

**DESIGN AND IMPLEMENTATION OF  
FIRING CIRCUIT USING  
COSINE CONTROL SCHEME**

*Thesis submitted in partial fulfilment of requirement for the award of degree of*

**MASTER OF ENGINEERING  
IN  
POWER SYSTEMS**

**Submitted by:**

**ASHISH AGRAHARI**

**Roll No-801241003**

**Under the supervision of:**

**Mr. SHAILESH KUMAR**

**LECTURER, EIED**



**ELECTRICAL AND INSTRUMENTATION ENGINEERING DEPARTMENT**

**THAPAR UNIVERSITY**

**PATIALA-147004**

**JULY-2014**

## CERTIFICATE

I, hereby, certify that the Thesis entitled “**Design and Implementation of firing circuit using cosine control scheme**” submitted in the partial fulfilment of the requirement for the degree of MASTER OF ENGINEERING in POWER SYSTEM, in the department of Electrical and Instrumentation Engineering, Thapar University, Patiala is an authentic work carried out by me under the guidance of **Mr. Shailesh Kumar**, Lecturer, EIED, Thapar University and refers other researcher’s works, which are duly listed in the reference section.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/institute for the award of any degree or diploma.

Date: 18 July, 2014

*Ashish Agrahari*

(Ashish Agrahari)

Roll no. 801241003

This is certifying that the above statement made by the student is correct and true to the best of my knowledge and belief.

Date: 18 July, 2014

*Shailesh Kumar*  
(Mr. Shailesh Kumar)

Lecturer, EIED

Thapar University

Countersigned by

*Dr. Ravinder Agrawal*  
(Dr. Ravinder Agrawal)

Professor and Head, EIED

Thapar University

*Dr. S.K. Mohapatra*  
(Dr. S.K. Mohapatra)

Dean (academic affairs)

Thapar University

## **ACKNOWLEDGEMENTS**

I am highly grateful to authorities of Thapar University, Patiala for providing this opportunity to carry out the thesis work.

I would like to express my sincere gratitude to my supervisor, **Mr. Shailesh Kumar**, Lecturer (EIED) for all his guidance and valuable advice throughout the progress. He has stimulated my interest in power engineering and inspired me for doing thesis on this topic.

**(ASHISH AGRAHARI)**

Roll No. 801241003

## **ABSTRACT**

Single phase fully controlled converter is used to convert the single phase AC into DC which is used for industrial applications such as DC motor loads. As per the industrial need, controlled DC voltage with linear transfer characteristic is important in many applications. The theme of this dissertation is to design and implement the firing circuit for the converter. The necessity of getting synchronised firing pulses for the gate of the thyristor is discussed. Most popular method cosine control scheme is described here and the functioning of each block is explained. Electric circuit of cosine control scheme has been tested on multisim software and hardware implemented on bread board. Both results have been captured. Experimental results obtained from oscillographic displays at important points are included.

## **LIST OF ABBREVIATIONS**

BJT	-	Bipolar Junction Transistor
MOSFET	-	Metal Oxide Semiconductor Field Effect Transistor
SCR	-	Silicon Controlled Rectifiers
IGBT	-	Insulated Gate Bipolar Transistor
PLL	-	Phase Locked Loop
VCO	-	Voltage Controlled Oscillator
UJT	-	Unipolar Junction Transistor
TCR	-	Thyristor Controlled Reactor
TCSC	-	Thyristor Controlled Series Converter
SVC	-	Static VAR Compensator
ZCD	-	Zero Crossing Detector
RMS	-	Root Mean Square
IC	-	Integrated Circuit
TSC	-	Thyristor Switched Capacitor

# CHAPTER1

## INTRODUCTION

### 1.1 Overview

Power electronic devices may be used as switches. An ideal switch is either open or closed and so dissipates no power; it withstands an applied voltage and passes no current, or passes any amount of current with no voltage drop. Semiconductor devices used as switches can approximate this ideal property and so most power electronic applications rely on switching devices on and off, which makes systems very efficient as very little power is wasted in the switch.

Several attributes dictate how devices are used. Devices such as diodes conduct when a forward voltage is applied and have no external control of the start of conduction. Devices such as thyristor, BJT and MOSFET transistors provide full switching control and can be turned on or off without regard to the current flow through them but Devices vary in switching speed. Some diodes and thyristors are suited for relatively slow speed and are useful for power frequency switching and control; certain thyristors are useful at a few kilohertz. Devices such as MOSFETS and BJTs can switch at tens of kilohertz up to a few megahertz in power applications, but with decreasing power levels so Power handling and dissipation of devices is also a critical factor in design. Power electronic devices may have to dissipate tens or hundreds of watts of waste heat, even switching as efficiently as possible between conducting and non-conducting states. In the switching mode, the power controlled is much larger than the power dissipated in the switch. The forward voltage drop in the conducting state translates into heat that must be dissipated. High power semiconductors require specialized heat sinks or active cooling systems to manage their junction temperature. Thyristors or Silicon Controlled Rectifiers (SCRs) [1]-[5] are widely used as a switching device in the medium and large power levels starting from few kilowatts to several mega watts at voltage levels of few hundred to several kilo volt levels. Insulated Gate Bipolar Transistors (IGBTs) are switching devices which have positive points over the MOSFETs and thyristors. The insulated-gate bipolar transistor (IGBT) is a three terminal power semiconductor device primarily used as an electronic switch and in newer

devices is noted for combining high efficiency and fast switching. However, their higher cost and inability to work at very high voltages makes SCR a better choice even today.

There are various methods for controlling the SCR by providing the pulses to the gate. Two popular methods are unit ramp signal and the cosine control method. In this dissertation, there is detailed description and functioning of each block of cosine wave crossing scheme is presented. The advantage of this method that the output voltage is proportional to the control voltage i.e., the output voltage is independent of variation in input voltage [25].

## 1.2 Literature Review

Here is review of some literature that is relevant to carry out this thesis work.

**Peter Geno et. al [6]** presented cosine wave crossing control is used for firing circuit. The advantage of this scheme is that the output voltage is proportional to the control voltage. He has included various protections like short circuit, under voltage and over voltage etc. The main purpose of this project is to design an efficient, simple, robust and economical control circuit.

**Gupta S.C. et al. [7]** presented delay angle function of a linear ramp or the cosine of the phase angle dissimilarity by using the generalized phase detector. A controlled offset voltage is introduced into the PLL to simulate an error signal within the loop. As the PLL tracks the reference signal, voltage control oscillator generates a phase coherent signal having a frequency which is a multiple of the reference frequency and possessing a finite phase difference with it, which is controllable. This signal gets locked with the line frequency signal and continuously tracks it. The phase detector compares the main line frequency with the VCO output after the counter.

**Shaikh A. B. et al. [8]** designed, simulated and fabricated a triggering circuit for converters used in DC drives applications. The objectives of this design incorporate the precise control of firing angle, provision for feed-back control for motor control applications and achieving pulse of designed nature.

**Ilango B. et al. [9]** presented the firing circuit for the three phase SCR bridge rectifiers used for industrial applications. It is a compact scheme using minimum integrated circuit components which gives a fast response for triggering angle correction and gives a full range control of voltage.

**Harade K. et al. [10]** presented a magnetic circuit to control the triggering of bridge inverter so that the area of the output voltage is independent of operating frequency and the variation DC source voltage.

**Abou-Elela M. et al. [11]** presented simple scheme for use in three phase firing circuit four wire ac voltage controller system it enables the firing circuit to adjust itself against any phase. It also detects if the system contains faulty thyristors.

**Subramanian K. et al. [12]** presented a linear ramp signal based synchronization technique has been propose and implemented successfully, for the capacitor switching operation of a simple power system. This feature leads to elimination of the phase locked-loop (PLL) control, are commonly used to synchronize the pulse generations with respect to the system the supply frequency.

**Saridis G. N. et al. [13]** presented a linear SCR control amplifier consist of two major portions fire circuit and bridge power circuit. The input signal is amplified and used to control the phase of UJT pulses. The relation between the input signal and firing angle is designed to be the inverse of the non linearity introduced by the power circuit. The power bridge balancing action is used to absorb the major portion of the negative power pulse caused by an inductive load and it improves the efficiency of the amplifier.

**Ainsworth J.D. et al. [14]** presented a thyristor controlled reactor(TCR) which is used to control the voltage of AC power system. It comprises a reactor in series with reverse parallel connected thyristor. A phase locked oscillator is used in which the oscillator controls the valve directly. A phase locked oscillator is sometimes used to establish a fixed phase for time reference.

**Daniels A.R. et al. [15]** presented a digital firing angle controller that can operate in conjunction with microcomputer or microprocessor for online control of DC machine using thyristor as a controller.

**Zaid S.A. et al. [16]** presented about thyristor controlled series converter which is the common circuit in SVC. TCSC is fired with firing circuit which are generated by the synchronization with sinusoidal line current. However the line current is not sinusoidal which contains some harmonics. He has discussed the possible firing technique for TCSC.

**Torseng S. et al. [17]** presented that the combination of TSC and TSR which is controlled by the thyristors. One method to damp power oscillation, using TSC with a certain

control strategy, is presented. The problem of unbalanced loads and load balancing methods has been also discussed. The whole combined system does not generate any harmonics.

**Tang Pei-Chong** *et al.* [18] has presented a microprocessor-based firing scheme. Together with software algorithm in microprocessor, the digitized ac power signals are used to find the correct firing output signals. This scheme uses less hardware components and has higher dynamic performance in four-quadrant operation.

**Simard Remy** *et al.* [19] presented equidistant pulse scheme, a single pulse train is generated whose phase can be shifted with respect to a control voltage. A ring counter is used to direct the train of pulses in six different paths through pulse amplifiers and isolating transformers. A maximum number of integrated circuits is used and the total number of discrete components is reduced to a minimum such as required for integrated circuits.

**Mirbod Ali** *et al.* [20] presented an advanced microprocessor-based control system for a phase-controlled rectifier which has the above-mentioned desired characteristics. It has a constant open loop gain even for the cases where the converter is fed by a weak ac system of unregulated frequency, while the processing delay of the control system is less than 20 $\mu$ s. With constantly declining microprocessor and digital hardware costs, the implementation of such a control system, for industrial applications, is relatively inexpensive.

**Rafique M. U.** *et al.* [21] presented a method which is fully isolated and provides full and stable control over the firing angle of the SCR from 0 to  $\pi$ . Isolation in interfacing of the high power AC/DC circuits from the low power digital control circuit is one of the key challenges in such designs. This method removes the pulse transformer that is not only expensive but also provides the means of magnetic coupling that is harmful for the circuit.

**Bolok H.M.** *et al.* [22] presented a microprocessor based scheme which can eliminate the use of three microprocessors with one microprocessor when it is working in variable three phase supply for inverse parallel connected thyristor to obtain the desired voltage variation.

**Krishnan Thadiappan** *et al.* [23] designed a thyristorized speed control unit for a separately excited DC motor. This motor is fed from a three phase fully controlled thyristor bridge. A loop of proportional and integral maintains a desired speed irrespective of load.

**Wade John Sperry** *et al.* [24] presented a scheme of common pulse triggering for a three-phase SCR bridge, which features a control circuit that derives its synchronization and power from the ripple potential of a three-phase half-wave rectifier, is the subject of this paper.

The ripple potential is separated from the average dc by clamping and after clipping is utilized as bias for a pulse forming UJT circuit. After firing the UJT is made to conduct for the balance of the bias waveform in order to prevent further pulses from forming and being applied to the SCRs through the pulse transformers. The three phase half-wave rectifier is conveniently in parallel across the delta-wye transformer bank that powers the output load. This design provides 25 to 100 percent control over the conduction angle.

**Lo Yu-Kang** *et al.* [25] presented a improved cosine control method for SCR. In this method monostable blocks is replaced by zero crossing detector (ZCD) and AND gates. The problem of bouncing of comparators output can be minimized by using the AND gates. So it prevents the false triggering of SCR.

**Kim J.M.S.** *et al.* [26] presented a DC magnet power supply which is based on frequency converter and a dual converter to solve the problem in conventional approach due to that there is the problem of power dissipation across the transistor banks. This method improve the dynamic response.

**Gupta Mukesh** *et al.* [27] presented a controlled electronics circuit by using cosine control method for a regulated dc voltage with linear transfer characteristic. He has also shown the desired results simulated in MATLAB/SIMULINK.

### **1.3 Objective of the Work**

The objective of the present work is to make firing scheme which linerarizes the transfer characteristic of bridge rectifier by using an indirect control variable as a substitute for firing angle and this scheme also provides automatic negative feedback to the change in input ac supply.

### **1.4 Organisation of the Thesis**

The work carried out in this thesis has been summarized in five chapters.

**Chapter1** briefs the overview of the problem, literature review, and objective of the work and it also consist of organization of the thesis.

**Chapter2** deliberates about the thyristor and it's conduction.

**Chapter3** discusses the cosine control method for generating firing pulses, all the used components in this method are briefly discussed in this chapter.

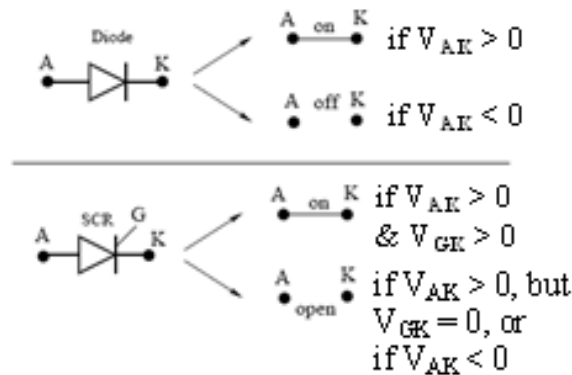
**Chapter4** Circuit simulation model and the results of simulation and experimental model have shown in this chapter.

**Chapter5** contains the conclusion and future scope.

THYRISTOR AND IT'S CONDUCTION

**2.1 Thristor**

A silicon-controlled rectifier (or semiconductor-controlled rectifier) is a four-layer solid state current control device shown in fig.2.1. In the normal "off" state, the device restricts current to the leakage current. When the gate-to-cathode voltage exceeds a certain threshold, the device turns "on" and conducts current. The device will remain in the "on" state even after gate current is removed as long as current through the device remains above the holding current. Once current falls below the holding current for an appropriate period of time, the device will switch "off". If the gate is pulsed and the current through the device is below the latching current, the device will remain in the "off" state. A thyristor will be in reverse blocking mode if  $V_{AK} < 0$  (anode to cathode voltage), irrespective of the fact that a gate pulse is present or not. On



**Fig. 2.1 Symbols for diode and thyristor**

the other hand the thyristor is said to be in the forward blocking mode, when  $V_{AK} > 0$  in absence of any gate pulse, some current will flow through the thyristor. In case of the thyristor is turning on either by exceeding the forward break-over voltage or by applying a gate pulse between gate and cathode, called forward conduction mode.

