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IMPROVEMENT OF CHARACTERISTICS AND APPLICATIONS OF THE MAGNETIC FREQUENCY TRIPLER WITH BRIDGE-CONNECTED REACTOR CIRCUIT

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ABSTRACT

This paper presents improvements and applications of magnetic frequency tripler which is composed of the bridge-connected reactor circuit reported in the previous papers. [1,2] Generally speaking, a frequency multiplier composed of nonlinear magnetic elements indicates the very difficult conversion operations as this tripler does. In such kind of problems, the numerical analysis of nonlinear equations will not be clarified the physical relations among several parameters. Sometimes it is difficult to solve the relations needed in the design.

Therefore, the experimental analysis of each parameter was done in this paper. As the result, quantitative relations between characteristics and circuit constants may be derived. It is possible to clarify the optimum circuit conditions. The new circuit composition with improved characteristics is obtained. Moreover, this paper indicates, as an example of applications, the nine times frequency multiplier composed of two bridge circuits connected in cascade.

INTRODUCTION

There are various kinds of magnetic frequency multipliers which are composed of reactors. The kinds of the multipliers consist of three-phase type and single-phase type. Three-phase type multiplier is divided into two types, i.e., harmonic type and rotating-m.m.f. type. Their principle is simple and it is suitable for high power so that many papers have been reported on this subject. [3~6] The single-phase type multiplier has already been reported. [7,8] This multiplier has essentially many excellent features as frequency multiplier compared to the three-phase type and they can be connected in cascade. But its operations are very complicated so that better characteristics have not been obtained in the single-phase type multiplier. Therefore, papers relevant to that subject have hardly been presented until now.

The tripler stated in this paper was derived from the bridge-core circuit and the bridge-connected reactor circuit. In principle its operation is not different from the single-phase type multiplier so far utilized. The uncertain operation may be clarified by the detailed experimental analysis. As a result, it is possible to improve the characteristics. The details will be discussed below.

IMPROVEMENTS OF CHARACTERISTICS

(a) Principle and fundamental circuit. The principle of this frequency tripler is to use the harmonic volt-

