NOVATEUR PUBLICATIONS
INTERNATIONAL JOURNAL OF INNOVATIONS IN ENGINEERING RESEARCH AND TECHNOLOGY
[IJIERT] ISSN: 2394-3696 Website: ijiert.org
VOLUME 10, ISSUE 1, Jan. -2023

STUDY OF CHARACTERISTICS OF THREE-PHASE ELECTROMAGNETIC CURRENT CONVERTERS FOR FILTER-COMPENSATION DEVICES OF ASYNCHRONOUS MOTOR REACTIVE POWER

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Abstract

In the article, with the help of the developed physical and mathematical models of the asynchronous motor three-phase electromagnetic current converter, according to the connection methods with two sensing element loops suitable for each phase, it has, series, parallel and differential and one loop. Static characteristics of the dependence of output signals of electromagnetic current converters on asynchronous motor stator current and dynamic characteristics of time dependence of output signals of asynchronous motor three-phase electromagnetic current converter are studied.

By studying the static characteristics, the output signals of the sensing element proportional to the corresponding stator current for each phase, the voltage U_1 supplied to the stator, the number windings of the stator w_1 and number windings of the sensing element w_{se}, the cross-sectional area of the sensing element S_{se} and it was found that the air gap δ depends on the parameters of the electromagnetic field.

Studying the dynamic characteristics of the voltage signal coming from the sensing element, taking into account the interaction of the quantities with different characteristics affecting the asynchronous motor three-phase electromagnetic current converter, differential equations characterizing the output signals and representing the transition processes were created. Determination of the dynamic characteristics of the three-phase electromagnetic current converter of an asynchronous motor was carried out on the basis of theoretical calculations and practical results determined by modern technologies.

Keywords: three phase electromagnetic current converter, filter-compensation devices, asynchronous motor, sensing element, static characteristic and dynamic characteristic.

1. Introduction

The results determined based on the mathematical models of the three-phase electromagnetic current converter of the reactive power of the asynchronous motor are necessary for the control and management of the filter-compensation devices of the reactive power of the asynchronous motor. The main characteristics of a three-phase asynchronous motor current converter include its static and dynamic characteristics.

Based on the static characteristics, the characteristics of the dependence of the output voltage signals of the three-phase electromagnetic current converter of the asynchronous motor on the stator current, the adequacy of the output signals of the three-phase electromagnetic current converter of the asynchronous motor by comparing the results of theoretical calculations with the practically determined results, the characteristics of the output indicators such as linearity, metrological indicators and the sensitivity of the electromagnetic current converter are determined [1].

It is important to research three-phase electromagnetic current converters for control and management of filter-compensation devices of asynchronous motor reactive power through dynamic characteristics. The parameters of the asynchronous motor and the sensing element, as well as the time-dependent change of the output voltage signal, are determined through dynamic descriptions.

Dynamic descriptions provide opportunities for theoretical and practical research by summarizing the expressions, physical and technical effects and descriptions of the electromagnetic current converter in different operating modes of the asynchronous motor using the graph model of the three-phase electromagnetic current converter. By studying the dynamic characteristics of an asynchronous motor electromagnetic current converter, it is important to study the properties and characteristics of nonlinear signals caused by transient processes, because nonlinear and unbalanced signals have a negative effect on the operation of the control and management device [2].

2. Materials and Methods

Based on the physical and mathematical models of the electromagnetic current converter with one sensing element loop suitable for each phase, the description of the dependence of the output signals on the stator current of the asynchronous motor is determined by researching the electromagnetic processes in the asynchronous motor electromagnetic current converter.

According to the loops number of sensing elements of the electromagnetic current converter and the method of connection, it will be possible to fully study the dynamic processes by analyzing the electrical and electromagnetic processes in the asynchronous motor. In this case, it is important to determine the dynamic characteristics of electromagnetic current converters with one sensing element loop and two sensing elements loops in series, parallel and differential connection and to compare them [3].

For the control and management of asynchronous motor filter-compensation devices, three-phase electromagnetic current converters have the same number of coils of sensing elements suitable for each phase, through this, it is possible to determine the amplitude and phase asymmetries and nonsinusoidality.

