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Synthesis, Design and Implementation of Power Electronic Converter using Electronic Triggering Circuit for Pedagogic Applications

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ABSTRACT

Thyristors are now widely used for power control inboth DC and AC circuits. Different methods are commonly used to provide voltage-controlled thyristor schemes. A number of different circuits can be used to provide load voltage variation to a Single phase and Three phase load using the phase control method.

Firing angle 'a'is required to control the phase of half bridge, center tapped and full bridge rectifier circuits. The desired firing angle 'a' is given by this firing circuit. This uses the operational amplifier, transforms the Synchronizing signal into the Ramp wave and this is compared with the variable DC to get required pulse. The negative pulse is eliminated by using diodes.

Closed loop operation to maintain the constant voltage for like battery charging. Because of load fluctuations, output voltage may vary then is automatically adjust the firing angle to maintain the constant voltage by using PI controller

KEYWORDS: *Thyristors, Load, OP-Amps, Pulse*

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I. Introduction

For accurate SCR gating, the firing circuitmust be synchronized with the AC line voltage being applied anode to cathode across the device. Without synchronization, the SCR firing would be random in nature and the system response erratic.

In closed-loop systems, such as motor control, an error detector circuit computes the required firing angle based on the system set point and the actual system output. The firing circuit is able to sense the start of the cycle, and, based on aninput from the error detector, delay the firing pulse until the proper time in the cycle to provide the desired output voltage. An analogy of a firing circuit would be an automobile distributor which advances or retards the spark plug firing based on the action of the vacuum advance mechanism. In analog control systems the error detector circuit is usually an integrated circuit operational amplifier which takes reference and system feedback inputs and computes the amount of error(difference) between the actual output voltage and the desired setpoint value. Even though the SCR is an analog device, now-a-days control systems are microprocessor based, digital, firing circuit to sense the AC line zero -crossing, measure feedback and compare it with the setpoint, and generate the required firing angle to hold the system in-balance.

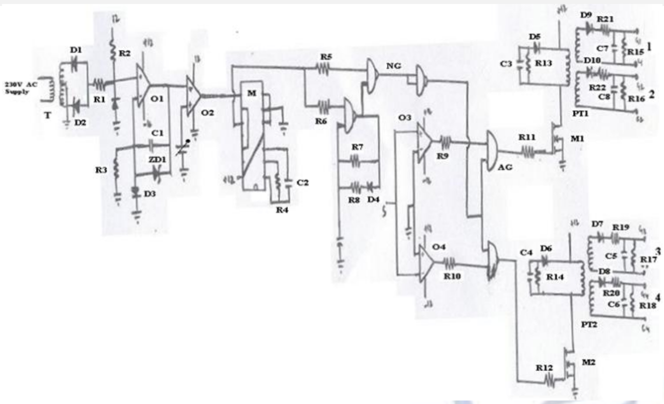


Fig 1Synchronization of firing Circuit with supply

Components and their values

1. T = 12-0-12 Center tapped transformer(230 – 12),
2. D1, D2, & D3 are IN4007,
3. D4 - D10 are FR 105,
4. R2 - R6 and R8 are 10K,
5. R11 and R12 are 270Ω,
6. R13 and R14 are 47Ω,
7. R15 – R22 are 10KΩ,
8. C1= 0.1μF, C2= 9nF, C3 and C4 = 0.47μF and C5 – C8 ARE 0.1μF,
9. Z_{D1}= Zener Diode (Zener clamped voltage 6.8),
10. O1, O3 AND O4 are LM324N OP-AMP,
11. O2=UA741CN OP-AMP,
12. NG= NAND GATE 4093B,
13. AG= AND GATE 4081BP,
14. M=CD4047BE MonostableMultivibrator and
15. M1 and M2 are MOS FETS IFR640

PT1 and PT2 are Three pin Pulse transformers 4503

II. Construction and Operating principle

The main motive of the circuit is to generate a firing pulse to the half bridge rectifier, center tapped rectifier and full bridge rectifier. It consist of power supply circuit, biasing point, synchronizing circuit, mono stable multi vibrator, gated oscillator, separator circuit and the firing circuit.

(a) Power Supply

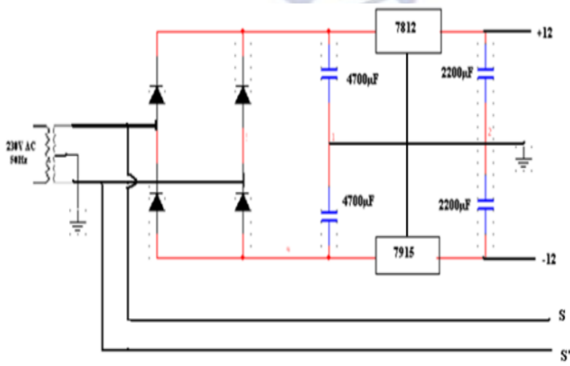


Fig 2 Power supply circuit

Centre tapped transformer is connected to the bridge rectifier then the rectifier two output pins are connected to the 7812 and 7915 regulators. With high capacitance at both input and output terminals because to maintain the constant output DC voltage for any load fluctuations. 7812 regulator is for the positive 12V and 7915 regulator is for the negative 12V DC. S and S' are the sinusoidal wave forms of the output wave forms of the power supply unit is drawn below.

