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Automated Diagnostic System for Power Transformers using a QR Code

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Abstract. This paper discusses approaches and methods of monitoring, diagnostics, and assessment for the effective maintenance, repair, and extension of the service life of transformers without the loss of reliability. It considers the newly developed option of the full automation of the power transformer diagnostics system using automated control systems. The system of monitoring, control, and diagnostics of electrical system transformer equipment is combined with an automated electrical equipment control system and an automated information measurement system for the commercial accounting of electric power. The novelty of the developed system consists of the use of QR codes and the Team Viewer program for the operational elimination of accidents and the detection of any abnormal operation of power transformers. The automation of the power transformer diagnostic system will reduce the time needed to perform repair work and restore the necessary protective modes as well as allow the efficient use of material and labor resources.

Keywords: Diagnostic System; Effective maintenance; QR code

1. Introduction

An analysis of the damageability of the power transformer stations belonging to the operators of the electrical and intersystem grids in Russia shows that the specific quantity of technological disturbances that led to automatic shutdowns by the action of protective devices or forced shutdowns by personnel on an emergency request is 1.8% per year. At the same time, about 30% of the total number of such technological malfunctions were accompanied by the occurrence of internal short circuits (Rozhentcova et al., 2019).

Since power transformers are some of the most expensive elements in the power grid, it is necessary to identify the initial stage of defect development and the pre-emergency and emergency modes of transformer equipment. In most cases, the decision is made to keep long-life transformers in operation. Therefore, the search for new approaches and methods of monitoring, diagnostics, and assessment for the effective maintenance, repair, and extension of the service life of transformers without the loss of reliability is becoming urgent (Alyunov et al., 2019; Dhini et al., 2020; Nemirovskiy et al., 2020; Wang et al., 2020). The issue of identifying defects at an early stage of their occurrence in normally operating transformers and, especially, in those that have reached the standard longevity of power

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equipment is an acute problem. Also, the introduction of an automated diagnostic system for power transformers is a prerequisite for the implementation of smart grid technology in industrial electrical networks. The currently existing tools and methods for diagnosing the state of a power transformer's insulation do not allow one to fully identify defects at an early stage of their formation.

In modern conditions, the role of diagnostics in the operation of equipment is increasing significantly. At the same time, it is known that the diagnostic system for transformers and other electrical equipment should have complete information, technical and regulatory support, and a decision-making strategy for the feasibility of the further operation of the equipment and the need to take it out for repair (Mackenzie et al., 2010; Junior et al., 2011; Rozhentcova et al., 2019). Currently, in world energy practice, one of the most effective ways to improve the reliability of transformer equipment is the introduction of systems for the continuous monitoring of changes in the main parameters of transformers during operation. Based on the analysis of control results, measures are developed to prevent the unfavorable development of defects and, ultimately, emergency shutdown.

The aim of this work is to develop a monitoring, control, and diagnostics system for transformer equipment in conjunction with an automated control system for electrical equipment and an automated information and measurement system for commercial metering of electricity using a QR code. This paper presents the main components and algorithms of the developed Supervisory control and data acquisition (SCADA)-based system. The novelty of this work consists of the use of QR codes and remote monitoring and control, which enables efficient elimination of equipment emergency modes and early detection of the abnormal operation of transformers.

2. Methods

2.1. Description of the Monitoring, Control, and Diagnostics System

The monitoring, control, and diagnostics system is used to control the insulation, record and analyze the partial discharge condition, and control the technical status of transformers. The main task of the system being developed is to ensure the maximum trouble-free service life of transformers. The system is based on an information-measuring system. The core of the system is the SCADA system, which is designed to perform the following tasks:

- Continuous measurement of various physical parameters with their conversion into electrical signals; displaying operational information on video frames and recording the main parameters of transformer equipment in normal, pre-emergency, and emergency modes; performing computational operations on the measured values and their combinations using analytical and mathematical models based on national regulatory and technical documentation and international standards; and forecasting the technical condition of transformer equipment;
- Formation of control commands for switching equipment, actuators, and other equipment with the issuance and control of the passage of the corresponding values of the output electrical signals through the system channels;
- Control of the cooling system.

