A NEW CONTROL SYSTEM FOR COMMON CATHODE AC POWER CONTROLLERS

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Abstract
In this research a design of a control (or firing) circuit is presented. The system is based on a cosine voltage and a DC control voltage scheme. The phase (delay) angle in this designed system shows a liner transfer relationship .The proposed method proved to be very reliable and can be extended to closed loop control. The proposed control circuit is used to control the electric power from the common cathode Ac controller.

List of Symbols
Eav: - average output converter voltage.
E: - rms input converter voltage.
Erms: - rms output converter voltage.
α:- delay angle.
Ec: - control dc voltage.
Emax1:-maximum output voltage of converter.
Ed: - negative complement of control dc voltage.

1. Introduction
Ac power control has a wide range of applications in various industrial fields. These fields range from light dimmers, Ac motors control ,power control and heat control

One of the main aspects in Ac power controllers is the control or firing circuit that control portion of the Ac wave. The period is defined by the phase or delay angle

Control methods based on zero crossing techniques was used .The controlled technique was manual that is varying the time constant of the certain 555 times using variable resistors [1]

This research presents a new system which is based on a cosine control voltage derived from the input supply voltage. The cosine voltage is intersected with a control voltage .The proposed system solves the synchronization problem

2. The Ac power controller
Ac power can be controlled using two anti parallel thyristors or a triac as shown in fig 1. Several circuit have been presented in this field such as the common cathode circuit shown in fig 2.this circuit does not require isolated gate signals because of the common –cathode connection of the two thyristors.

The control or firing (triggering) circuit should be designed according to acquired specification and the required power control range.

The effective and widely used method of controlling the average power to a load is by phase control method which is merely a utilization of the triac to apply the ac supply to the load for a controlled fraction of both positive and negative cycles. In this mode of operation, the triac is held in off or open condition at a time in the first half cycle which is determined by the proposed control circuitry. In the on condition, the circuit is limited only by the load .Hence the applied voltage to the load is the input less the forward drop of the triac

In spite of its usefulness, phase control has some disadvantages .The main disadvantage in phase control is the generation of electromagnetic interference. For every time the triac is fired (or triggered) the current rises from zero to load limited current during a very short time interval .The resulting di/dt generates a wide spectrum of noise that may interfere with the operation of adjacent electronic equipment which calls for proper filtering techniques.

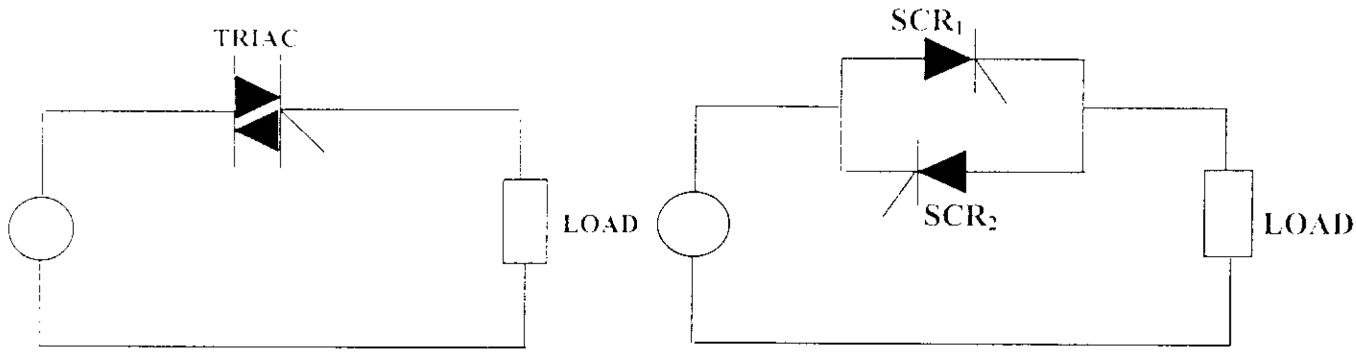

Fig 1 Ac power controllers

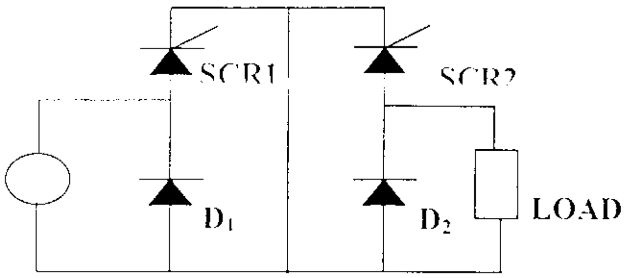

Fig 2 the common cathode circuit

3. The Ac power as a function of the delay angle

The various relations of current and voltage are first derived, and then an attempt is shown to derive the power delivered to the load as a function of the angular period (or delay angle α).