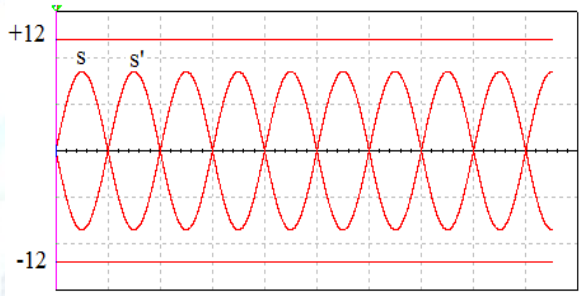


Fig 3 Output from power supply circuit

(b) Synchronization Circuit

As the figure below shows the transformer to which the circuit is connected is called as synchronizing transformer. Their inputs are connected to the same supply to which power circuit transformer is connected. The function of the synchronizing circuit is to drive low voltage signals to the control circuit which operates at low voltage these low voltage signals must besynchronized to the voltage supplied to the main power circuit. This is done by synchronizing transformer. The waveform at point 'a' is shown below. In between point 'a' and point 'b' we are having biasing circuit, by using this circuit wave form shifts towards positive side and negative part of the wave form is grounded by the diode. The wave form at point 'b' and 'c' are shown below.

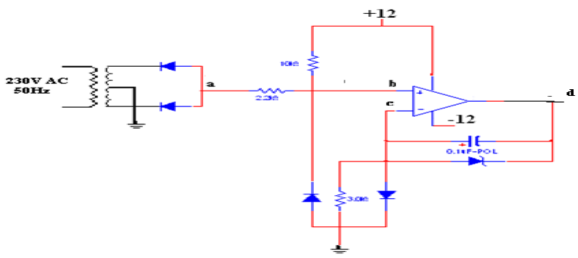


Fig 4 Synchronizing circuit

The operation of synchronizing circuit is shown in the wave forms. During the positive spike of the voltage wave available at non inverting terminal of the first op-amp output at point 'd' goes $+V_{sat}$. The zener diode (ZD) will be reverse biased and the diode is forward biased. Thus the capacitor will take an impulse voltage of 6.8V (Zener clamped voltage). During the negative part of the voltage wave, the circuit at point'd' goes $-V_{sat}$. Diode is reverse biased. The capacitor will discharge through the variable resistor, as shown in the circuit. This discharge generates the rampwave form at point 'd' The final output of this circuit is Ramp wave form which is synchronized with the input sinusoidal wave form at point'd'.

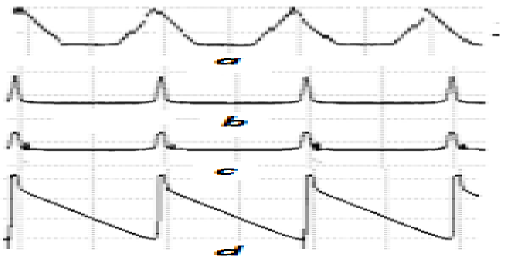


Fig 5 Output from the synchronizing circuit

(c)Comparator Circuit

The output of the synchronization circuit is given to the inverting terminal and variable DC voltage is given to the non-inverting terminal of the UA741CN Op-amp. It compares the two inputs and produces the square pulse at the output terminal. The output pulses of different DC levels are shown below.

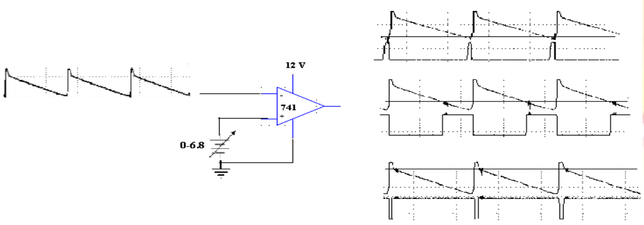


Fig 6 Comparator Circuit and it's output

(d) MonostableMultivibrator

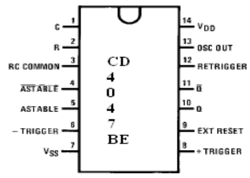
(i)General Description

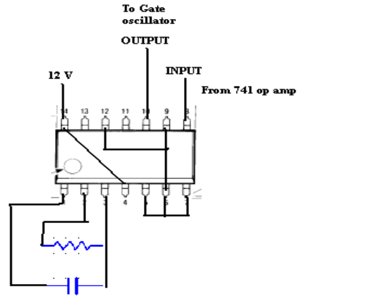
The CD4047B is capable of operating in either the monostable or astable mode. It requires an external capacitor (between pins 1 and 3) and an external resistor (between pins 2 and 3) to determine the output pulse width in the monostable mode, and the output frequency in the astable mode. Monostable operation is obtained when the device is triggered by LOW-to-HIGH transition at + trigger input or HIGH-to-LOW transition at - trigger input. The device can be retriggered by applying a simultaneous LOW-to-HIGH transition to both the + trigger and retrigger inputs. A high level on Reset input resets the outputs Q to LOW, Q to HIGH.

