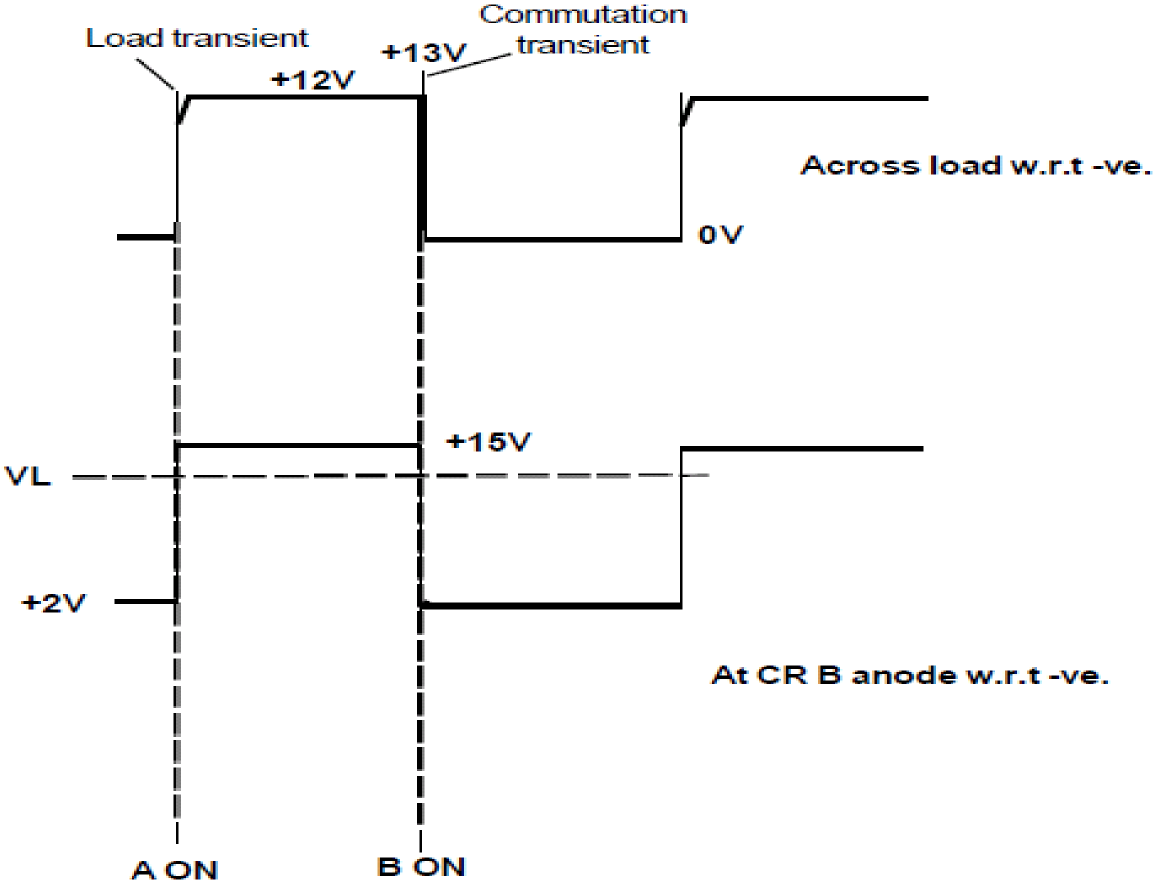


FIG 4b.
waveforms of fig 4a ckt.

5. The class E commutation circuit.

Connect the circuit with given power source, the RL, and trigger source as shown in fig 5a bold lines. Draw the circuit upon paper.
In this circuit the gate trigger require two pulses, as trigeer ON and trigger OFF.
Switch on the power. If connections is made as per fig 5a, than the LED fitted nearby RL will glow at trigger rate (12.5 Hz).
Connect CRO across the RL as its ground lead connected to -ve supply. The CRO should be DC coupled.
Trace the waveform across RL. Observe transition pulse appear atRL due to presence of secondary inductance of T.
Disconnect trigger source A (shown in dotted line) to observe the peak commutation pulses at cathode of SCR.
From waveforms in fig 5b, it is observed that CRB cathode is bring to large +ve transient (>> VL) by external pulse applied through transformer

T, which commutate SCR.

