HIGH-FREQUENCY DIAGNOSTICS OF INSULATION OF WINDINGS OF LOW-VOLTAGE INDUCTION MOTORS

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Justification. Electrical motors make up the vast majority of all electric since motors these are mass-produced machines. They are installed in practically all common and industrial devices and mechanisms. These machines are simple in design and construction, which is a guarantee of reliability. That is why the producers always try to do these motors as brussless motors. Induction motors with different types of rotors occupy a special place among them. However, the main advantage and disadvantage of these machines are the stator winding that is easy to manufacturing made of enamelled wire of round section.

Despite the considerable interest of researchers in this field, the problem of creating highly sensitive techniques for detecting short-circuited coil in multi-turn coils has not been fully solved yet. In many works the idea of high-frequency diagnosis of windings was used. These methods can be considered as advanced in the diagnosis of insulation of windings of electric machines and finding of short-circuited turns, as they are non-destructive methods of control. The advantage, first of all, is that the test can be performed repeatedly without damaging the winding during the tests themselves. It is very important for the production and repair of electrical machines, as it allows economizing during their manufacturing, it gives the possibilities to detect a defect in the early stages of production or repair, for example, immediately after the winding in the grooves.

It is also important that with the modern development of conversion technology and the low cost of low power semiconductor devices, the high frequency methods proposed below are the most cost effective.

Their versatility is that they can be applied to all types of machines, despite their power. High-frequency methods are easily automated to monitor or to control constantly the state of the winding of an electric machine in responsible drives.

That is why this work is an important prolongation of the development of methods for finding inter-turn short circuits at high frequency.

Aims and Objectives of the Research. The purpose of the dissertation is to evaluate the diagnostic parameters under the conditions of thermal effects on low-power electric machines of general purpose with bulk windings when using high-frequency processes and modeling integral and local defects of insulation.

The objectives of the research are:

1) to investigate a mathematical model of winding and experimentally determine the winding parameters;

2) to determine experimentally high-frequency characteristics;

3) to compile the scheme of substitution in the MatLab Simulink package and calculate its parameters;

4) to model the frequency characteristics in the MatLab Simulink package.

Materials and research results. During developing the methods for diagnosing electrical equipment, the main task is to determine the optimal set of parameters that characterize the technical condition of the controlled object. Parameters whose values should be measured during diagnostics of electrical equipment are characterized by nominal values and tolerances, as well as dependencies of nominal values on the external environment, for example, the leakage currents of insulation by the degree of moisture, patterns of change depending on the time of operation and the required accuracy.

Grandi et al. [1] have developed a basic simulation scheme for winding an electric machine that can be applied over a wide frequency range(Fig. 1). A method for estimating the initial parameters of a simulation scheme is proposed. It is described that the parameters were determined by trial and error, so that the results of the experiment coincide with theoretical calculations. Aldo Bogliett et al. [2] extended the application of the simulation scheme, in particular, induction, synchronous and brushless motors were considered. To analyze the behavior of high-frequency current, single-phase circuits with single-phase equivalent parameters were used. It is shown that the simulation scheme does not depend on the type of AC motor. The model parameters were estimated using phase-to-ground and phase-neutral impedance and phase measurements in the frequency range from 1 kHz to 1 MHz.