The reason for using this Monostable multivibrator is to reduce the loading effect. By increasing the value of variable DC in the comparator circuit pulse width is increasing. This pulse is AND with high frequency pulse at Gated oscillator than load affects the input dc voltage. In order to reduce that effect theMonostableMultivibrator is used in the present project. By using this constant pulse irrespective of the width of the pulse of comparator output are generated.

Table 1 Function table of monostablemultivibrator

Function	Terminal Connections			Output Pulse From	Typical Output Period or Pulse Width
	To V_{DD}	To V_{SS}	Input Pulse To		
Monostable Multivibrator					
Positive-Edge Trigger	4, 14	5, 6, 7, 9, 12	8	10, 11	
Negative-Edge Trigger	4, 8, 14	5, 7, 9, 12	6	10, 11	t_M (10, 11) = 2.48 RC
Retriggerable	4, 14	5, 6, 7, 9	8, 12	10, 11	
External Countdown (Note 1)	14	5, 6, 7, 8, 9, 12	Figure 1	Figure 1	Figure 1

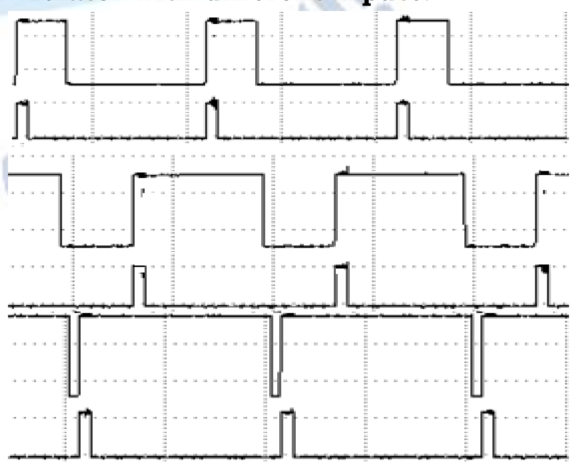




(ii) Features of MonostableMultivibrator

1. Positive or negative-edge trigger
2. Output pulse width independent of trigger pulse duration
3. Retriggerable option for pulse width expansion
4. Long pulse widths possible using small RC components by means of externalcounter provision.
5. Fast recovery time essentially independent of pulse width.
6. Pulse-width accuracy maintained as duty cycles approaching 100%.

(iii) Output wave forms of monostabe multi-vibrator with different inputs.



(e) Gated Oscillator

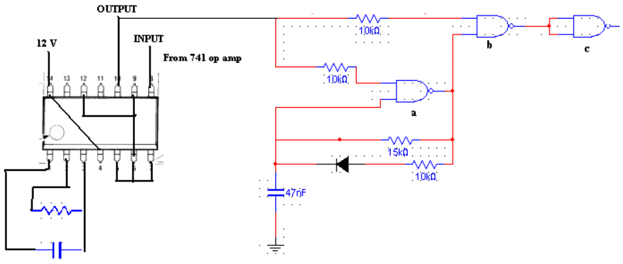


Fig 7 Gated oscillator circuit

By using gated oscillator circuit one can generate more number of pulse in one pulse of the MonostableMultivibrator. When one input of the NAND 'a' is high and assume that second input of the NAND 'a' is low then the output of this NAND is high, nothing but $+V_{sat}$. So capacitor is charged through 10kΩ resister and diode.When it is fully charged second input of the NAND gate 'a' is high then the output of this NAND gate is low. Then the diode is reverse biased. So it discharges with 15kΩ resister. Then one pulse is generated at output at NAND gate 'a'. The time taken for charging and discharging is very low, that means very high frequency. This will be the actual output of the monostable multivibrator. So in one pulse, number of pulse generated by using gated oscillator. The output wave forms are shown below

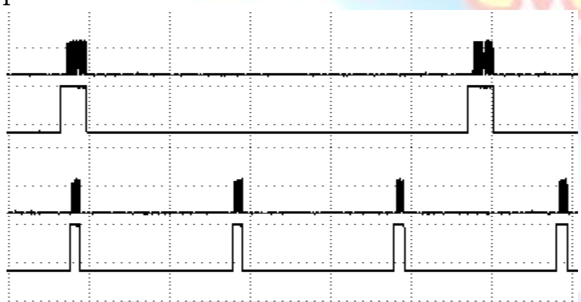


Fig 8 Output waveform of gated oscillator

(f) Pulse Separator Circuit

Actually in full wave rectifier there are four Thyristors. In those four Thyristors two are fired with first half pulse and another two are fired with second half pulse. Both the pulses are available at gated oscillator. So as to separate both the pulse two LM324N op-amps are used. One op-amp inverting and another op-amp non-inverting are grounded. And remaining two inputs are connected to the pulse transformer output terminal 'S'. Negative part of the pulse is grounded by the diodes. One input of two AND gates are shorted and given to the gated oscillator output. First AND gate output has number of pulse in first half cycle and second AND gate output has number of pulse in second half cycle. Output wave forms AND gate are as shown below.