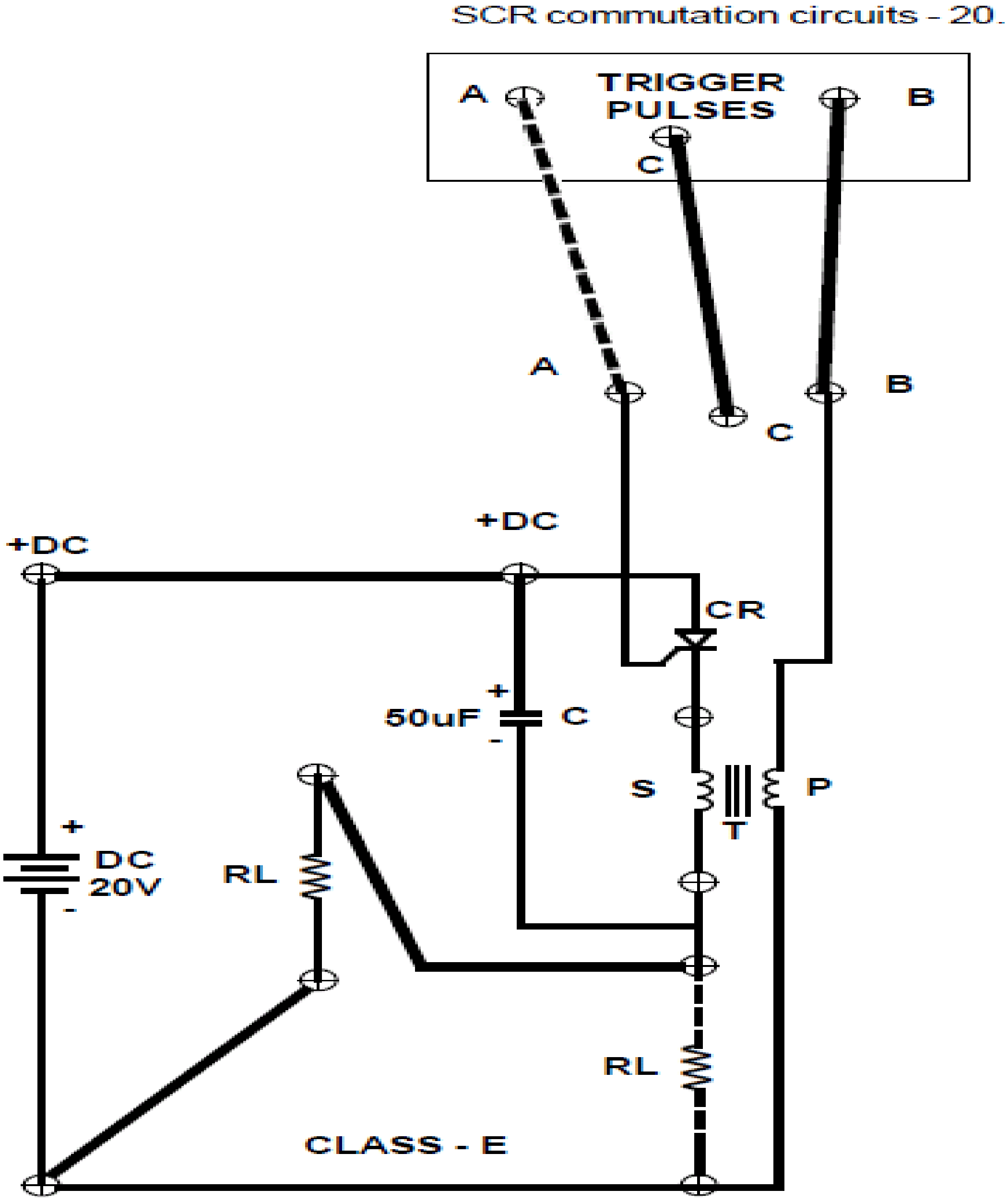

SCR commutation circuits - 20.
A
TRIGGER PULSES
B
C
A
C
B
+DC
+DC
CR
+
50uF
C
-
S
T
P
+
DC 20V
-
RL
RL
CLASS - E

FIG 5a.
Connection diagram for class E commutation circuit.
Bold lines are shown for patch cords.

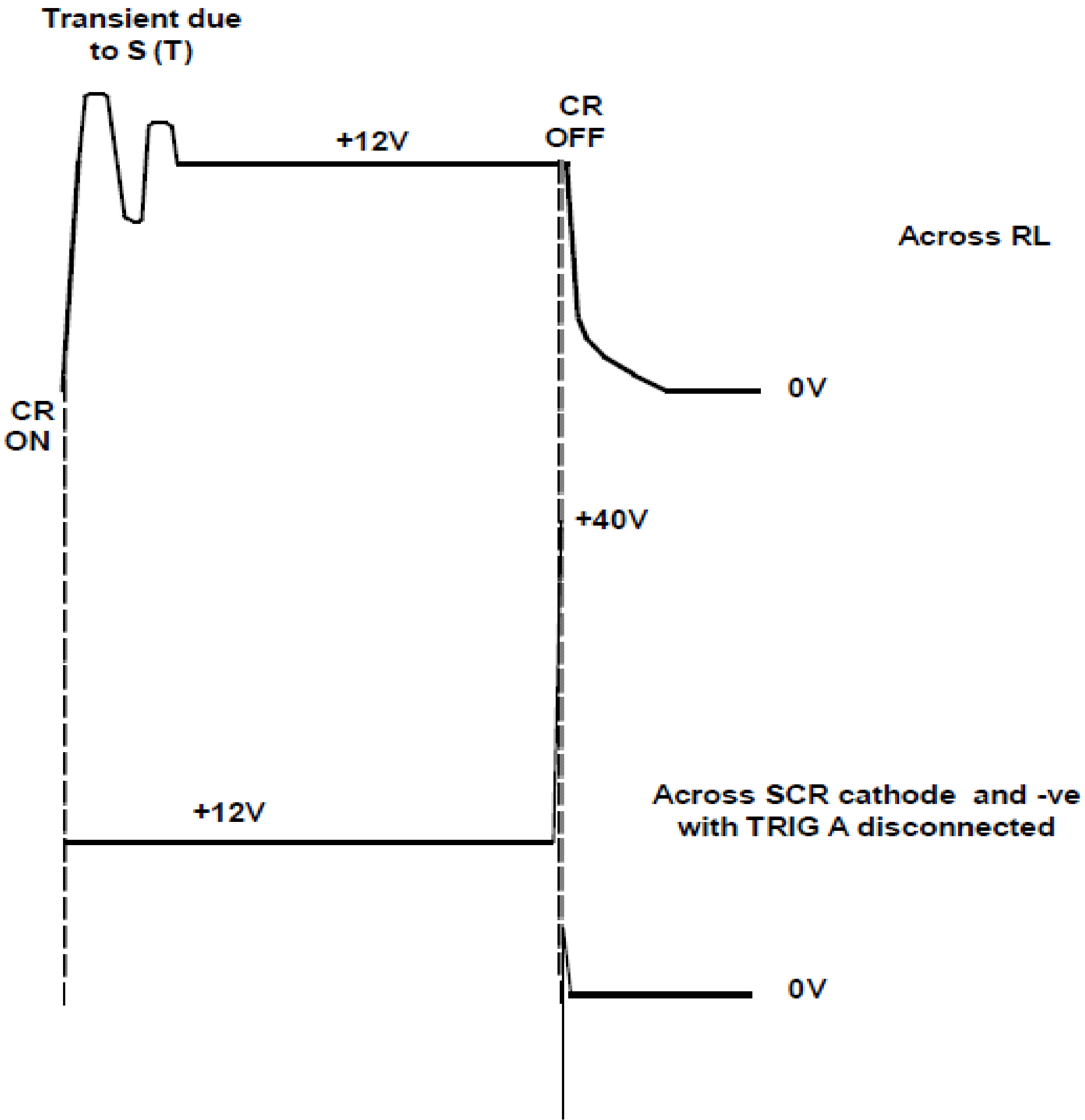

Transient due to S (T)
+12V
CR OFF
Across RL
0V
CR ON
+40V
Across SCR cathode and -ve with TRIG A disconnected
+12V
0V

Fig 5b.
waveforms of fig 5a circuit.

