Improvement of characteristics and applications of the magnetic frequency tripler with bridge-connected reactor circuit

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) <u>Principle and fundamental circuit.</u>   The principle of this frequency tripler is to use the harmonic volt-
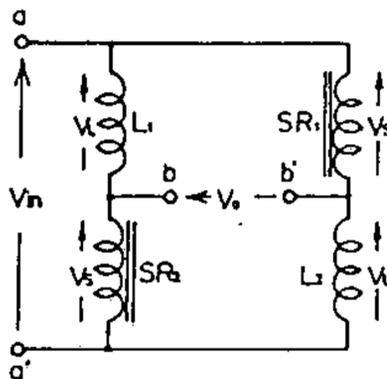

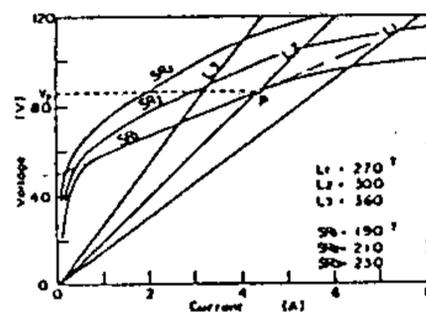Fig.1. Bridge-connected reactor circuit where $L_1 = L_2$, $SR_1 = SR_2$

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.
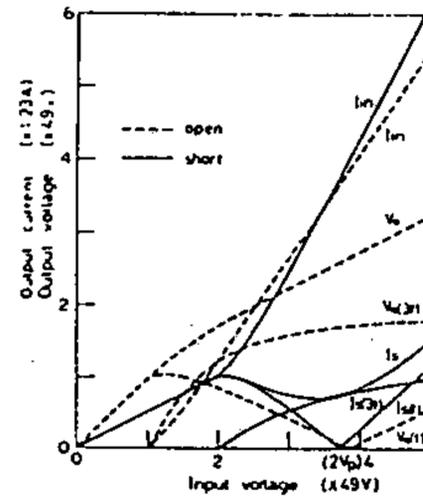

Fig.3 Characteristics of bridge circuit on open circuit and short circuit condition
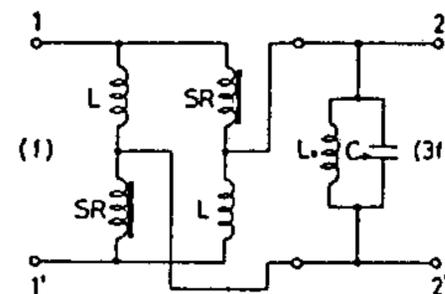

Fig.4 Fundamental circuit

(b) <u>Relation between characteristics and circuit constants.</u>   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 (Co) 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
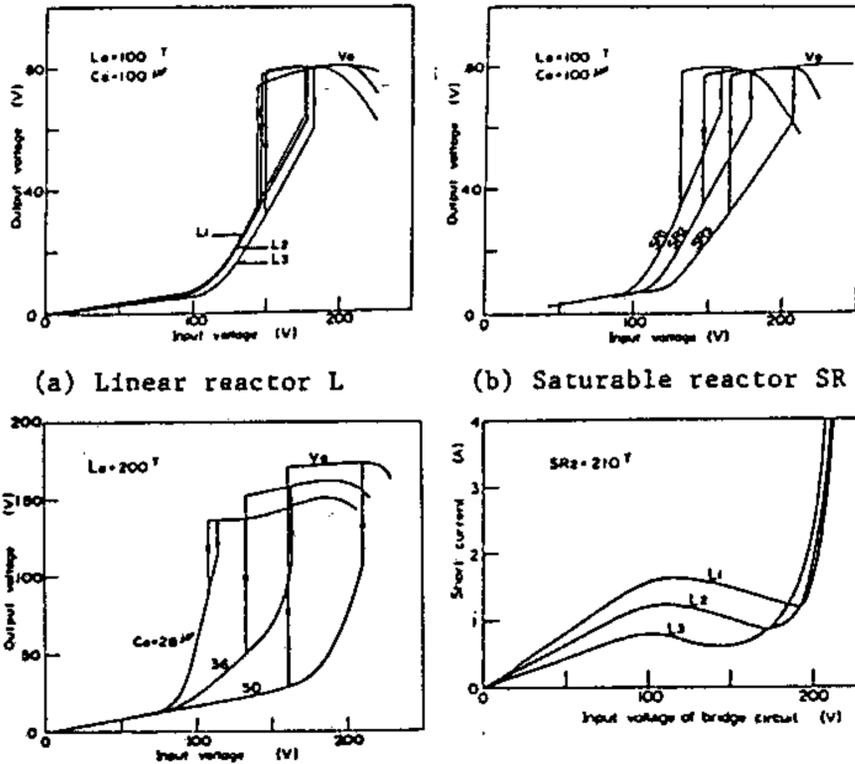
(a) Linear reactor L   (b) Saturable reactor SR