The system consists of the following elements:

- A transformer monitoring cabinet based on intelligent system modules consisting of a P 06/P 06 DIO module processor and the following input-output modules: one T3102 (6 channels of analog input signal with individual galvanic isolation, version for an extended temperature range from -40 C to +50 C), one TCC8-220 DC (8 channels of discrete output signals on electromechanical relays with individual galvanic isolation, version for an extended temperature range from -40 C to +50 C), and one TC B 08 RT (8 channels of discrete output signals on electromechanical relays with individual galvanic isolation, version for an extended temperature range of –40 C to +50 C).The cabinet also contains additional equipment, connecting terminals, circuit breakers, signal lamps, etc.

- Additional equipment, primary sensors, and control devices for individual technological units of transformer equipment;
- A server cabinet for the system equipped with two input supplies (primary and redundant) for supplying the main equipment cabinet. Automatic circuit breakers with auxiliary contacts are installed on each power input. In the server cabinet, two uninterruptible power sources with batteries are installed to provide autonomous operation of the cabinet for 30 minutes. To ensure an uninterrupted power supply for the server cabinet, an automatic transfer switch is implemented.
- Software for the system, consisting of the project application, called ISaGRAF, and the project SCADA system, running on the workstations of the system operators (Figure 1).

Figure 1 An automated workstation

An automated workstation is a software and hardware complex designed to automate activities. It combines software and hardware that ensure human-computer interaction and provide the ability to enter information and display it on a monitor continually. An automated workstation is part of an automated control system.

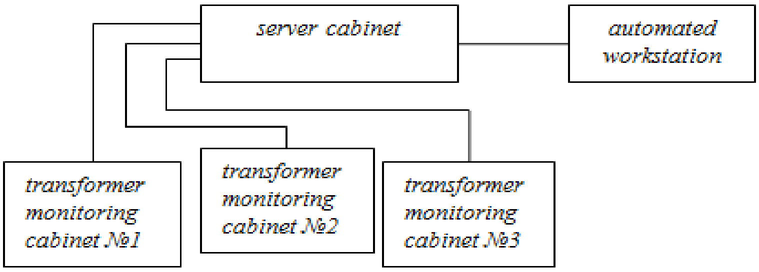


Figure 2 Structural diagram of the transformer monitoring, control, and diagnostics system

Transformer monitoring cabinets and server cabinets are connected by a redundant fiber optic line. The system server cabinet can perform the functions of a single diagnostic center, combining the functions of the upper level of the monitoring system, for example, a switchgear, power transformers and reactors, generators, high-voltage switches, etc. (Figure 2).

2.2. Implementation of an Automated Control System

Currently, there are two main approaches to creating monitoring and control systems for power facilities. The first is based on the architecture defined by the IEC 61850 standard (IEC, n.d.). This approach is usually used for medium and large power facilities. The architecture involves the creation of automated systems with a distributed structure.