In the study of static and dynamic characteristics, 4AA63A4Y3 type asynchronous motor with a nominal power of $P=250$ *W*, with stator windings connected in the form of a star, was obtained. Active resistance of the stator winding $R_1=38.51$ Ohm, inductive resistance $X_1=21.05$ Ohm, active resistance of the rotor $R`_2=35.94$ Ohm, inductive resistance of the rotor $X`_2=21.05$ Ohm, magnetization resistance $X_m=359.43$ Ohm, the number of stator windings $w_1=169$, the number of nominal rotations $n=1380$ per/min.

At the nominal values of the asynchronous motor, the stator currents reached stability in the time interval $t=0.07\div0.075$ *sec*. The time for the stator currents to stabilize can be seen through the oscillograms determined practically using the CassyLAB device (Figure 1) [4].

The static characteristics of the signals coming from the electromagnetic current converter for the control and management of the filter-compensation devices of the reactive power of the three-phase asynchronous motor are determined by the analytical expressions of the model developed on the basis of the graph theory. Analytical expression of the voltages coming out of the loop of one sensing element loop arranged in a suitable order with the stator windings representing the stator current of an asynchronous motor and suitable for each phase is as follows:

$$U_{out} = K_{U_{out}F_\mu} \Pi_\mu K_{I_1F_\mu} I_1$$

where $K_{U_{out}F\mu}$ – $F_{\mu x}$ is the inter-chain coupling coefficient of the conversion of the magnetomotive force in the air gap Fmx into the output voltage U_{out}, $K_{I1F\mu}$ – $F_{\mu x}$ is the inter-chain coupling coefficient of the conversion of the stator current $F_{\mu x}$ into the magnetomotive force in the air gap, Π_μ – U_{out} is the magnetic parameter related to the output voltage U_{out}.

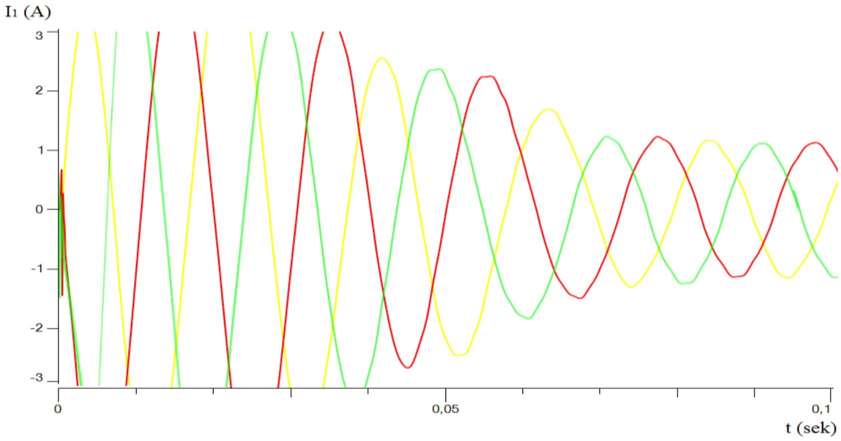

Figure 1. Description of the dependence of stator currents on time.

The static characteristics of the signals coming from the electromagnetic current converter for the control and management of the filter-compensation devices of the reactive power of the three-phase asynchronous motor are determined by the analytical expressions of the model developed on the basis of the graph theory. Analytical expression of the voltages coming out of the loop of one sensing element loop arranged in a suitable order with the stator windings representing the stator current of an asynchronous motor and suitable for each phase is as follows:

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Since the number of windings of the sensing element is proportional to the output signals, their number is selected based on the geometric size of the gap between the winding and the wedge on the stator groove, and in addition, the normalized output voltage from the sensing element (5 V) signals are required. The expression of the dependence of the stator current on the output voltage is given below (for phase A) [5, 6].

$$U_a = \frac{4.44 f w_{se} I_A \mu \mu_0 S_{se}}{\delta}$$

where f is the mains frequency, I_A is the stator current, S_{se} is the surface of the sensing element loop, w_{se} is the number of sensing element windings, δ is the air gap, μ is the magnetic permeability, μ_0 is the magnetic constant.

Figure 2 shows the dependence of the output voltage signal of the three-phase electromagnetic current converter of an asynchronous motor with one sensing element loop suitable for each phase, on the stator current.

