Improving the reliability of power supply facilities in the agro-industrial sector

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Abstract. This article presents a system for monitoring and diagnosing the performance of operating equipment, in particular power transformers. Since power transformers are the main element of an electrical installation, the reliability of the power supply system depends on their technical state (TS). In our country one of the promising systems for monitoring and diagnostics is Transformer Diagnostics Monitor. The authors have considered the algorithm of this monitoring system and the possibility of its application in digital substations (DSs). Implementation of Transformer Diagnostics Monitor in the automatic control system of a substation prevents electrical equipment from failing, reducing the economic damage from power shortage.

1. Introduction

A power supply system is a set of electrical installations designed to provide electricity to consumers. The reliability of a power supply system depends on the performance of the individual elements: transformer stations, transmission lines, switchgear. The main element of the power equipment of transformer substations is a power transformer. It is a complex and costly element. The rated service life of power transformers is 20 years. The failure of power transformers causes great economic damage due to the disruption of power supply to a large number of consumers and also leads to high material costs for their repair.

Monitoring [1-2] of transformer (Tr) parameters [3] of the power supply system in the agro-industrial sector is a promising direction to improve the reliability of networks. The results of monitoring allow extending the service life of transformers based on the results of their technical evaluation, thus optimizing the costs of routine maintenance, reducing the volume of repair work. In addition, monitoring systems allow the performance of other types of high-voltage equipment to be monitored [4-5], which ultimately extends their service life, and therefore companies can raise additional funds.

Russian integrated monitoring and diagnostics system Transformer Diagnostics Monitor (TDM) can be considered the most promising. It is designed for:

- Controlling of compliance of current transformer operating parameters with regulatory requirements.
- Automated expert of diagnosing defects and technical evaluating of the transformer.
• Transmitting of the primary and processed data from the system to a higher level automated process control system (APCS) for its use in more complex integrated control systems.

2. Materials and methods

Figure 1 presents a scheme of the data processing levels of a TDM type monitoring system.

![Figure 1. Information structure of the monitoring system.](image)

Level I (primary sensor level) is the technical level of primary data collection. It includes all primary sensors of the TDM system as well as all additional sensors and devices that monitor the transformer performance.

Level II (module level of the TDM system) is the technical and software level of primary data processing from sensors, the level of implementation of parametric diagnostics of the transformer performance.

Level III (diagnostic level of the substation) is the software level of comprehensive expert evaluation of the technical state of transformers. It represents an automated workstation (AWS).

Level IV (diagnostic level of the energy company) is the technical and software level of visualization of data on the state of equipment of all substations of the energy company (AWS). At this diagnostic level, risks of defects in the most critical equipment are evaluated and integral diagnostics of the impact of the transformer(s) state on electricity transit can be performed.

The monitoring system uses a single multilevel software iNVA, which implements the functions of monitoring and automated diagnostics. Elements of this software are installed in the primary monitoring modules, in the transformer's AWS, the substation's AWS, the territorial energy company's AWS. The hierarchical structure of iNVA enables a comprehensive solution of transformer performance control tasks.

The modular structure of the hardware, connected to a common data bus, makes it possible to quickly create monitoring and diagnostic systems with the required properties. This minimises the economic costs of organising diagnostic monitoring.

Multilevel parametric diagnostics and automated expert evaluation of the transformer state based on mathematical models and algorithms are implemented in the TDM and iNVA software modules.

Parametric diagnosis is based on monitoring the values of critical transformer parameters for which there are normative status thresholds. Parametric diagnostics is based on the analysis of three critical parameter values:

- The current steady-state values of the critical parameters.
- The jump of critical parameters, reflecting the rapid changes of the transformer state.
- The trend of the critical parameters reflecting slow changes in the transformer performance.

Based on the results of analyzing the diagnostic algorithms, we calculated a single coefficient for the current technical state of the transformer in iNVA software. This coefficient comprehensively
reflects the state of the transformer and is therefore most useful in higher-level HV equipment performance control systems.