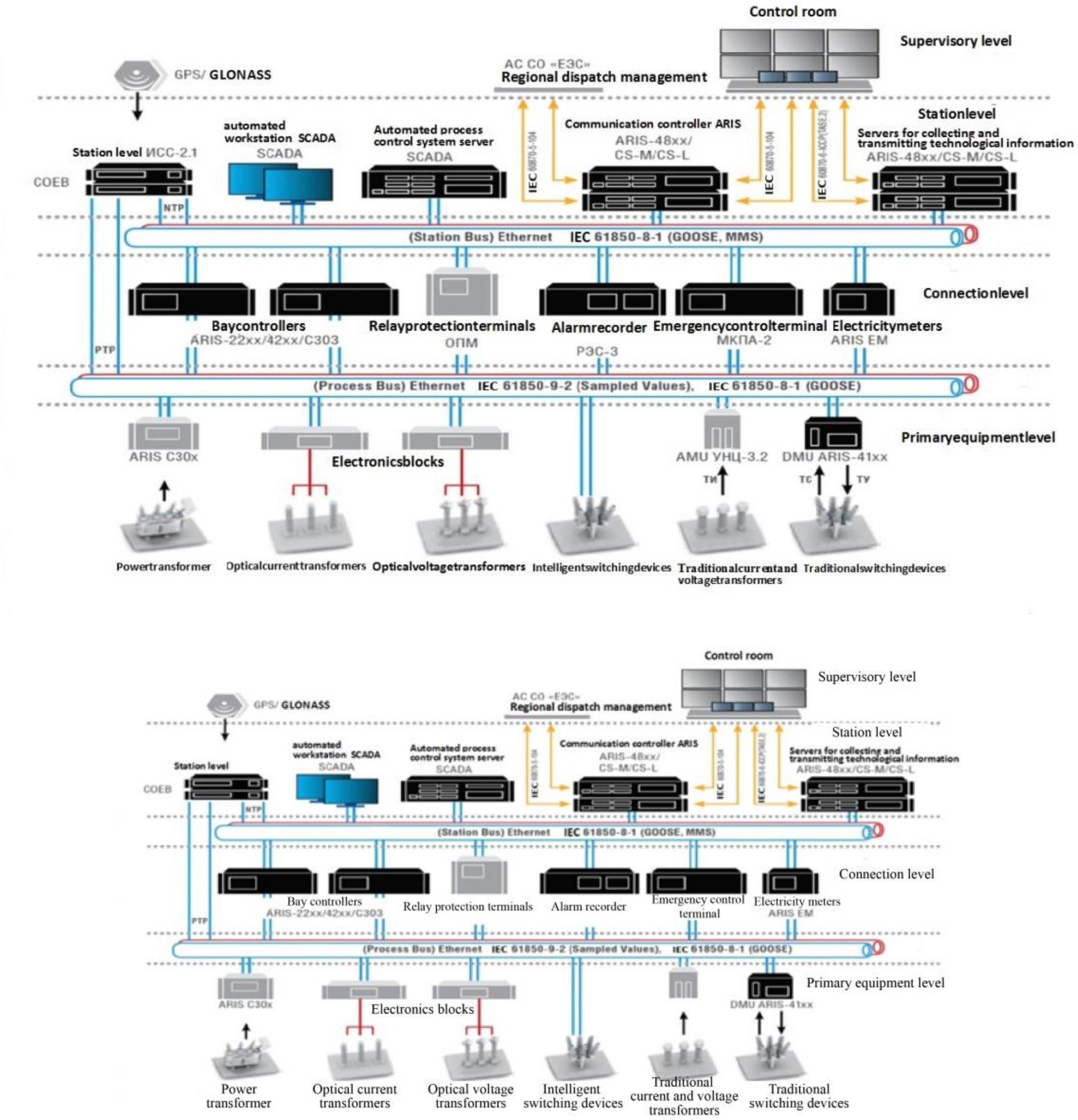


Figure 3 Structure of an automated system based on IEC 61850

The main elements in them are intelligent electronic devices (IEDs), which can be bay controllers, relay protection and automation terminals, and other devices, usually controlling one or more substation bays and forming the field level of the system. All IEDs are included in the technological local area network and interact with each other according to certain rules. Special communication controllers form the middle level of the system and integrate all IEDs into a common SCADA. These systems are characterized by a large number of signals (several thousand or tens of thousands), integrate various devices and subsystems into a single information space, and provide convenient monitoring and control of an object using modern SCADA packages.

