Concept of intellectual diagnostic system of traction electrical supply devices

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Abstract. This article presents questions on creating a diagnostic system for traction power supply. The relevance of this area is confirmed by significant quantitative violations that occurred due to the development of defects. In addition to power low-voltage transformers, which include electric and electric voltage, as well as converters, smoothing filters, controlled and uncontrolled means, providing reactive power and other equipment, the diagnostic system under consideration allows you to accurately perform all the necessary technical and technical work in railway transport. services, etc. allows you to increase the reliability of traction power supply systems and train safety. In addition to monitoring the concentration of gas dissolved in the transformer oil, monitoring the high-voltage bushings of transformers and switches, oil leaks, the proposed system should include monitoring the parameters of special electrical installations. An integration diagnostic system using existing measurement methods allows us to synthesize and further test the diagnostic methods taking into account the specifications of traction power supply. The implementation of an intellectual device diagnostic system as part of a decision support system allows you to switch to an organization system that provides the actual state and thereby reduce operating costs.

1. Introduction

An analysis of the operating conditions of power and switching equipment in the electric power industry shows that a significant part of failures is associated with developing defects. To monitor developing defects in power and switching equipment, various monitoring systems have been developed that have found application in Russia. The monitoring system is a complex of measuring equipment, information transmission devices, data analysis and processing based on the statistical base and calculation models. Systems of this type that implement various sets of diagnosed parameters and methods for processing measurement results are used in the implementation of digital energy projects both in Russia and abroad [1 – 5]. The railway economy is not an exception, in which the use of diagnostic systems for power and switching equipment has been launched as part of the concept of a digital traction power supply system being developed. The relevance of this direction is due to both a decrease in accident rate and an increase in the reliability of power equipment, as well as an increase in the safety of train traffic.

2. Question Status
The composition of traction power supply equipment differs from the traction power supply system and includes power, switching equipment of direct and alternating current, rectifier and rectifier-inverter converters, reactive power compensation devices and other power devices for increasing and converting electricity (table 1).

| Equipment                   | Voltage |
|-----------------------------|---------|
|                             | 3.3 kV  | 25 kV | 2x25 kV |
| Power step-down transformer | +       | +     | +       |
| Converter transformer       | +       | –     | –       |
| Rectifier converter         | +       | –     | –       |
| AC circuit breakers         | +       | +     | +       |
| DC circuit breakers         | +       | –     | –       |
| Autotransformer points      | –       | –     | –       |

The use of diagnostic systems for traction power supply devices is aimed at increasing the reliability of the operation of devices of both power and switching equipment, especially beyond the standard operating periods [10].

The system for monitoring the status of power and switching equipment must comply with the requirements for systems included in the digital energy project, in particular, digital traction substation. Unified approaches in terms of collecting, processing and presenting the results of monitoring the condition of the equipment make it possible to use it in the future at all levels of operational management and repair planning.

The development strategy of digital electric networks and digital substations implies the widespread dissemination of technologies to improve the efficiency of the electric grid complex as a whole. Digitalization in the electric grid complex is aimed at optimizing operating modes, increasing the reliability of equipment operation, ensuring the operation of distributed integration in the electric grid complex, obtaining the effect of reducing the level of electricity and power losses and reducing the reserve of generating capacities, integration with renewable energy sources, etc.

The structure of the digital traction substation consists of three levels:

- process level (current and voltage measuring transformers, substation switching devices, diagnostic sensors and devices, etc.)
- the level of connection (relay protection and automation devices, monitoring systems for the status of power and switching equipment, automated information and measurement systems for commercial accounting of electricity, power quality control systems, etc.)
- substation level (substation server, automated workstations (AWS) of the operational standby substation, dispatcher, AWS of relay protection, remote access, etc.)

Elements of the considered levels in one form or another are present at traction substations of railway transport equipped with microprocessor relay protection, automation, telemechanics and diagnostics systems, commercial metering of electricity, etc.

Currently used data transfer protocols are similar, but do not comply with IEC 61850 protocol. The source of information for these systems are secondary circuits of analog measuring transformers, sensors for monitoring and measuring power and switching equipment.

Effective control of the traction power supply system requires a significant amount of information characterizing the state of the equipment (diagnostics), the position of the switching devices and operating modes, containing data on the operation and status of the following systems:

- relay protection and automation
- systems for recording emergency events
• switching devices, power circuits and sectioning of the contact network and traction substations, linear devices
• about the load of connections and voltages in the key nodes of the traction power supply system
• on ongoing and planned maintenance work
• on accounting and measurements of electricity with a given sampling rate for connections
• on the results of equipment diagnostics (insulation control of high-voltage bushings of power transformers: measurement of leakage currents, dielectric loss tangent, relative changes in insulation capacitance; monitoring of transformer oil leakage; monitoring of partial discharges, etc.)