The current technical state factor (CTSF) (figure 2) is different from the commonly used and standardised technical state index (TSI). The technical state index describes the state of the equipment over the complete service life of the equipment, which usually includes several interrepair cycles (IRC).

These two coefficients describe different aspects of the current technical state of the equipment, their values at the time of measurement and state monitoring do not usually coincide and rather weakly correlate with each other, as shown in the figure.

The technical state index TSI varies within one interrepair cycle, while the current technical state factor CTSF usually decreases monotonically, changing only slightly as defective states occur and are corrected.

The iNVA software can be used in conjunction with the TDM system hardware for recording and primary data processing.

The iNVA software includes a set of algorithms and programs that deal with the collection of primary data, its storage, expert processing and the formation of final diagnostic conclusions about the state of the monitored transformer.

Elements of iNVA software operate at different levels of TDM implementation.

Technical state monitoring and expert evaluation of the transformer is the main purpose of TDM systems.

Since the processes of the transformer are complicated and interconnected, the final diagnostic procedure is multi-parameter, complex and therefore performed in several algorithmic levels and stages in the iNVA software:

- Operating parametric evaluation of the transformer state.
- Expert evaluation of transformer state and diagnosis of defects.

Based on the results of parametric and expert diagnostics, iNVA automatically generates transformer state reports. The reports are presented in the MS Word format, allowing experts to refine and correct the data if necessary.

To facilitate analysis of a transformer as an element (station, substation) or an integral part of the energy transit, iNVA calculates a generalised technical state factor. This makes it possible to use the results of the TDM system in a "weak link search" type of diagnostics.

3. Results

The considered system of monitoring can be integrated into the APCS, which will solve the following tasks:

- Obtaining operating data on the transformer performance in the APCS at levels III and IV to the extent necessary for the operating staff to evaluate the current state and make decisions.
- Possibility of obtaining primary data on the transformer performance from other subsystems of the APCS without using additional sensors in the TDM.
- Automatic synchronization of the "internal time" of the TDM software with the time of the APCS and the "global time".
- Local and remote access to the "authorised" data and results of the TDM system using the resources of the APCS, including WEB access.
- Remote control of correct performance and serviceability of technical and software tools of the TDM system.

4. Discussion
The International Council on Large Electric Systems (CIGRE) claims that the use of monitoring systems prevents most failures of electrical equipment. It entails avoiding the negative effects of a sudden failure of electrical equipment. For example, in the detection of dissolved gases in transformer oil, increased moisture content, and abnormal heating, the monitoring system found out a defect detection rate of over 85%. From the internal pressure evaluation, defect detection is up to 90%. Due to the monitoring of mechanical and electrical parameters of transformers with on-load tap-changers the detection of defects is more than 80%.

In particular, the installation of the monitoring system in the cooling system has increased the defect detection rate to over 95%, reducing the number of failures from 1.18 per year to 0.91. Failure rates of several hundred 220 kV power transformers were considered according to the following indicators:

Nsk of failure \( r_n \), degree of failure \( d_n \). The calculation of the total probability of failure detection \( P_{tot} \) was calculated according to the formula:

\[
P_{tot} = f \cdot \sum_n (r_n \cdot d_n)
\]  

Where \( f = 1.18 \) is the failure rate, \( r_n \) and \( d_n \) are tabulated.

To calculate the savings from failure prevention, the probability ratio is multiplied by the costs resulted from equipment failure. This includes the repair and partial rewinding costs, and undersupply of energy, which can be assumed to be about half the cost of a new autotransformer.

The annual saving is then calculated as:

\[
S = P_{tot} \cdot E_{mul}
\]  

Where \( E_{mul} \) is the cost in case of failure.

5. Conclusion
Thus, for an expected service life of 10 years of monitoring, savings may amount to about 10% of the total cost of a single autotransformer [6].

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