The analytical expression of the voltages coming out of the two sensing element loops corresponding to each phase representing the stator current of a three-phase asynchronous motor is as follows:

$$\begin{cases} U'_{out} = K_{U'_{out}F_{\mu}} \Pi'_{\mu} K_{I_1 F_{\mu}} I_1 \\ U''_{out} = K_{U''_{out}F_{\mu}} \Pi''_{\mu} K_{I_1 F_{\mu}} I_1 \end{cases}$$

where $K_{U'outF\mu}$ – $F'_{\mu x}$ and $K_{U''outF\mu}$ – $F''_{\mu x}$ for the first and second loops are the coefficients of inter-circuit coupling of the conversion of the magnetomotive forces in the air gap into the output voltages U'_{out} and U''_{out}, $K_{I1F\mu}$ – $F'_{\mu x}$ and $K_{I1F\mu}$ – $F''_{\mu x}$ – the coefficients of inter-chain coupling of the conversion of the stator current into magnetomotive forces in the air gap, the magnetic parameters related to the output voltages Π'_{μ} – U'_{out} and Π''_{μ} – U''_{out}.

The static description of the electromagnetic current converter with two sensing element loops suitable for each phase, corresponding to the loops of the stator windings, placed between the poles and connected in series is defined as follows (for phase A) [7, 8].

$$U_{out} = U'_a + U''_a = \frac{4.44 f I_A \mu_0}{\delta}\left(w'_{se}\mu' S'_{se} + w''_{se}\mu'' S''_{se}\right)$$

where f is the mains frequency, I_A is the stator current, U'_a, U''_a are the voltages from the first and second sensing elements, S'_{se}, S''_{se} are the surfaces of the loops of the first and second sensing elements, w'_{se}, w''_{se} are the number of the first and second sensing element windings, δ is the air gap, μ is the magnetic permeability, μ_0 is the magnetic constant.

Figure 3 shows the dependence of the output voltage signal of the three-phase asynchronous motor electromagnetic current converter with two sensing element loops placed between the poles of the asynchronous motor stator, suitable for each phase, and the stator current.

The static description of an electromagnetic current converter with two sensing element loops, corresponding to the stator windings, placed between the poles and connected in parallel is defined as follows (for phase A) [9].

$$U_{out} = \frac{U'_a U''_a}{U'_a + U''_a} = \frac{4.44 f I_A \mu_0 w'_{se}\mu' S'_{se}}{(w'_{se}\mu' S'_{se} + w''_{se}\mu'' S''_{se})\delta} w''_{se}\mu'' S''_{se}$$

Figure 4 shows the dependence of the output voltage signal and stator current of a three-phase asynchronous motor electromagnetic current converter with two sensing element loops placed between poles and connected in parallel.

The static description of an electromagnetic current converter with two sensing element loops, corresponding to the wedges located on the stator windings, placed oppositely and mutually differentially connected, is determined as follows (for phase A) [10].

$$U_{out} = \frac{4.44 w_{se} f I_A \mu \mu_0 \sum S_{se}}{\delta}$$

where $\sum S_{se}$ is the sum of the surfaces of sensing elements.

Figure 5 shows the dependence of the output voltage signal of the three-phase asynchronous motor electromagnetic current converter with two oppositely connected sensing element loops on the stator current.

In the transient process of an asynchronous motor, its reactive power is also non-steady. The output voltage of the electromagnetic current converter is affected by the electrical and electromagnetic mechanical parameters of the asynchronous motor. The method of interconnection and placement of sensing element loops placed in the stator slots directly evaluates the sensitivity of the electromagnetic current converter and the accuracy of the output signals [11].

As a result of the magnetic currents generated by the three-phase stator currents $i_A(t), i_B(t), i_C(t)$, the output voltage $u_{a.out}(t), u_{b.out}(t), u_{c.out}(t)$ signals are obtained from the sensing elements. The output voltage in each phase is affected by the magnetic currents in the other two phases. Depending on the parameters of the sensing element with one loop, the output voltages from the electromagnetic current converter are as follows:

$$u_{a.out}(t) = -R_{a.se} \cdot i_{a.se}(t) - L_{a.se}\frac{di_{a.se}(t)}{dt} + w_{se}\left(\frac{d\Phi_b(t)}{dt} + \frac{d\Phi_c(t)}{dt}\right);$$

