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Analysis of Innovative Methods for Ensuring Operational Reliability and Safety Used in the Energy Systems of Azerbaijan

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Abstract: The high rates of restoration work carried out in the territories of Azerbaijan recently liberated from the occupation and the technological requirements for the projected power plants and electric grids of modern design and high power require the use of reliable and effective methods of control and protection of these facilities from failures and damage, as well as possible cyberattacks. In this regard, the article analyses the actual questions of the use of modern technologies and developments for the protection of power systems, provides the best options for the management and protection of electrical networks, which are most suitable for long-term plans for the development of the region on the principle of smart cities.

Keywords: Power plant, Automation, Microprocessor, Relay, Busbar, Transmission line

Introduction

Large-scale projects are being implemented in Azerbaijan to restore infrastructure in the territories recently liberated from occupation on the principle of smart cities. This includes, among other things, the construction of new modern power plants and electrical networks of modern design and high capacity. This, in turn, requires the application of reliable and effective safety methods and the protection of these systems from any failures or damage.

Changing the management structure of the electric power industry and the process of its reform requires paying increasing attention to the development and modernization of systems for collecting, transmitting, and displaying information at control points, which play a significant role in ensuring the controllability and reliability of the energy system (Papkov, 2021). The introduction of modern digital technologies in the electric power industry makes it possible to generate large amounts of data on the state of connections, equipment at substations and the power system. The article Antamoshin et al. (2016) analyzes the prospects for using methods based on multiple modeling, statistical processing of results and machine learning, in relay protection and automation of electrical networks. At the same time, the problems of collecting information not only about the position of the equipment and the values of the mode parameters should be considered as much as possible, but also the issues of maintenance, the tasks of technical and commercial electricity metering, registration of emergency events and processes, determining the place of damage, diagnosing the main equipment, organizing a single time system (Tsypkin, 2017). The study conducted in Ilyushin (2019). proves the possibility of using parameters calculated in offline mode to implement a system of daily and emergency control for the further transition to online software calculations of established and transient processes.

It should be noted the need to ensure the cybersecurity of automatic control systems, such as relay protection devices, mode control and emergency control devices, automated control systems. In the article [6], the authors propose a methodical approach to the analysis of the structure of automatic means of regime and emergency control from the point of view of their impact on the reliability and survivability of power systems, taking into account the known cybersecurity. The authors of the article (Makarov et al.,2018) analyzed methodological and model developments on the study of energy security problems and describe the features of new challenges in energy security research at present, emphasizing the need to develop modern methods, models and tools. In this

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regard, this article examines a set of aspects of the use of modern technologies and developments to protect energy systems and analyzes the optimal concepts for managing the electric networks of Azerbaijan in the context of accelerated restoration work on the lands liberated from occupation.

Qualitative Analysis of the Electric Power Systems of Azerbaijan, Their Reliability and Safety

Along with long-existing power plants and substations, (Azerbaijan Thermoelectric Power Plant, Mingachevir Hydroelectric Power Plant, Sumgait, Northern, Southern Power Plants, Khachmaz, Absheron, Ganja Electric Substations), the country has many reconstructed and new stations of medium and small power. New hydroelectric power plants and substations are being designed in the recently liberated territories of the Karabakh and East Zangezur economic regions of Azerbaijan, where the most modern electrical equipment and technologies of foreign manufacturers will be used. It is also planned to use alternative energy sources in the construction of smart cities in these territories.

The country's electricity economy includes not only a wide network of hydro- and thermoelectric power plants, but also intensive energy exchange systems with neighboring countries such as Turkey, Georgia, Russia and Iran, which plays an important role in providing the country with sustainable electricity and is an important element of its stability and security. For the effective management of this extensive network, high-quality electrical equipment of foreign manufacturers such as AREVA, ABB, GE, Schneider, Siemens, NR-China, etc., as well as modern technologies of international energy companies from Turkey, Japan, Russia, Ukraine, Italy, Germany, and others are used. All this increases the professional level of the local specialists, playing an important part of reliable management and maintenance of large-scale energy systems.

Despite the introduction of modern technology, intervals appear in the supply of electrical energy at times (unexpectedly). The appearance of these intervals is accompanied by accidents in the power system. It is especially important to carry out frequent monitoring during operation, when the probability of such failures is high. The main means of improving reliability are:

- Application of high-quality materials, structures and manufacturing technology,
- Wide application of automation of regulation of normal modes,
- Correct selection and installation of emergency automation devices,
- Ensuring correct and uninterrupted operation of relay protection devices..