Since the load voltage is symmetrical over the origin, it s average value over a complete cycle is zero. However, the average rectified voltage over the half –period is important and is,

$$E_{av} = (\sqrt{2}\,E/\pi)\,(1+\cos\alpha) \qquad (1)$$

In order to obtain the power delivered to the resistive load, the rms value of the load voltage is,

$$E_{rms} = E\,[1-(\alpha/\pi)+\sin(2\alpha)/2\pi]^{1/2} \qquad (2)$$

Therefore the rms load current is,

$$I=I_o[1-(\alpha/\pi)+\sin(2\alpha)/2\pi]^{1/2} \qquad (3)$$

Where

$$I_o=E/R_L$$

It's clear that the maximum rms load current occurs at $\alpha=0$
The RMS current through each SCR is

$$I_{SCR}=0.707I_o[1-(\alpha/\pi)+\sin(2\alpha)/2\pi]^{1/2} \qquad (4)$$

The rms SCR current referred to it s maximum value is,

$$I_{SCR\,rms}/I_{SCR\,max}=[1-(\alpha/\pi)+\sin(2\alpha)/2\pi]^{1/2} \qquad (5)$$

The form factor of SCR current is.

$$FF_{SCR}=I_{SCR\,rms}/I_{SCR\,av}=(1/1+\cos\alpha)\,[\pi(\pi-\alpha+\sin(2\alpha)/2)]^{1/2} \qquad (6)$$

The peak current through the SCR depends upon the value of the delay angle. The ratio of peak to mean SCR current is

$$I_{SCR\,peak}/I_{SCR\,av}=(2\pi/1+\cos\alpha) \qquad \text{for } 0\leq\alpha\leq\pi/2 \qquad (7)$$

$$I_{SCR\,peak}/I_{SCR\,av}=(2\pi\sin\alpha/1+\cos\alpha) \qquad \text{for } \pi/2\leq\alpha\leq\pi \qquad (8)$$

The load power is.

$$P_L=P_o(\pi-\alpha+\sin(2\alpha)/2) \qquad (9)$$

where

$$P_o=E^2/\pi R_L$$

The normalized curves of various electric quantities against firing angle are shown in fig 3.

