Research Paper Engineering

Design and Simulation of Cosine Firing Scheme for Thyristor Triggering

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ABSTRACT

The Class of firing schemes for Thyristors consist various analog and digital circuits used to create gate pulses which are given to the gate of thyristor in order to trigger it. The various circuits like UJT relaxation oscillator triggering, RC triggering, Ramp and Pedestrial Triggering, etc undergoes the problem of limited firing angle. One cannot reduce the firing angle below α = 26° using such circuits, as the value of capacitor and resistor limits the firing angle. For the very precise control of firing angle, Cosine Firing Scheme (CFS) can be implemented. Added advantage of CFS is that it can be controlled digitally using microcontrollers also, thus can be used in closed loop applications. In this paper, authors have reported design methodology and simulated results of the CFS used for thyristor triggering.

Keywords : SCR Triggering, Digital Triggering of SCR, Close loop triggering, Firing of Full wave controlled rectifiers.

I. INTRODUCTION

Basically, an SCR can be switched from off-state to on-state in several ways; these are forward-voltage triggering, / triggering, temperature triggering, light triggering and gate triggering. The instant of turning on the SCR cannot be controlled by first three methods listed above. Light triggering is used in some applications, particularly in a series - connected string. Gate triggering is, however, the most common method of turning on the SCRs, because this method lends itself accurately for turning the SCR at the desired instant of time. In addition, gate triggering is an efficient and reliable method.[1]

The gate control circuit is also called firing, or triggering circuit. These gating circuits are usually low-power electronic circuits. A firing circuit should fulfill the three following functions:

(i) If the power circuit has more than one SCR, the firing circuit should produce gating pulses for each SCR at the desired instant for proper operation of the power circuit. These pulses must be periodic in nature and the sequence of firing must correspond with the type of thyristorised power controller.[1]
(ii) Synchronization: The basic requirement from a trigger control circuit is to produce sharp pulses at specific instant of time scale. These pulses appear at variable positions to make the control possible. It is said to have produced a definite and desired time delay from a specific mark. It is at this mark where from the time delay is counted.

These marking for instant are derived, for a 1-ϕ converter, from the instant the ac wave crosses zero.

The synchronization circuits are essentially zero crossing detectors. For M-1 converters, only positive zero crossing is to be detected. For M-2 converters, only positive zero crossing of each phase voltage on secondary winding is detected or alternatively detection of positive and negative zero crossings of one of the source voltage is necessary.

For M-3 converters, it is not the zero crossing detection of the phase voltage but the positive zero crossing of the voltage of the incoming line with respect to outgoing line called Commutating Voltage is to be detected.

For Bridge Configuration, both positive and negative zero crossings of line voltages are to be detected.[3]

(iii) The control signal generated by a firing circuit may not be able to turn-on an SCR. It is therefore common to feed the voltage pulses to a driver circuit and then to gate-cathode circuit. A driver circuit consists of a pulse amplifier and a pulse transformer. [1]

In [3], researcher have considered some circuits which used R-C circuit or comparison between a control voltage and time varying voltage to produce time delays corresponding to required value of trigger angle by analog circuits.

Time delays can also be produced digitally by setting a counter to count down from a set value and producing output pulse when count goes to zero.

A general layout of firing circuit scheme is shown in Fig 1. A regulated DC power supply is obtained from an alternating voltage source. Pulse generator, supplied from ac and dc sources, gives out voltage pulses which are then fed to pulse amplifier for their amplification. Shielded cables transmit the amplified pulses to pulse transformers. The function of pulse transformer is to isolate the low-voltage gate-cathode circuit from high voltage anode-cathode circuit.[1]

