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SOME EXPERIMENTS AND CONSIDERATIONS ON THE BEHAVIOR OF A NEW MAGNETIC FREQUENCY TRIPLER WITH BRIDGE-CONNECTED REACTOR CIRCUIT

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ABSTRACT

Some magnetic frequency triplers using the saturation characteristics of an iron core have been reported. In this paper a new frequency tripler which is based on the bridge-connected reactor circuit is proposed. The features of this tripler are that an applied source is single phase and ferro-resonance circuits are formed in both the output and input side. Consequently, the circuit becomes very simple, the power factor is greatly improved and the triple frequency output voltage holds constant. This paper presents some experiments and considerations on a new tripler. Moreover, various circuits which have equivalent operating characteristics are proposed.

INTRODUCTION

Dr.P.P.Biringer et al. proposed the magnetic frequency tripler which is fed from a three-phase fundamental source.^{2,3} In this tripler the secondary windings of a star-delta connection transformer are open and are connected to a ferro-resonance circuit. Consequently, the fundamental frequency voltage cancels in the circuit and a harmonic voltage which is associated with a nonlinear magnetic core is produced in the output terminals. This kind of tripler uses the triple frequency component. However, the new frequency converter proposed by the authors is based on the bridge-connected reactor circuit and the source is single-phase. A triple frequency output is easily obtained from a single-phase source in this bridge circuit. The structure and performance of the bridge circuit are described in the following.

Figure 1 shows the bridge-connected reactor circuit which forms an important part of the new frequency tripler. The authors stated in the previous papers that the performance of this circuit was essentially

the same as that of the Paraformer proposed by S.D. Wanlass et al. in 1967.^{4,5} This is composed of two linear reactors and two saturable reactors. Each two reactors have the same volt-ampere characteristics. Figure 2 shows the relation between the input and output voltage which is found from the vector method by taking into account the fundamental wave only. But harmonics generated in a core are included in the output and the output voltage is expressed in the dashed line. The output voltage at the input voltage $2V_k$ is entirely harmonic component. The output waveform at $2V_k$ is shown in Fig.3. The triple frequency is the major component of the output voltage. This is the mechanism of the frequency conversion in this tripler.

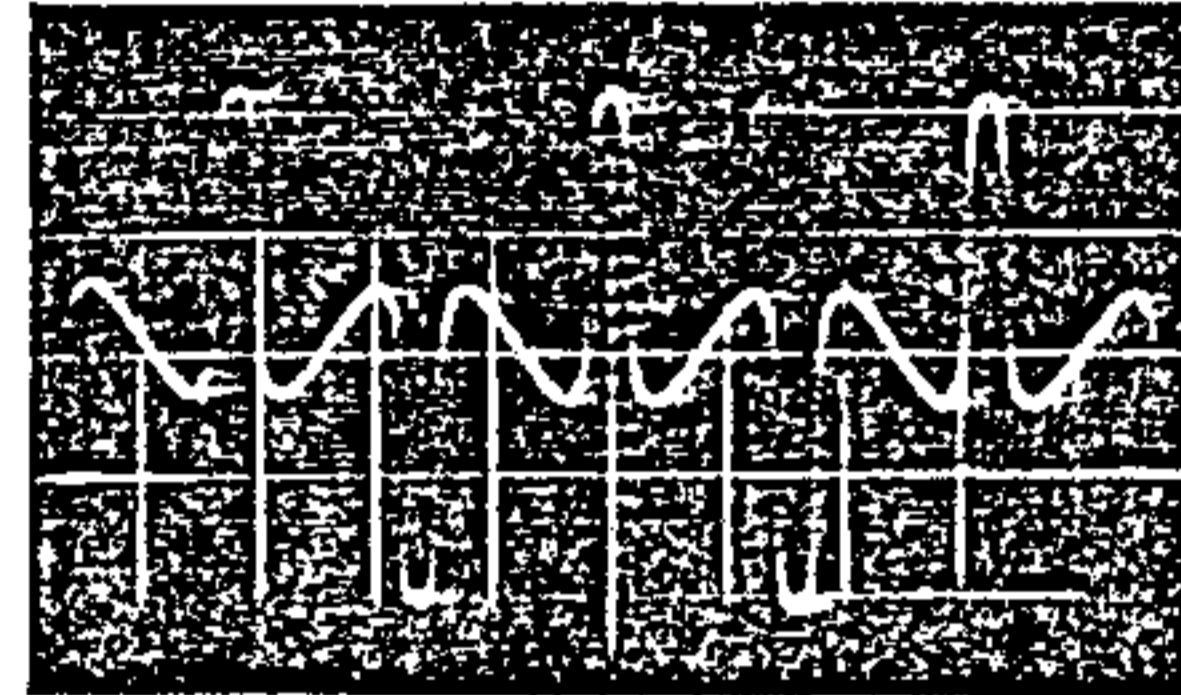


Fig.3 Waveform of output voltage in the bridge circuit

The bridge circuit as shown in Fig.1 is composed of four cores and the opposite sides of the bridge circuit are under the same voltage condition. Therefore, opposite reactors can be fabricated with single core. In this structure, the unbalance of the voltages does not arise in the opposite reactors and the bridge circuit can be composed of fewer cores. The structure is utilized in the frequency triplers which are shown in the following figures.

CIRCUIT STRUCTURE AND PERFORMANCE

A new frequency tripler proposed by the authors is shown in Fig.4. The tripler is divided into three parts and each part has an independent function. The circuit Part I includes a linear reactor L_{in} and a capacitor C_{in} . The capacitor and an equivalent saturable reactor (the input impedance of a bridge circuit) form a ferro-resonance circuit. The circuit Part II is a bridge-connected reactor circuit. The application of a fundamental frequency source to the circuit produces a triple frequency voltage. The saturable reactor is substituted equivalently for the bridge circuit at the input terminals(a-a'). Equivalent circuit at the output terminals(b-b') is represented as a triple frequency source and a linear reac-

