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Digital substation conceptual model for the complex full-scale-model diagnostics

R G Oganyan, N D Narakidze, D V Shaykhutdinov, E V Kirievskiy, S S Kostinskiy

Platov South-Russia State Polytechnic University (NPI), 132, Prosveschenia Str., Novocherkassk, 346428, Russia

E-mail: roman.work18@gmail.com

Abstract. This article describes the development of the detailed conceptual model of digital substation and to a research of opportunities of digital substation on the basis of the comparative characteristic of digital and traditional substations. Accurate accounting of all components of system and their interaction is necessary for efficient development of methodology of modelling of similar complex technical systems. It will give a powerful spur to development of systems of diagnostics, the considered complex technical system. A review of existing projects related to the implementation of the "Digital Substation" Technology has been conducted with a view to generalizing the approaches to the realization of this technology.

1. Introduction

A well-known fact is increases the production of electricity from year to year, which leads to an increase in the load on the energy system. The existing energy infrastructure, in most cases is overloaded, which exacerbates the problem of ensuring the reliability of energy supply. In addition to this, the term of operation of the equipment used to date has long since expired, which indicates a high probability of failure of the equipment operated. From the economic and technical point of view, it is impossible to replace equipment at the same time, which aggravates the problem of the normal functioning of the energy sector.

Based on the above, it is necessary to build new substations, and taking into account the development of modern technologies, the new substations are digital substations. Digital substations have a number of advantages and differences in comparison with traditional substations. According to the November conference "Digital Network", transition to digital substation is inevitable. However, for a detailed study of a new facility, a thorough analysis of its structure and differences from the traditional substation is necessary in order to use them effectively. Besides, there is no most common structure of digital substation for realization of systems of monitoring and diagnostics on their basis. In this article, it is proposed to develop such a structure on the basis of an analysis of existing projects for the implementation of a digital substation.

2. Materials and methods

When developing the conceptual model, the first step is to model the model to identify the properties of the system in accordance with the purpose of modeling - the development of a unified structural description of a digital substation. The next step in the development of the conceptual model is the choice of the level of detail of the model (stratification). The system model is represented as a set of parts (subsystems, elements). The model must have all the elements that implement the execution of all technological processes. In addition, the model includes elements that serve to manage resources and processes, as well as to store the information needed for management (detailing). The next step in creating a conceptual model is its localization, which is carried out by representing the external environment in the form of generators of external influences included in the model as elements.

3. Results and Discussion

Application of optical measuring transformers belongs to the first main difference of digital substations from traditional:

Table 1. Comparative characteristics based on measuring transformers of digital and traditional substations

Digital substation (Optical measuring transformers)	**Traditional substation (Electromagnetic measuring transformers)**
Ecological compatibility	Oil-filled transformers - explosion and fire hazardous
Increased measurement accuracy, wide frequency range	Inadequate frequency range, which imposes a restriction on the development of relay protection, diagnostics, the error due to imbalance in the load
Absence of ferroresonance	The emergence of ferro-resonance, which leads to improper operation of electric power equipment, its failure, the development of major accidents
Reduced weight and dimensions	High weight and dimensions
Safe current measuring transformers	Danger when opening secondary circuits of the current transformer
Not exposed to electromagnetic interference	Secondary circuits of analog voltage transformers are subject to electromagnetic interference
Changing the transformation ratio	The need for additional equipment to change the ratio of transformation
Elimination of the effect of "overload" on secondary circuits	The presence of the effect of "overload"

However, there is a problem of optical measuring transformers, which is their cost.
The second major difference between the digital substation and the traditional one is the use of the IEC 61850:

Table 2. Comparative characteristics based on the used protocols of digital and traditional substations

Digital substation (IEC 61850)	**Traditional substation (MEK 60870-101/103/104, Modbus, DNP3 etc.)**
Ethernet with speed 100 Mbit/s	The speed of information exchange based on the use of serial interfaces is not more than 0.0192 Mbit / s
Transmission of instantaneous current and voltage values	Lack of real-time data transmission (delay)
The ability to transfer a large amount of information	Limiting the transfer of large amounts of information
Built-in ability to work with other protocols	Reassignment of signals in firm protocols and vice versa leads to loss of information

