

PERFORMANCE CHARACTERISTICS OF A NOVEL CHOPPER USING PSPICE

خصائص الأداء للقاطع المتلوب جديد باستخدام PSpice

M. A. Abdel-Halim
Cairo University, Faculty of Eng.,
Electrical Engineering Dept.,
Cairo, Egypt

and R. A. AbdelRassoul, *Senior Member, IEEE.*
Mansoura University, Faculty of Eng.,
Electronics & Communications Eng. Dept.
Mansoura, Egypt

خلاصة:

تستخدم القواطع المتلوبة ذات التيار المستمر على نطاق واسع في التحكم بالمحرك في الجر وليس في الدوافع المحركة في الصناعة، وفي التطبيقات الأخرى التي تحتاج إلى مصدر تيار مستمر منظم. وتلك القواطع الثايرستور المتلوبة تطبيقات في الدوافع المحركة في الصناعة والجر الكهربائي، حيث يتم التحكم في قدرة عالية. وتعتبر القواطع المتلوبة العادية (الكلاسيكية) ، و من نوع جون ، ومن نوع القطرة هي أكثر دوائر الثايرستور المستعملة في الحياة العملية. ومن أجل رفع الاعتمادية وتصحيح أشكال موجات الخرج وتكبير مدى التحكم ، فقد تم اقتراح قاطع متلوب معدل. وقد تمت دراسة خصائص الأداء للقاطع المتلوب الجديد ومقارنتها مع تلك للقواطع المتلوبة الأخرى ، وذلك باستخدام برنامج PSpice. وتمت أيضا دراسة تأثير بزا مترات القاطع المتلوب على الأداء. وقد تمت مقارنة نتائج المحاكاة مع النتائج التجريبية وأعطت مطابنة جيدة، وقصنا بتحديد أسباب وجود بعض الاختلافات.

Abstract:

DC choppers are widely used for traction and industry drives motor control and in other applications where a regulated dc source is required. Thyristor choppers find applications in industry drives and electric traction where high power is controlled. Normal (classical) chopper, Jone's chopper and bridge chopper are the most thyristor circuits used in practice. In order to increase reliability, improve the output waveforms, and enlarge the range of control, a modified chopper has been suggested. The performance characteristics of the new chopper are determined and compared with other choppers using Pspice. The effect of the chopper parameters on its performance have been determined. The simulation results have been compared with experimental results. Good agreement has been obtained. Causes of some discrepancies have been determined.

Keywords:

DC Chopper, dc-dc converter, Thyristor, Spice.

1. Introduction

DC-to-dc converters, commonly called choppers, are employed to vary the average value of the direct voltage. The manner in which the average load is reduced below that of the source is illustrated in Fig. 1, which shows the circuit connection (Fig. 1-a) and the output voltage waveform (Fig. 1-b) for an ideal chopper. This shows that an ideal chopper applies a train of unidirectional voltage pulses to the load. Load voltage may be varied in one of three different ways, namely: pulse-width modulation, frequency modulation and combination of these two ways [1].

DC choppers have many applications in industrial drives and electrical traction [2-4]. They are widely used for traction motor control in electric automobiles, trolley cars, marine hoists, forklift trucks, and mine haulers. They provide smooth acceleration control, high efficiency, and fast dynamic response. Choppers can be used in regenerative braking of dc motors to return energy back into the supply, and this feature results in energy savings for transportation systems with frequent stops. Choppers may be also used in the rotor circuits of induction motors to control the speed. In these applications the chopper deals with high power, thus it uses thyristors as electronic switches [2]. There are many types of thyristor choppers such as normal chopper, Jone's chopper and bridge chopper [2,5]. The actual operation of choppers

deviates from the required ideal performance due to practical limitations. It is very advantageous to have a chopper whose characteristics are very near to the ideal one. This means that its operation is free from these restrictions which limit the range of duty cycle and its output voltage waveform is closer to the square train of pulses.