$$u_{b.out}(t) = -R_{b.se} \cdot i_{b.se}(t) - L_{b.se}\frac{di_{b.se}(t)}{dt} + w_{se}\left(\frac{d\Phi_c(t)}{dt} + \frac{d\Phi_a(t)}{dt}\right);$$

$$u_{c.out}(t) = -R_{c.se} \cdot i_{c.se}(t) - L_{c.se}\frac{di_{c.se}(t)}{dt} + w_{se}\left(\frac{d\Phi_a(t)}{dt} + \frac{d\Phi_b(t)}{dt}\right);$$

where $R_{a.se}$, $R_{b.se}$, $R_{c.se}$, $L_{a.se}$, $L_{b.se}$, $L_{c.se}$ are the active resistances and inductances of each phase of the stator winding, w_{se} is the number of windings of the sensing element, $i_{a.se}$, $i_{b.se}$, $i_{c.se}$ - currents in each phase of sensing elements [12].

Determining the dynamic description of the output voltages using mathematical expressions determined by the graph model of an asynchronous motor electromagnetic current converter with one sensing element loop is given below:

$$\begin{cases} U_{a.out} = K_{U_{a.out}F_\mu} W\,(F_{\mu s}, F_{\mu x}) K_{I_A F_\mu}\left(I_{A.d}\sin\omega t + I_{A.n} e^{-\frac{t}{T}}\right) \\ U_{b.out} = K_{U_{b.out}F_\mu} W\,(F_{\mu s}, F_{\mu x}) K_{I_B F_\mu}\left(I_{B.d}\sin(\omega t + 120^0) + I_{B.n} e^{-\frac{t}{T}}\right) \\ U_{c.out} = K_{U_{c.out}F_\mu} W\,(F_{\mu s}, F_{\mu x}) K_{I_C F_\mu}\left(I_{C.d}\sin(\omega t - 120^0) + I_{C.n} e^{-\frac{t}{T}}\right) \end{cases}$$

where $I_{A.d}$, $I_{B.d}$, $I_{C.d}$, $I_{A.n}$, $I_{B.n}$, $I_{C.n}$ are the periodic and non-periodic values of each phase current of the stator [13].

Determining the dynamic description of the output voltages using mathematical expressions defined by the graph model of an asynchronous motor electromagnetic current converter with two sensing element loops is given below:

$$\begin{cases} U'_{a.out} = K_{U'_{a.out}F_\mu} W\,(F'_{\mu s}, F'_{\mu x}) K_{I_A F_\mu}\left(I_{A.d}\sin\omega t + I_{A.n} e^{-\frac{t}{T}}\right) \\ U''_{a.out} = K_{U''_{a.out}F_\mu} W\,(F''_{\mu s}, F''_{\mu x}) K_{I_A F_\mu}\left(I_{A.d}\sin(\omega t - 180^0) + I_{A.n} e^{-\frac{t}{T}}\right) \\ U'_{b.out} = K_{U'_{b.out}F_\mu} W\,(F'_{\mu s}, F'_{\mu x}) K_{I_B F_\mu}\left(I_{B.d}\sin(\omega t + 120^0) + I_{B.n} e^{-\frac{t}{T}}\right) \\ U''_{b.out} = K_{U''_{b.out}F_\mu} W\,(F''_{\mu s}, F''_{\mu x}) K_{I_B F_\mu}\left(I_{B.d}\sin(\omega t - 60^0) + I_{B.n} e^{-\frac{t}{T}}\right) \\ U'_{c.out} = K_{U'_{c.out}F_\mu} W\,(F'_{\mu s}, F'_{\mu x}) K_{I_C F_\mu}\left(I_{C.d}\sin(\omega t - 120^0) + I_{C.n} e^{-\frac{t}{T}}\right) \\ U''_{c.out} = K_{U''_{c.out}F_\mu} W\,(F''_{\mu s}, F''_{\mu x}) K_{I_C F_\mu}\left(I_{C.d}\sin(\omega t - 300^0) + I_{C.n} e^{-\frac{t}{T}}\right) \end{cases}$$

where $I_{A.d}$, $I_{B.d}$, $I_{C.d}$, $I_{A.n}$, $I_{B.n}$, $I_{C.n}$ are the periodic and non-periodic values of each phase current of the stator.

