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MONITORING OF 110 kV POWER TRANSFORMERS

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Abstract: The paper considers the system of monitoring and diagnostics of power transformer in regional network companies.

Until now, the diagnostics of power transformer equipment in the course of its operation was considered as an intermittent monitoring of the condition of protective and measuring devices (such as, gas relay, oil level indicator, etc.). Testing generally involves high-voltage tests, chromatographic analysis of gas content in oil, etc. [1, 2].

The given way of control is not always effective for the quick detection of the defects appearing in the intervals between sampling, testing and measuring as well as those leading to emergency failures of the equipment. Modern level of automation enables to expand the possibilities of this control by means of application of stationary systems of monitoring and diagnostics of the power transformer equipment and to improve, thereby, the reliability of its work.

1. System of diagnostic monitoring of 110 kV and above power transformers

The stationary system of monitoring and diagnostics of power transformers in the regional network companies is either supplied together with the new transformer, or mounted on the transformer which is in operation, in the course of modernization of the system of protection and can be executed under the following scheme (Fig. 1).

The system is based on the results of the tests which are carried out in an automatic mode by sensors installed on the working transformer, and enables to determine the current technical condition of the transformer, the defects of subsystems and a residual resource of work.

The set of the tests (sensors) used by the system of monitoring for a definite transformer, is determined at the designing stage, and it is hardly ever modernized in the course of its further operation, therefore when designing the system of monitoring it is important not to make two mistakes: simplification and excessive complication of the system.

Simplification leads to the production of unreliable estimation of the technical condition and impossibility to determine a residual resource, while complication causes redundant information and conclusions about the condition of the unused parts of the equipment.

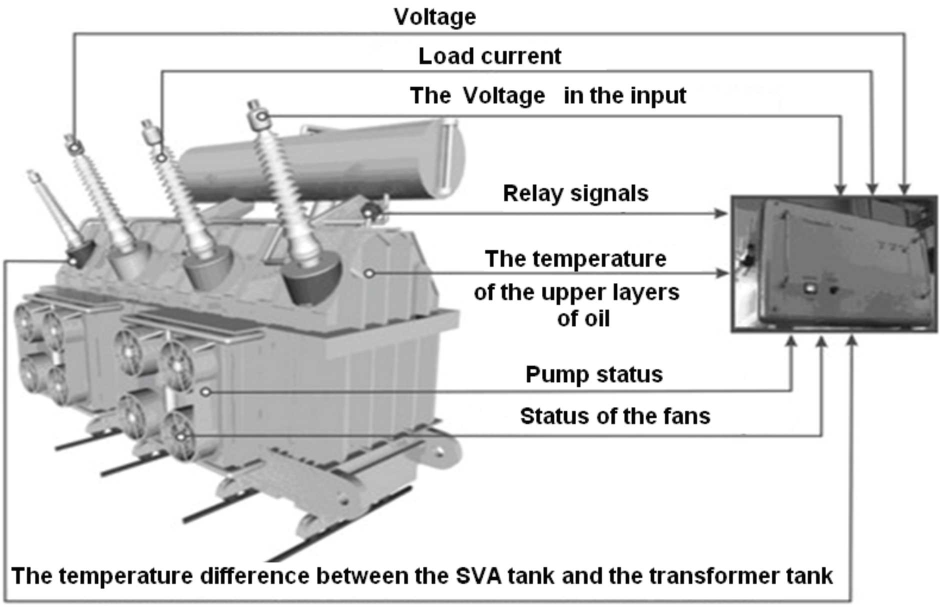

Fig. 1. Stationary system of monitoring and diagnostics 110 kV and above power transformers

The depth of recommendations made by the system of monitoring can vary from simple registration of excess in the parameters of threshold values to fairly reasonable proposals for the repair work. The more elaborate and sophisticated is the integrated expert system, the higher is the reliability of operational information on the current technical condition of the controlled transformer, which fully complies with the requirements of technical policy in Electricity Distribution Network, conducted in each regional network company [3].

All major equipment of the monitoring system is located near the transformer, which is installed in a protective control cabinet and consists of modules which are connected to sensors (see Figure 1). The number of sensors can be different, depending on the parameters controlled by the monitoring system, such as:

– Temperature (upper and lower layers of oil, environment, etc.);
– Vibration;
– Voltage and current;
– Control of isolation of high-voltage inputs;
– Gas content and a moisture content in oil;
– Pressure of oil in inputs;
– oil level in the expander transformer and switching voltage regulator (**SVR**) under load;
– Control of condition SVR, etc.

