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RESEARCH OF ASYMMETRICAL AND NONSINUSOIDAL CURRENTS OF ASYNCHRONOUS MOTOR REACTIVE POWER

Abstract: *In this article, the generation of asymmetric and non-sinusoidal currents affecting the reactive power of the asynchronous motor and their effects on the operation modes of the asynchronous motor are mentioned. Information on the types and descriptions of high harmonic currents that form non-sinusoidal currents occurring in an asynchronous motor is given. The results of the research were formed on the basis of practical and theoretical data.*

Key words: *asynchronous motor, asymmetrical current, non-sinusoidal current, magnetic flux, high harmonics, reactive power, power factor.*

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Introduction

Asynchronous motors are the main consumers of electricity, they are designed to work under symmetrical and sinusoidal voltages, but due to the connection of various loads to the power supply system and several faults that occur in asynchronous motors, asymmetrical and non-sinusoidal currents appear in asynchronous motors and they have a negative effect on the operation modes of the asynchronous motor [1].

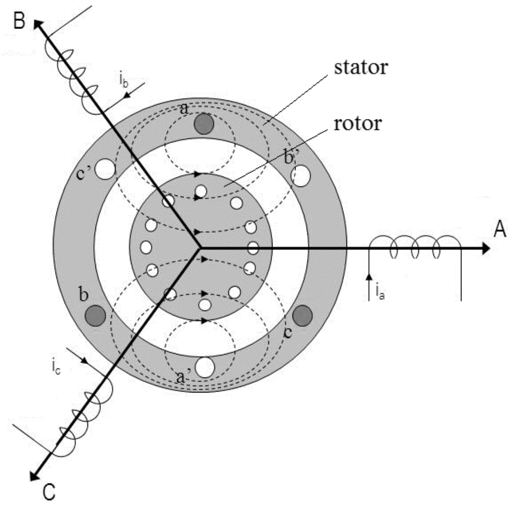

Figure 1. Schematic diagram of a three-phase asynchronous motor.

The formation, types and negative effects of asymmetric currents caused by various effects during the operation of an asynchronous motor are considered. In the stator of an asynchronous motor, symmetric windings are placed at an angle of 120° from each other, when voltage is applied to these windings, corresponding magnetic currents are generated in each phase according to the magnitude of the voltage (Fig. 1) [2].

Methods: Asynchronous motors have amplitude asymmetry and phase angle asymmetry. As a result of various effects, the asymmetric currents in the asynchronous motor lead to the asymmetry of the magnetic fluxes in the stator (1) and it is as follows [3].

$$\Phi_A(\theta,t)=\frac{1}{2}\Phi_m\{\sin(\theta-\omega t)+\sin(\theta+\omega t)\} \tag{1}$$

$$\Phi_B(\theta,t)=\frac{1}{2}\Phi_m\left\{\sin(\theta-\omega t)+\sin\left(\theta+\omega t-\frac{2\pi}{3}\right)\right\}$$

$$\Phi_C(\theta,t)=\frac{1}{2}\Phi_m\left\{\sin(\theta-\omega t)+\sin\left(\theta+\omega t)-\frac{4\pi}{3}\right)\right\}$$

where θ – the angle between the magnetic flux and the stator current, Φ_m – main magnetic flux.

Analysis of asymmetrical currents in asynchronous motors.

In three-phase asynchronous motors, asymmetrical currents occur when the amount of currents in each phase differs from each other. The causes of asymmetrical currents in asynchronous motors are as follows:

- Damage to the stator coil
- Bearing damage
- Damage to the magnetic circuit
- Operation in extreme load mode
- Asymmetrical supply voltage

Based on the above reasons, asymmetrical currents cause the following negative effects in asynchronous motors:

- Causes the power factor to decrease
- Causes an increase in the temperature of the asynchronous motor
- Leads to a decrease in stator torque
- Causes the stator current to increase
- Increases the amount of noise and vibration
- Asynchronous motor shortens the operating cycle

The asymmetrical currents that occur in asynchronous motors are as follows:

1. Amplitude asymmetry (if the currents in each phase differ in amplitude).
2. Phase asymmetry (if the currents in each phase do not form an angle of 120° from each other).

Amplitude-asymmetric currents occur when the amount of currents in each phase differs from each other in terms of amplitude, and the coefficient of asymmetry is different from one. (Fig. 2) Amplitude-asymmetrical currents create a magnetic flux in the opposite direction in the stator of the asynchronous motor, which causes a decrease in torque, mechanical power, and heating of the asynchronous motor [4].