**2.2 Triggering Of Thyristor**

Turning on the thyristor by giving a gating pulse to it is known as triggering. With anode positive with respect to cathode, a thyristor can be turned on by any one of the following techniques:

**2.2.1 Forward Voltage Triggering**

### 2.2.2 Gate Triggering

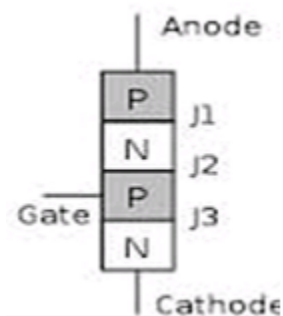
### 2.2.3 dv/dt Triggering

### 2.2.4 Temperature Triggering

### 2.2.5 Light Triggering

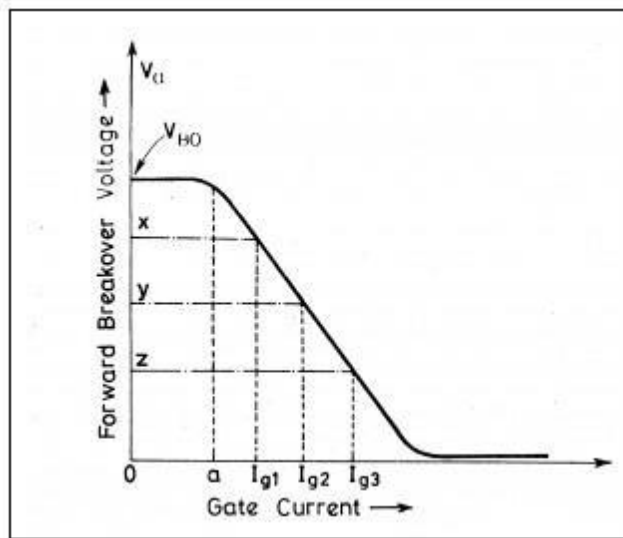
These methods of turning-on a thyristor are now discussed one after the other.

**2.2.1 Forward Voltage Triggering:** When anode to cathode forward voltage is increased with gate circuit open, the reverse biased junction  $J_2$  will break. The four layer image of SCR has shown in the fig.2.2. This is known as avalanche breakdown and the voltage at which avalanche occurs is called forward break over voltage  $V_{B0}$ . At this voltage, thyristor changes from off-state (high voltage with low leakage current) to on-state characterized by low voltage across thyristor with large forward current. As other junctions  $J_1$ ,  $J_3$  are already forward biased, breakdown of junction  $J_2$  allows free movement of carriers across three junctions and as a result, large forward anode-current flows. As stated before, this forward current is limited by the load impedance. In practice, the transition from off-state to on-state obtained by exceeding  $V_{B0}$  is never employed as it may destroy the device. The magnitudes of forward and reverse break over voltages are nearly the same and both are temperature dependent. In practice, it is found that  $V_{BR}$  is slightly more than  $V_{B0}$ . Therefore, forward break over voltage is taken as the final voltage rating of the device during the design of SCR applications. After the avalanche breakdown, junction  $J_2$  loses its reverse blocking capability. Therefore, if the anode voltage is reduced below  $V_{B0}$  SCR will continue conduction of the current. The SCR can now be turned off only by reducing the anode current below certain value called holding current.



**Fig. 2.2. Four layer image of SCR**

**2.2.2 Gate Triggering:** Turning on of thyristors by gate triggering is simple, reliable and efficient; it is therefore the most usual method of firing the forward biased SCRs. A thyristor with forward break over voltage (say 800 V) higher than the normal working voltage (say 400 V) is chosen. This means that thyristor will remain in forward blocking state with normal working voltage across anode and cathode and with gate open. However, when turn-on of a thyristor is required, a positive gate voltage between gate and cathode is applied. With gate current thus established, charges are injected into the inner p layer and voltage at which forward break over occurs is reduced. The forward voltage at which the device switches to on-state depends upon the magnitude of gate current. Higher the gate current, lower is the forward break over voltage.



**Fig. 2.3. Gate current versus break over voltage**

When positive gate current is applied, gate P layer is flooded with electrons from the cathode. This is because cathode N layer is heavily doped as compared to gate P layer. As the thyristor is forward biased, some of these electrons reach junction  $J_2$ . As a result, width of depletion layer around junction  $J_2$  is reduced. This causes the junction  $J_2$  to breakdown at an applied voltage lower than forward break over voltage  $V_{B0}$ . If magnitude of gate current is increased, more electrons will reach junction  $J_2$ , as a consequence thyristor will get turned on at a much lower forward applied voltage.

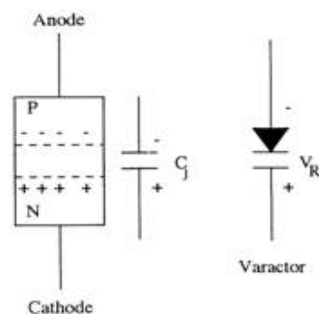
Fig.2.3 shows that for gate current  $I_g = 0$ , forward break over voltage is  $V_{B0}$ . For  $I_{g1}$ , forward break over voltage, or turn-on voltage is less than  $V_{B0}$ . For  $I_{g2} > I_{g1}$ , forward break over voltage is still further reduced. The effect of gate current on the forward break over voltage of a

thyristor can also be illustrated by means of a curve as shown in Fig. 1.3. For  $I_g < oa$ , forward breakover voltage remains almost constant at  $V_{B0}$ . For gate currents  $I_{g1}$ ,  $I_{g2}$  and  $I_{g3}$  the values of forward breakover voltages are  $ox$ ,  $oy$  and  $oz$ , respectively as shown. In Figure the curve marked  $I_g = 0$  is actually for gate current less than  $oa$ . In practice, the magnitude of gate current is more than the minimum gate current required to turn on the SCR. Typical gate current magnitudes are of the order of 20 to 200 mA.

Once the SCR is conducting a forward current, reverse biased junction  $J_2$  no longer exists. As such, no gate current is required for the device to remain in on-state. Therefore, if the gate current is removed, the conduction of current from anode to cathode remains unaffected. However, if gate current is reduced to zero before the rising anode current attains a value, called the latching current, the thyristor will turn-off again. The gate pulse width should therefore be judiciously chosen to ensure that anode current rises above the latching current. Thus latching current may be defined as the minimum value of anode current which it must attain during turn-on process to maintain conduction when gate signal is removed.

Once the thyristor is conducting, gate loses control. The thyristor can be turned-off (or the thyristor can be returned to forward blocking state) only if the forward current falls below a low-level current called the holding current. Thus holding current may be defined as the minimum value of anode current below which it must fall for turning-off the thyristor. The latching current is higher than the holding current. Latching current is associated with turn-on process and holding current with turn-off process. It is usual to take latching current as two to three times the holding current. In industrial applications, holding current (typically 10 mA) is almost taken as zero.

**2.2.3 dv/dt Triggering:** Depletion layer of SCR works as a capacitance  $C_j$  shown in fig.2.4. The



**Fig.2.4. Junction capacitance**

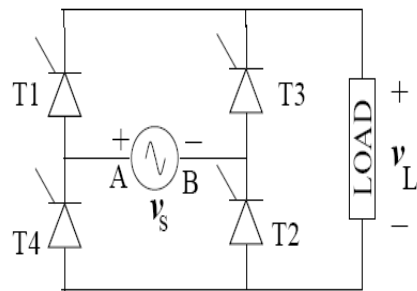
current passes through it is charging current. High  $dv/dt$  increases the charging current and if this charging current is greater than the latching current, the device may turn-on.

**2.2.4 Temperature Triggering:** If temperature is increased near the reverse bias gate terminal junction of the depletion layer than more no. of electron hole pairs are produced in the depletion layer and this initiates the turn-on process. It is generally not preferred.

**2.2.5 Light Triggering:** When the light radiation of certain wavelength is incident near the gate terminal of the depletion layer, it absorbs the light energy and more no. of electron hole pairs are produced and this initiates the turn-on process. The light intensity required to turn-on the device depends on the voltage bias given to the gate. Higher the voltage (or current) bias, lower the light intensity required.

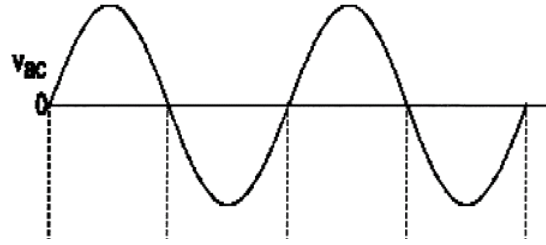
### 2.3 Thyristor as a Rectifier and Its Waveform

A single phase fully controlled bridge with four thyristors is shown in Fig.2.5. Appropriate pulses between the gates and cathodes of the thyristors T1 to T2 are to be supplied with a provision to vary the firing angle  $\alpha$ . With reference to the single phase converter circuit shown in Fig. 2, we note that when  $V_{AB} > 0$  or positive, two diagonally opposite thyristors T1 and T2 are forward biased and other two thyristors T3 and T4 are reversed biased.

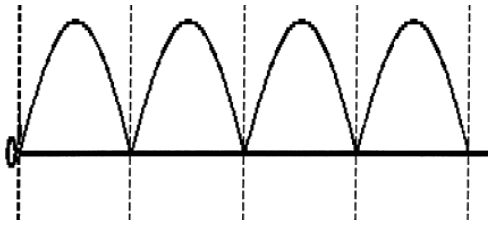


**Fig.2.5.Fully controlled converter**

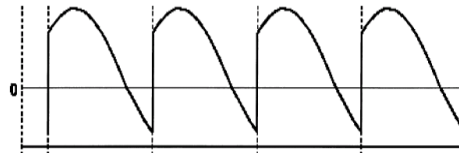
The input waveform is shown in fig.2.6. The rectified waveforms at  $0^\circ$  firing angle is shown in the fig.2.7 and the waveform after changing the firing angle is shown in fig.2.8.



**Fig.2.6. Input AC waveforms**



**Fig.2.7. Waveforms after DC converters**



**Fig.2.8. Waveforms after changing firing angle**

### 2.3.1 Expression for the output voltage

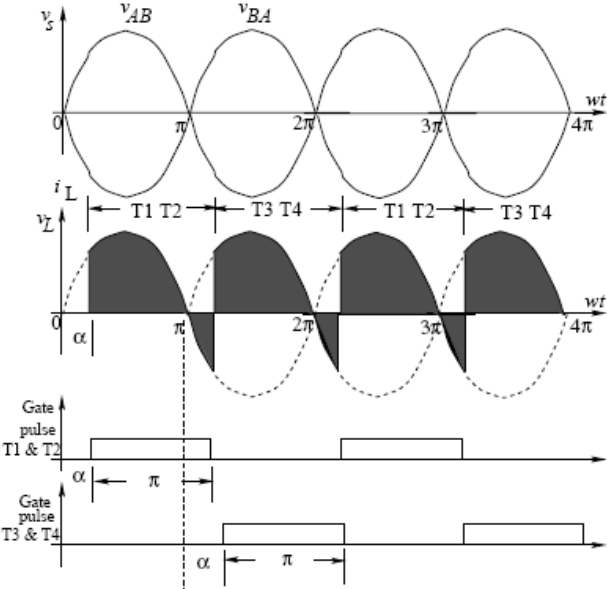
Assuming the rms value of the supply voltage to be  $V_s$ , the output voltage  $V_o$  can be obtained below.

$$\begin{aligned}
 V_o &= \frac{1}{\pi} \int_{\alpha}^{\pi+\alpha} \sqrt{2} V_s \sin \omega t \, d(\omega t) \\
 &= \frac{2\sqrt{2}}{\pi} V_s \cos \alpha \\
 &= 0.9 V_s \cos \alpha
 \end{aligned}$$

### 2.4 Necessity of Getting Synchronizing Pulses

If we use two different power supplies in the main circuit and firing then the firing angle required is not matched with the firing angle produced in the firing circuit. Because the zero crossing of the main power supply is not co-incident with the power supply in the firing circuit. Therefore, there must be a common reference to count the firing angle in the main circuit as well as the firing circuit. This common reference will not produce any error in the firing angle. Therefore we have to use same power supply in the main circuit as well as firing circuit as a common reference. This is known as synchronization. Typical waveform of the supply voltage,

gate pulses necessary are shown in Fig.2.9. It is quite clear how the firing angle  $\alpha$  is to be fixed and measured.



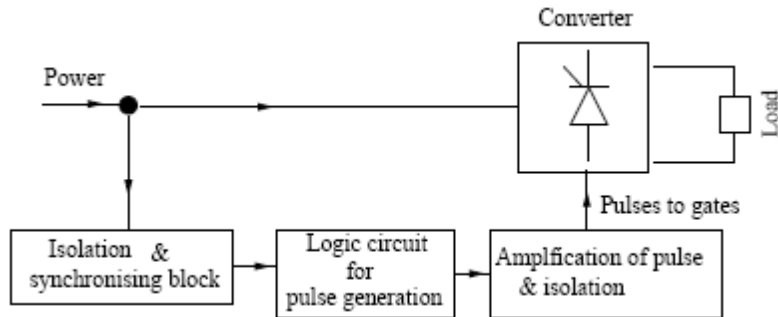
**Fig.2.9. Typical waveforms of a single phase converter**

## CHAPTER 3

### COSINE CONTROL METHOD

#### 3.1 Basic Block Diagram For Firing Circuit

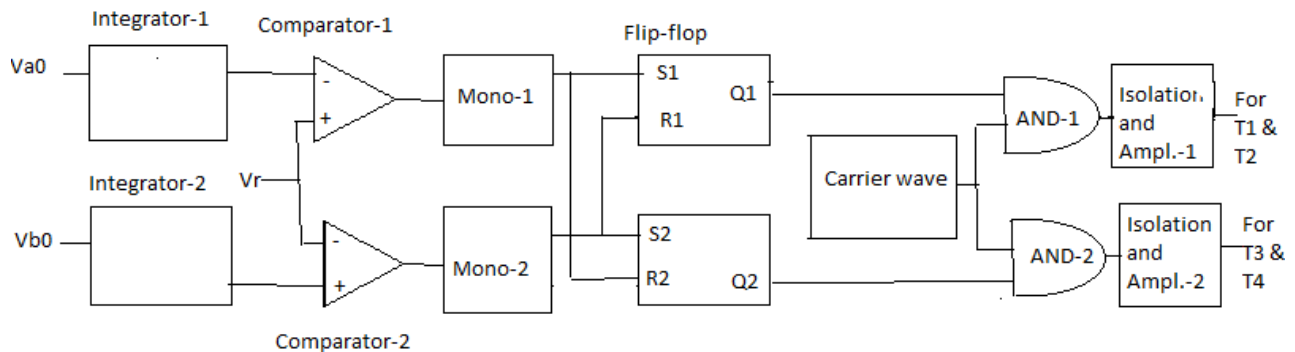
Basic blocks are essential for any firing circuit shown in the fig.3.1. It is a single line diagram which shows that the main supply is given to the converter and the logic circuit for pulse generation, it is used for the synchronization. Isolation and amplification is provided to the firing pulses. Isolation is provided as the control circuit uses very low Power devices and amplification is provided because the strength of pulses produced by the circuit is low.