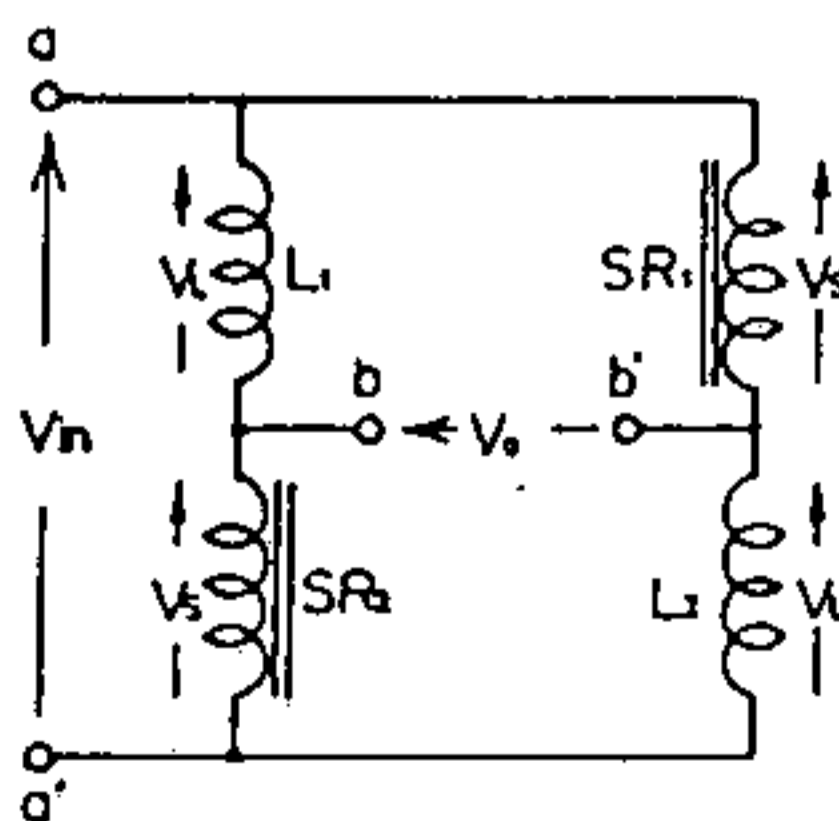


Fig.1. Bridge-connected reactor circuit where $L_1=L_2, SR_1=SR_2$

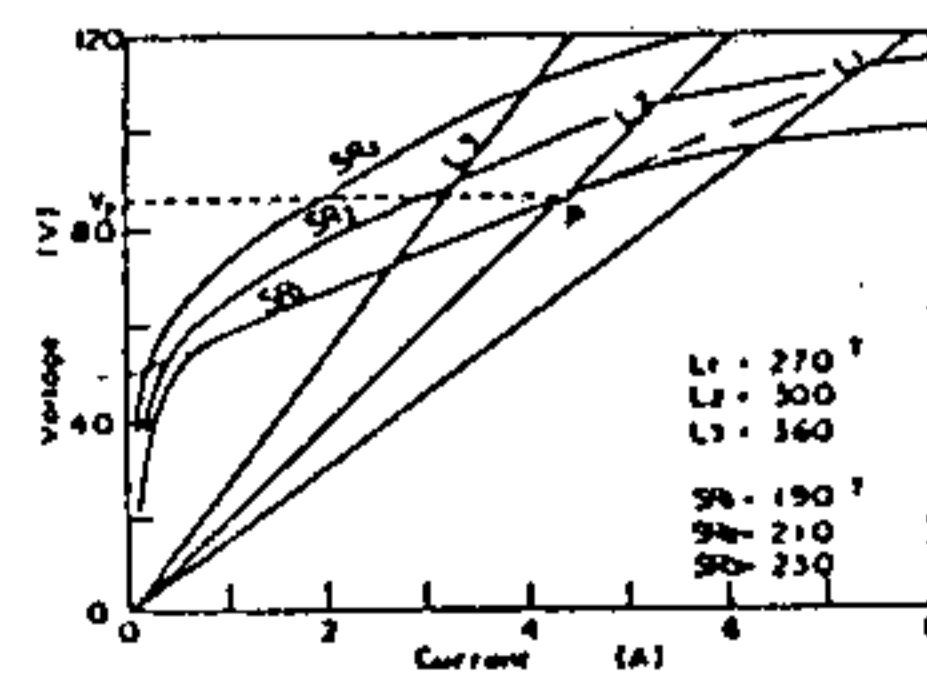


Fig.2 Volt-ampere characteristics of L and SR

ages which are induced in a bridge-connected reactor circuit as shown in Fig.1. The linear reactor (L) and nonlinear reactor (SR) which constitute a bridge circuit have the volt-ampere characteristics as shown in Fig.2. The application of alternating voltage across terminals a-a' produces the harmonic voltage across terminals b-b'. Figure 3 shows the characteristics of a bridge circuit (L_2 and SR_1) where the nonlinear reactor is approximated in a chain line. The solid lines indicate each harmonic voltage induced across output terminals under the open circuit condition. The dotted lines indicate each harmonic of short circuit current flowing through the output terminals under the short circuit condition. When the input voltage reaches $2V_p$ as shown in these figures 2 and 3, it is found that the fundamental frequency voltage disappears across the output terminals.

The fundamental circuit in Fig.4 is composed of bridge circuit and parallel ferro-resonance circuit. This parallel resonance circuit acts as a resonance circuit only for third harmonic voltage and acts as a low impedance circuit for fundamental frequency voltage.

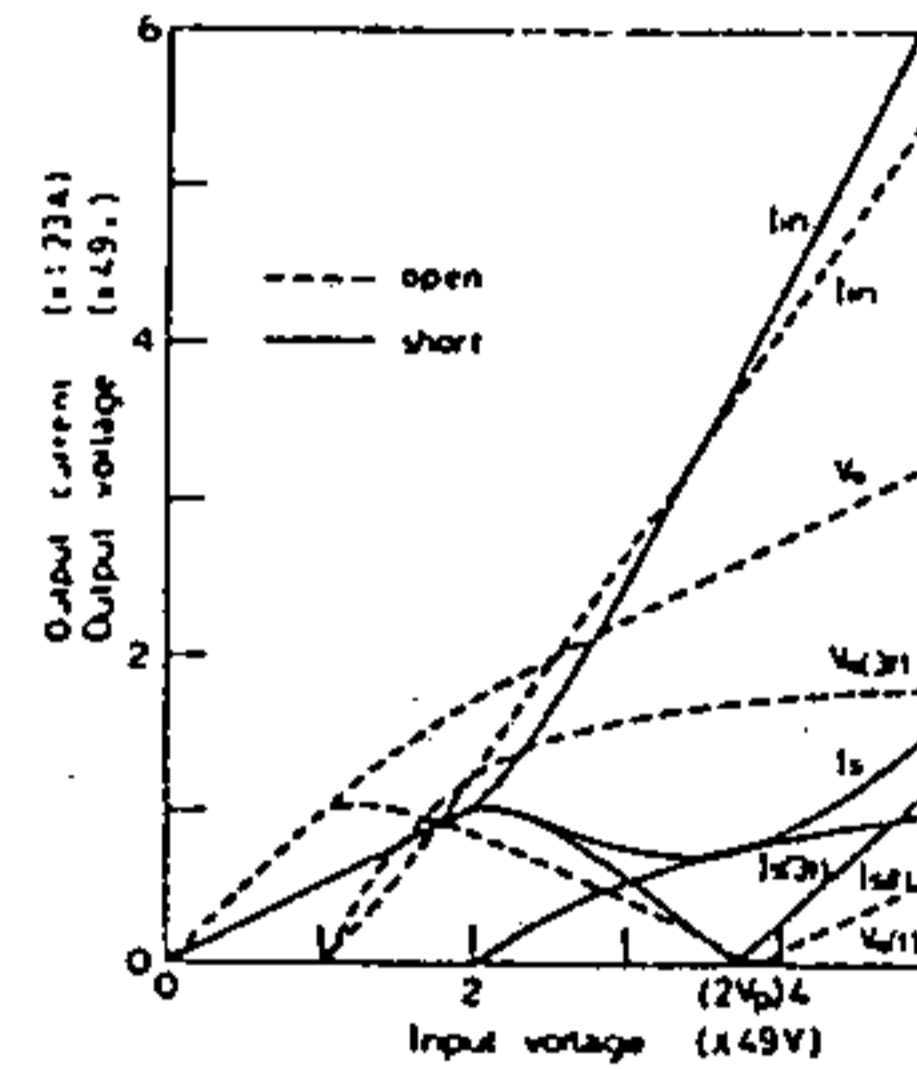


Fig.3 Characteristics of bridge circuit on open circuit and short circuit condition

