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Diagnostics of insulating transformer properties

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Abstract

Article presents experimental analyses of transformers by insulating progressive time method RVM (Return Voltage measurement). The first part of article deals with the possibilities of diagnostic insulating analysis of power transformers. In the conclusion are the results which have mainly shows moisture content in distribution transformer 22/0.4kV. Thanks transformer diagnostics is assured higher protection of the environment from possible accidents of certain transformer.

Keywords: transformer, diagnostics, insulation, moisture

1. Introduction

With regard to the development of world and national economics, also control, maintenance and their analysis by mathematic calculations becomes an important sphere. This sphere also includes power transformers, where their proper function has a positive impact on the trouble-free supply of electricity and heat for industries and households. The importance of diagnostics at the premises of strategic significance, results not only from an economic viewpoint, but also because of safety and faultless operation, i.e. reliability of technical equipment in the power industry.

It is therefore necessary, in the absence of scientific and research potential in a distribution organizations (e.g. power plants, heating plants), to achieve the objectives of the proposed activities, i.e. in-depth analysis of undesirable impacts on the state of devices, design of measurements and their verification, and design of new diagnostic procedures for improving reliability of power transformers [1].

The presence of large amounts of moisture in the transformer results in a deterioration of the insulating state of the paper insulation resulting in an acute risk of thermal or electrical failure. Dielectric heating can be so high that the temperature rise becomes uncontrollable and the transformer becomes dangerous for its surroundings and the operation itself.

State evaluation of insulating the high-voltage oil equipment, particularly of oil conductivity and paper moisture, is becoming more significant for aged power transformers and also for quality control of new transformers in the manufacturing factory. The interest for reliable and easy to use diagnostic technique drove the development of dielectric response methods.

We need to know how transformer insulation cooperates between dielectric elements and how it works for running of the machine in operating ideal conditions.

The first approach, called recovery voltage method (RVM), is now obsolete. The newer methods, polarization and depolarization currents (PDC) and frequency domain Spectroscopy (FDS), have proven their suitability for transformer diagnostics and are now frequently used [2].

Thanks transformer diagnostics is assured higher protection of the environment from possible accidents of certain electrical devices (this particularly relates to power oil transformers, where oil leaks into the soil can cause disastrous consequences for the surrounding environment).

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2. The Basic Diagnostic Methods of Power Transformers

The most often methods use measurements of winding resistance and impedance, voltage ratio, insulation resistance, winding capacities are also measured in some cases. If it is possible in terms of machine dimension partial discharges are measured or by means of acoustic sensors implemented directly on the machine. The thermal camera can capture the distribution of the temperature fields of machines in their surface under load, etc. [3], [4].

Considering the influence of short-circuit forces, switching currents, overvoltage and other effects which damage coil of windings, electric or magnetic circuit and taps, the next measurements can be realized at disconnected power electric machines:

- Measurement of impedance parameters of electric machine depending on the frequency characteristics using the SFRA method (Sweep Frequency Response Analysis),
- Time measurement of machine coils of windings using the high-voltage pulse source - impact test,
- Measurement of basic parameters of transformer windings (resistivity, inductive, impedance) during short-circuit test,
- Structural analysis of the quality of insulating oil using chromatographic test [5],
- Breakdown analysis of insulating oil of high-voltage machines with regard to impact of operation,
- Measurement of insulation resistances, DC currents and voltages with combination of time dependency (PDC and RVM method)
- Measurement of values of capacity and loss factor,
- Measurement of parameters of isolation using dielectric spectroscopy,
- Combination of measuring methods according to the proposed diagnostic procedures.