Automated systems for small objects (small power plants) are built on the basis of a classical structure. A centralized architecture means the presence of two main levels: a central controller and USO modules (discrete and analog input/output modules), and separate measuring instruments. The collection of measurement data in this structure is carried out using microprocessor-based measuring converters. The collection of alarm data and the issuance of control commands and unified analog signals are performed using discrete input/output and analog input modules. Such an architecture with a central controller is easy to implement, but it has some functional and technical limitations, such as low transmission speed, a large number of copper connections, limited performance of the central controller, and a single point of failure (the central controller), which can lead to the loss of an automated system and to the need to reserve it for important systems.

The proposed technology can be improved by introducing an automated control system for electrical equipment and integrating it with an automated information and measurement system for the commercial metering of electricity (Figure 4).

3. Results and Discussion

An automated control system for electrical equipment is designed to control the operating mode of each electrical part and display this information for operational and other personnel, increase the efficiency of dispatch and technological control, optimize the operating modes and electrical equipment of the main circuits, increase the reliability and trouble-free operation of the electrical equipment of the main circuits, increase the efficiency of managing the repairing process, lower operating costs, and control the switching devices at the lower level (Nikulin and Kargavsky, 2014).

An automated information and measurement system for the commercial metering of electricity is designed to collect, process, and store the measurement data of the amount of electric energy generated, received, and consumed by both its own needs and metered power consumers, as well as monitor the power and record the power parameters of the calculations in the volume of services.

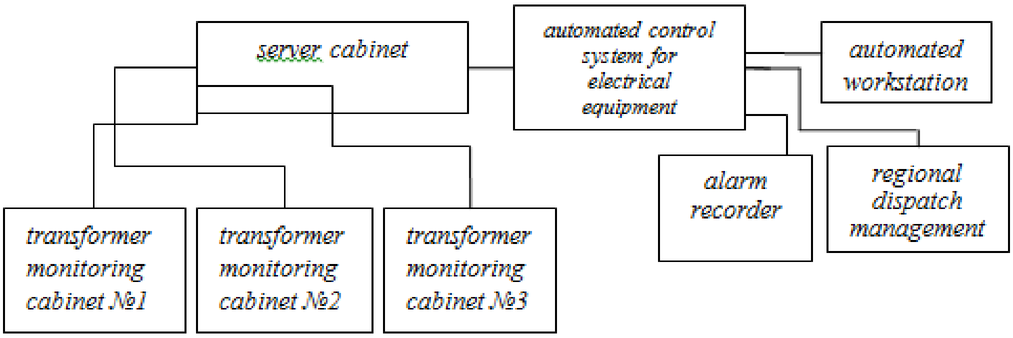


Figure 4 Structural diagram including both an automated control system for electrical equipment and an automated information and measurement system for the commercial metering of electricity

3.1. *The Algorithm of the System*

In the structure of an automated process control system, the following components of the software and hardware complex, as the main component of the monitoring system, function in the control and diagnostics of the transformer:

- In terms of the boundaries of the complex and the connections to other components of the system—input and output terminals (connectors) in an electrical cabinet with a programmable logic controller, intelligent system modules, and network equipment located in cabinets and racks or autonomously, to which sensors or third-party information collection and processing systems are connected;
- In terms of the functionality of the complex—a set of all information and service

functions implemented using computing tools in accordance with these specifications.

Communication between different levels of the system, as well as with adjacent subsystems, is implemented through a local area network (Prosoft Systems, n.d.). A typical block diagram of the internal local area network of the transformer-monitoring cabinet is shown in Figure 5.

