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FIRING CIRCUITS FOR PHASE-CONTROLLED CONVERTERS

دوائر شحنات التشغيل للمغيرات ذات التحكم الوجهي

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ملخص البحث:

هذا البحث يشتمل على تصميم أربعة دوائر جديدة لأنتاج نبضات تشغيل دائرة توحيد تحكمية باستخدام أقل المكونات الشائعة الأستخدام والرخيصة الثمن. فالدائرة الأولى تتكون أساسا من أربعة ترانزستور. أما الدائرة الثانية فالجزء الرئيسي بها هو المكبر 741 الشائع الأستخدام مع تقطيع النبضات بوسيلة مبسطة جدا وفي هذا وفر للطاقة المفقودة بدائرة التشغيل. والدائرة الثالثة يستخدم فيها مولد ذبذبات واحد فقط من النوع الشائع الأستخدام رقم XR-555. أما الدائرة الرابعة فيستخدم بها مولد ذبذبات تزامن واحد اخر هو XR-320 الذى يختلف فى بعض المواصفات عن المزامن XR-555 وقد تم الأستفادة بجميع مكوناته. هذا وقد نفذت عمليا هذه الدوائر الأربعة وجربت مع دائرة موحد تحكمي وجه واحد مع أحمال تشغيل مختلفة وقد وجد أن جميع هذه الدوائر متزنة. بالأضافة الى رخصها لقلة مكوناتها اذا ماقورنت بالدائرة المتكاملة UAA145 وهى أول دائرة متكاملة صنعت خصيصا لتوليد نبضات التشغيل كما فى هذه الدوائر الأربعة.

ABSTRACT

This paper presents four new circuits to fire the single-phase or the three-phase converters. Each of these circuits is synchronized with the supply-voltage using an optic-configuration which utilizes the galvanic separation between the low-power and the high-power parts and bridges over the distortion of the supply voltage due to the commutation. The firing circuits are performed with minimum components which are generally available and used in many applications. These firing circuits are tested using different load types. The obtained results show that the invented circuits are stable and can be practically used to fire the constant frequency sources as well as the variable frequency sources. In addition, their cost is also low compared to the other used firing circuits.

1. INTRODUCTION

Firing of the supply commutated converters is carried out in many ways. Special integrated circuits, as UAA145 of Telefunken, are designed mainly to fire these types of converters. Such integrated circuits are expensive and sensitive. Other firing circuits [7] containing many components are also costly and their maintenance is difficulty. Some circuits using the LM-555 timers [8], [9] are introduced for single-phase and three-phase converters. In this paper, four new firing circuits involved few and cheap components are invented, performed, and tested to fire single-phase converter. Modifications for three-phase converters are very simple.

The Block diagram of any firing scheme used, for medium and high supply commutated converters, is depicted in Fig.1. It may consists of the following parts:

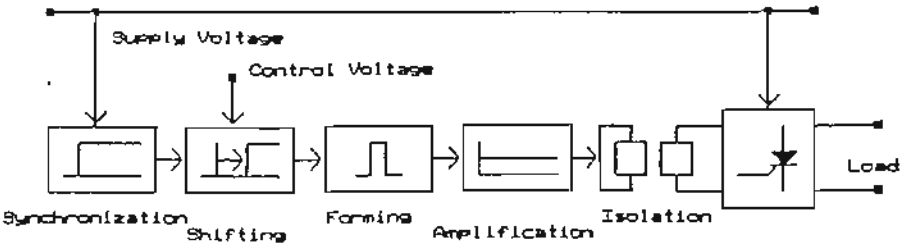


Fig.1 Components of a Firing Scheme

a. The Pulse-synchronizing unit:
In this part, the zero-crossing points of the phase-voltages or the line voltages are detected and thereafter the firing instant for each thyristor can be defined.

b. The Pulse-shifting unit:
Here the instant of firing is correctly defined by a dc voltage generally named the control voltage V_c and is normally obtained from the control circuit.

c. The Pulse-forming unit:
The form and width of the firing pulses are defined in this unit. A square wave form with a width of 200 μs is preferred.

d. The Pulse-amplifying unit:
This unit define the steepness of the firing current and amplify it to sufficient value.