Digital substation (IEC 61850)	**Traditional substation (MEK 60870-101/103/104, Modbus, DNP3 etc.)**
Horizontal data exchange between devices (GOOSE)	There is no horizontal data exchange
Self-diagnosis of communication channels	Low level of diagnostics of communication channels

The use of digital data channels makes it possible to simplify secondary connections, due to the use of optical fiber. In addition, the transfer of information in digital form is safe, in contrast to analog transmission of data. With these differences in mind, the IEC 61850 protocol certainly has advantages, however, this protocol also has drawbacks [1].

To take into account all components of this complex technical system, a model approach is proposed. To simulate such complex technical systems, the most accurate scheme is needed, allowing to evaluate the interaction of all elements. At the current time, there are many structural diagrams of the digital substation, however, each of the schemes is oriented for a particular object, but the most detailed and general scheme is not presented. For the development of the scheme, it is necessary to analyze existing projects related to the implementation of the digital substation.

One of the pilot projects "Digital substation" is a substation "Sosnovaya" 110/10 kV located in Snezhinsk, Chelyabinsk region. The whole complex "Digital substation" (optical current and voltage transformer and digital information and measuring system (DIMS) was put into trial operation in February 2013. This project is implemented in compliance with the requirements of IEC 61850 [2].

The architecture of the digital substation according to the pilot project is as follows:

• The process level includes a primary current and voltage transducer NXVCT-230

• The bay level is represented by an intelligent electronic device with data reception according to the IEC 61850 protocol 9-2LE: "SysteLLogic Emergency Events Recorder", "SysteLLogic device for measuring parameters" and "SysteLLogic Unified Power Quality Index"

• The station level is represented by a server of digital substation, an automated workstation (AWP), a time synchronization server.

The physical implementation of the station bus and process bus is performed on Ethernet switches. To synchronize time, the SSV-1G time server is used, which provides 1PPS reference signals and supports NTP and SNTP protocols. A three-phase set of fiber-optic current and voltage converters was placed on an open switchgear parallel to the basic traditional measuring equipment. The architecture of this substation is shown in Figure 1.

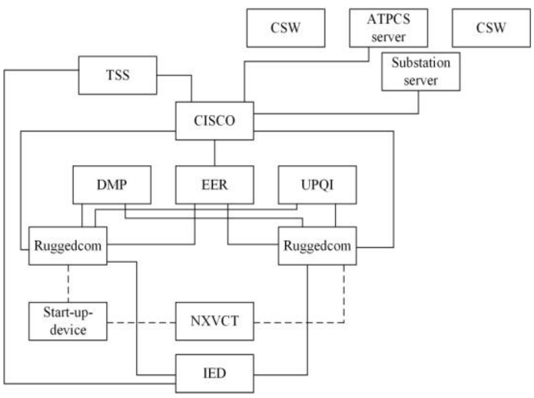

Figure 1. The architecture of the digital substation at 110/10 kV Substation "Sosnovaya"

The secondary measuring equipment is the IED:

a) "SysteLLogic device for measuring parameters (DMP)" - the device for measuring electrical energy parameters. Transmission of operational and archival data to the upper level is carried out according to IEC 61850-8-1 protocol or by intra-company protocol SystelNet in XML format.

b) "SysteLLogic Unified Power Quality Index" - a device for changing the power quality indicators and their comparison with regulatory values (in accordance with GOST R 54149-2010). Transmission of operational and archive data to the upper level is identical to "SysteLLogic DMP".
c) "SysteLLogic Emergency Events Recorder" - the device provides recording and storage of oscillograms of stationary and transient processes preceding and accompanying emergency modes in electrical networks.
During the commissioning of the DIMS for the digital substation, the mobile verification complex was used. The results of metrological studies showed that the digital substation and traditional telemechanics are in good agreement within the limits of the declared errors.
Another pilot project for the implementation of the technology "Digital substation" is the automation of a 10 kV Distribution Transformer Substation located in Moscow [3]. The contractor proposed a solution for the implementation of the concept by installing on its own a software and hardware complex called iSAS [4].
The elements of the digital substation at the substation "Emelino" in the Sverdlovsk region have been successfully introduced. The integrated system is based on the automated process control system implemented through the modern IEC 61850 data exchange standard [5].
The implementation of the "Digital substation" at the Nizhniy Novgorod HPP of JSC RusHydro [6,7]. In 2013, JSC RusHydro decided to implement the pilot implementation of equipment that operates using the technology of a "digital substation", based on the Nizhny Novgorod HPP. The hydroelectric power station is equipped with 8 hydraulic units with a total installed capacity of 520 MW. Within the framework of the pilot project, a digital automatic control system was implemented in one block № 6 of the generator-transformer of the Nizhny Novgorod hydroelectric power station.
The pilot-industrial sample of the software and hardware complex consists of three levels.