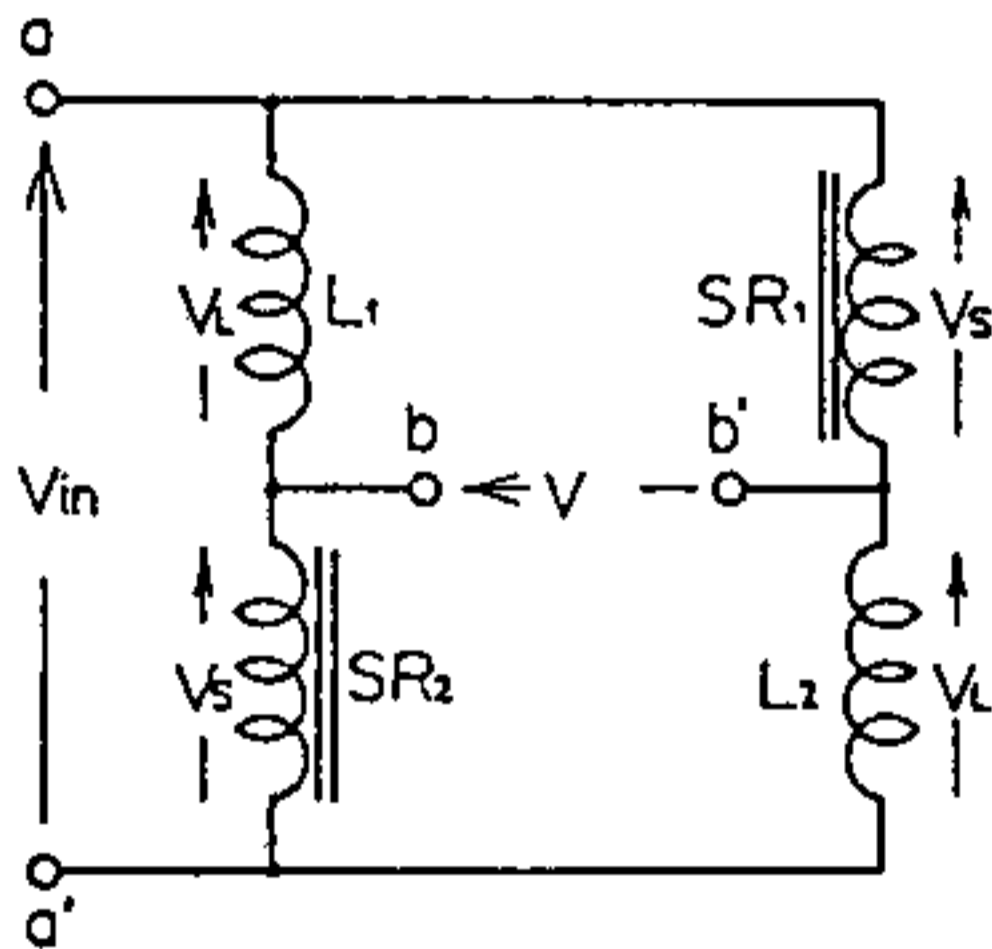


Fig.1 Bridge-connected reactor circuit where $L_1=L_2$, $SR_1=SR_2$

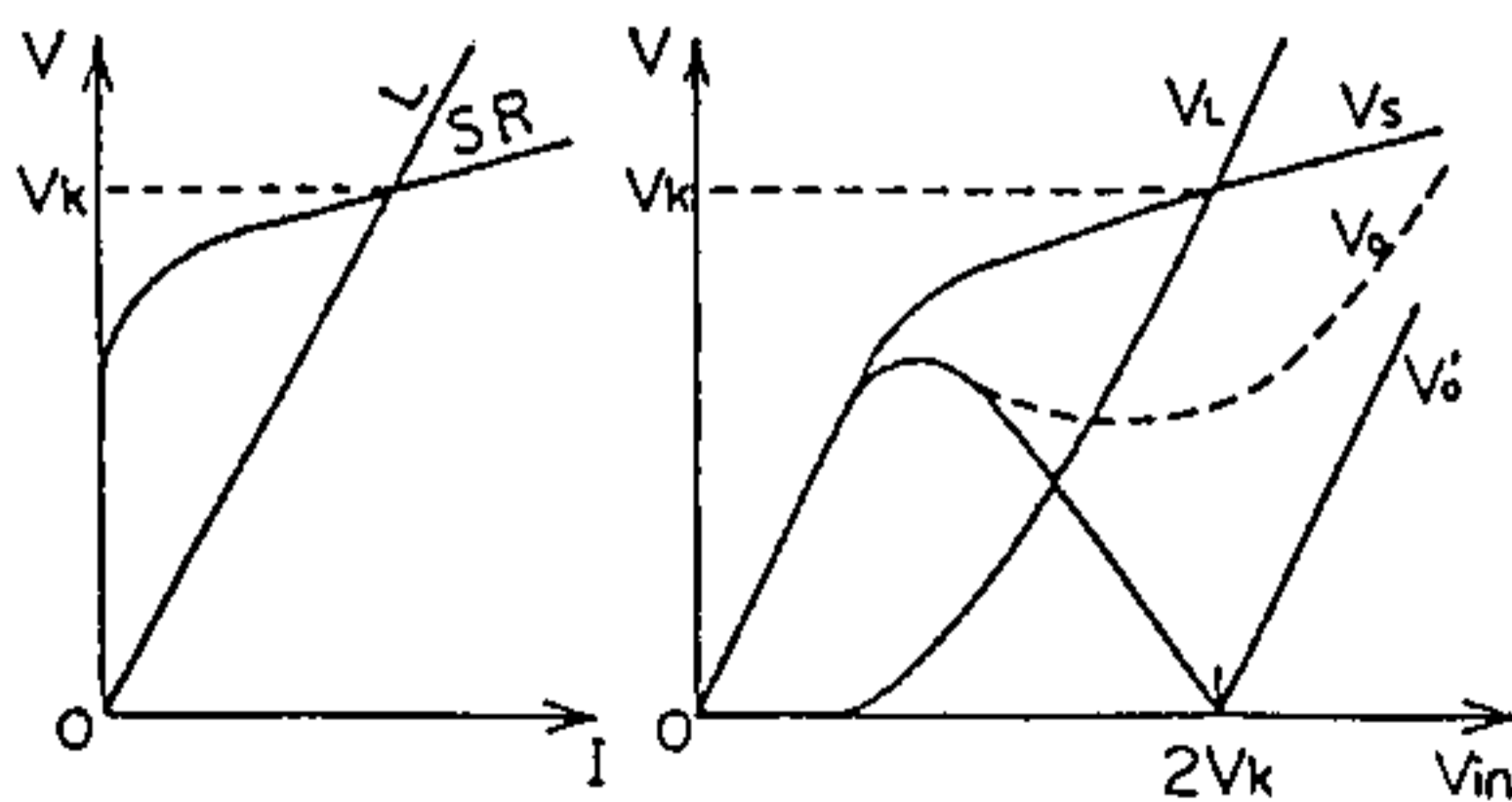


Fig.2 Qualitative characteristics of a bridge-connected reactor circuit

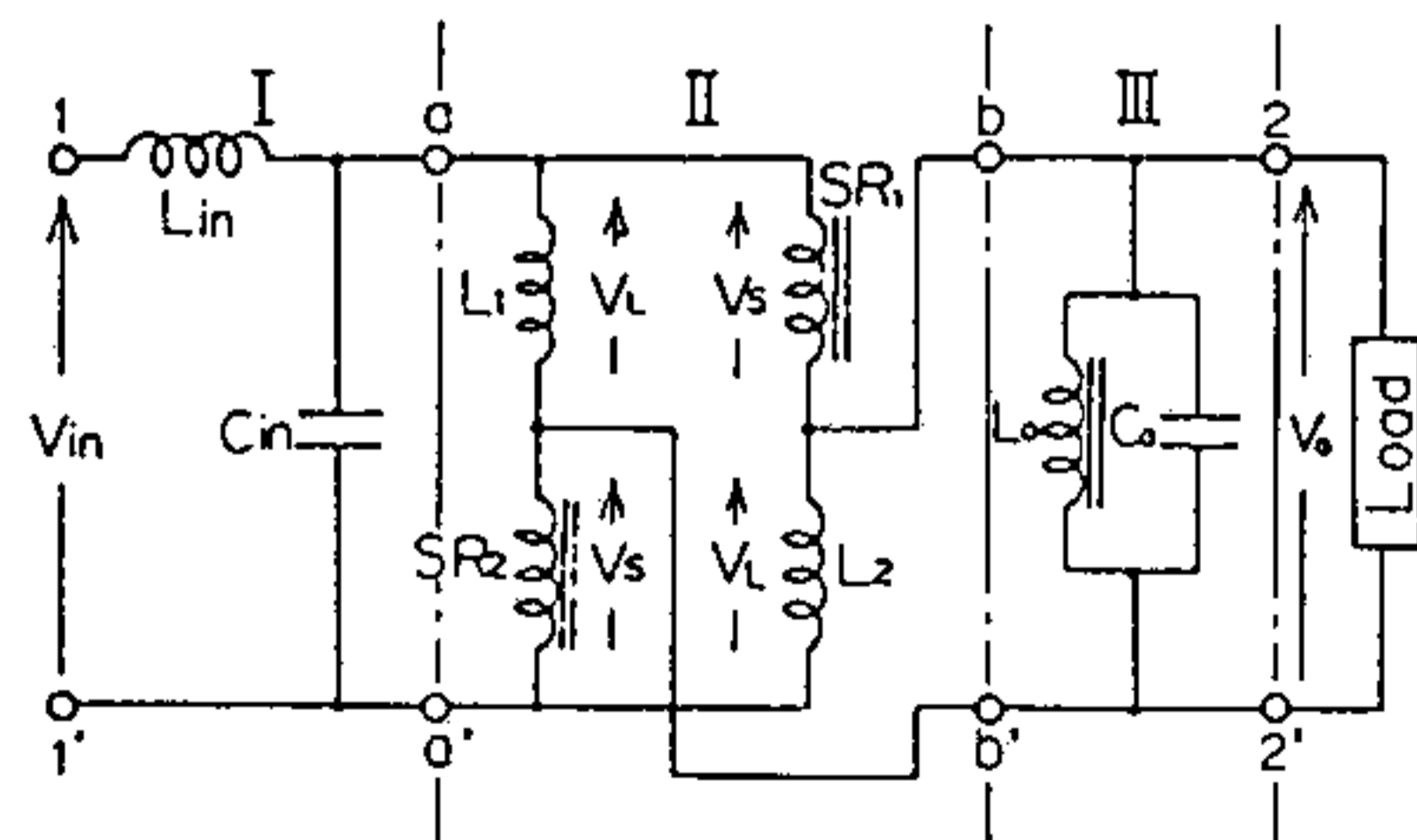


Fig.4 A new magnetic frequency tripler

tor connected in series. These are very important for a triple frequency output to obtain the constant voltage characteristics. The circuit Part III is a ferro-resonance circuit for a triple frequency voltage. The resonance circuit and the equivalent reactor of the bridge circuit form a constant voltage circuit. Thus, the new frequency tripler has two constant voltage circuits for both fundamental and triple frequency voltage.

Figure 5(a) shows the volt-ampere characteristics of the saturable reactor SR and the linear reactor L.

The characteristics of the ferro-resonance circuit in Part III are shown in Fig.5(b). It is not a resonance circuit for a fundamental frequency voltage as described in the solid line. Therefore, the impedance is low and the circuit filters a fundamental frequency voltage. For a triple frequency, it forms a ferro-resonance circuit as drawn in the dashed line. The mechanism of performance is explained in the following.