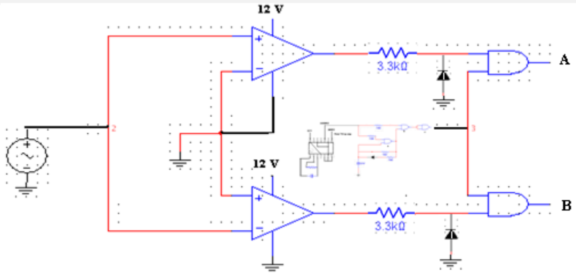


Fig 9 Pulse separator circuit

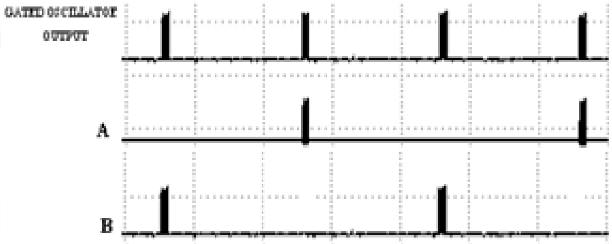
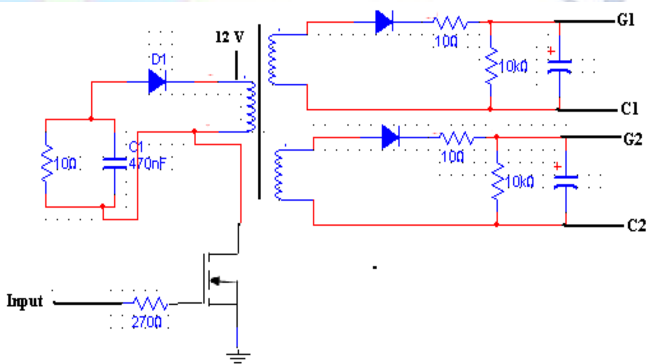


Fig 10 Output waveform of Pulse separator

(g) Firing Circuit

The main motive of the circuit is to provide isolation between control circuit and power circuit using a three pin pulse transformer 4503.When positive pulse given at the input of the firing circuit MOSFET IRF640 is turned on. Then the firing pulse is obtained at Gate and Cathode terminals. This firing pulse is similar to the input pulse of the firing circuit.The following circuit is used for half bridge thyristor rectifier. It requires one firing pulse in one half cycle.So this circuit is sufficient for half bridgeas it is having one thyristor.



. *Fig 11 Firing Circuit*

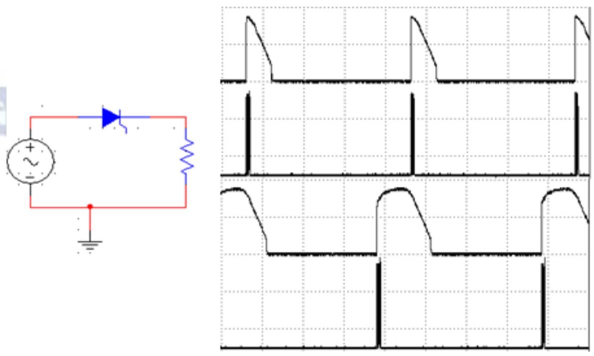


Fig 12 1-Phase half bridge circuit

Full bridge Centre tapped transformer rectifier is having two Thyristors. Thyristor T1 is controlled in the first half cycle, and thyristor T2 is controlled in the second half cycle. So in the following circuit to work pulse transformers 1 and 3 or 2 and 4; G1,C1 and G3, C3 are required. Remaining two pulse transformers are standby units.

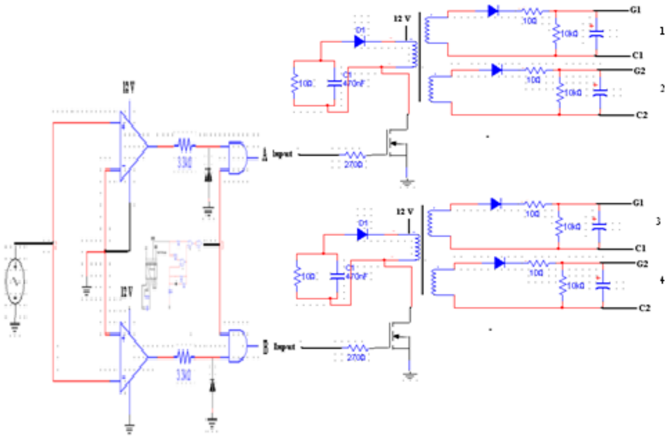


Fig 13 Full bridge centre tapped transformer rectifier

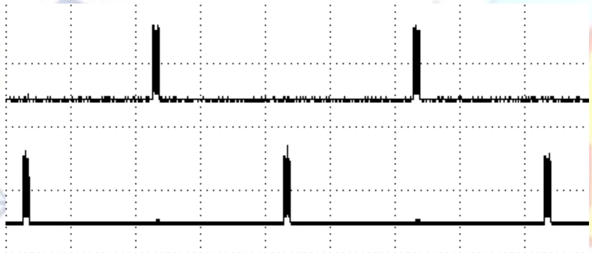


Fig 14 Output Full bridge centre tapped transformer rectifier

The circuit arrangement of a single-phase **Full converter** is shown below. During the positive half cycle thyristor T1 and T4 are forward biased. And these tow Thyristors are fired simultaneously at 'α' , the load is connected to the input supply through T1 andT4. If it is inductive load T1 and T4 will continue to conduct beyond 'α'. During the negative half cycle of the input voltage , Thyristors T2 and T3 are forward biased; and firing of thyristors T2 and T3 will supply voltage across Thyristor T1 and T4 as reverse blocking voltage. T1 and T4 are turned off due to line or natural commutation.