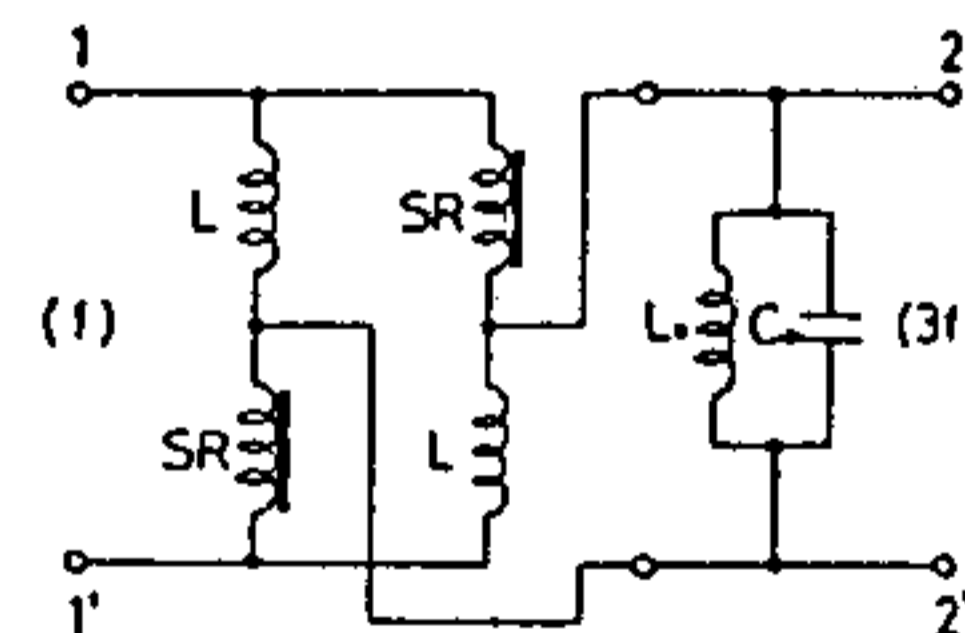


Fig.4 Fundamental circuit

(b) Relation between characteristics and circuit constants. Figure 5 shows the voltage characteristics for various parameters in the fundamental circuit. These figures allow quantitative relations between circuit constants and voltage characteristics to be clarified. Figures (a) and (b) show voltage characteristics for various reactances of linear reactor and saturation voltages of nonlinear reactor, respectively. It is known in Figs.(a) and (b) that an input voltage at the establishment of an output voltage (three times frequency voltage) depends on the saturation voltage of the nonlinear reactor. Figure (c) shows voltage characteristics for various values of capacitor (C_0) included in a parallel ferro-resonance circuit. As a value of the capacitor becomes high, an input voltage becomes high at the establishment of an output voltage

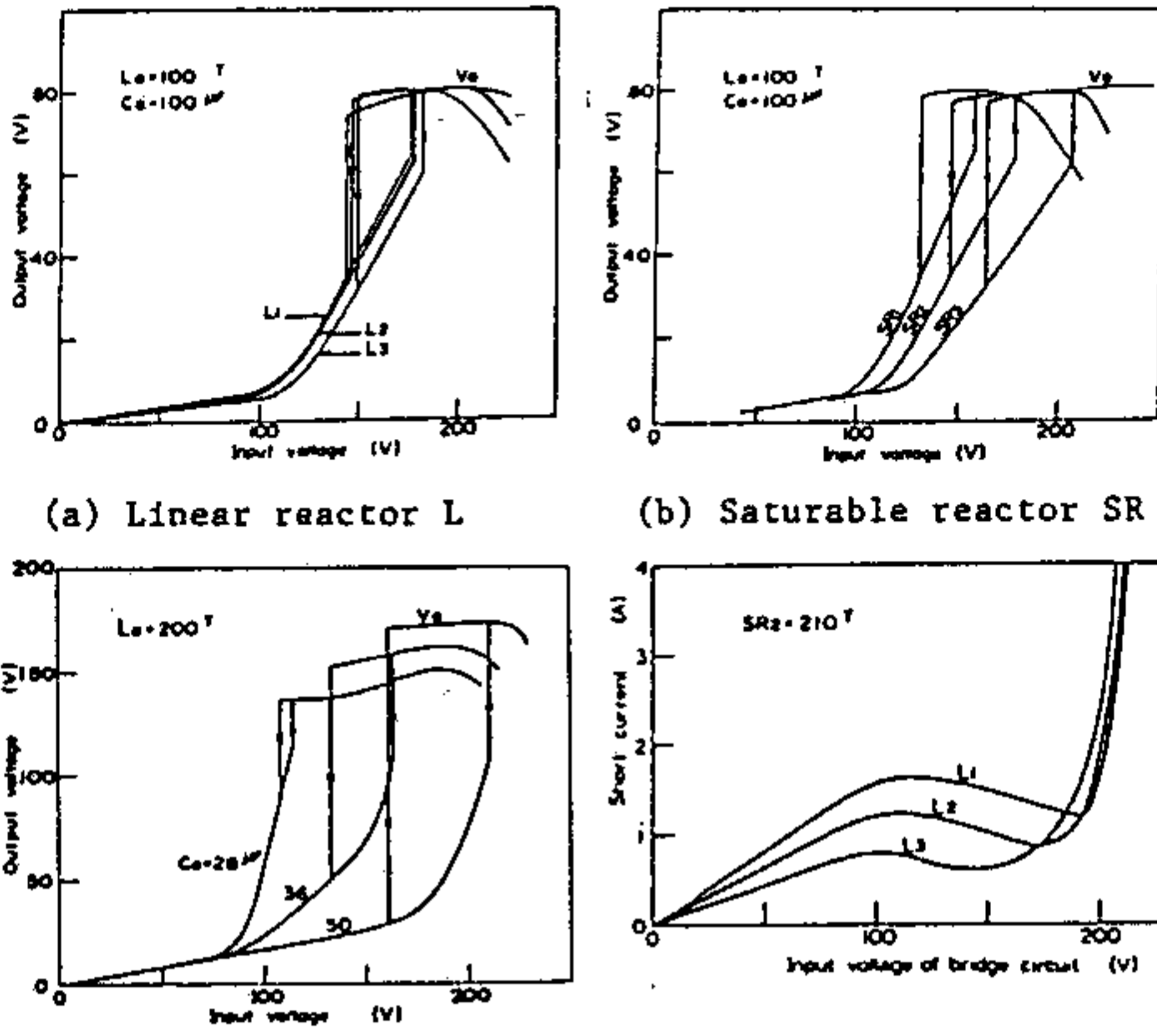


Fig. 5 Relation between characteristics and circuit constant

and then the loss increases. It is understood from the figure that the value of the capacitor may be limited. The characteristics mentioned above are some examples. Since the many relations are investigated in detail, the optimum circuit conditions can be obtained easily.

(c) Rated input voltage. Figure 6 shows the short circuit current (I_s) flowing through the output circuit for various values of the linear reactor (L). It is clear from the figure that the short circuit current has a minimum value in the bounds where an output voltage is established. The input voltage at the minimum short circuit current is equal to $2V_p$ (see, Figs. 2 and 3) and the short circuit current is the same in the load characteristics (see, Fig. 7). Therefore, as an input voltage becomes greater than $2V_p$, the drooping characteristics becomes poor and the loss increases rapidly.

Figure 7 shows the load characteristics for various input voltages. In order to obtain the better load characteristics and high power factor, an input voltage must be equal to $2V_p$ which is determined from the linear and nonlinear reactors. Thus, rated input voltage depends upon L and SR .

