Development of “digital substation” technology for power supply of railways

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Abstract. The paper considers the application of the “Digital Railway” project at the traction substation. The “Digital Railway” project should become a centralized system uniting the programs for the control of railway elements. In the traction power supply system, the application of digital technologies is often understood as the application of data transfer protocols of the International Energy Commission “IEC 61850”. The substations that switched to this information protocol are usually called “digital”. An attempt to introduce the “digital substation” technology only by completing a set of corresponding equipment can give a negative result of its application. The efficiency achieved through the technical upgrading of equipment (reduction of losses for own needs, reduction of electromagnetic influence, reduction of analog signal input channels, reduction in the number of cable products used, and improvement of the measurement accuracy class) may not be sufficient to pay for the project. The qualitative integration of all involved services in a single information process of monitoring and controlling the digital substation will increase the efficiency of its application. As a positive experience when considering the use of digital technologies in traction power supply systems, one can cite the Automated system for monitoring the railway transport infrastructure developed and implemented by the staff of the Far Eastern State Transport University at a number of traction substations of the Far Eastern operating domain and at the 2ES5K “Ermak” electric locomotive. In addition, this system already has a support of IEC 61850 protocols.

1 Introduction

According to the Minutes of the meeting of the Joint Scientific Council of Open Joint Stock Company “Russian Railways” of October 26, 2017 № 86 “The definition of directions of scientific research in the field of digitalization and the formation of recommendations for the implementation of the concept of “Digital Railway”, the “Digital Railway” project should become a centralized system uniting the programs for the control of railway elements” [1].

“Digital Railway” (DR) is developing in the context of the development of Intelligent Transport Systems - applications of electronics, information technology, informatics and other innovative sciences in the field of transport systems in terms of improving the efficiency of the transport system and reducing the negative aspects of transport processes of the

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systems[2]. This innovative approach on railway transport will facilitate the integration of various railway subsystems and the integration of the railway system with other modes of transport in terms of the development of a mobility service base.

The very concept of the “Digital Railway” (DR) exists in several countries for the last several decades [3]. During this time, digital technology, information systems and related technologies have undergone significant development and renewal and even a change in the technological order. At the same time, the approaches to the DR project were changing. At present, the DR can be defined as a new concept for the organization and control of the railway transport system based on a digital support system that uses digital systems to increase efficiency and reduce the negative aspects of the railway transport system [2]. Introduction of the DR project assumes a return in the form of an increase in the amount of transported goods, while simultaneously increasing energy efficiency and lowering the cost price. This should be achieved by improving the efficiency of the railway and improving the safety of service personnel. One of the features of the project is the gradual transfer of intellectual functions from human to information systems. The innovative approach is to link railway vehicles with related infrastructure [4,5].

2 Digital substation

One of the most important elements of such an infrastructure is the traction power supply system. Speaking of power supply systems, there is also a new concept – “Digital Substation” (DS). Unlike the DR, the DSs are more widely spread now, since the introduction of this technology is possible within a single substation with subsequent analysis of best practices, unlike the railway network that combines infrastructure facilities that are large both in volume and diversity.

A series of standards, combined in the IEC 61850 collection, allows replacement of information channels at the substations with their digital analog. This requires significant or complete technical upgrading of all equipment. The main information protocols are MMS protocol of 61850-8.1 standard, GOOSE protocol of 61850-8.1 standard, and SV protocol of 61850-9.2 standard. [6, 7]

The experience of implementing the DS technologies showed that it is more expedient first to implement the MMS protocol on the operating objects. It is implemented in the station data-bus and is less demanding of the digital power of its systems, and is a modification of the common TCP/IP network protocol with a special way of generating a data table. This protocol is often supported by equipment manufacturers and it can now be found in the characteristics of many devices [8]. The implementation of GOOSE protocols is complicated by the higher requirements for the computing power of information systems, since it is a fast protocol and replaces operational chains, making rapid transfer of discrete information within the process data-bus uniting the main equipment of the substation and secondary equipment [9]. The SV information protocol provides the transmission of continuous data (current and voltage values) in real time with series of 80 or 256 strokes per period. The implementation of this protocol requires the installation of electronic current/voltage transformers, as well as the transition of all protection, automation, metering and measuring devices to support this protocol [10].