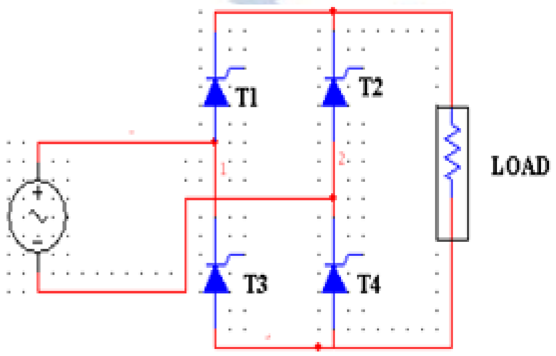


Fig 15 1-Phase full converter

III. Closed Loop Operation

Following circuit is used for the closed loop operation using an op-amm, which describes how the battery-charger can be controlled in closed-loop. Traditionally systems use controllers such as a PI controller or a PID controller for feedback control. By using this one can maintain constant speed of the motor for any voltage fluctuations.

Supply (-12) is connected to the resistor and Zener diode, which is clamped at a voltage of 6.8V. So the non-inverting terminal voltage of an Op-amp is 6.8V, by varying the resistance R3. Rectifier output is connected to the inductor and capacitor. So DC voltage is appears across the terminals 'a' and 'b'. By adjusting the values of R and R' set the value of DC voltage equal to Zener clamped voltage 6.8V. In case of any disturbance, rectifier output may change. In order to make it constant one should vary the firing angle. If any fluctuations in voltage at point 'c', then potential deference is there at non inverting terminal of op-amp, then automatically adjust the firing angle through SPDT switch.

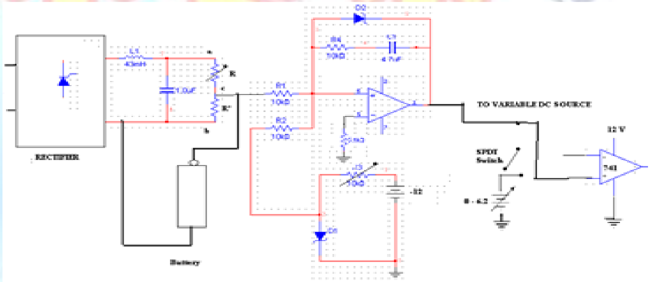


Fig 16 Closed loop operation

IV. Three Phase Controlled Rectifier Circuit

The three phase bridge rectifier has six Thyristors as shown in above figure. The upper thyristors are called positive group and lower thyristors are called negative group. At any instant of time one thyristor from each leg is in conduction.

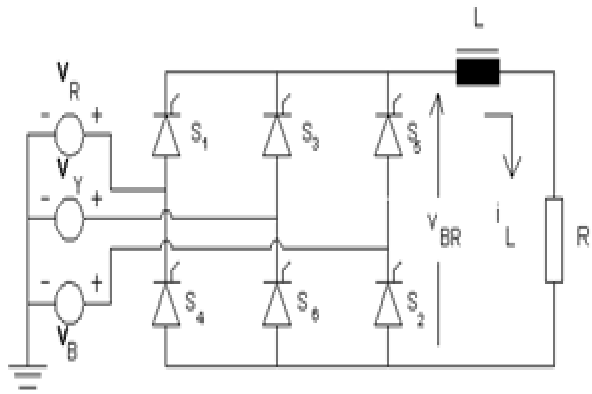


Fig 17 3-Phase full converter

If SCRs are used, their conduction can be delayed by choosing the desired firing angle. When the SCRs are fired at 0° firing angle, the output of the bridge rectifier would be the same as that of the circuit with diodes. For instance, it is seen that D_1 starts conducting only after θ = 30°. In fact, it can start conducting only after θ = 30°, since it is reverse-biased before θ = 30°. The bias across D_1 becomes zero when θ = 30° and diode D_1 starts getting forward - biased only after θ =30°. When $V_R(\theta)$ = E*Sin (θ), diode D_1 isreverse - biased before θ = 30° and It is forward - biased when $\theta > 30°$. When firing angle to SCRs is zero degree, S_1 is triggered when θ = 30°. This means that if a synchronizing signal is needed for triggering S_1, that signal voltage would lag $v_R(\theta)$ by 30° and if the firing angle is θ, SCR S_1 is triggered when θ = α + 30°. Given that the conduction is continuous, the following table presents the SCR pair in conduction at any instant.