Functions of the sensors used for the system of diagnostic monitoring of 110 kV and above power transformers are presented below.

2. Sensors of the diagnostic monitoring system

2.1. The sensor of oil temperature in the tank enables to conduct temperature monitoring through the activation of a signal in case of temperature excess. Pt 100 3-wire connection thermometer is used. It is mounted above the transformer in the thermometer slot. The change in the sensor resistance caused by the change in temperature is converted into an analogue signal by a contact input.

2.2. Oil temperature sensor in the cooling system is used to optimize the thermal conditions of the transformer and control the condition of the electric motors of the cooling system. Background information for the thermal management of the transformer is the temperature values at the input and output of coolers. The additional information on oil temperature in the transformer tank comes from other sensor. By means of the relays which are available in the module, the monitoring system can turn on and off the equipment of the cooling system in the automatic mode (control starters).

2.3. The environment temperature sensor. The Pt100 resistor thermometer with 3-wire connection is used. It is installed in the lower part of the control cabinet. The sensor is supplied by low current through the transmitter, and the built-in contact input gives the temperature value in the form of analogue signal. Fault LED indicates the sensor fault (such as, wire breakage).

2.4. The wall tank vibration sensor. Under short circuit of the transformer electromagnetic fields arising between the windings and the tank wall lead to the tank wall vibrations, which are tracked by the system of acceleration measurement. Measurement of tank wall vibrations enables the system to preserve signatures of these events in order to assess the impact on the clips and the windings. Active acceleration sensor is used to measure the tank wall acceleration. The sensor is mounted on a magnetic fixing on the tank wall.

2.5. Voltage sensor is a parallel connection of up to three separate condensers. The recorded values of operating voltages and cross-currents of short circuit are used in the design models built in the system to determine the residual life of the winding insulation. The same information is used to generate the output signals of the system of automated position control of the switching voltage regulator of the transformer. On the basis of this information the algorithms of control of Zk parameter of the transformer windings under voltage is made. Knowing this information, along with the analysis of changes in the phase currents and voltages it is possible to keep track of transient processes arising in the transformer during its operation.

2.6. The current sensor. Thanks to the current sensors monitoring system allows simultaneous measurements of currents of three bushings of one voltage and current measurement of one phase bushings but of different voltages. The received information is sufficient to construct the vector diagram of the resulted transformer and analytical calculation of Zk parameter of the transformer phases. This makes it possible to control the change in the shape of the windings, which can occur after flow of through-fault currents through the transformer.

2.7. Control sensor of high-voltage insulation bushings is designed to implement one of the most important functions of the system of monitoring of the transformer technical condition which is to ensure control of the insulation bushings. For each bushing controlled by high (**HV**) and medium voltage (**MV**) and in the neutral of the transformer the sensor of current conduction and partial discharges are installed; the output signal; its structure contains the conduction current of the bushing and pulses of partial discharges (**PD**). Conduction currents of bushings and partial discharges are recorded and transferred to a specialized module of the monitoring system. Additionally, corona sensors can be installed. In transformers registration of PD is a complex task because of the strong influence of corona discharges close to the parameters of PD pulses. For this reason, in the module it is necessary to implement technical and algorithmic capabilities of detuning from the noise as much as possible. Partial discharge measurement makes it possible to carry out an effective non-invasive diagnostics of electrical insulation and helps prevent costly unscheduled downtimes by detecting problems of isolation at an early stage before they cause an accident.

2.8. Hydran Sensor of dissolved gases. Since the effects of partial discharge and reloading of the windings lead to the flow of gaseous decomposition products into the oil, the availability and the increase in the concentration of harmful gases dissolved in the oil may be a sign of problems with the isolation transformer.

Hydran sensor measures the accumulated amount of gas (hydrogen, carbon monoxide, acetylene, and ethylene) in ppm, as well as the moisture content of oil. The increase in the amount of gas can be used as the basis for conventional gas analysis to diagnose the type of fault.

The principle of the sensor is based on electrochemical converter and gas-permeable membrane. Gases dissolved in the oil, pass through the membrane and come into contact with a miniature gas detector. A signal generated by the gas detector is directly proportional to the concentration of gas in oil.

The sensor is equipped with its own microprocessor and has a number of internal functions, such as two programmable alarms, and story mode. It is recommended to install the sensor in the return pipe cooler through a special tube and welded shut-off valve.