3 Discussion

The possibilities for partial implementation of IEC 61850 series standards allow performing substation projects of various stages and depth of digitalization, while achieving various technical and economic effects. Moreover, a characteristic feature of the DS is a decrease in

the economic effect when the voltage class of the substation circuits decreases due to the rise in price of digital equipment in comparison with the traditional one. Thus, the payback of the cost of the DS with the voltage class of 220/110 kV will be lower than a large network DS.

It should be noted that a number of manufacturers motivated to improve their products and implement best practices in the use of information systems already today support the IEC 61850 protocols in the manufactured devices, which are also installed in traction substations.

Also, the situation with the integration of the DS with the surrounding infrastructure is ambiguous. The cornerstone here is the intellectualization and digitalization of data channels within the substation, when the combining with higher control centers is carried out through the obsolete communication protocols IEC 60780-5-104, DNP3, MODBUS [7,11,12,13,14]. Therefore, the integration into the vertical control structure of digital and traditional substations does not differ, in which a significant part of advantages of the DS over the latter are lost in the case of the implementation of the DR concept. The basis of the DR concept is just a wide vertical integration of the train and the road infrastructure. Thus, the implementation of the DS concept in the traction substation has a risk of meeting the following problems:

- The substation will not be sufficiently integrated into the DR system at the level of interaction of information protocols.
- Construction of the substation will be very expensive, and this cost will not be covered during the subsequent operation, which can be a positive effect only for interested manufacturers and equipment suppliers.

As a result, the total effect of one failed pilot project can permanently exclude the project of integration of the power supply system into the DR infrastructure, and the term “Digital Traction Substation” can remain a definition without any practical implementation.

To date, the concept of a digital traction substation (DTS) requires serious consideration. It should not be the replacement of analogue data channels with digital ones that will drive this technology, but information integration of infrastructure of the power supply system with rolling stock and other objects within the DS. It is here where the authors see the enormous potential for increasing the efficiency of the economic effect from the operation of infrastructure and rolling stock [15,16,17]. The volumes of this information, its type, structure and other issues require elaboration. It will be inefficient to spend money on the introduction of expensive technologies and equipment that will not be in demand or will not produce the proper return during the period of their operation, and in the context of the DR, will not significantly affect the quantity and quality of information exchange. At the same time, when installing intelligent systems, it should be understood that the lifetime of the equipment is decades, and it should have a modernization potential by changing or introducing new software packages and algorithms, which in the long term will significantly reduce the cost of the implementation of new technologies, the development of which is much faster than the lifetime of the equipment.

The general view of information interaction within the DR is presented in Figure 1. The figure shows the three main elements of the railway transport: railway vehicles, railway infrastructure, including the power supply system, and dispatchers, operational personnel as an element of human influence on the system. Information environment (digital support system) connects them. The digital traction substation should become a component of this system, including data collection, its processing, and generation of control actions.

The active influence on this process is made not only by the data of the infrastructure itself and by the control actions of the personnel but also by information from railway vehicles. Also, the railway transport and traction power supply system make a significant impact on each other through the process of supplying electric traction. This connection is highlighted in red in the figure.

Fig. 1. High-level functional diagram of the DR.

4 Experimental part

As a positive experience when considering the use of digital technologies in traction power supply systems, the Automated Railway Transport Infrastructure Monitoring System (AMS) developed and implemented by FESTU staff at a number of traction substations at the Far Eastern operating domain and at the 2E5K “Ermak” electric locomotive can be cited. The purpose of the development of the AMS was to create an on-line monitoring system for the experimental section characterized by extremely heavy operating conditions of the rolling stock and railway infrastructure facilities.

The purpose of the AMS monitoring system is the immediate display of train and technical information of the monitored objects, which allows quick identification of the facts and conditions for the occurrence of overloading regimes of the main equipment, as well as identification of the elements with abnormal or accelerated degradation parameters. All information is transferred to consumers in accordance with their level of control activity. Among the main functions of the AMS Nakhodka system are the measurement of the physical quantities of the main infrastructure objects, the automatic collection, storage and initial processing of measurement data, including protection against information loss and unauthorized access.