**Fig. 3.1 Basic block diagram**

#### 3.2 Block Diagram Representation Of The Cosine Control Scheme

Assume  $V_{ab}$  as the supply voltage feeding the converter for which the control pulses are to be generated. With the help of a step down centre tapped transformer,  $V_{ab}$  is transformed into



**Fig.3.2 Blocks for cosine control scheme**

two power level voltage  $V_{a0}$  and  $V_{b0}$ , these are  $180^\circ$  out of phase.  $T_1$  and  $T_2$  are fired when  $V_{a0}$  is positive and  $T_3$  and  $T_4$  are fired when  $V_{b0}$  is positive. The range of variation of firing angle is  $0$  to  $180^\circ$  from the instant when  $V_{a0}$  is crossing zero and increasing in positive direction.

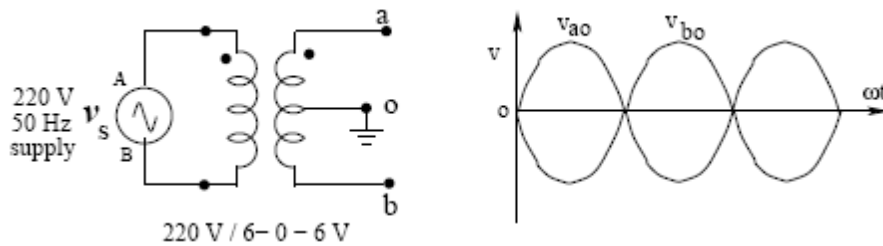
The signal  $V_{a0}$  is integrated with integrator-1 and generate cosine wave and then it is compared with the comparator with the reference voltage  $V_r$  for generating the square wave, monoshot blocks are used for generating the pulses of small width which are displaced by  $360^\circ$ . Same is done with  $V_{b0}$  by using integrator, comparator and monoshot block-2 and the pulses generated by monoshot-1 and monoshot-2 are shifted by  $180^\circ$ . The output of monoshot-1 and monoshot-2 can be used in conjunction with two SR flip-flop so as to generate two square waves each having a fixed width of  $180^\circ$ .

### 3.3 Description Of Each Block

In this section, each part will be discussed separately. The type of component used and their connections will also be explained.

#### 3.3.1 Centered Tapped Transformer

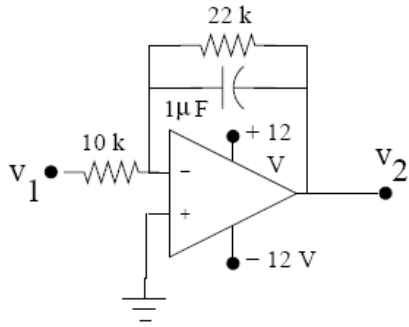
A 220/6-0-6 V 50 Hz centered tapped transformer is selected for the purpose of stepping down 220 V to 6-0-6 V.



**Fig.3.3 Centered tapped transformer**

#### 3.3.2 Integrator

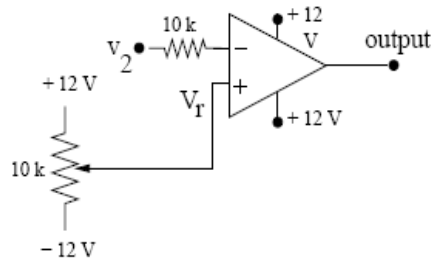
Integrator uses an op-amp along with resistors and capacitors to realize the integrator function. It provides a phase shift of  $90^\circ$  to the input voltage  $V_{a0}$  and thus a cosine wave is obtained.



**Fig.3.4 Integrator using OP AMP 741**

### 3.3.3 Comparator

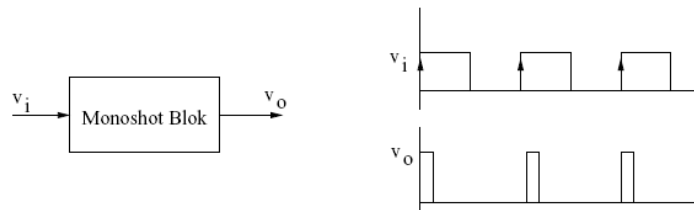
An op-amp is used as comparator. The variable dc voltage is applied to the non-inverting terminal and the cosine wave is applied to the inverting terminal of the comparator.



**Fig.3.5 Comparator using OP AMP IC 741**

### 3.3.4 Monoshot Block Using Exclusive OR-Gate

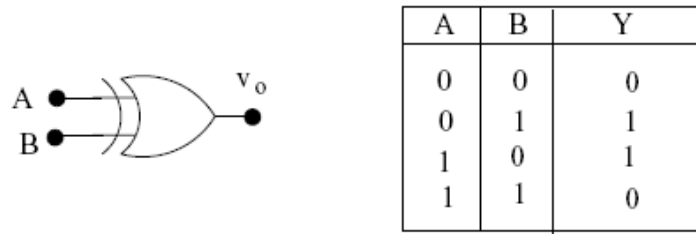
A monoshot block is supposed to produce the thin pulses when the input rectangular input signal  $V_i$  changes state from 0 to 1 as shown in Fig.3.6, a Monoshot block is shown with input signal  $V_i$  and with the desired output signal  $V_o$ .



**Fig.3.6 Characteristics of a monoshot**

In this project work under this paper, the Monoshot is implemented in an interesting way by using Exclusive OR Gate. The truth table and representation of Exclusive OR Gate is shown

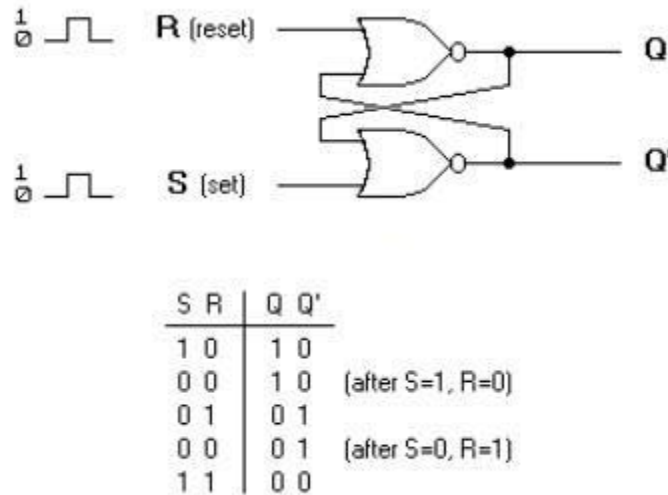
Fig3.7. In Exclusive OR gate, the output is high or 1 when one of the inputs is high (1) or odd matching with the others and the output is low or 0 when both the inputs are same or even nature.



**Fig.3.7 Exclusive OR gate & its truth table**

### 3.3.5 SR Flip-Flops to Get 180° Width Pulse

In the previous section we have seen that the variable width pulse obtain from the comparator output is converted into a train of thin pulses separated by 360° at the output of the Monoshot in Fig.3.8.



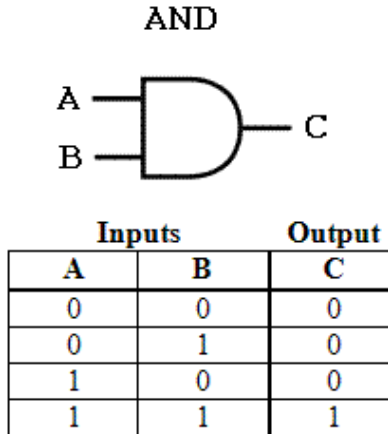
**Fig.3.8 Basic logic diagram and truth table**

### 3.3.6 High Frequency Waves

Pulse gating of thyristor is not suitable for RL loads, this difficulty can be overcome by using continuous gating. However, continuous gating may lead to increased thyristor losses and distortion of output pulse. So, a pulse train generated by modulating the pulse gate at high frequency is used to trigger the thyristor. This high frequency wave is known as carrier wave and is generated by using 555 timer.

### 3.3.7 AND Gate

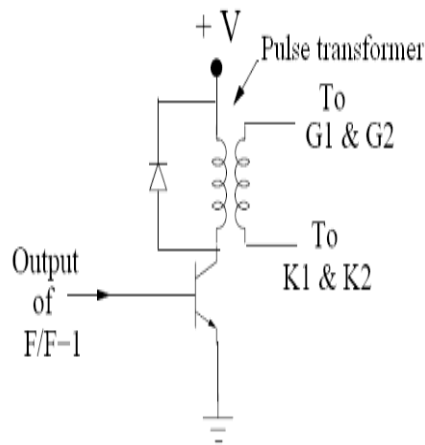
AND operation is performed between SR flip-flop outputs and carrier wave thus pulses required for triggering the thyristors called firing pulses or gate pulses are obtained. The logic diagram and truth table is shown in fig.3.9.



**Fig.3.9 Logic diagram and truth table**

### 3.3.8 Pulse Amplification and Isolation Circuitry

The gate pulses obtained from AND operation may not be able to turn on the thyristor. It is therefore common to feed these gate pulses to a pulse amplification and isolation circuitry to meet the two objectives of strengthening these pulses and providing proper isolation.

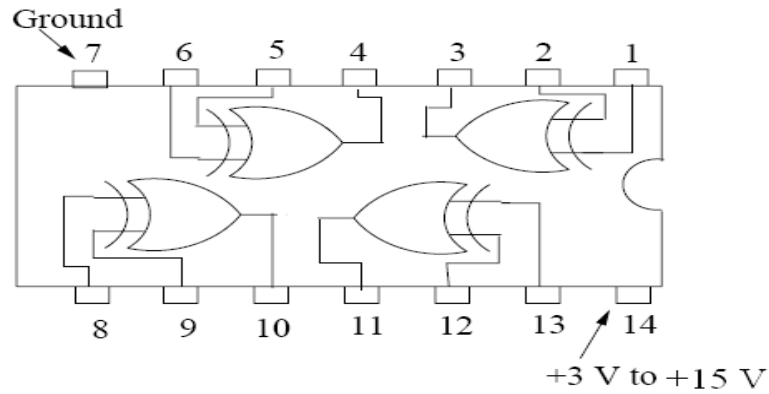


**Fig.3.10. Showing amplification & isolation circuit**

### 3.4 Component Used For Hardware Model

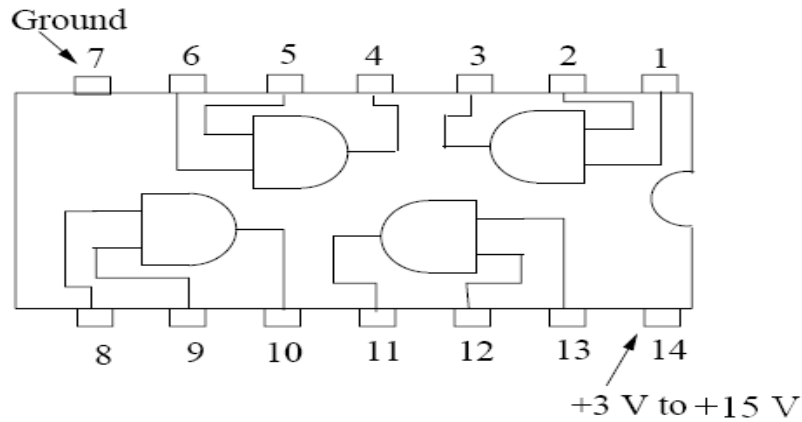
1. One centered tapped transformer: 220/6-0-6V.

2. Two IC 741 op amp for two integrators one corresponding to  $V_{a0}$  and the other to  $V_{b0}$ .
3. Two IC 741 op amp for two comparators and one potentiometer.
4. One IC 4070 consists of 4 EX-OR gates. This chip works with DC supply of +3 to +15 V. In our case +12 V supply is used. It has 14 pins shown in the fig.3.11.



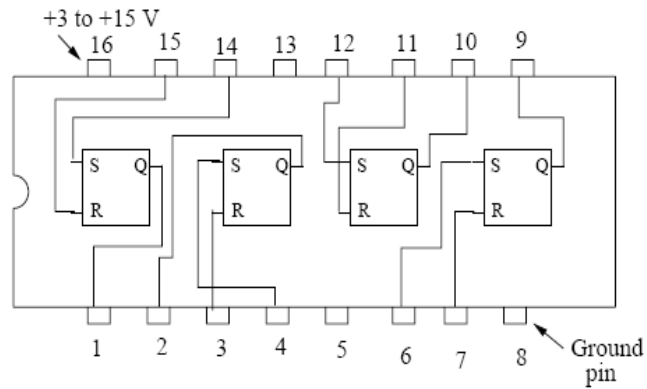
**Fig.3.11. Pin description of IC 4070**

5. One IC 4081 consists of 4 AND gates. This chip works with DC supply of +3 to +15 V. In our case +12 V supply is used. It has 14 pins shown in fig.3.12.



**Fig.3.12. Pin descriptions IC 4081**

6. One IC 4043 consists of 4 SR flip flops. This chip works with DC supply of +3 to +15 V. In our case +12 V supply is used. It has 16 pins shown in fig.3.13.



**Fig.3.13. Pin descriptions IC 4043**

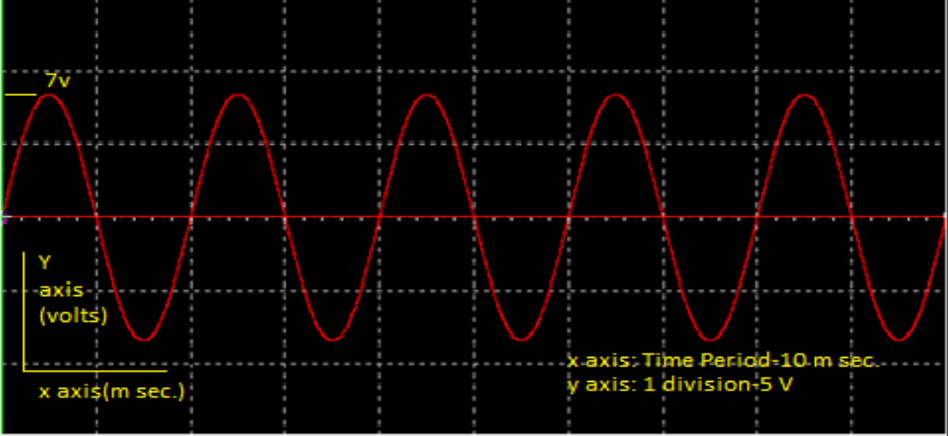
7. One 555 timer for generating high frequency pulses.
8. Numbers of resistors and capacitors of various values.
9. Few diodes for making the  $\pm 12$  V power supply and also to clip the negative half of rectangular pulse obtained at the output of the comparator.
10. One  $10\text{ K}\Omega$  potentiometer for having variable DC voltage  $V_r$ .