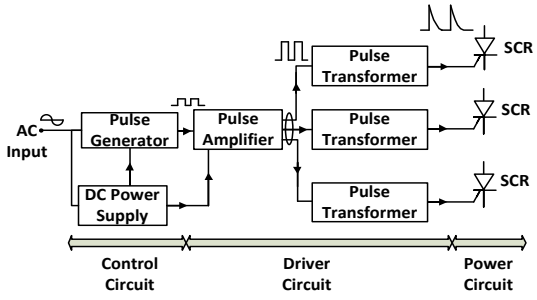


Fig 1 : General Layout of the Firing circuit scheme for SCRs

II. principle of opEration

CFS is used to trigger thyristors for practical applications in AC to DC controlled rectifiers and in dual convertors. The main feature of this firing scheme is that it provides a very precise control of firing angle i.e. α = 1°. In addition, the firing angle in this scheme can also be controlled by the microcontroller and digital circuits, which provides the ease of automatic control and closed loop operation.[4] In CFS, the sine wave

of power source which is fed to the thyristors is step down to low voltage and given to Integrator. As a consequence, we get the cosine wave at the output of integrator which is synchronized with the source sine wave. This cosine wave is further compared with some reference DC Voltage in a comparator giving square waves at the output. The obtained square wave is then given to the clock pulse generator which essentially generates the clock pulses on the bases of change of amplitude of square waves. The generated pulses are fed to JK Flip-Flop, the output which finally gives the triggering pulses of SCR.[1] This single circuit discussed here can be used to trigger four SCRs connected in bridge, thus a Controlled Full Wave Rectifier can be triggered using this scheme. [5]

III. SYSTEM DESIGN

a. block Diagram:

Block Diagram of CFS for thyristors in single-phase converters is shown in fig 2.

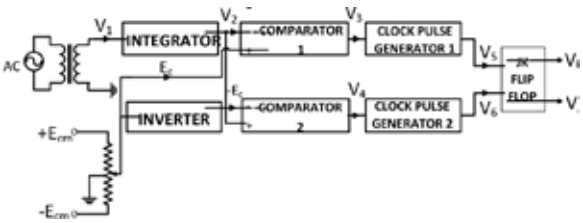


Fig 2: Cosine Firing Scheme (Block Diagram)

The synchronizing transformer steps down the supply voltage to 9 volt AC. The input to this transformer is given from the same source from which converter circuit is energized. The output voltage 1 of synchronizing transformer is integrated to get cosine-wave 2. The dc control voltage Ec varies from maximum positive Ecm to maximum negative –Ecm so that the firing angle can be controlled from zero to 180°. The cosine wave 2 is compared in comparators 1 and 2 with Ec and -Ec. When Ec is high as compared to 2, output voltage 3 is available from comparator 1. Same is true for comparator 2. So the comparators 1 and 2 give output pulses 3 and 4 respectively as shown in Fig 3.

It is seen from this figure that the firing angle is governed by the intersection of 2 and Ec. When Ec is maximum, firing angle is zero. Thus, firing angle α in terms of V2m and Ec can be expressed as

$$V_m \cos\alpha = E_c \text{ or } \alpha = \cos^{-1}\left(\frac{E_c}{V_m}\right) \quad \ldots(1)$$

;Vm = maximum value of cosine signal 2.

The signals v3, v4 obtained from comparators are fed to clock-pulse generators 1, 2 to get clock pulses 5, 6 as shown in Fig 3.

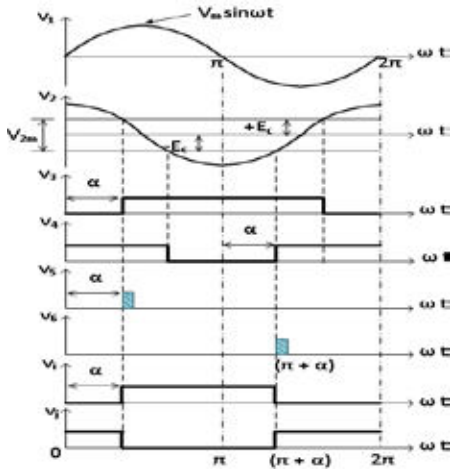


Fig 3: Waveforms for CFS

These signals 5, 6 energize a JK flip flop to generate output signals i and . The signal i is amplified through the pulse gating circuit (not discussed here) and is then employed to turn on the SCRs in the positive half cycle. Signal , after amplification, is used to trigger SCRs in negative half cycle. For a single-phase full wave converter, average output voltage is given by

