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Design and Implementation of Firing Control Circuit for a Three-Phase Fully Controlled thyristor Bridge Dual-Converter

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ABSTRACT:

A firing control scheme for a three-phase fully controlled thyristor bridge dual-converter is described. By adapting the cosine wave crossing method, in the scheme, the converter operates as a linear power amplifier. The firing circuit has a fast response for triggering angle correction. The scheme requires minimum number of integrated circuit component since it utilizes the same circuit for both rectification and regeneration modes of operation. The experimental waveforms are correlated with predicted waveforms.

KEY WORDS: *DC motor, cosine wave technique, dual-converter, crossing point, and control voltage.*

الخـلاصــــــة

تم وصف دائرة قدح لمحول قدرة مزدوج يحول قدرة متناوبة الى مستمرة، ثلاثي الطور من نوع قنطري. تعتمد الفكرة على طريقة تقاطع موجة الجيب تمام، حيث تجعل محول القدرة كمضخم قدرة خطي. أن دائرة القدح تمتلك أستجابة سريعة لتصحيح زاوية القدح للثايرستور. ان دائرة القدح تتطلب عدد قليل من الدوائر المتكاملة نظراً لأستخدام نفس الدائرة لتشغيل المحول بخاصية تحويل القدرة المتناوبة الى مستمرة وبالعكس. وجدت النتائج العملية متفقة مع النتائج النظرية.

1. INTRODUCTION

The individual phase control of three-phase converters for industrial applications uses a large number of components. But it has an advantage in the form of minimum delay of one sixth of period for the corrections of the firing angle [1]. A single full-wave converter provides a unidirectional current at the dc terminals, but the voltage of the dc terminals can be reversed provided that a high inductance at the dc side. It is thus capable of providing only two-quadrant operation. If two full- wave converters are connected back-to-back (antiparallel), both the voltage and the current at the dc terminals can be reversal, and therefore the system will provide four-quadrant operation. Such a system is called a *dual-converter*. This system is frequently used in industry.

Two separate firing units can be used for the two converters of the dual-converter system. However, when a dual-converter is operated in free-circulating current mode; only one converter conducts at any given instant. It is therefore possible to have only one firing unit switch the firing pulses to the appropriate converter mode of operation [1].

In this paper a simple firing scheme suitable for three-phase fully controlled bridge dual-converter is presented. The scheme uses cosine wave crossing technique to generate firing pulses. The detailed description of the scheme as well as the experimental and theoretical waveforms is also presented.

2. DESCRIPTION OF POWER CIRCUIT

Fig. 1 shows a three-phase fully controlled dual-converter power circuit, the voltage and current waveforms, and firing sequence of thyristors. The three-phase six-pulse bridge can be operated in a converter or inverter mode depending upon the delay angle to be less than or above 90°. Each SCR remains on for 120° duration and is turned off only when the next SCR of the same portion in sequence is gated. Once SCR each in upper and lower portions of the bridge conducts at a time for 120° duration and is turned off only when the next SCR of the same portion in sequence is turned on. SCRs are switched on in a sequence at every 60° angle thus the gate pulses should have a frequency six times higher than the source frequency. Moreover, to keep each SCR on for 120° duration either each SCR should be gated twice at the interval of 60° by short gate pulses or each gate pulse should be for more than 60°. The large duration of pulse needs carrier frequency ANDING to reduce saturation in pulse transformer [2]. In the proposed scheme the later technique is used.

In a closed loop control system, it is desirable that the power amplifier should exhibit a linear output-input characteristic. This requires the linear variation of cosine of delay angle with the control voltage [3].