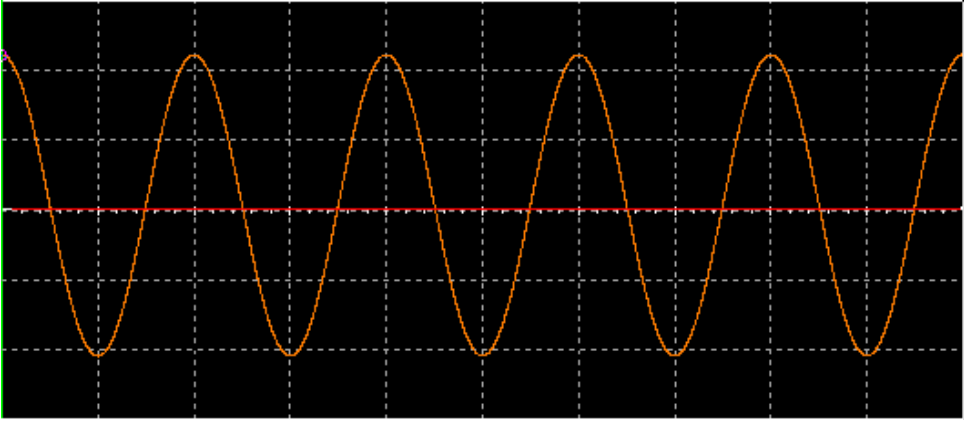
**4.2 Simulation Results**

Firing pulses using Cosine control are supplied on bridge rectifier and then it is used to drive different types of load. The simulation results at different stages are discussed.

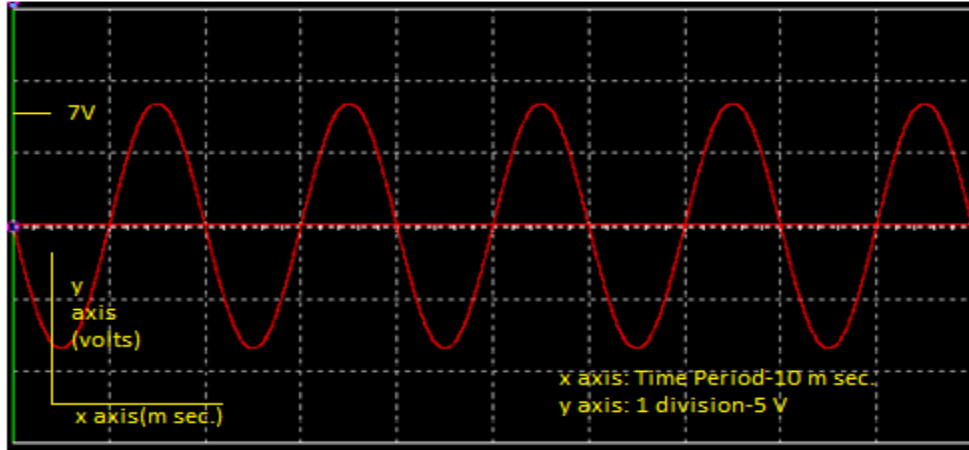
**4.2.1 Cosine wave generator-** The output of cosine wave generator is shown in figure. The positive input wave  $V_{a0}$  and output cosine wave is represented in figure 4.1(a) and (b) and negative input wave  $V_{b0}$  and output cosine wave is represented in figure 4.1(c) and (d).



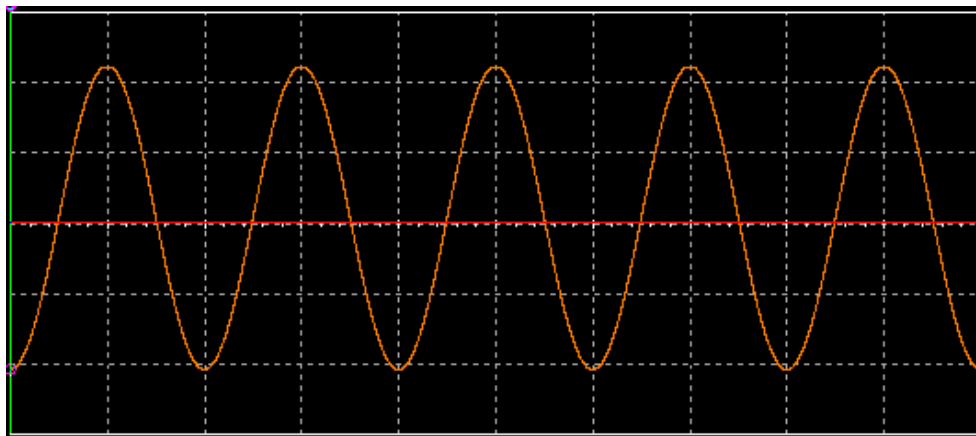
**Fig.4.1(a) Waveform of  $V_{a0}$**



**Fig. 4.1(b) Waveform of Integrator-1**

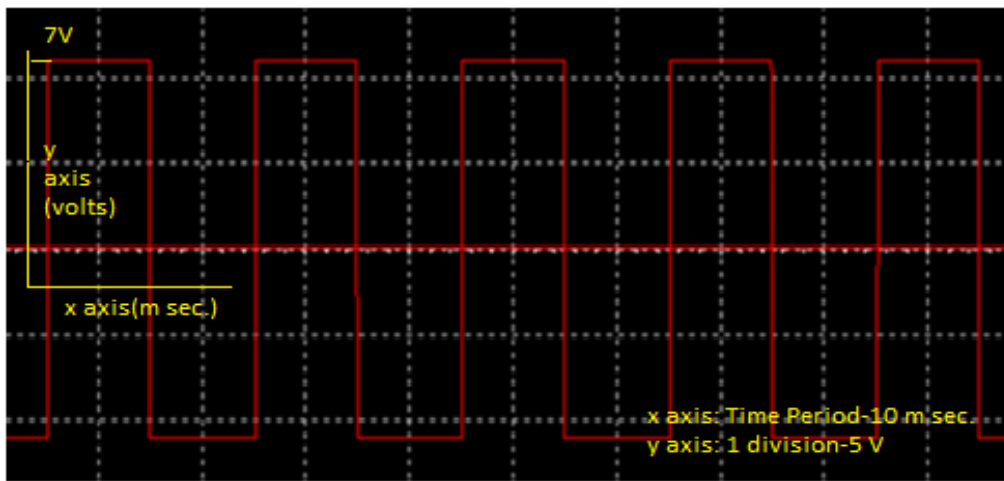


**Fig.4.1(c) Waveform of  $V_{b0}$**



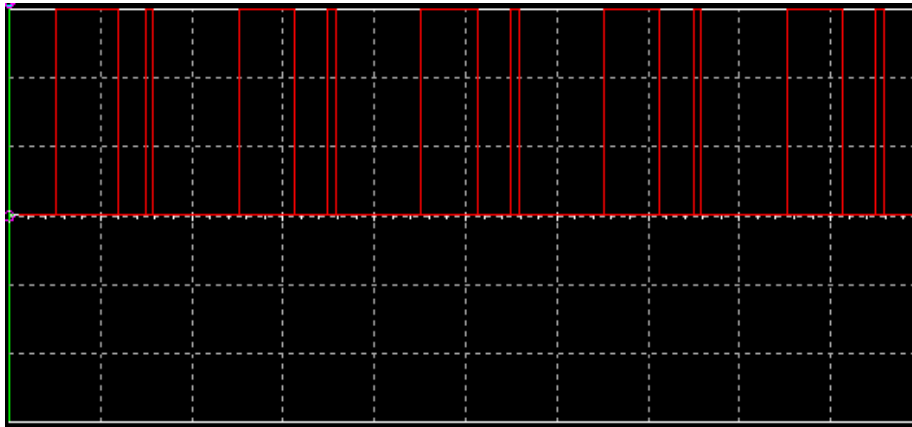
**Fig.4.1(d) Waveform of Integrator-2**

**4.2.2 Comparator-** The output of the comparator1 is shown in figure 4.2.



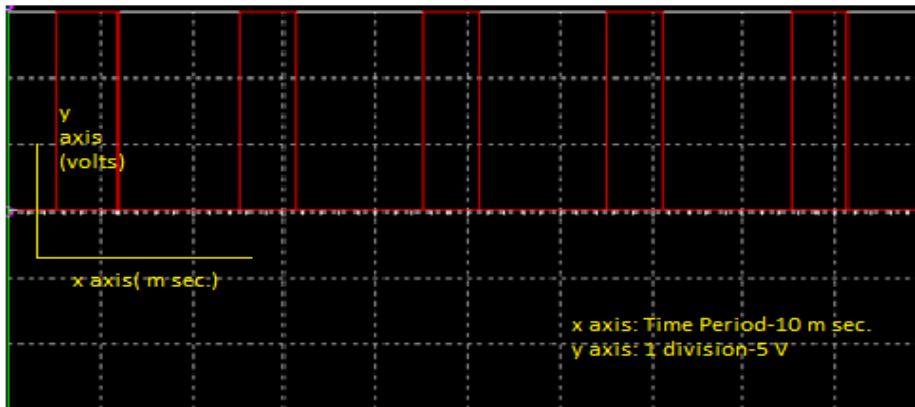
**Fig.4.2 Waveform of comparator1**

**4.2.3 Output of EX-OR gate** - The simulation result of EX-OR gate are shown in figure 4.3.



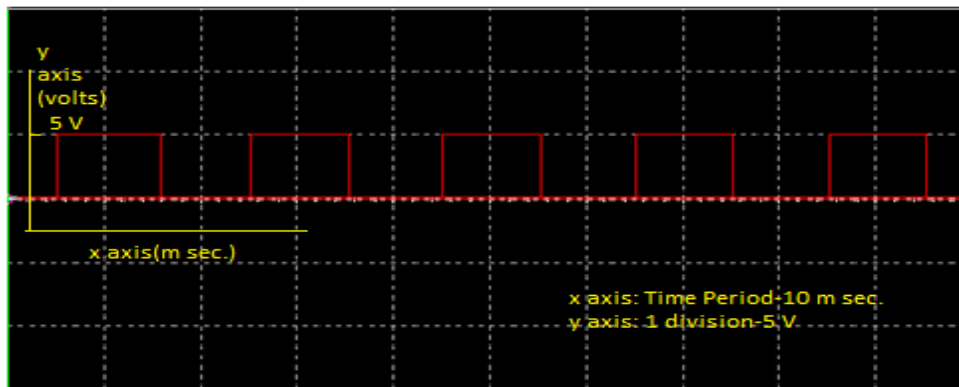
**Fig.4.3 Waveform of EX-OR gate**

**4.2.4 Output of First AND gate** - The simulation result of first AND gate are shown in fig.

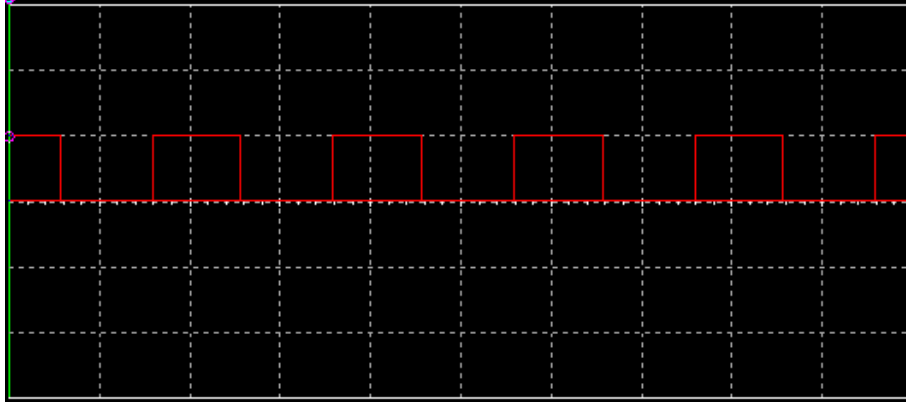


**Fig.4.4 Waveform of first AND gate**

**4.2.5 Output of SR flip-flop** - The simulation result for generating the 180° pulse width of SR flip flop-1 and 2 are shown in figure 4.5(a) and 4.5(b).

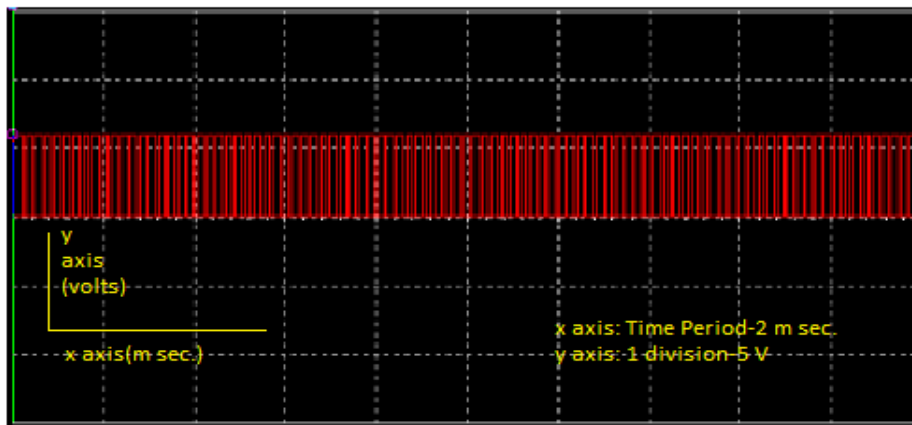


**Fig.4.5(a) Waveform of SR-flip-flop-1**



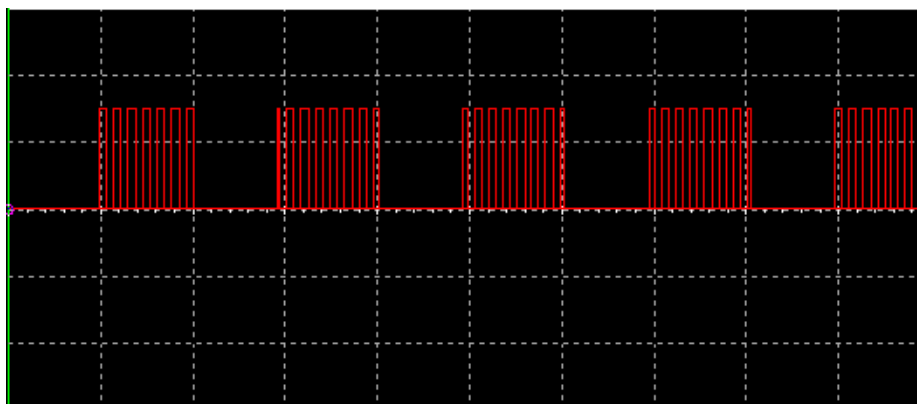
**Fig.4.5(b) Waveform of SR flip-flop-2**

**4.2.6 Waveform of 555 timer-** The simulation result of 555 timer which is used to generate the frequency of 1.67KHz is shown in figure 4.6.

