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Development of advanced winding condition control technology of electric motors based on pulsed method

Alexey V. Mytnikov*, Valeriy A. Lavrinovich, Arina M. Evseeva, Ivan A. Stepanov

Institute of Power Engineering, National Research Tomsk Polytechnic University, 7 Usova street, 634050, Tomsk, Russia

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ABSTRACT

More than 80 percent of all electrical energy customers are electric motors. Therefore one of the prospects of resource-effective technologies in power industry is control of rotating electric equipment condition. Winding defects are one of the main causes of electric motor failures. Reliable control of winding condition is an urgent task of modern electrical engineering technology. The present article is devoted to the research of pulsed method application of transformer winding control for electric motor winding condition control. The procedure of winding condition control technology is described. The proposed method is based on the known pulsed method. The essential difference between the two methods is that only one probing impulse is used which is a probing impulse and response signal at once. The results of diagnostic procedure research at different winding defects are given. It is established that the place of winding damage corresponds to characteristic impulse changes. The defect of definite types causes specific changes of the probing impulse form. Therefore, different winding defects could be found with high accuracy along winding.

1. Introduction

Electric motors of different power and voltage range levels are key elements of many industrial and technological processes. Control of electric motor condition is necessary to provide a stable work of a wide range of production plants. Winding damages are one of the reasons for electric motor failures. Therefore the development of technologies of electric motor winding condition control is an urgent task of modern electrical engineering. In industry a method of measuring winding resistance is widespread enough. However, this method can detect only absolute damage of winding. Spectral analysis of Park's vector modulus of current and voltage is promising among modern non-destructive technologies. Nevertheless, this method is rather complicated and needs further research [1,2]. Surge test is used and actively researched to found short-to-short circuit winding fault [3,4]. Vibration Analysis is popular control technology also [5,6]. Interesting approach is diagnosis method for turn-to-turn short-circuit insulation failure in winding based on frequency spectrum investigation [7]. Main requirements of the so called "ideal" modern method of diagnosing electric motor condition are formulated in [2]. They are the following:

- High reliability and accuracy of detecting malfunctions and electric motor damages;
- Possibility of detecting most electric and mechanical damages of electric motors and related mechanical devices;
- Carrying out diagnostic measurements remotely which is important when access to the equipment is complicated;
- Simplicity of diagnostic procedure stages and measurements);
- Possibility of carrying out analytical processing of the obtained measurement results within a short period of time, by means of software application.

Nowadays there are different technologies to reach of the above mentioned requirements. One way is pulsed method.

We are conducting the research on diagnostics of transformer windings. Our approach to the given problem lies in applying a pulsed method of transformer winding condition control to the electric motor. The pulsed method for controlling the mechanical condition of transformer windings was proposed and described in 1966. The method lies in applying a standard probing lighting impulse of 1.2/50 μs with an amplitude of 100–500 V to one of the windings. Other windings are short-circuited and the shunt giving a response to a probing impulse is installed in them. The response represents the signal corresponding to the transient, arising in windings, as reaction to the probing impulse influence. First of all, it was necessary to measure the so-called normogram – a re-

* Corresponding author.
E-mail address: mytnikov66@mail.ru (A.V. Mytnikov).

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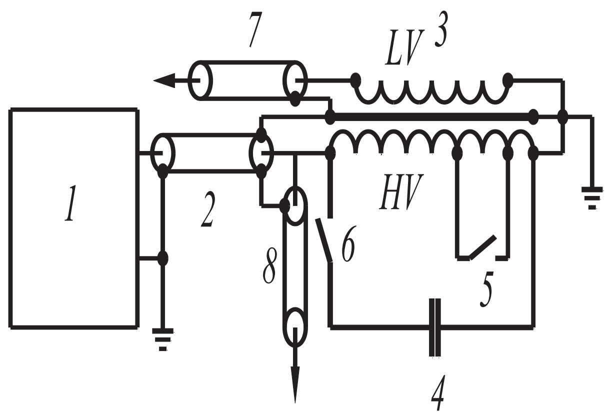

Fig. 1. Electric circuit of the experiment: 1 – the generator, 2 – the connecting coaxial cable with a wave resistance (impedance) of 75 Ohms and 2 m length, 3 – the diagnosed transformer (HV—high voltage, LV – low voltage), 4 – the condenser for change of the front of a probing impulse, 5 – short-circuit of turns, 6 – the commutator (switch) for connection of the condenser 4;7, 8 – probes for connection to a multichannel oscilloscope TDS 2024.

sponse from the winding of the transformer working properly. At the next tests the procedure of sounding is repeated. The comparison of normograms and current sounding (defectograms) allowed making a conclusion about the condition of the winding. The difference between the normogram and defectograms is the evidence of the problem in the winding. At the moment it is a routine method of transformer winding condition control which received the name the Low-Voltage Impulses method (LVI). At present it is used in more than 45 countries.

