V International Scientific and Technical Conference Actual Issues of Power Supply Systems

Frequency Tripler with Output Voltage Stabilizer

AIPCP25-CF-ICAIPSS2025-00477 | Article

Frequency Tripler with Output Voltage Stabilizer

Nuritdin Khalilov[1], Doston Sheraliev[2, a)], Sobir Eshmuradov[2], Bozorqul Abdulazizov[2], Yusup Hamidov[2], Abbosjon Xoliyorov[2]

[1]*Tashkent state technical university named after Islam Karimov, Tashkent, Uzbekistan*
[2] *Termez State University of Engineering and Agrotechnologies, Termez, Uzbekistan*

[a)] *Corresponding author: sheraliyevdostonbek899@gmail.com*

Abstract. This article presents the results of experimental studies of a frequency tripler based on the excitation and maintenance of autoparametric oscillations with phase splitting and output voltage stabilization.

INTRODUCTION

Ferromagnetic frequency multipliers, which in the general case consist of a nonlinear inductive element and a capacitor, have recently found wide and diverse application. These frequency multipliers are significantly more reliable than electromechanical or other types of multipliers and exhibit a good waveform of the output voltage, close to a sinusoidal shape, as well as a stiff external characteristic. A disadvantage of ferromagnetic frequency multipliers in comparison with semiconductor ones is the impossibility of smooth variation of the output frequency. Therefore, they are not suitable for continuous control, for example, of electric motor speed. However, in applications where a constant output frequency is required, ferromagnetic multipliers usually surpass modern semiconductor multipliers in a number of performance indicators. As is well known, frequency multiplication becomes possible when the magnetic flux density reaches values located on the nonlinear regions of the magnetization curve. The required degree of core saturation depends on the frequency multiplication factor and increases with increasing multiplication order. In ferromagnetic frequency multipliers, frequency multiplication is based on the superposition of electrical sinusoidal oscillations at the supply frequency f , which may originate from a transformer or a choke with saturated cores . As is known, the magnetization curve of magnetic flux density in iron cores has a characteristic trapezoidal shape, and it can be expanded into a series containing odd harmonics [1,2].

$$B_1(t) = B_{1m} \, Cos\, \omega t - B_{3m} \, Cos\, 3\omega t - B_{5m} \, Cos\, 5\omega t + \ldots.. \tag{1}$$

In this case, the magnetic field strength curve exhibits a characteristic peaked (spike-shaped) waveform and cannot be expanded into a series containing only odd harmonics. Frequency multipliers that operate with an even multiplication factor require polarization of the cores by a DC magnetic field. This polarization is achieved by means of special DC bias windings, a permanent magnet, or by utilizing the self-polarization effect, i.e., the excitation of a DC magnetic field in ferromagnetic media when oscillations of a single frequency are superimposed, whose magnitudes are related by a frequency ratio of /5/. The necessity of core polarization in even-order frequency multipliers is explained by the fact that, in the harmonic series of the input oscillation, the waveforms in two successive half-periods must be unequal. Otherwise, the even harmonic components do not appear. Consequently, the magnetic field strength $H(t)$can be expanded into a series containing both even and odd harmonics:

$$H(t) = H_{1m} \, Cos\, \omega t + H_{2m} \, Cos\, 2\omega t + H_{3m} \, Cos\, 3\omega t \tag{2}$$

Ferromagnetic saturated elements of frequency multipliers serve not only to excite oscillations at an increased frequency, but also represent the only elements of the multipliers that convert the energy of oscillations at the input frequency into the energy of oscillations at the output frequency. All other elements of the multiplier are linear components and do not participate in the energy conversion process. In the nonlinear element, the average power $P_p$is nonzero and depends on the amplitudes of the other harmonic components. In order to obtain a clear representation of the distribution of currents and voltages of a given frequency in individual branches of the multiplier, each element of the multiplier should be replaced by a single sinusoidal electromotive force (EMF) of the corresponding frequency, with the output short-circuited. An m-times frequency multiplier ($m > 1$) represents a system in which the oscillations of the supply network frequency are transformed, through frequency multiplication, into oscillations of an m-fold frequency. As is well known, the excitation of autoparametric oscillations of the output voltage in ferromagnetic frequency multipliers is achieved either by the parametric method [2] or by the compensation method [3].

With this method, it becomes possible in practice to almost completely eliminate fluctuations of the output voltage caused by variations of only a single parameter, such as the amplitude of the input voltage, load fluctuations, supply frequency variations, and other factors. In the parametric stabilization method, the objective is to stabilize the input voltage of the frequency multiplier, since this leads to stabilization not only of the output voltage, but also of the electromagnetic operating conditions within the multiplier. In addition, ballast linear reactors connected in series with the frequency tripler have also been used for stabilizing the output voltage. This method of stabilization is widely applied in various types of frequency multipliers.