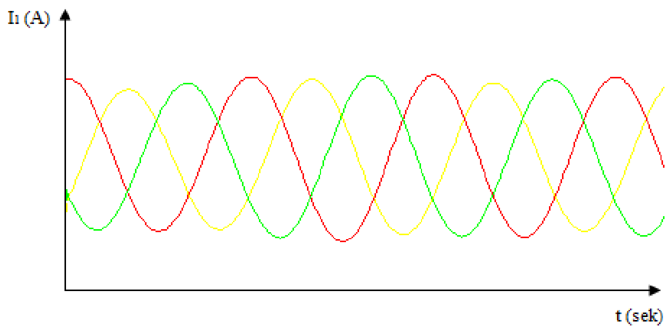

Figure 2. Time-dependent description of amplitude asymmetry currents.

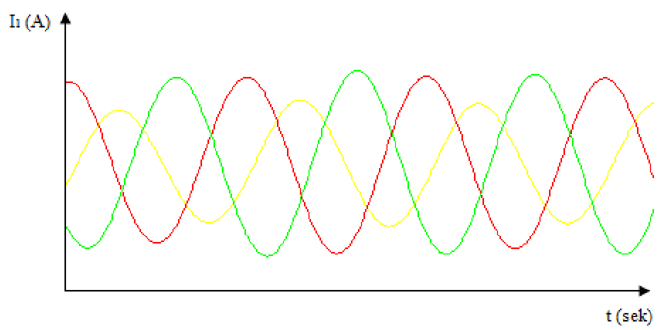

Figure 3. Time dependence description of phase asymmetry currents.

Phase-asymmetrical currents occur when the phase angles of the currents in each phase differ from each other, that is, the angle between the phase currents is not 120°. Phase asymmetry currents, like amplitude asymmetric currents, create a magnetic flux in the opposite direction in asynchronous motors, which leads to a decrease in the torque and mechanical power of the asynchronous motor, as well as its heating (Fig. 3). Phase asymmetry currents have a greater negative impact on the operation of an asynchronous motor compared to amplitude asymmetry currents [5].

The main negative effects of asymmetrical currents are overheating of asynchronous motors and generation of a torque opposite to the direction of the main electromagnetic torque, which has a negative effect on the insulation of the stator winding. Exceeding the specified amount of asymmetrical currents in an asynchronous motor leads to a shortening of its working life. If the amount of network voltage asymmetry is 4%, it causes the operation period of the asynchronous motor to be reduced by two times [6].

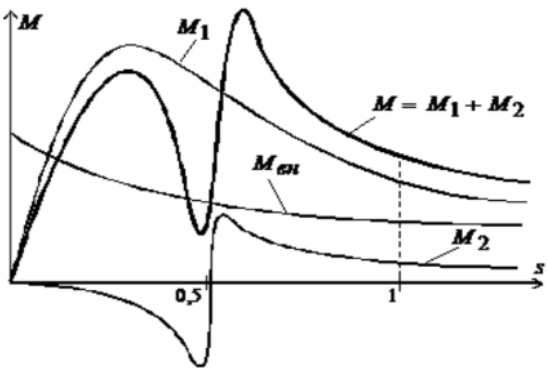

Figure 4. Mechanical description of a three-phase asynchronous motor under the influence of asymmetrical currents.

As a result of asymmetrical currents creating an electromagnetic moment of equal and opposite direction in the stator of an asynchronous motor, the slip coefficient of an asynchronous motor is also divided into two, and it is described in the following mechanical description (Fig. 4).

The slip coefficient of an asynchronous motor in the direction of the electromagnetic field is determined as follows:

$$s_m = \frac{\omega_s - \omega_r}{\omega_s} = 1 - \frac{\omega_r}{\omega_s} \qquad (2)$$

The slip coefficient of an asynchronous motor against the direction of the electromagnetic field is determined as follows:

$$s_q = \frac{-\omega_s - \omega_r}{-\omega_s} = 1 + \frac{\omega_r}{\omega_s} \qquad (3)$$

where ω_s – angular velocity of the magnetic flux in the stator, ω_r – angular velocity of rotor.