According to the dynamic characteristics, the electromagnetic current converter with one sensing element loop and two sensing elements loops, suitable for each phase, has a single sensing element loop and two sensing element loops by means of the settling time of the output signals, the location of the loops in the stator grooves and the connection methods. Time dependence descriptions of series, parallel and differential connected electromagnetic current converters were determined [14].

A graph of the time dependence of the output voltages determined by the CassyLAB device based on the nominal values of a three-phase electromagnetic current converter with one sensing element loop for each phase placed on the stator grooves is presented (Figure 6).

Time dependence graphs of the output voltages determined by the CassyLAB device based on the series, parallel and differential connections of the asynchronous motor three-phase electromagnetic current converter loops, which are suitable for each phase of the stator grooves and have two sensing element loops placed between the poles, and based on the nominal values are given. (Figure 7, Figure 8, Figure 9) [15, 16].

3. Results and Discussion

The static characteristics of the dependence of the output voltage signals on the stator current of an asynchronous motor with one sensing element loop or two sensing element loops suitable for each phase of the three-phase electromagnetic current converters were determined by applying intermediate loads equal to the shaft of the asynchronous motor, and they are as follows;

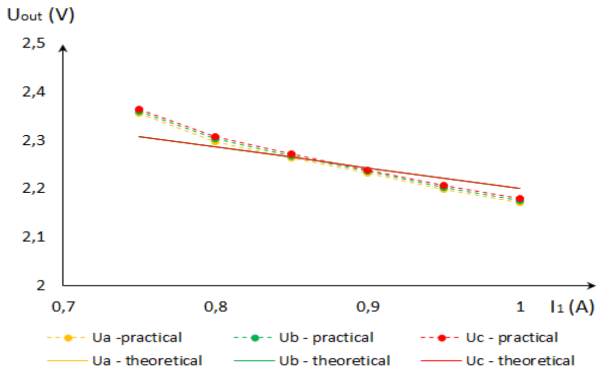

Figure 2. Dependence of the output voltage of an electromagnetic current converter with one sensing element loop suitable for each phase on the stator current of an asynchronous motor.

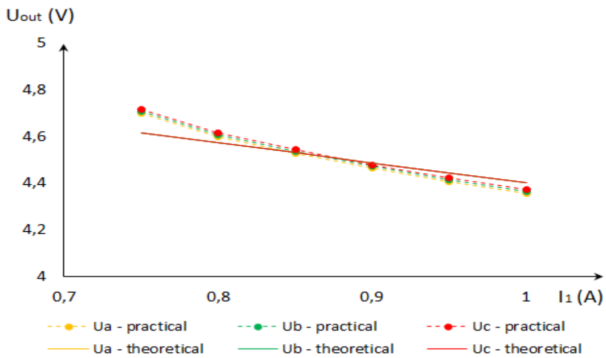

Figure 3. Dependence of the output voltage of an asynchronous motor stator current of an electromagnetic current converter with two sensing element loops placed between the stator poles and connected in series for each phase.

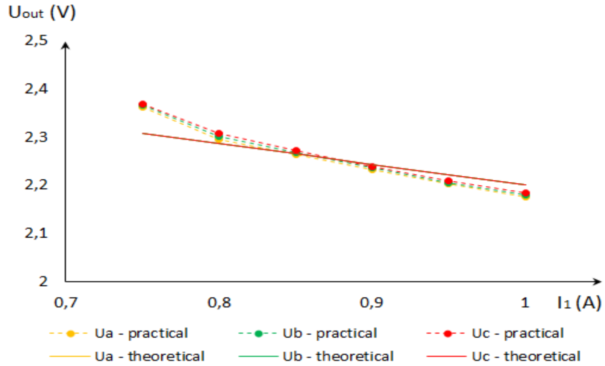

Figure 4. Dependence of the output voltage on the stator current of an electromagnetic current converter with two sensing element loops, which are placed between the stator poles and connected in parallel for each phase.