Its disadvantage is that the external characteristics of such a frequency multiplier become softer than in the absence of reactors. In recent years, the compensation method has also been applied for stabilizing the output voltage of frequency multipliers [3].

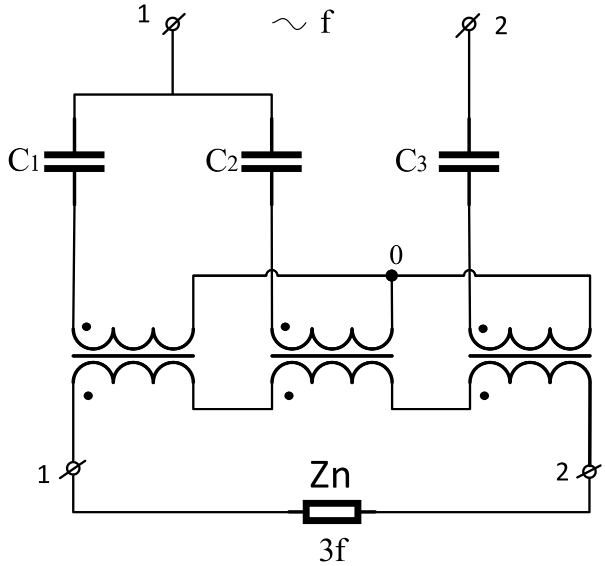

FIGURE 1. whose primary windings are connected in a star (Y) conFigureuration through intermediate capacitors C_1, C_2, C_3

Unlike existing designs, the frequency tripler considered in this chapter provides a stabilized output voltage when operating with various types of loads, namely resistive, resistive–inductive, and resistive–inductive–capacitive loads. The proposed circuit of a ferroresonant stabilizer with an m-fold frequency (m=3) consists of three nonlinear saturation reactors, whose primary windings are connected in a star (Y) conFigureuration through intermediate capacitors C_1, C_2, C_3(Figure. 1). Their secondary windings are connected in phase and in series, forming the output circuit of the frequency tripler. At a certain input voltage and for specific values of the capacitances, autoparametric oscillations are excited in the circuit at the supply frequency. The extraction of oscillations at the multiplied frequency is based on the fact that the initial single-phase voltage is first converted into a three-phase system of nonsinusoidal voltages or currents, which form a zero-sequence system, being in phase with each other [4].

When all nonsinusoidal voltages or currents are combined, the oscillations with frequencies that are multiples of three form a positive sequence, being in phase. During the summation of all nonsinusoidal voltages or currents of the phase system, the harmonic components that are not multiples of three mutually cancel, whereas those that are multiples of three and generated by the frequency tripler remain.

The summation of voltages at the $3f$ frequency takes place at the junction point of the secondary windings, which are connected in an open-delta conFigureuration. The load is connected between the free terminals of the delta, denoted as [5,6].

The voltage at terminals [5,6] i.e., at the tripled frequency, remains stable under variations of the input voltage and load.

EXPERIMENTAL RESEARCH

Stabilization in the considered frequency tripler is achieved through the excitation of autoparametric oscillations (APO), whereby the ratio of the stored energy to the oscillation frequency, $E/\nu =$ const, remains constant. In the region of excitation of ferroresonant oscillations, the process within the frequency tripler is governed by the energy accumulated in the system. Under such operating conditions, variations of the output voltage caused by changes in the amplitude of the input signal are practically eliminated [7,8].

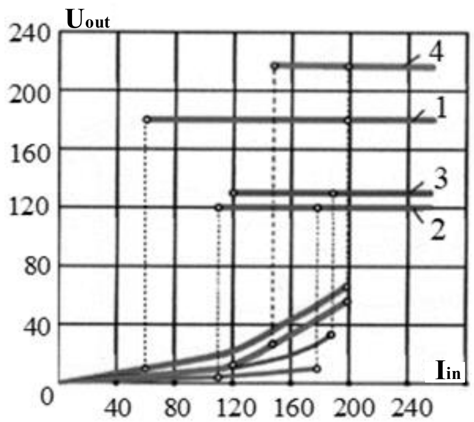

FIGURE 2. When the input voltage was varied from 140 V to 222 V, the output voltage remained constant at 123 V.

The same Figureure also shows the dependence $U_{\text{out}} = f(U_{\text{in}})$under no-load conditions and for nonsinusoidal load conditions (curve 2, 3, and 4).