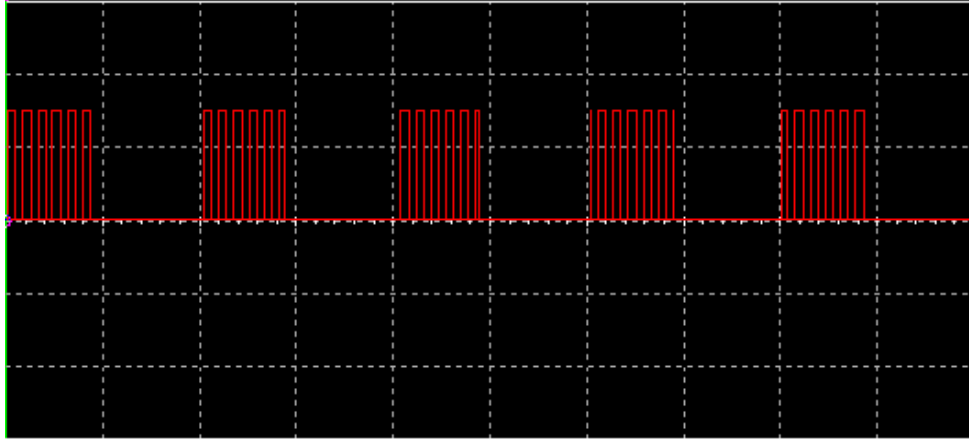


**Fig.4.6 Waveform of 555 timer**

**4.2.7 Output of Second AND gate-** The simulation result of second AND gate for positive polarity and negative polarity are shown in figure 4.7(a) and 4.7(b).

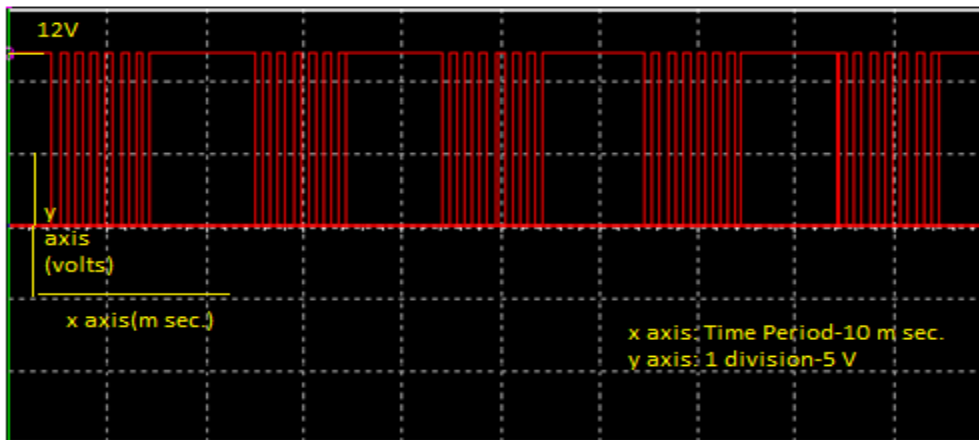


**Fig.4.7(a) Waveform of second AND gate for positive polarity**

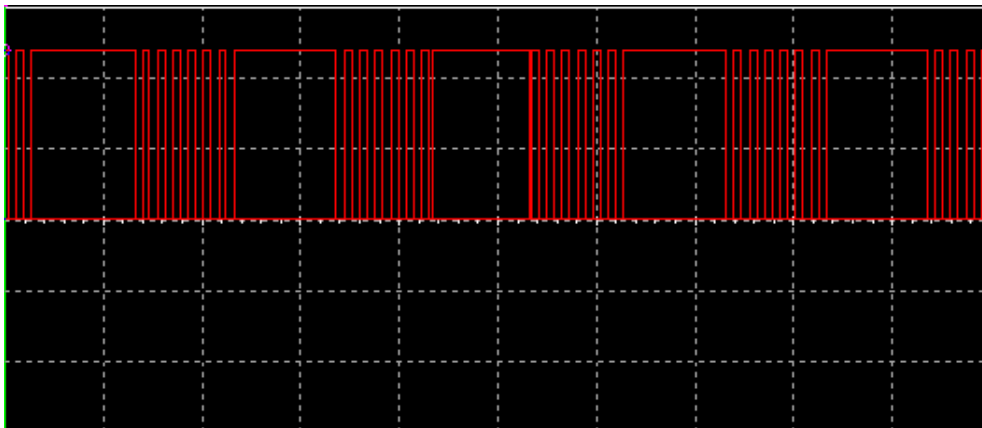


**Fig.4.7(b) Waveform of Second AND gate for negative polarity**

**4.2.8 Waveform after amplification using BJT**– Simulation result after amplification of the output of second AND gate using BJT are shown in figure 4.8(a) and 4.8(b).

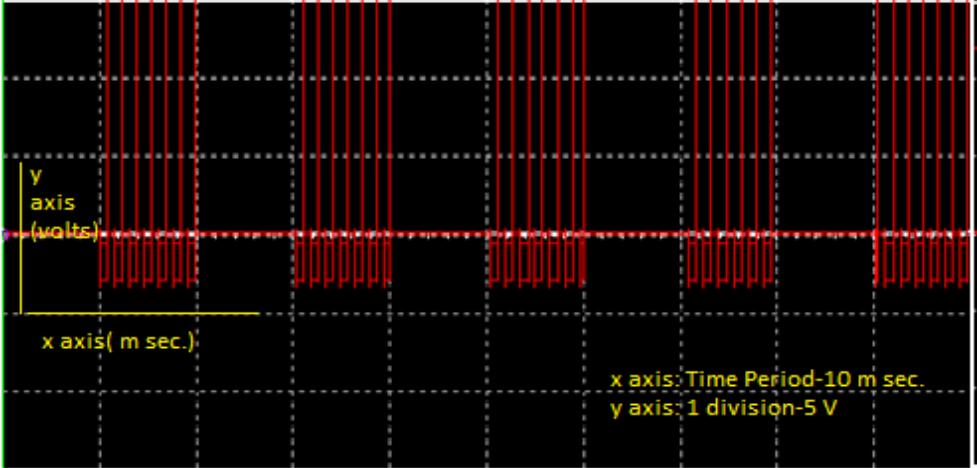


**Fig.4.8(a) Waveform after amplification using BJT**

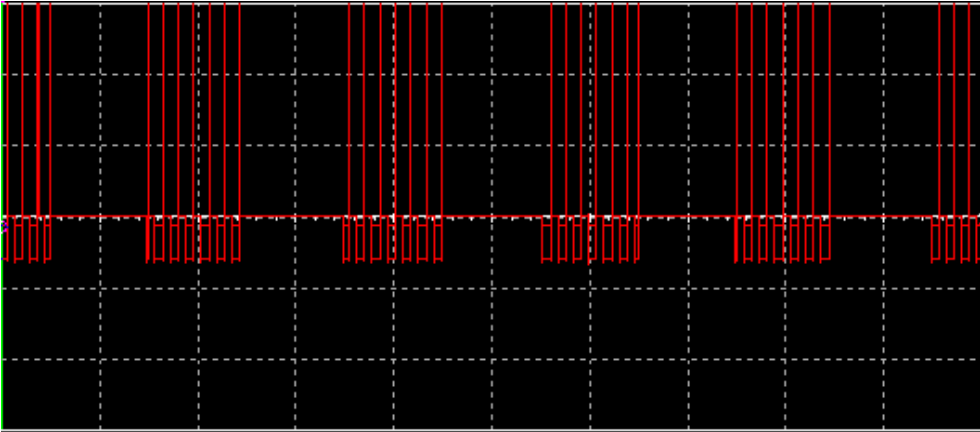


**Fig.4.8(b) Waveform after amplification using BJT**

**4.2.9 Final pulses after isolation using pulse transformer-** Final pulses after isolation using pulse transformers for T1 and T2 and for T3 and T4 shown in fig.4.9(a) and 4.9(b).



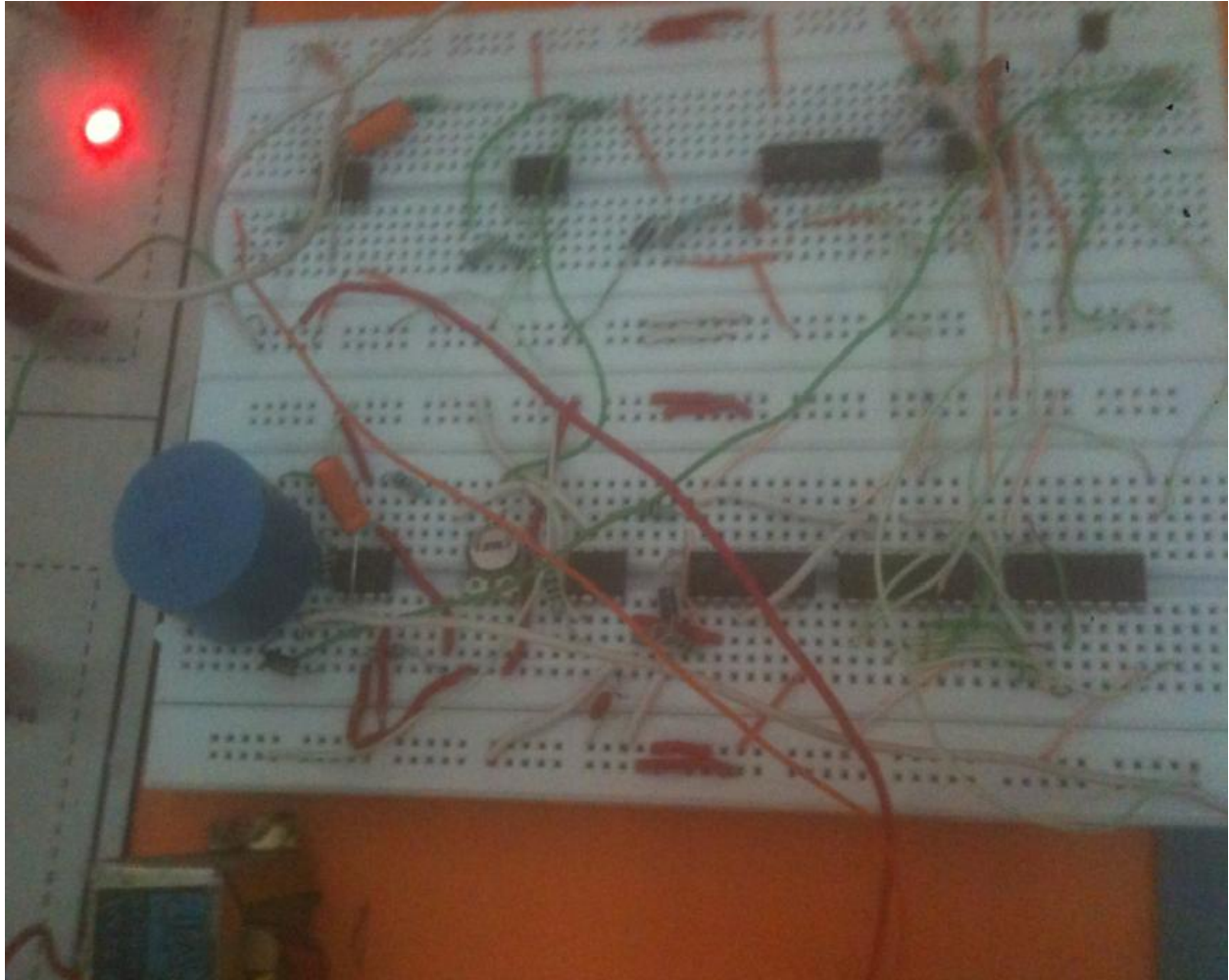
**Fig.4.9(a) Final pulses after isolation for T1 and T2**



**Fig.4.9(b) Final pulses after isolation for T3 and T4**

### 4.3 Practical Firing Circuit

The entire triggering circuit is implemented on hardware shown in fig.4.9. Firing pulses using Cosine control is implemented on hardware. The experimental results at different stages are discussed.

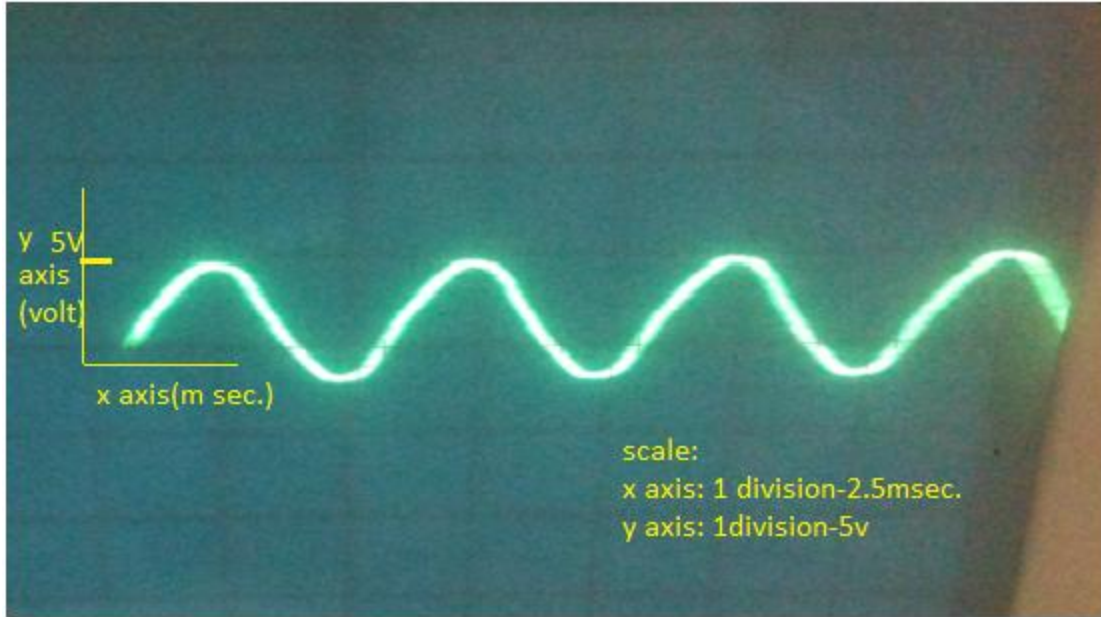


**Fig.4.9 Practical firing Circuit**

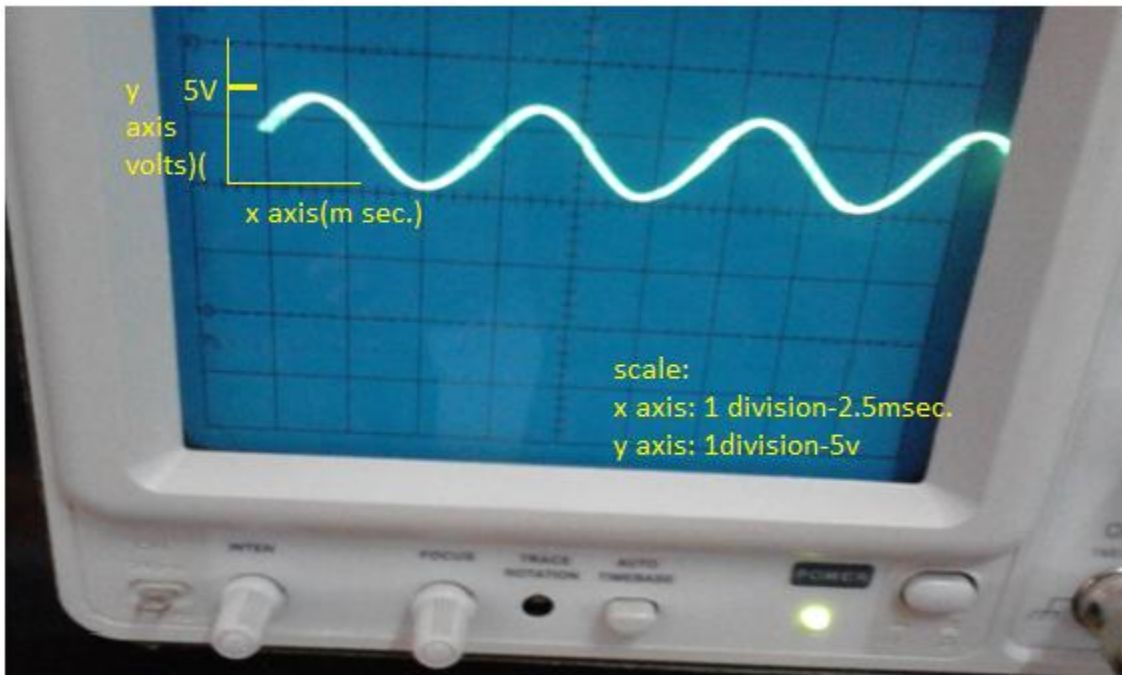
### 4.4 Hardware Results

Firing pulses using Cosine control is implemented on hardware. The experimental results at different stages are discussed.