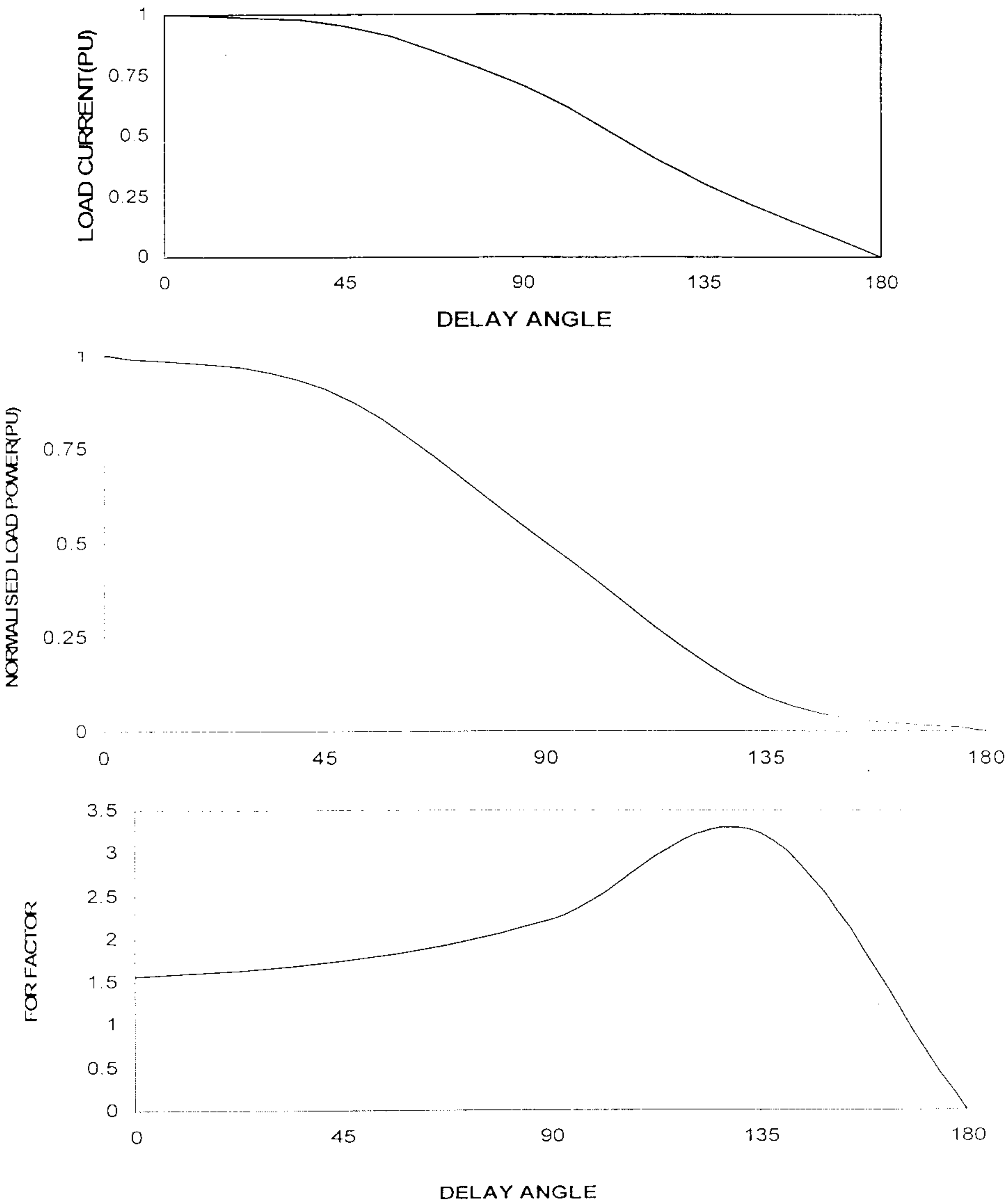

Fig 3 Normalized electrical quantities versus delay angle

4. Cosine control of phase (delay) angle

In this scheme of control, a control DC voltage E_C generates the firing pulses for SRC1and SRC2 of the common cathode Ac power controller. The proposed system which is designed in this research generates the pulses at the crossing points of the control voltage and a synchronously generated cosine voltage which is to be derived from the input voltage supply. One of the most important consideration in the design of any firing circuit used in AC controllers is the way of synchronizing the power circuit with the relevant control (or firing)circuit ,such that the phase (delay)angle is measured with respect to the same voltage zero as that of the power circuit . A general block diagram of the proposed control scheme is shown in fig 4. The timing diagrams are shown in fig 5.

The problem that now arises is how to modify the proposed method such that two firing pulses are obtained in order to fire SCR1 and SCR2 of the common cathode Ac controllers. This problem was solved by introducing the control voltage E_C and it's negative complement $-E_C$ (referred to as E_d). These two voltages are compared with the cosine voltage derived from the input Ac supply. The firing pulses for SCR1 is generated from the crossing points of E_C and the cosine voltage , however the firing pulses of SCR2 is generated from the crossing points of $-E_C$ with the derived cosine voltage. the block diagram of the proposed method is now modified to that of fig 6.