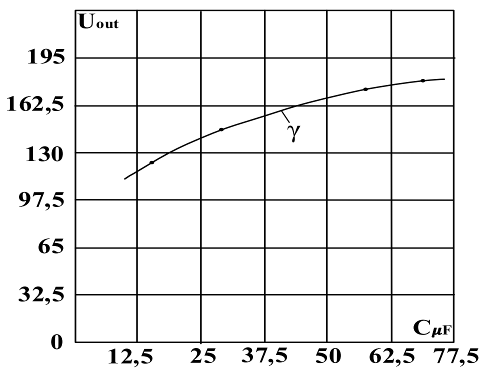

FIGURE 3. The amplitude of the output signal increases

The graph demonstrates that, with changes in the load characteristics, the amplitude of the output voltage increases, while the excitation region of oscillations at the frequency $3f$ shifts within a range of ±30 V. The amplitude of the output voltage remains within a certain regulation range of the input voltage, regardless of the type of load.

The Figure shows the dependence $U_{\text{out}} = f(U_{\text{in}})$within the stabilization region. The stabilization region of the output voltage shifts to the right as the capacitance C_1increases. When the capacitance $C_1$is varied from 20 to 80 μF at an input voltage of $U_{\text{in}} = 200$ V, the amplitude of the output signal increases (Figure. 3) up to a certain value of $U_{\text{out}} = 184$ V. With further increase of U_{in}, the output voltage remains constant. The larger the capacitance, the greater the achievable amplitude of the output signal; however, in this case the frequency tripler operates at a higher voltage. Thus, the converter can be regulated not only by increasing the input voltage, but also by adjusting the capacitance, while maintaining output voltage stabilization [9,10].

The dependence $U_{\text{out}} = f(C)$(Figure. 3) makes it possible to select the output value at the tripled frequency. Figureure 5 shows typical external characteristics of frequency triplers under a purely resistive load (curve 1), a resistive–inductive load (curve 2), and with series (longitudinal) compensation (curve 3).

In the absence of capacitors in the output circuit, the voltage decreases smoothly with increasing load current due to the voltage drop across the internal inductive impedance. In the case of series compensation, the voltage drop across the internal inductive impedance is compensated by the voltage drop across the capacitor, and the external characteristic becomes stiff.

By selecting appropriate values of the series-compensation capacitances, it is possible to obtain an external characteristic with the desired stiffness. It follows that the maximum output power that the frequency tripler can develop, without considering heating effects, is significantly higher in the presence of series compensation. Ferromagnetic elements of frequency multipliers with capacitive compensation are considerably lighter and more compact than those without compensation.

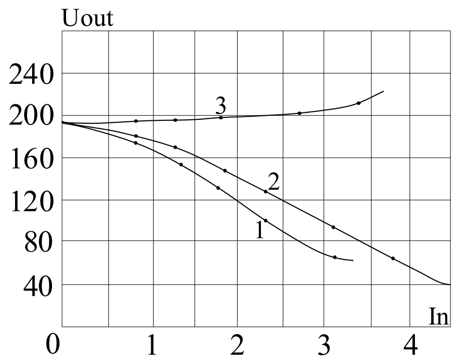

FIGURE 4. shows the dependence of the efficiency on the converter power, $\eta = f(P_{\text{in}})$, for various capacitance values. It can be seen that the efficiency increases with increasing power.

RESEARCH RESULTS

The converter exhibits a high efficiency at large capacitance values $C_1 = C_2 = C_3$of the primary circuit. When designing ferromagnetic frequency multipliers, it is necessary to select a specific electromagnetic operating mode and the geometric dimensions of the ferromagnetic cores, which determine the parameters characterizing the frequency converter [11].

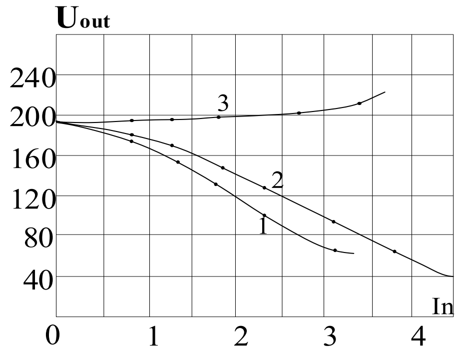

FIGURE 5. Shows the waveform of the output voltage

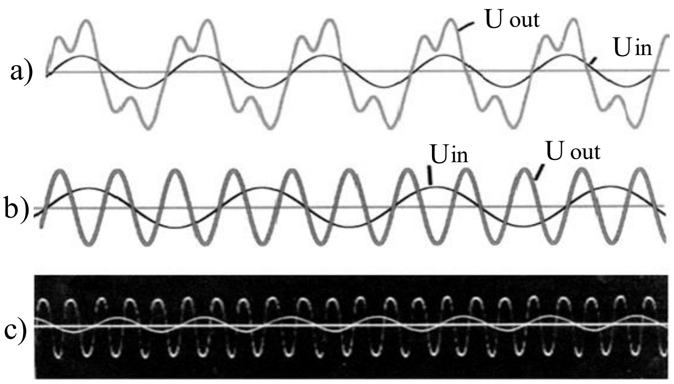

FIGURE 6. before the excitation of autoparametric oscillations (APO) and after resonance

As can be seen, the waveform is close to sinusoidal. The remaining distortions are mainly associated with the presence of the fundamental frequency component in the waveform, which is caused by core asymmetry. The application of the frequency tripler can be summarized as follows:

1. increase in the stabilization factor;
2. expansion of the output voltage regulation range;
3. output voltage waveform close to a sine wave.