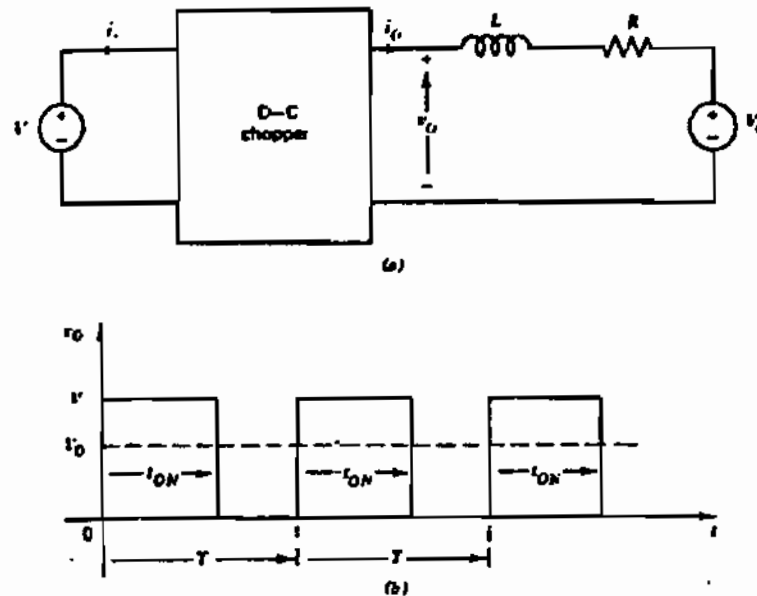


Fig. 1 Ideal chopper circuit

a. Circuit connection b. Output voltage waveform

In this paper, a modified chopper, which has better characteristics compared with both normal and Jone's chopper, is presented. Its modes of operation are determined and analyzed. Pspice has been used to simulate the operation performance of the new chopper and the other conventional choppers for the sake of comparison. Also, the control characteristics have been determined for a wide range of duty cycle. The effects of the chopper element sizes on the performance have been investigated. The results obtained have been compared with previously published experimental results [5].

2. Conventional Choppers

The normal, Jone's and bridge choppers are well known choppers which use the parallel capacitor technique for commutation [1-3]. Fig. 2 shows the circuit diagrams for the normal (Fig. 2-a) and Jone's (Fig. 2-b) choppers when feeding a resistive load and including the supply internal impedance. The normal chopper has the disadvantage of needing a pre-charging of the capacitor to insure proper commutation. This is achieved by triggering the auxiliary thyristor first at the beginning of the chopper operation. In Jone's chopper the necessary commutating capacitor charge is accumulated at the beginning by the transformer secondary current resulted through transformation action due to the flow of the load current in the primary side.

The performance characteristics of both choppers deviate from the ideal chopper due to the load capacitive current during the off period in addition to many operation restrictions. The following are some of these restrictions:

- i) The minimum allowable repetition rate is governed by the duration through which the capacitor can maintain the commutating charge before it leaks off through the auxiliary thyristor S_2 .
- ii) The maximum allowable repetition rate is governed by the minimum ON and OFF periods of chopping which is governed by the thyristors characteristics [3,4] and the commutation circuit capability.
- iii) For large duty cycle, the available time for reversing the capacitor charge will not be enough, i.e. S_2 is still conducting when the next cycle begins and S_1 fails conducting when the next cycle begins and thus S_1 fails to trigger.