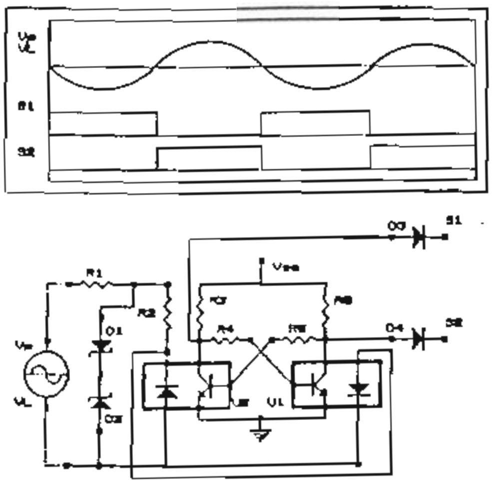
e. The Pulse-transfer unit:
This unit isolates the low-power part of the system from the high-power

part. It may consist of pulse transformers or optic devices.

2. THE IMPLEMENTED CIRCUITS

2.1. The Zero-Crossing Unit:

Due to commutation, the supply voltage is disturbed and therefore the Zero-Crossing Points (ZCPs) of phase or line voltages are floated. According to this wrong detection of zero firing-angle, the firing of converters may be shifted either right or lift from the undisturbed supply voltage. In some circuits, to avoid the distortion, the synchronizing voltages are filtered and the introduced phase shift may be corrected using special apparatuses like induction regulators or static phase shifters [2].



a.

b.

Fig.2 The Zero-Crossing Unit (ZCU)

In the implemented circuits, depicted in Fig.2, the ZCPs of the phase-voltages (for single-phase converter) or of the line-voltages (for three-phase converter) are directly detected, using connections involving transistorized opto-couplers, without intermediate measuring circuits of the voltages it selves. This circuit consists mainly of the two opto-couplers U1 and U2. The photo-transistors are connected in flip-flop configuration and therefore the distortions in the measured voltages are bridged over and the ZCPs are correctly defined. By these units the phase-voltages or line-voltages are changed to square waves of width of 180°. The input voltage of each opto-coupler is limited with two zener diodes.

The operation of this unit is as follows:
By positive voltage half-wave U1 conducts and the Signal S1 becomes high level where U2 turns off and signal S2 becomes low level. In the negative voltage half-wave U2 conducts and S2 becomes high logic where U1 turns off and S1 is low. The diodes D3 and D4 protect the opto-couplers against any back-signal coming from the next circuit.

2.2 Transistorized Firing Circuit

This circuit and the corresponding signal diagram are given in Fig.3. The circuit in Fig.3.b consists mainly of two NPN transistors, two capacitors, and two diodes. The thyristor opto-couplers U3 and U4 are used to separate the pulses, amplify the firing current and to isolate the converter from the firing and control circuits.

Before triggering the circuit (the pulses S1 and S2 are zeros), capacitors C1 and C2 have no charges, the effective base-emitter voltages of Q1 and Q2 are negative and no collector currents flow. The photo-diodes of U3 and U4 darken and the logic level of the firing pulses P1 and P4 are low.

