論 文
30~1~1

# 交流 電動機 驅動을 위한 廣域 電流源 콘버어터
## 第2部：12-스텝 인버어터

# A New Wide Range Current Source Converter for AC Motor Drives: Part II: Twelve-Step Inverter

曺 圭 亨* • 朴 松 培**
(Gyu-Hyeong Cho • Song-Bae Park)

**Abstract**

In the current source inverters (CSI), which are widely used recently in many applications, in order to reduce the harmonic contents in the output line current, twelve-step waveform is synthesized usually by a phase-shifted addition of the output currents of two single CSI's. In this paper a new method of synthesis of the 12-step current waveform is suggested which employes a main and a new auxiliary inverters having lower capacity, and thus is economically advantageous over the conventional scheme. DC-side commutation and energy rebound circuit as described in Part I are also employed in this proposed twelve-step CIS for effective commutation and high reliability. Experimental results are also given in oscillgrams.

## 1. Introduction

In part I we have described a six-step CSI designed with a new approach [6]. One disdvantage of such a single current source inverter(SCSI) is that it is rich in harmonics which cause motor heating and torque pulsations. These torque pulsations may be sometimes dangerous to certain systems due to reasonances between the harmonic torque and the mechanical systems especilly for low operating frequencies [5]. One method for harmonics reduction is to synthesize twelve-step waveform by a phase shifted addition of the output currents of two inverters. The inverter using this method is called dual current source converter (DCSC). We are going to introduce, in the following, a new twelve-step CSI, which does not employ such a DCSC method.

Fig. 1 shows three typical DCSC's [1]–[4]. In these the output currents of two complete SCSI's are shifted in phase by 30° and added in order to obtain twelve-step waveform. In this case,

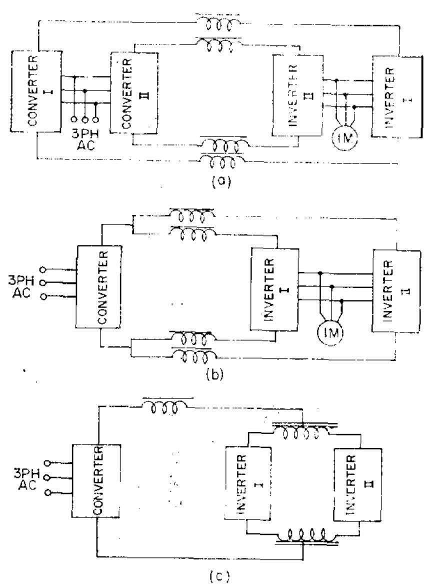


**Fig. 1.** Three typical configurations of conventional twelve step CSI's

* 正會員：韓國科學技術院 電氣電子科 博士過程
** 正會員：韓國科學技術院 敎授(學士擔當副院長)
接受日字：1980年 9月 10日

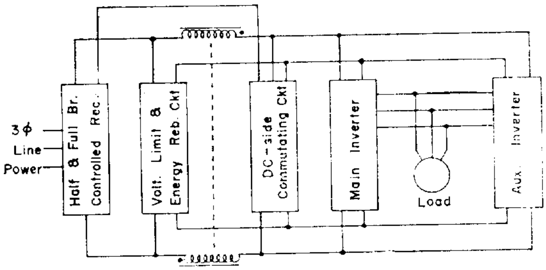


**Fig. 2.** Block-diagram of the new twelve-step CSI.

reactors with considerably large inductance must be inserted between the two inverters in order to suppress the circulating current generated by the motor emf. In Fig. 1(a) and (b) two pairs of independent reactors are inserted, each between the controlled rectifier(s) and one of the inverters. The reactor size can be considerably reduced in Fig. 1(c) by using two current balancing inductors. The balancing inductor, which has two identical windings wound on the same core, with no air-gap, may be of a small size and yet is very effective in suppressing the circulating

