Concept of control and data acquisition system for modern digital power substation

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Abstract. The article deals with the issue of standardization of approach to definition of modern digital substation is considered. The approaches proposed and partially implemented by equipment manufacturers are described, such as data collection and processing by means of relay protection and automation with the use of proprietary algorithms, wireless and optical current and voltage sensors, etc. The authors propose the use of a unified system for collecting and processing data generated and used in the operation of an electric substation. The structure of the signal transmission system for the main groups of electrical power equipment is described, the requirements for the predictive diagnostics system that allows maintaining the equipment based on its technical condition are described.

Despite the fact that the group of International Electrotechnical Commission (IEC) protocol 61850, describing the concept of construction and operation of relay protection and automation systems, electricity metering, automated process control system, registration of emergency events, communication networks, data processing systems, etc. for substations with a class of supply voltage of 110 kV, operates in the Russian Federation since the mid-2000s, many customers do not have a unified approach to building the digital substation structure.

Manufacturers do not have a single complete concept describing the list of elements and systems that a modern digital substation should include. Therefore, manufacturers are implementing those individual solutions in the production of which they specialize, such as wireless temperature control in switchgears, technological video surveillance, constant self-diagnosis of equipment, etc.

Some manufacturers suggest that digitalization degrades reliability by introducing additional elements, combining the functions of several devices in one device. For example, each stage of the traditional three-stage overcurrent protection line operates independently, current and time tuning does not interfere with the failure of one unit and absolutely does not affect the operation of other terminals. As part of the digitalization of the substation, it is proposed to install an additional relay protection and automation terminal in the switchgear of 10 kV, which receives signals from all connections. The principle of operation is as follows: if this terminal receives a signal of failure from one of the terminals, its functions are assumed by this additional terminal [1].

It should also be noted that all substations currently under construction or under reconstruction with a voltage of 35-110 kV are digital in themselves. All information on modern substations is processed by microprocessor devices, and the difference from a digital substation is only in the point of conversion of an analog signal into a digital one. For a modern substation not operating under IEC 61850 protocol,
the current or voltage measuring transformer is separated by some distance from the analog-to-digital Converter. The analog signal is transmitted via copper cables to the analog-to-digital converter with subsequent conversion. In digital substations convert the measured signal into a digital sequence occurs at the place of installation of the measuring device – an optoelectronic current transformer working on the principle of magneto-optical Faraday effect, or photoelectric voltage transformer working on the principle of electro-optic effect Pockels. Such measuring devices in comparison with traditional current transformer and voltage transformer exclude the phenomenon of hysteresis, magnetic saturation and residual magnetization, hence the greater dynamic range of measurements and their accuracy, which is an undeniable advantage. Also, optoelectronic devices are safe for the environment, do not allow the occurrence of fires, as they do not contain harmful substances and conductive materials. The disadvantage of these measuring instruments is the high price. However, this disadvantage, according to the authors, is compensated by the possibility of introducing into the General substation system of data collection and analysis more accurate information about the operating parameters of the supply and outgoing lines.

Based on the analysis, it can be concluded that the basis of a modern digital substation should be a system that performs the functions of collecting, processing and analyzing all the necessary initial data generated in the process, summarizing them and managing all the advanced developments from domestic equipment manufacturers.

First of all, signals must be collected from field-level devices, such as:

- relay protection and automation terminals;
- controllers connections;
- electricity meters;
- diagnostic devices (measuring transducers parameters involved in the calculation algorithms of failure models);
- devices of quality control of electric energy;
- uninterruptible power supplies;
- operational direct current system;
- multifunctional measuring transducers;
- regulators under load;
- variable frequency drive;
- reactive power compensation devices;
- devices for determining the damaged feeder;
- emergency automation devices;
- diesel generator sets;
- registrars of emergency events;
- outdoor lighting control system.

Information exchange with the above devices is carried out via digital interfaces and IEC protocols 61850-8-1 and Modbus TCP. The data transmission diagram for the digital substation is shown in figure 1.

