Research algorithm and dynamic characteristics of three-phase electromagnetic current transducers in filter-compensation devices

Mokhirbek Makhsudov[1*], *Dilyorbek* Karimjonov[1]

[1]Andijan Machine - Building Institute, 170019, Uzbekistan, Andijan, Bobur shakh St. 56

Abstract. The article presents a three-phase current transducer for filter-compensation devices, representing the value of the stator current of an asynchronous motor. An algorithm for determining the values of the output electric quantities in them was developed based on the methods of interconnecting the loops of the sensitive element of the three-phase electromagnetic current transducer arranged in accordance with the stator slots of the asynchronous motor. In addition, based on this algorithm, the time-dependent dynamic characteristics of the output signal of the sensitive element loops are determined according to the connection method. Based on the dynamic description, it is possible to see the time for the output voltage signal of the three-phase current transducer to reach stability and the effect of high harmonic currents affecting it. Theoretical studies were carried out in Matlab program, and practical studies were carried out using CassyLab device. The theoretical and practical results determined because of research are compared with each other.

1 Introduction

It is important to research three-phase electromagnetic current transducers for the control and management of filter-compensation devices of asynchronous motor reactive power based on the time-dependent characteristics of the values of the output signals. The parameters of the asynchronous motor and the sensitive element, as well as the time-dependent change of the output voltage signals, are determined by dynamic descriptions [1-3].

Dynamic descriptions combine the expressions formed by the graph model of the electromagnetic current transducer, FTEs and descriptions of the electromagnetic current transducer in different operating modes of the asynchronous motor. By researching the dynamic characteristics of an asynchronous motor electromagnetic current transducer, 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.

Taking into account the interaction of the quantities with different characteristics affecting the electromagnetic current transducer, the dynamic characteristics of the voltage signal coming out of the sensitive element are studied, the differential equations characterizing the output signals and representing the transition processes are created. Determining the dynamic characteristics of an asynchronous motor electromagnetic current transducer is carried out on the basis of theoretical calculations, i.e., the formed graph model, its analytical expressions, simulation models developed using the Matlab program, and practical results determined by modern technologies [4].

A complete study of dynamic processes is achieved based on the analysis of the electrical and electromagnetic processes of the asynchronous motor based on the number and connection scheme of the sensitive elements of the electromagnetic current transducer. It is important to determine the dynamic characteristics of series, parallel and differentially connected electromagnetic current transducers with one sensitive element loop or two sensitive element loops and to compare them [5-7].

2 Experimental research

For the control and management of asynchronous motor filter-compensation devices, the number of sensitive element coils suitable for each phase of three-phase electromagnetic current transducers is taken at an equal value, as a result, it is possible to determine the amplitude and phase asymmetries generated between phases [8,10].

In the study of dynamic characteristics, a 4A63 type asynchronous motor with a rated power of P=250 W, with stator windings connected in a star form, was taken. The active resistance of the stator winding R_1=38.51 Ohm, the inductive resistance X_1=21.05 Ohm, the active resistance of the rotor $R`_2$=35.94 Ohm, the inductive resistance $X`_2$=21.05 Ohm, the

* Corresponding author: mohirbek2702@mail.ru

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magnetizing resistance X_m=359.43 Ohm, the number of windings of the stator windings w_1= 169, the number of nominal revolutions n=1380 rpm.

It was found that at the nominal values of the asynchronous motor, the stator currents reach stability in the time interval t=0.07÷0.075 sec. The time of stator currents reaching stability can be seen through the simulation model created in the Matlab program and the oscillograms determined practically using the CassyLab device (Fig. 1 and Fig. 2).

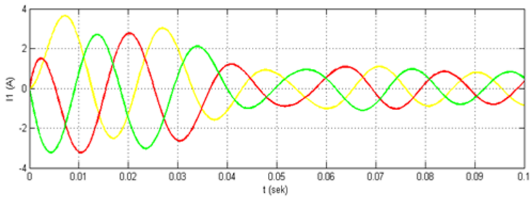

Fig. 1. Dynamic description of the stator currents determined by Matlab software through the switching scheme of an induction motor three-phase electromagnetic current transducer.

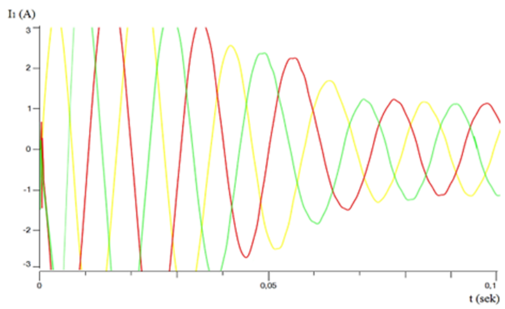

Fig. 2. Dynamic characterization of stator currents practically determined by the CassyLab device.