(c) Resonance capacitor Co
Fig.5 Relation between charac-
teristics and circuit
constant

Fig.6 Short current of
bridge circuit

(a) Resonance voltage

(b) Matching transformer
Fig.8 Impedance matching

Fig.9 Magnetic frequency tripler

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 (Is) 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 volt-
age is established. The input voltage at the minimum
short circuit current is equal to 2Vp (see, Figs.2 and
3) and the short circuit current is the same in the
load characteristics (see, Fig.7). Therefore, as an in-
put voltage becomes greater than 2Vp, the drooping
characteristics becomes poor and the loss increases
rapidly.

Figure 7 shows the load characteristics for vari-
ous input voltages. In order to obtain the better load
characteristics and high power factor, an input volt-
age must be equal to 2Vp which is determined from the
linear and nonlinear reactors. Thus, rated input volt-
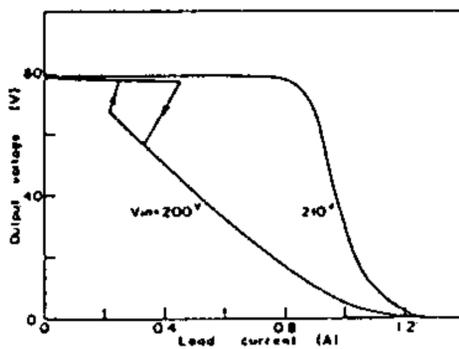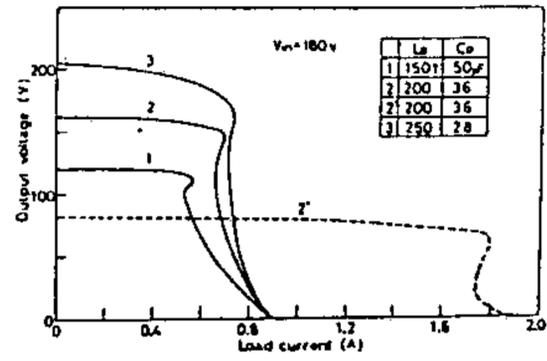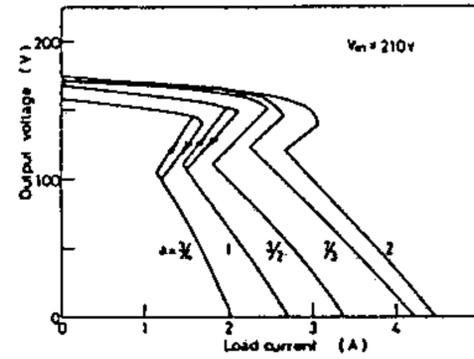age depends upon L and SR.

Fig.7 Load characteristics at a suitable input voltage

(d) Impedance matching.   The output voltage is deter-
mined from the resonance voltage of parallel ferro-
resonance circuit. Figure 8(a) indicates the load char-
acteristics for various saturation voltages of satu-
rable reactor (Lo) included in the ferro-resonance cir-
cuit. It is understood from the figure that the appli-
cation of a high resonance voltage increases the max-
imum power. However, as the resonance voltage becomes
greater than the maximum voltage determined from the
bridge circuit, the maximum power decreases and con-
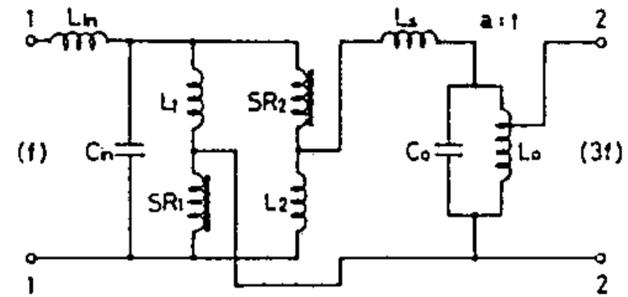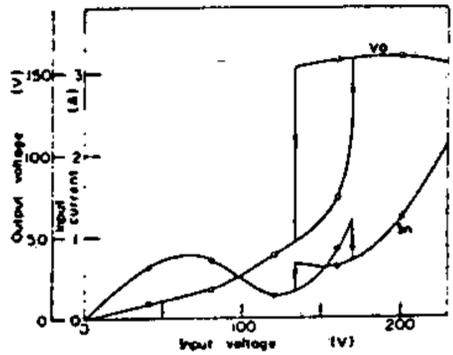
stant voltage characteristics become poor. Since the
optimum resonance voltage depends on the bridge circuit,
the output power decreases owing to the difference
between the voltages depending on the bridge circuit and
resonance circuit. Simultaneously the constant voltage
characteristics become poor. Therefore, in order to
obtain the suitable output voltage, taps must be pre-
pared for saturable reactor in order to use as output
terminals.(see, Fig.9). The dotted line indicates the
load characteristics measured at these terminals. Fig-
ure 8(b) shows the load characteristics for various
turn ratios on the matching transformer (autotrans-
former) 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 op-
eration of frequency conversion in this tripler depends
on the nonlinear reactor in the bridge circuit and the
nonlinear reactor operates in deep saturation. There-
fore, there arises a remarkable loss. In order to de-
crease 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 hyster-
esis 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 oper-
ation. 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 re-
actor (Lin) and capacitor (Cin) are connected with the
input side of bridge circuit as shown in Fig.9. In this
circuit, the capacitor and the bridge circuit consti-
tute a parallel ferro-resonance circuit. The ferro-