The information about the current state of the section is displayed using the web interface. Reporting information is generated in the form of a post-fault protocol of the same type, which is sent to all control levels of service, and a daily extended report on the situation on the section over the past day. Statistical information consists of reports that are generated on a periodic basis using standard data processing procedures and issued based on indicators of related services. Also, with significant deviations in the operation of controlled objects (accidents, abnormal operating modes), a special report is formed. The report contains information about the object, including its location and name, background and history of changes in the measured values. The data is displayed with a high resolution of the discrete

time sampling, which makes it possible to fully monitor the ongoing processes.

Over several years of operation, the automated monitoring system for traction substations developed and used by the scientists of the FESTU [17, 18, 19] allowed accumulation of a unique statistical base for analyzing the operation modes of traction power supply system under various conditions of train traffic and train traffic density. Pilot projects were implemented and put into operation at traction substations of Far Eastern Railways, as well as at the 2ES5K “Ermak” locomotive. The structural diagram of the AMS is shown in Figure 2.

Fig. 2. Structural diagram of the AMS.

Nowadays, the monitoring system allows us to combine information flows of any infrastructure facility. To do this, the object measuring complexes that implement a distributed algorithm for processing and storing information are used. Measurements are carried out both through additionally installed sensors and using existing measuring complexes at the facility. At the moment, the object measuring system AMS has support for the digital protocols MODBUS (RS-232/422/485 /, TCP), DNP3, IEC 60870-5-101/103/104, IEC 61850 (MMS, GOOSE, SV (80 samples/period)). The IEC 61850 protocols are supported both as a data receiver (SUBSCRIBER) and as its source (PUBLISHER). So the system can both read the values of an electric current/voltage transformer and convert measured signals to SV format in real time mode. In order to control fast processes of discrete and analog character, a speed measurement module was developed and implemented. [19] The operation of this module is demonstrated in Figure 3.

In this example, the algorithm includes monitoring of the arrival time of the synchronization pulse PPS (Pulse Per Second), recording of the time of this event, and also recording and displaying of the current phase and frequency of the measured signal (voltage). Both the PMU (Phasor Measurement Unit) measurement system and the recording/synchronization of fast processes of any infrastructure facility equipped with AMS are implemented in this way (20).

For carrying out measurements and tests on substations non-equipped with AMS system, mobile object measuring systems were developed.

Fig. 3. Operation of the speed measurement module in the AMS system.

A comparison of the characteristics of stationary and mobile object measuring systems is given in Table 1.

Table 1. Characteristics of object measuring systems of AMS.

Parameter	Object measuring system of AMS (inline version)	Object measuring system of AMS (mobile version)
Number of channels of controlled analog circuits	81	55
Sampling rate of ADS	32 thousand samples/sec per channel	32 thousand samples/sec per channel
Inline server for primary data processing	+	-
Intranet communication channel	+	-
GPS / GLONASS synchronization of server's system time	+	-
GPS / GLONASS of measuring unit	+	+
Support for the protocol 61850 8-1 MMS	+	+
Support for the protocol 61850 8-1 GOOSE	+	-
Support for the protocol 61850 9-2 SV	+	-

Number of supervised substation signaling circuits	72	2
Support for synchronous vector measurements (PMU)	+	+
Event recording period	25 nsec	25 nsec
Presence of a voltage regulator and uninterruptible power supply	+	-
Oscillograph recording of emergency events	+	+
Electricity quality recorder	+	+

5 Conclusions

The processes of globalization, informatization, and development of electronic and intelligence systems create prospects for controlling the railway transport system with the use of intelligent systems and means.

The introduction of digital technologies on heavy-duty lines ensures an increase in the reliability of the power supply system, an objective assessment of the load operation modes of traction substation equipment and the contact network. In low-activity sections, the digitalization of substations creates conditions for the introduction of minimally manned service operations.

Experience in the development and operation of an automated monitoring system confirms the possibility of developing economical and, at the same time, high-performance systems with relatively low costs for design, manufacturing and installation.

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