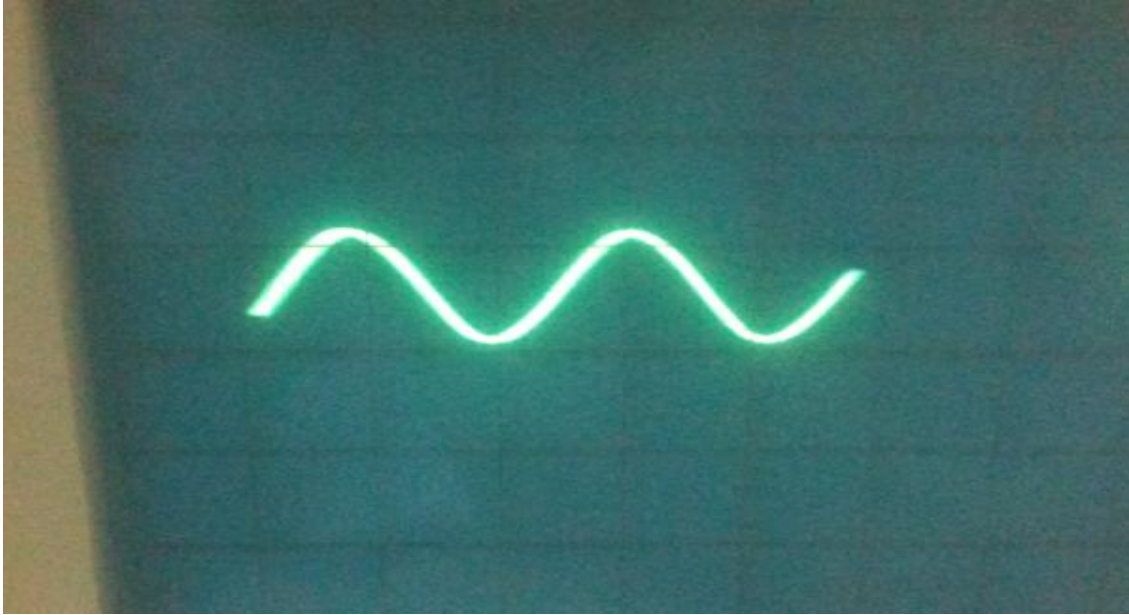
**4.4.1 Cosine wave generator-** The output of cosine wave generator is shown in figure. The positive input wave  $V_{a0}$  and output cosine wave is represented in figure 4.10(a) and (b) and negative input wave  $V_{b0}$  and output cosine wave is represented in figure 4.10(c) and (d).



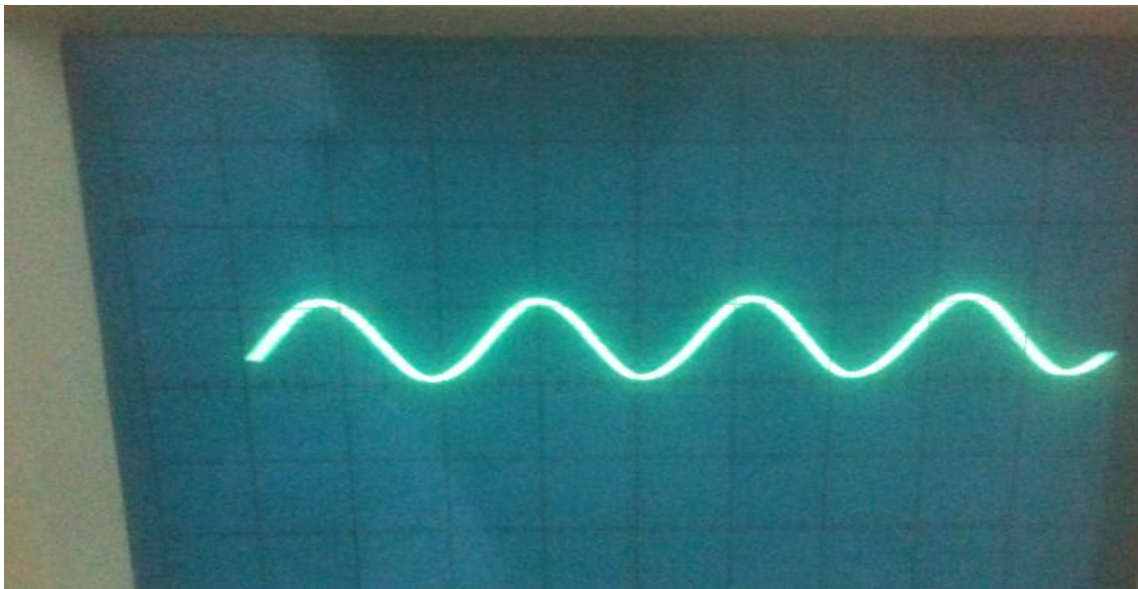
**4.10(a) Waveform of  $V_{a0}$**



**Fig. 4.10(b) Waveform of cosine wave generator-1**

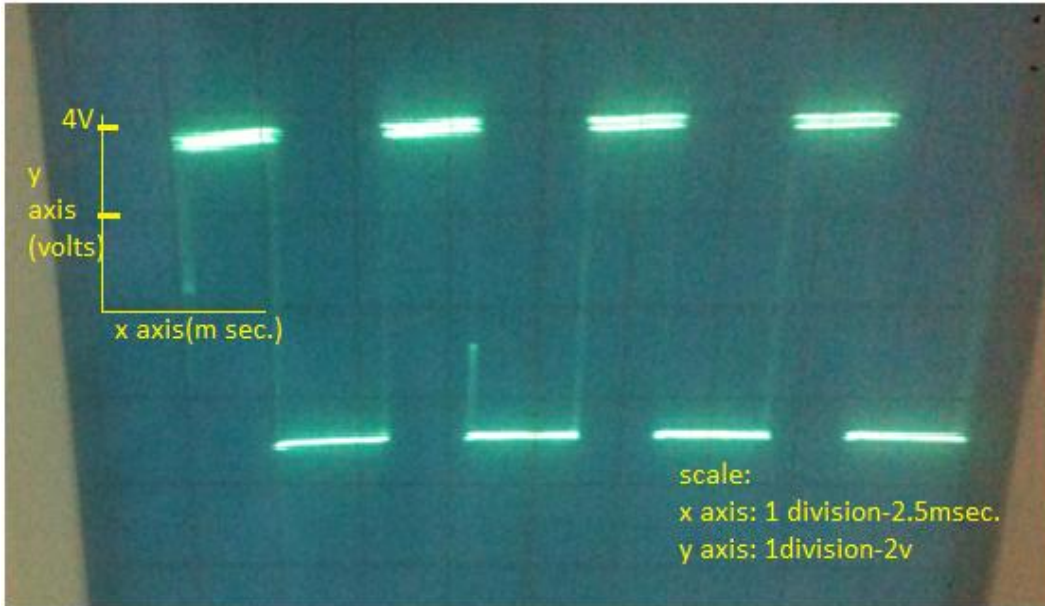


**Fig.4.10(c) Waveform of  $V_{b0}$**

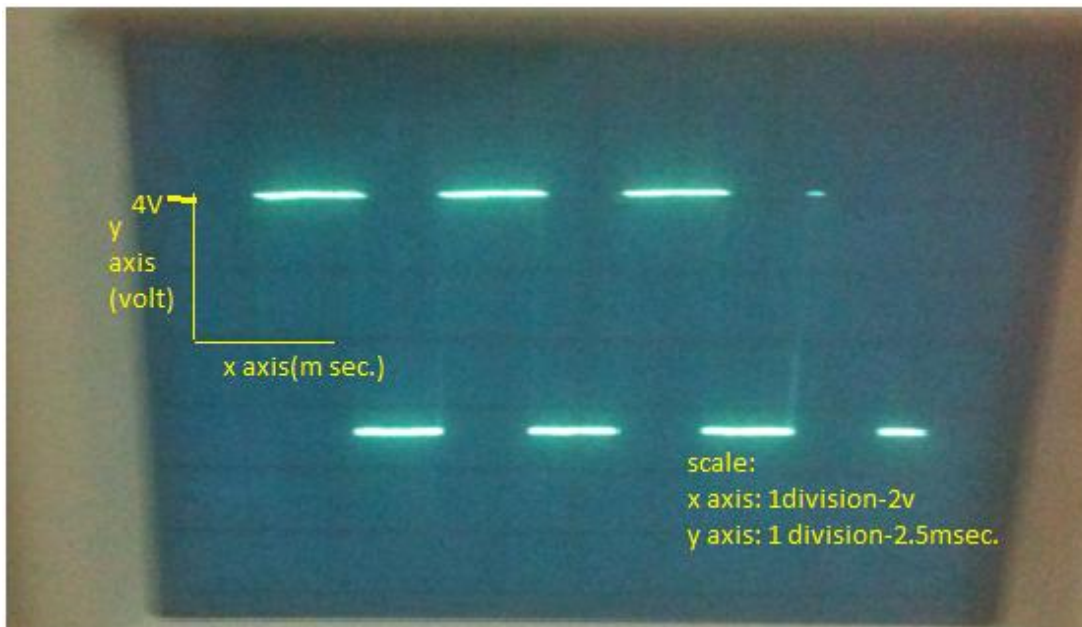


**Fig.4.10(d) Waveform of cosine wave generator-2**

**4.4.2 Comparator-** The experimental result of the output of the comparator-1 and 2 are shown in fig4.11(a) and 4.11(b).