A drawback of the converter is that, when operating under load conditions, a sharp increase in the current of the primary winding is observed.

It should be noted that frequency multipliers based on the conversion of an m-phase voltage system into a single-phase system, with unidirectional frequency multiplication by an n-fold factor, generally outperform frequency multipliers with a single-phase input that are based on other principles of extracting higher harmonics.

CONCLUSIONS

Experimental investigations of the frequency tripler and the results of its pilot operation with output voltage stabilization have demonstrated the following positive features of the proposed circuit:

a) by connecting the secondary windings in phase in an open-delta configureuration, it is possible to obtain a voltage stabilizer operating at the tripled frequency;

b) stabilization of the symmetry of the output quantities under variations of the load power from 40% to 140% of the rated value is achieved automatically, without the use of regulating devices;

v) a relatively high power factor and efficiency are obtained (respectively, cosφ and к.п.д. η).

An analysis of the experimental and techno-economic indicators has revealed a number of positive properties of the developed frequency tripler:

1. High stabilization level and a wide regulation range of the output voltage.
2. Near-sinusoidal waveform of the output voltage.
3. Possibility of regulating the output voltage by varying the capacitance values of the ferroresonant circuit.

REFERENCES

1. Nuritdin Khalilov., Nematjon Qurbanov., Qahramon Jabborov., Doston Sheraliev., Sobir Eshmuradov (2025). Autoparametric single-phase converter of phase number and frequency tripler with stable output voltage AIP Conf. Proc. 3331, 070016. https://doi.org/10.1063/5.0305730
2. Nuritdin Khalilov., Doston Sheraliev., Sobir Eshmuradov (2024). Analysis and experimental study of a three-phase auto parametric voltage stabilizer with a ferroresonant structure. AIP Conf. Proc. 3152, 040033. https://doi.org/10.1063/5.0219924
3. Sharofiddin B., Yusupov., Suhrob E. Qurbonazarov., Zinatdin J., Saymbetov., Rinat K. Kenesbayev (2024). Ways to increase the efficiency of growing products in greenhouses. E3S Web of Conferences 548, 01034. https://doi.org/10.1051/e3sconf/202454801034
4. Sultonkhoja Makhmutkhanov., Yunus Ochilov., Hamid Nurov., Sukhrob Kurbonazarov (2024). Increasing the environmental cleanness of industrial enterprises. AIP Conf. Proc. 3152, 060012. https://doi.org/10.1063/5.0219213
5. B. Khushbokov., K. Khakimov., J. Kodirov., F. Khursanov, "Increasing the quality of receiving current through the current receiver by improving the fixator," in AIP Conference Proceedings, AIP Publishing, 2024, p. 020006. Accessed: Oct. 06, 2025. [Online]. Available: https://doi.org/10.1063/5.0197788
6. Nodir Eshpulatov., Botir Khushboqov (2024). Determination of the influence of the electrohydraulic effect on succulent plant raw materials. BIO Web of Conferences 105, 04005. https://doi.org/10.1051/bioconf/202410504005
7. Romanskiy, L. L. Statistical Electromagnetic Frequency Converters. Moscow–Leningrad: Gosenergoizdat, 1959.
8. Geyer, A. V. Frequency Tripler Providing Stable 420 Hz Supply Voltage. Electronics (Russian translation). Energiya Publishing House, No. 18, 1963.
9. Zaitsev, I. A. Autoparametric Excitation of Oscillations in Circuits with Iron and Capacitors.Proceedings of the Leningrad Polytechnic Institute (LPI), Electrical Engineering Section, No. 3, 1948.
10. Bamdas, A. M., Kupshin, V. A., Shapiro, S. V. Statistical Electromagnetic Frequency and Phase Number Converters. Moscow–Leningrad: Gosenergoizdat, 1961.
11. Taxir Bayzakov., Sharofiddin Yusupov., Rustem Yunusov., Ilxom Xolmirzaev., Jahongir Esanov., Shakhnoza Kulmamatova (2023). Modeling the process of growing seeds of vegetable crops with ultraviolet light. IOP Conf. Series: Earth and Environmental Science 1231 012065. doi:10.1088/1755-1315/1231/1/012065