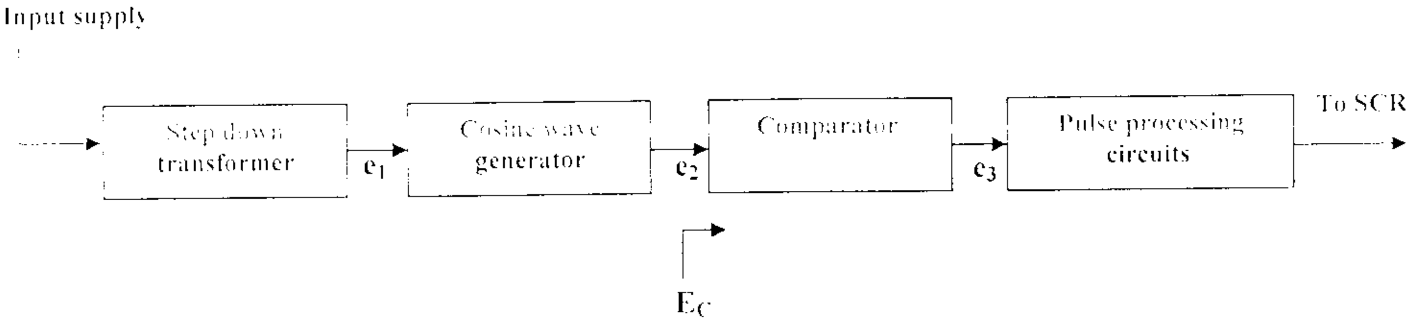

Fig 4 block diagram of the proposed cosine control method

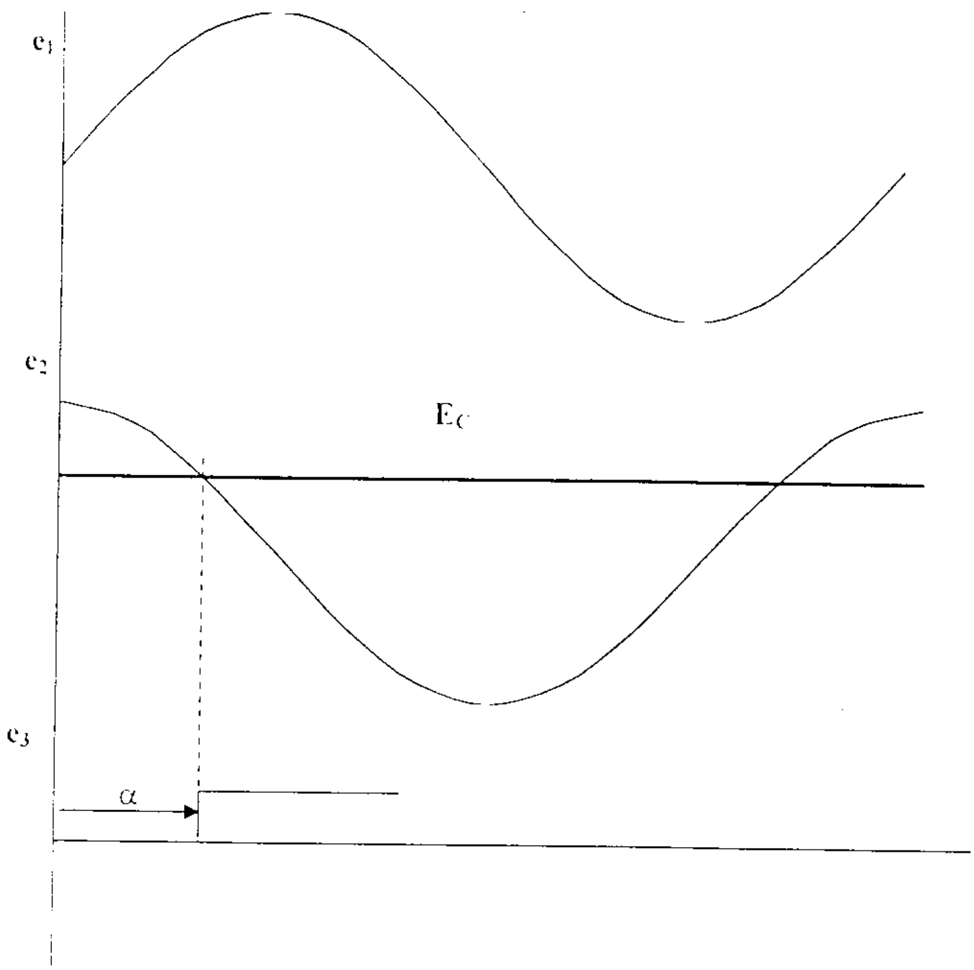

Fig 5 timing diagrams

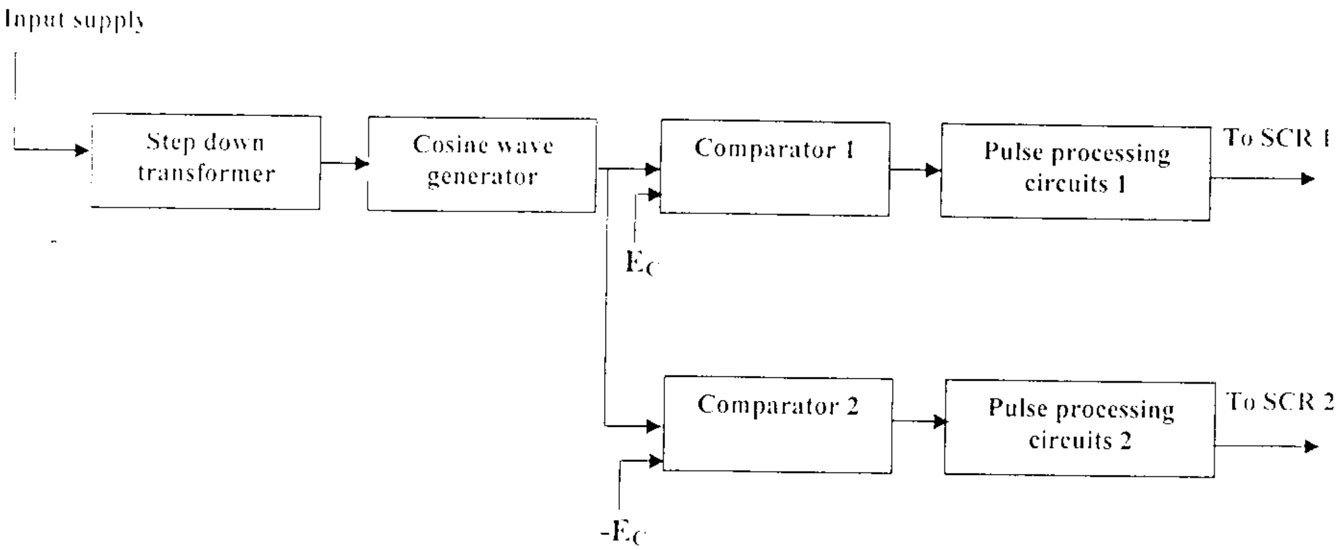

Fig 6 modification of the proposed system

4.1 Mathematical analysis of the proposed cosine control method

For the cosine method, the attempt is made to derive the phase angle in terms of the control signal E_C.