The use of different measuring methods and diagnostic procedures is useful for tests of connected electric machine. These are for example thermovision, measurement of electromagnetic radiation, measurement of acoustic emission, on-line monitoring of temperature and moisture of electric machine. The electromagnetic radiation with other electrical devices may change depending on the result of shift or inter-turn short-circuits of the coil. [6]

The stated measurements allow us to detect the effects of short-circuit forces, overvoltage and over-currents. These effects can damage coils of windings and electric and magnetic circuit of the electric machine. The repair of electric machine is costly and time-demanding. [7]

Measurement of impedance and phase characteristics in dependence frequency by the SFRA method, measurement of time responses of coils of windings by the high-voltage impulse source and measurement of parameters of windings at short-circuited state belong to non-invasive diagnostic methods of transformers. There is no need of changing of the construction of the measured machine. Moreover they can be performed at disconnected electric equipment [8].

3. Diagnostics of Insulating Transformer Properties by Time Method PDC and RVM

In last few years several diagnostic techniques have been developed and used to determine the power transformer insulation. That means this techniques must determine insulator composed from transformer oil and paper in main. Named techniques are DGA (Dissolved Gas Analysis), DP (degree of polymerization) and Furan analysis by HPLC (High Performance Liquid Chromatography). In nowadays is possible to capture very low current involved in dielectric relaxation process. This is door open to technique like RVM (Return Voltage Measurement) or PDC (Polarization Depolarization Current). Those techniques have been introduced in 90's. This measurements technique has gained popularity for its ability to assess the condition of oil and paper separately without opening the transformer tank [9].

For PDC analysis is DC voltage step (amplitude U0) of some 100 V is applied between HW (high voltage) and LV (low voltage) windings during a certain time, the so-called polarization duration. Thus a charging current of the transformer capacitance, i.e. insulation system, the so-called polarization current, flows. It is a pulse-like current during the instant of voltage application which decreases during the polarization duration to a certain value given by the conductivity of the insulation system. After elapsing the polarization duration, the switch goes into the other position and the dielectric is short circuited via the ammeter. Thus, a discharging current jumps to a negative value, which goes gradually towards zero.

The simple measurement system of RVM method is shown in Fig.1 [10].

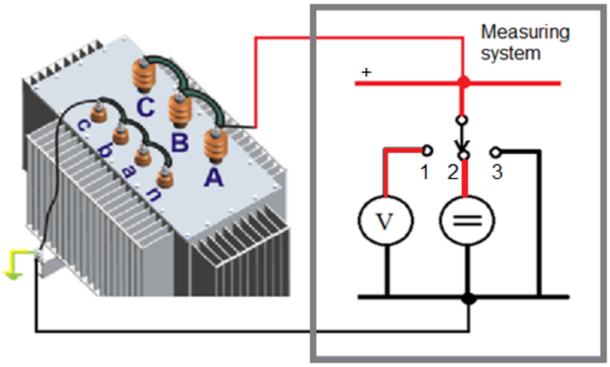

Fig. 1. Principal scheme of measurement on transformer by RVM method.

The RVM method consists of plotting the measured maximum response times with respect to the charging time, from which it is possible to determine the moisture content of the insulation in high-voltage oil equipment. In general, this method is intended for non-destructive, off-line determination of the state of the isolation system of transformers, cables or other devices that are comprised of the conductor and the insulator [11].

If the method is applied to an oil transformer, it determines the moisture content at the oil-paper dividing line. Measured values determine the time constant and the slope of the voltage response rise.

Based on the relationships listed in [12], paper moisture and conductivity in oil can be calculated with sufficient precision.

4. Experimental Measurement

The evaluation of the measurement and therefore the determination of the moisture content in the paper part of the isolation system of the oil power transformer 22/0.4 kV can be determined from the analysis of the charging time and the maximum U_{max} voltage response according to Fig. 2 till Fig. 4.

For this evaluation, it is sufficient to write real time and measured voltage to the SD card. From this stored text document, time and voltage values are evaluated on a separate PC in one of the available computational programs. These text documents are named as *rvmx*, where *x* is the serial number of the measurement. For better orientation, the creation time is also indicated.

Measurement of the voltage response depends largely on the temperature difference between the object and the surroundings. Since the measured transformer is unconnected to the grid and is located in the laboratory, the temperature difference is zero. This is confirmed by measuring the winding temperature on the transformer by incorporating the Neoptix temperature probes and measuring the outside temperature with a 22 °C by thermometer.