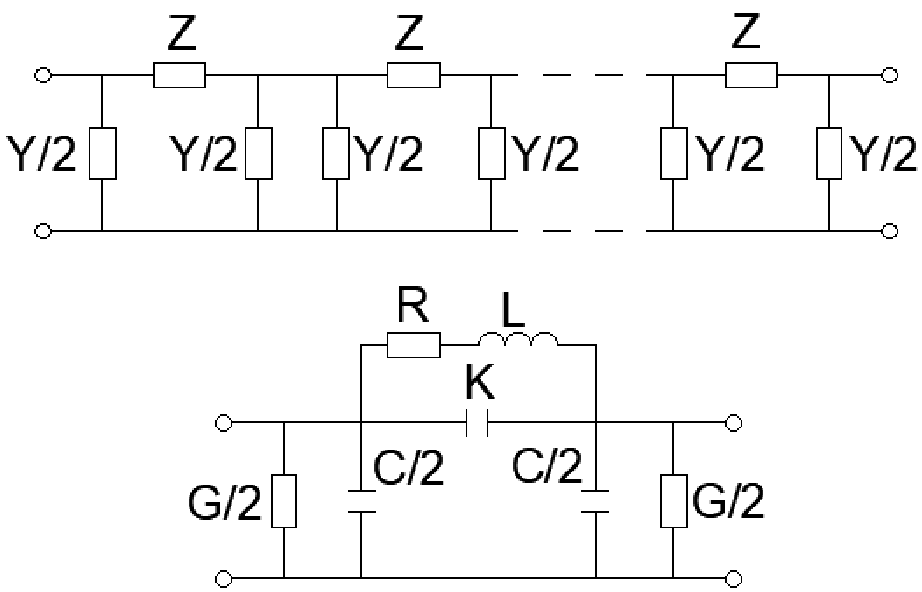

Figure 1 – Simulation scheme

Krause at al. [3] were among the first to propose a method of analysis convenient for modeling transmission systems and to demonstrate the function of a computer to simulate traveling waves in such systems. Computer analysis is also shown to describe the linearly charged transients of two coupled three-phase transmission systems.

Today, the most accurate tool for modeling high-frequency processes in electric machines is the MATLAB program. A scheme for modeling is proposed by Moreira et al. [4].

The main advantages of the scheme are as follows.

The voltage pulse created on the inverter can be adjusted to better represent the reality. This is important because the overvoltage characteristics are highly dependent on the harmonic voltage pulse content.

The engine parameters are obtained from the analysis of the experimental frequency characteristics of the motor resistances; as a result, for the analysis of overvoltages, the better visibility of the machine system is achieved.

The results of the simulation and experiment(Fig. 2 and Fig. 3) were presented, showing the utility of the program in the analysis of overvoltage.