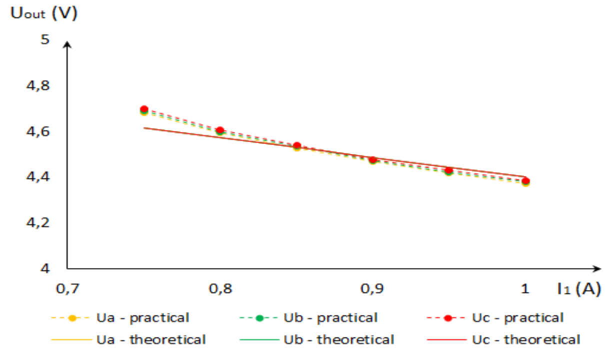

Figure 5. Dependence of the output voltage of an asynchronous motor stator current of a differentially connected electromagnetic current converter with loops of two sensing elements suitable for each phase.

The dynamic description of the electromagnetic current converter with one sensing element loop suitable for each phase, according to Figure 6, it can be seen that the output voltages are quantitatively small and the influence of high harmonics on the sinusoidal shape of the output signal, and the time for the output voltage to reach the stability of the stator current, we can see that it is slightly larger than the arrival time.

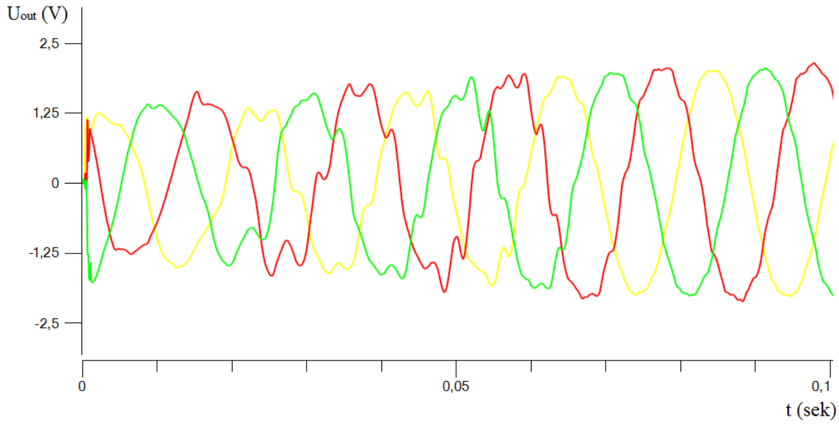

Figure 6. Time-dependent graph of the output voltage of an electromagnetic current converter with one sensing element loop suitable for each phase.

The dynamic description of the electromagnetic current converter formed by the series connection of two sensing elements suitable for each phase through the CassyLAB device, according to Figure 7, the output voltages are close to the standard 5 V, the time for the output voltage to reach the stability of the stator we can see that the current is almost equal to the settling time and that the influence of higher harmonics on the output signal of the electromagnetic current converter during the starting of the induction motor is less than that of the single-phase current converter.

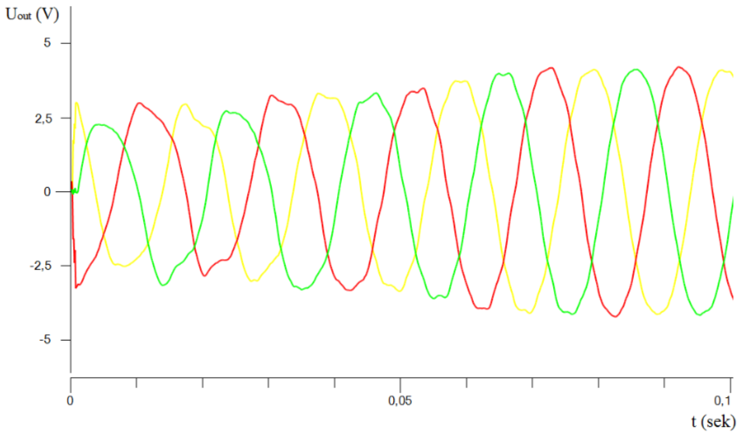

Figure 7. Time graph of the output voltage of an electromagnetic current converter with two sensing element loops placed between the stator poles and connected in series for each phase.

The practical dynamic description of the output signal of an electromagnetic current converter with two sensing element loops, suitable for each phase and connected in parallel, placed on the interpole heads of the stator. According to Figure 8, the output voltage is equal to the output voltage of an electromagnetic current converter with a single loop, and the high harmonics of the output we can see the effect on the signal.