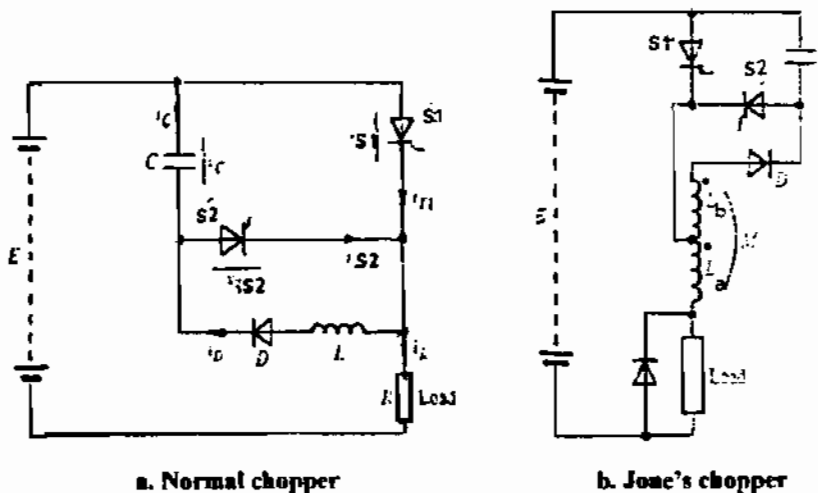


Fig. 2 : The circuit diagrams for the normal and Jone's choppers

- iv) For small duty cycle, the commutation of S_1 fails as the charge of the capacitor will not be enough to handle the needed commutating current.
- It is clear from the above discussion that the duty cycle, γ , has maximum and minimum values such that

$$\gamma_{\min} \leq \gamma \leq \gamma_{\max} ; \gamma_{\min} \neq 0 \text{ and } \gamma_{\max} \neq 1$$

In view of the foregoing discussion, it is evident that a modified chopper is needed to achieve proper commutation and avoid the duty cycle restrictions.

3. The New Chopper

A new chopper has been proposed and implemented by the authors [5] to get better performance compared with the normal and the Jone's choppers. This has been achieved by adding a series element combination L_1 & D_1 across S_1 , and L_2 & D_2 across S_2 to Jone's chopper, as shown in Fig. 3. The purpose of the modification of Jone's chopper is to trap the capacitor charge after commutation, thus preventing the capacitive load current during OFF period of chopping. Also, the capacitor commutating capacity increases due to trapping. Thus, the maximum value of the duty cycle; γ , increases, i.e the range of duty cycle increases.

3.1. Modes of operation

Specific details of the new developed chopper are illustrated in the following description of modes of operation;

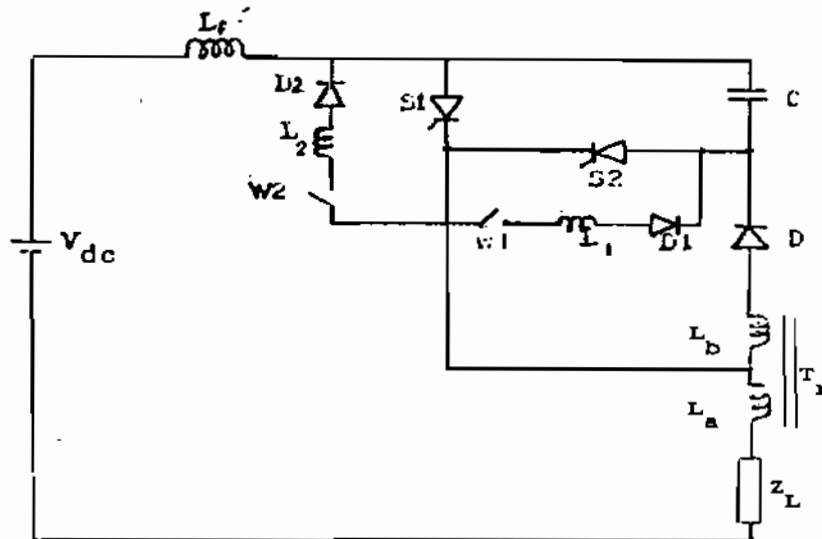


Fig. 3 : The new chopper

3.1.1. Mode 1

At the beginning of an ON period, the following currents flow through thyristor S_1 (Fig. 4-a):

- Current i_1 flows through the path L_f, S_1, L_a and Z_L which is connected through the d.c output terminals.
- Current i_2 flows through the circuit of L_b, D, C & S_1 due to the induced e.m.f in the secondary winding of the transformer.
- Current i_3 flows through the loop S_1, L_1 & C due to the charge voltage of the capacitor. This current flows during the half cycle only due to the blocking effect of D_1 .

Simple equivalent circuits for the three currents of mode 1 are given in Fig. 4-b.

3.1.2. Mode 2

At the end of an ON period and the start of an OFF period, thyristor S_2 is turned on. This means that the negative voltage of the capacitor is applied across thyristor S_1 turning it off. Also, two currents will flow as shown in Fig. 5-a.

