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METHOD OF QUASIFREQUENCY-PHASE SPEED CONTROL OF INDUCTION MOTORS

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Summary. Method of speed control of induction motors down from the nominal, multiple of integer, by overturning the corresponding half-waves of sinusoidal voltage is proposed. Through the use of the phase method of voltage regulation, this method allows to withstand the constant ratio between the frequency and voltage. The circuit diagram that implements quasifrequency-phase method is developed, and design formula for determination of the moment of time of the phase angle t_α of the speed of asynchronous motors. Figs. 3, sources 20.

Key words. Quasifrequency-phase method, speed control, underfrequency, speed control, induction motor

INTRODUCTION

Speed control of induction motors (IM) is necessary for many technological processes. For example, IM are used as a drive in the exhaust fan on the boiler and, depending on the intensity of the burning fuel is necessary to adjust the value of draught in the exhaust air ducts, notably, induction motor speed.

There are following methods of speed control of IM: change in the number of pole pairs, undervoltage, rheostatic control (only for IM with wound rotor), frequency control. Undervoltage is inefficient because the voltage drop leads to a reduction in the rigidity of the mechanical characteristics,so this method is used for speed control drives with a fan loading. Rheostatic speed control of IM is used only for motors with wound rotor, and electric drive that implements this method has low efficiency. These two methods allow to adjust the speed of IM just down from the nominal. Frequency method allows to adjust the speed of IM both up and down from the nominal. However to realize this method is not always possible, because it is expensive due to the presence of controlled rectifier, autonomous inverter, which should work in the modes of forced, artificial and natural commutation. For IM of high capacity to solve problems with commutation is rather difficult because of the large inductance value. [Chilikin M.G., 1981]

UNDERFREQUENCY OF SUPPLY SINUSOIDAL VOLTAGE OF IM BY PARTIAL RECOMMUTATION OF HALF-WAVE

The essence of the proposed method is to lower the frequency of supply sinusoidal voltage in integer number of times by turning relative to the axis of time t some half waves of sinusoid. For example, with decreasing of frequency in half, as shown in fig. 1, is necessary in the first period $T1$ to turn the negative half-wave, and the second $T2$ turn positive half. Next, in odd periods all repeats as in the first period $T1$, and in even periods, as in the second period. As a result, in odd periods will be two positive half-wave, and in even two negative.

From the oscillogram in the fig. 1, shows that the 1st harmonic of voltage on the phase winding of IM has period:

$$T_{1/2} = T_1 + T_2 \qquad (1)$$

Hereby, the frequency of the supply voltage in BP drops two times, compared to the frequency of the network, properly, and the speed decreases two times.

In this case, the ratio should be maintained:

$$\frac{U}{f} = \text{const} \qquad (2)$$

where: U - the effective voltage on winding of IM, f - the frequency of 1st harmonic of supply voltage of IM [Gusev V.G., 1990].

Fulfillment of the correlation (2) is realized by using the phase method of regulating the effective supply voltage, notably, control valves are opened to the delay in the phase angle α and, properly, the winding of the IM is fed by only the shaded part of the half-wave of sinusoid (fig. 1). Due to this, the area of half-wave of the first harmonic of supply voltage with low frequency could be equal to the sum of the areas of shaded parts of two half waves of supply voltage and the condition (2) will be implemented.