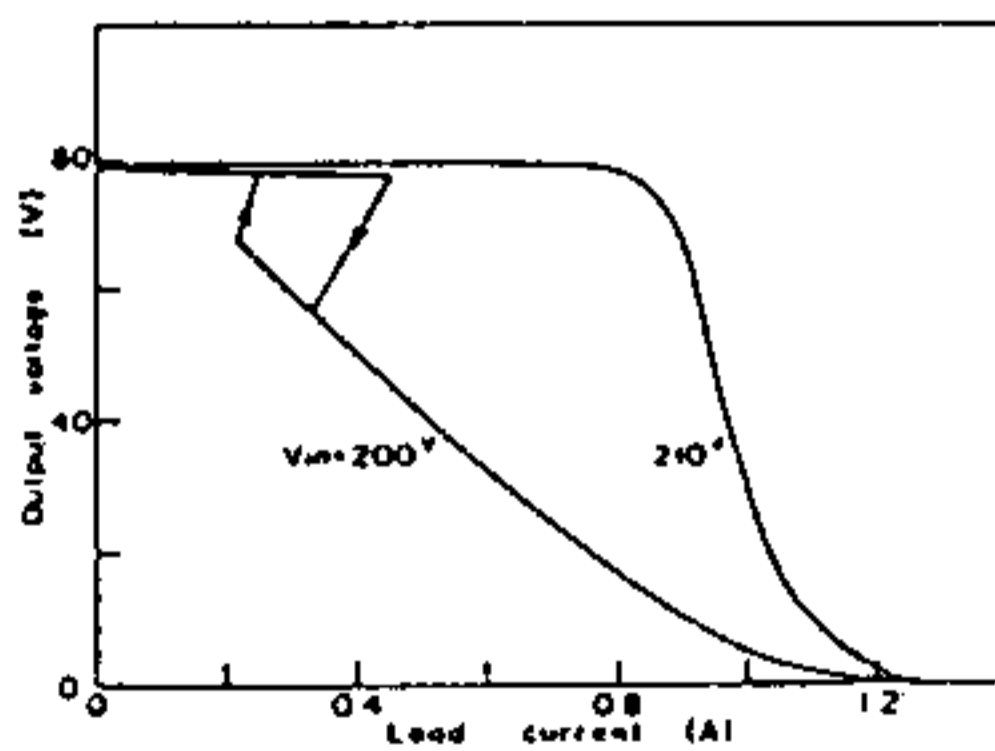
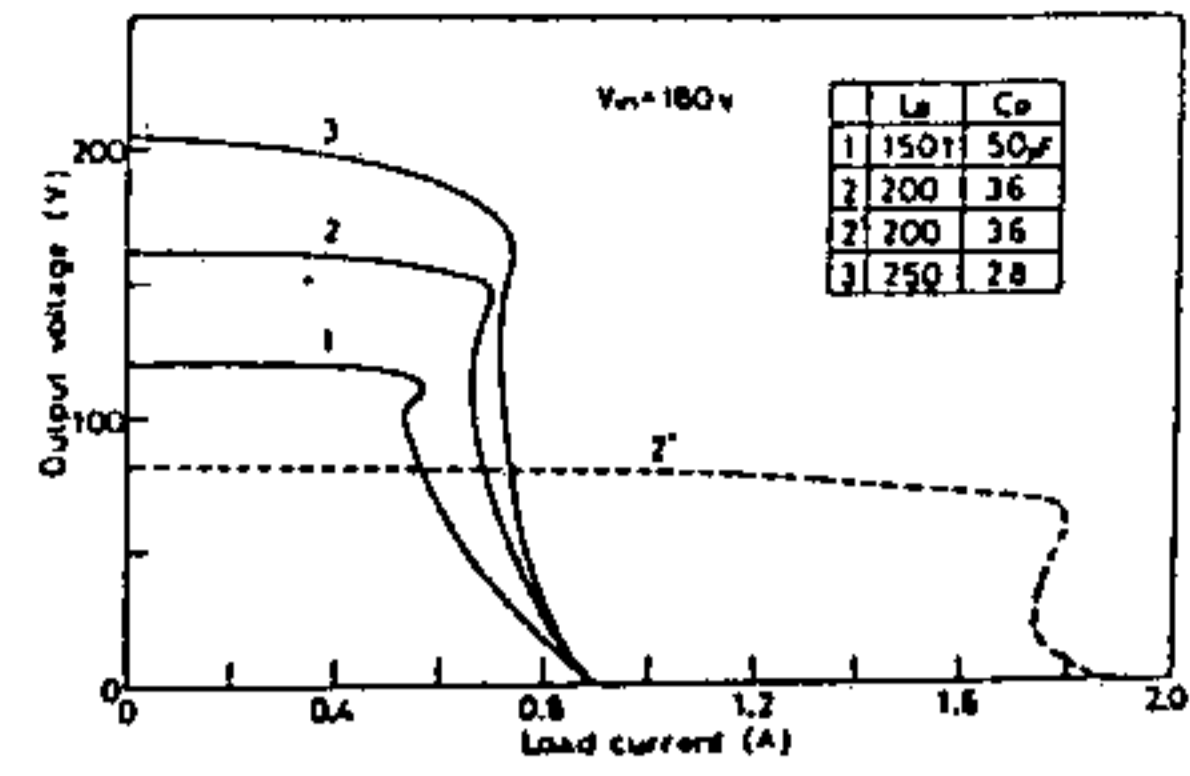
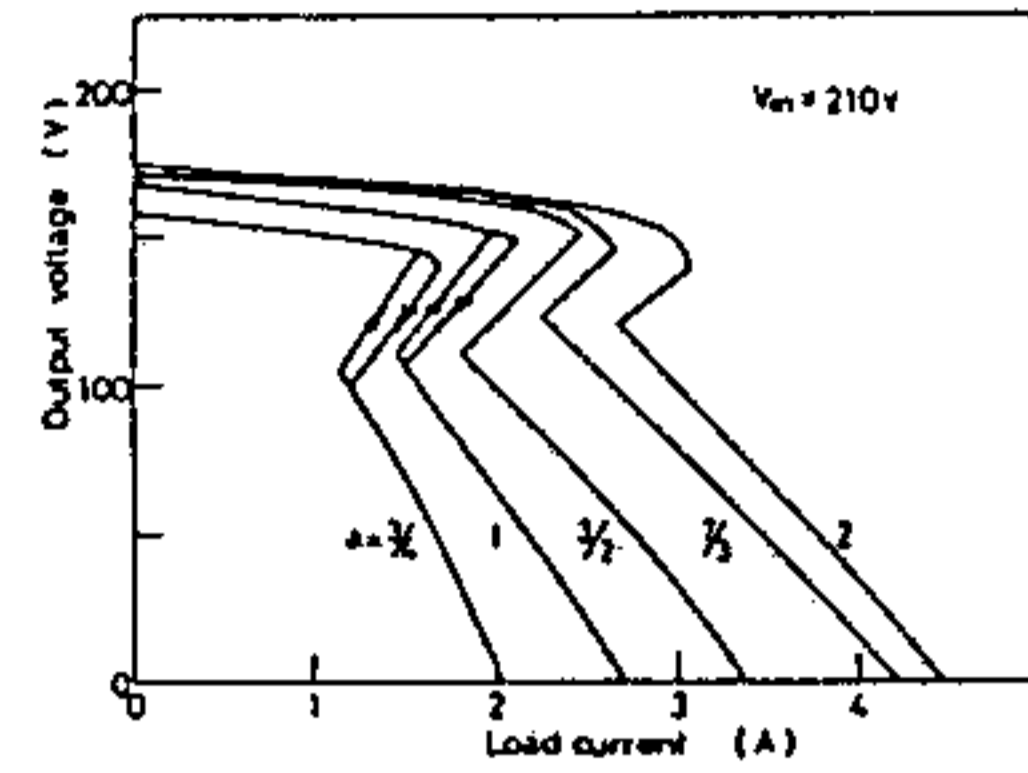