Table 2 SCR conduction sequence

Period, range of α	SCR Pair in conduction
□ + 30° to □ + 90°	S_1 and S_6
□ + 90° to □ + 150°	S_1 and S_2
□ + 150° to □ + 21(	S_2 and S_3
□ + 210° to □ + 27(	S_3 and S_4
□ + 270° to □ + 33(	S_4 and S_5
□ + 330° to □ + 360° ar + 0° to □ + 30°	S_5 and S_6

(a)Three-phase Controlled rectifier Firing Circuit

The figure shows bellow is three phase firing circuit. Compared to single phase circuit it requires firing pulse for every 120 degrees so three similar single phase firing circuits are connected to the three phase transformer. Then it produces firing pulse individually for every 120 degrees. But at the comparator circuit there is a DC value it should be same for every individual circuit. 2, 4 and 6 pulse transformer outputs are need to have 60°delay to 1, 3 and 5 respectively for that we need to have a back up pulse to every pulse transformer.

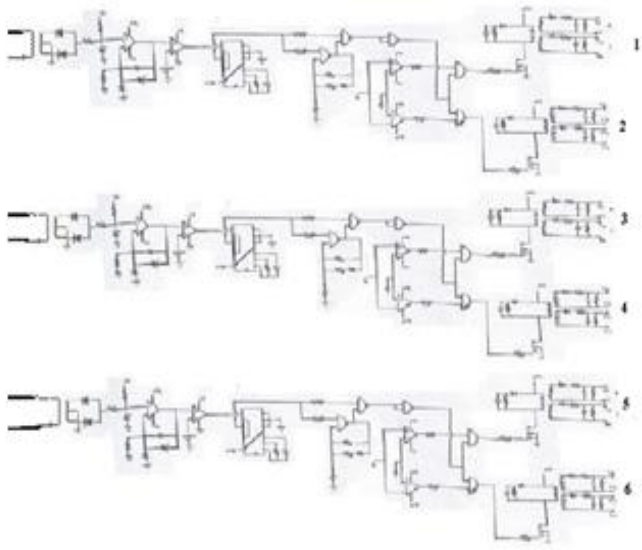


Fig 18 Firing circuit of three phase rectifier

V. Single phase and three phase Dual converter

If two of full converters are connected back to back as shown in fig below both the output voltage and the load current flow can be reversed. The system will provide Four-quadrant operation and is called a dual converter. Dual converter is normally used in high power variable speed drives. If α1 and α2 are the delay angles of converter 1 and 2, respectively. The delay angles are controlled such that one converter operates as **Rectifier** and other converter operates as **Inverter**; but both converters produce the same average voltage output. The output wave forms for two converters, where the two average output voltages are the same.

If rectifier firing at α, then the inverter should fire at π- α.

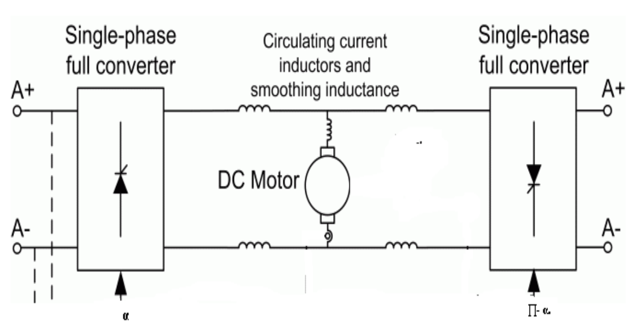


Fig 19 Dual converter

VI. Simulation of Dual Converter Firing Circuit

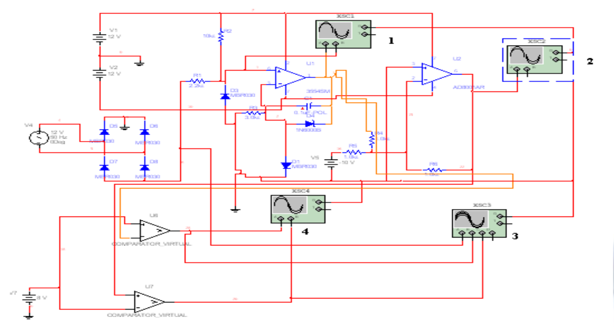


Fig 20 Dual converter firing circuit

Above diagram shows that simulation of dual converter firing pulse generation. Initially the ramp signal is generated then it is compared with the -10V. Both the ramps are compared with the variable DC source. Then the αandπ- αpulses are obtained. If these pulses are fed individually AND with gated oscillator then the required firing pulses are obtained as shown in figure below.