- Current i_4 flows in the path formed of L_f, C, S_2, L_a and D_2 during the positive half cycle only to the blocking effect of the diode D_2 .
- Current i_5 flows in the loop formed by C, L_2 and during the positive half cycle only due to the blocking effect of the diode D_2 .

Simple equivalent circuit for mode 2 is shown in Fig. 5-b.

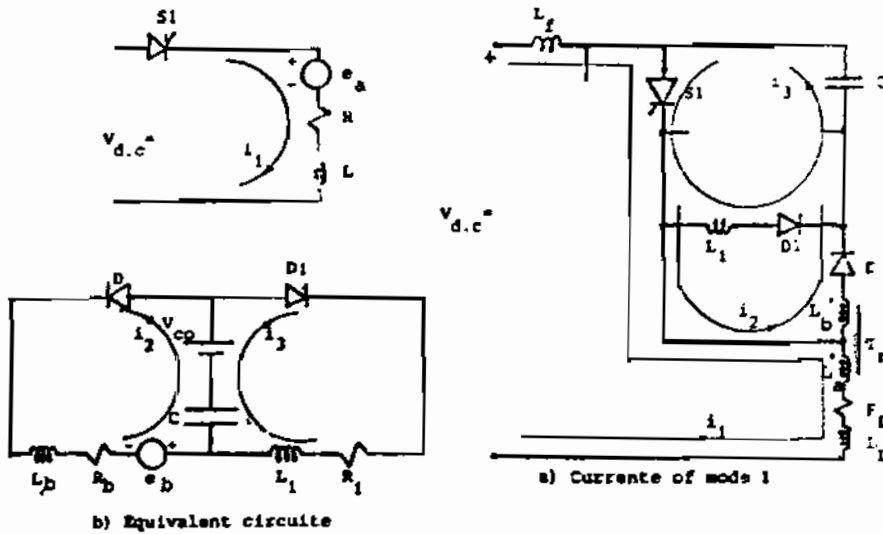


Fig. 4 : Equivalent circuits for the three currents of mode 1

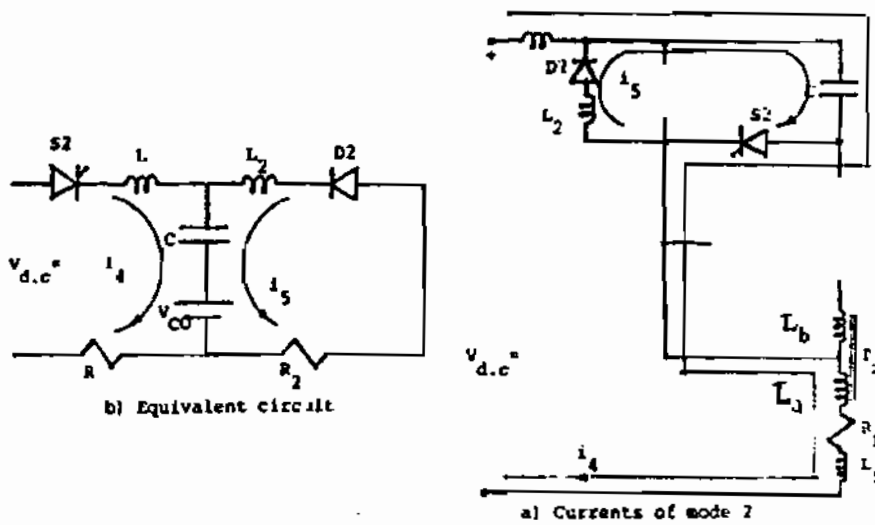


Fig. 5 : Equivalent circuits for the three currents of mode 2

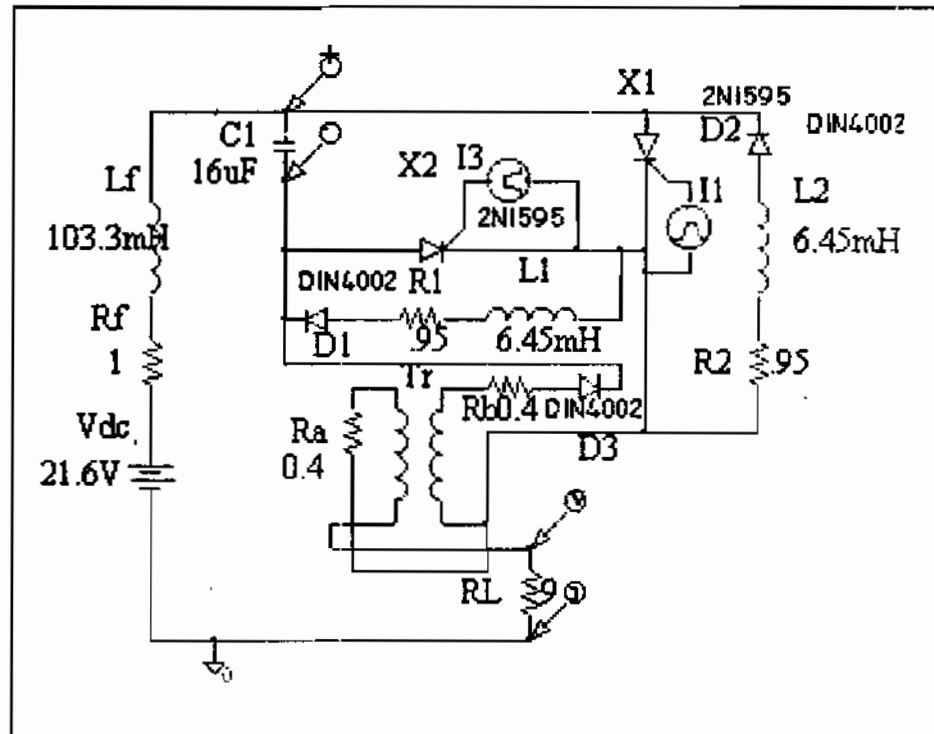
4. Simulation Results

The performance of the new chopper was simulated using Pspice [6]. The circuit used in simulation is shown in Fig. 6, and the parameters of the circuit used in simulation are shown in Table (1), which are the same parameters reported for the experimental circuit in [5]. Fig. 7 shows the simulation results : capacitor voltage, output voltage and current for this circuit.

Table 1: Parameters of the new chopper

Choke L_1	0.95 Ω , 6.45 mH
Choke L_2	0.95 Ω , 6.45 mH
Transformer T_r	$R_a = R_b = 0.4 \Omega$ $L_a = L_b = 1.4 \text{ mH}$ Turns ratio 1 : 1
Choke L_r	1 Ω , 103.3 mH
Capacitance C	8, 16, 24, and 32 μF

A dc voltage of 21.6 V is applied to the chopper and a resistive load of 9 Ω is used. A chopping frequency of 180 Hz was used [5]. A typical thyristor (2N1595) and a typical diode (D1N4002) were used in the Pspice simulations.

**Fig. 6 Circuit used for Pspice simulation of the new chopper**

4.1 Effect of Inductors L_a and L_b

We also studied the effect of the inductors L_a and L_b on the chopper performance. Fig. 8 shows the simulation waveforms for output voltage, load current, and commutating capacitor voltage for the new chopper, with all parameters the same as in Fig. 7, except that the value $L_a = L_b$ is now 0.3 mH instead of 1.4 mH for Fig. 7. It is clear that spikes appear in the load current in this case. Smoother waveforms are obtained for $L_a = L_b = 1.4 \text{ mH}$.