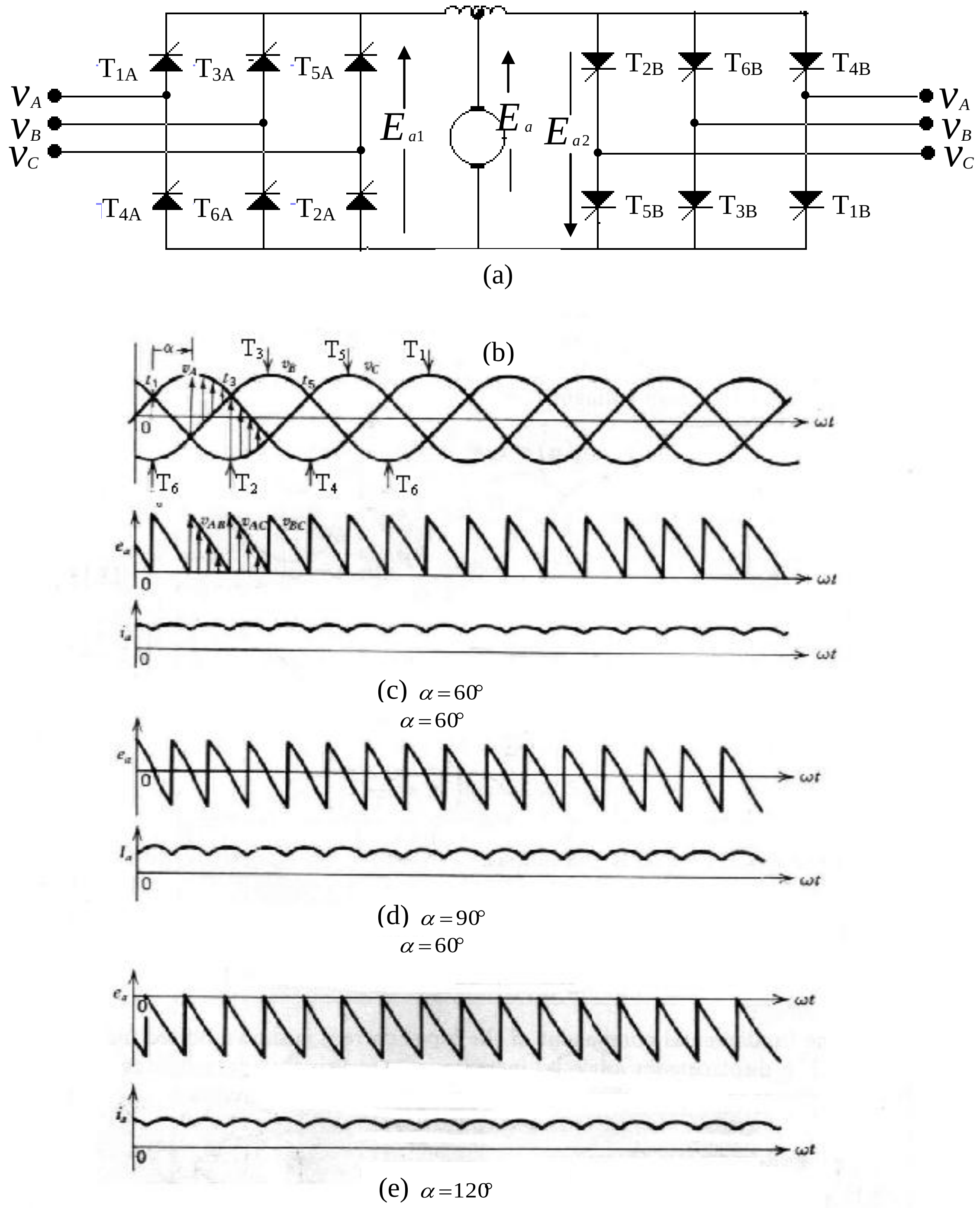


Fig. 1:Three-Phase Fully-Controlled Dual-Converter Drives System. (a) Power Circuit. (b) - (e) Waveforms at Different Firing Angles for Continuous Motor Current.

The basic principle of this firing control scheme is shown in Fig. 2. The reference for triggering angles of the thyristors is the crossing points of the phase voltages. For thyristors T_1 for both banks A and B in Fig. 1, the reference for the trigger pulse is the instant t_1 shown in Fig. 2a. If the voltage v_A is phase shifted (advanced) by 60° to produce a voltage e_A, its peak voltage will coincide with this instant t_1. A control voltage (E_C) can be used to produce triggering pulses for T_{1A} at the crossing points with e_A. Similarly, a voltage e_A', which is the inverse of e_A, can produce triggering pulses for T_{1B} to operate in inversion mode. Triggering pulses are shown in Fig. 2c [4].

However, phase shifting of the voltage by 60° can be avoided. Fig. 2a shows that, at t_1, the voltage v_B is at negative maximum.

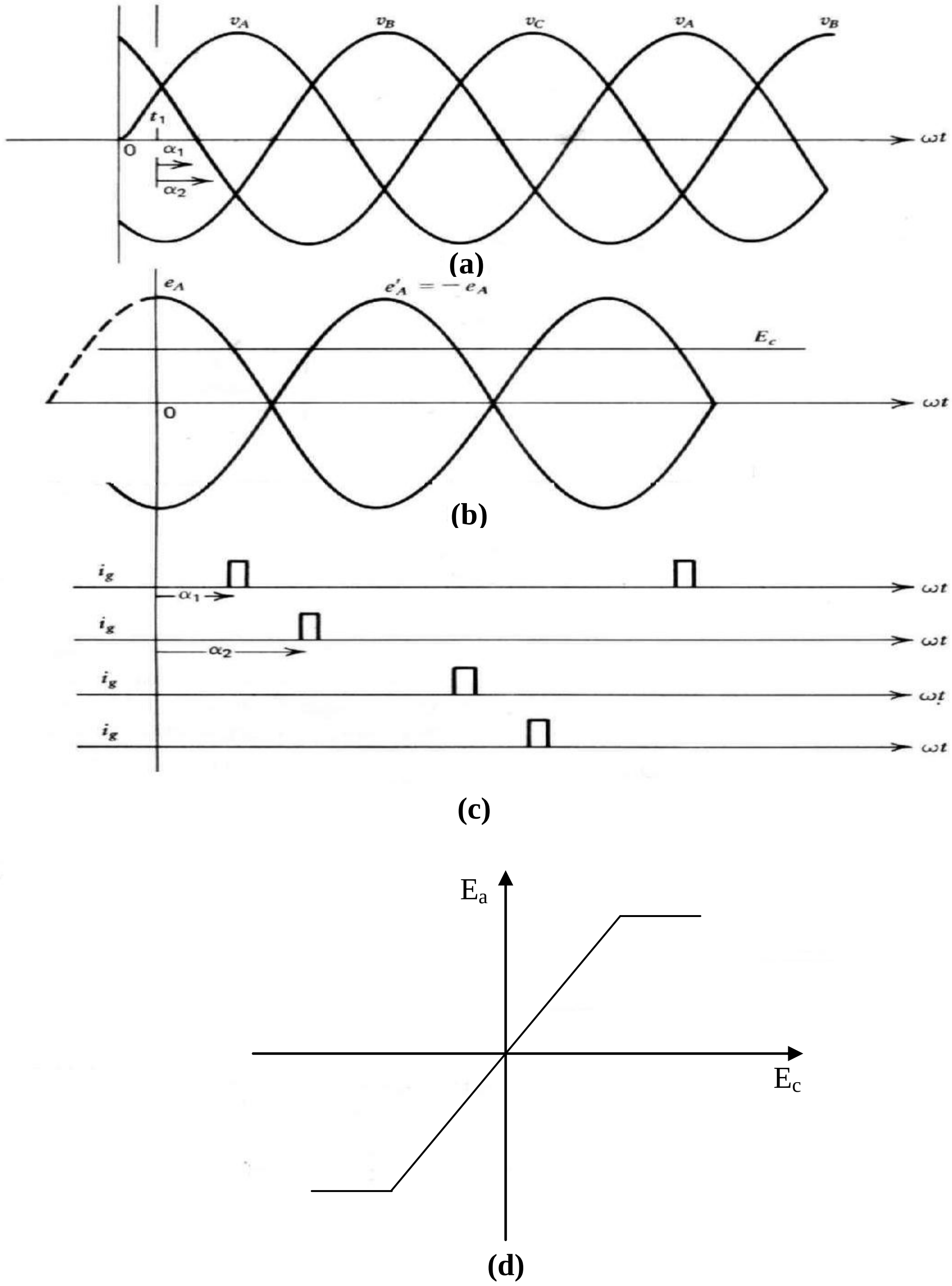


Fig. 2: Cosine Firing Scheme. (a) Supply Voltages. (b) Phase-Shifted Supply Voltage and Control Voltage. (c) Firing Pulses for Positive Control Voltage. (d) Voltage Transfer c/c.