Table 1. Failure flow / Recovery time

Elements	Failure flow ω 1/year	Time of recovery T_r , hour/ 1
Power units 250-300 MB 500 MW	8.26 21.36	45 70
Transformers 110 kV 220 kV 330 kV	0.075 0.025 0.053	95 60 45
Air switches 110/220 kV 330 kV	Per connection 0.02 0.03	45/122 161
Busbar 110 kV - 500 kV	0.013	5
Power transmission line 110 kV 220 kV 330 kV 500 kV	Per 100 km Length 0.66 0.36 0.3 0.15	11 9.3 15.3 13

Parameters and characteristics of reliability of the main elements of the system are determined by probabilistic statistical methods. Here it is necessary to take into account the presence of random processes of the functioning of the power system, that is:

- Various normal operating states and pre-emergency mode parameters

- Probability of failure of an element
- The duration of equipment repair and the likelihood of an emergency in the repair scheme, when part of the equipment of the power plant or substation is disconnected for repair.

The main indicators of reliability of a complex electric power system are:
- Emergency loss frequency or failure flow parameter (specific damage, ω 1/year)
- The average duration of emergency repair of the failed element (average recovery time, Tr).

As an example, it can be cited data on some electrical engineering equipment. For power transmission lines it is necessary to consider the coefficient of unstable failures (Siemens smart process instrumentation tutorials for scaling and calibration, 2015.

Taking them into account, the number of expected outages of overhead systems should be made as shown in Table 2:

Table 2. Transmission line failures

Power transmission	ω	Coefficient	ω'= ω/k (per 100 km)
110	0.66	0.24	2.75
220	0.36	0.25	1.44
330	0.3	0.25	1.2
500	0.15	0.36	0.42

For busbar of 110-500 kV with at least six connections, the failure flow will be ω'=n·ω=6·0,013=0,078 1/year. The necessary technical measures are taken in the power system in accordance with a certain value of the probabilities. For example, all high voltage air circuit breakers have been replaced by German circuit breakers (SF6) in the country power system (Aleksandrovskaya, 2018).

Increasing the short-circuit currents and capacities require special measures to limit them not only in size, but also in duration. The increase in short-circuit current levels imposes an increase in the requirements in relation to the electrodynamic and thermal resistance of the elements of the devices of the energy system, - for example, the increase in the levels of short-circuit current is one of the main reasons for the decrease in the operational reliability of power transformers and can cause their damage. Thus, it is necessary to:

- Improve the performance of traditional switching equipment
- Introduce new ultra-fast switching devices capable of limiting and disabling the short-circuit current during the first half of the period
- Use non-inertial and inertial current-limiting devices.

The conditions of flow, limitation, and shutdown of the short-circuit current presented in the Figure 1 below:

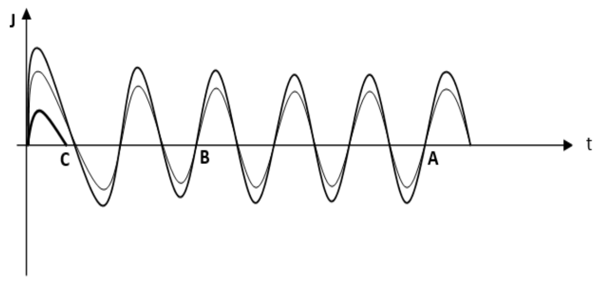

Figure 1. Relay response in case of short-circuit current

Shutdowns occur after 4-5 periods t = 0.,8 – 0,1 seconds, depending on the speed of relay protection moment A. Reducing the shutdown time to 2 periods t = 0.04 sec will allow to disable the short circuit at time B. Sine wave characterizes the processes of limiting the short-circuit current to non-inertial current-limiting devices. The curve shows the limitation of the short-circuit current by the current-limiting switching apparatus and the current shutdown at the moment C.

Thermal resistance switch is defined as

$$B_T = J_{p0}^2 \, (t_{off} + T_a) \quad (1)$$

where,

J_{p0} - periodic component of the short-circuit current (initial values)
t_{off} - shutdown time Ta is the damping time of the aperiodic component.

Electrodynamic resistance of the switch is defined as

$$B_d = i_{sc}^2 = 2\, k_{sc}^2 \cdot J_{p0}^2 \quad (2)$$

where, i_{sc} is the shock current, k_{sc} is the impact coefficient.

Total exposure to current

$$B_\Sigma = \phi_1(B_T) + \phi_2\,(B_d) \quad (3)$$

where, $\varphi_{1,2}$ - is the phase angle of the current

Thus, by reducing the shutdown time and the amount of shock current, it is possible to increase the reliability of the switching apparatus.