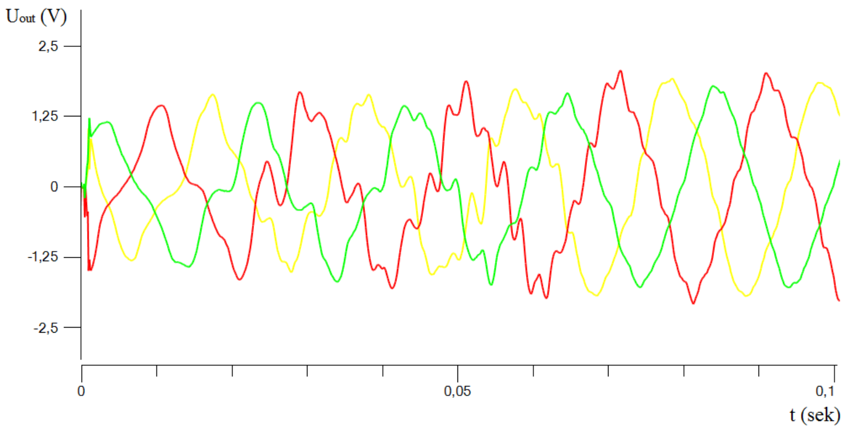

Figure 8. Graph of the time dependence of the output voltage of an electromagnetic current converter with two sensing element loops placed between the stator poles and connected in parallel for each phase.

The determined dynamic description of the output signal of an electromagnetic current converter with loops of two sensing elements placed in the slots where the stator windings are located and differentially connected. According to Figure 9, the value of the output voltages is equal to the signals of the current converter whose loops are connected in series, to the output signals of the upper harmonics we can see that the effect is small and the settling time of the signal is equal to the settling time of the stator current.

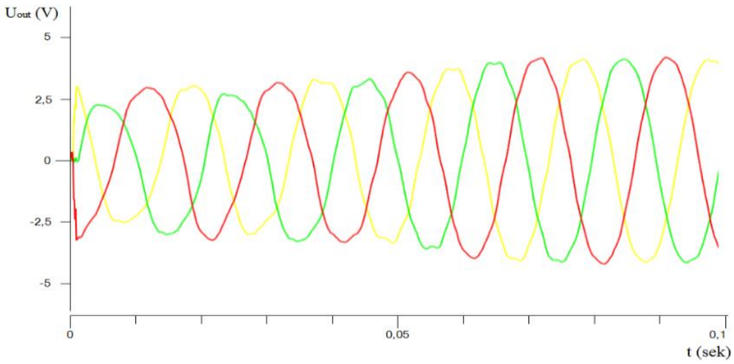

Figure 9. A time-dependent graph of the output voltage of a differentially connected electromagnetic current converter with two sensing element loops suitable for each phase.

4. Conclusion

Based on theoretical calculations and practical results and graphs using the CassyLAB device, the output voltages from the series, parallel and differential connected sensing elements of the three-phase electromagnetic current converter of an asynchronous motor with one sensing element loop and two sensing element loops, based on the time dependence characteristics of $U_{out}=f(t)$, we come to the following conclusion, that is, the start-up time of an asynchronous motor at nominal load is after $t=0.07\text{-}0.075$ *sec*, depending on the parameters of the asynchronous motor reached steady state (Figure 1), according to which we can see that the stator current and output voltages take the same time to reach the steady state.

Adequacy of output signals of three-phase electromagnetic current converters of asynchronous motor with one sensing element loop or two sensing elements loops suitable for each phase was determined by static characteristics.

Based on the dynamic characteristics, the influence of high harmonics during the transient process and the time to reach stability of the output signals of the asynchronous motor three-phase electromagnetic current converters with one sensing element loop or two sensing elements loops suitable for each phase were determined.

According to the static and dynamic characteristics of electromagnetic current converters with one sensing element loop or two sensing elements loops, compatible with the stator windings discussed above, three-phase electromagnetic current converter output with sensing element loops is differentially connected (Figure 5 and Figure 9), suitable for each phase. it was found that the accuracy of the voltage signal is high.

Based on the results of the research, we can conclude that the time of reaching stability of the output voltages of three-phase electromagnetic current converters with one sensing element loop or two sensing elements loops are almost equal to the time of reaching stability of the stator currents, and because the output voltage signals represent reactive power, the asynchronous motor is reactive. It is effective to use three-phase currents as electromagnetic current converters for the control and management of power filter-compensation devices.

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