To use the information provided digitally as part of a digital project, the following tasks must first be solved:
• a mathematical apparatus has been developed that allows to determine the optimal operating modes of the traction power supply system, performing operational localization of accidents at the substation and the contact network, allowing the analysis of power consumption
• created methods and algorithms for determining the current and forecast states of power and switching equipment
• algorithms have been created for managing the power reserve, reactive power level, the operation of electric energy storage systems, the operational management of switching devices, taking into account the state of the power supply circuit and sectioning of the contact network, etc.

3. The main tasks and algorithms of traction power supply equipment monitoring systems

The construction of systems for monitoring the status of power and switching equipment of traction substations should be based on the results of solving the following problems:
• substantiate the composition of the equipment, the parameters and performance of which will be determined by the monitoring system
• determine a list of parameters and performance indicators for each type of power and switching equipment
• select key equipment nodes for installing sensors and measuring instruments on them;
• develop methods and algorithms for processing measurement data to determine the status of equipment
• determine the procedure for integrating elements of the equipment status monitoring system with the digital traction substation platform

The development of recommendations for making decisions on further operation is based on an analysis of instantaneous values, changes in levels and trends presented in figure 1.

The main methods for monitoring the status of power transformers include:
• measurement of the concentration of gases dissolved in transformer oil. Using this method, control is carried out over the development of two groups of defects: overheating of live parts and structural elements of the transformer core; electrical discharges in transformer oil. Comparison and analysis of changes in the concentration of gases dissolved in the oil reveals a corresponding change in operating conditions (with an increase in concentration: residual gas concentrations after repair of the transformer, increase in the load of the transformer, mixing of fresh oil with old residues, top-up with used oil, welding on the tank damage to oil pumps, overheating due to defects in the cooling system, overheating of oil by heaters during its processing in degassing other installations, the flow of gases from the tank of the on-load tap-changer contactor to the tank of the transformer expander, having the on-load tap-changer type RS-3 or RS-4, seasonal changes in the intensity of the aging process, the effect of short-circuit currents, etc.; when the concentration decreases: nitrogen purge, reduction of the transformer load, silica gel replacement, long shutdown, oil degassing, refilling with degassed oil, partial or complete oil change in the transformer tank, oil filling under vacuum, oil change, etc.) and determine the precautionary state of equipment.
- continuous monitoring of the insulation state of the high-voltage bushings of power transformers (measurement of leakage currents of the bushings insulation, determination of the dielectric loss tangent, relative changes in the insulation capacitance)
- leakage control of transformer oil

![Diagram of experimental system](image)

**Figure 1.** Decision support system for further equipment operation.

### 4. Using data from other measurement systems

In addition to factors related to the operating system (performing repairs, changing the oil, decommissioning, etc.), the influencing factors include the load level, the number and characteristics of emergency conditions.

Electric energy metering and metering systems at traction substations make it possible to construct a graph of the electrical load for each connection with a high degree of detail. As an example, figure 2 shows the load graph of rectifier converters of one of the DC traction substations.

![Load graph of rectifier converters](image)

**Figure 2.** The results of measuring the volume of electricity processing rectifier converters.

The change in the load level of the connections in the state assessment methods can be estimated by the average current or on the basis of frequency distributions (figure 3).
When diagnosing complete switchgears, methods for monitoring partial discharges in the gas volumes of complete switchgears and the state of high-voltage circuit breakers based on measuring operation parameters are used. Controlled parameters include insulation status parameters of high-voltage switch inputs, oil level and SF$_6$ pressure for oil and SF$_6$ switches, respectively, etc.

The system of monitoring and diagnostics of power and switching equipment of traction power supply is aimed at solving the following problems:

- assessment of the technical condition of power and switching equipment and the dynamics of changes in indicators and parameters of their work
- early detection of defects to prevent the development of equipment failures
- improving conditions and increasing the safety of staff
- forecasting the residual life of power and switching equipment
- reduction of the level of operating costs due to the implementation of service technology in actual condition
- analysis of the causes of equipment accidents by expanding the list of data on operating modes preceding the development of equipment failures

5. Conclusions

The creation and development of an intellectual diagnostic system for traction power supply devices is carried out as part of the development of a digital traction substation project. The composition of the traction power supply equipment, the state of which is monitored, and the list of parameters must be determined on the basis of a feasibility study. Making decisions on the basis of changes in the controlled parameters for further operation should take into account the modes of its operation and allow to increase the reliability of the traction power supply devices within the framework of the diagnostic system.

References

[1] Brncala P, Guttena M 2019 13th Int. Sci. Conf. on Sustainable, Modern and Safe Transport (Novy Smokovec)
[2] Cheng Q, Zhao Z, Tang C, Qian G and Islam S 2019 Diagnostic of Transformer Winding Deformation Fault Types Using Continuous Wavelet Transform of Pulse Response Measurement
[3] Žarković M and Stojković Z 2017 Electric Power Systems Research 149
[4] Mejia-Barron A, Valtierra-Rodriguez M, Granados-Lieberman D, Olivares-Galvan J C and Escarela-Perez R 2017 Electric Power Systems Research 152
[5] AJ C, Salam M A, Rahman Q M, Wen F, Ang S P and Voon W 2018 Renewable and Sustainable Energy Reviews 82