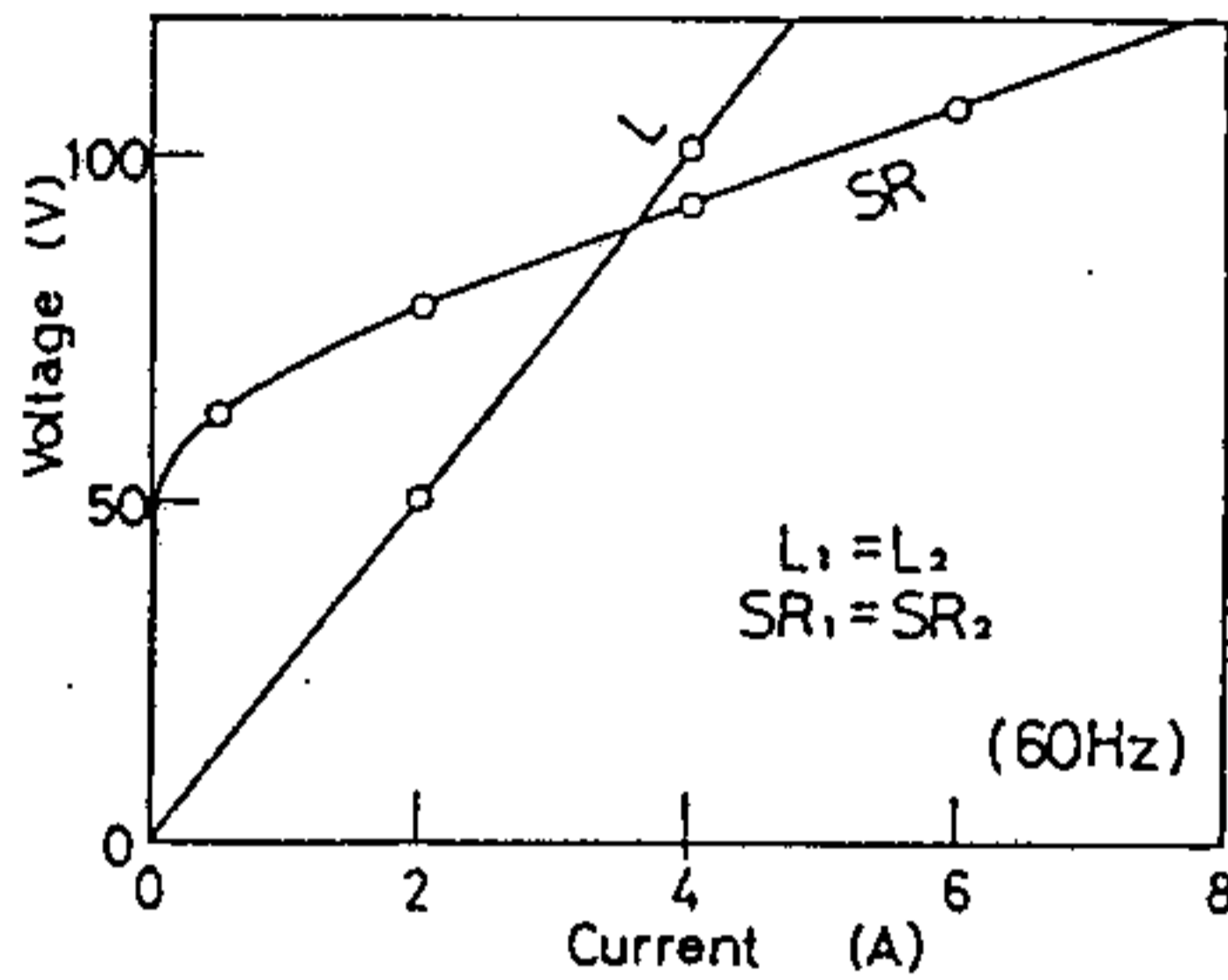


Fig.5(a) Characteristics of L and SR

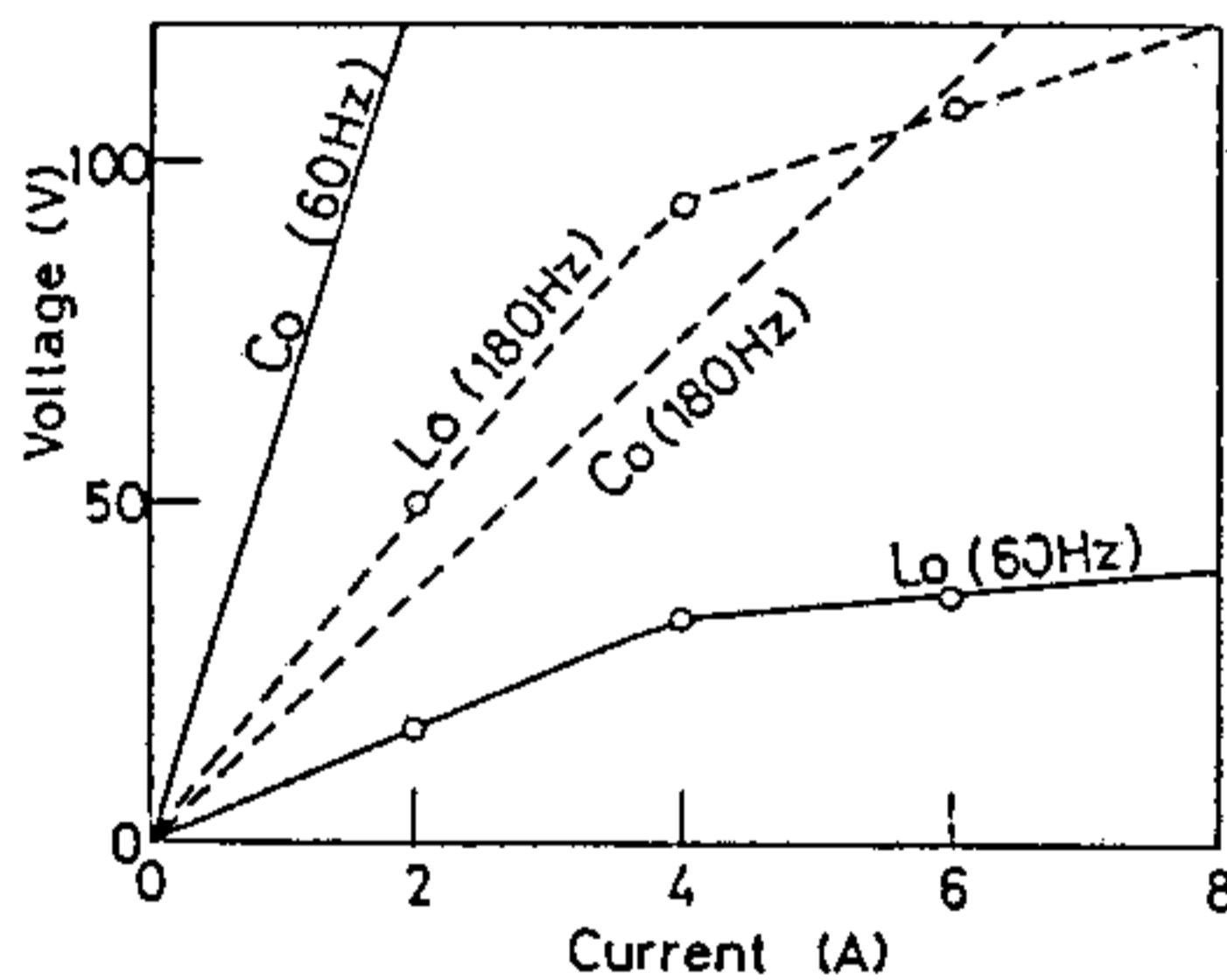


Fig.5(b) Characteristics of the ferro-resonance circuit on 60 and 180 Hz

There is an equivalent constant voltage circuit at the input side. Therefore, the input current of a tripler(1-1') decreases and the power factor is greatly improved. In addition, the fundamental frequency voltage at the input terminals of the bridge circuit (a-a') holds constant even if the input voltage fluctuates. Therefore, the voltage is chosen as $2V_k$ which is determined by the bridge circuit as shown in Fig.2 (b). In this case, the output voltage of the bridge circuit hardly includes the fundamental frequency component and the waveform of a triple frequency becomes sinusoidal. Moreover, the equivalent voltage source of a triple frequency becomes a constant voltage source and the regulation of a triple frequency output is greatly improved. The equivalent constant voltage circuit of a triple frequency yields good regulation of the load characteristic. There are a lot of features and merits in the new frequency tripler. The experimental verification of the above consideration is shown in the next section.

EXPERIMENTAL RESULTS

Figure 6 indicates the voltage characteristics. A triple frequency output voltage (V_o), each voltage of reactor (V_l) and saturable reactor (V_s) in the bridge circuit, and the input current (I_{in}) are shown in the figure. Only the triple frequency voltage can be obtained for every input voltage. As voltages of each bridge side are almost identical, the fundamental voltage is removed and does not appear at the output terminals of a bridge circuit. The output voltage is established at a low input voltage and has a good constant voltage characteristic. As the input current has a minimum point, the power factor is remarkably improved. The feature is very desirable for a power source.

Figure 7 shows the characteristics with resistance load. The output voltage also indicates a good constant voltage characteristic. A maximum load current