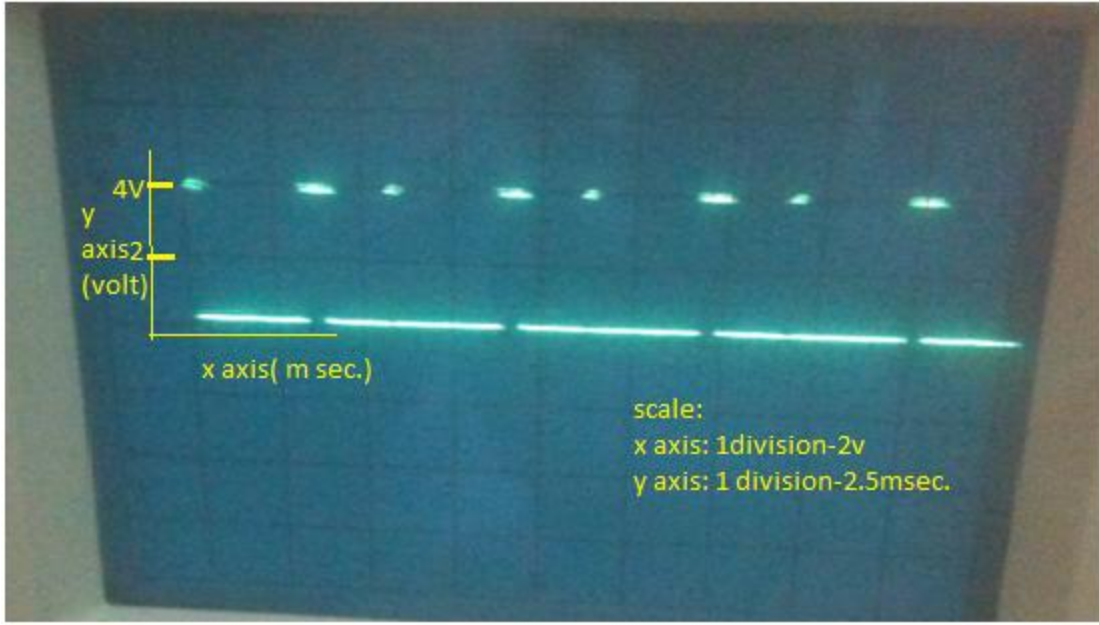


**Fig.4.11(a) Waveform of comparator-1**

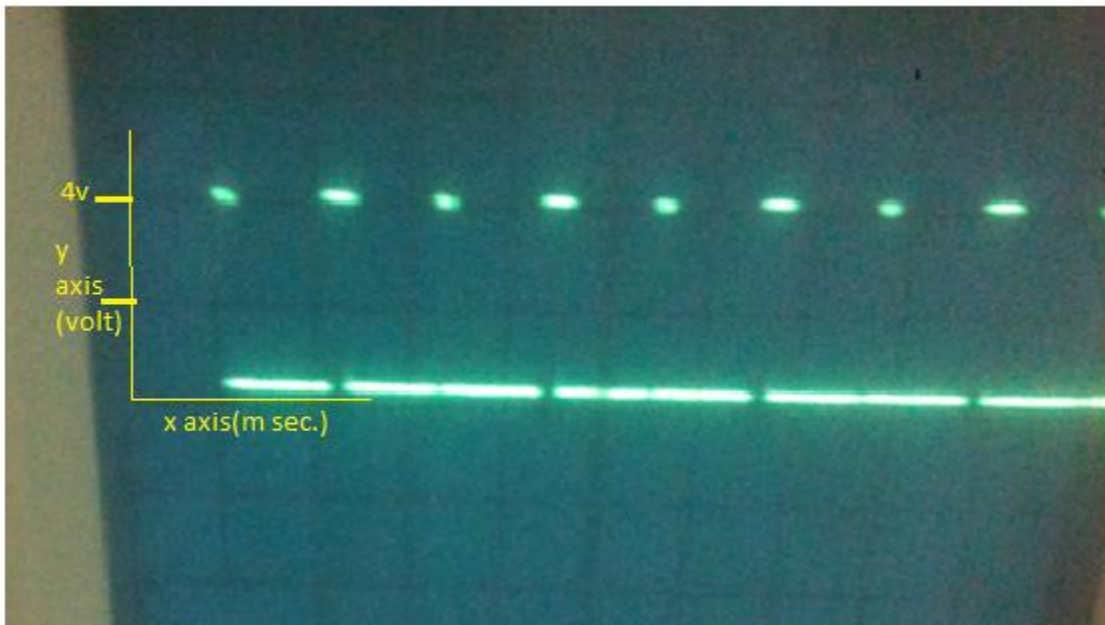


**Fig.4.11(b) Waveform of comparator-2**

**4.4.3 Output of EX-OR gate** - The experimental result of EX-OR gate1 and 2 are shown in fig.4.12(a) and (b).

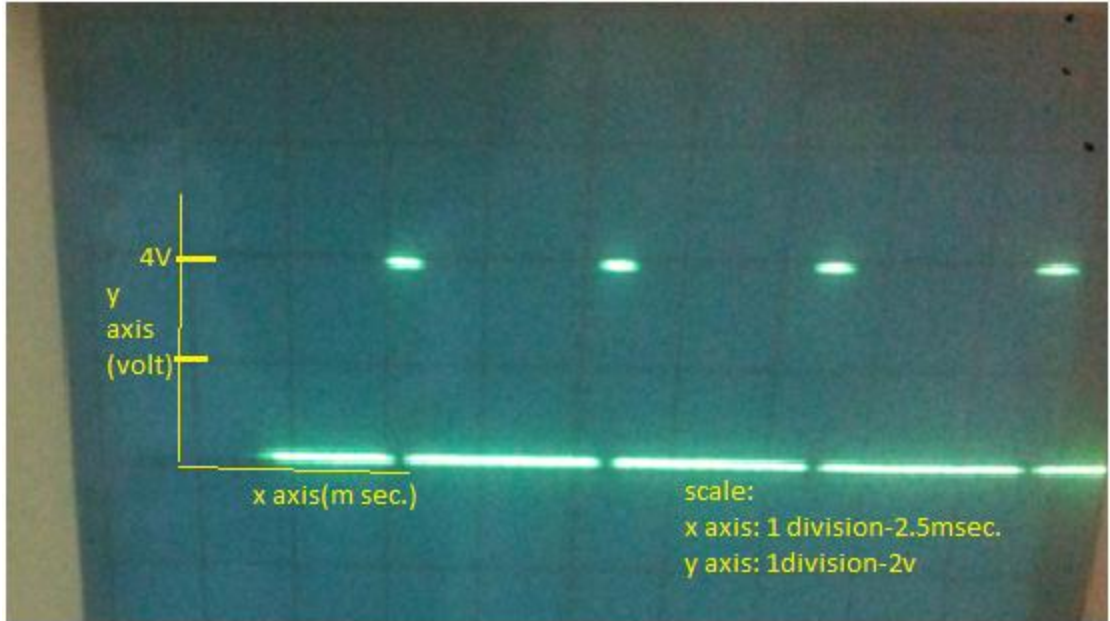


**Fig.4.12(a) Waveform of EX-OR gate-1**

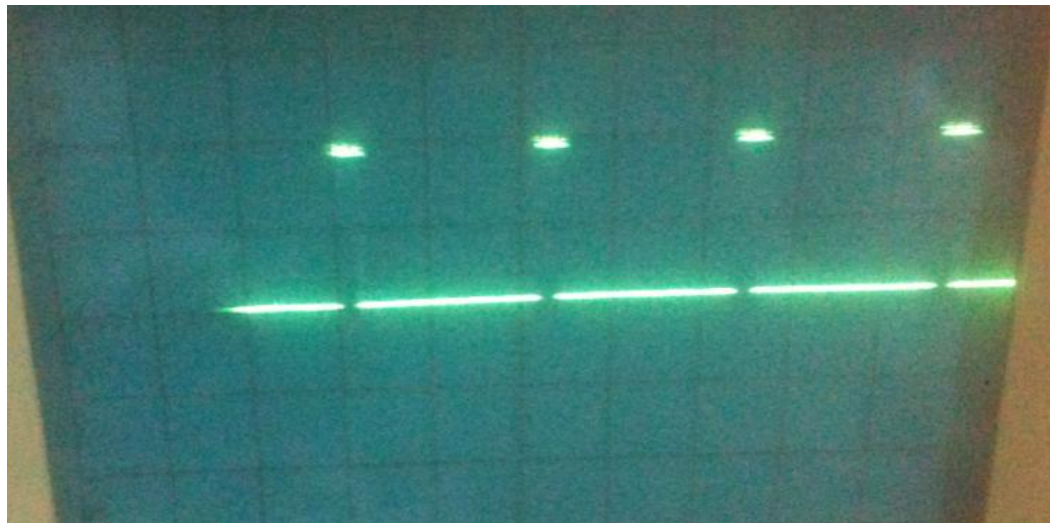


**Fig.4.12(b) Waveform of EX-OR gate-2**

**4.4.4 Output of first AND gate-** The experimental output of first AND gate of monoshot block-1 and 2 are shown in the fig.4.13(a) and (b).

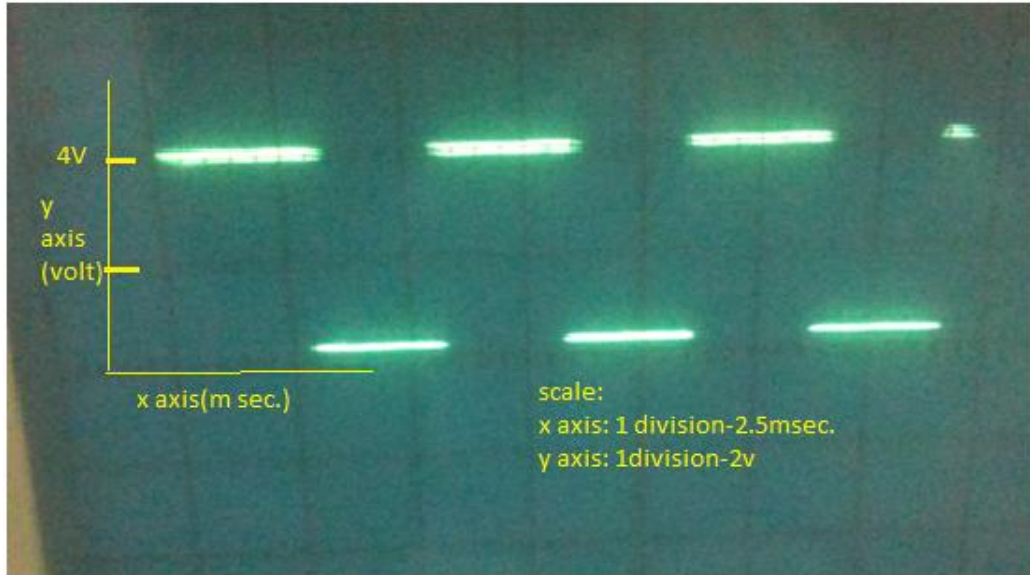


**Fig.4.13(a). Waveform of first AND gate of monoshot block-1**

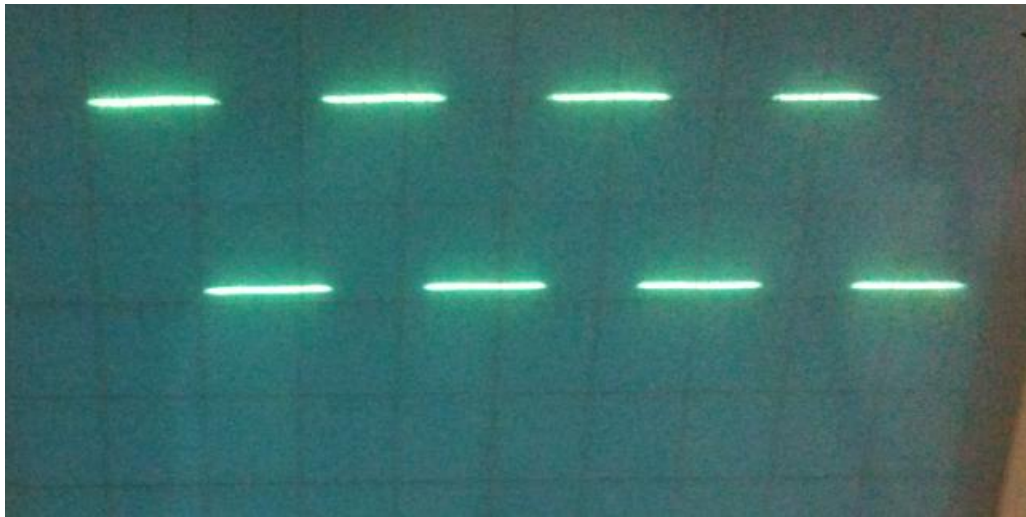


**Fig.4.13(b). Waveform of first AND gate of monoshot block-2**

**4.4.5 Waveform of SR flip-flop-** The experimental output of SR flip-flop-1 and 2 are shown in the fig.4.14(a) and (b).

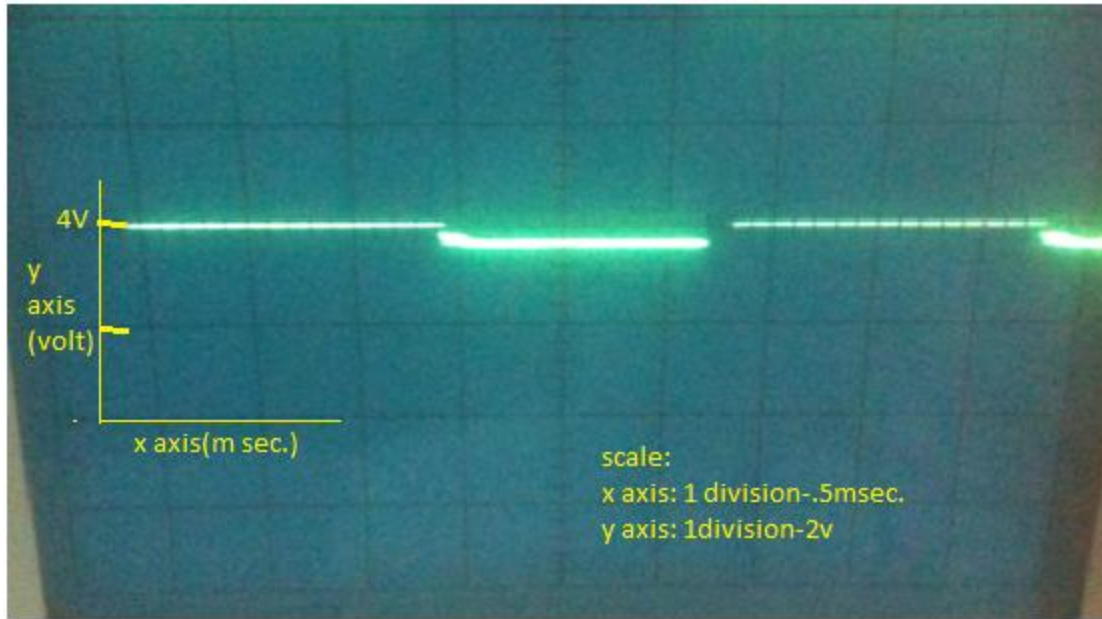


**Fig.4.14(a). Waveform of SR flip-flop-1**



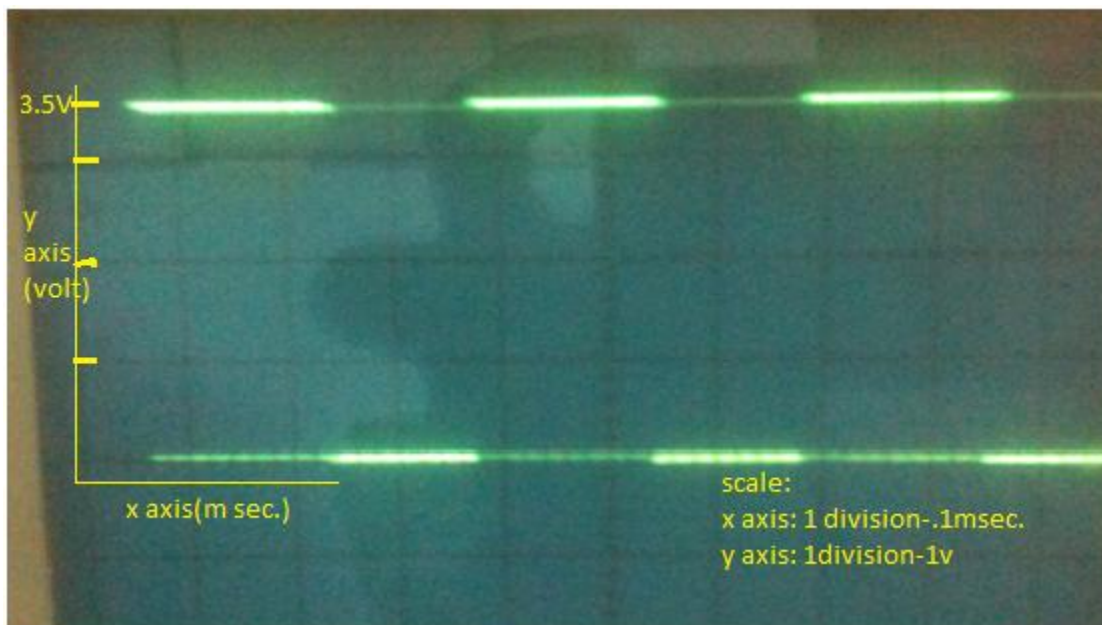
**Fig.4.14(b). Waveform of SR flip-flop-2**

**4.4.6 Waveform of 555 timer-** 555 timer is used to generate the frequency of 1.65KHz. The experimental result of 555 timer are shown in figure 4.15.