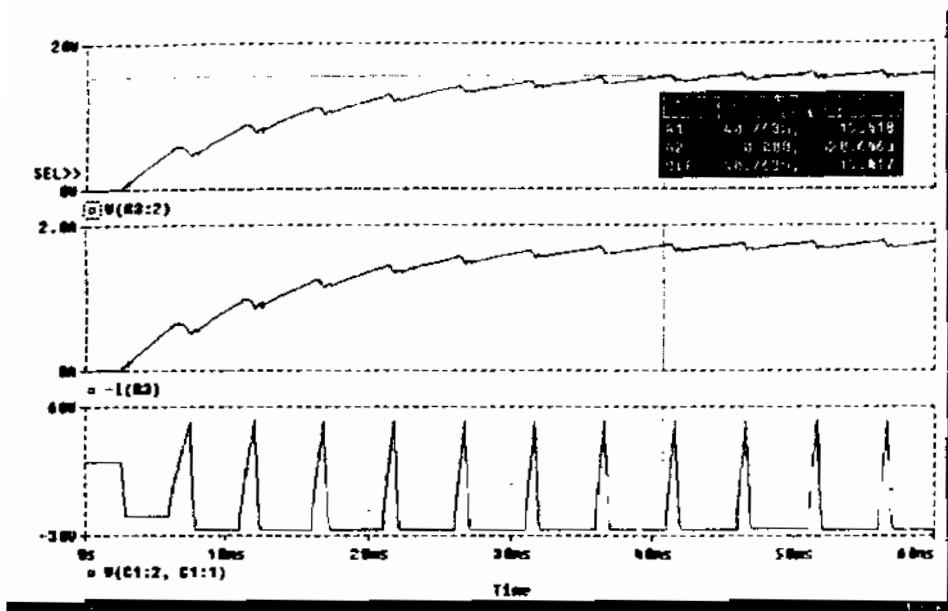


Fig. 7 : Simulated waveforms for output voltage , load current, and commutating capacitor voltage ($L_a = L_b = 1.4$ mH)

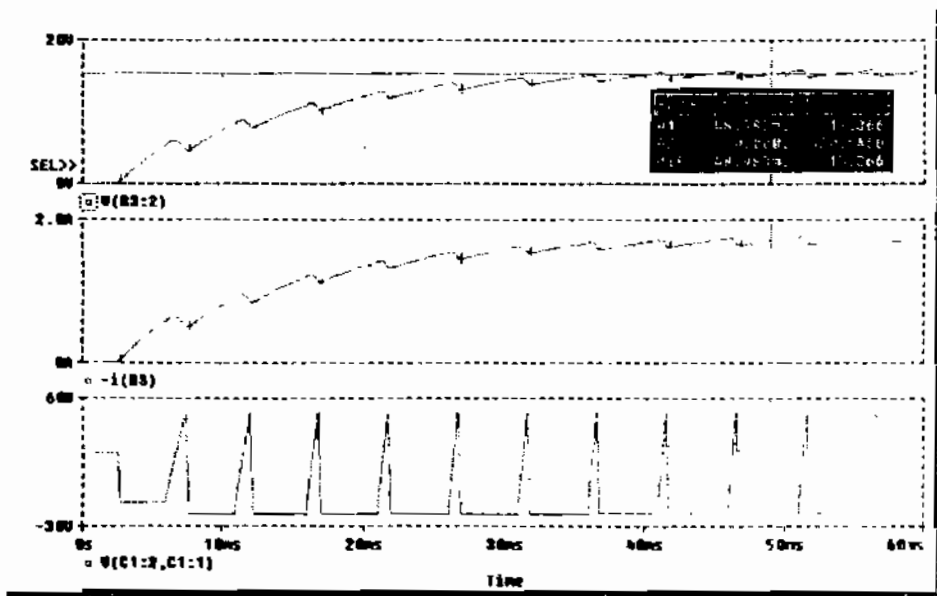


Fig. 8 : Simulated waveforms for output voltage , load current, and commutating capacitor voltage ($L_a = L_b = 0.3$ mH)