2. Method of diagnostics

Experimental method of diagnostics is the same for transformer winding. A nanosecond rectangular impulse was supplied on entrance of the high voltage coil. The response signal was measured on exit of the low voltage coil. Ocilloscopes Tektronix TDS 2024 were used to control the form of a probe impulse and response signals. The electric circuit of the diagnostics method is given in Fig. 1.

Any, even the most minor changes of windings geometry due to deformations, shifts, damages as a result of short-circuit currents, lead to change of capacities and inductances of winding turns. Hence, a winding reaction to a probing pulse changes as well. Specific change of the response frequency range depends on the size and nature of deformations. The rectangular impulse created by the generator was applied to a high-voltage winding of the transformer, the impulse-response was measured on a low-voltage winding of the transformer. Preliminary experiments have confirmed principal possibility and high sensitivity of the proposed method [8,9].

3. Preliminary results

We modified the LVI method in our High voltage laboratory. The proposed pulsed method is based on a short probing impulse (nanosecond range). Our experiments confirmed the effectiveness of nanosecond probing impulse use. The detailed results of this research are given in [8,9]. A nanosecond pulsed method was applied to control AC electric motor windings. The nanosecond probing impulse was applied to one of the motor phases; a response pulse was recorded from the other ones. The probing impulse has the main parameters of 200 V, 400 ns. Measurements of all signals were performed by oscilloscopes “Tektronix TDS 2012”. A diagnostic complex includes a nanosecond pulsed generator, designed for

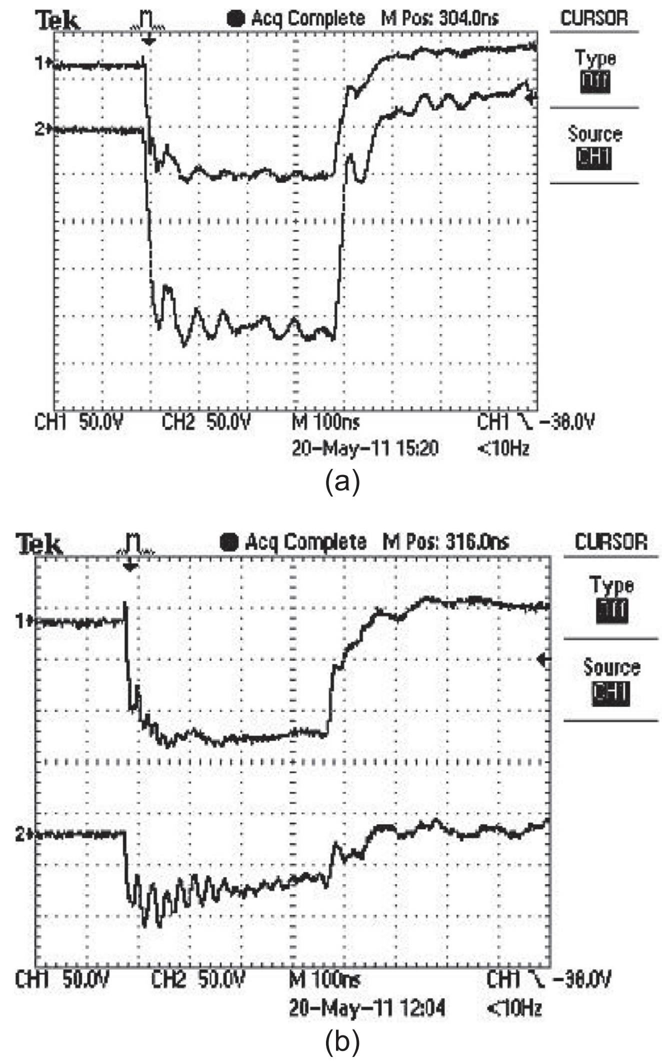

Fig. 2. Oscillograms for the case where the probing impulse is applied to “phase A-ground” and the response pulse is recorded in “phase B-ground”: (a) “healthy” motor, (b) winding A is damaged.