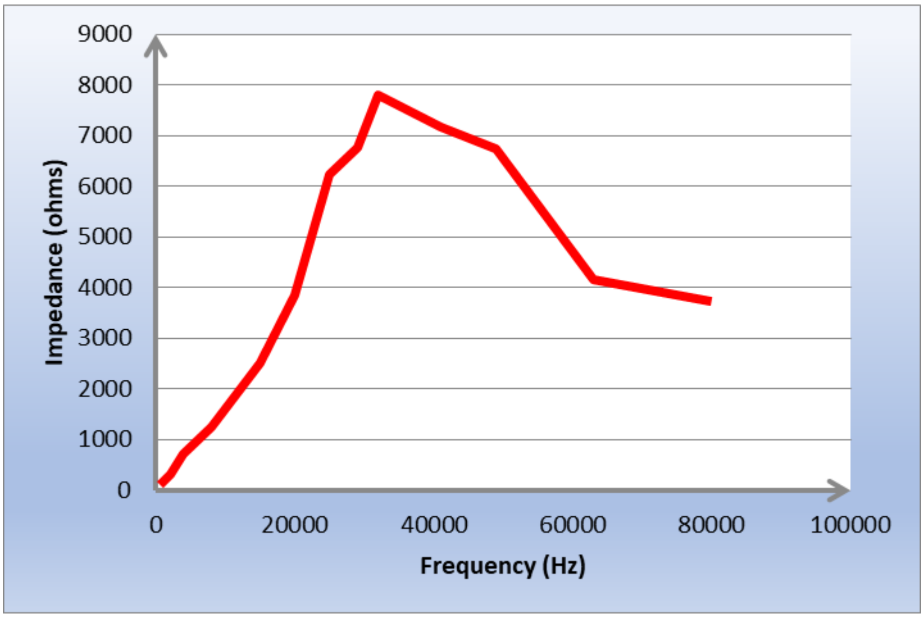

Figure 2 – Experimental results

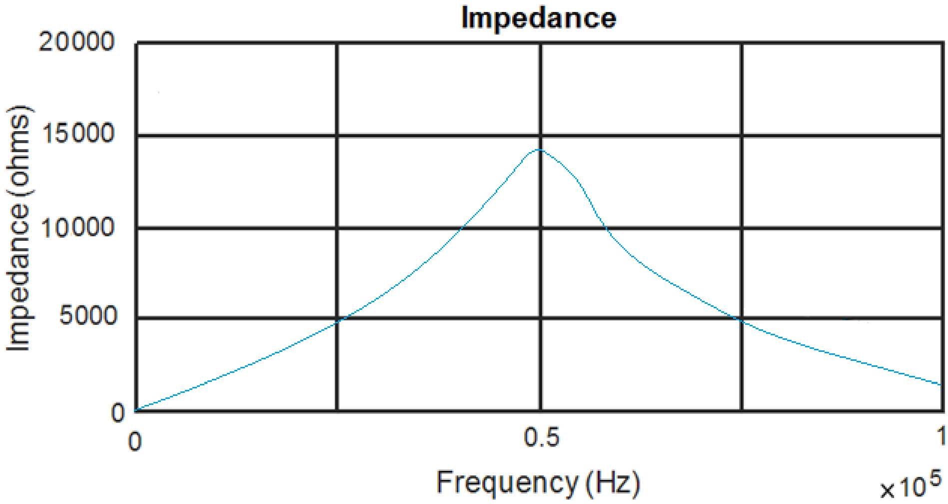

Figure 3 – Simulation results

Oslinger and Castro [5] noted that individual high frequency winding elements are characterized by a specific simulation scheme. It should be noted that such a scheme characterizes the winding elements in the pulse and wave processes. In experimental studies, the greatest difficulty is the allocation and determination of capacity. With a limited range of frequencies considered by the researcher, for example, at frequencies of the first and second resonance, the effect of the capacitance in the experiments is to some extent equivalent to some change in the basic parameters. Kaufhold at al. [6] have shown the possibility of dividing the capacitances at very high frequencies measured by megahertz; however, such experiments present considerable difficulties.

Tests related to artificial aging of insulation are widely used to investigate the methods of windings insulation of electric machines in order to simulate the deterioration mechanism in a short period of time. Farahani at al. [7] presented the results of extensive studies of the behavior of thermal insulation systems with thermal class F during artificial aging. These studies showed the dependences of several insulation properties of the state of the insulation structure, such as the scattering coefficient and the insulation resistance. A comparative analysis of the electrical and dielectric properties of insulation is performed, showing how changes in insulation occur during accelerated aging. Moisture is usually associated with changes in temperature conditions. The process of defect formation and the destruction of insulation proceeds initially quite slowly and only in the last stages it is abrupt, ending with a short circuit, explosion and destruction of the insulator. Sometimes the moisture has time to evaporate under the action of the released heat. If no conductive channel is formed, the defect development process may be paused, but if the conductive isolation channel is formed, permanent damage will be caused.

Conclusions. The frequency characteristics of the stator winding of a generator can be analyzed using its transfer function, similar to the method used for the frequency analysis of the transformer winding described by Tenbohlen at al. [8]. By applying low sinusoidal voltages of different frequencies at one end and measuring the response to it at the other end, the magnitude and phase of the transfer function can be determined. These values are comparable to the typical transmission functions of the transmission line and the ladder capacity of the network. Based on the differences in their characteristics, a frequency range within which a winding can be modeled, such as a power line or a ladder capacity, can be determined. Frequency components of the impulse transmission through the winding can be determined by using digital filtering methods, making it simple to determine the impulse behavior within a certain frequency range.

References

1. G. Grandi, D. Casadei, and A. Massarini,(1997) “High frequency lumped para-meter model for AC motor windings,” in Proc. EPE Conf., Trondheim, Norway, 1997, vol. 2, pp. 578–583.

2. A. Boglietti; Cavagnino A.; M. Lazzari (2007). Experimental High-Frequency Parameter; Identification of AC Electrical Motors. In: IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, vol. 43 n. 1, pp. 23-29. - ISSN 0093-9994

3. C. Krause, K. Carlsen, "Analysis and Hybrid Computer Simulation of Multiconductor Transmission Systems", *IEEE Transactions on Power Apparatus and Systems*, vol. 91, pp. 465-477, Mar/Apr 1972.

4. Alessandro F. Moreira, Member, IEEE, Thomas A. Lipo, Fello (2002) High-Frequency Modeling for Cable and Induction Motor Overvoltage Studies in Long Cable Drives, IEEE, Giri Venkataramanan, and Steffen Bernet, Member, IEEE

5. Jose Luis Oslinger, Luis Carlos Castro, "Correlation between capacitance and dissipation factor used for assessment of stator insulation", *Intern'l Journal of Electrical Engg.*, vol. -6, no. 3, 2012.

6. M. Kaufhold, K. Schafer, K. Bauer, A. Bethge, J. Risse, “Interface phenomena in stator winding insulation — challenges in design, diagnosis, and service experience,” IEEE Electrical Insulation Magazine, vol. 18, pp. 27-36, 2002.

7. M. Farahani, E. Gockenbach, H. Borsi, M. Kaufhold, K. Schäfer, "Behavior of machine insulation systems subjected to accelerated thermal aging test," IEEE Trans. Dielectrics and Electrical Insulation, vol.17, pp. 1364-1372, October 2010.

8. S. Tenbohlen, C. Breuer, F. Devaux, R. Lebreton, N. Schmidt, and T. Stirl, «Evaluation of the thermal performance of transformer windings by numerical investigations and measurements», CIGRE 2016, Paris, A2-309, 2016.