2.9. AMS 500 Calisto sensor monitoring the concentration of dissolved hydrogen and water. The measurement of dissolved hydrogen is carried out with Calisto sensor in two stages. First, the dissolved hydrogen is continuously removed from the oil a specially designed probe, made from capillary tubes. Then, once the probe is completed and stabilized, the continuous measurement of hydrogen content (and a map in ppm) using high-precision detection technology on the basis of hydrogen thermal conductivity begins.

The content of water in the oil dissolved in the transformer is continuously measured by means of thin-film capacitive sensor immersed directly into the circulating oil. The moisture content can be displayed in ppm or percentage.

Calisto sensor is mounted on the transformer and the oil circulates through the device with a small internal pump (flow rate 60 ml / min), which is located inside the main building.

For further analysis of the moisture content of oil thin film capacitive MMT 318 sensor which is separately mounted can also be used. The sensor is located in the cooling pipe. It is connected to the oil circuit through a valve or a combination of the flange to the Hydran sensor.

2.10. Transfix gas analyzer. It extracts the gases from the oil transformer and analyzes their composition on the principle of photoacoustic spectroscopy. The contents of eight gases (hydrogen and methane, ethane and ethylene, acetylene and carbon monoxide, carbon dioxide and oxygen) and moisture content of the transformer oil is measured.

All the equipment for the DGA is installed in stainless steel casing with IP56protection degree and is connected to the transformer pipes made of stainless steel. For the analysis no additional consumables (gas-fillers) are required; the analysis is performed for one hour. Built-in microprocessor with the internal volatile memory enables you to store the measured data (10000 measurements) and exchanges the data between the analyzer and the monitoring system.

2.11. Oil pressure sensor in the input of the transformer. Piezo-resistive sensor measures the relative oil pressure in high- voltage input and compares the readings of sensors installed in the other phases. Thus, it is possible to eliminate the variations of pressure owing to temperature and loading changes and to detect leak or oil loss. The pressure sensor is located on the manometer.

2.12. Oil level sensor in the dilator of the transformer and SVR. Measuring the level of oil in order to detect leaks is performed by ultrasonic sensor. Ultrasonic pulses emitted by the sensor are reflected from the boundaries of the oil and air and returned to the sensor. The sensor calculates the oil level on the time elapsed from the transmission of ultrasonic pulses to obtain the echo. The measured distance is converted into a current signal proportional to it and is analyzed by the monitoring system. Ultrasonic sensor is installed on the upper lid tank. The adapter is welded to the bottom of the tank and supplied with the sensor.

2.13. Buchholz sensor. The state of the insulation system of the oil transformers is controlled mainly by a gas relay. This device is designed to detect gaseous decomposition products going from the transformer tank during operation and warning of the presence of gas.

A disadvantage of the gas relay is that when the alarm goes, it is only known how much gas is in the relay, and when it was last ventilated. The history of the gas evolution is unknown. Buchholz relay is unable to distinguish between long-term failures with low energy, such as partial discharges from short-term failure of high-energy, such as local overheating.

In order to analyze effectively the failures of this sort is necessary to measure the rate of gas generation. This is the problem of Buchholz gas relay, while the protective function of the gas relay is not affected. The sensor is connected to a vent of the gas relay. Measuring the amount of gas is performed using a float located in the sensor, and the transducer position. The position of the float is converted into a current signal proportional to the level of oil in the sensor. If the monitoring system indicates zero ml, this means that the sensor is completely filled with oil. If the system shows 69 ml, the sensor is completely filled with gas. If gas continues to emit, it is accumulated in the gas relay until the warning is generated.

2.14. The control sensors of the SVR condition:

– SVR tank temperature control (oil temperature) and its comparison with the temperature of the transformer tank (the sensor is described above);

– Control of partial categories in SVR tank in intervals between on/off (the sensor is described above);

– Registration of vibrogram of each switching that allows assessing the presence and duration arch burning in SVR contacts (the sensor is described above);

– Registration of the capacity consumed by the drive motor during each switching to get the information on the mechanical condition of SVR.

– The measuring converter of active capacity is located in a control case of a drive of the engine. It is established on the front side of the main contractor.

3. Comparative characteristics of diagnostic monitoring systems and efficiency of introduction

At present almost all monitoring systems aim to assess the state of isolation as the most important and most commonly subjected to the destruction of the element of the oil transformer. In order to achieve this the assessment loading mode of the transformer, the control over the temperature of the hot point, the determination of moisture content in paper insulation and the definition of dielectric loss tangent are used.