Since

$$V(t) = E_{max} \, Cos(wt) \tag{10}$$

At the crossing point between the control voltage E_C and cosine voltage.

$V(t)=E_C$ and $wt=\alpha$

Then

$$E_C=E_{max} \, Cos\alpha \tag{11}$$

$$\alpha=Cos^{-1}(E_C/E_{max}) \tag{12}$$

The output voltage of the converter is given by.

$$E_o=E_{max1} \, Cos\alpha \tag{13}$$

$$=E_{max1} \; Cos\,[cos^{-1}(E_C/E_{max})] \tag{14}$$

Then

$$E_o=K_1E_C \tag{15}$$

Where

$K_1=Emax_1/E_{max}$

It s clear that the cosine control scheme provides a linear transfer characteristics between the output voltage E_O and the control voltage E_C.

Referring to eq 12, the AC normalized power can be re written using eq 9, so,

$$P_L= [\pi\text{-}Cos^{-1}(E_C/E_{max}) + Sin2\,(Cos^{-1}(E_C/E_{max}))] \tag{16}$$

The power output from the controller is a function of the control voltage E_C. Using this proposed control scheme the delivered power is varied by varying the control voltage. Closed loop control may also be implemented using this proposed scheme.

4.2 Implementation of the proposed cosine control scheme

The designed system is split in to the following stages:-

4.2.1 Stage one

In this stage the input voltage (of the Ac controller) is stepped down and then integrated to generate a synchronized cosine voltage. Then it s compared to the control voltage E_C and it s negative complement E_d. The two zener diodes connected back to back clamp the control voltage E_C below the peak value of the cosine voltage (E_{max}). The control voltage E_C is inverted by a unity gain amplifier to give it s inverse signal (E_d). Comparing E_C and E_d with the cosine voltage will produce signals e_2 and e_3 respectively. These signals are FED to mono stable M_1 and M_2 to produce signal e_g and e_h respectively. These signals trigger a set –rest flip –flop (F-F) to generate signals e_j and e_i.

4.2.2 Stage two

This stage consists of modulating signal e_j and e_i at a high frequency (usually 15 -20 KHZ). This stage was implemented by Anding each signal (e_j and e_i) by a high frequency from a 555 timer. It's clear that a modulated firing pulse for SCR1and SCR2 will reduce gate dissipation and ensure firing therefore reducing the risk of misfiring.

4.2.3 Stage three

The proposed system has generated two pulse (e_j and e_i) . These pulses should be strong enough to ensure firing the relevant SCR (the criteria for this is V_{GT} & I_{GT}). Therefore a suitable amplifier is designed using a Darlington transistor amplifier to amplify the pulse current. In addition an adequate isolation between the power circuit (Ac controller) and the control circuit implemented. hence pulse transformer isolation is suggested.

The complete designed system and relevant timing diagram are shown in fig 7 and fig 8 respectively