The trigger pulses generated by comparing the control voltage (E_C) with v_B and its inverse can be used to trigger T_{1A} and T_{1B}. These two schemes are shown in Fig. 3.
Let

$$e_A = K\cos\theta \qquad ...(1)$$

$$e_A' = -K\cos\theta \qquad ...(2)$$

Thus,

$$E_C = K\cos\alpha_1 \qquad ...(3)$$
$$E_C = -K\cos\alpha_2 \qquad ...(4)$$

from equations (3) and (4)

$$\cos\alpha_1 + \cos\alpha_2 = 0$$

or

$$\alpha_1 + \alpha_2 = 180^\circ$$

Since the output voltage of converter is:

$$E_{a1} = E_{\max}\cos\alpha_1$$

$$E_{a2} = E_{\max}\cos\alpha_2$$

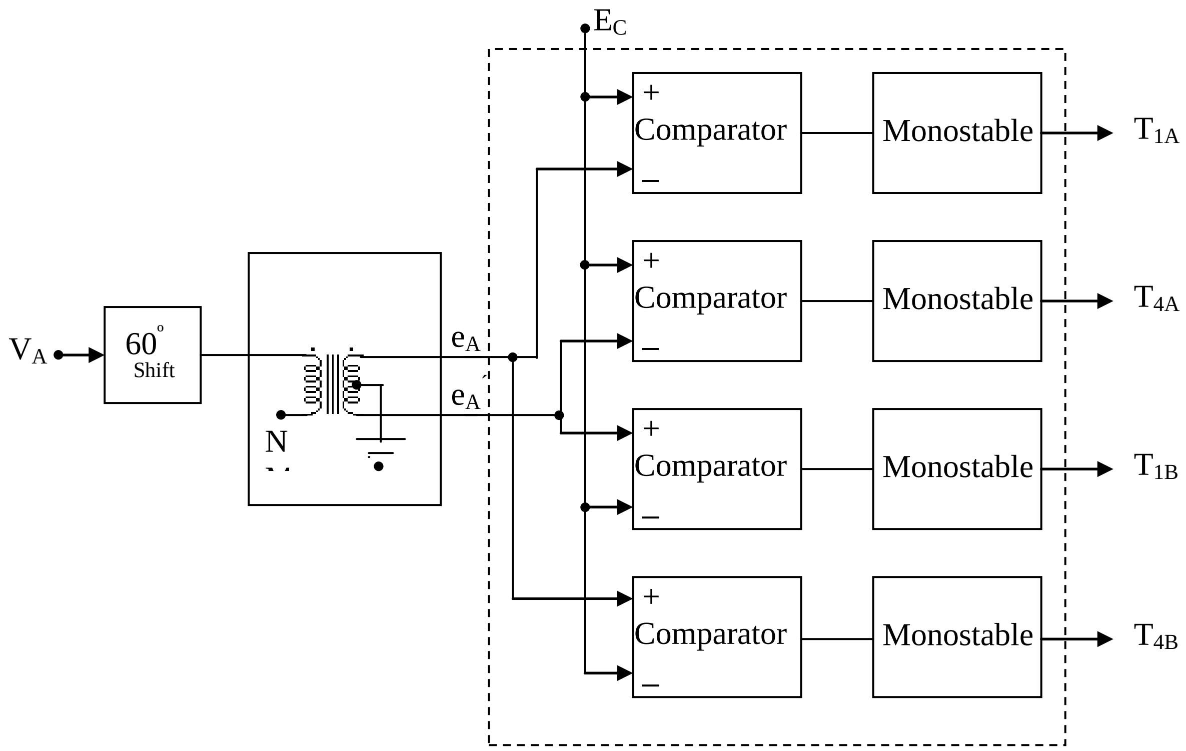
Then;

$$E_{a1} = E_{\max}\cos\alpha_1 = E_{\max}\cdot\frac{E_C}{K} \qquad ...(5)$$
$$E_{a2} = E_{\max}\cos\alpha_2 = -E_{\max}\cdot\frac{E_C}{K} \qquad ...(6)$$
$$E_a = E_{a1} = -E_{a2} = \frac{E_{\max}}{K}\cdot E_C = K_C\cdot E_C \qquad ...(7)$$

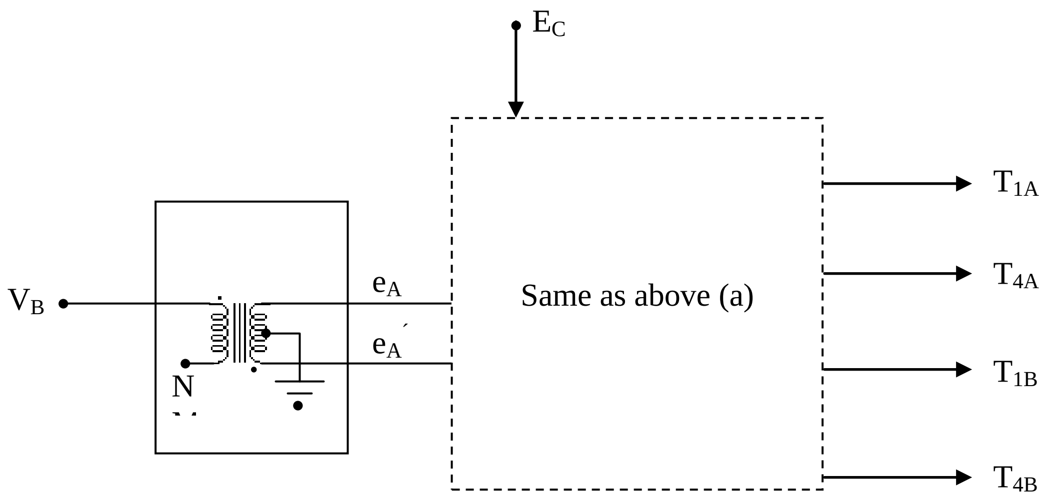
where

$$K_C = \frac{E_{\max}}{K}$$
$$E_{\max} = \frac{3\sqrt{6}V_{ph}}{\pi}$$
$$K = 7.7v$$
$$V_{ph} = 120v$$