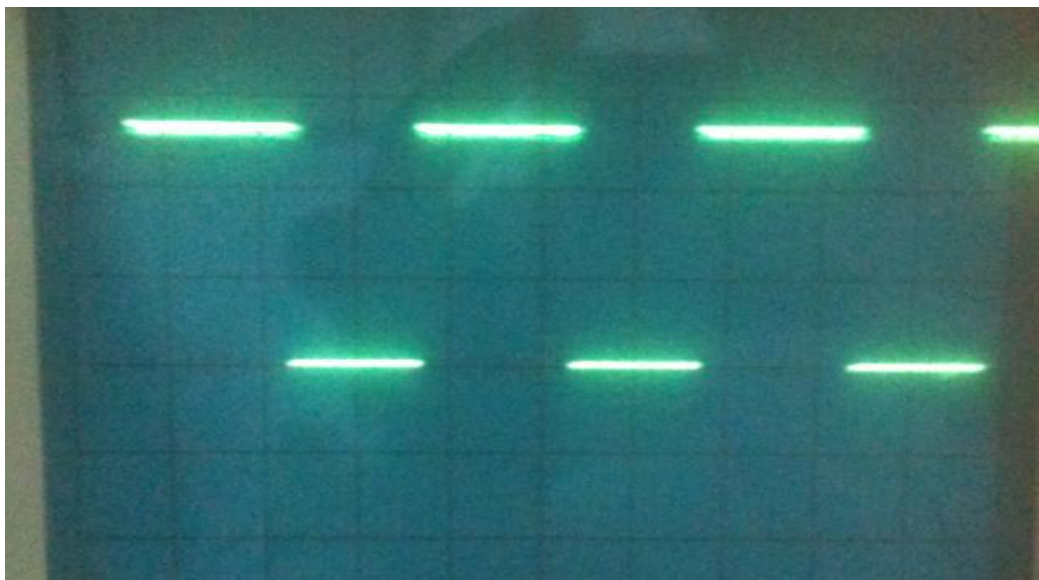


**Fig.4.15 Waveform of 555 timer**

**4.4.7 Output of Second AND gate-** Frequency after anding the output of SR flip flop with carrier pulses is 930 Hz. The experimental result of second AND gate for positive polarity and negative polarity are shown in figure 4.16(a) and (b).

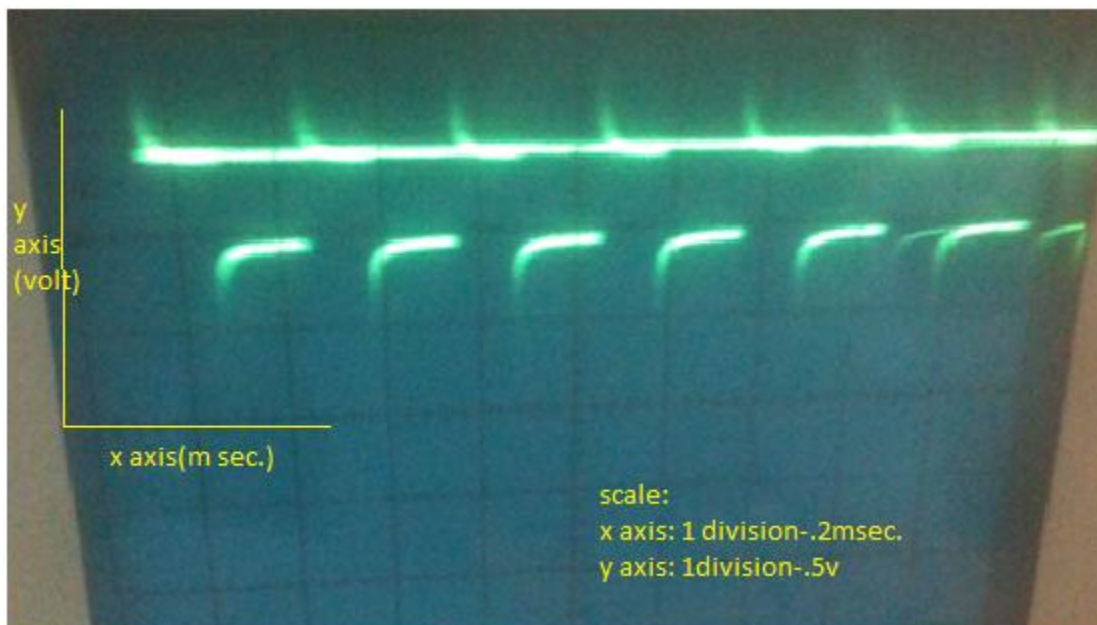


**Fig.4.16(a) Waveform of second AND gate for positive polarity**



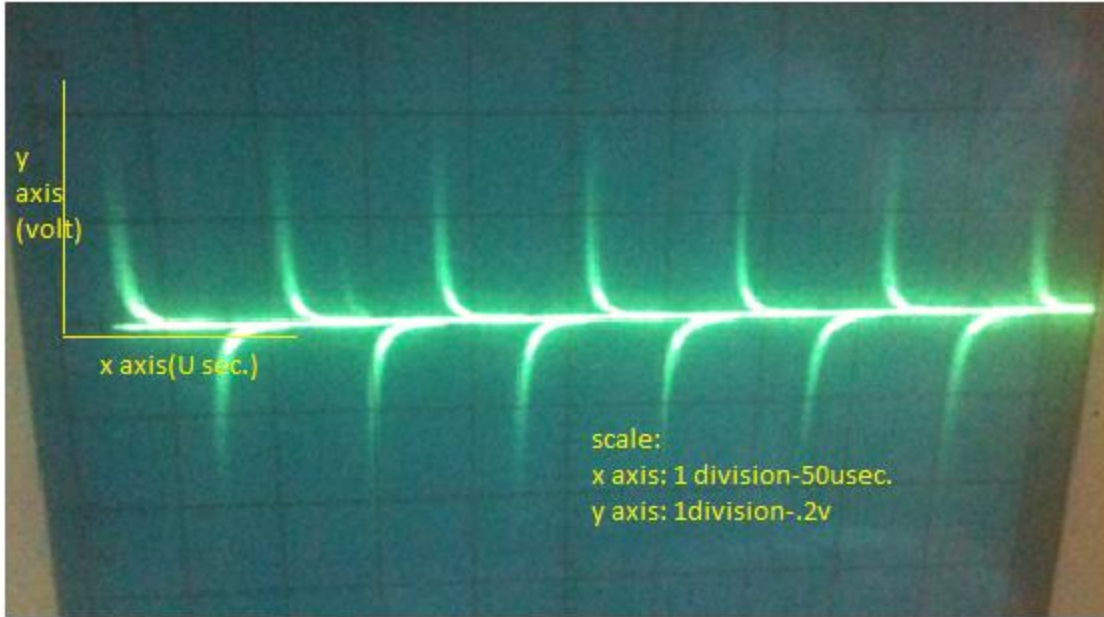
**Fig.4.16(b) Waveform of Second AND gate for negative polarity**

**4.4.8 Waveform after amplification using BJT**– Experimental result after amplification of the output of second AND gate using BJT are shown in fig.4.17.



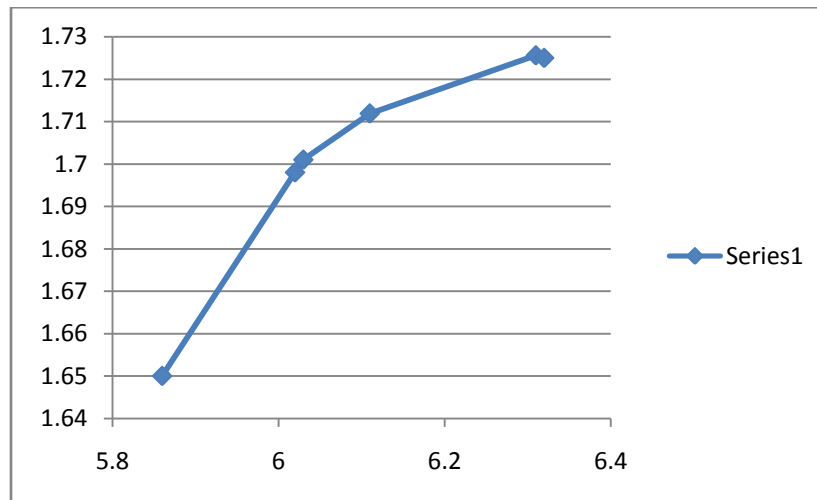
**Fig.4.17 Waveform after amplification using BJT**

**4.4.9 Final pulses after isolation using pulse transformer**- Final pulses after isolation using pulse transformers for T1 and T2 shown in fig.4.18.



**Fig.4.18 Final pulses after isolation for T1 and T2**

**4.4.10 Experimental result of changing frequency of the triggering signal corresponding to the changing variable resistance used at the comparator**



X axis: Resistance of potentiometer in KΩ

Y axis: Frequency in KHz

### CONCLUSION AND FUTURE SCOPE

#### **5.1 Conclusion**

In this work, the firing circuit is tested on multisim software and fabricated on bread board using resistors, capacitors and IC chips. The firing circuit is tested on fully controlled single phase converter on resistive and inductive load. The experimental results and simulation results are in co-ordination. So, we can use it for industrial purposes.

#### **5.2 Future Scope**

In the future we can expand the work in the following area:

1. To produce smooth dc a filter may be introduced in the output.
2. Various protection schemes such as under voltage, over voltage and short circuit protection can be included in the circuit.

## REFERENCES

1. Rashid M. H., Power Electronics, Prentice Hall of India Publishers Ltd., 2009
2. Sen P. C., Modern Power Electronics, Wheeler Publishing, 1998.
3. Krein P. T., Elements of Power Electronics, Oxford University Press 2003.
4. Zbar P. B. and Malvino A. P., Basic Electronics: A Text- Lab Manual, 5<sup>th</sup> edition, Tata Mc Graw-Hill Publisher, 2005.
5. Arora O. P., Power Electronics Laboratory: Experiments and Organisation, 1<sup>st</sup> edition, Wheeler Publishing, 1993.
6. Peter Geno, "Design Of Single Phase Fully Controlled Converter Using Cosine Wave Crossing Control With Various Protections" International Journal of Engineering Science and Technology, Vol. 2(9), 2010, pp. 4222-4227.
7. Gupta S.C., Member, IEEE, K. Venkatesan, and K. Eapen "A Generalized Firing Angle Controller Using Phase-Locked Loop for Thyristor Control", IEEE Transactions On Industrial Electronics And Control Instrumentation, VOL IECI-28, NO. 1, Feb. 1981, pp. 46-49.
8. Basit S. A., Soori P. K., and Omkar M., Heriot Watt University Dubai Campus, Dubai, "Firing Circuit for Converters Used in Drives Applications", IEEE 7<sup>th</sup> International Power Engineering and Optimization Conference, Langkawi, Malaysia, DOI 10.1109/PEOCO.2013.65644628, June 2013, pp.652-657.
9. Ilango B., Krishnan R., Suramanian R. and Sadasivam S., "Firing Circuit For Three Phase Bridge Rectifier", IEEE Transactions On Industrial Electronics And Control Instrumentation, VOL. IECI-25,NO. 1, Feb. 1978, pp.45-49.
10. Harada K., Senior Member, IEEE and Sakamoto H., "On the Magnetic Firing Circuit for an Inverter", IEEE Transactions On Magnetics, VOL 6, issue 3, DOI:10.1109/TMAG.1970.1066890, April 21-24, pp.658-659.
11. Abou-Elela M., Alolah A. I., "A Novel Self-Adjusting Firing Circuit For Phase Angle Control Applications", IEEE, IMTC' 94 , VOL 2, May 10-12, pp.619-622.
12. Subramanian k., Ray K. K., "Synchronised Linear Ramp-Pulse Based Triggering Pulse Generation ON/OFF Control for Solid-State Switches: Capacitor Switching Applications", WSEAS Transactions On Power Systems, E-ISSN: 2224-350X, Issue 2, Volume 7, April 2012.

13. Saridis G. N., Member, IEEE, And Learner Karl O., II, Member, IEEE, "A Linear SCR Control Amplifier", IEEE Transactions On Industry And General Applications, VOL. IGA-4, NO. 6, November/December 1968, pp.619-624.
14. Ainsworth J.D., BSc, MIEE, "Phase-locked oscillator control system for thyristor-controlled reactors", IEE PROCEEDINGS, VOL. 135, Pt. C, No. 2, March 1988, pp.146-156.
15. Daniels A.R., Control System Laboratories, School Of Electrical Engineering, University Of Bath," Digital Firing-Angle Circuit For Thyristor motor Controllers" PROC. IEE, Vol. 125, No. 3, March 1978, pp. 245-246.
16. Zaid S.A., Department of Electrical Power and Machines Faculty Of engineering, Cairo University, "Thyristor Firing Circuit Synchronization Techniques in Thyristor Controlled Series Capacitors", ICCEP, 2011 International Conference , pp. 183-188.
17. Torseng S., "Shunt-connected reactors and capacitors controlled by thyristors", IEEPROC, Vol. 128, Pt. C, No. 6, November 1981, pp.366-373.
18. Tang Pei-Chong, Lu Shui-Shong, And Wu Yung-Chun," Microprocessor-Based Design of a Firing Circuit for Three-Phase Full-Wave Thyristor Dual Converter", IEEE Transactions On Industrial Electronics, VOL. IE-29, NO. 1, February 1982, pp.67-73.
19. Simard Remy and Rajagopalan V., Member, IEEE," Economical Equidistant Pulse Firing Scheme for Thyristorized DC Drives", IEEE Transactions On Industrial Electronics And Control Instrumentation, Vol. IECI-22, No. 3, August 1975, pp.425-429.
20. Mirbod Ali, Member, IEEE, And El-Amawy Ahmed, Member, IEEE," A General-Purpose Microprocessor-Based Control Circuit for a Three-Phase Controlled Rectifier Bridge", IEEE Transactions On Industrial Electronics, VOL. IE-33, NO. 3, August 1986, pp. 310-317.
21. Rafique Muhammad Usman, "A Universal and Optimized Embedded System to Control Firing Angle of Thyristors with Double-Sided Isolation", 2011 Third International Conference on Communications and Mobile Computing, IEEE, DOI 10.1109/CMC.2011.79, pp. 99-102.
22. Bolok H. M., "A Microprocessor-Based Firing Circuit for Thyristors Working Under a Three-phase Variable-Frequency Supply", IEEE Transactions On Industrlal Electronics. VOL. 37. NO. 2., April 1990, pp. 152-155.

23. Krishnan Thadiappan And Ramaswami Bellamkonda,” A Fast-Response DC Motor Speed Control System”, IEEE Transactions On Industry Applications, VOL. IA-10, NO. 0, September/October 1974, pp. 643-651.
24. Wade John Sperry, Jr., Member, IEEE, And Aya Luis Gabriel, Student Member, IEEE,” Design for Simultaneous Pulse Triggering of SCRs in Three-Phase Bridge Configuration”, IEEE Transactions On Industrial Electronics And Control Instrumentation, VOL. IECI-18, NO. 3, August 1971, pp. 104-106.
25. Lo Yu-Kang and Chen Chem-Lin, “An Improved Cosine-Mode Controller for SCR Converters”, IEEE Transactions On Industrial Electronics, VOL. 42, NO. 5. October 1995, pp. 552-554.
26. J. M. S. Kim, Dept. of Electrical and Computer Engineering, University of Victoria, S. B. Dewan and F. P. Dawson, Dept. of Electrical Engineering, University of Toronto, “Four-Quadrant Dc Magnet Power Supply With Fast Dynamic Response And Low Ripple Content”, CH2839-9/90/0000-0, IEEE, 1990, pp.651.
27. Gupta Mukesh, Kumar Sachin and Karthik Vagicharla, “Design and Implementation of Cosine Control Firing Scheme for Single Phase Fully Controlled Bridge Rectifier”, International Journal of Emerging Trends in Electrical and Electronics (IJETEE – ISSN: 2320-9569), Vol. 3, Issue. 1, May-2013, pp.40-46.