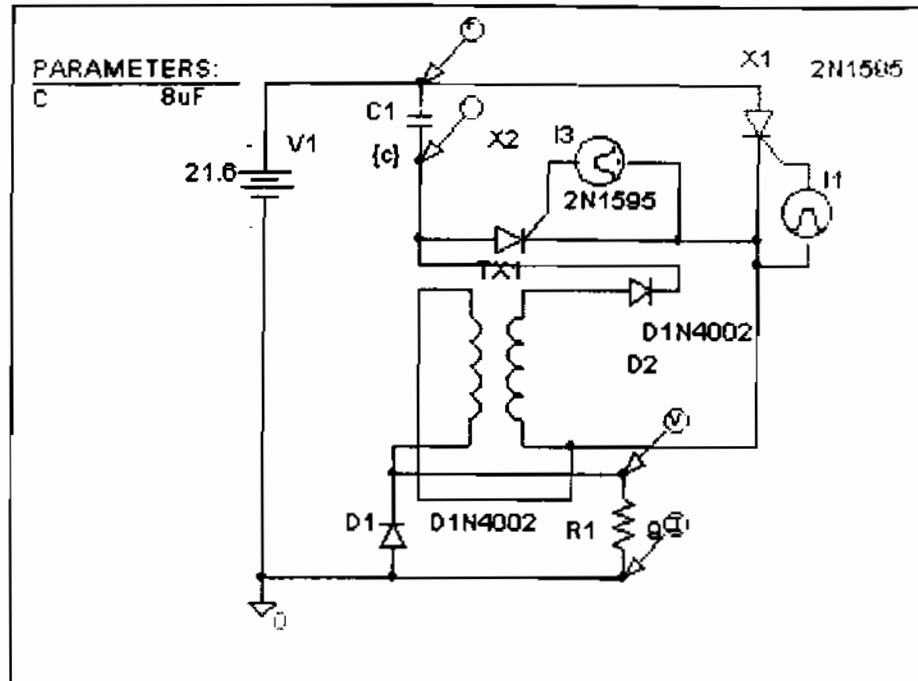


Fig. 9 Circuit used for Pspice simulation of the Jone's chopper

4.2 Effect of Commutating Capacitor

We also studied the effect of the commutating capacitor on the performance of the new chopper, and compared that with its effect on the performance of the Jone's chopper (circuit used for simulation is shown in Fig. 9). Fig. 10 shows the simulated waveforms for output voltage, load current, and commutating capacitor voltage for the new chopper, and Fig. 11 shows the same waveforms for the simulated Jone's, with the same parameters. Four different values have been used for the commutating capacitor: 8, 16, 24, and 32 μF .

The waveform of the voltage across the commutating capacitor obtained by simulation of the new chopper and the Jone's chopper are compared to those obtained experimentally (Fig. 13). The waveform for the new chopper has a similar shape but with a higher and taller peak. The simulated waveform for the Jone's chopper has a more flat top than that obtained experimentally, probably due to different components used in the experimental circuit than those used in simulation.

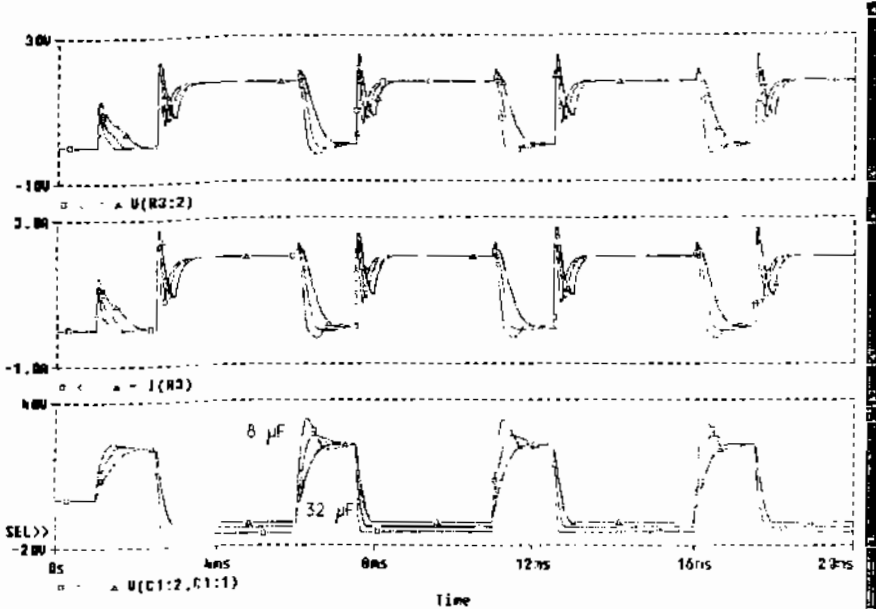


Fig. 10 : Simulated waveforms for output voltage , load current, and commutating capacitor voltage for the new chopper (C=8, 16, 24, and 32 μF)