The dc terminal voltage of the dual-converter is thus directly proportional to the control voltage (E_C). The above firing technique makes each converter behave essentially as a power amplifier with a linear voltage transfer characteristic [R_{T1}, R_{T15}], as shown in Fig. 2d.



(a)



(b)

Fig. 3: Schemes to Generate Firing Pulses for a Dual-Converter. (a) Phase-Shift Input Supply Voltage. (b) Unshifted Input Voltage.

3. PROPOSED FIRING CONTROL CIRCUIT

The block diagram of the scheme is shown in Fig. 4a. The relevant waveforms at different points of firing circuit are shown in Fig. 4b and Fig. 4c. The scheme consists of step-down transformer, comparator, differentiator, monostable multivibrator, AND gate, OR gate and power amplifier blocks.

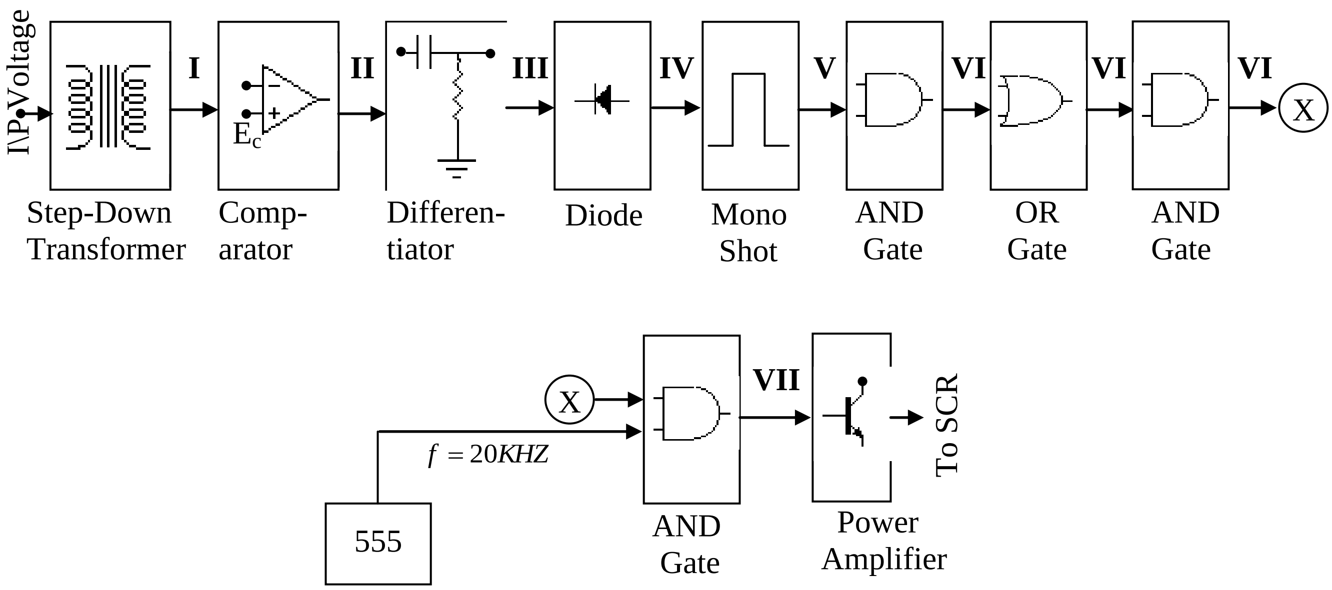


Fig. 4a: Block Diagram of Firing Circuit.