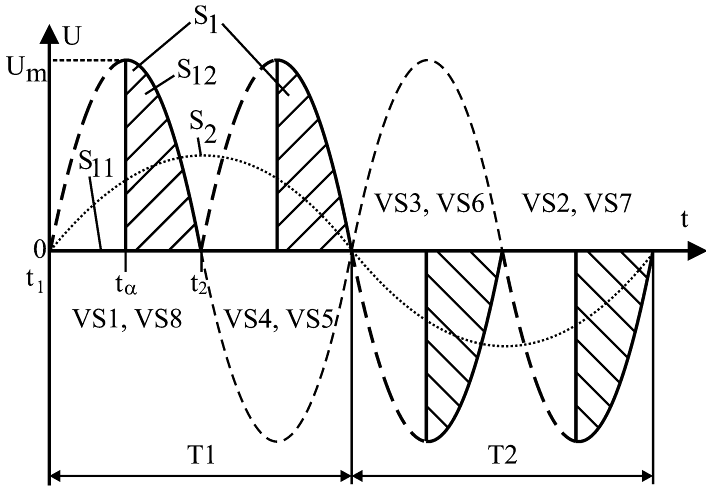

Fig.1. Oscillogram of underfrequency of supply voltage in 2 times

With decreasing frequency in three times as shown in fig. 2, it is necessary in the first period T1 to turn a negative half-wave, the second period T2 to leave intact and in the third T2 to turn a positive half-wave. Next, all repeats in a cycle: in 4, 7, 10, ... periods of half-waves turn, as in the 1st period, 5, 8, 11, ... periods remain intact, as in the second period, and periods of 6, 9, 12, ... half-waves turn, as in the 3rd period.

From the oscillogramin the fig. 2, shows that the 1st harmonic of voltage on the phase winding of IM has period:

$$T_{1/3} = T_1 + T_2 + T_3 \tag{3}$$

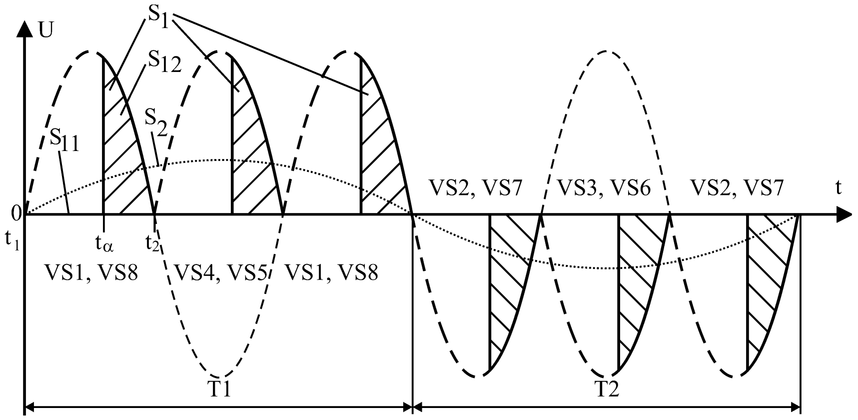

Fig.2. Oscillogram of underfrequency of supply voltage in 3 times

The proposed method allows to adjust the speed of IM down from the nominal and in reasonably wide range, while the frequency of supply voltage of IM is a multiple integer.

SCHEME AND OPERATION OF QUASIFREQUENCY-PHASE CONVERTER

The process of turning half-waves of sinusoidal supply voltage is realized by thyristor quasifrequency-phase converter, by commutation of windings ends of BP at a certain time with a corresponding phase, or "zero".

The stator winding of IM is connected to one end through a thyristor or transistor group of valves (thyristors or transistors) of converter by turn with phase and with "zero" (single-phase or three-phase motor, connection –star) or the other phase (three-phase motor, connection –delta). The other winding end of IM is also connected through another group of valves (thyristors or transistors) of converter by turn with phase and with "zero" (single-phase or three phase motor, connection – star) or the other phase (three phase motor, connection – delta), but in antiphase relatively the first group of valves of the converter.