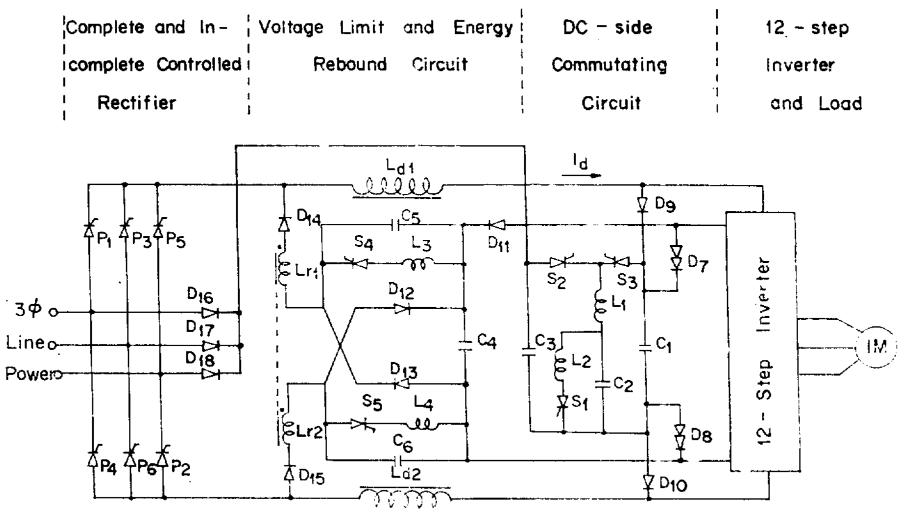


**Fig. 3.** Circuit diagram of controlled rectifier, energy rebound and DC-side commutating circuit.

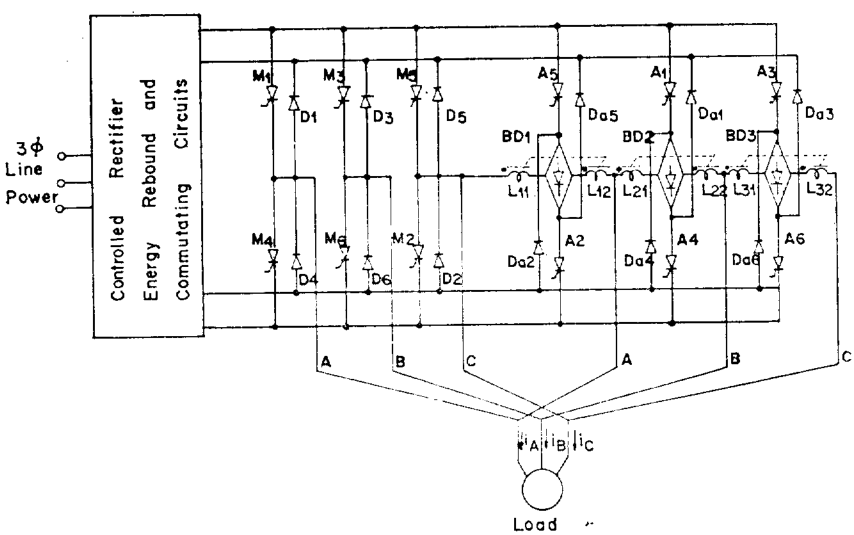


**Fig. 4.** Circuit diagra:n of the new twelvestep CSI.

current since the fluxes generated by the bisected DC current components flowing through inverters I and II cancel each other while it exhibits a large impedance for the circulating current component. These systems may be useful for large power applications but expensive because two independent inverters are used, each having its own commutating capability.

In the following we present a new twelve-step CSI in which the size of current balancing inductors is further reduced and which is obtained by adding one auxiliary inverter to the proposed six-step CSI described in part I. Fig. 2 shows that the block diagram of the proposed twelve-step CSI, from which we see that one auxiliary inverter is added and only one commutating circuit is used effectively in common for the main and auxiliary inverters.