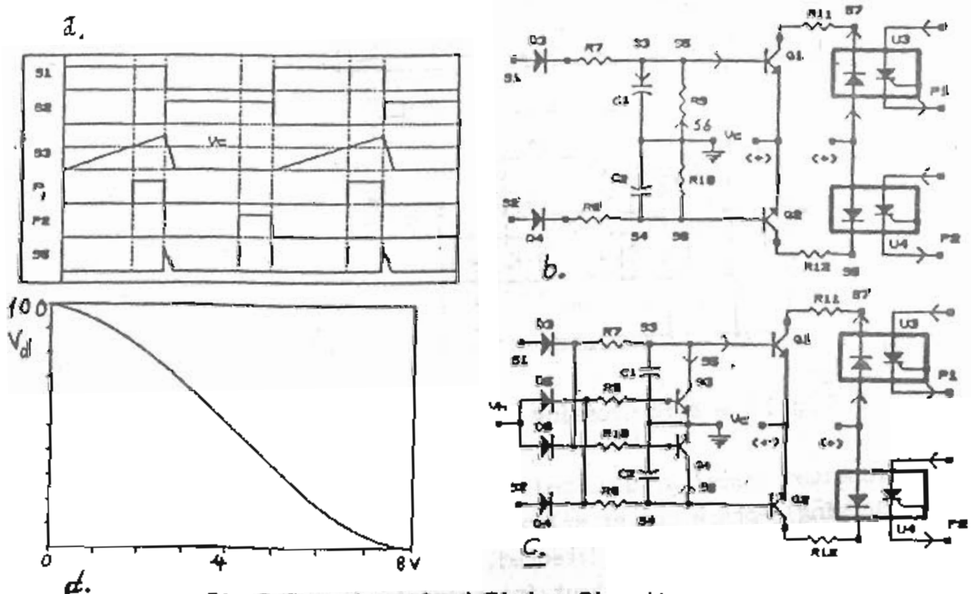


Fig.3 Transistorized Firing Circuit

For the upper half of the circuit, once the signal S1 becomes high level, the voltage of capacitor C1 increases, and in consequence the effective voltage of the loop (C1-Q1-Vc) is going to become positive. Charging of C1 is not linear but by increasing the charging time constant the voltage increases approximately as ramp wave form. Starting from the point at which the capacitor voltage S3 begins to exceed the control voltage Vc until the end of the signal S1, the loop voltage (C1-Q1-Vc) is positive, the base current i_B (S3) flows, and Q1 conducts. The photo-diode of opto-coupler U3 conducts and the logic level of the firing pulse P1 becomes high and afterward the thyristor coupled to it conducts. At the end of the signal S1, the capacitor C1 discharges (S5) through the resistor R8.

If the voltage level of the signal S1 is given by V_i and the voltage of C1 is given by E_{cc}, then the capacitor C1 is charged according to the relation

$$E_{cc} = K[1 - e^{-t/\tau}] \qquad (1)$$

where the charging time constant τ_c is given by:

$$\tau_c = \left[\frac{R_7 . R_9}{(R_7 + R_9)}\right] . C1 = R_{79} . C1 \qquad (2)$$

and the voltage constant K is calculated as:

$$K = R_{79} . V_i \qquad (3)$$

Beginning from the conduction of the transistor Q1 (or Q2) until the end of the signal S1 (or S2), (conducting period), the voltage of capacitor C_1 is nearly equal the control voltage.

$$E_c = V_c \qquad (4)$$

Thus, after the end of S1 until its next positive edge (the discharging time τ_d) the capacitor voltage is followed according to the relation

$$E_{cd} = V_c . e^{-t/\tau} \qquad (5)$$

where $\tau_d = R_9 . C1$ (6)

If the R_9 >> R_7, then the charging time-constant τ_c can be approximated to;

$$\tau_c = R_7 . C1 \qquad (7)$$

As seen from Eqs. 6 and 7, in order to have a nearly linear charging of the capacitors, the charging time constant $R_7.C$ (or $R_8.C$) must be large and this makes the discharging time constant $R_9.C$ (or $R_{10}.C$), which must be smaller than the charging time, also very large. That means, the resistance R_9 (or R_{10}) must be very large in the charging period and very small in the discharging period. To fulfill that, the resistors R_9 and R_{10} are replaced with NPN transistors which are turned on with the pulse S_2 or S_1 respectively as shown in Fig.3.c. In this case the discharging time-constant τ_d is nearly zero and the charging time-constant τ_c can be made very large to have approximately ramp function. The firing pulses can be inhibited by the positive voltage Vh.