Result:-

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EXPERIMENT NO.:-6

AIM:- TO study single phase dual converter (speed - direction control of dc motor)

BRIEF THEORY :-The fully controlled converter can produce a direct (& reversible upon large active loads) voltage with direct current in one direction, is said to be operate in two quadrents. The dual converter allows operation in four quadrents, by rectification and inversion. The basic principle of operation of the dual converter can be explained with refrence to fig 1. Assume the active load is present. In fig (1a) a fully controlled converter operates in two quadrants.
In 1st quadrant it acts as rectifier and in 4th it act as inverter. If the connections of converter are interchanged the quadrants also interchanged. In dual converter, two converters are employed to fulfill the requirement to operate in required quadrent. There are two type of converters. One has the non - circulating current scheme and other one is with circulating current scheme.

Experiment procedure
Object : To study operation of single phase non - circulating current dual converter and to verify its current control and reversal action.
Other apparatus : CRO
Observation of gate trigger (angle) pulses.
1. Connect the CRO as shown in fig 6b. Keep the α adjust control knob to fully counter - clockwise. Trigger CRO from LINE (trigger option in CRO). Select OPERATING MODE in OFF position.
2. Observe the position of trigger pulses. Note, that the 1st instance from left hand side (trigger pulse) is accounted as firing pulse.
3. Move a control and observe the position of trigger pulse. Observe at near 900 (approx centre) both pulse position is same.
4. Further move of control changes the pulse position in reverse order. If a pulse position measured with line signal (see fig 6a) then the other pulse position can obtained by subtracting measured value from 1800.

Circuit Diagram:-

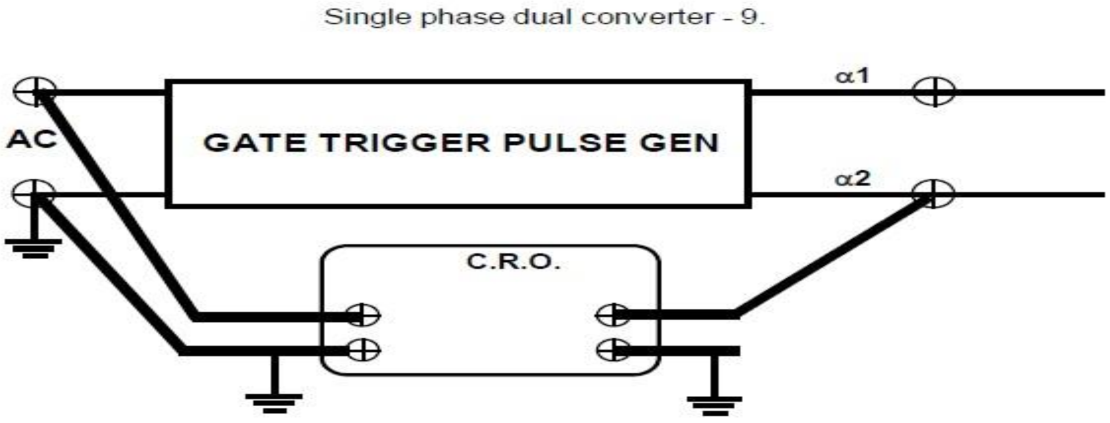
Single phase dual converter - 9.
AC
GATE TRIGGER PULSE GEN
α1
α2
C.R.O.

Fig 6a.
The measurement of α exp.CRO trigger with internal LINE.

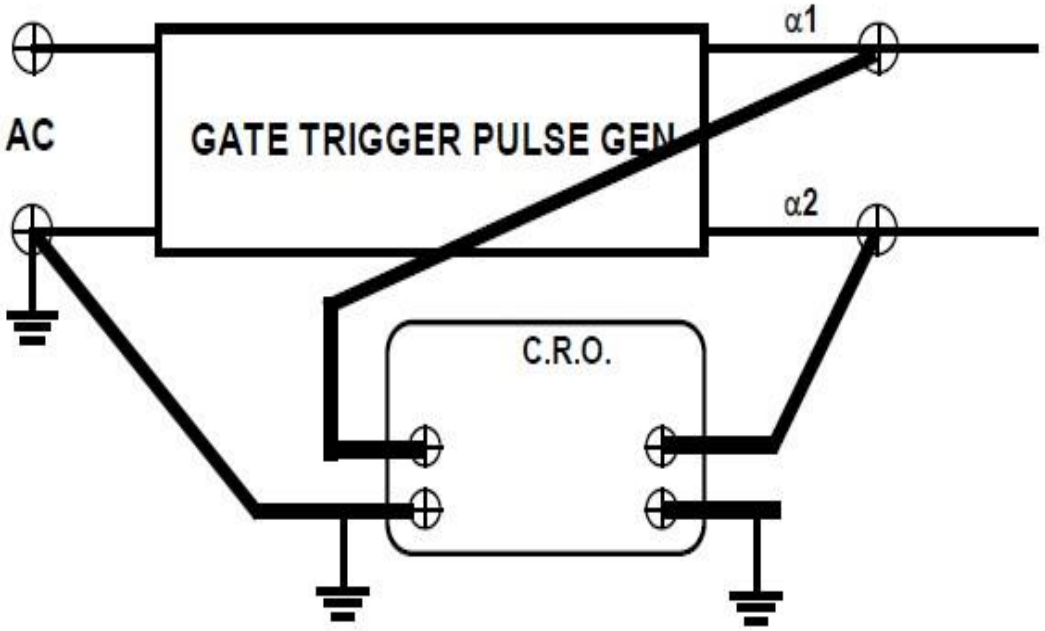
AC
GATE TRIGGER PULSE GEN
α1
α2
C.R.O.