(a) Voltage characteristics
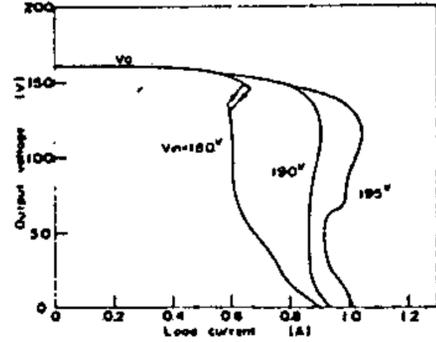
(b) Load characteristics
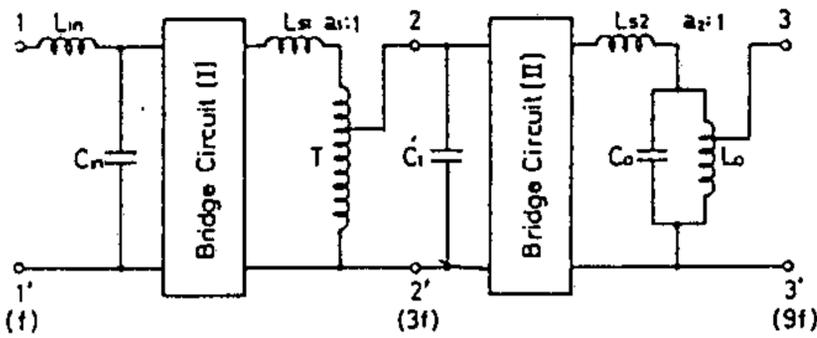Fig.10 Characteristics of magnetic frequency tripler

(a) Voltage characteristics

(b) Load characteristics

540 Hz

180

60

(c) Waveforms
Fig.12 Characteristics of nine times
frequency multiplier

Fig.11 Nine times frequency multiplier

resonance circuit and the linear reactor (Lin) 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.
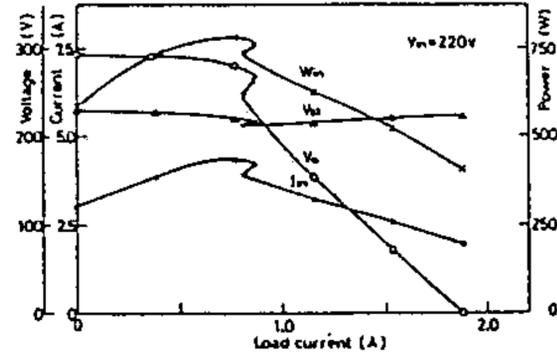
FREQUENCY MULTIPLIER BY CASCADE CONNECTION

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 (Ls1) , matching autotransformer (T) and capacitor (C1) 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 (Lo) 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. Figgure 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.
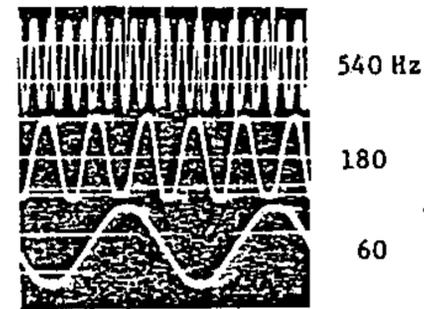
CONCLUSION

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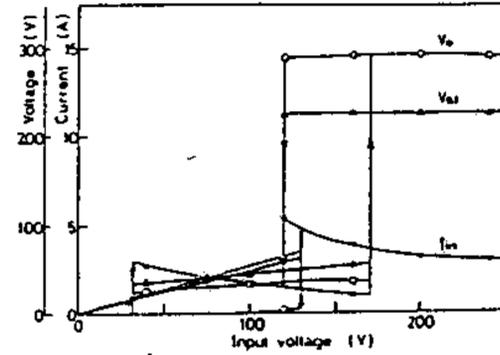
easily obtained by the cascade connection. Moreover, since three triplers are connected with a three-phase source and each output voltage (three times frequency) has the same phase, the high power multiplier (single-phase output) can be constructed.

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

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