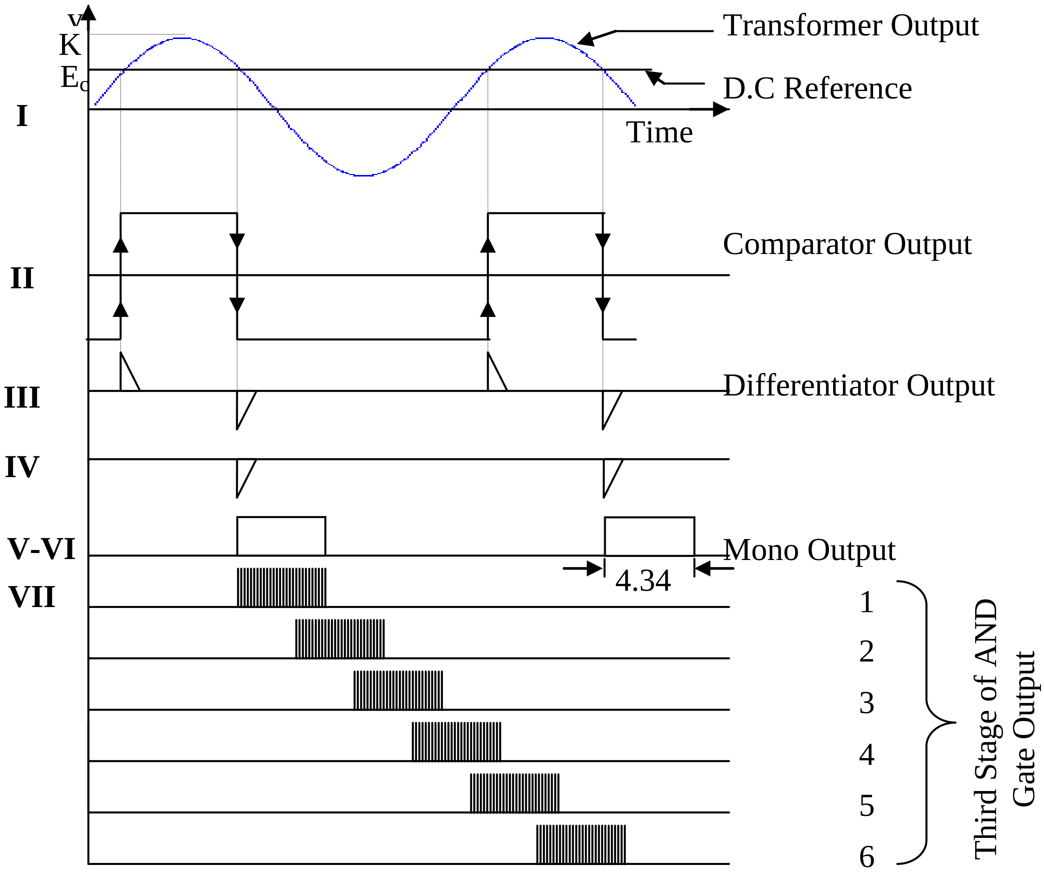


Fig. 4b: Waveforms at Different Points of Firing Circuit for Conversion Mode Operation.

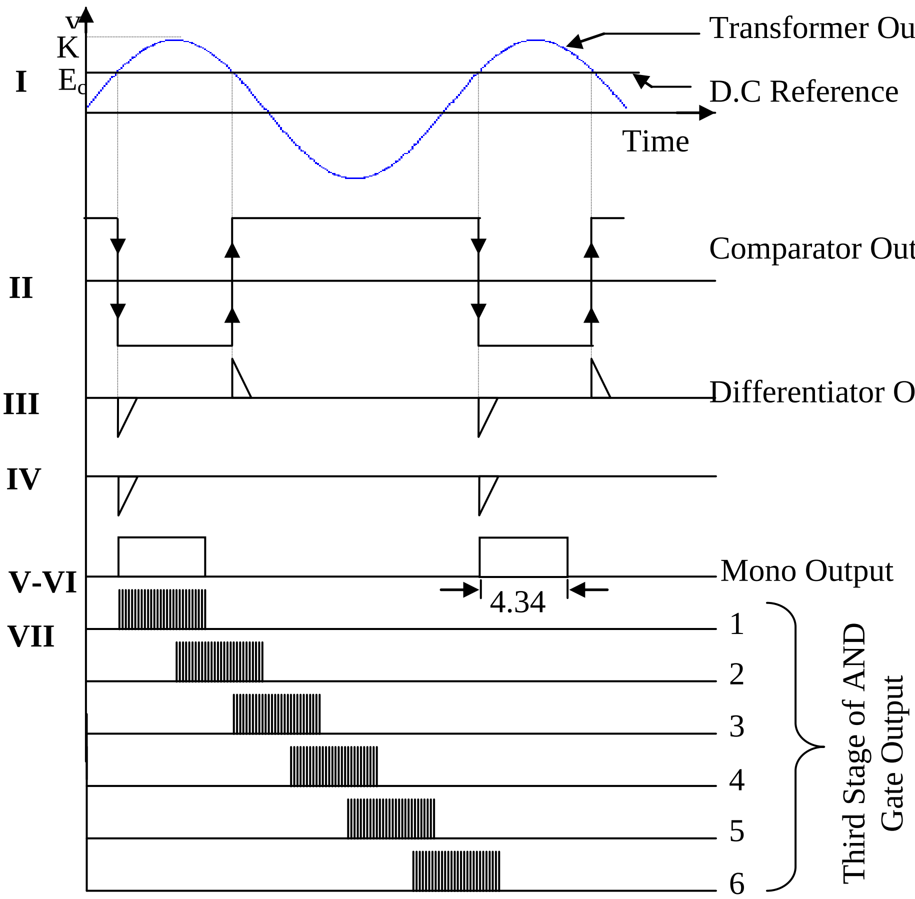


Fig. 4c: Waveforms at Different Points of Firing Circuit for Inversion Mode Operation.

A brief description along with design features is given below. The detailed wiring diagram is shown in Fig. 5.

3-1 Step-down transformer:

Three single-phase transformers with center tapped secondary windings have been used. The primary windings being arranged in star connection while the secondary windings are arranged to have a six-phase configuration to produce six-channels. Each channel generates a firing pulse to trigger an SCR.

3-2 Comparator:

The secondary voltage of the transformer is compared with a dc reference signal using a 741C op-amp comparator to produce an alternating rectangular waveform of a variable pulse width.

3-3 Differentiator and Monoshot blocks:

A simple R-C differentiator is used to differentiate the rectangular voltage waveform. The elements R and C are selected as 10KΩ and 0.01μF, respectively. A Monoshot block produces an output pulse of 4.34ms using a positive going edge trigger of dual monostable to produce a delay angle between 0° and 90° for the conversion mode of operation and between 90° and 180° for the inversion mode of operation. The positive spike of the differentiator is blocked by a reverse connected diode. The number of comparators and monostable blocks are 12 blocks to produce firing pulses for conversion and inversion mode together. The values of R & C for the dual-monostable are chosen according to the formula:

$$\tau_d = K \cdot R_X \cdot C_X \left(1 + \frac{0.7}{R_X}\right) \qquad \ldots(8)$$

Where,

R_X = External resistor of monostable.

C_X = External capacitor of monostable.

τ_d = Pulse duration.

$K \approx 0.28$

Since $\tau_d = 4.34$msec and by taking $C_X = 0.47$μF then, $R_X = 33$kΩ.

3-4 First stage of AND gate:

The first stage of the AND gate is used to block one of the firing pulses of the two operating modes (conversion and inversion modes), by using a signal (S-control signal). When the S-control signal is logic “0” then the firing pulses for conversion mode are passed and the firing pulses for inversion mode is blocked, and when S-control signal are logic “1” the trigger pulses for inversion mode operation are passed and the trigger pulses for conversion mode operation are blocked.