Fig 6b.
The observation of trigger pulses. CRO trigger with AC signal

Experiment procedure

Object : To study operation of single phase non - circulating current dual converter and to verify its current control and reversal action.

Other apparatus : CRO

Observation of P converter.

1. Connect the CRO as shown in fig 7. Keep the α adjust control knob to fully counter clockwise. Select operating mode P converter while N is in off state. Adjust CRO time base to appear one cycle of ac upon screen. Trigger CRO with this signal.
2. Slowly adjust α adjust control to observe the output / input with the control position. It is observed that the α increase as control knob moves clockwise.
3. Adjust the α = 900. Disconnect CRO from socket V and connect it with I socket. Note the current is in +ve (towards forward) direction only.
4. Move α control and observe the current through power circuit is +ve. conc : It is verified that the converter operations is in 1st quadrant. Since no current reversal is possible the regeneration cannot performed. Observation of N converter.

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Waveforms:-

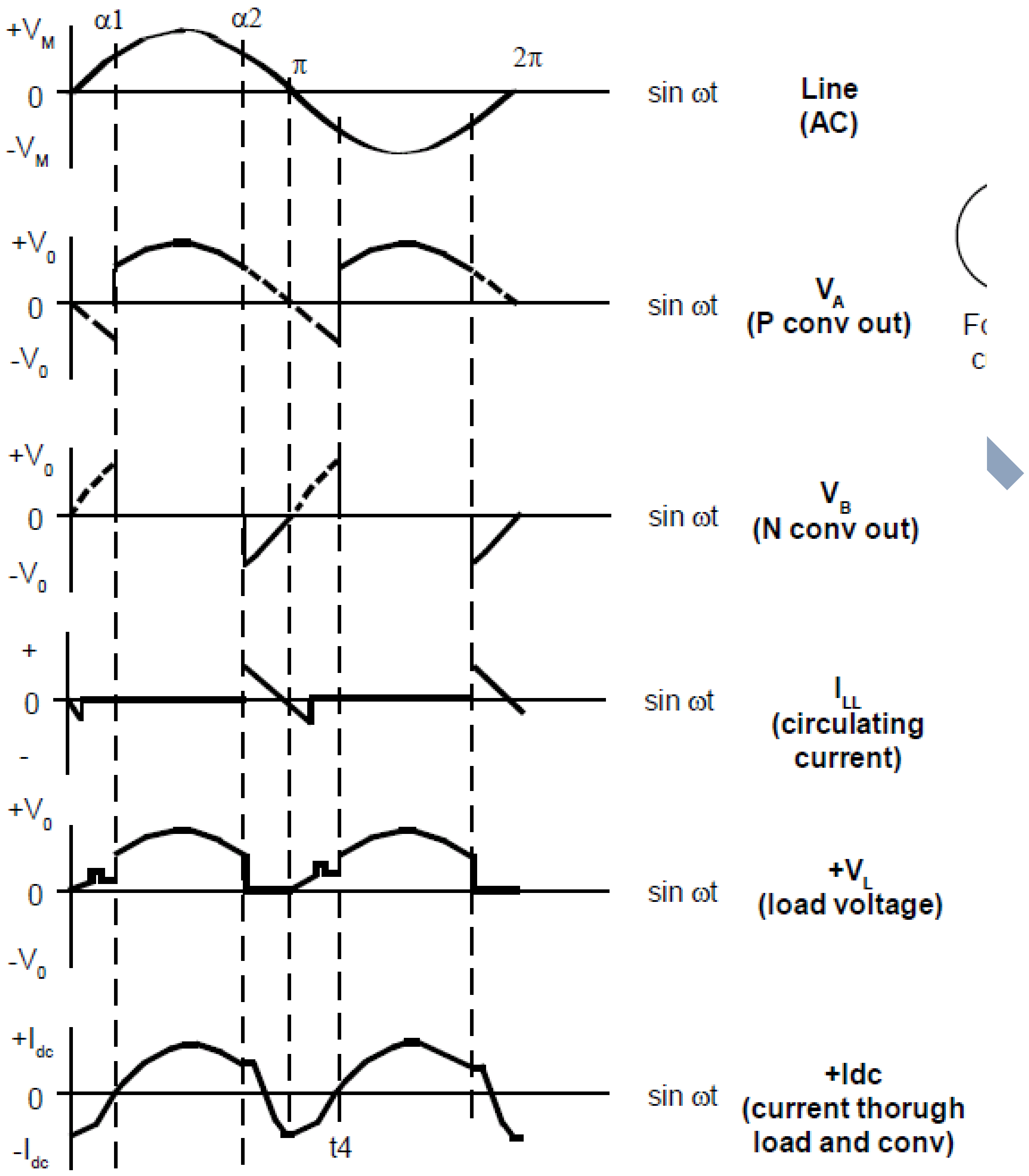
+V_M
α1
α2
π
2π
0
-V_M
sin ωt
Line
(AC)
+V_0
0
-V_0
sin ωt
V_A
(P conv out)
+V_0
0
-V_0
sin ωt
V_B
(N conv out)
+
0
-
sin ωt
I_LL
(circulating
current)
+V_0
0
-V_0
sin ωt
+V_L
(load voltage)
+I_dc
0
-I_dc
t4
sin ωt
+Idc
(current thorugh
load and conv)

Fig 5 : Typical waveforms for Mode I$^+$ circulating current operation. α1 <90^0 & α2 >90^0

Result:-

EXPERIMENT NO.:-7

AIM:- SINGLE PHASE HALF & FULL WAVE CONVERTER (speed control of dc motor using converter)

Theory:- The kit is designed to study SCR half wave/ full wave (bridge) fully controlled converter output characteristics. The kit consists isolated ac supply, firing angle control circuit with two, 1 : 1 pulse transformer with four 600Vac 10 amp silicone controlled rectifier wired in half wave/full wave bridge (mode selectable) rectifier/converter configuration. One small dc motor connected at output as load. Effect of freewheeling diode can be realized with given DFW. Sockets are provided at input/output places to observe the waveforms.