Mathematical expressions for determining the dynamic characteristics of the output voltages through the graph model of an asynchronous motor three-phase electromagnetic current transducer with one sensitive element loop suitable for each phase are 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.

The dynamic description of the output voltages is determined using mathematical expressions defined by the graph model of an induction motor three-phase electromagnetic current transducer with two sensitive element loops suitable for each phase is given below:

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

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.

In the transient process of an asynchronous motor, its reactive power is also unstable. The output voltage of the three-phase electromagnetic current transducer is affected by the electrical and electromagnetic mechanical parameters of the asynchronous motor. The number of loops of sensitive elements placed in the stator slots, their interconnection methods and their location directly evaluate the sensitivity of the electromagnetic current transducer and the accuracy of the output signals [9].

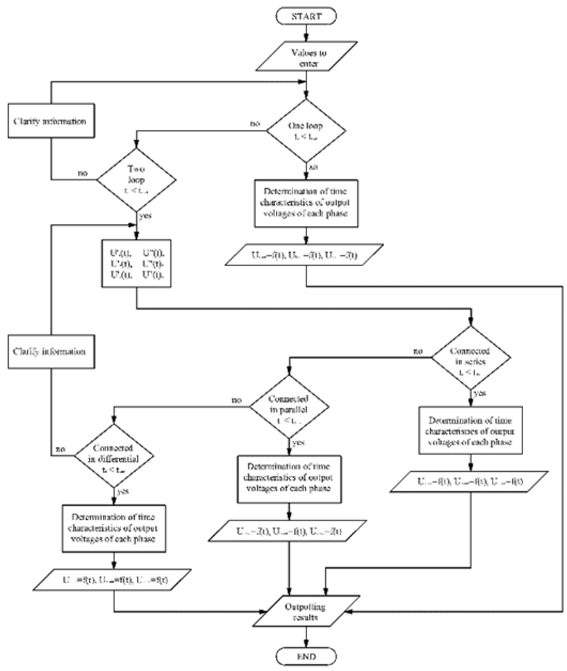

Fig. 3. Algorithm for studying the dynamic characteristics of the three-phase electromagnetic current transducer of an asynchronous motor.

Dynamic characteristics of three-phase electromagnetic current transducers with one sensitive element loop or two sensitive element loops suitable for each phase of the stator coils are studied based on the algorithm showing dynamic characteristics. The dynamic characteristics of series, parallel and differentially connected three-phase electromagnetic current transducers with one sensitive element loop suitable for each phase and two sensitive element loops are determined by the time of output signals reaching stability, location of loops in the stator wedges and connection methods (Fig. 3) [11].

3 Research results

Based on the above-mentioned expressions and algorithm, the simulation model of the three-phase electromagnetic current transducer with one sensitive element suitable for each phase, based on the commutation scheme, developed in the Matlab program and the dynamic descriptions determined by them are presented below (Fig. 4 and Fig. 5);

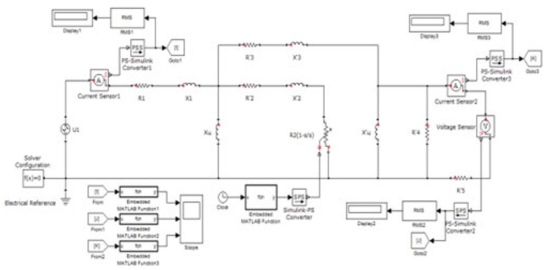

Fig. 4. A model for researching the dynamic characteristics of a three-phase electromagnetic current transducer with one sensitive element for each phase using the Matlab program.

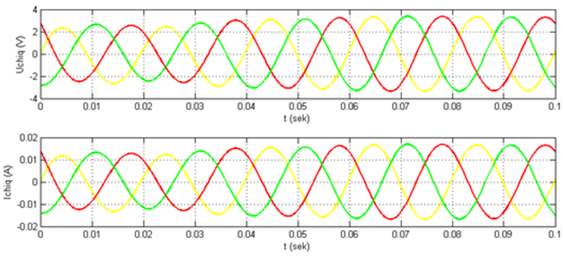

Fig. 5. Dynamic characteristics of a three-phase electromagnetic current transducer with one sensitive element for each phase determined using the Matlab program.