## 2. Operation

Fig. 3 and Fig. 4 show the complete circuit diagram of the proposed twelve-step CSI. The front part shown in Fig. 3 is identical to that in Part I and hence the operating principle is the same except that the commutating frequency becomes twice in this case. The inverter part consists of a main inverter which has the same configuration as in the six-step CSI, and an

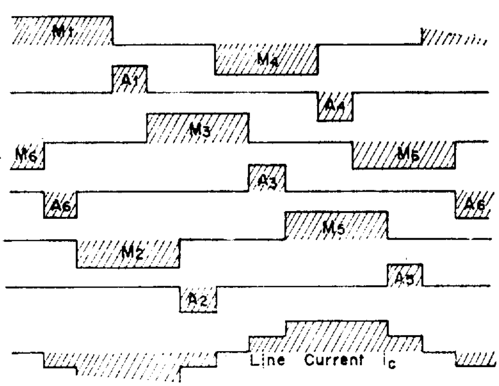


**Fig. 5.** Firing sequence of the new twelve-step CSI.

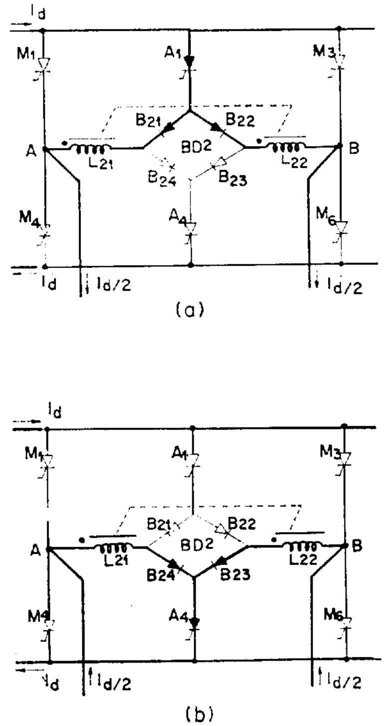


**Fig. 6.** One branch of auxiliary inverter. (a) $+I_d/2$ step. (b) $-I_d/2$ step.

auxiliary inverter, which has quite a different configuration. Fig. 5 shows the firing sequence of the proposed twelve-step CSI, from which we see that the main SCR's and the auxiliary SCR's are turned on and off alternately and a half current step is formed in the line current in the conducting state of each auxiliary SCR.

Fig. 6 shows the conducting state at the positive half current step for one branch of the auxiliary inverter. Each branch of the auxiliary inverter consists of a set of bridge diodes and a pair of inductors. As can be seen from Fig. 6 the role of the bridge diodes is two fold; it makes a current path through $B_{21}$ and $B_{22}$ when $A_1$ is ON and through $B_{23}$ and $B_{24}$ when $A_4$ is ON, while it isolates points $A$ and $B$, causing no magnetization of $L_{21}$ and $L_{22}$, when both $A_1$ and $A_4$ are OFF. In this way $L_{21}$ and $L_{22}$ play the same role as the current balancing inductor in Fig. 1(c) when one of the auxiliary SCR's is ON. $L_{21}$ and $L_{22}$ are wound on the same core with no air-gap. The same for $(L_{11}, L_{12})$ and $(L_{31}, L_{32})$. Thus, one more core is required compared with Fig. 1(c). However, the core size can be considerably reduced since in Fig. 5 current flow through the current balancing inductor during only one-sixth of the period, while in Fig. 1(c) current flow continues through the whole period. The three sets of inductors can even be wound on the same core due to the action of the bridge diodes as described above.

Both the main and the auxiliary SCR's which have been in the conducting state are turned off simultaneously by the operation of the commutating circuit. Diodes $D_{a1} \sim D_{a6}$ can be of a very small capacity since they are used only to secure

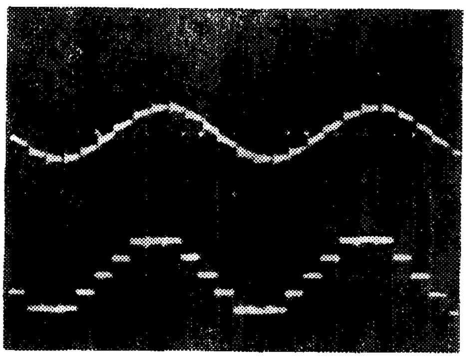

**Fig. 7.** Oscillograms of line-to-line voltage(top) and phase current (bottom) for the new twelve-step CSI. Vertical: 50V/div. (top), 5A/div. (bottom). Horizontal: 10 msec/div.