The half wave converter with RL load : With refrence to fig 1, when mode HALF (half wave) selected, thyristor CR1, can be fired into on state anytime after line A goes positive than B. In on state, the current flows through the path A - CR - load - B. During next half cycle, when line B is positive than A, thyristor does not receive any trigger pulse. However once current starts flowing through inductive load at instant α, it continued even after zero cross (π) as shown in fig 2, and thyristors remains in on state till current approaches zero at β. This is due to the fact that current through the inductance cannot be reduced to zero. During instant π to β, the input cycle changes the phase (negative cycle appears as observed from waveforms), current continuous to flow till the enrgy stored in the inductance is dissipated. After which the load current is zero and due to line B is +ve then A, thyristor is commutated. The conduction in negative cycle shows that the average load voltage reduced in case of inductive load. The load current is always discontinuous.

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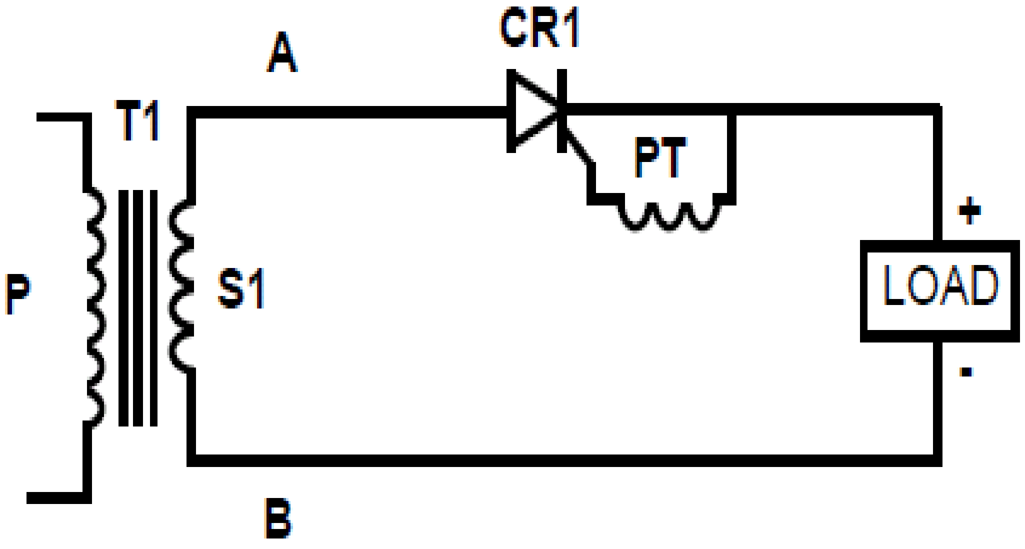
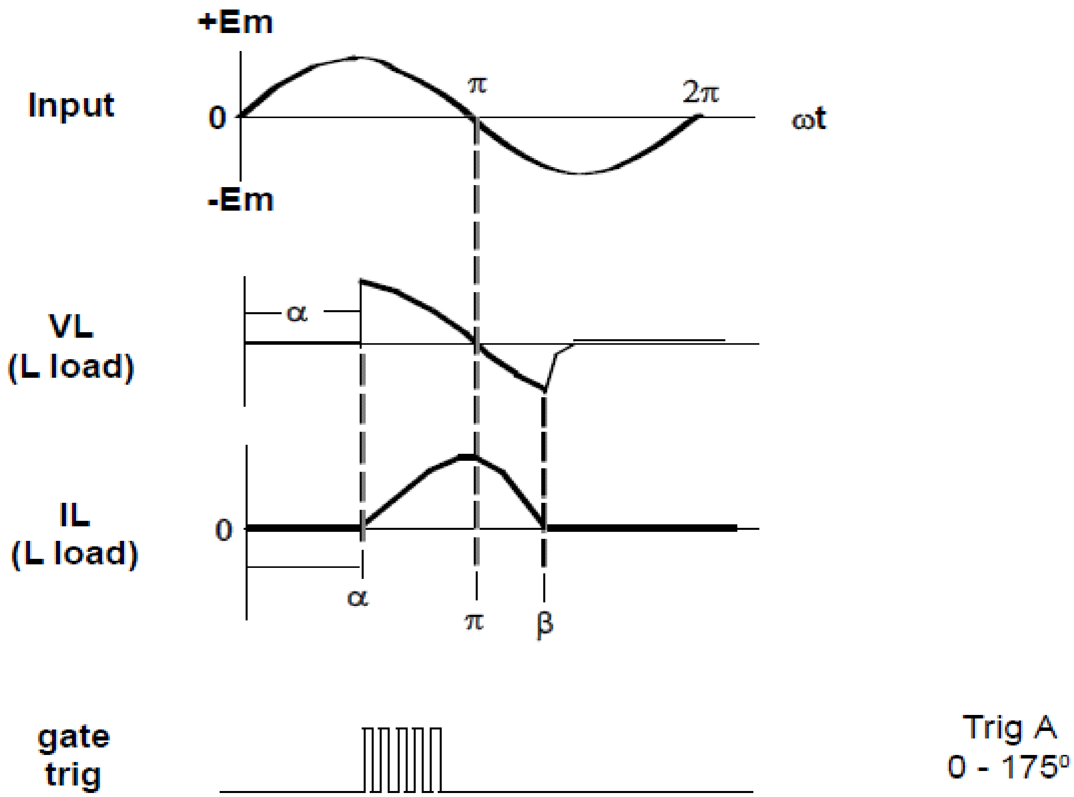

CR1
A
T1
PT
P
S1
+
LOAD
-
B

Fig 1

Eq circuit diagram of half wave controlled converter.