The simulation model for the study of three-phase electromagnetic current transducers developed using the Matlab program, with two sensitive element loops placed between the poles and in line with the stator coils, connected in series and parallel, and placed opposite to the slots where the stator coils are located and differentially connected, and their dynamic descriptions are presented below (Fig. 6, Fig. 7, Fig. 8 and Fig. 9);

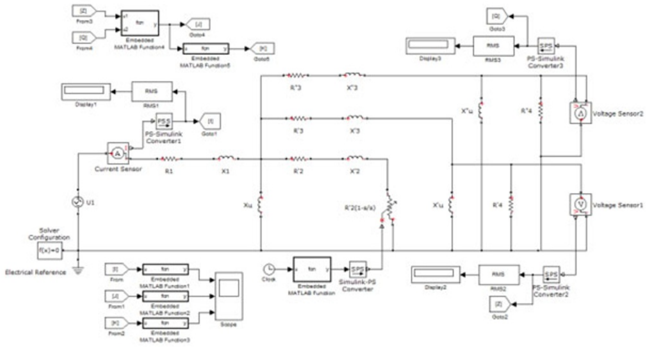

Fig. 6. A model for studying the dynamic characteristics of a three-phase electromagnetic current transducer with two sensitive element loops suitable for each phase using Matlab software.

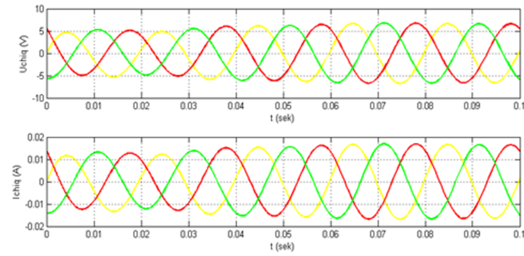

Fig. 7. Dynamic characteristics of a three-phase electromagnetic current transducer with series-connected sensitive element loops determined using the Matlab program.

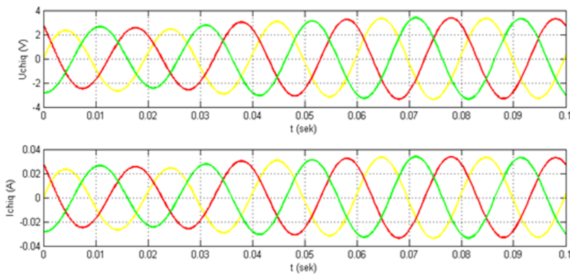

Fig. 8. Dynamic characteristics of a three-phase electromagnetic current transducer with parallel-connected sensitive element loops determined using the Matlab program.

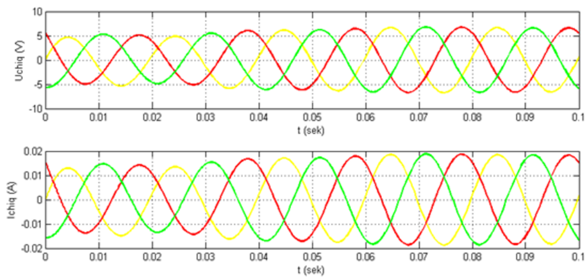

Fig. 9. Dynamic characteristics of a three-phase electromagnetic current transducer with differentially connected sensitive element loops determined using the Matlab program.

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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 transducer with one loop, suitable for each phase placed on the stator wedges, is presented (Fig. 10).

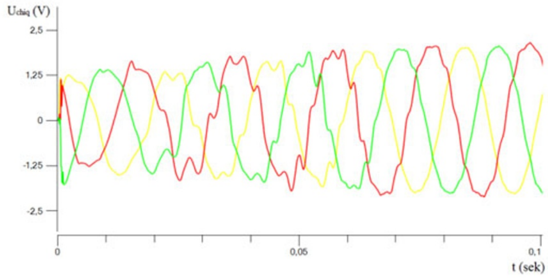

Fig. 10. A plot of the output voltages versus time of a three-phase electromagnetic current converter with sensitive element rings, determined practically by the CassyLab device.

Asynchronous motor three-phase electromagnetic current transducer loops with matching and two sensitive element loops for each phase placed in the stator slots are connected in series, parallel and differential and based on the nominal values, the graphs of the time dependence of the output voltages determined by the CassyLab device are presented below (Fig. 11, Fig. 12, and Fig. 13);

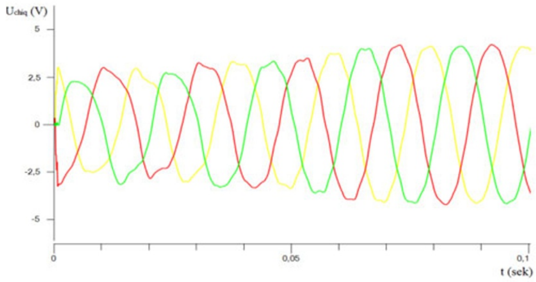

Fig. 11. Time-dependent graph of the output voltages of a three-phase electromagnetic current transducer with series-connected sensitive element loops, determined practically by the CassyLab device.