Fig. 7 Load characteristics at a suitable input voltage

(d) Impedance matching. The output voltage is determined from the resonance voltage of parallel ferro-resonance circuit. Figure 8(a) indicates the load characteristics for various saturation voltages of saturable reactor (L_0) included in the ferro-resonance circuit. It is understood from the figure that the application of a high resonance voltage increases the maximum power. However, as the resonance voltage becomes greater than the maximum voltage determined from the bridge circuit, the maximum power decreases and con-



(a) Resonance voltage



(b) Matching transformer
Fig. 8 Impedance matching

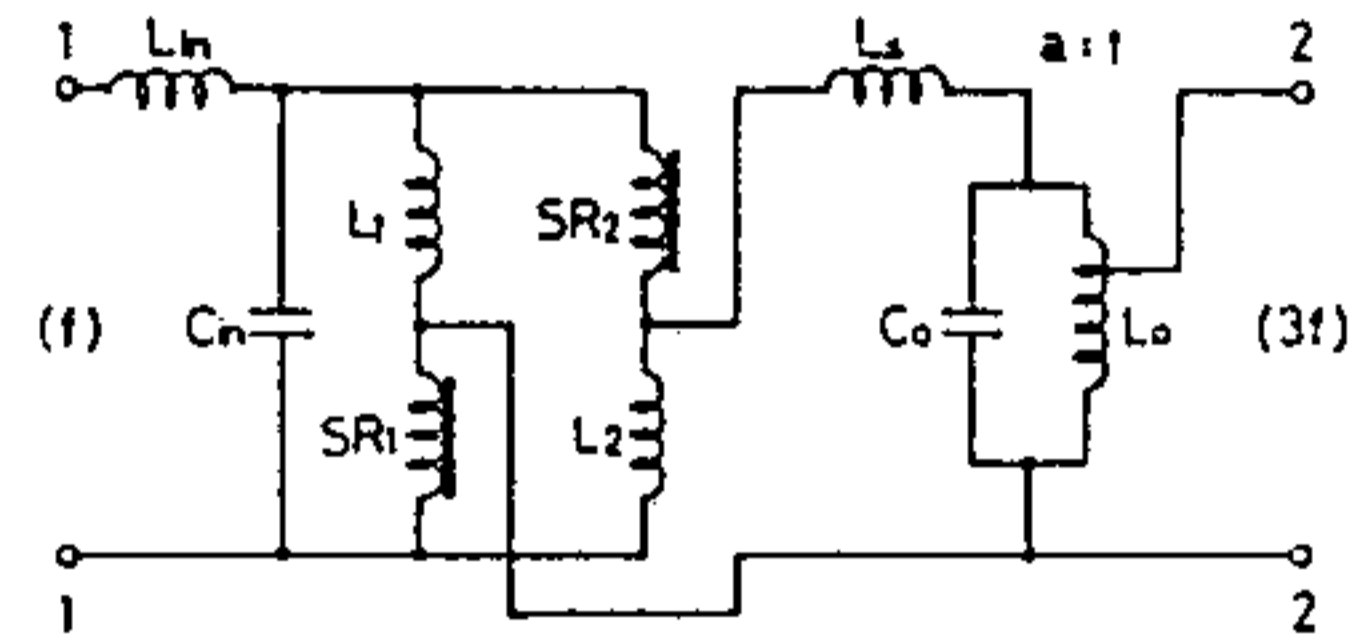
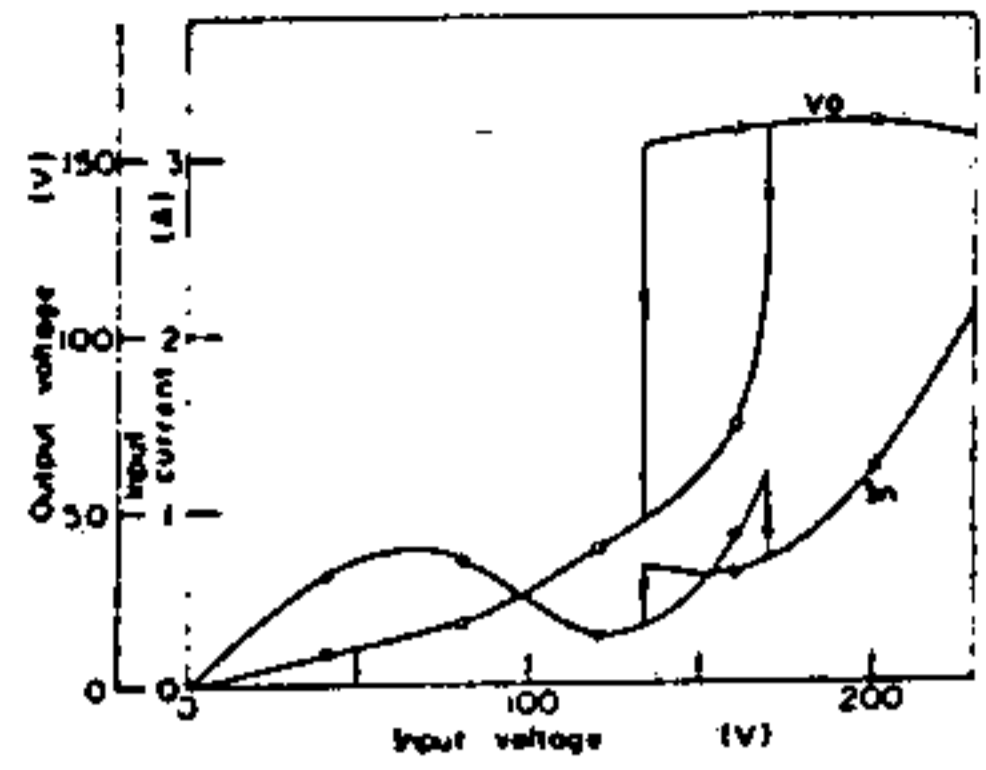