Next on the priority list is the control of the cooling system, with the determination of temperature of the upper layers of oil, the temperature difference of oil on the input and output of the cooling system, ambient temperature, the condition of oil pumps and fans. The ability of the system to analyze the content of gases in oil and the integration into automated process control system (**APCS**) of the substation is very important; it implies support for standard data exchange protocols.

Likewise the system can perform additional functions such as control over the cooling system, measuring of the load factor, etc.

Table shows the comparative characteristics of systems for monitoring domestic and foreign production.

The comparative characteristics of systems for monitoring domestic and foreign

Parameter	Monitoring System (Manufacturer)				
	MS3000 (AREVA)	ШУМТ (ВЭИ, Moscow)	TDM (the center, Perm)	СКИТ (ШШЖ St.-Petersburg)	Л2Ш (Sterling Groups, Ukraine)
Temperature of the top oil layers	+	+	+	+	+
Performance of the cooling system	+	+	+	+	+
Tangent delta	+	+	+	+	+
Concentration of gases in oil	+	+	+	+	+
Moisture content in isolation	+	+	+	+	+
SVR Condition	+	+	+	+	+
Currents and pressure HV, MV, LV	+	+	+	+	+
Pressure in inputs	+	–	–	–	–
Partial categories in isolation	+	–	–	+	+
Measurement of temperature of windings	+	–	–	–	–
Loading factor	+	–	–	–	–
Quantity and speed of changing the gas quantity in the gas relay	+	–	–	–	–
Tank vibration, SVR	+	–	–	–	–
Oil level in the dilator and SVR	+	–	–	–	–
Integration into APCS	+	+	+	+	+

The analysis of the conducted developments leads to the conclusion of their possibilities, but a significant difference is observed in the application of mathematical models to assess the results of monitoring and the interpretation of these results.

For the effective implementation and further development of monitoring systems it is necessary to change the ideology of their construction, and the requirements for these systems.

Most producers, both Russian and foreign ones have developed the systems taking into account the fact that the operational staff are qualified expert diagnosticians and are able to interpret the diagnostic information from the system to make some kind of conclusions about the state of equipment in operation and subsequent decision [4].

In fact, it turns out that the operational staff has an additional burden on the continuous monitoring of the current parameters of the controlled transformer, which do not represent any diagnostic value due to the lack of appropriate qualifications.

The cost of the monitoring system and its installation is that the money spent on the supply and installation of the monitoring system is enough to perform a comprehensive survey to 4–8 transformers.

For this reason, it is advisable to equip the transformers over 25 MV·A with a load of more than 50 % with diagnostic monitoring systems installed on the major central substations and / or supplying the responsible consumers. Another reason for the installation of the stationary monitoring and diagnostic system on the transformer is the establishment of substation control system.

In this case, the cost of the installation of the monitoring system will be no more than 3–7 % of the cost of the transformer.

Since the monitoring system is built in a modular fashion, it is possible to use some of its components to monitor only the required parameters. First of all, it is about the most informative instruments for monitoring of the transformer equipment status, i.e. the instruments for gas analysis of oil and the evaluation of water content in it (Transfix, Calisto, Hydran, etc.). In this case, from the standpoint of economic feasibility it is advisable to equip the old transformers subject to frequent monitoring and the equipment installed in a closed reactor facility and at high heat with such monitoring devices.

Thus, to maximize the use of diagnostic systems of 110 kV and above power transformers the regional network companies must conduct extensive preparatory work, which includes determining the list of diagnosed equipment, controlling the settings and used diagnostic tools, preparing skilled staff with regard for the criticality of the equipment condition. Only then a decision can be made on the introduction of diagnostic monitoring of the transformer equipment with a mandatory feasibility study.

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Контроль силовых трансформаторов 110 кВ

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Ключевые слова и фразы: региональная сетевая компания; система мониторинга и диагностики.

Аннотация: Рассмотрена система мониторинга и диагностики силовых трансформаторов региональных сетевых компаний.

Kontrolle der Krafttransformatoren von 110 kV

Zusammenfassung: Es ist das System des Monitorings und der Diagnostik der Krafttransformatoren der regionalen Netzgesellschaften betrachtet.

Contrôle des transformateurs de force de 110 kV

Résumé: Est examiné le système du monitoring et du diagnostique des transformateurs de force des compagnes régionales de réseau.

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