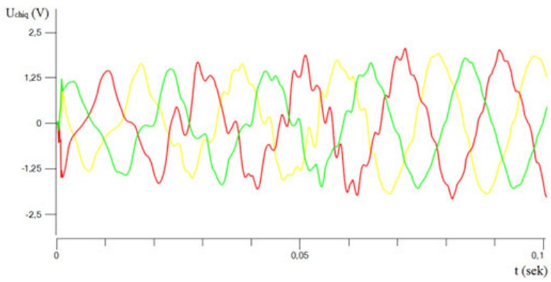

Fig. 12. Time-dependent graph of the output voltages of the three-phase electromagnetic current transducer with parallel-connected sensitive element loops, determined practically by the CassyLab device.

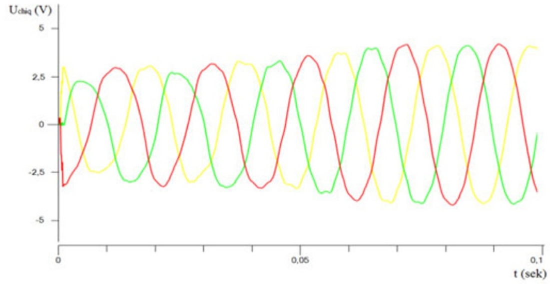

Fig. 13. Time-dependent graph of the output voltages of a three-phase electromagnetic current transducer with differentially connected sensitive element loops, determined practically by the CassyLab device.

During the start of the asynchronous motor, the number of rotations of the rotor and the inductance of the stator coils increase the stator current several times, as a result of the number of rotor revolutions approaching the nominal value and the interaction of magnetic currents, the stator currents become sinusoidal [12].

4 Conclusion

1. On the basis of theoretical calculations, simulation model of Matlab program and CassyLab device, based on practical results and graphs, asynchronous motor three-phase electromagnetic current transducer with one sensitive element loop and two sensitive element loops with serial, parallel and differential connected sensitive elements. voltages U_{out}=f(t) and stator currents I_1=f(t) based on the time dependence characteristics, it was determined that the start-up time of an asynchronous motor at nominal load reaches a steady state after t=0.07-0.075 seconds, depending on the parameters of the asynchronous motor.

2. Dynamic description of a three-phase electromagnetic current transducer with one sensitive element suitable for each phase, according to Figure 10, we can see 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 stability is t=0.068 seconds.

3. The dynamic description of the three-phase electromagnetic current transducer formed by the series connection of two sensitive element loops suitable for each phase, determined practically by the CassyLab device, according to Figure 11, the output voltages are close to the standard 5 V, the time for the output voltage to reach stability t =0.04 seconds, and we can see that the influence of higher harmonics on the output signal of the three-phase electromagnetic current transducer duloop the starting of the asynchronous motor is less than that of the single-phase current transducer.

4. Practical dynamic description of the output signal of an electromagnetic current transducer with two sensitive element loops placed on the interpolar heads

of the stator and connected in parallel. Based on Figure 12, the output voltage is equal to the output voltage of an electromagnetic current transducer with one loop, the effect of higher harmonics on the output signal and achieving stability It was determined that the time is t=0.072 seconds.

5. Based on Figure 13, the determined dynamic description of the output signal of the three-phase electromagnetic current transducer, which has loops of two sensitive elements placed in the slots where the stator coils are located and differentially connected, the value of the output voltages, the equality of the loops with the signals of the current transducer connected in series, according to the output signals of high harmonics we can see that there is little mystery and the time to reach stability is t=0.033 seconds.

6. Based on the results of research, we come to the conclusion that the three-phase electromagnetic current transducer with two sensitive element loops, placed opposite the wedges where the stator windings are located and differentially connected, has a short time to reach the stability of the output signals, and it was found that the influence of high harmonic currents on the output voltage signals is small. Since the output voltage signals of the investigated three-phase electromagnetic current transducers represent reactive power, it is effective to use three-phase currents as electromagnetic transducers for the control and management of filter-compensation devices of the reactive power of an asynchronous motor.

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