stable turn-off of the auxiliary SCR's by forming a demagnetizing current path, during the commutating interval, for the current balancing inductor which has been magnetized by the motor emf during the operation of the auxiliary inverter. Also, the power rating required for the auxiliary SCR's is about one-half that for the main SCR's, since, as can be seen from Fig. 5 the ratio of conducting intervals is one to three while the conducting current magnitudes are the same in the two sets of SCR's. Finally the power rating required for the bridge diodes is one-half that for the auxiliary SCR's, since the current through the auxiliary SCR is bisected in the bridge arms.

Fig. 7 shows the oscillograms of the phase voltage and the line current obtained with an experimental twelve-step CSI.

### 3. Distinctive Features

The auxiliary inverter which is added to the six-step CSI in order to obtain twelve-step waveform, does not require a separate commutating circuit; one DC-side commutating circuit controls simultaneously both the main and the auxiliary SCR'S. The current balancing inductor in the auxiliary inverter can be of a very small size compared with the one of DCSC. Power rating required for the auxiliary SCR's is about one-half that for the main SCR's, and that for the bridge diodes is further reduced. Furthermore, all components can have low voltage ratings due to the particular peak voltage limit and energy rebound method employed. Firing control of the SCR's in the proposed twelve-step CSI is simple since only the alternating ON time durations for the main and auxiliary SCR's need be considered in timing the firing pulses, which is different from the situation in DCSC where a rather elaborate firing control is needed taking into account the difference of the powers delivered by two CSI's.

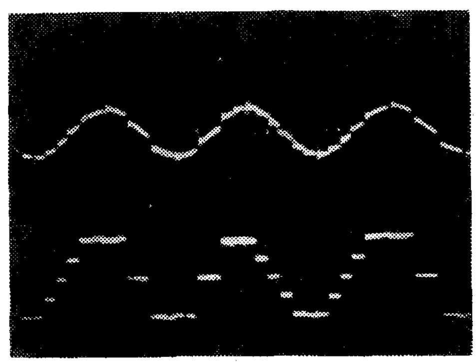

**Fig. 8.** Oscillogram of the waveform resulting from periodical switching between twelve-step and six-step. Vertical: 50 V/div.(top), 5A/div. (bottom). Horizontal: 10msec/div.

In all, the proposed twelve-step CSI has an economic advantage and can be used for low and medium power applications as well as for higher power applications, where the harmonics is the main concern.

By slightly modifying the firing sequence, namely, by sending the gating pulses only to the main inverters the twelve-step CSI can be smoothly converted to a six-step CSI, which is advantageous at high frequency operation of the motor since the commutating frequency is halved. Fig. 8 shows smooth transition of twelve-step to six-step conversion and vice verse.

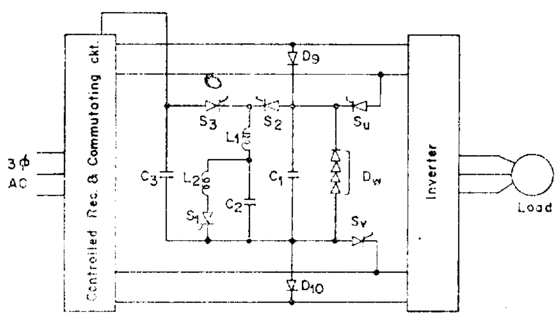


**Fig. 9.** Modified DC-side commutating circuit for halving the commuating energy.

## 4. Commutating Energy Reduction

Use of low speed SCR's in the inverter is made possible by extending the turn-off time, which means increase of the commutating energy. As stated in Part I, the commutating circuit in Fig. 3 must have a commutating capability to handle twice of the DC current and requires more commutating energy in order to be able to turn off low speed SCR's. Increase of commutating energy means increse of commutating loss which is proportional to the operating frequency.