$$V_o = \frac{2V_m}{\pi}\cos\alpha \quad \ldots(2)$$

Thus, from Eq. (1), we get,

$$V_o = \frac{2V_m}{\pi}\cos\left[\cos^{-1}\frac{E_c}{V_m}\right] = \left[\frac{2V_m}{\pi}\cdot\frac{1}{V_m}\right]\cdot E_c$$

$$V_o = k\,E_c \quad \ldots(3)$$

This shows that cosine firing scheme provides a linear transfer characteristic between the average output voltage Vo and the control voltage Ec. This scheme, on account of its linear transfer characteristics, improves the closed-loop response of the converter system. [1]

B. Implementation:

As shown in the below circuit, OP-AMP U1A is configured as differentiator so that the Sine wave from the synchronous transformer can be converted into – Cosine. OP-AMP U1B serves as the inverting amplifier which changes the phase of Cosine wave received from Differentiator by 180°. Thus the output of U1A is Cosine while that of U1B is Cosine. In U1C, the Cosine wave so obtained is compared with a control voltage E_c. U1C is a simple OPAMP based comparator in which (-) input is given cosine wave while (+) input is given control voltage E_c.

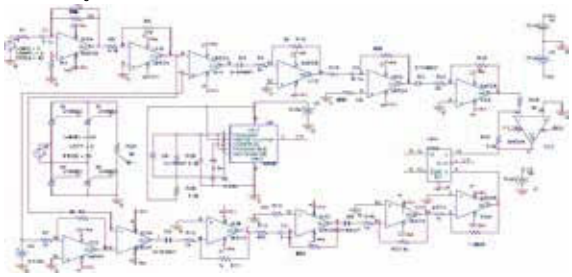


Fig 4: Circuit Schematic of CFS

Diode D1 to D4, all serves to clip of the negative cycle of comparator output, while U1D works as a clock pulse generator. U1D generates pulses which after certain processing can be given to the J input of the Flip-Flop. U2A is again an inverting amplifier having gain 0.3 in order to reduce the comparator output voltage + 15 V to +5 V. We need to reduce this voltage so that it safely can be given to the J-K Flip Flop. The output of U2A is pulses having amplitude of – 5V. So it is again fed to an inverting amplifier U2B to give the pulses having amplitude of + 5 V. Further U2C works as the inverter module of our block diagram. The functioning of U2D, U3A, U3B, U3C and U3D are identical to that of U1C, U1D, U2A, U2B and U2C respectively. The output of U3D is been fed to the K input of J-K Flip-flop.

The output Q of JK Flip Flop can be used to trigger the pair of thyristors in Full Wave configuration which are in forward blocking for positive half cycle of source voltage. While output can be used to trigger the pair of thyristors which are in forward blocking mode during negative half cycle of source.

Also, the clock pulses of 5 KHz are given to the JK-Flip Flop using an astable multi-vibrator based on timer IC 555. Opto-isolator should be used between the firing circuit and thyristors for safety purpose.

C. Simulation:

Simulation of CFS using ORCAD Capture has been carried

out by the authors and results are discussed along with the simulation waveforms. Simulation is carried out in ORCAD PSpice 9.2 with simulation parameter configuration of Time Domain (Transient) type General Setting's type for the run time from 0.02 seconds to 0.04 seconds.

ORCAD Capture Schematic has developed for the entire circuit of CFS in order to observe the impact of DC voltage on firing angle and triggering of Thyristors.

Fig. 5 (a) and Fig 5 (b) shows the simulation result for firing pulses obtained from the circuit topology discussed in Fig. 2. In Fig 5 (a), the pulses obtained from Q output of terminal of JK Flip Flop are shown by square pulses. The DC value is kept 9 V so that the firing angle is very close to 0°. The Fig 5 (b), shows the pulses obtained from output of JK Flip-Flop.