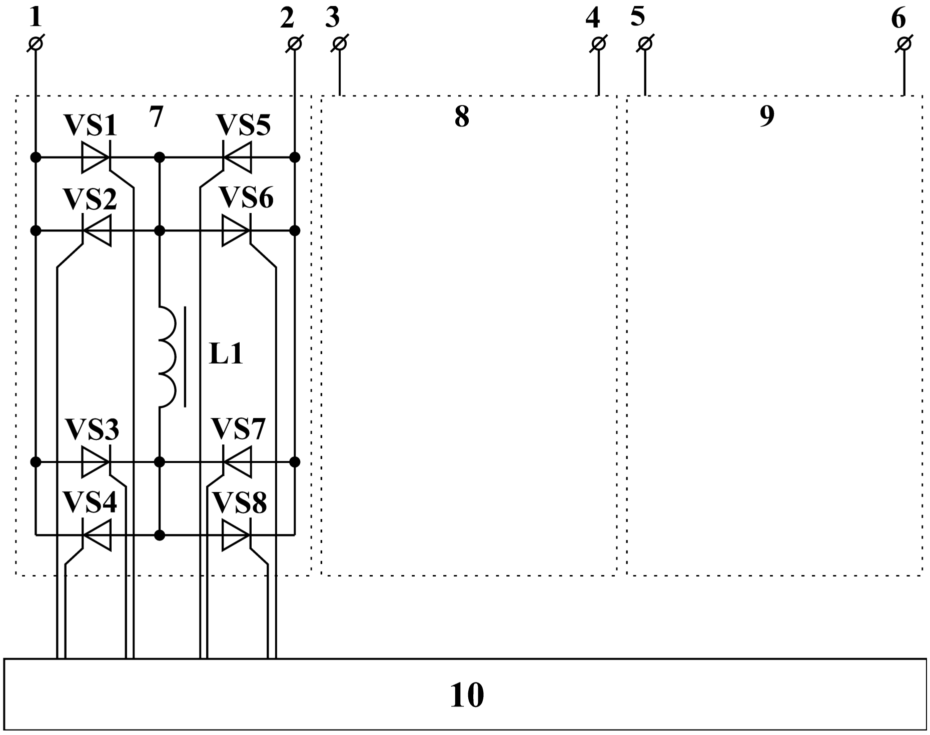

Fig. 3. Scheme of thyristor quasifrequency-phase converter

In parallel, oppositely connect thyristors VS1 with VS2, VS3 with VS4, VS5 with VS6 and VS7 with VS8. Winding beginning of the phase L1 is connected with thyristors VS1, VS2, VS5 and VS6, and the end of this winding is connected with thyristor VS3, VS4, VS7 and VS8. Not connected to the phase winding of IM leads of thyristors VS1, VS2, VS3 and VS4 are connected with the phase of the power supply 1, not connected to the phase winding of IM leads of thyristors VS5, VS6, VS7 and VS8 are connected with another phase of the power supply (or the neutral wire) 2. Block 7 maps connection of winding L1, thyristors VS1-VS8, phase 1 and second phase (neutral wire) 2 for one phase winding of induction motor. Controlling electrodes of thyristors VS1-VS8 are connected with control circuit 10. The other two phase windings of the induction motor, which are contained in blocks 8 and 9 in fig. 3, are connected with other phases of the power supply (or neutral wire) 3, 4, 5 and 6 through the thyristors, which as well as phase windings are not shown in blocks 8 and 9. Blocks 8 and 9 are structurally the same as block 7, but connected with other phases of supply voltage. Controlling electrodes of thyristors in blocks 8 and 9 are also connected with control scheme 10.

When dividing the frequency of power by 2 circuit in fig. 3 works as follows. In the first period of network frequency when on phase 1 comes a positive half-wave, then must be opened thyristors VS1 and VS8 (see fig. 2), but when comes a negative half-wave, then must be opened thyristors VS4 and VS5. Hereby, in the first period on the winding beginning of phase L1 will pass only the positive voltage half-waves. In the second period the network frequency when on phase 1 comes a positive half wave, then must be opened VS3 and VS6 (see fig. 2), but when comes a negative half-wave, then must be opened VS2 and VS7. Hereby, during this period on the winding beginning of phase L1 will pass only the negative voltage half-waves.