The power of an asynchronous motor is determined as follows:

$$P = P_m + P_q \qquad (4)$$

$$P_m = \frac{3R_r(U_{1m})^2}{s_m\left\{\left(\frac{R_r}{s_m}\right)^2 + X_r^2\right\}} \qquad (5)$$

$$P_q = \frac{3R_r(U_{1q})^2}{s_q\left\{\left(\frac{R_r}{s_q}\right)^2 + X_r^2\right\}} \qquad (6)$$

where P_m – active power in the appropriate direction (5), P_q – active power in the opposite direction (6).

The effect of asymmetrical currents on the electromagnetic torque of an asynchronous motor is determined as follows:

$$M = M_m + M_q \qquad (7)$$

$$M_m = \frac{P_m}{\omega_s} = \frac{3R_r(U_{1m})^2}{s_m\left\{\left(\frac{R_r}{s_m}\right)^2 + X_r^2\right\}} \frac{1}{\omega_s} \qquad (8)$$

$$M_q = \frac{P_q}{\omega_s} = \frac{3R_r(U_{1q})^2}{s_q\left\{\left(\frac{R_r}{s_q}\right)^2 + X_r^2\right\}} \left(-\frac{1}{\omega_s}\right) \qquad (9)$$

where M_m – electromagnetic torque in the appropriate direction (8), M_q – electromagnetic torque in the opposite direction (9).

The torque in the opposite direction due to the asymmetrical currents reduces the amount of the main electromagnetic torque and, as a result, reduces the electromagnetic torque of the induction motor and is defined as:

$$M = \frac{3R_r(U_{1m})^2}{s_m\left\{\left(\frac{R_r}{s_m}\right)^2 + X_r^2\right\}}\frac{1}{\omega_s} - \frac{3R_r(U_{1q})^2}{s_q\left\{\left(\frac{R_r}{s_q}\right)^2 + X_r^2\right\}}\frac{1}{\omega_s} \quad (10)$$

Power losses due to asymmetrical currents are determined as follows:

$$\Delta P = s\left(\frac{3R_r(U_{1m})^2}{s_m\left\{\left(\frac{R_r}{s_m}\right)^2 + X_r^2\right\}} + \frac{3R_r(U_{1q})^2}{s_q\left\{\left(\frac{R_r}{s_q}\right)^2 + X_r^2\right\}}\right) \quad (11)$$

Due to asymmetrical currents, the occurrence of a magnetic flux in the opposite direction in the stator of an asynchronous motor leads to an increase in reactive power, which leads to a decrease in the useful efficiency of the asynchronous motor, which is defined as follows:

$$\eta = \frac{P_2}{P_1} = \frac{(1-s_m)P_m}{P_m + P_q} \quad (12)$$

$$\eta = \frac{P_2}{P_1} = \frac{(1-s_m)}{1+\left(\left(\frac{U_{1q}}{U_{1m}}\right)^2 \frac{s_m\left\{\left(\frac{R_r}{s_m}\right)^2 + X_r^2\right\}}{s_q\left\{\left(\frac{R_r}{s_q}\right)^2 + X_r^2\right\}}\right)} \quad (13)$$

where U_m – appropriate direction voltage in the stator windings, U_q – opposite direction voltage in the stator windings.

The analysis of the asynchronous motor asymmetrical currents shows that by reducing the amount of electromagnetic torque in the opposite direction generated in the stator with the help of compensating devices, it is possible to increase the useful efficiency of the asynchronous motor.

Analysis of non-sinusoidal currents in asynchronous motors.

In three-phase asynchronous motors, non-sinusoidal currents occur due to high harmonic currents generated in the stator. The formation of high harmonic currents in electric energy consumers in enterprises is not desirable, which leads to the deterioration of the technical and economic indicators of electrical devices [7].

In asynchronous motors, high harmonic currents are formed due to the following effects:

- Increased asynchronous motor load
- Low power of the asynchronous motor supply transformer
- Length of asynchronous motor supply cable
- Control of asynchronous motors through devices consisting of semiconductor elements
- Faults in the electromagnetic system of the asynchronous motor
- Malfunctions in the mechanical system of the asynchronous motor
- Non-symmetry of rotating parts of an asynchronous motor
- Operation of asynchronous motors in a network with different non-symmetrical loads

Due to the above reasons, non-sinusoidal currents cause the following negative effects in asynchronous motors:

- Reduces active power factor
- Leads to reduction of asynchronous motor torque
- Asynchronous motor causes overheating
- Affects reactive power compensation and starting capacitors
- Affects the winding insulation of the asynchronous motor stator
- Increases the error in the counters for determining the active and reactive energies of asynchronous motors
- Causes a malfunction of the switching devices in the protection system of the asynchronous motor