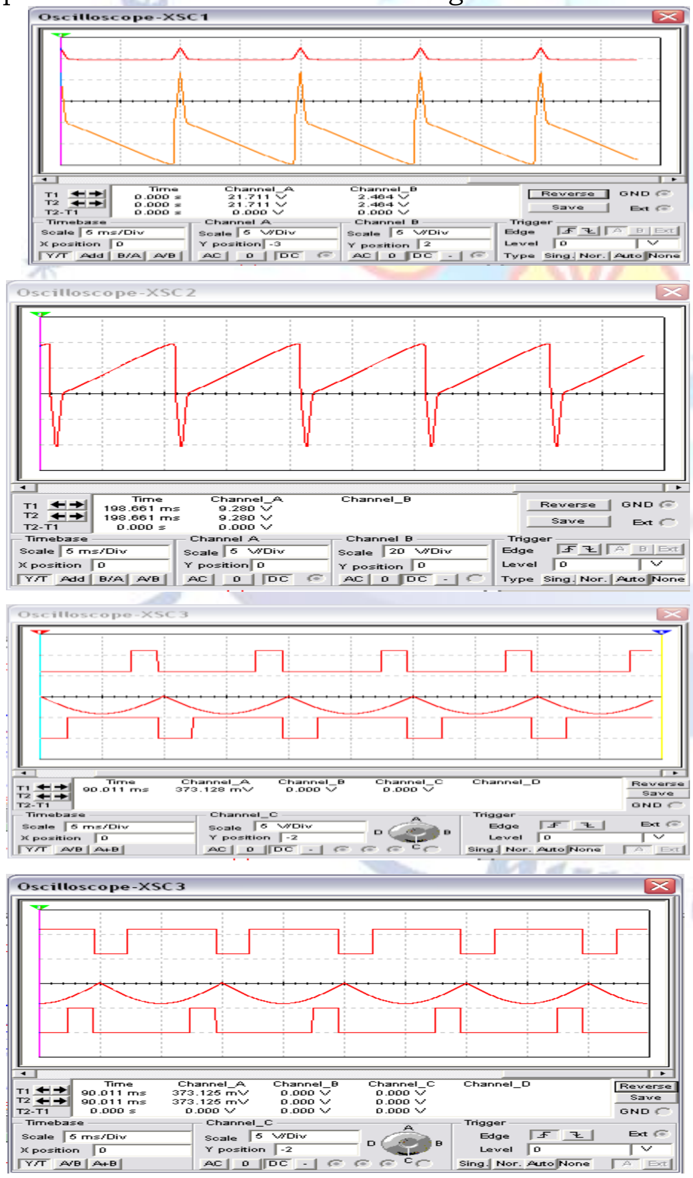


Fig 21 Firing circuit of a dual converter

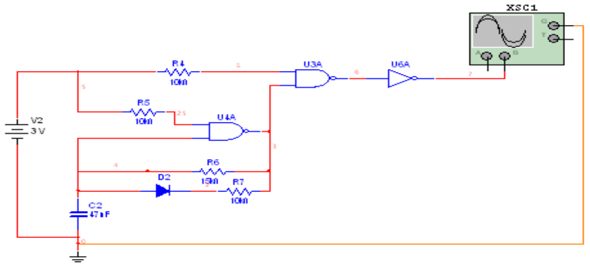


Fig 22 Gated oscillator circuit

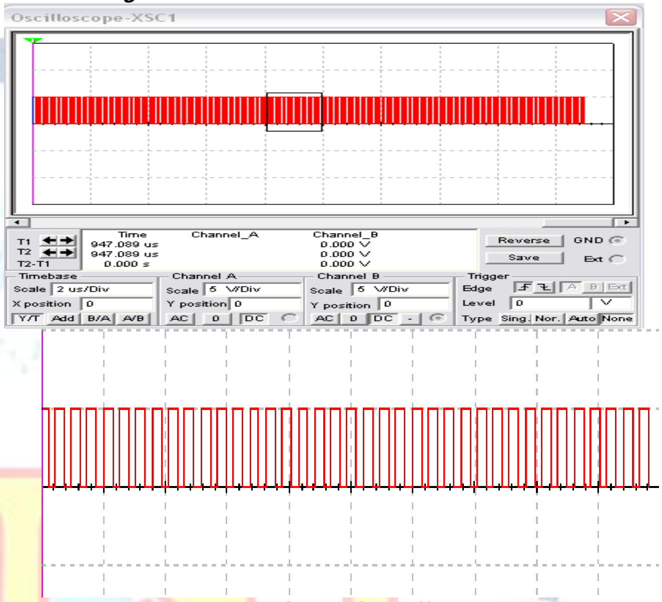
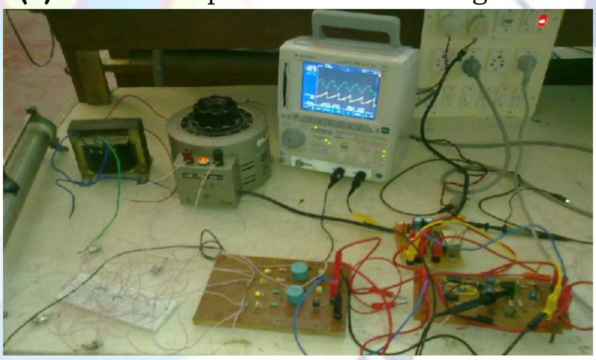


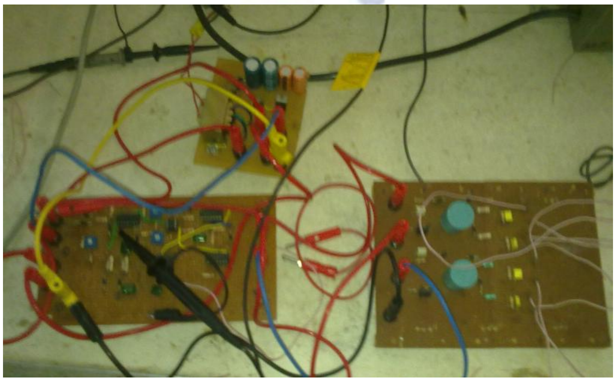
Fig 23 Output of Gated oscillator circuit