In the control circuit 10 implemented phase voltage regulation, ie by changing the angle of thyristors unlocking α, which is shown in fig. 1 and fig. 2. Changing the order of the turning on of thyristors can be obtained decrease of frequency by 3 times (see fig. 2), as well as any other integral number of times.

DETERMINATION OF THE DEPENDENCE OF INSTANT TIME OF PHASE ANGLE t_α ON VALUE OF REQUIRED SUPPLY VOLTAGE FREQUENCY

Since it is necessary to comply with correlation (2), for voltage and frequency, as well as frequencies and voltages, decreased in 2, 3, 4, etc. correlation (2) is written:

$$\frac{U_N}{f_N} = \frac{U_2}{f_2} = \frac{U_3}{f_3} = \ldots = \frac{U_k}{f_k} = \mathrm{const} \tag{4}$$

where: U_N, U_2, U_3, U_k – effective network voltage, voltages by dividing the frequency by 2, 3 and k, f_N, f_2, f_3, f_k – network frequency, the frequencies of 1st harmonic, obtained by dividing the network frequency by 2, 3 and k [Gusev V.G., 1990].

Network frequency f_N and voltage U_N are known values. Decreased frequencies f_2, f_3, ..., f_k can be determined through network frequency f_N:

$$f_2 = \frac{f_N}{2};\ f_3 = \frac{f_N}{3};\ \ldots; f_k = \frac{f_N}{k} \tag{5}$$

Hereof we get the correlation for determining the required voltage with decreasing frequency.

$$U_2 = \frac{U_N}{2};\ U_3 = \frac{U_N}{3};\ \ldots; U_k = \frac{U_N}{k} \tag{6}$$

In the phase regulation effective voltage with decreasing frequency is determined for the half-period as:

$$U_k = \frac{(t_\alpha - t_1)\cdot U_{N1} + (t_2 - t_\alpha)\cdot U_{N2}}{t_2 - t_1} \tag{7}$$

where: t_1, t_2 – instant time of beginning and end of a half period of network frequency, sec., t_α - instant time of beginning of thyristor unlocking at the phase angle α, sec. U_{N1}, U_{N2} –effective network voltage before and after thyristors unlocking [Nevzlin B.I., 2007].

Accept $U_{N1} = \dfrac{S_{11}}{t_\alpha - t_1} = 0$, since thyristors at this site of half-period are closed. Effective voltage is determined as:

$$U_{N2} = \frac{S_{12}}{t_2 - t_a} = \frac{\int_{t_\alpha}^{t2} U_{m2} \cdot \sin(2 \cdot \pi \cdot f \cdot t)dt}{t_2 - t_\alpha} \tag{8}$$

where: S_{11} and S_{12} – curvilinear area on plots from $t_1 = 0$ to t_α and from t_α to t_2 (see fig. 1 and fig. 2).

Since voltage $U_{N1} = 0$ (see fig. 1 and fig. 2), the effective voltage with decreasing frequency is determined for the half-period as:

$$U_k = \frac{\int_{t_\alpha}^{t_2} U_{m2} \cdot \sin(2 \cdot \pi \cdot f \cdot t)dt}{t_2 - t_1} \tag{9}$$

Since effective voltages of network and decreased frequencies must be equal, it is appropriate to switch over stom the correlation of equality of effective voltages to the correlation of areas equality of the half-period of decreased frequency:

$$S_1 = k \cdot \int_{t_\alpha}^{t_2} U_{m2} \cdot \sin(2 \cdot \pi \cdot f \cdot t)dt \tag{10}$$

$$S_2 = \int_0^{k \cdot t2} \frac{U_{m2}}{k} \cdot \sin(2 \cdot \pi \cdot \frac{f}{k} \cdot t)dt \tag{11}$$

where: S_1 –the total area which consists of k half-periods in the half-period of decreased frequency, S_2 - the area of half-period of decreased frequency.