Measurement of return voltage by RVM consists of the four steps acording to Fig. 2. In the first step, the low-voltage (LV) and high-voltage (HV) transformer terminals are connected to the test voltage for the charging time t_N. This step is called charging. In the second step, there is a discharge for $t_V = t_N / 2$, where the LV and HV terminals are short-circuited. In the third step, the measurement of the voltage response and the time itself is carried out until the maximum voltage is reached. The last fourth step of measuring the voltage response consists of a recovery before another cycle for a time at least equal to t_N.

The time behaviour and the individual measurement steps are shown in the Fig. 2 and the graphical representation with the maximum value of the measured voltage response values (Fig. 3).

The measurement of the voltage response of the insulation system consists of determining the moisture content of the paper part. This determination is derived from the characteristics of Fig. 4, which are obtained by actual measurements on samples of different humidity at different temperatures. These evaluation curves in another version are also reported in the literature [13].

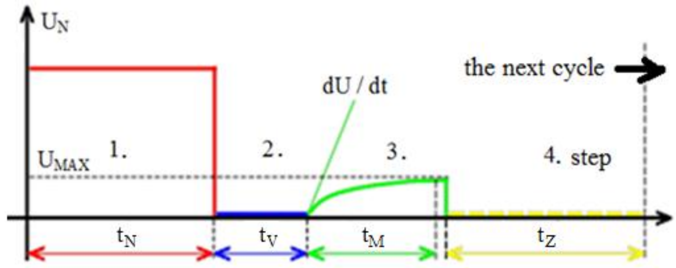

Fig. 2. The shape of the test voltage by RVM method.

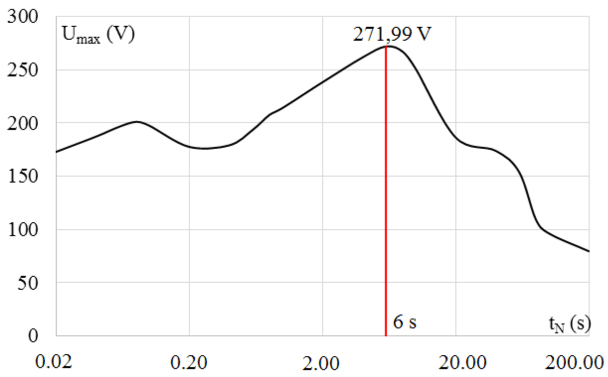

Fig. 3. The time behaviour of voltage response of the insulation system.

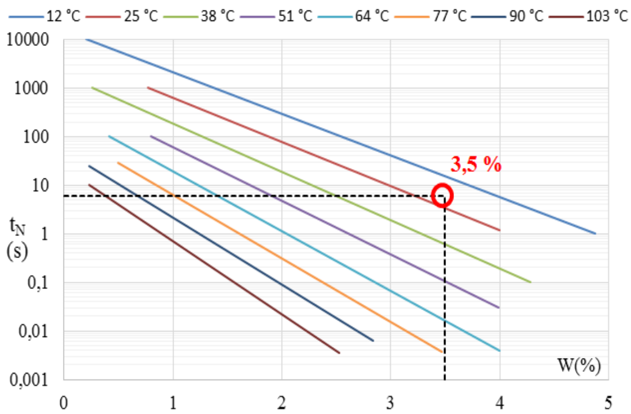

Fig. 4. Evaluation curves for the voltage response measurement method.

In Fig. 4 shows the intersection for moisture (W) content of 3.5% corresponding to the highest possible moisture value in the paper portion of the insulation. Since the moisture content was also controlled by the frequency response method of dielectric spectroscopy and the result of the evaluation was the same, it is obvious that no significant amount of sludge is deposited on the paper. The slurry itself in the oil does not have a more serious effect on the result of this measurement.