VII. Experimental Results

(a) Practical implementation of firing circuit



(b) Control circuit

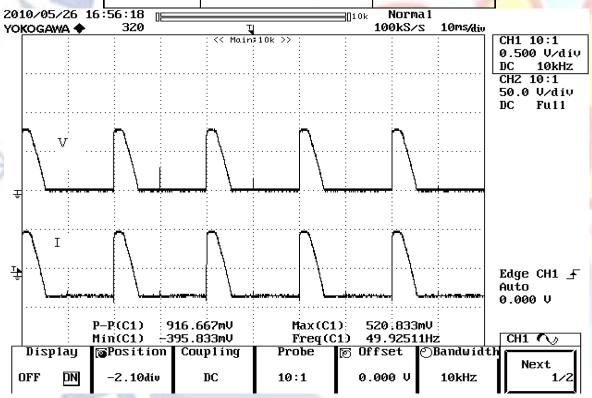


(c) Speed control of DC Motor using single phase rectifier

(d) Output Wave Forms Of Half Bridge Rectifier at different Firing Angles

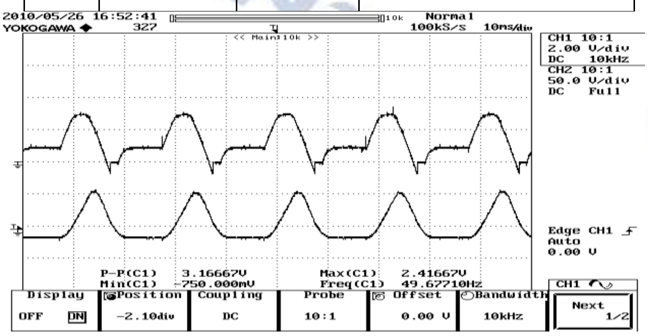
With **R-** Load

S No	Firing angle	Va
1	α=90%	4.34V
2	α=50%	14.11V
3	α=5%	24.89V



With **RLE** Load

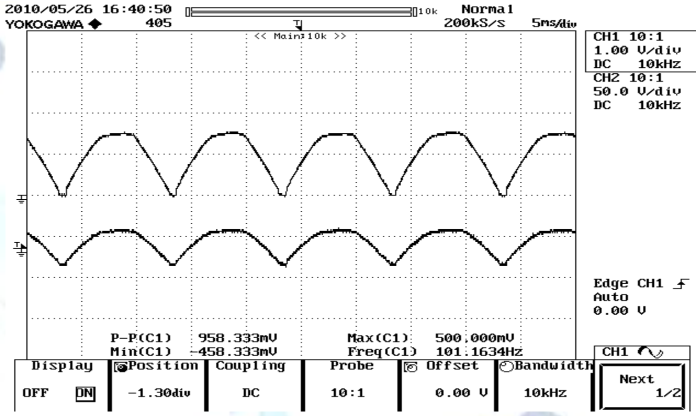
S No	Firing angle	Va	Vs 2V/1000(Rev/Min)
1	α=90%	4.2V	1.12V
2	α=50%	10.3V	3.06V
3	α=5%	24.89V	9.42V



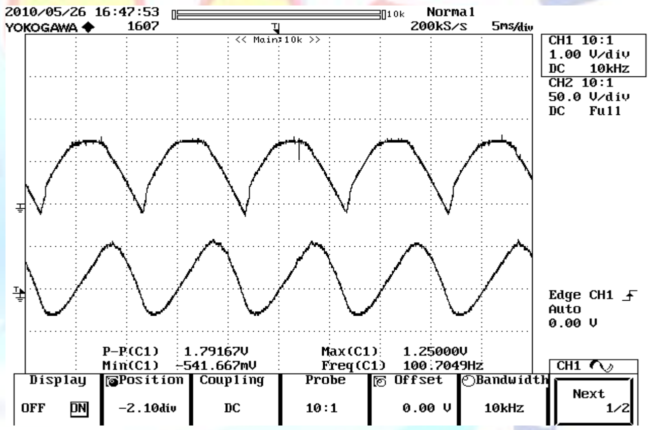
(e) Output wave forms of full bridge rectifier at deferent firing angles

With 'R' load

S.No	Firing angle	V_a
1	α=90%	2.73V
2	α=50%	28.7V
3	α=5%	49.5V



With ' RLE' load



VIII. Conclusion

The Synchronized firing scheme for thyristor, working under single phase and three phase rectifiers is practically implemented. Dual converter firing angles are also obtained by using this scheme.

Practically the entire scheme is implemented and it is compares with simulation.

The closed loop mechanism is also implemented to maintain the constant output voltage by adjusting the PI controller. Which automatically adjust the firing angle practically.

By using this scheme one can control the speed of separately excited DC Motor and other applications like battery charging units, FACT devices, and other power system applications.

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