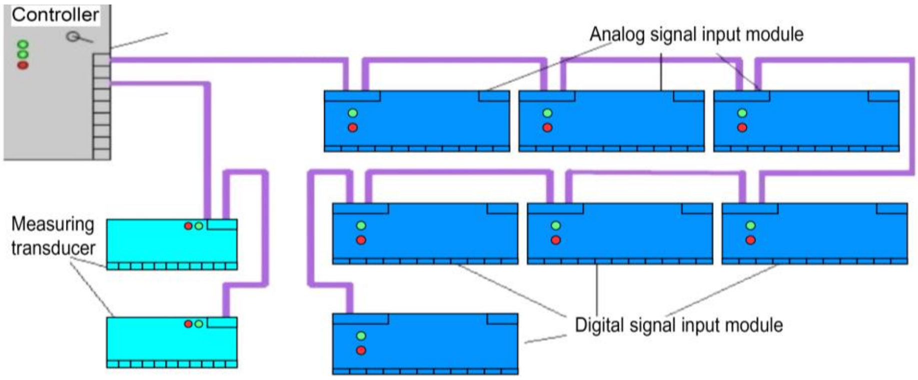


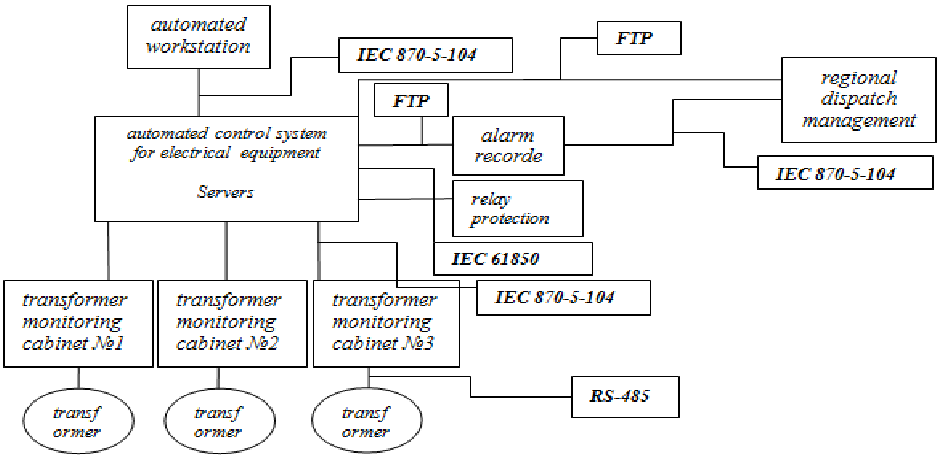
Figure 5 Typical block diagram of a local area network of a transformer-monitoring cabinet

A local area network is a set of technical nodes that provide controlled information exchange among system components. The structure of the local area network includes active and passive components, including software that ensures the normal functioning of the technical means of the local area network (active). Passive components include cable products (optical and copper cables, including patch cords, and pigtails), network cabinets (including patch panels and optical distribution frames), cable organizers, cable ducts, trays, cable sockets, and connectors. The active components of a local area network include network switches, routers (with firewall function), media converters, interface converters, serial port servers, network cards of workstations, and servers.

Since an automated information and measurement system for the commercial metering of electricity is an information and computing system with centralized control and distribution functions, it includes the following levels:

- The information-measuring complexes
- The information and computing complex

The first level includes measuring current and voltage transformers, multifunctional meters of active and reactive electricity, and secondary measuring circuits. The second level includes an industrial computer (Figure 6).