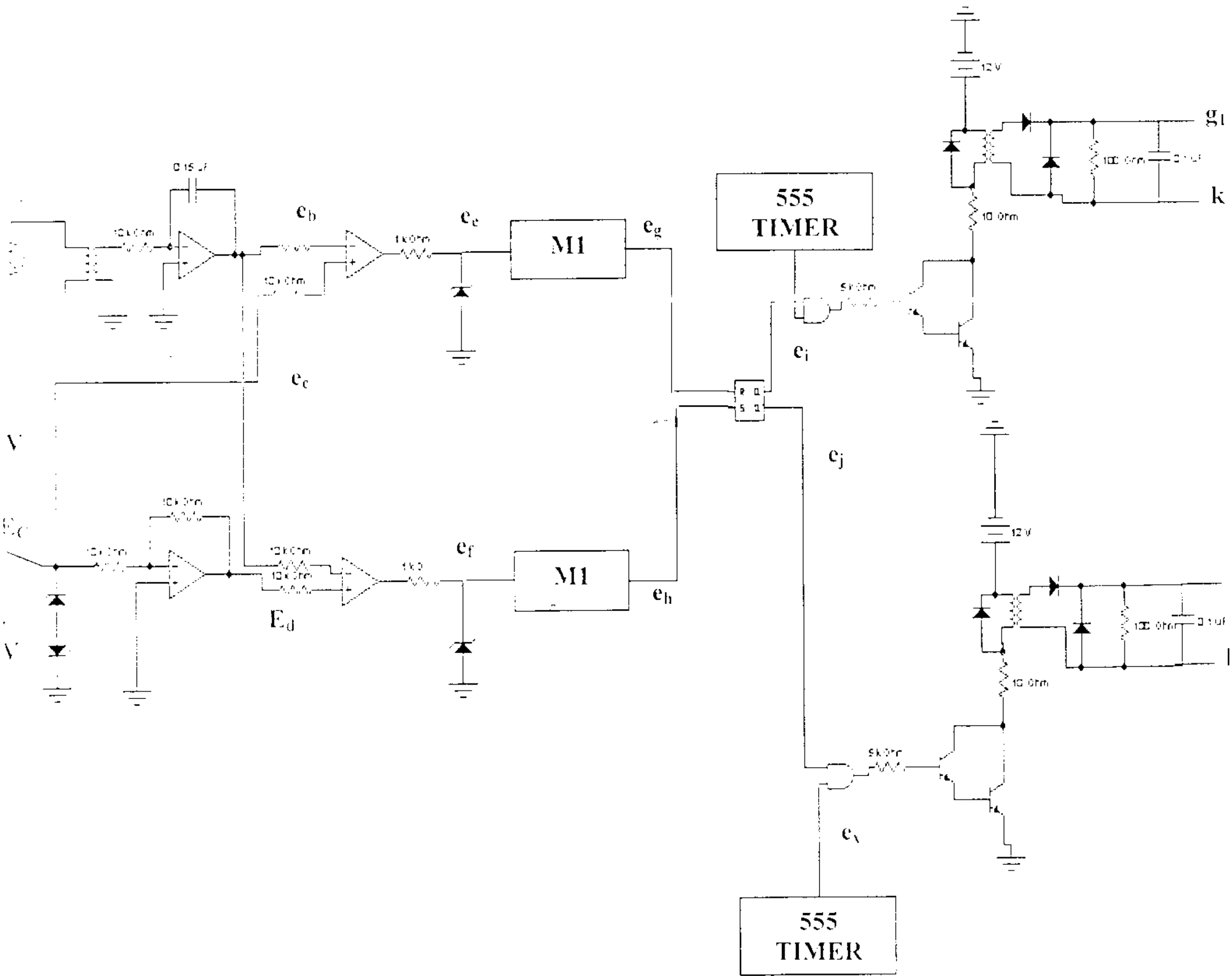

Fig 7 implementation of the proposed system

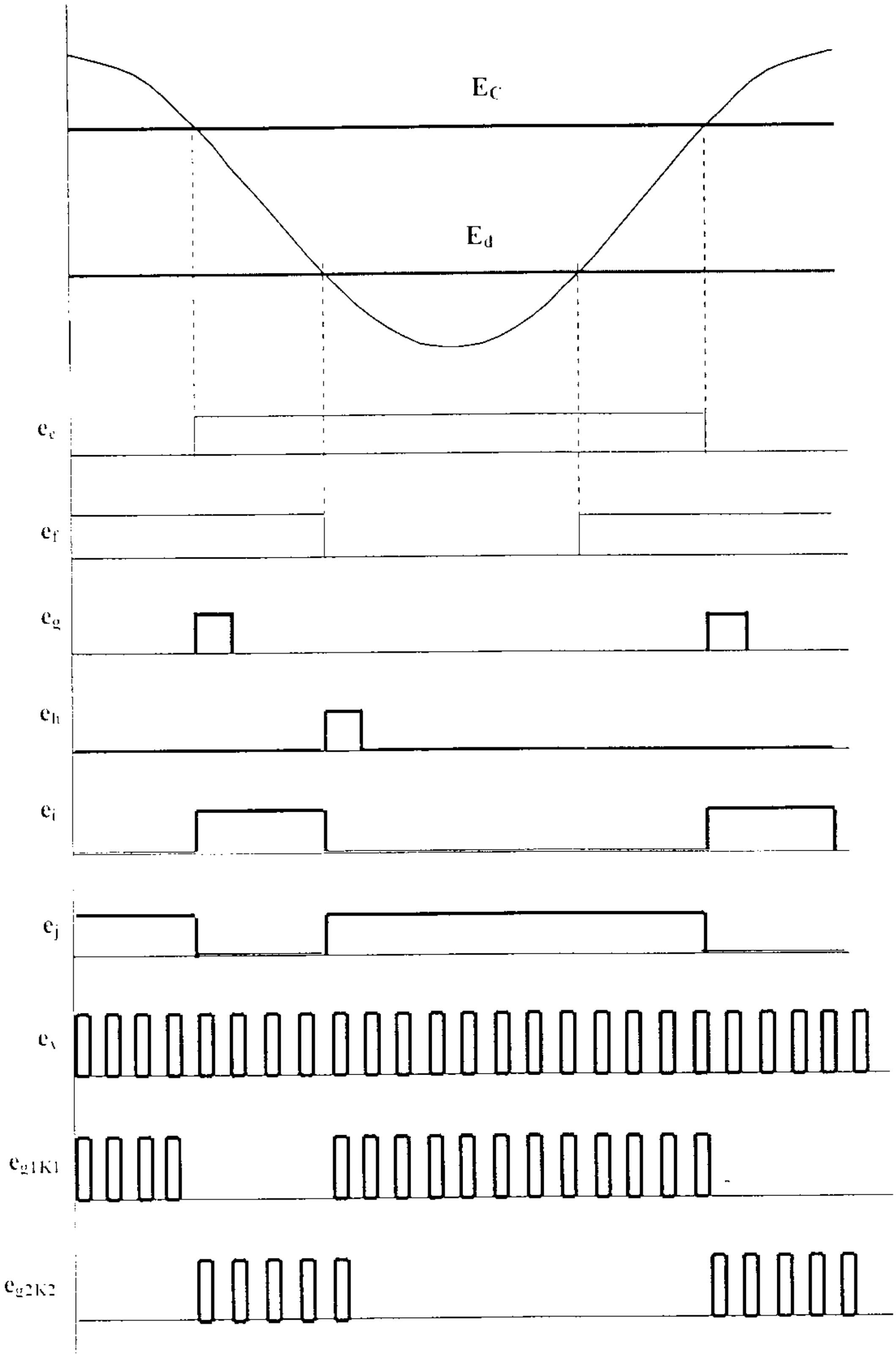

Fig 8 timing diagrams of the proposed system

5. Experimental Results

The proposed control circuit was simulated and tested with variable load condition. The results show that there is a linear variation between electric quantities such as delivered load power load current and the form factor. The relevant graphs are shown in fig 9, fig 10 and fig 11 respectively. It s also seen that the proposed method gives reliable phase control (from 10% to 95% of the AC sine wave).