5. Conclusion

The proposed system, in comparison with other commercial devices, can evaluate the humidity status of the transformer insulation paper section. Precise determination of moisture content is very complex, but in general, the measured object in which the maximum voltage response is reached at shorter charging times, the moisture content of the insulation is greater. The maximum voltage response of the new transformers is achieved with longer charging times.

Workers from individual test centers formulated their proposals and suggestions during the preparation phase as well as realization phase of the system development. Once the system was brought into life, measurements of transformers became easier, safer and more accurate – in accordance with requirements from valid IEC standards.

Elaboration of the calculation of the paper moisture by PDC method is possible to calculation using formulas in [12].

Thanks this transformer diagnostics is assured higher protection of the environment from possible accidents of certain electrical devices (this particularly relates to power oil transformers, where oil leaks into the soil can cause disastrous consequences for the surrounding environment).

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References

[1] Bartlomiejczyk M, Gutten M, Hamacek S. A combined TOPSIS and FA based strategic analysis of technical condition of high power transformers. *Advances in Electrical and Electronic Engineering*, 2013; 11(4):251-259.

[2] Koch M, Krueger M, Puetter M. Advanced insulation diagnostic by dielectric spectroscopy. *Omicron Electronics*, 2011.

[3] Petráš J, Kurimský J, Balogh J, Cimbala R, Džmura J, Dolnǩ B, Kolcunová I. Thermally stimulated acoustic energy shift in transformer oil. *Acta Acoustica United with Acoustica*, 2016; 102(1):16-22.

[4] Kozak C, Sebok M, Kucera M. The effect of direct voltage polarity on the value of electric arc burning on the W10 switch contacts. *Przeglad Elektrotechniczny*, 2012; 88:96-98.

[5] Simko M, Chupac M. Synthesis of symmetrical delay line with surface acoustic wave for single-mode oscillator of electrical signals with the application in the temperature sensor. In: *DEMISEE 2016, International Conference Diagnostic of Electrical Machines and Insulating Systems in Electrical Engineering*, 2016:99-103.

[6] Simko M, Chupac M. Non-destructive method of measurement of radio transmitters antenna systems. *Elektronika ir elektrotechnika = Electronics and electrical engineering*, 2011; 107(1):33-36.

[7] Glowacz Z. Recognition of thermal images of direct current motor with application of area perimeter vector and bayes classifier. *Measurement Science Review*, 2015; 15(3):119-126.

[8] Werelius P, Öhlen M, Adeen L, Brynjebo E. Measurement considerations using SFRA for condition assessment of power transformers. In: *International Conference on Condition Monitoring and Diagnosis*, 2008.

[9] Shayegani AA, Hassan O, Borsi H, Gockenbach E, Mosheni H. PDC Measurement evaluation on oil-pressboard samples. In: *International Conference on Solid Dielectrics*, 2004, zv. 4: 50-62.

[10] Leibfried T, Kachler AJ. Insulation diagnostics on power transformers using the Polarisation and Depolarisation Current (PDC) Analysis. In: *International Symposium on Electrical Insulation*, 2002, zv. 10: 170-173.

[11] Gutten M, Korenciak D, Kucera M, Sebok M, Opielak M, Zukowski P, Koltunowicz TN. Maintenance diagnostics of transformers considering the influence of short-circuit currents during operation. *Eksploatacja i niezawodnosc-maintenance and reliability*, 2017; 19(3):459-466.

[12] Janura R, Jurčík J, Gutten M, Korenčiak D. Transformer insulation analysis by time domain method, In: *Acta Technica Corviniensis - Bulletin of engineering*, 2015; 8(1):m27-30.

[13] Kucera M, Sebok M. Electromagnetic compatibility analysis of electrical equipment. In: *DEMISEE 2016, International conference Diagnostic of electrical machines and insulating systems in electrical engineering*, 2016:104-109.

[14] Neimanis R. On estimation of moisture content in mass impregnated distribution cables. In: *Royal Institute of Technology Stockholm*, 2001.