As shown in Fig. 9, by adding SCR's $S_u$ and $S_v$ with small capacity to the commutating circuit, the commuating energy required is halved. Comparison with Fig. 3 shows that $D_7$ and $D_8$ are replaced by $S_u$ and $S_v$ and $D_w$ is connected anew across $C_1$. During commutation, either $S_u$ or $S_v$ is turned on. When $S_u$ ($S_v$) is turned on keeping $S_v$ ($S_u$) off, those SCI's in the lower (upper) side of the inverter which have been in the conducting state are turned off simultaneously. The reverse voltage across the off SCR's in this case is determined by the forward voltage drop across $D_w$, which, in turn, can be adjusted by the number of diodes in the string. By one of SCR's, $S_u$ or $S_v$, which is blocked during commutation, the load current is prevented from flowing into the commuating circuit and hence the commutating energy is halved with the same turn-off time as compared with the method in Fig. 3.

Another modification is possible in Fig. 3 by simply replacing diodes $D_9$ and $D_{10}$ by two small SCR's, $T_u$ for $D_9$and $T_v$ for $D_{10}$. In this case, $T_u$ ($T_v$) is turned on keeping $T_v$($T_u$) off in order to turn off the upper(lower) side SCR's of the inverter during commutation.

On the other hand, one disavantage of this type of commuting circuit is that the capacitor ($C_2$) voltage must be reversed twice during each commutation, which causes additional loss. However, in general, the lower the blocking voltage capability of the SCR is, the faster the switching characteristic, for the same grade SCR's. In this sense, the proposed inverter scheme has inherent advantages of commutating energy saving and high speed operation.

## 5. Conclusion

A new twelve-step current source inverter with DC-side commutation and energy rebound features are described together with some experimental results. Almost ideal twelve-step waveform with considerably reduced total harmonics compared to a single CSI is obtained simply by adding an auxiliary inverter with power requirement fairly smaller than that of the main inverter. The main inverter has the same configuration as the new six-step CSI described in Part I. Consequently, the proposed twelve-step CSI has all the merits

f the new six-step CSI in addition to the har-
ıonic content reduction.

In the new twelve-step CSI the DC-side commutating circuit is more effectively used for the oubled number of SCR's to be commutated. In oite of the apparent circuit complexity and the oubled commutating loss accompanied by the oubled frequency, the new 12-step CSI is thought ) be more economic and easier to implement ompared to the DCSC methods.

In conclusion, the new twelve-step inverter may e a good choice in such cases where the harmonic ontent is of the main concern or an econimic low equency operation is required.

**Acknowledgement**

The authors wish to thank Mr. W.C. Song for elping the design of the control part and experiiental works and Dr. J.D. Cumming, visiting rofessor from University of California, Berkeley, or careful reading of the manuscript and helpful omments.

**References**

1. R. Palanippan and J. Vithayathil; "The Current-fed Twelve-step Current Source Inverter," IEEE Trans. Ind. Electr. Contr. Instrum., Vol. IECI-25, Nov. 1978.
2. R. Palanippan, J. Vithayathil and S.K. Data; "Principal of a Dual Current Source Converter for AC Motor Drives," IEEE Trans. Ind. Appl., IA-15, Jul.-Aug. 1979.
3. B.D. Bedford and R.G. Hoft; "Principles of Inverter Circuits," John Wiley & Sons, Inc., 1964.
4. J.M.D. Murphy; "Thyristor Control of AC Motors," Pergamon Press, 1973.
5. W. Lienau, A.M. Hellmann, and H.C. Skudelny; "Power Converters for Feeding Asynchronous Traction Motors of Single-Phase AC Vehicles," IEEE Trans. Ind. Appl., IA-16, No. 1, Jan./Feb. 1980.
6. G.H. Cho and S.B. Park; "A New Wide Range Current Source Converter for AC Motor Drives: Part I-Six-Step Inverter," KIEE Trans, Vol. 29, No. 11, Dec. 1980.