However, in this case, in each case, an analysis of the sensitivity of the relay protection to the short-circuit current in the constraint mode is necessary. This may lead to the need to develop fundamental new relay protection and automation devices (Thomas et al.,2020).

Currently, to limit short-circuit currents, the following are used:
- Permanent and automatic network division
- Current-limiting reactors and resistances
- Power transformers with a winding of lower voltage.
- Parts of power transformers of 110 kV network grounded to neutral.

Solutions Provided by Integration of Microprocessor Protection Relays into the SCADA Power Grid System

The reliability of the electricity transmitted to the consumer should be at a high level. With the growing need for electricity supply in Azerbaijan, there is a constant increase in the load, which requires the expansion and an increase in the capacity of the systems. Currently, modern computer technology allows to fully automate the main functions of electric power systems (production, transmission, distribution).

SCADA system technology with most modern standard functions, as well as remote terminals at various substations and power plants, is necessary for the economical and reliable operation of Azerbaijan's power grids. The disadvantage of the existing system is poor coordination of relay protection and automation, which causes interruptions that can be avoided. Therefore, it is recommended to use contactless microprocessor digital relays together with old electromechanical ones, (Kovalevet al.,2018).

The main operational functions of the SCADA system, necessary for reliable monitoring and control of the power systems of Azerbaijan, include:

- Monitoring of all thermal and large hydroelectric power plants, all high-voltage lines in the system (all lines of 500 kV, 330 kV, 220 kV and most lines of 110 kV, etc.) and electrical substations.
- Control of generating means at economical operation (economical load division, monitoring of reserve, calculation of production cost) and reliable operation (adjustment in order to match the production of load)
- Monitoring and control of electrical system components such as switches, transformers, relays and reactive devices
- Alarms, event logging and storage of statistical data files for subsequent access to them and all kind of requests
- Load forecast for short-term operational requirements and analysis of the design of the load schedule of the units

- Analysis of the operation of the power grid in present and designed conditions with standard applications such as dispatching energy flow, network sensitivity, optimal energy flow analysis, emergency analysis, short circuit analysis and safety analysis, etc.

Microprocessor relay protection performs the following measurement and control functions:

- Control of phase rotation direction measurement of phase currents and zero wire,
- Measurement of phase stresses relative to grounding,
- Measurement of active, reactive and full power,
- Measurement frequency,
- Control of switches operation time, and so on.

One of the advantages of microprocessor devices is the development of diagnostic devices themselves. Communication processors and servers ensure the joint operation of all devices, as well as information processing, calculations, record keeping and archives. For diagnostics of generators and other station equipment, it is necessary to use non-electric co-meter, pressure, temperature, consumption.

Each terminal allows communication with the highest level of the Automated Control System (ACS) of substation, while being its lower level. Unlike conventional ACS of Technological Process, where a relatively long response time is allowed (industry, thermal part of power plants, etc.), these terminals have high computing characteristics and their own "intelligence", i.e., autonomously perform the functions of protection and automatic control of electrical equipment with an impact on switching elements. Terminal microprocessor of relay protection as part of ACS TP can also be used to collect current information about the electrical parameters of the protected equipment (currents, voltage, power, frequency) and switching equipment.

The internal terminal database stores information about any changes in input and internal logical signals. Additionally, if the power grid is damaged, a digital record of emergency waveforms of analog and discrete signals in indestructible memory, i.e. a database of oscillograms of emergency processes, is formed. This database is used for the analysis of accidents. These databases can be made available in the local relay network and operational personnel with the help of special software. Access to information and changing terminal settings is governed by the Administration Rights of each registered user.

The reliability of the terminal is ensured by continuous functional control and self-diagnostics of the hardware and software part of the device. The controlled area begins with the conversion of the analog and ends with the windings of the output relay. The device uses small, closed, not decipherable, output electromechanical relays with guaranteed parameters that do not require periodic adjustment and cleaning of contacts. Reduce circuit and voltage power consumption, allowing to use modern, small, software-controlled current and voltage sources to configure and test devices. An important feature of the protection of domestic MP terminals is that developers have the opportunity to respond quickly to customer requirements that are not taken into account in standard protection options.

Conclusion

Diagnostics of the main equipment was carried out. The issues of reliability are considered, and the failure rate is estimated, as well as the conditions for the flow, limitation, and shutdown of the short-circuit current are analyzed.

Qualitative analyses show that to ensure the stability of the power system and improve the reliability of power supply to the consumer, it is necessary to perform the following measures:

- Quick shutdown of short circuits
- Automatic re-activation of all kinds.
- Automatic frequency unloading
- Automatic power on
- Emergency automation
- Integration of microprocessor protection relays into the SCADA system of the global power network for operational control of emergency modes

Notes

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