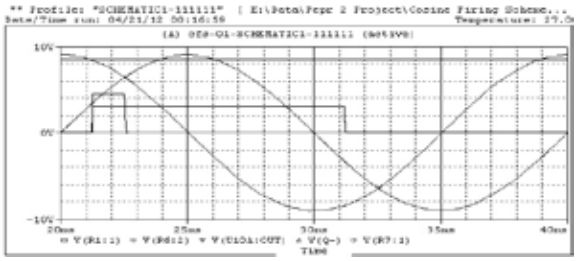


Fig 5(a): Simulation Result for the CFS (Vj)

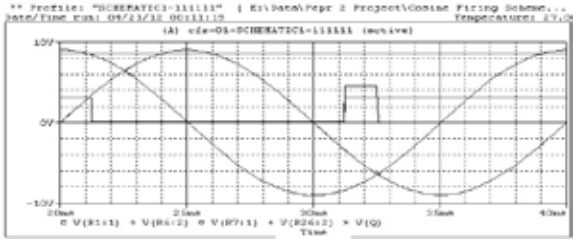


Fig 5(b): Simulation Result for the CFS (Vj)

D. Practical output:

The various waveforms obtained on oscilloscope are shown below. These practical waveforms are in correspondence with the theoretical waveforms as well as the simulation results also. The waveforms only show the input sine wave, cosine wave and the triggering pulses generated by CFS circuit. It does not show any waveform for Full Wave Controlled rectifier.

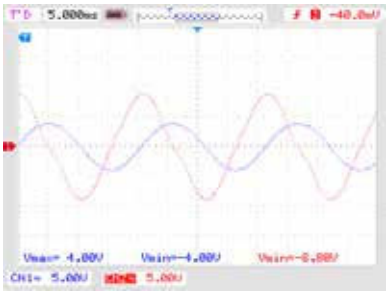


Fig 6(a): Integrator Output

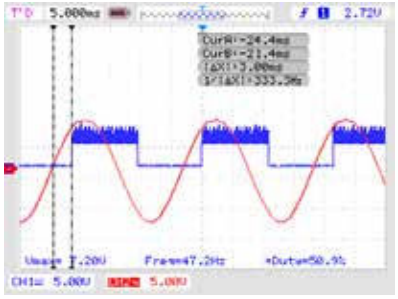


Fig 6(b): CH1 – Sine wave input
CH2 – JKFF output Q (α = 45°)

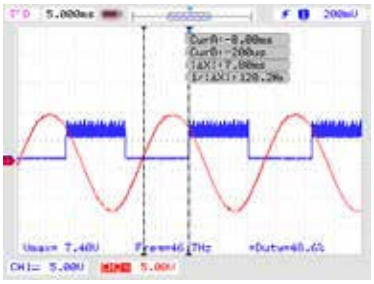


Fig 6(c): CH1 – Sine wave input
CH2 – JKFF output Q (α = 135°)

The Fig 6 (a) shows input sine wave in blue colour and the cosine wave which is obtained from integrator in red colour waveform of CH 1 and CH 2 respectively. Fig 6 (b) shows

Fig 6 (b) shows input sine wave as CH 2 waveform while CH 1 waveform shows the firing pulses obtained at Q output of JK-Flip Flop for firing angle α = 45°. These firing pulses can be used in practice to trigger thyristor.

In Fig 6 (c), CH 1 shows the firing pulses for angle α = 135° in blue colour, while the red waveform is of input sine wave at CH 2.

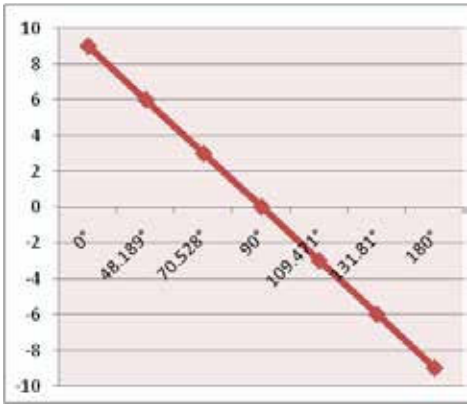
IV. ANALYSIS

The authors have prepared the data on the basis of simulation results and calculations using the equations indicated in section of system design which is tabulated in Table 1 given below:

TABLE 1 : Values of Ec and Firing Angle α

Sr. No.	Vm	Control Voltage (Ec) [+9 V to -9 V]	Firing Angle α = cos-1(Ec/Vm)
1	9	9	0°
2	9	6	48.189°
3	9	3	70.528°
4	9	0	90°
5	9	-3	109.471°
6	9	-6	131.81°
7	9	-9	180°

The values of Control Voltage (Ec) which is compared with the Cosine Wave in order to generate firing pulses are plotted on a graph on Y – axis while the corresponding firing angles are plotted on X – axis as shown in Graph 1:



Graph 1 : Control Voltage (Ec) VS. Firing Angle (α)

As seen from the above graph, the relation between the firing angle and the Control Voltage which determines the firing angle is exactly linear which depicts that the transfer characteristics between the average output voltage Vo and the control voltage Ec is linear as indicated by eq V0 = k Ec.[1]

Following Fig 7 (a) to Fig 7 (c) shows the simulated output waveform of Full Wave Convertor using thyristor which is triggered using CFS for firing angle 45°, 90° and 135° respectively. [5]

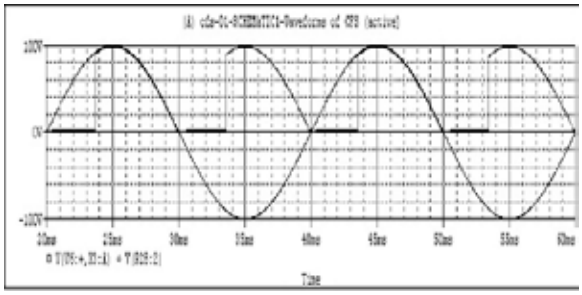


Fig 7(a): Input & Output Waveform of Full Wave Converter for α = 45° (Ec = 4.5 V)

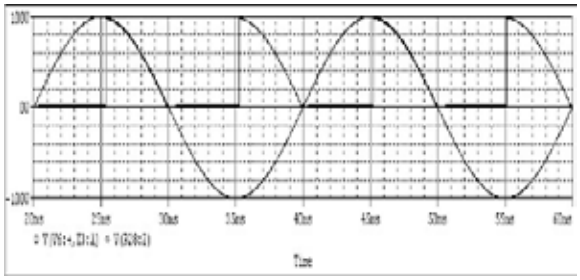


Fig 7(b): Input & Output Waveform of Full Wave Converter for α = 90° (Ec = 0 V)

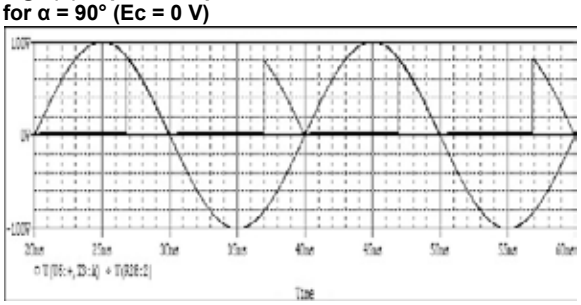


Fig 7(c): Input & Output Waveform of Full Wave Converter for α = 135° (Ec = -4.5 V)

All the simulation results are in accordance with the theoretical analysis of the circuit.

V. FUTURE SCOPE

The authors have simulated the circuit for CFS and have got successful results. Authors are looking forward to implement this circuit on hardware and use it to make Dual Convertors with Automatic Control of the Control Voltage Ec on the basis of feedback received by the dual converter. Thus, this closed loop dual converter can be used for the precise speed control of DC Motor in four quadrants on the basis of feedback, providing efficient speed regulation.[7]

VI. CONCLUSION

Low cost Firing Scheme have been designed and simulated for the Thyristor Triggering. As discussed above, the linear relationship between the firing angle and control voltage is provided by CFS. As the firing angle is decided by the control DC Voltage, it is possible to control the firing angle using microcontroller and A/D, D/A converters.

It has been observed that the minimum firing angle of α = 10.8° is obtained from the CFS implemented using analog circuits. The very first triggering pulse is obtained at 400 µsec from the instant of zero crossing of sine wave.

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