Fig. 9 Magnetic frequency tripler

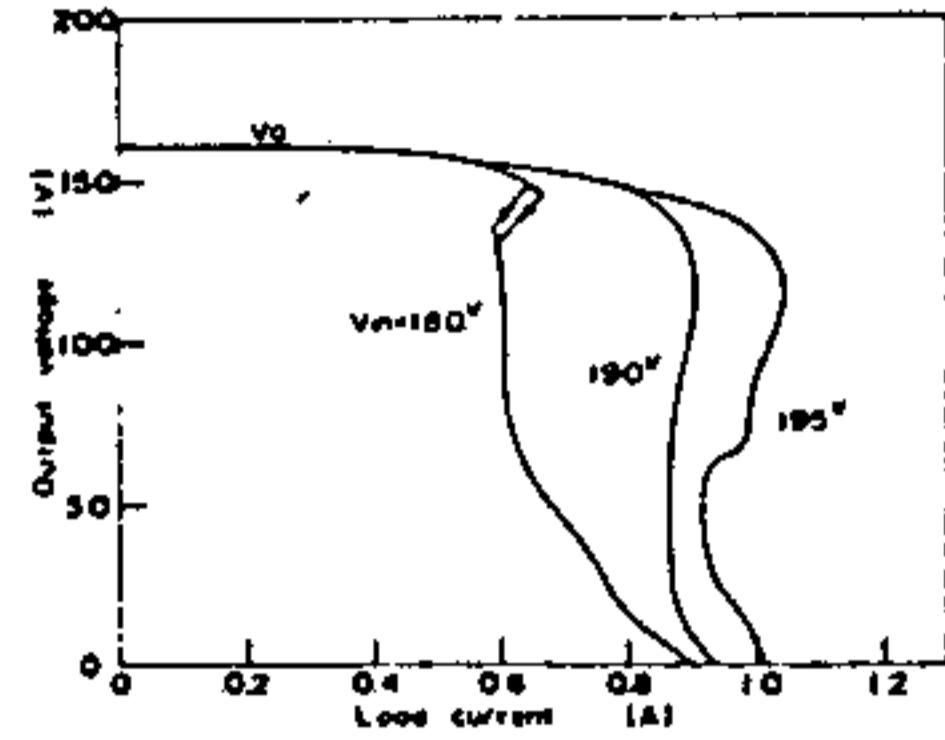
stant voltage characteristics become poor. Since the optimum resonance voltage depends on the bridge circuit, the output power decreases owing to the difference between the voltages depending on the bridge circuit and resonance circuit. Simultaneously the constant voltage characteristics become poor. Therefore, in order to obtain the suitable output voltage, taps must be prepared for saturable reactor in order to use as output terminals. (see, Fig. 9). The dotted line indicates the load characteristics measured at these terminals. Figure 8(b) shows the load characteristics for various turn ratios on the matching transformer (autotransformer) in Fig. 11. Thus, it is possible to learn the function of an impedance matching from Fig. 8.

(e) Stabilizing reactor. As mentioned above, the operation of frequency conversion in this tripler depends on the nonlinear reactor in the bridge circuit and the nonlinear reactor operates in deep saturation. Therefore, there arises a remarkable loss. In order to decrease the loss and to improve the efficiency of the tripler, it is necessary to use iron which has the rectangular hysteresis curve. The bridge circuit is composed of saturable reactors with rectangular hysteresis characteristic, so that the nonlinear oscillation occurs and the operation becomes unstable. Under this condition, the connection of a linear reactor to each saturable reactor helps the stabilization of its operation. In the practical circuit, one linear reactor may be connected in series with an output terminal of the bridge circuit as shown in Fig. 9. We term the linear reactor "stabilizing reactor".