3-5 OR Gate stage:

This stage is used to achieve OR operation between symmetrical outputs of first stage of AND gate. The inputs to this stage are 12-lines (6-lines for firing pulses of conversion mode and the other 6-lines for firing pulses of inversion mode), but the outputs of this stage are 6-lines either firing pulses of conversion mode operation or inversion mode operation.

3-6 Second AND gate stage:

This stage is used with two control signals, signal “A” and signal “B”, to enable and disable appropriate bank of dual-converter. These two control signals come from a control unit such as microprocessor, microcontroller or PLA.

3-7 Third AND gate stage:

As operation of bridge converter/inverter requires conduction of each SCR for two consecutive 60° duration, the scheme uses gating of each SCR greater than interval of 60°. This is long pulse, they may saturate the pulse-transformer and the whole width of the pulse may not be transmitted. The whole pulse-width may not be necessary. In such a case, the pulse is modulated at a high frequency (20 kHz) as shown in Fig. 5, using a 555 oscillator. The duty cycle of the timer should be less than 50% so that the flux in the transformer can reset.

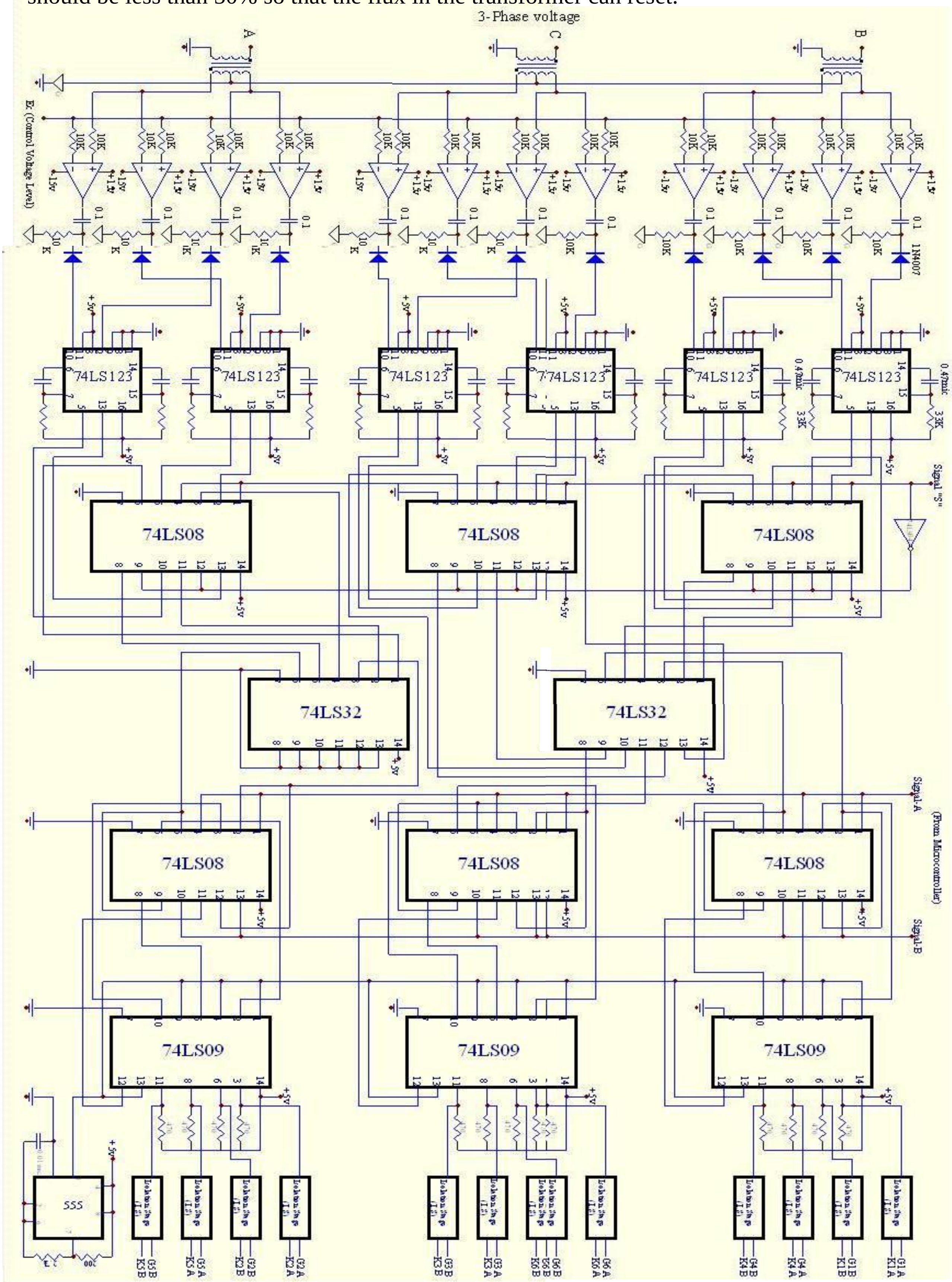


Fig. 5: Detailed Firing Circuit of Three-Phase Fully Controlled Bridge Dual Converter.

3-8 Power amplifier and isolation blocks:

The firing pulses at the output side of third AND gate stage may not be strong enough to turn on an SCR. Besides, the control circuit is to be isolated from the power circuit. An optical isolation or pulse-transformer isolation is commonly used in practice to provide physical isolation between the control circuit and the power circuit. Fig. 6 shows a pulse amplifier circuit using pulse-transformer isolation. Transistor type BC441 is employed to amplify the pulse current. The transistor is protected from the high voltage pulses induced on the primary of the pulse-transformer due to transistor switching off. Protection is achieved by connecting a diode across the primary of the pulse-transformer.