- Process level

The cabinet of field controllers based on the NPT microRTU controller, optical current transformers installed at 110 kV voltage from the higher voltage side of the block transformer, optical flexible current transformers at the main terminals of the 13.8 kV voltage generator, and also generator neutral, electronic voltage transformers, controllers with built-in multiplexer NPT MU board.

- Bay level

Microprocessor relay protection and automation devices, NPT BAY connection controller (9.2), electricity meter.

- Station level

Server hardware and software SCADA NPT Expert.
The process bus and the station bus are made in the form of a single optical ring and are separated using VLAN technology. The discrete signals at the field level are collected by NPT microRTU devices and, in the form of GOOSE messages, are transmitted via the station bus to the level of connections. The digitized measured values are transferred to process bus switches in the form of Sampled Values (SV) messages. The system of single time is built on the basis of the Meinberg M400 / PTP exact time server, which provides high-precision synchronization of devices over the LAN.
The important result was the provision of joint work of intelligent electronic devices from 7 manufacturers (Energoprom Automation, PROFOTEK, EKRA, Brestler, ABB, Alstom, Prosoft Systems). At the moment, according to the November conference "Digital Network", work on this facility continues, with the task of further expanding the level of accession and cybersecurity of the substation.
In addition, at present, work is underway on digital substation projects implemented on energy clusters "Elgaugol" [8] and "Vanino" [9].
August 15, 2017 was put into operation substation of the Rostov region " Sportivnaya" [10]. The automated control system allows employees to monitor and control technological and operational parameters with their visualization, to receive information about the state of the substation's electrical circuits in real time, to signal the output of process parameters for permissible norms. All the equipment used at the substation "Sportivnaya" is equipped with a full amount of locks and

protections, including locks from erroneous actions, modern design solutions provide a high degree of safety for maintenance personnel. Operative control of the substation can be carried out in several ways - traditional dispatching control, remote control of switching devices from the workplace of the dispatcher, remote telecontrol from the dispatching office of the production department. The software complex conducts continuous diagnostics of the temperature of the active part, the state of isolation of high-voltage bushings, the parameters of transformer oil, and the content of dissolved gases.
June 4, 2018 opened the first in the Moscow region digital substation 110 kV, "Medvedevskaya" [11]. Using the latest digital technology, it allows you to carry out online monitoring of electrical equipment. All probable malfunctions will be eliminated upon their occurrence. Measurement of electrical and technological parameters of the primary equipment, control of its condition and control is carried out using digital technologies in accordance with the international standard IEC 61850. Two power transformers with a capacity of 80 MVA are installed at the substation; Complete switchgear with gas-insulated insulation (SF6) 110 kV; 4-section switchgear 20 kV with vacuum switches, designed for 20 linear cells; complex relay protection and automation and automated process control system. The loss reduction for the new substation for the first time in Russia will exceed 30%.
There are also polygons "Digital substation", namely:

- JSC "Scientific and Technical Center of FGC UES" Center "Experimental polygon Digital substation" [12]
- JSC "ChEAZ" (Test Center LLC) - Testing area of the software and hardware complex of the automated process control system in the Information Storm mode [13]
- JSC "NTC UES" a test stand of JSC "NTC UES" (LLC "Energoprom Automatization") [14]
- "NRU MEI" "Laboratory for the study of the interoperability of devices operating in accordance with the IEC 61850 standard" [15]

4. Conclusion
Combining information from various structural diagrams, we obtain the scheme of a digital substation, which is depicted in Figure 2.