these purposes and electron oscilloscopes. A detailed description of the experimental equipment is given in [5–7]. Measurements were performed for two electric motors – new AC motor and a damaged electric motor with failed windings. The motors have the same type and construction. Fig. 2(a) illustrates the probe and response oscillograms for a “healthy” motor. The probing impulse was applied to the contact pair “phase A-ground”, the response impulse was recorded in the pair “phase B-ground”. Fig. 2(b) shows the same oscillograms, but for a damaged motor case. It is seen that, firstly, the probing impulse depends on winding condition; secondly, the response impulse has a lot of changes in case of the winding defect where the probing impulse is applied. Thus, the nanosecond pulsed technology (NPT) is sensitive enough for diagnostics of electric motor winding condition.

The comparison forms of response impulses for ‘healthy” and damaged cases showed that impulse distortion takes place in both cases. Specific changes of the impulse form allow determining the defect winding condition with high accuracy. This fact allows concluding that NPT could be successfully applied to electric motor winding diagnostics. In this case NPT is even more effective than for transformers, therefore, changes of both signals form – probing and response – are used for analysis. Fourier series expansion is not used in our analysis.

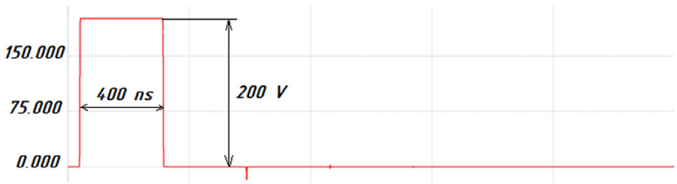

Fig. 3. View of the probing impulse used in model experiments of the condition control procedure.

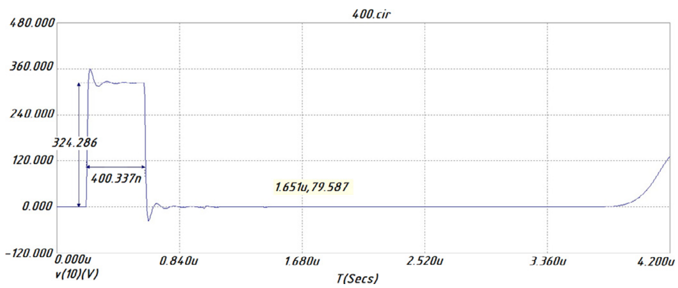

Fig. 4. View of the impulse at normal situation in winding.

4. Application of pulsed method to electric motor winding condition control

One of the main conclusions of the above experiments is principal possibility to control electric motor windings. During measurements it was noted that probing impulse changes depend on the situation in the winding studied. It allows carrying out condition control by means of one probing impulse.

To figure out this possibility a number of experiments was carried out. The above measurements were performed at the operating plant equipment. It is complicated if a complex technological regime is taken into account. Next experiments were carried out in the computer model of the electric motor winding. A special program “Microcap” was used for this purpose. The equivalent circuit of the nanosecond pulsed generator and winding was realized in the program. Values of resistances, inductances and capacitances of every turn of the winding were chosen very close to real ones. The view of the probing impulse used in model experiments of the condition control procedure is shown in Fig. 3.

Two defects were modeled, namely turn to turn short circuit and short circuit to the motor housing. The defects were modeled by changes of inductances and capacitances values. For example, at the turn to turn short circuit type defect, the values of inter –inductance, –resistance and –capacitance were considered as zero. The total number of turns in the winding is 60. Modeling of the condition control procedure lies in feeding the probing impulse to the winding input and recording all changes of the initial impulse form. Thus, as at this stage only one impulse is used, it is more appropriate to use the term “impulse” instead of “probing impulse”. At first the defect of “turn to turn short circuit” type is modeled. The view of the impulse at normal situation in the winding (no defects) is shown in Fig. 4.

Figs. 5–7 show impulse views for the winding defect of turn to turn short circuit type in the winding beginning, middle and end respectively.

At the second stage, the defect of “short circuit to ground” type is modeled. Figs. 8–11 show the impulse views for the winding defect of short circuit to the motor housing type in the winding beginning, middle and end respectively.