After integration, the dependence (10) and (11) take the form:

$$S_1 = k \cdot U_{m2} \cdot \frac{\cos(2 \cdot \pi \cdot f \cdot t_\alpha) - \cos(2 \cdot \pi \cdot f \cdot t2)}{2 \cdot \pi \cdot f} \tag{12}$$

$$S_2 = \frac{U_{m2}}{k} \cdot \frac{\cos\left(2 \cdot \pi \cdot \frac{f}{k} \cdot 0\right) - \cos\left(2 \cdot \pi \cdot \frac{f}{k} \cdot t2\right)}{2 \cdot \pi \cdot \frac{f}{k}} \tag{13}$$

With the fulfillment of condition of areas S_1 and S_2 equality (see fig. 1.) obtain:

$$k \cdot U_{m2} \cdot \frac{\cos(2 \cdot \pi \cdot f \cdot t_\alpha) - \cos(2 \cdot \pi \cdot f \cdot t2)}{2 \cdot \pi \cdot f} = U_{m2} \cdot \frac{1 - \cos(2 \cdot \pi \cdot f \cdot t2)}{2 \cdot \pi \cdot f} \tag{14}$$

As a result of (14) gives the dependence of instant time of the phase angle t_α on network frequency and division factor of frequency:

$$t_\alpha = \frac{\arccos\left(1 - n - \cos\left(2 \cdot \pi \cdot t_2 \cdot \frac{f}{k}\right) \middle/ k\right)}{2 \cdot \pi \cdot f} \tag{15}$$

Parameter t_2 directly depends on network frequency f and can be defined as:

$$t_2 = \frac{k}{2f} \tag{16}$$

After the transformation (15) with (16) finally obtain the dependence of instant time of the phase angle t_α on network frequency and division factor of frequency:

$$t_\alpha = \frac{\arccos\left(\frac{2-k}{k}\right)}{2 \cdot \pi \cdot f} \tag{17}$$

The results of calculations with underfrequency in 2-6 times are tabulated in Table. 1

Table. 1. The dependence of the instant time of phase angle t_α on the division factor k of frequency at network frequency $f = 50\text{Hz}$

k	2	3	4	5	6
$t_{\alpha x}$, sec.	0,005	0,006082	0,006667	0,007048	0,007323

The received analytical dependence of instant time of phase angle t_α on network frequency f and division factor of underfrequency k, allows to calculate precisely instant time of phase angle t_α at which the ratio will be observed (4).

CONCLUSIONS

1. The proposed method quasifrequency-phase speed control of induction motors allows discretely control the speed with constant rigidity of mechanical characteristics of IM.

2. The analytical dependence of instant time of phase angle t_α on network frequency f and the frequency decrease factor k at which the observed correlation $U / f = \text{const}$ is obtained.

3. Proposed a method for decreasing of electrical losses in BP with quasifrequency-phase speed control of IM by changing the instant time of phase angle $t_{\alpha x}$ depending on sequence number of half-wave of supply voltage during half-period of decreased frequency.

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СПОСОБ КВАЗИЧАСТОТНОФАЗОВОГО РЕГУЛИРОВАНИЯ ЧАСТОТЫ ВРАЩЕНИЯ АСИНХРОННЫХ ДВИГАТЕЛЕЙ

Борис Невзлин, Дмитрий Половинка, Дмитрий Сергиенко

Аннотация. Предложен способ регулирования частоты вращения асинхронных двигателей вниз от номинальной, кратной целым числам, за счет переворачивания соответствующих полуволн синусоидального напряжения питания. За счет использования фазового метода регулирования напряжения этот способ позволяет выдерживать постоянным соотношение между частотой и напряжением. Разработана принципиальная электрическая схема, реализующая квазичастотнофазовый способ, и предложены расчетные формулы для определения момента времени фазового угла t_α от частоты вращения асинхронных двигателей. Рис. 4, ист. 20.

Ключевые слова. Квазичастотнофазовый способ, регулирование частоты вращения, понижение частоты, асинхронный двигатель.