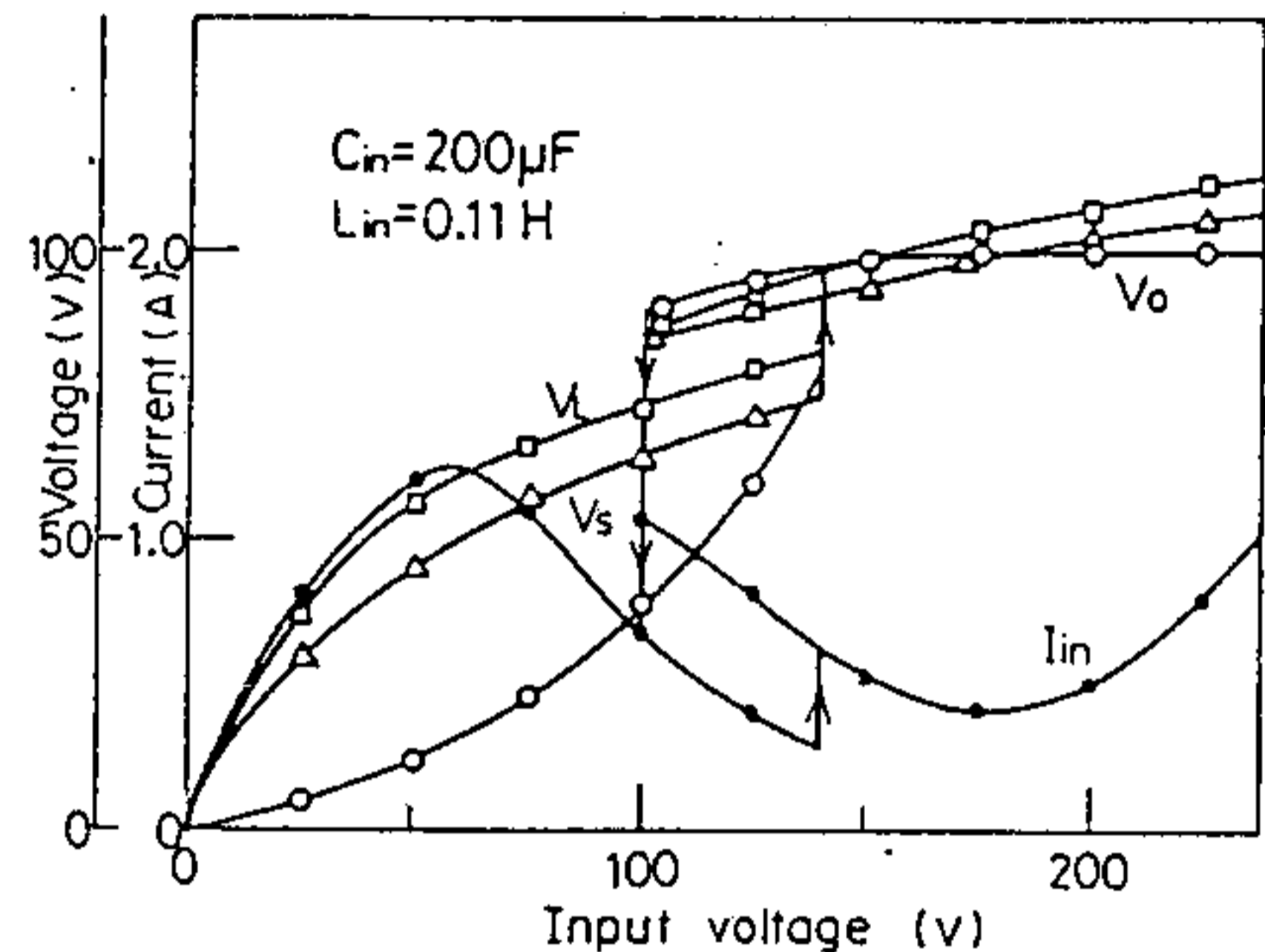


Fig.6 Voltage characteristics of a new tripler

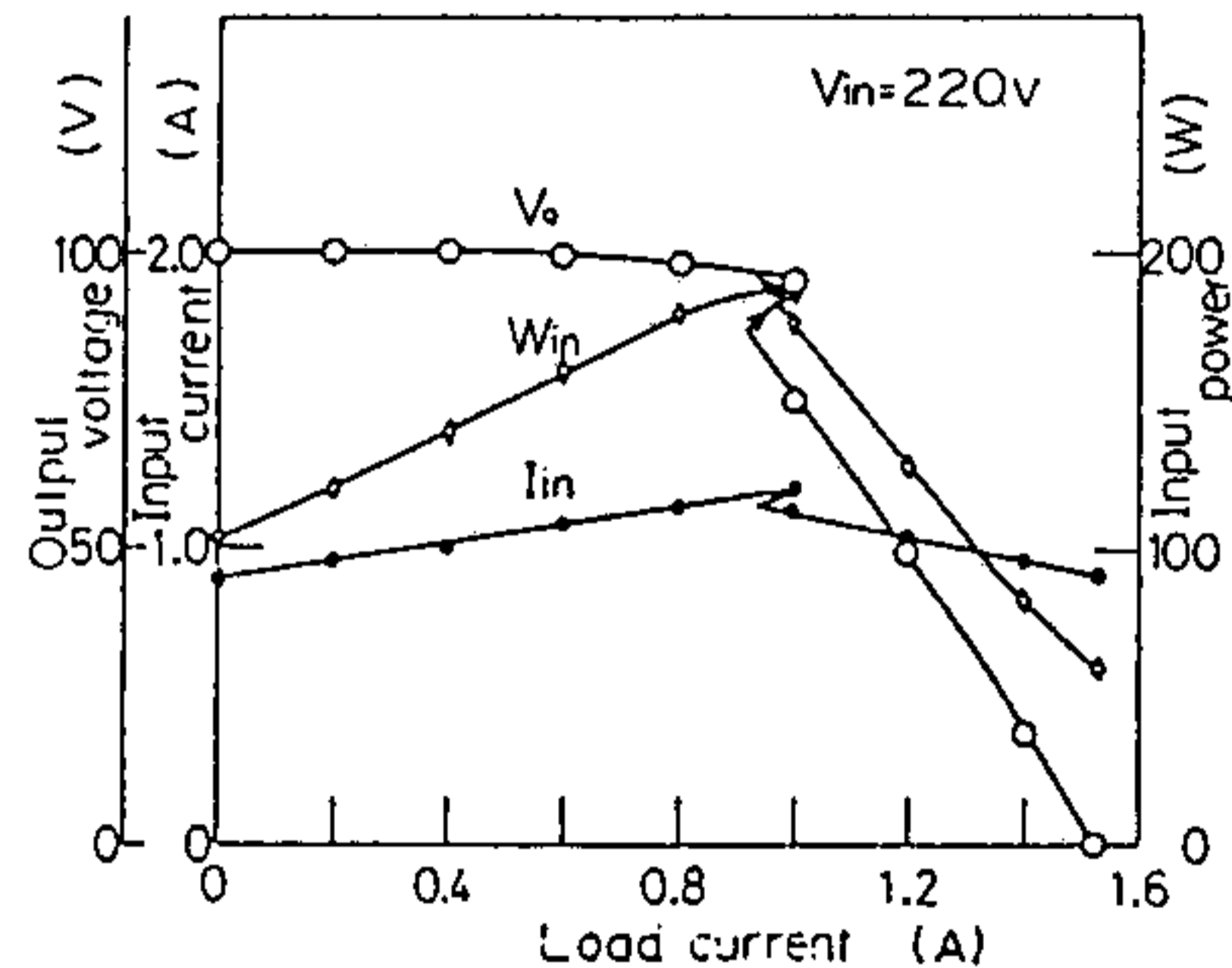


Fig.7 Load characteristics

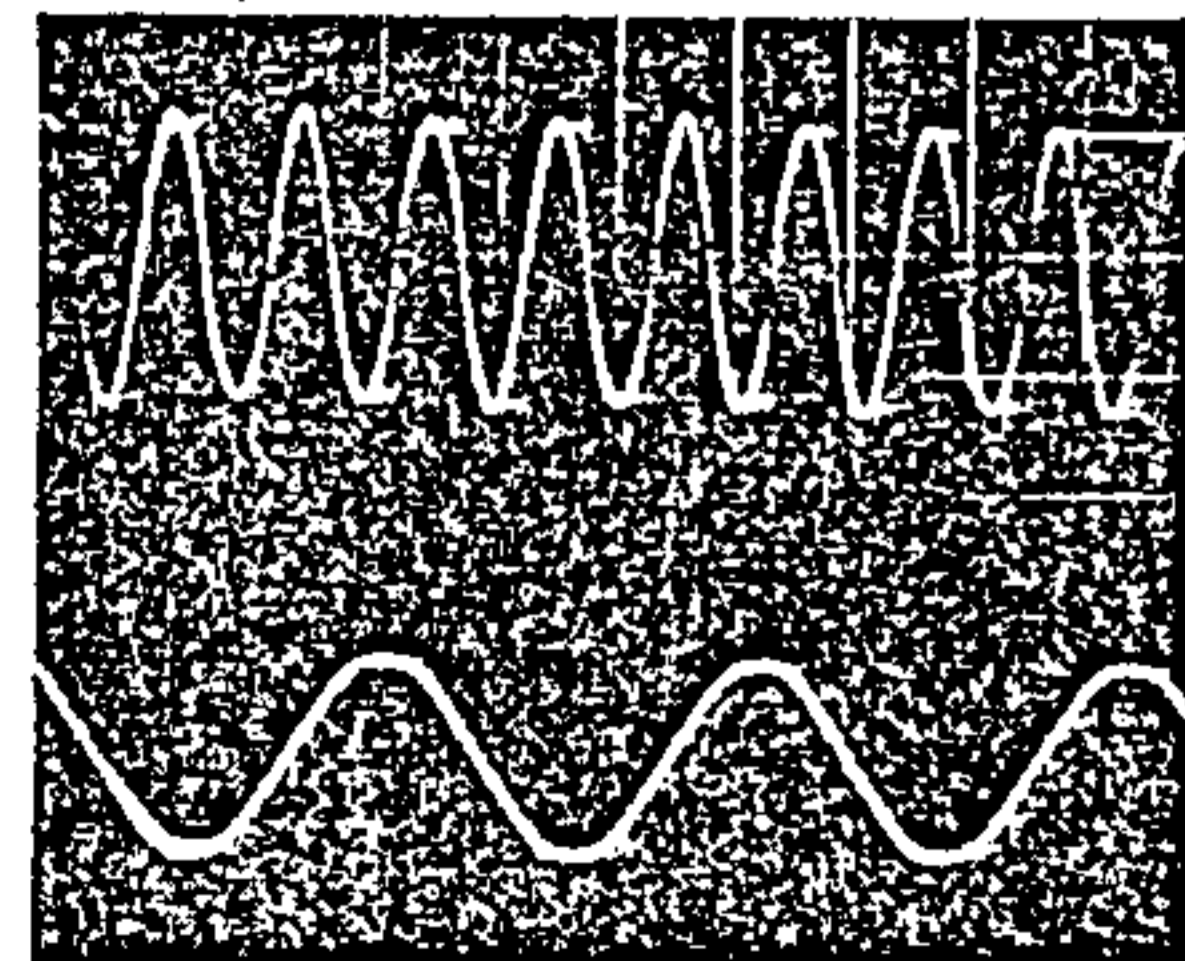


Fig.8 Waveforms of triple frequency voltage(upper) and fundamental frequency voltage(lower)

increases with increasing input voltage. It is understood that the saturable reactor SR in the bridge circuit operates more deeply in saturation as the input voltage increases. As the output voltage drops from a constant voltage during the overload condition, input current decreases. This feature is not obtained by the conventional constant voltage regulators. The maximum efficiency is about 50%. It can be improved by using a magnetic material suitable for high frequency.

Figure 8 shows the oscillogram of the waveforms of a triple frequency output voltage and a fundamental frequency voltage. It hardly changes on any load and the distortion is about 10%. Only the triple frequency component is sustained even for overload condition. The waveform of the input current is almost the fundamental frequency and the harmonic distortion is very small. It is understood that the filter of L_{in} and C_{in} eliminates the harmonic component produced in the bridge circuit. The tripler is very stable and other harmonic voltage does not appear.

SOME NEW STRUCTURE OF TRIPLER

The tripler, as is illustrated in Fig.4, is based on the bridge circuit. The bridge circuit can be transformed into the circuits as shown in Fig.9. The operating conditions in both Fig.9(a) and (b) are the same. As the bridge circuits are divided into similar circuits as shown in Fig.9(b), the circuit is simplified