For incoming data, the main module of processing and visualization should be a dispatching system with the function of data transmission to a higher power electrone network for organization, analytics, signaling and registration of emergency events. There are lots of proven and ready-made solutions in this direction.

Quite interesting is the module of predictive diagnostics of equipment, which has not yet received wide distribution. It monitors the status parameters of the main equipment, such as:

- operating time parameters characterizing the "age" of the equipment;
- residual life, characterizing the evaluation of the period of time before the repair or next maintenance;
- parameters of state of "health" of equipment, which characterize the compliance status of the equipment to carry the specified load and meet specified operating parameters.
Figure 1. Block diagram of data transmission.

The algorithm of the predictive diagnostics system is shown in figure 2.

Figure 2. The algorithm of predictive diagnostics of equipment.

An example in modern world practice is the opening in December 2017 at the New York Energy Authority (NYPA) of a new integrated intelligent operations center (iSOC), which is based on the collection of data from more than 24,000 sensors that monitor the operation of 16 power plants and 1,400 miles of power lines, analysis with the help of special software Predix equipment performance in real time, comparison with the projected performance, detection of problems long before scheduled preventive maintenance.

Investments in iSOC amounted to about $ 7 million. In the first five months of the system's operation, savings in terms of avoided costs amounted to $ 5 million. In addition, according to the company’s management, due to the introduction of cisco managed to avoid suboptimal investments of about $ 170 million [2].

For calculating these parameters, the suppliers, together with the main equipment, should provide the methods for calculating these parameters, as well as the methods determining in real time the need for preventive maintenance, technical service and repair of equipment.

In terms of monitoring the condition of the equipment included in the consideration:
• high power equipment;
• high-voltage equipment;
• equipment ensuring process safety;
• equipment where the probability of failure is higher than average during normal operation and start/stop periods;
• equipment with limited resource on/off;
• equipment whose condition depends on external factors.

Among the selected pieces of equipment:

• power transformer;
• electric motors, electric drives of pumping equipment, compressors, draft mechanisms;
• frequency converters and soft starters;
• high and medium voltage switches;
• uninterruptible power supplies and operating current systems;
• backup diesel units;
• gas insulated switchgear.

Below are lists of diagnostic signals that can be used in equipment condition monitoring models.

Transformer equipment:

• overcurrent and voltage parameters;
• winding and cooling system temperature;
• insulation resistance;
• partial discharge control;
• oil level;
• gas and moisture content of oil;
• operating parameters of oil pumps and cooling system fans;
• acoustic location of defects;
• state of surge protectors;
• state of the voltage regulation system.

Electric motors of driving mechanisms:

• insulation status of the stator windings;
• winding temperature;
• bearing temperature;
• vibration level;
• number of starts;
• total operating hours.

Diesel power plant:

• oil level;
• coolant temperature;
• frequency;
• voltage level;
• power;
• fuel level;
As one of the digital substation systems can be identified control system for indoor and outdoor lighting, the management of which can be implemented in two scenarios: basic and advanced.

The basic scenario is to have two control modes: automatic (lighting device is activated according to the indications of the light sensor or the clock real-time) and manual (light fixture included operational staff).

Automatic mode can be realized from the light sensor (on/off depending on the degree of illumination) or from the real-time clock (on/off astronomical time).

The manual mode can be initiated by a local command from the control Cabinet or by a remote control command from the dispatcher of the automated power control system.

Advanced script must allow to enable weak illumination (the minimum required level of illumination for industrial objects) or false targets (the maximum level of illumination for nonessential objects).

Thus, using a system combining all of the above functions, it is possible to build a digital substation concept that meets modern requirements, taking into account all the latest and promising developments. Beyond the scope of this review is technological video surveillance and its analysis system, which is a topic for separate consideration.

As part of the digitalization of the electricity sector, one should keep in mind the urgent need for replacing worn-out power equipment, bare wires of distribution networks of 6-10 kV with a self-supporting insulated wire-3, as well as the reconstruction of outdated 0.4 kV networks (especially in rural areas), where there are high losses due to their low capacity.

References
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