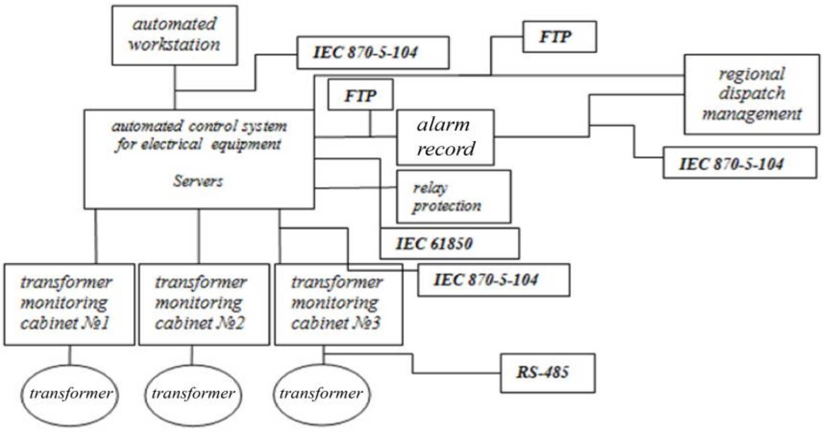


Figure 6 System operation algorithm

3.2. Using a QR Code in Manufacturing

A QR code is a two-dimensional barcode that contains encoded information. Our idea is to create a single database based on software, which will contain all the information about each piece of electrical equipment, including passport and static data.

Figure 7 An example of a QR code

The main advantage of a QR code is its quick recognition by any equipment that can scan. Scanning a QR code gives a high-quality and prompt receipt of all information about the device or equipment that has the code. Anyone can scan using a smartphone equipped with a camera and a scanning application.

The personnel responsible for the technical condition of electrical equipment must keep logs for accounting, technical inspection, and equipment repair and draw up plans for the next repair. Based on these data, it is possible to track when equipment was installed, when it passed the last check, what activities were carried out in the process, and what results were obtained (Denisova et al., 2019).

However, applying the proposed idea makes it possible to speed up the process of searching for the latest information about the electrical equipment and see the actual readings of the parameters—temperature, voltage at the terminals, etc.—which will save time when examining certain equipment defects; therefore, operating personnel will be able to start diagnostics to eliminate any defects without preliminary operational discussions.

TeamViewer is a software package for the remote control of computers, file exchange between controllers and controlled machines, and video communication and web conferencing. We suggest using this technology for all the equipment at a power station.

Having installed a QR code on a transformer, operating personnel can scan the code using the installed application on their phones. To do this, they will point the camera, catch the code in the frame, and automatically receive the entire information base about the transformer. If necessary, one can diagnose the problem from a distance by using a remote workstation (laptop, phone, tablet) and connect to the equipment using the remote administration program TeamViewer. If a malfunction is detected, the administrative staff at a distance can give a verbal order to carry out any measures to eliminate the problem. At the same time, the operating personnel, using the QR code, will be able to start diagnosing the equipment, taking all the necessary information about the previous diagnostics from a single database (Figure 8).

Figure 8 Scanning QR code: 1—QR code; 2—transformer; 3—authentication/scanning

4. Conclusions

Damage to power transformers disrupts the operation of the power system and affects electricity consumers, and abnormal and emergency modes create the likelihood of damage or instability in the power system. To provide consumers with uninterrupted power supply and ensure trouble-free operation of the power system, it is necessary as quickly as possible to detect the cause of failure and restore the damaged area of the network to normal working conditions. Dangerous consequences of abnormal conditions can be prevented by the timely detection of deviations from normal operation and by taking measures to eliminate them (reducing the current during its buildup, reducing the voltage when it is increasing, etc.).

An analysis of the current statistics of failures reveals that about 40% of transformers in use have passed their peak performance time and continue to work with increased losses, and 60% of transformer stations need to be overhauled (Denisova et al., 2019).

The implementation of systems such as we have proposed, which combines an automated system for the monitoring, control, and diagnostics of transformers, an automated control system for electrical equipment, an automated information and measurement system for the use of commercial metering of electricity using QR codes and remote monitoring, and the use of the TeamViewer remote administration program to control and track all of the above systems, will help to increase efficiency in the elimination of emergency modes and in the early detection of abnormal operation, making production more efficient, saving time for examining certain equipment defects, and reducing the cost of operating the equipment.

The automation of the power transformer diagnostic system will reduce the time needed for performing repair work and restoring the necessary protective modes as well as allow the efficient use of material and labor resources. Thus, we have proposed the full automation of the power transformer diagnostics system using automated control systems.

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