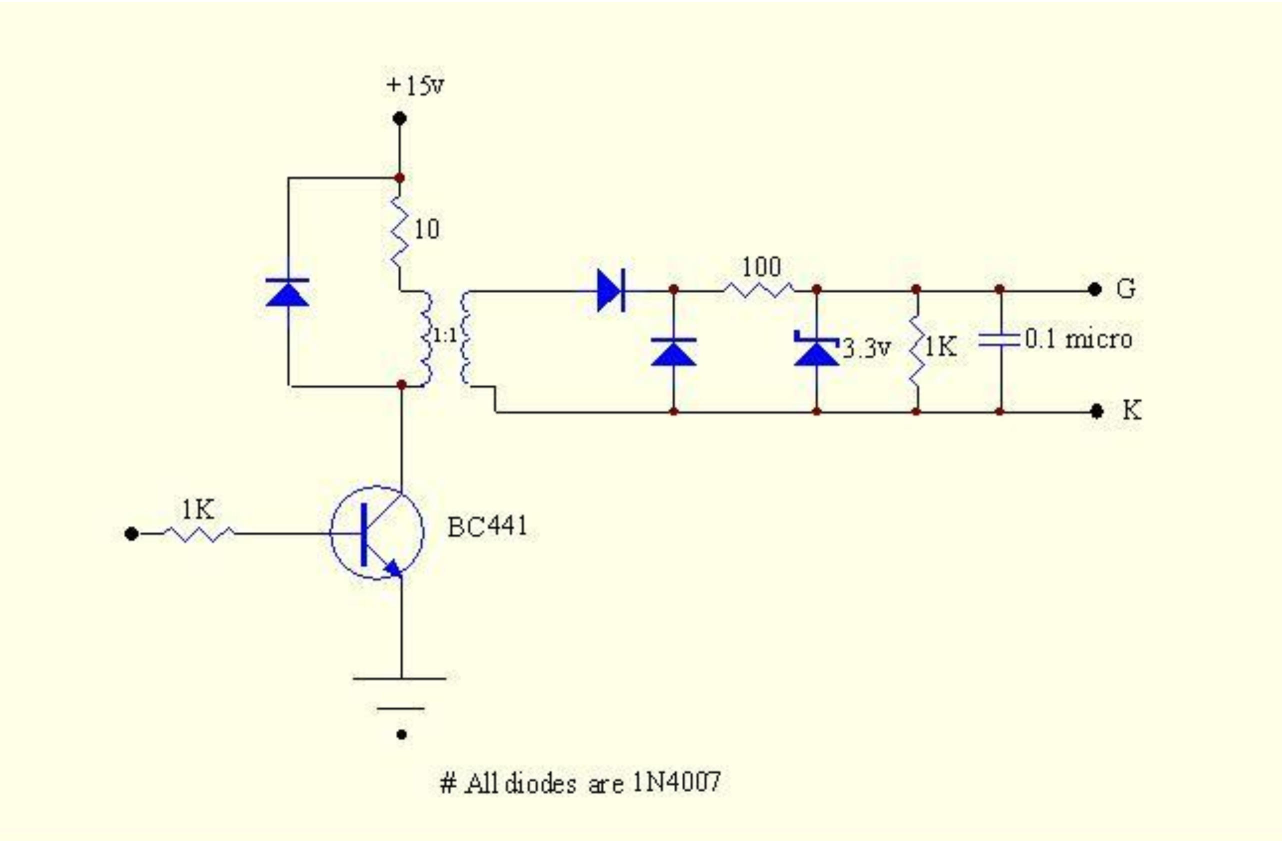
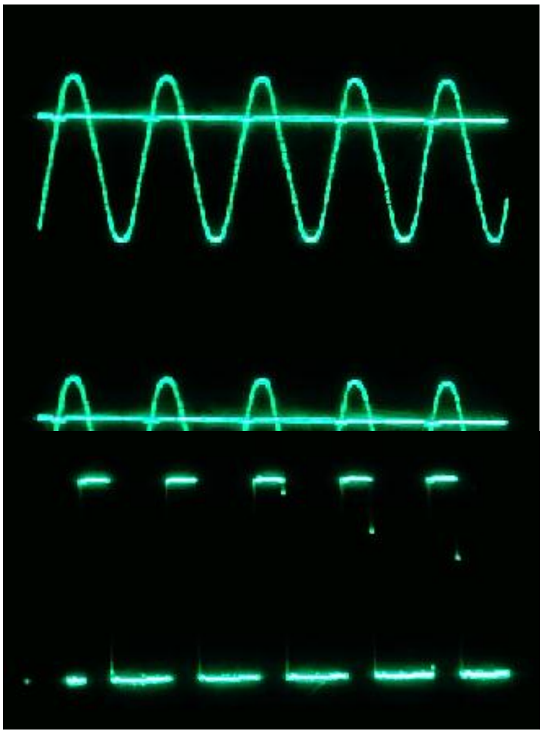


Fig. 6: Isolation and Amplification Circuit.

4. EXPERIMENTAL RESULTS

The circuit is built and tested, and the experimental waveforms at different points of firing circuit are shown in Fig. 7a. The theoretical waveforms are correlated with the experimental waveforms. The operation of the scheme had been found to be stable. The dc line voltage against control voltage characteristic to achieve converter operation is obtained experimentally and is shown in Fig. 7b, this characteristic is almost linear.