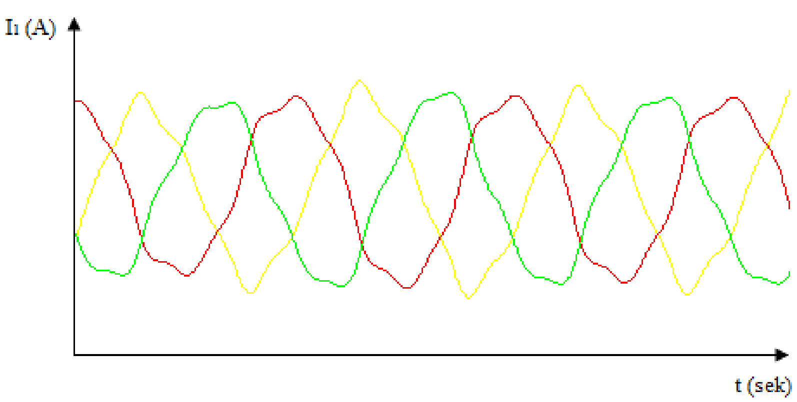

Figure 5. Time dependence description of asynchronous motor nonsinusoidal currents.

Higher harmonics are divided into the following types:

3, 6, 9, 12, 15, 18, 21, 24, 27, 30... zero-sequence (triple) harmonics, such harmonics are generated in asynchronous motors due to single-phase loads in the mains, three-phase loads connected to the mains are triple does not produce harmonics. This type of higher harmonics has a low current value, so this type of higher harmonics has almost no effect on the main magnetic flux.

4, 7, 10, 13, 16, 19, 22, 25, 28, 31... suitable sequence harmonics, such higher harmonics generate magnetic fluxes in the direction of the main magnetic flux of asynchronous motor, high frequency magnetic fluxes generated by higher harmonics are asynchronous causes the temperature of the motor to increase.

2, 5, 8, 11, 14, 17, 20, 23, 26, 29... reverse sequence harmonics, such type of super harmonics produce magnetic fluxes opposite to the main magnetic flux direction of induction motor, these higher harmonics high-frequency magnetic currents in the opposite direction caused by the asynchronous motor lead to a decrease in the electromagnetic moment and an increase in the temperature and reactive power [8].

Each higher odd harmonic current generates electromagnetic torques in the stator, respectively. These torques in turn have corresponding slip coefficients for each of the odd harmonics and is illustrated in the mechanical description below (Fig. 6).

Result: non-sinusoidal currents are generated due to high harmonic currents generated in the stator of an asynchronous motor depending on certain factors (Fig. 5). Negative effects of odd harmonics can be seen mainly in asynchronous motors. Double harmonics are compensated in the magnetic field, so their effect is absent. High harmonics mainly cause heating of asynchronous motors and reduction of active power factor [9, 10].

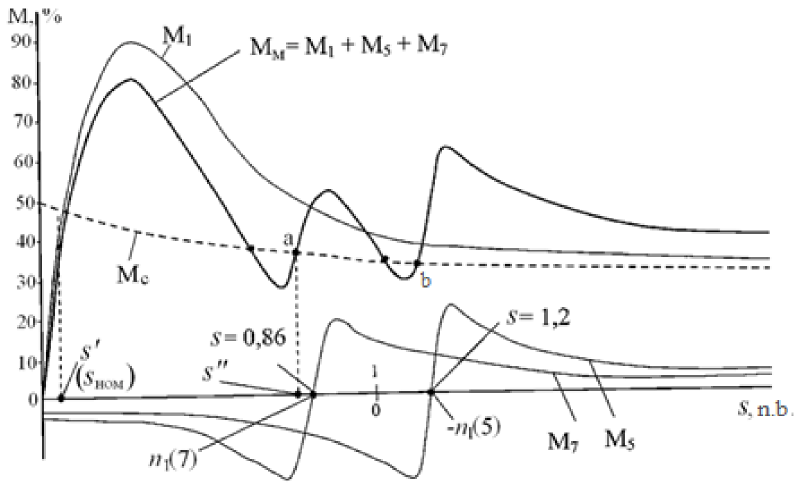

Figure 6. Mechanical description of a three-phase asynchronous motor under the influence of non-sinusoidal currents.