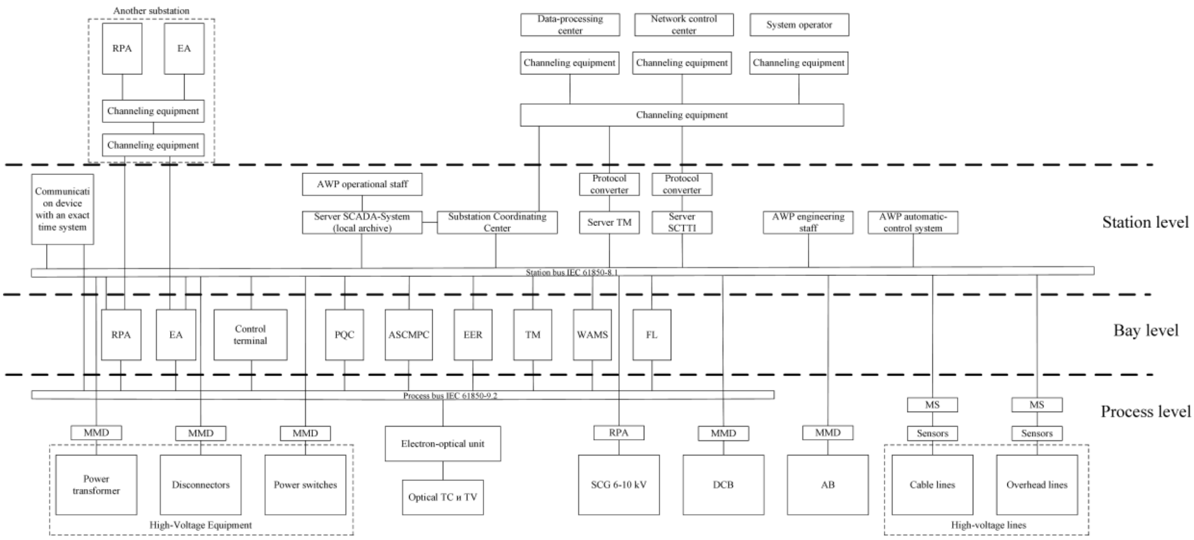

Figure 2. Structural diagram of the digital substation

The notation in Figure 3: MMD – man-machine device; DCB – direct-current board; AB – auxiliaries board; MS – monitoring system; RPA – relay protection and automation; EA – emergency automation; PQC – power quality control; ASCMPC – automatic system for commercial measurement of power consumption; EER – emergency event recorder; TM – telemechanics; WAMS – wide-area measurement system; FL – fault localization; AWP – automated workstation; SCTTI – system for the collection and transmission of technological information; SCG – switchgear and control gear

From the above described it follows that at present there is a mass introduction and approbation of solutions of the class "Digital substation" based on the standards of the IEC 61850 series. The application of the technology of the "Digital substation" should allow in the future to significantly reduce the costs for the design, commissioning, operation and maintenance of power facilities. However, at the moment, efforts are focused on implementing this technology, forgetting about the diagnosis of such a complex technical system. Repeatedly the energy community stressed that it is impossible to transfer the methodology of diagnostics from a traditional substation to a digital substation, which is an obstacle to the introduction of innovative technology. It is necessary to improve the methodological basis on the basis of taking advantage of the digital substation, and given the complexity of the system under consideration, the model approach is the best option. When developing the model, the following stages of the description are distinguished: conceptual, mathematical, program. In this article, the first step is the development of a conceptual model. Based on this model, together with the use of substation data, a mathematical model can be developed.
Thus, for full-scale-model diagnostics implementation of the "Digital substation" technology in the Russian energy sector, it is necessary to overcome the obstacle associated with the development of diagnostic bases. The application of fundamentally new approaches to the evaluation of the state of the equipment of digital substations will allow accelerating the introduction of innovative technology and will also solve one of the problems of IEC 61850 - the development of full-fledged diagnostic tools.

5. Acknowledgments
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