(f) Other. In the practical circuit, the linear reactor (L_{in}) and capacitor (C_{in}) are connected with the input side of bridge circuit as shown in Fig. 9. In this circuit, the capacitor and the bridge circuit constitute a parallel ferro-resonance circuit. The ferro-



(a) Voltage characteristics



(b) Load characteristics

Fig.10 Characteristics of magnetic frequency tripler

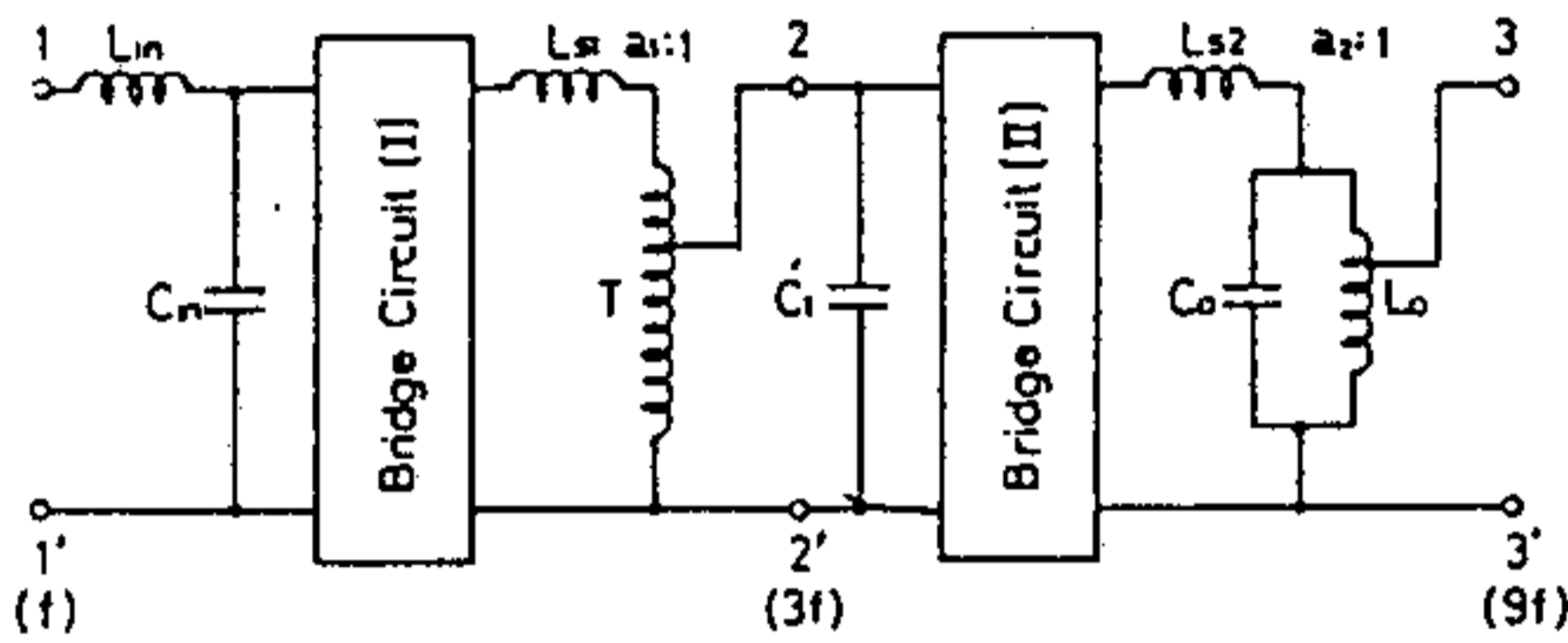


Fig.11 Nine times frequency multiplier

resonance circuit and the linear reactor (L_{in}) act as a constant voltage circuit in the input side. It results that the voltage across the input terminals of bridge circuit is constant and the power factor can be improved.

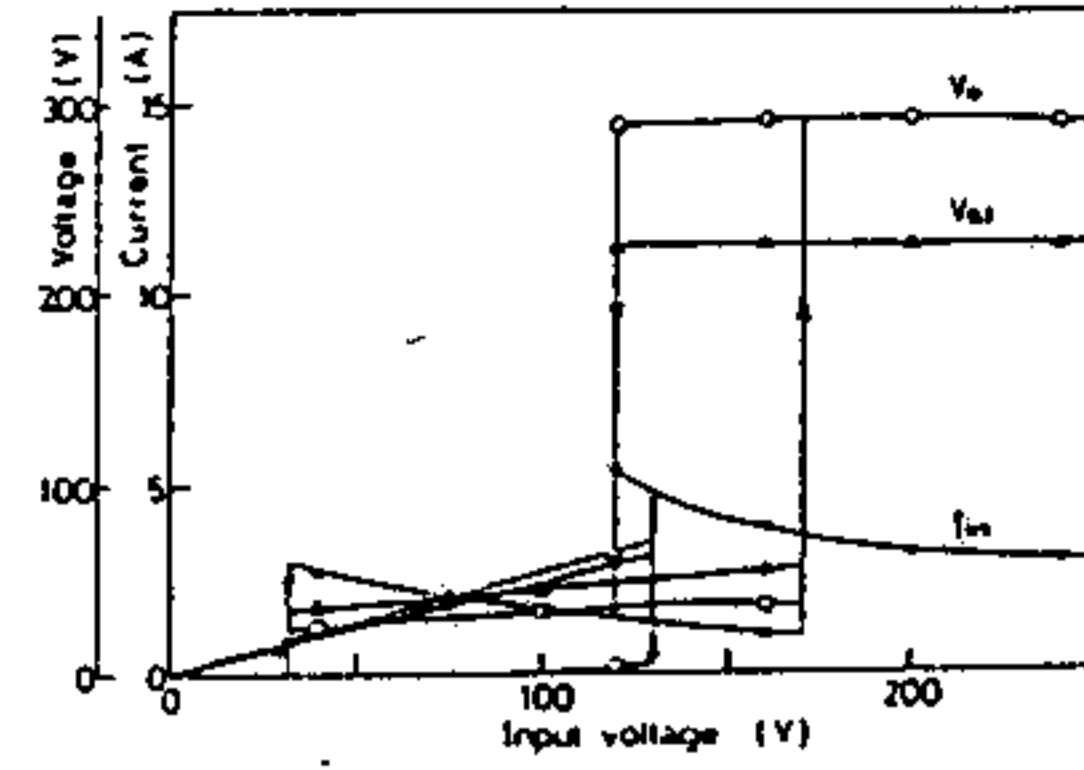
Figure 10 shows the conversion characteristics of the tripler in consideration of the relations as mentioned above. The maximum efficiency is 65 percent and the power factor is 0.7.