To develop pulsed method for motor winding diagnostics we built experimental bench - physical model winding. It is a pipe with diameter about 10 cm and 60 cm length. Wire from mate-

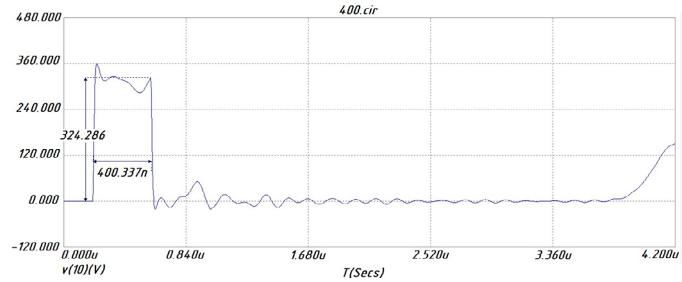

Fig. 5. View of the impulse at the turn to turn short circuit in area of 5–6 turns.

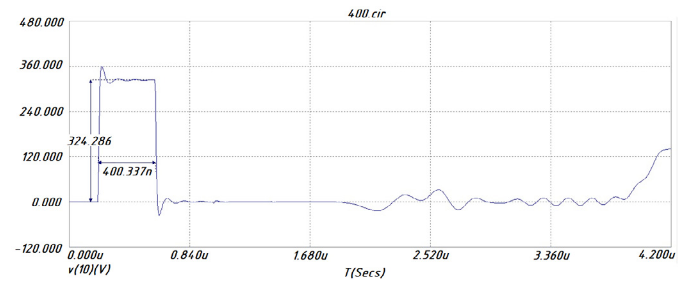

Fig. 6. View of the impulse at the turn to turn short circuit in area of 30–31 turns.

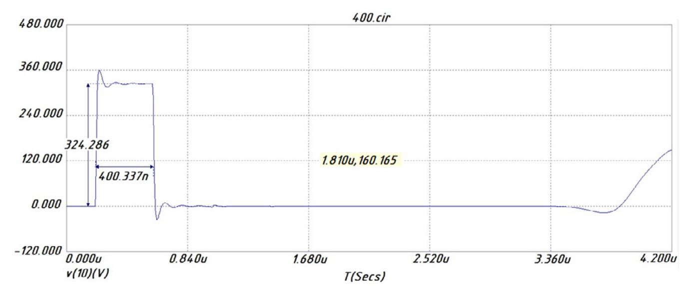

Fig. 7. View of the impulse at the turn to turn short circuit in area of 55–56 turns.

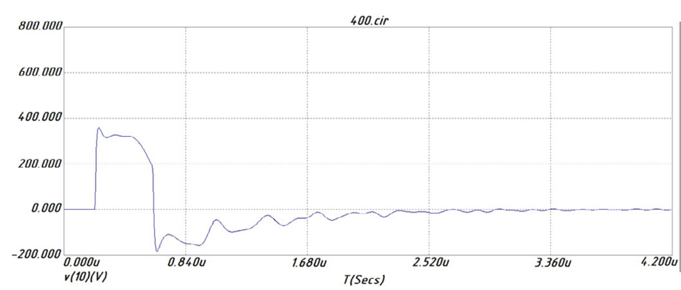

Fig. 8. View of the impulse at the short circuit to the motor housing in area of 5–6 turns.

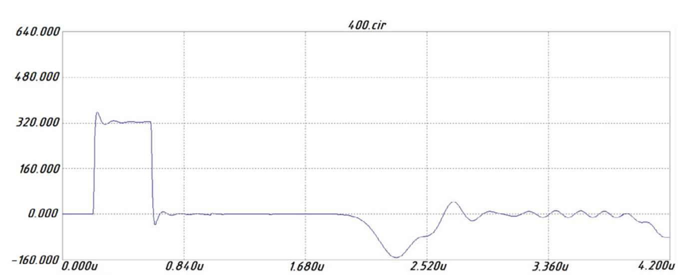

Fig. 9. View of the impulse at the short circuit to the motor housing in area of 30–31 turns.