+Em
Input
0
π
2π
ωt
-Em
VL
(L load)
α
IL
(L load)
0
α
π
β
gate
trig
Trig A
0 - 175°

Experiment procedure

Object : To study input - output waveform of single phase fully controlled half wave / full wave converter circuit with LR load.
Other apparatus required : Dual trace CRO , multimeter. Select MODE to HALF (wave).

1. Keep α control pot at centre i.e. midway of its travel. Switch on power.
2. Connect CRO ch A across the T1, transformer secondary (between socket AC' close to power on) to display input ac single waveform upon CRO screen adjusting its volt and time / div controls. Trigger CRO with this signal.
3. Connect multimeter across given load sockets as shown in fig 3. Connect ch B of CRO at rectifer dc output marked (Attenuated) with + and - marking in such manner that CRO ground lead should be connected with -ve socket.
4. Observe and trace the waveform upon paper. Observe the -ve leading portion of output voltage after zero crossing (negative voltage part).
5. Change the firing angle α at different positions (measuring by CRO) and observe its effect upon the output voltage waveforms. Note dc output voltage VL, by multimeter. Disconnect the CRO lead from transformer secondary and connect it across 5 Ω resistance to observe load current waveform. Observe that the motor speed vary with the firing angle α (the converter output is related linearly with α). To observe the line current, disconnect the CRO from load current and connect it across 5 α sockets . Care should be taken that CRO should not be connect across input. For refrence see waveforms at previous pages. Now select FULL , MODE to convert circuit in full wave bridge.
Repeat the steps from 3 and note the observations.

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Connection Diagram:-

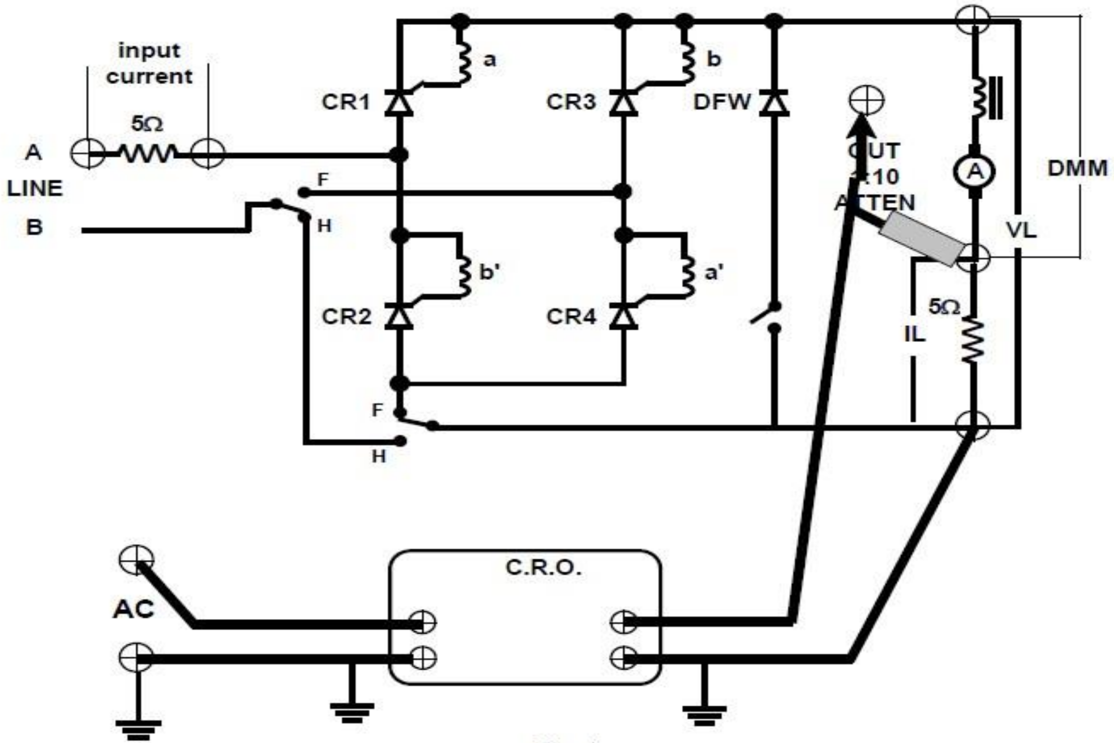
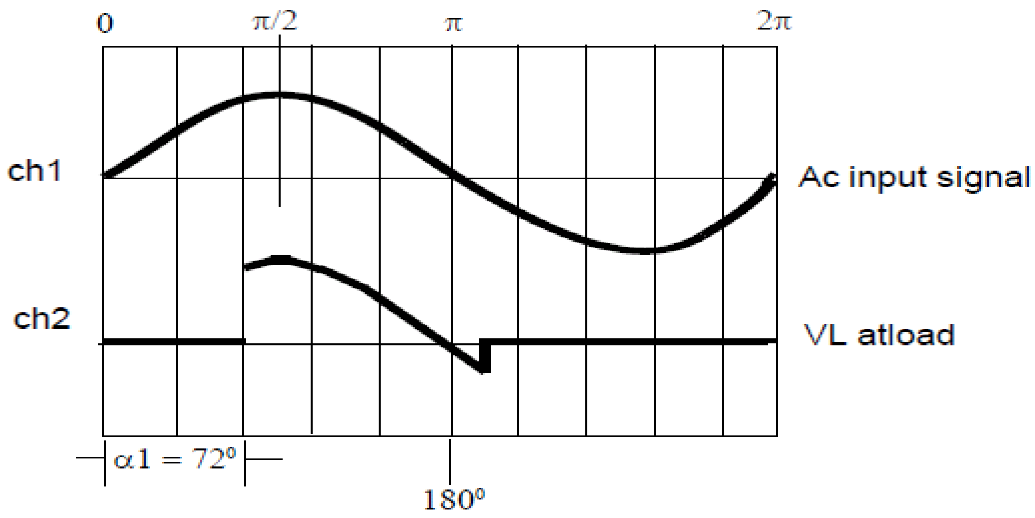


Fig 1.
The PT connections for exp.