2.3 Chopped Firing Pulses

In this circuit the output firing pulses are chopped through feed-back loops to save the control power of the gate circuit. It can also inhibited with positive signals.

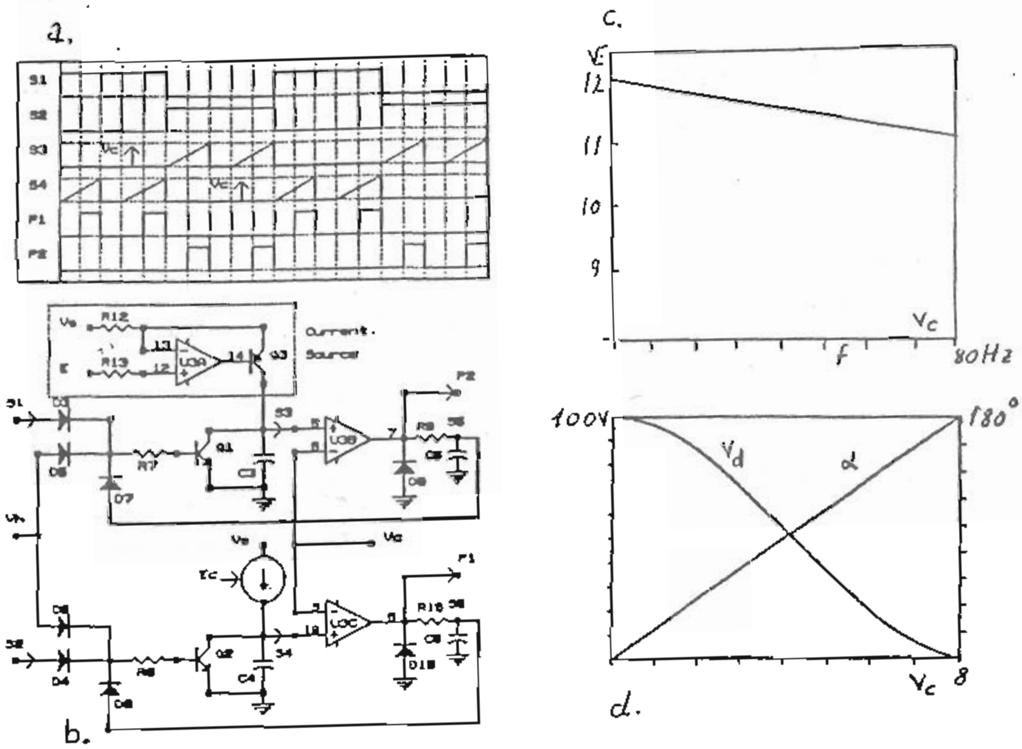


Fig.4. Chopped Firing Pulses

The implemented circuit and the corresponding signal diagram are shown in Fig.4. Capacitors C3 or C4 are charged linearly using simplified current sources [3] and [4]. The output ramp-voltage S3 or S4 of the transistor Q1 or Q2 are synchronized and controlled with the supply voltage through the signal S1 or S2.

The ramp-voltages are compared with the control-voltage Vc using the operational amplifiers U3B or U3C to obtain the square pulses P2 and P1. The firing pulses are delayed and connected back with the control signals S1 or S2 to control the ramp-voltages again. The result of the feedback diode-loops, the pulses P1 and P2 are chopped. This is a very simple and very cheap method to have chopped pulses without using additional high frequency oscillators [7]. The width of the chopped pulses depends on the delay time and also on the control voltage (the final amplitude of the ramp-voltage). The number of pulses in one half-period is inversely proportional to the control voltage.