The effect of high harmonic currents generated in asynchronous motors on asynchronous motors is as follows:

The effect of zero-sequence and even harmonics on the main magnetic flux of a three-phase asynchronous motor is almost non-existent, mainly 5, 7, 11, 13, 17, 19, 23, 25, 29, 31... higher odd harmonics have a negative effect . Moments in the corresponding direction caused by non-sinusoidal currents were determined by the expression 6n+1, and moments in the opposite direction by the expression 6n-1 [11, 12].

The slip coefficient generated by high harmonics corresponding to the direction of the electromagnetic field of an asynchronous motor is determined as follows:

$$s_{6n+1} = \frac{\omega_{6n+1} - \omega_r}{\omega_{6n+1}} = 1 - \frac{\omega_r}{\omega_{6n+1}} \qquad (14)$$

The slip coefficient of the asynchronous motor generated by high harmonics opposite to the direction of the electromagnetic field is determined as follows:

$$s_{6n-1} = \frac{-\omega_{6n-1} - \omega_r}{-\omega_{6n-1}} = 1 + \frac{\omega_r}{\omega_{6n-1}} \qquad (15)$$

where S_{6n+1} – the slip coefficient generated by higher harmonics in the appropriate direction (14), S_{6n-1} – the slip coefficient generated by higher harmonics in the opposite direction (15).

Torques in the opposite direction lead to a decrease in the main electromagnetic torque and are given below:

$$\sum M = M_{main} + \sum_{n=1}^{N} M_{m.(6n+1)} - \sum_{n=1}^{N} M_{q.(6n-1)} \quad (16)$$

$$M_{m.(6n+1)} = \frac{3R_r (U_{1m.(6n+1)})^2}{s_{m.(6n+1)}\left\{\left(\frac{R_r}{s_{m.(6n+1)}}\right)^2 + X_r^2\right\}} \frac{1}{\omega_{(6n+1)}} \quad (17)$$

$$M_{q.(6n-1)} = \frac{3R_r (U_{1q.(6n-1)})^2}{s_{q.(6n-1)}\left\{\left(\frac{R_r}{s_{q.(6n-1)}}\right)^2 + X_r^2\right\}} \left(-\frac{1}{\omega_{(6n-1)}}\right) \quad (18)$$

where M_{main} – main electromagnetic torque of an induction motor, $M_{m.(6n+1)}$ – electromagnetic torque generated by higher harmonics in the appropriate sequence (17), $M_{m.(6n-1)}$ – is an electromagnetic moment generated by higher harmonics in the opposite sequence (18).

The value of the total harmonic distortion of non-sinusoidal currents generated in an asynchronous motor is determined as follows and its value is expressed in %:

$$THD_I = \sqrt{\sum_{n=2}^{N}\left(\frac{I_k}{I_1}\right)^2} \quad (19)$$

In three-phase asynchronous motors, high harmonic currents lead to a decrease in power factor, which is given below:

$$\cos\varphi_I = \frac{\cos\varphi}{\sqrt{1+(THD_I)^2}} \quad (20)$$

In three-phase asynchronous motors, due to the effect of high harmonics, there is an increase in electrical and electromagnetic power losses and a decrease in mechanical power.

The active power resulting from higher harmonic currents is given below:

$$P_{out} = (1-s_1)P_1 - \sum(1-s_{6n-1})P_{6n-1} + \sum(1-s_{6n+1})P_{6n+1} \quad (21)$$

The useful duty factor resulting from high harmonic currents is given below:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{(1-s_1)P_1 - \sum(1-s_{6n-1})P_{6n-1} + \sum(1-s_{6n+1})P_{6n+1}}{P_1 - \sum P_{6n-1} + \sum P_{6n+1}} \quad (22)$$

where P_{out} – is the active power generated by the asynchronous motor shaft (21), P_{in} – is the active power consumed by the asynchronous motor from the network.

Conclusion: Since the amount of asymmetrical and non-sinusoidal currents in an asynchronous motor directly depends on the amount of reactive power, it is important to determine and analyze the occurrence of asymmetrical and non-sinusoidal currents of reactive power in an asynchronous motor and their negative effects on the operation modes of the asynchronous motor.

The analysis shows that by reducing the amount of high harmonic currents generated in the stator of the asynchronous motor, it is possible to increase the active power factor, prevent overheating of the asynchronous motor, and ensure the efficient operation of electricity consumers in the electric network by filtering high harmonic currents.

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