0
π/2
π
2π
ch1
Ac input signal
ch2
VL atload
α1 = 72⁰
180⁰

Measurement of α.

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Result:-

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Experiment:-8

AIM:- SINGLE PHASE NON - CIRCULATING BRIDGE CYCLOCONVERTER (AC induction motor speed control)

Theory :-The given set up works upon an isolated ac source which provide ac supplies to the resistive or inductive load through dual converter configurrated as bridge cycloconverter. The complete system is block printed upon the panel. A clear look upon the system is made covering the entire set up with see through cover. In panel layout systematic circuitry is given, and four operating controls are given which are (1) the power on / off toggle switch meant for apply ac power to the cycloconverter, (2) load select toggle switch selct the inductive or the resitive load connected across the output, (3) the mode control selector which select the frequency 25,16.3 and 12.5 Hz as F/2,F/3 and F/4. A cycloconverter oftenly called as 'cycle converter' changes the frequency of a single (or three phase) alternating power source without an intermediate ac to dc conversion stage. A cycloconverter require multiple control device of a single or three phase excitation, and are limited to low output frequency only. The output of a cycloconverter has a relatively large ripple voltages but comparatively small ripple currents, which is what contributes to motor heating. One thing is to be pointed out that higher the output frequency higher the ripple currents will be since there will be fewer supply pulses per output cycle. This practically limit the upper frequency of a cycloconverter to 1/4 if a half converter is used and 1/3 if a full converter is used. The cycloconverter applications are in elevaters, traction motors , in aircrafts and some other places where low speed is required without using gears. There are two types of cycloconverters in single phase input to single phase output, one is the midpoint cycloconverter and other is bridge configurrated.

The single phase bridge cycloconverter :

As the name state it is a single phase input and single phase output cycloconverter, where the power and frequency reduction is controlled by bridge configurrated converters. Since it is ac to ac converter thus dual converter is used one to convert positive half cycle and other for conversion of negative half cycle. In fig 1, such cycloconverter is shown. There are two bridge configurrated circuits shown as P group and N group. When input line A is positive w.r.t line B and positive conversion required the bridge P group is gated such pair of SCRs CR1 and CR4 conducts simultaneously.

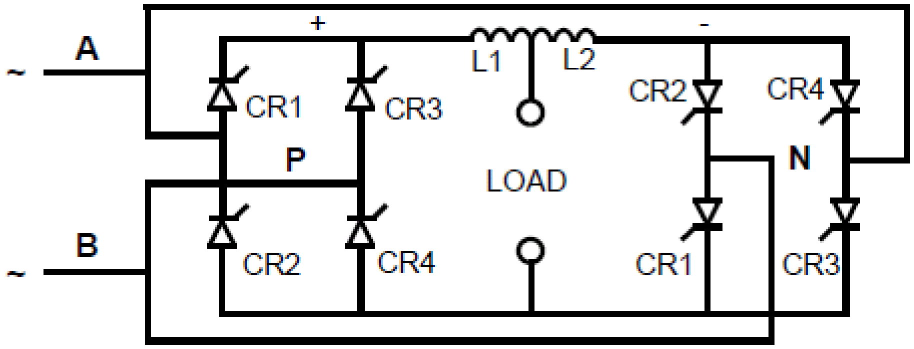

FIG 1.
The bridge configurrated single phase cycloconverter

Circuit Diagram:-

Experiment procedure:-
Object : To study single phase bridge cycloconverter output characteristics.
To reduce induction motor speed by freq conversion.
Other apparatus required : Dual trace CRO.

1. Keep α 'ADJUST' control at centre of its travel.
2. Connect CRO one channel with the AC, socket situated at secondary of T, and the other channel across the VM sockets which are attenuated to observe the output voltage waveforms. [Attenuation 1 : 25]
3. Select output frequency F/2. Switch on power. The cycloconverter output waveform will be get stable within few cycle. Adjust CRO time base to display two waveforms one for input and other for output. Trigger CRO from output waveform [VM].
5. Adjust firing angle control potentiometer for different settings for symmetrical waveform and observe its effect upon the output waveform amplitude and wave shape.
6. Now disconnect CRO from AC socket and connect it across IM socket. Observe the current waveform. Trace it upon paper and find out the frequency of fundamental current (25 Hz).
7. Now select the frequency f = 1/3. Observe the voltage and current waveforms.
Find out frequency of fundamental current (16.3 Hz).
8. In same way find out the frequency at f = 1/4 (12.5 Hz). Now the induction motor speed is proptional to frequency as given by, N (rpm) = 120f/P where f is frequency and P are No. of poles (4). As the frequency is converted low in submultiples of input frequency the motor speed is reduced, which can be observed by shaft speed.

Waveform:-

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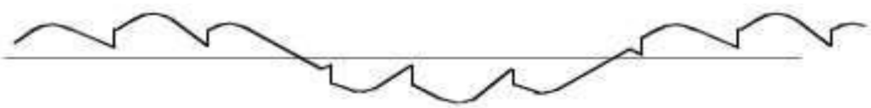
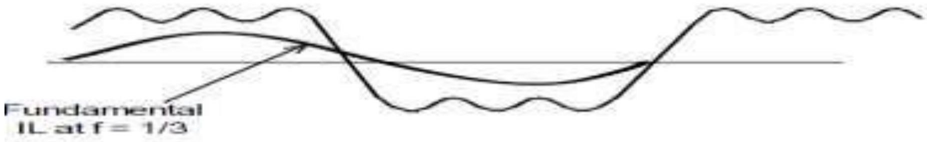
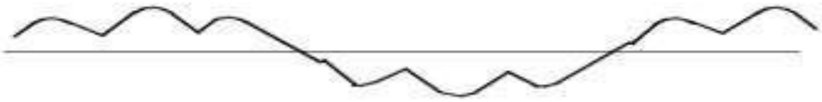