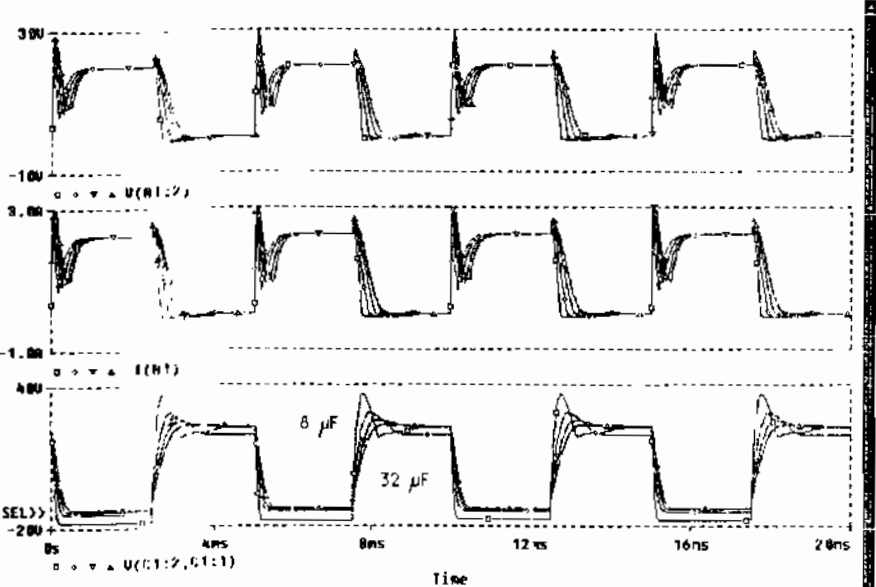
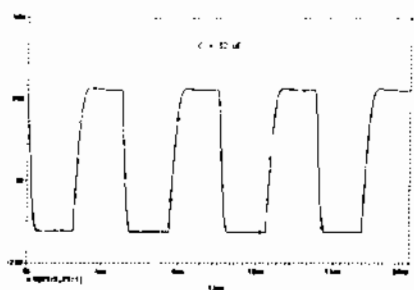
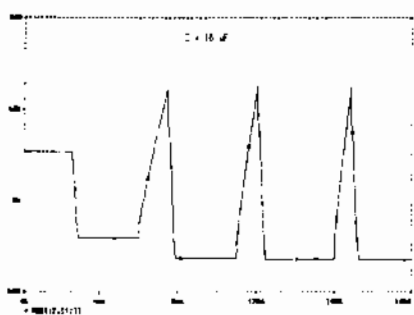


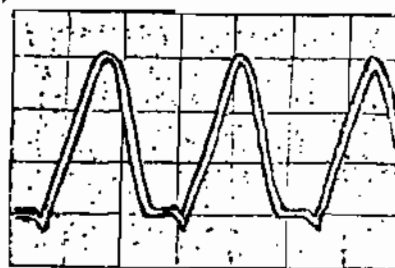
Fig. 11 : Simulated waveforms for output voltage , load current, and commutating capacitor voltage for the Jone's chopper (C=8, 16, 24, and 32 μF)



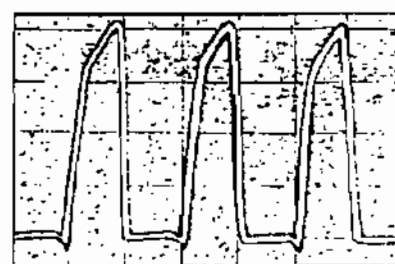
(a) Jones's chopper



(b) New chopper



(a) Jones's chopper



(b) The new developed chopper

Fig. 12 Waveform for commutating capacitor voltage from Pspice simulation of the new and the Jones's choppers

Fig. 13 Waveform for commutating capacitor voltage from experimental measurements of the new and the Jones's choppers

5. Conclusions

The performance characteristics of a new developed chopper are determined and compared with other choppers using Pspice. The effect of the chopper parameters on its performance have been determined. The simulation results have been compared with experimental results. Good agreement has been obtained. Causes of some discrepancies have been determined.

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