FREQUENCY MULTIPLIER BY CASCADE CONNECTION

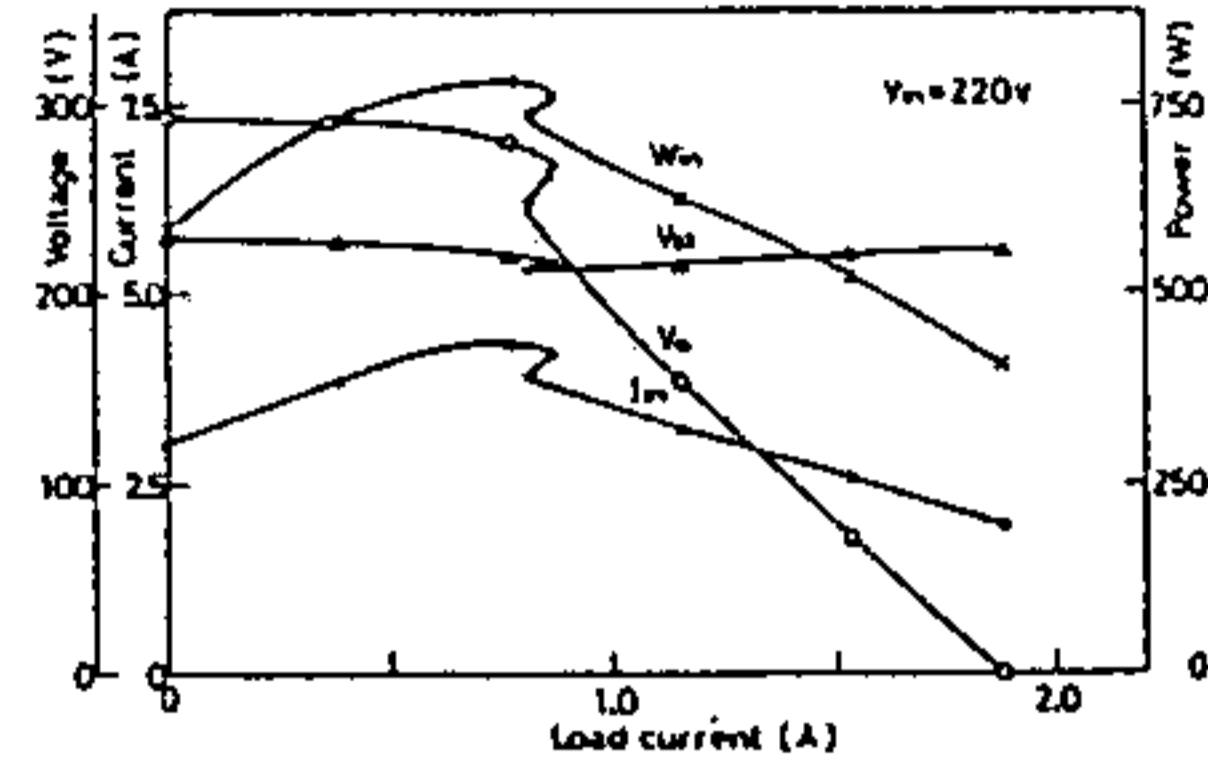
As one of the features of this tripler is to utilize a single-phase source, it is easy to obtain higher frequency voltage by connecting triplers in series. Figure 11 shows the nine times frequency multiplier which is composed of two bridge circuits connected in series. In this circuit, stabilizing reactor (L_{s1}), matching autotransformer (T) and capacitor (C_1) for the parallel resonance circuit are connected between two bridge circuits. The capacitor and the secondary bridge circuit constitute a parallel ferro-resonance circuit which operates in triple frequency. On the other hand, resonance reactor (L_o) in the output circuit works as an autotransformer under this condition and fulfills the impedance matching. Relations mentioned above are independent of the number of cascade connections. Figure 12 shows the conversion characteristics of the nine times frequency multiplier. Figure (c) shows waveforms of each voltage. The maximum efficiency is 30 percent and the power factor is 0.8.

CONCLUSION

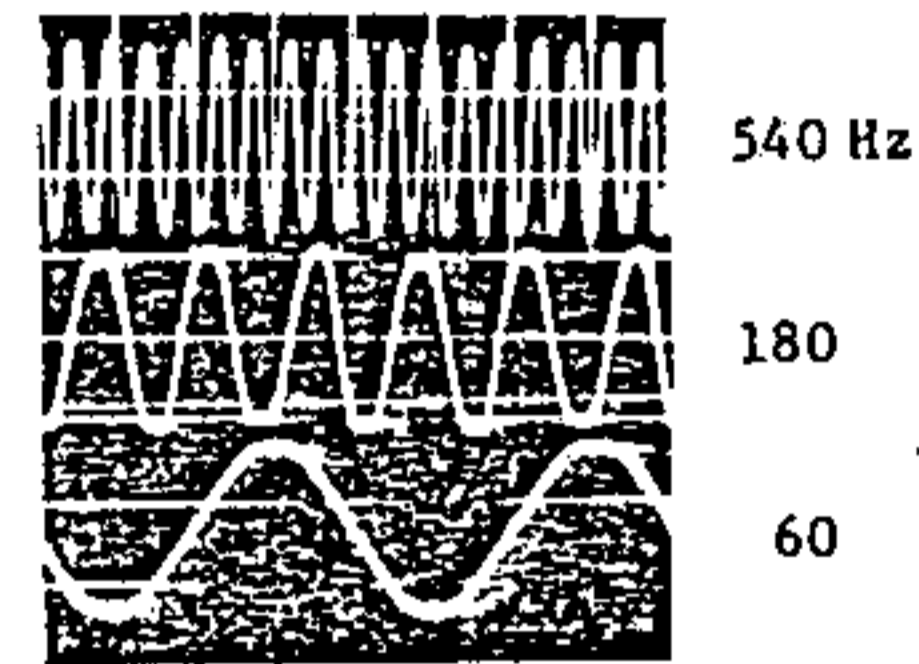
Characteristics of the tripler are remarkably improved under the optimum circuit condition as clarified in this paper and they are considered to be useful for a practical device. Higher frequency voltage is



(a) Voltage characteristics



(b) Load characteristics



(c) Waveforms

Fig.12 Characteristics of nine times frequency multiplier

easily obtained by the cascade connection. Moreover, since three triplers are connected with a three-phase source and each output voltage (three times frequency) has the same phase, the high power multiplier (single-phase output) can be constructed.

In future, the more accurate analysis will be performed by making use of the numerical analysis together with a design method to be established.

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