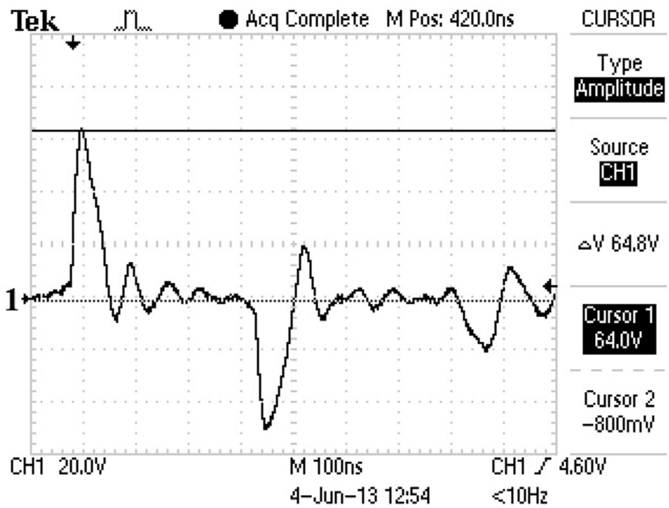

Fig. 10. View of the impulse at the short circuit to the motor housing in area of 30–31 turns, obtained in physical model of electric motor.

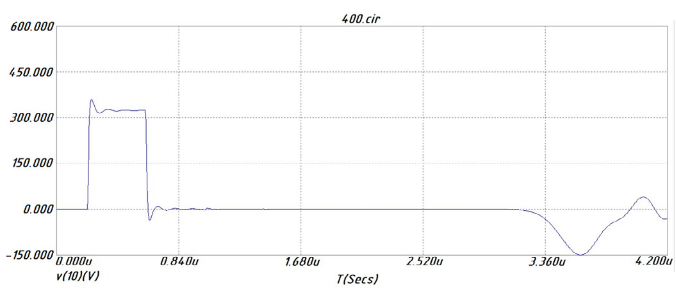

Fig. 11. View of the impulse at the short circuit to the motor housing in area of 55–56 turns.

rial of typical stator winding is reeled up on pipe. Special metal taps have been made along a winding to organize short-circuited turns. Scheme of probing impulse application and response signal measurement is illustrated on Fig. 1. Just one difference is instead transformer winding, model stator winding (pipe) is used. Probing impulse is applied to one side of the pipe, response is measured on other pipe by oscilloscope Tektronix TDS 2024.

Probing impulse has the main parameters of 200 V, 400 ns. Number and place of turns which are involved in short circuit corresponds to number and place of turns in computer model.

Fig. 10 illustrates a waveform of the probing impulse obtained in a physical model of electric motor. A coincidence is good enough.

The analysis of the obtained pulse waveforms for different situations in the winding shows that the impulse form changes depending on the defect type. One of the main results of the experiments is the fact that the proposed method can determine the place of the defect along the winding. All changes which are an evidence of the defect condition in the winding take place in the final part of the impulse, at the "after-impulse" region. A common rectangular form of the impulse main part is kept practically without changes. Some changes in the main part area are negligible and don't influence the whole picture. All important changes in the impulse form are at the area between the end of the main impulse and the end of the whole winding. Fig. 4 corresponds to normal condition of the winding; it does not have any emissions or splashes excluding the first peak which is common for all next pulse forms. In case of the defect, specific peaks occur corresponding to the defect place. Figs. 5–7 illustrate the place of the defect, which could be recorded exactly enough. Specific emissions and splashes on the impulse curve allow identifying namely this type of defect. The same situation takes place in case of the defect "short circuit to the motor housing" type. Specific emission in the "negative" part of the axis is characteristic of this defect type. The first peak corresponds to the place of the defect along the winding. Thus, the form of the impulse (first of all after-impulse area) correlates with the defect type.

5. Conclusion

The obtained results can be given as:

The pulsed method of the winding condition control of power transformers can be successfully applied for diagnostics of electric motor windings.

A coincidence of modeling and real construction results is good enough.

The presented condition control procedure allows revealing the defect type of the winding (turn to turn short circuit and short circuit to the motor housing.

The proposed method allows determining the place of the defect replacement along the winding.

The proposed method is based on the use of one impulse which is a probing impulse and response signal at once. No normograms are used at all.

The proposed method is simple for interpretation of results. It has good prospects in industry, because simplicity is one of the main requirements of modern technologies of condition control.

The results given are preliminary ones. The proposed method requires further detailed research; nevertheless, it is promising for the real industry.

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