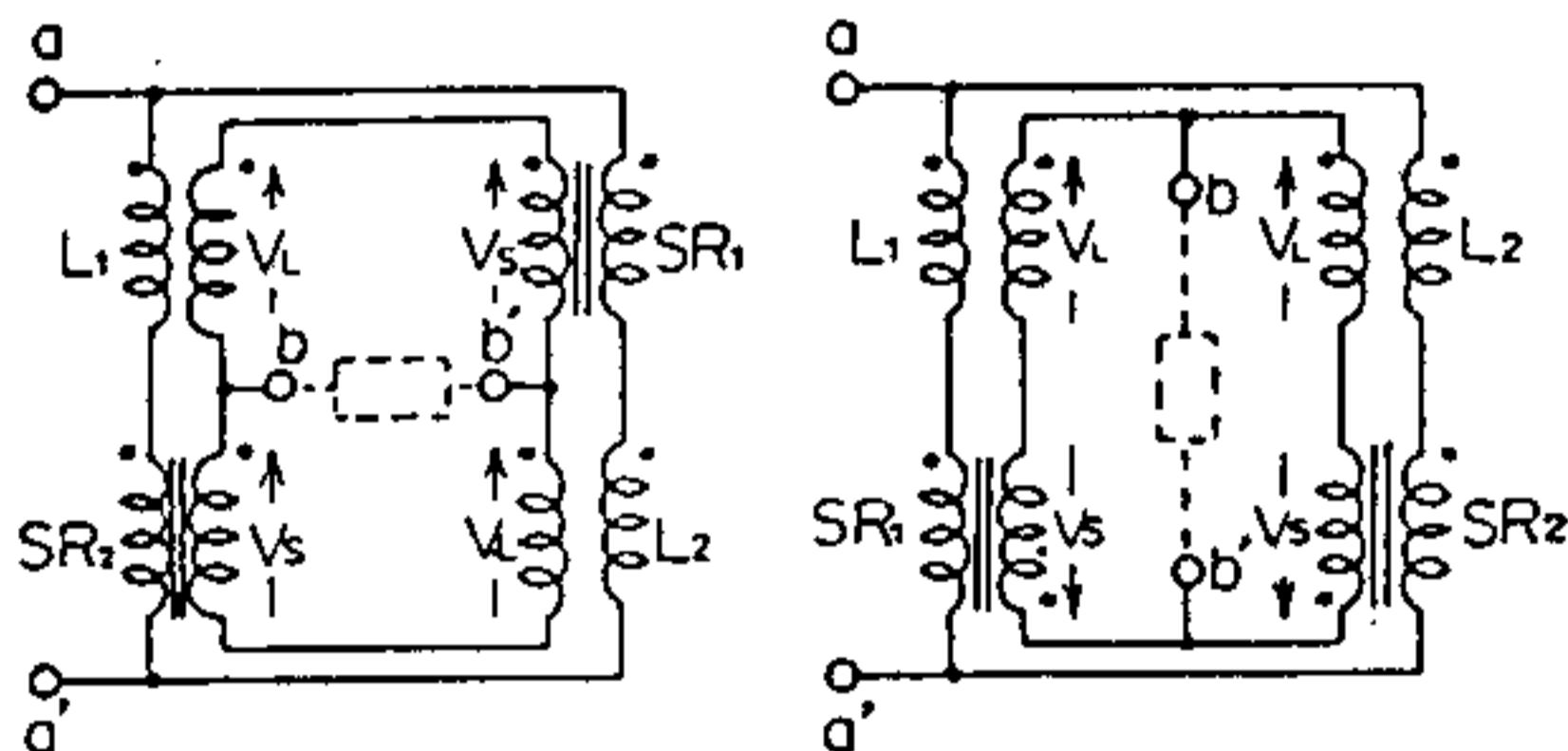


Fig.9 Transfigurations of the bridge-connected reactor circuit

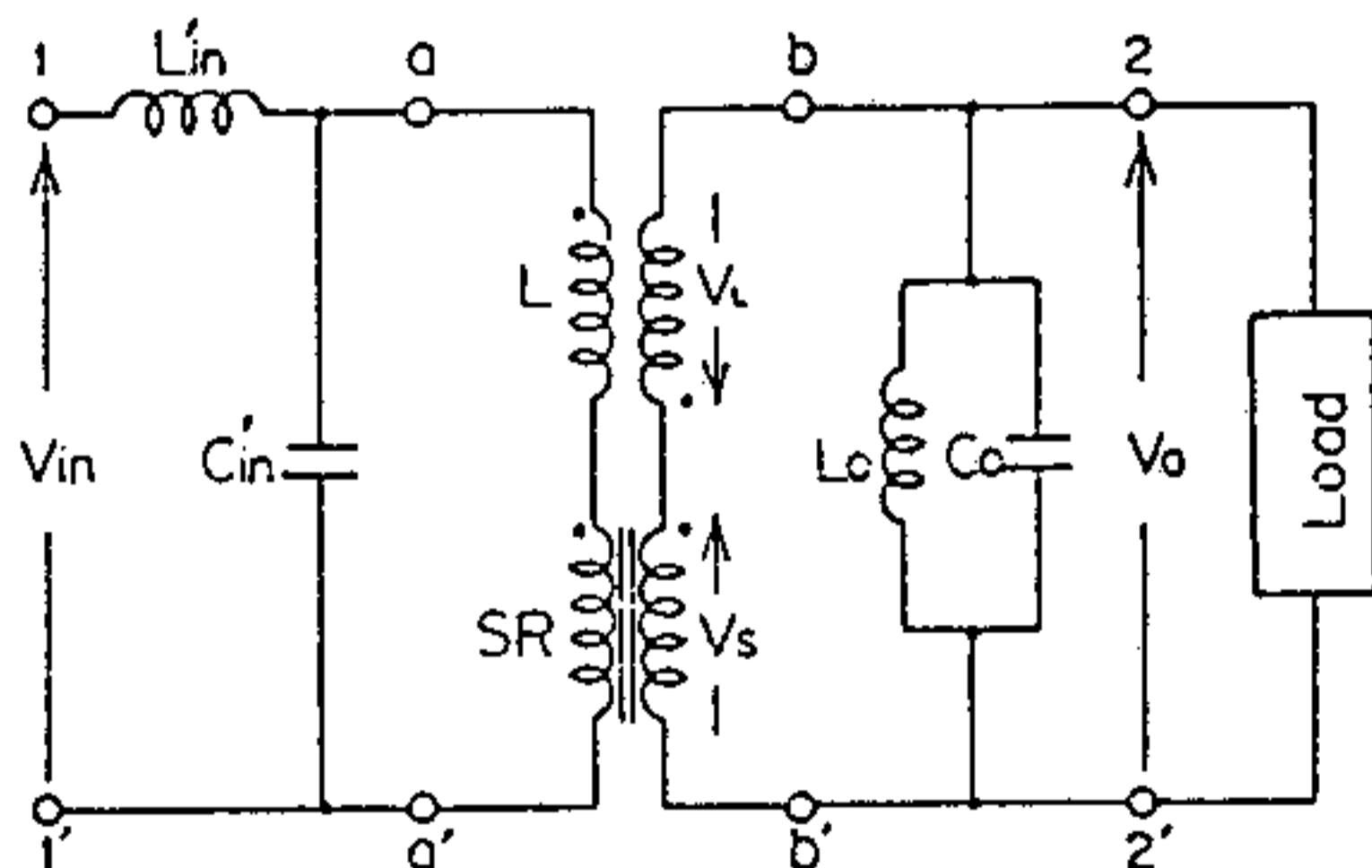


Fig.10 New tripler with a simple structure

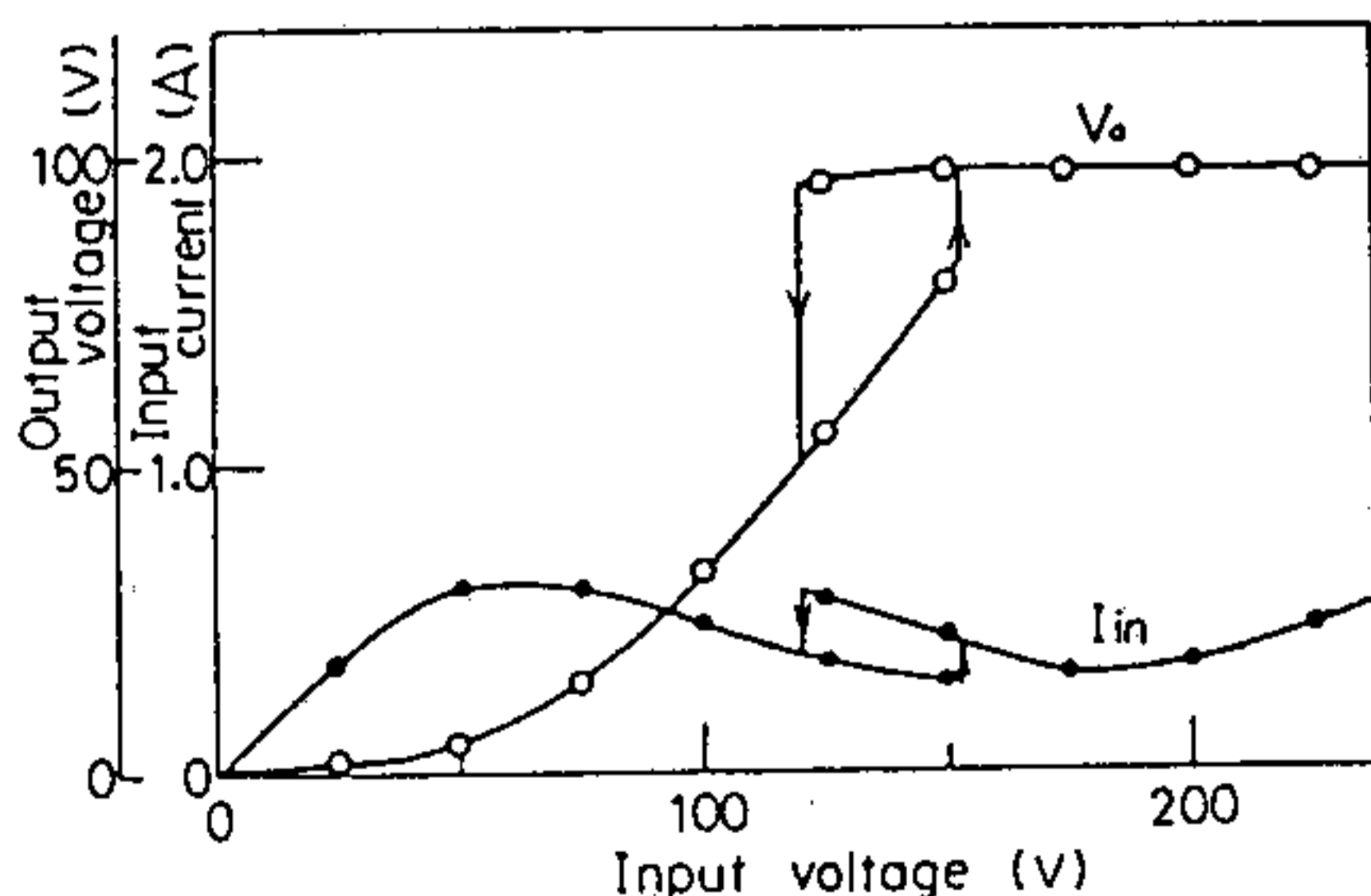


Fig.11 Voltage characteristics of the tripler shown in Fig.10

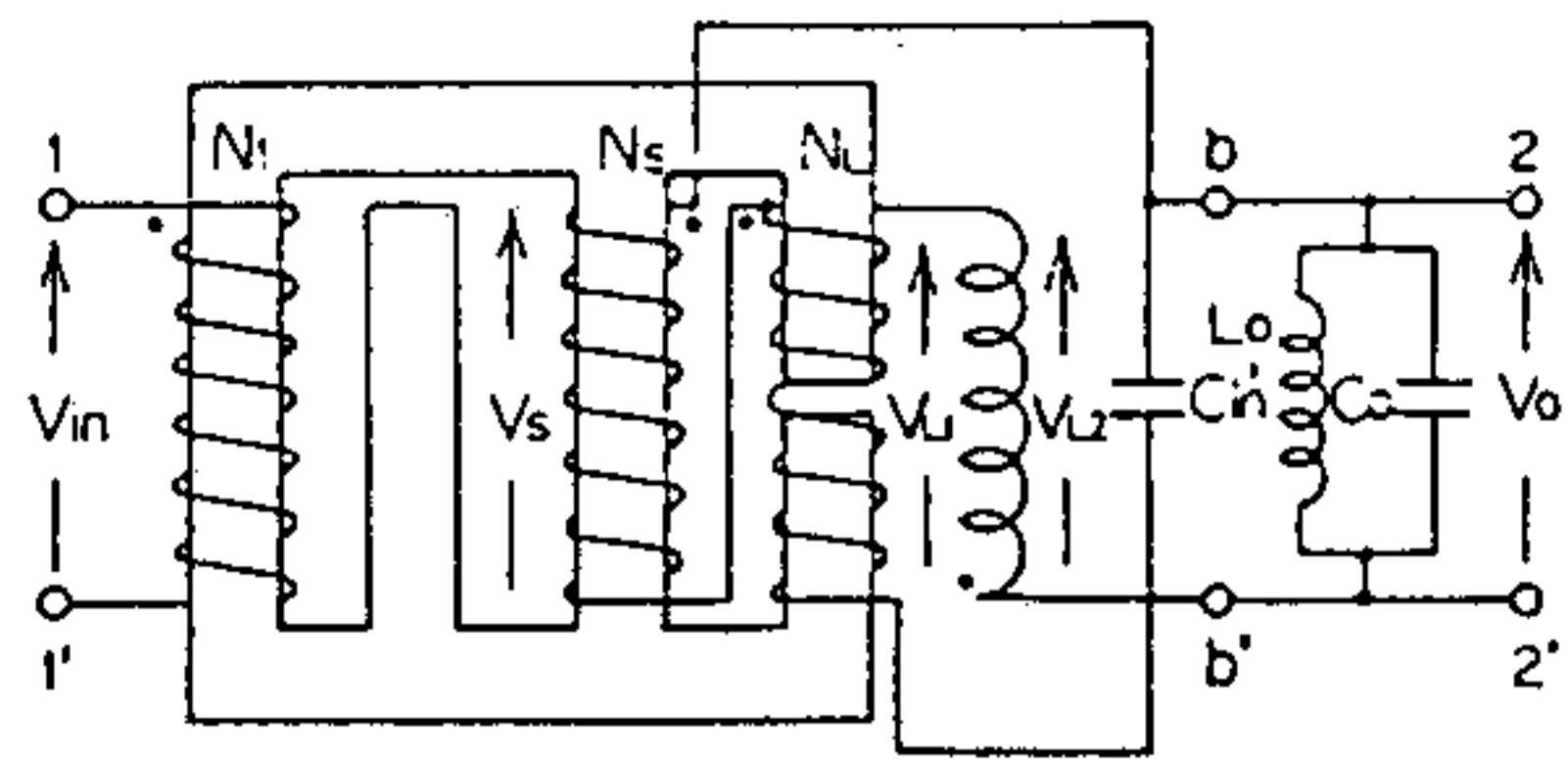


Fig.12 Tripler composed of fewer cores

as shown in Fig.10. In order to obtain the same output voltage, the linear reactor $L_{in'}$ and the capacitor $C_{in'}$ should be chosen as,

$$L_{in'} = 2L_{in}, \quad C_{in'} = C_{in} / 2 \quad \dots\dots(1)$$

As secondary windings are isolated from primary windings in this circuit, the arbitrary voltage can be obtained by changing a turn ratio. The voltage characteristics of the tripler are shown in Fig.11. It is the same as shown in Fig.6. The maximum load current is half of that obtained by the bridge circuit.

Some parts of the circuits shown in Fig.10 can be fabricated by single core. The single core type tripler is shown in Fig.12. Primary coils for a capacitor $C_{in'}$ and secondary coils are wound as is illustrated in Fig.12. This device is suitable for a small power tripler.

CONCLUSION

A new frequency tripler which is composed of a bridge-connected reactor circuit has been proposed and some experimental results and considerations are described in this paper. The salient results are summarized below.

- (1) As for a frequency, the bridge-connected reactor circuit operates as if the output is independent of the input.
- (2) The equivalent of a constant voltage circuit is shown at the input side. Consequently the power factor and the efficiency are remarkably improved. This is very suitable for a practical application.
- (3) As the ferro-resonance circuit is connected to the output terminals of the bridge circuit, good constant triple frequency voltage is obtained in both the load and voltage characteristics.
- (4) A single-phase source is used for the tripler. Therefore, as these circuits are connected in cascade, higher frequency voltage conversion is easily obtained.
- (5) A new tripler can be realized with various structures. These are composed of fewer cores and can be simplified.

In this paper, we assert that it is possible to obtain splendid characteristics in the new frequency tripler. Our investigation of the new tripler has been started recently, and further efforts are necessary.

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