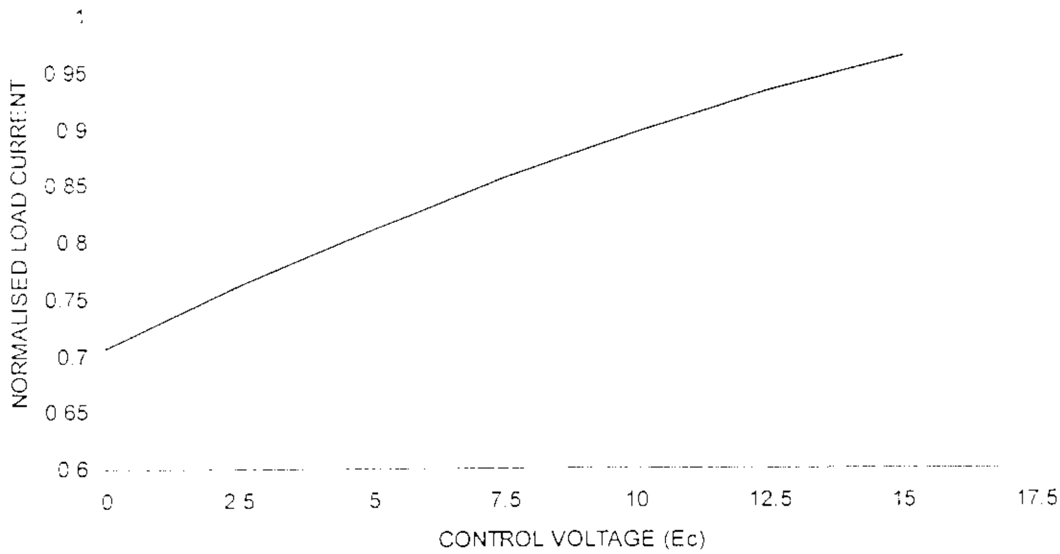

Fig 9 normalized load current versus control voltage

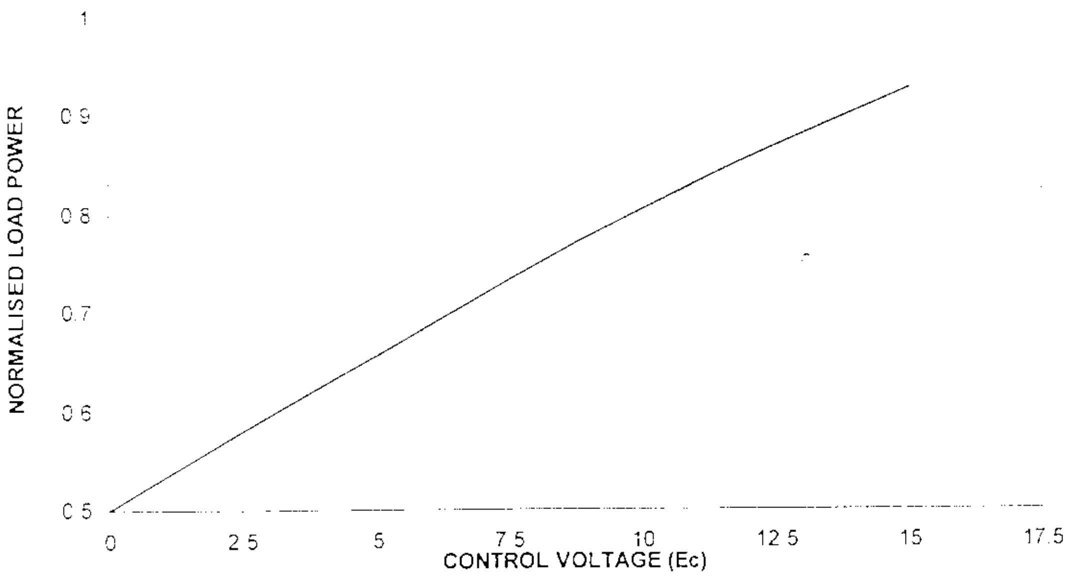

Fig 10 normalized load power versus control voltage

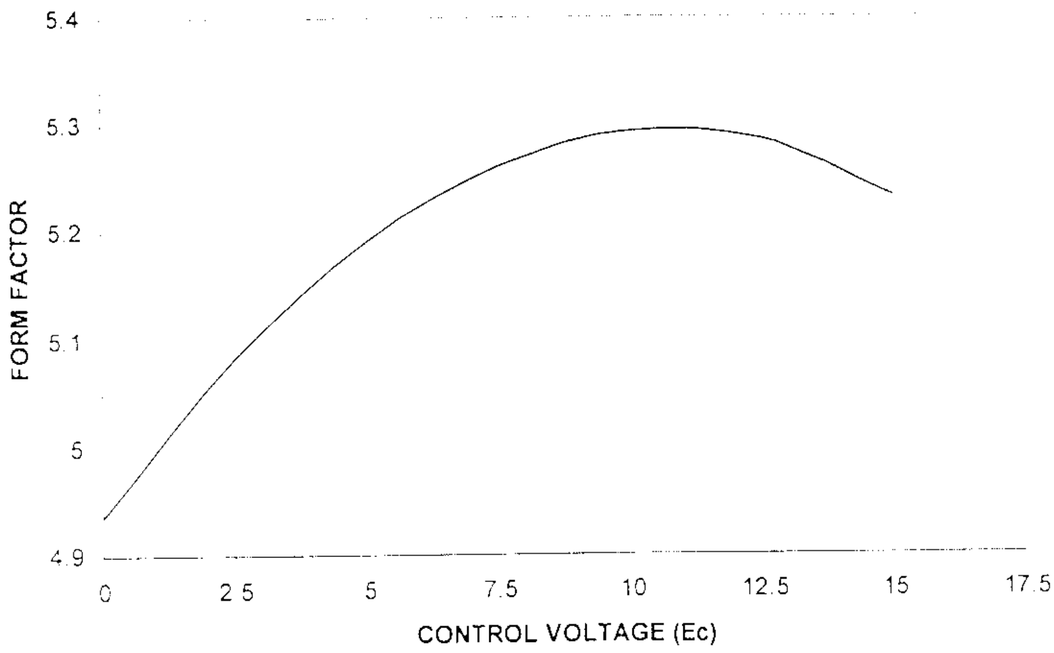

Fig 11 form factor versus control voltage

Conclusions

From the results obtained the following conclusions can be drawn:-

1. The proposed system offers a reliable phase control scheme.
2. The delay angle can be varied by changing the value of the control voltage Ec.
3. Synchronization is automatically achieved since the cosine voltage is derived from the step down input voltage of the Ac controller.
4. Closed loop control can easily be implemented. This is done by feeding the output signal back to the input and comparing it with a reference value.
5. A wide range of control of the phase (delay) angle can be achieved by varying the control voltage.
6. The proposed system is very much suitable for light dimmers, heat control systems and Ac motor control.
7. The proposed system gives a linear relationship between the converter output voltage and the control voltage.
8. A linear relationship is observed between the power delivered to the load and the control voltage.

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الخلاصة

يتناول هذا البحث تحليل و تصميم منظومة سيطرة (اوقدح) للدائرة تقوم بالسيطرة على مقدار القدرة الكهربائية المتناوبة. تقوم هذه الطريقة على اساس اشتقاق فولتية جيب تمامية و تقاطعها مع فولتية سيطرة DC. لقد تم بواسطة هذه الطريقة حل مسألة التزامن بين دائرتي السيطرة و دائرة القدرة. من الممكن استخدام هذه الطريقة في نظم عملية كثيرة منها السيطرة على سرع محركات التيار المتناوب والتحكم بشدة الانارة ونظم السيطرة الحرارية.