The amplitude of the ramp-voltage corresponding to 180° depends on the charging current which can be controlled through an external source. This phenomena was used in order to synchronize the same circuit with a voltage of variable frequency. The frequency was changed between 10 Hz and 70 Hz and the final amplitude of the ramp-voltage was recognized. The change (if found) was corrected again by changing the control voltage of the current source E. It was found (Fig.4.c) that, for a final ramp-voltage of 8 Volts, the control voltage E of the current source was changed from 12 to 11 Volts. This means that such circuit can be used within the mentioned frequency rang of the commutating voltage with error less than 10% of the firing angle. For wide range of frequency, the control voltage E of the current source may be changed (through closed loop) to have zero error in the firing angle. The pulses can be inhibited through the logic signal Vh which also controls the transistors Q1 and Q2.

2.4 Firing Circuit using one XR-555 - timer

In this third firing circuit only one XR-555 timer is used to obtain the two firing pulses for a single phase converter. The circuit diagram depicted in Fig.5.b includes the functional block diagram of the timer XR-555 to clarify the operation of the circuit. The corresponding signal diagram is given in Fig.5.a.

The timing cycles of the timer start with the negative edges of the pulses

S1 and S2 obtained from the ZCU [4], [5], and [6]. The comparator UB changes its state and forces the connected control flip-flop to change its output at pin 3 (signal S4) to a high level and to turn off the internally connected transistor Q1. The external capacitor C1 starts to charge linearly through the external current source (signal S3). When the voltage of the capacitor C1 (ramp wave form) equals the threshold voltage of the comparator UA [$V_t = (2/3).V_s$], the comparator UA changes its output signal and resets the flip-flop, the output at pin 3 becomes low, and in the same instant the transistor Q1 turns on allowing a rapidly discharge of the external capacitor C1.

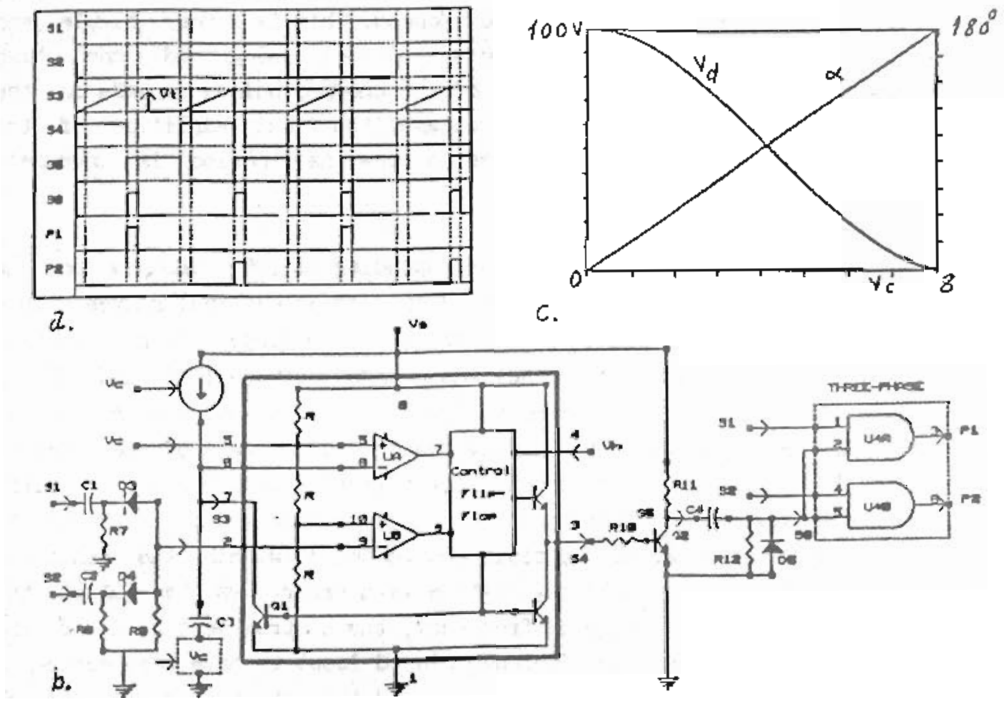


Fig.5 Firing Circuit using One XR-555 - timer

The output signal S4 is high only from triggering the timer until the voltage of the external capacitor C1 equals the threshold voltage of the comparator UA. This charging time (width of the output pulse at pin 3) can be changed in different ways:

(1) The control voltage Vc is injected to change the threshold voltage of comparator UA at pin 5.

(2) The slop of the ramp voltages is changed by controlling the charging

current of the external capacitor C1 if the control voltage is connected to the current source.

(3) The ramp-voltage is shifted by injecting the control voltage between the capacitor and ground.

When the signal S4 is inverted (signal S5) and then differentiated, the firing pulses S6 are obtained with a definite width. Adding this pulses to the pulses S1 or S2 with two AND gates, the two pulses are separated (by three-phase systems) and thereafter can be transferred to the corresponding thyristor through thyristor-opto-couplers. Injecting positive voltage to the timer at pin 4 (signal Vh), the firing pulses are inhibited.

2.5 Firing Circuit using one XR-320 - Timer

In this circuit, the monolithic timing circuit XR-320 is used instead of the previous discussed XR-555 timer [4]. This timer includes a current source and therefore operates on the linear ramp generation principle. Figure 8:b shows the functional block diagram of the XR-320 as a part of the firing circuit which can be used for single-phase or three-phase converters. The signal diagram is illustrated in Fig.8.a.

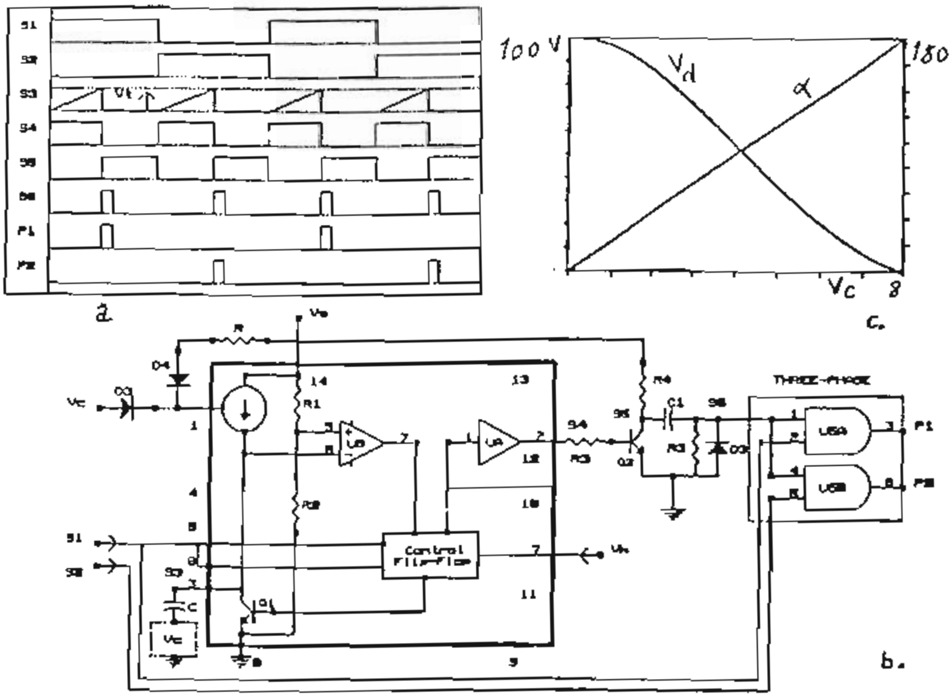


Fig.7 Firing Circuit using XR-320 - Timer

The control flip-flop of this XR-timer can be triggered by either the positive or the negative edges of the pulses S1 or S2. When the trigger pulses are applied on any one of the set terminals (connected to each other in Fig.6.b), the output at pin 12 (signal S4) becomes high level and in the same time the internal transistor Q1 is turned off. This allows the external capacitor C to charge linearly through the internal current source. The constant current is set by an external resistance R connected to the voltage source Vs and generates a linear ramp-wave form (signal S3) across the external capacitor C. The slope of this voltage is defined by