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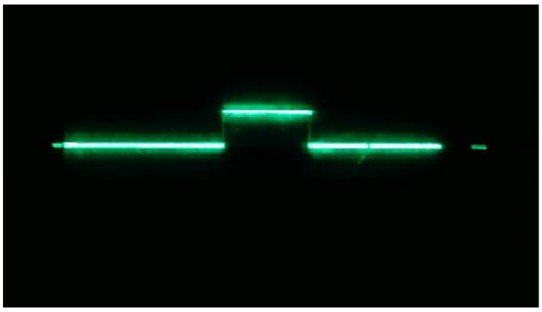

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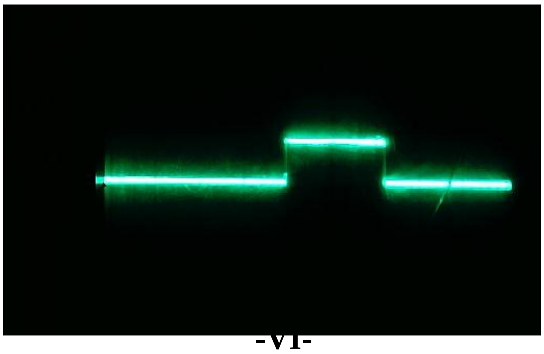

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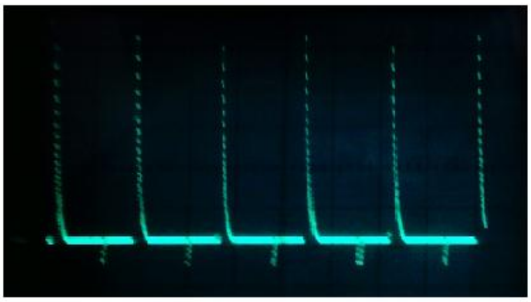

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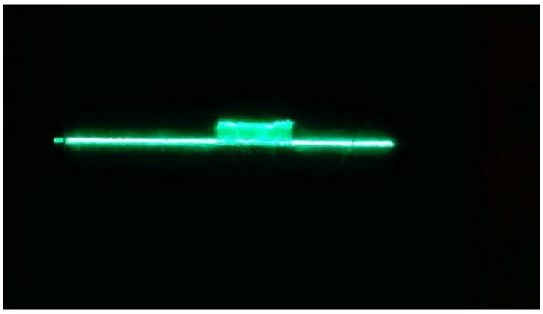

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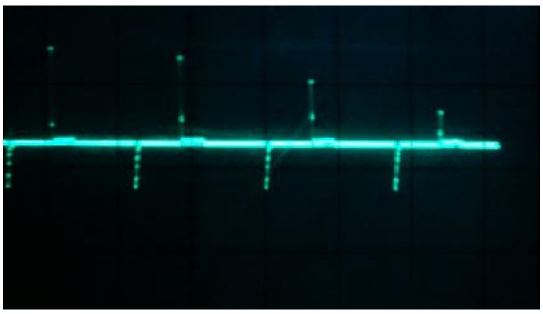

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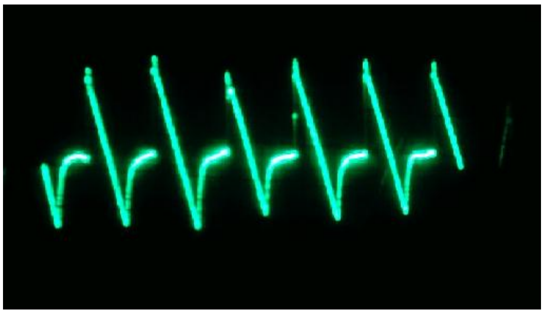

-converter output voltage-

Fig. 7a: Experimental Waveforms at Different Points of Firing Circuit (Hint: The Above Photos are Named According to Fig. (3.5a)).

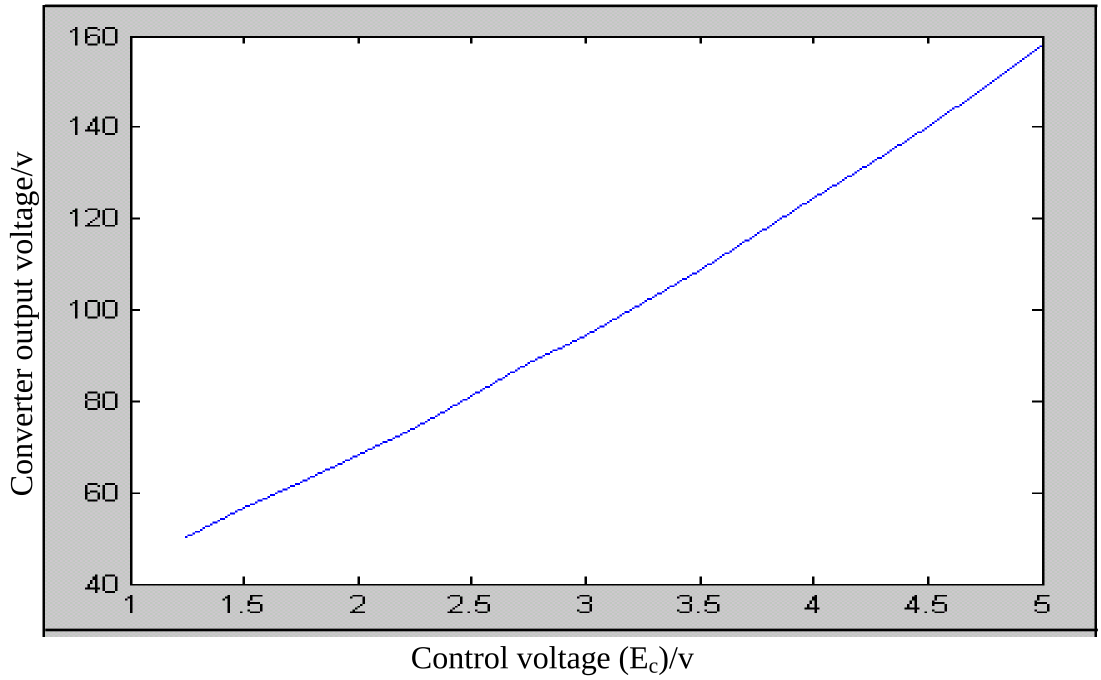

Fig. 7b: Direct Armature Voltage Against Control Voltage Characteristic.

5. CONCLUSIONS

A firing scheme for three-phase fully controlled dual-converter is described and built. The scheme utilizes the same circuits for both rectification and regeneration modes of operation. A cosine wave technique is used to generate firing pulses to result a dual-converter as linear power amplifier. The triggering of thyristors is achieved by using a train of pulses to make the scheme more appropriate for high inductive load. Response of the firing angle to control voltage is almost instantaneous. The developed scheme is found to be suitable for closed loop speed control of dc motors.

6. REFERENCES

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