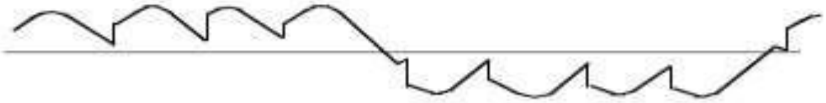
V. Waveform. f =1/3
α 30°



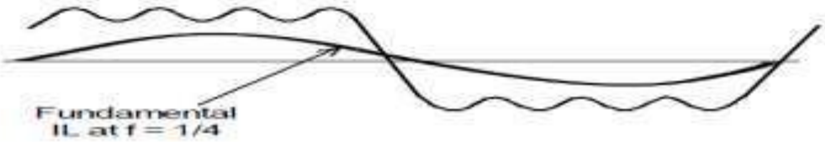
I. Waveform. f = 1/3
α 30°



V. Waveform. f =1/3
α 5°



V. Waveform. f =1/4
α 30°



I. Waveform. f = 1/4
α 30°

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Experiment-9

Aim:- STUDY OF FIRING CIRCUIT FOR THYRISTOR CIRCUITS (based upon ICs 555,3140 & 7408)

Circuit theory :- In ac circuits the SCR can be turned on at any angle α with respect to the applied voltage polarity. The angle α is oftenly called the firing angle. Power If load is resistive only than there is no need of commutation since SCR is turned off when current passed through it becomes zero during crossover point of the input cycle. Which is called line synchronization. The line synchronization signal is taken from step down transformer T1 secondary and fed to RESET pin of IC1(NE555). This cause to reset 555 at end of each half cycle, thus its output is line synchronized. The input half wave signal start timer 555 (IC1), which generate a saw tooth voltage (0 - 2.5V approx) across timing capacitor. This saw tooth wave is then compared with dc reference voltage (VR) obtained from alpha control potentiometer (VAR) , at IC2 inputs. The compared output fix the position of firing angle α. The comparator output is AND ed (IC4, 74LS08) with output of pulse generator IC3,(NE 555)called carrier modulation to obtain high frequency (1KHz approx) gating pulses. The output of this AND gate again then AND ed again with the half wave rectified outputs (F and F') of synchronizing transformer, which gives the firing angles (α) and (α +π).

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study of firing ckt for thyristor - 2

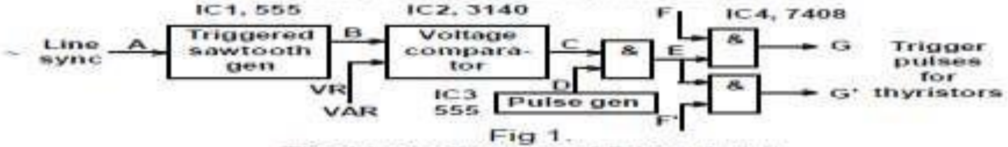
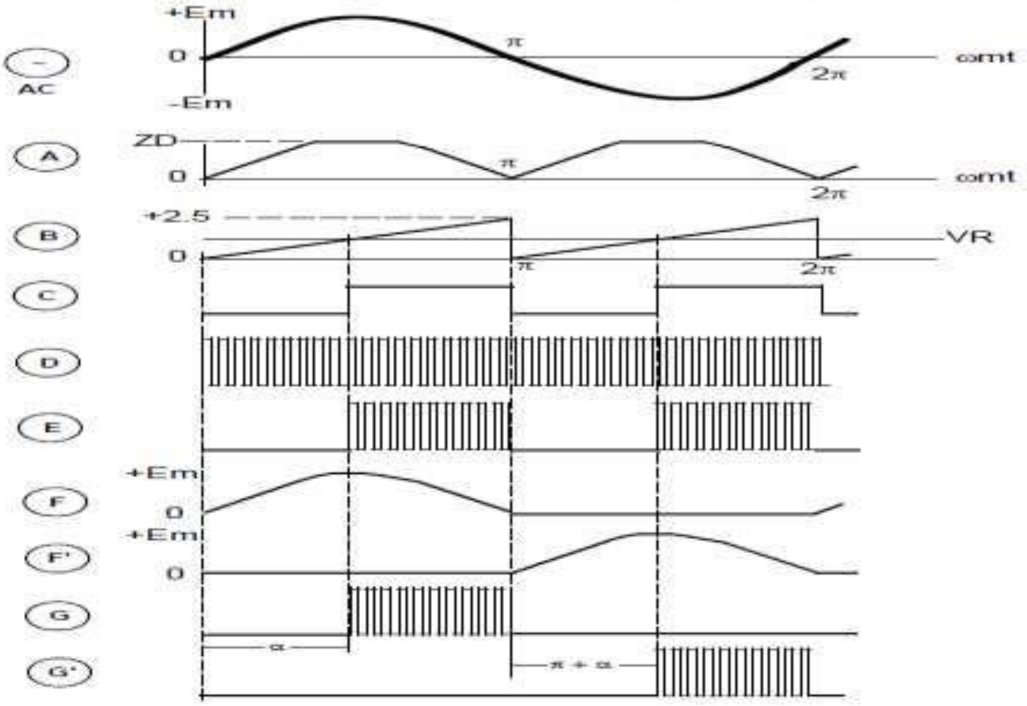

IC1, 555
IC2, 3140
IC4, 7408
Line sync
A
Triggered sawtooth gen
B
Voltage compara-tor
C
&
E
F
&
G
&
G'
Trigger pulses for thyristors
VR
VAR
IC3 555
D
Pulse gen
F'

Fig 1.
The block diagram of firing circuit
below waveforms at different points



Procedure : (CRO required)

1. Connect one channel of CRO with AC and (ground) COM socket. Connect other channel across given sockets and trace the waveforms.
2. Vary the position of pot (VAR) and observe its effect upon the output waveform (the α position). Observe the waveforms given in previous page.

Note : The thyristor trigger upon very first pulse, however in case of inductive load the wider pulse duration required. Since the frequency of pulses is high, therefore little gate current dissipate after trigger of thyristor. The control characteristics (the control voltage, VR v/s α) is inversely proportional and linear function, see below. The voltage VR can measured at given socket.