$$dS3/dt = I/C \tag{8}$$

The charging current can be controlled by applying an external control voltage Vc to the current source at pin 1, or by injecting the control voltage between the capacitor and ground as by the 555 timer.

When the voltage of the external capacitor C reaches the threshold voltage Vt of the comparator UB, the state is changed, the flip-flop is reset, the output reverts to its original low level, the internal transistor Q1 is turned off, and the external capacitor C is momentary discharges.

As by the XR-555 timer, the output (signal S4) is inverted (S5) and then differentiated the signal pulse train S6 is obtained with a width determined by C1.R3. Adding this pulse train to the pulses S1 or S2, the two firing pulses are separated. Injecting a high logic signal Vh to the timer at the external reset pin 10, the pulses are inhibited.

In single-phase system the pulse train can transferred to each thyristor without separation in the third and fourth circuit, because the thyristor is fired only when it is positive in the forward direction.

2.6 The Three-phase Converters

Firing of the three-phase converters is followed either according to the linear-technique or to the cos-technique. If the first is used, three similar circuits of the above invented four circuits are used to fire the three phases. In the case of cos-technique, the synchronizing pulses S1 and S2 are obtained not from the phase voltages but from their cosines. Additional circuits to integrate the phase voltages are used or the line voltages are exchanged to verify the cos-technique [7]. In three-phase systems, the separation of the two pulses in the third and fourth circuits is preferred, because the width of the firing pulse is limited and the obtained pulses are mixed to gather in order to fire each thyristor with two pulses apart 60° to ensure its firing. In the first and the second circuits no mixing of the pulses is needed because their widths are variable.

3. RESULTS

The implemented circuits were tested with a single-phase half-controlled bridge supplied through a 100 v source and connected to the loads:

A. a resistive load R = 35 Ω,

B. an inductive load R = 35 Ω + L = 20 mH,

C. a small dc machine 500 watts; 220 volt.

The following points were remarked.

1. The linearity of the charging wave form in the first circuit of Fig.3 is improved by a time constant of 10 ms.
2. The best point to inject the control voltage in the third and fourth circuits was directly between the lower end of the external capacitor and ground. The ramp-voltage was shifted rapidly according change of the control voltages and this improves the dynamics.
3. A cost comparison between the performed circuits for a single phase converter and the circuit used the integrated circuit UAA145 of Telefunken is followed. This I.C. is chosen because it is the first special circuit that produces two firing square pulses apart 180°.

Percentage Cost of	UAA145	1st. C.	2nd. C.	3rd. C.	4th. C.
Integrated circuits	80	10	30	15	35
External Components	20	15	20	15	15
Total Cost	100	25	50	30	50

4. The measured steady-state relation (V_d - V_c) for the resistive load were given beside each circuit. The illustrated curves are cosine-relations and the four circuits give nearly the same curves.

4. CONCLUSION

In this paper, four invented firing circuits were wholly theoretically discussed, practically performed and then tested with a single phase half-controlled converter. Additional changes to fire the three phase converters are also given. The practical applications showed that all the four circuits are stable and can be used with medium and high power drives. These circuits are constructed of the generally available (in our market) integrated circuits. The used I.Cs. are cheaper compared to the standard. UAA145 integrated circuit. These firing circuits can also be used with variable frequency supplies depending on their band widthes without additional circuits. If the supply frequency changes extremely, additional simplified control circuits can be used to extend the linear range of the used circuit

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