**УДК 622.69.44** **DOI:10.30724/1998-9903-2023-25-5-83-90**

# APPLICATION OF MODERN TECHNOLOGIES TO ENSURE OPERATIONAL RELIABILITY AND SAFETY IN ENERGY SYSTEMS OF AZERBAIJAN

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***Abstract:*** *Currently, Azerbaijan is implementing large-scale projects to restore infrastructure in the territories recently liberated from occupation. This includes, in particular, the construction of new modern power plants and electrical networks of modern design and high power. This, in turn, requires the use of reliable and effective methods of safety and protection of these systems from any failures or damage. In this regard, this article considers a wide range of issues on the use of modern technologies and developments for the protection of power systems, as well as analyzes the optimal concepts of management and protection of power grids, which are most suitable in the local conditions of the regions, as well as on the scale of the energy system of the whole country.*

***Keywords:*** *multifunctional microprocessor devices; modern technologies; cyber threats; operational reliability.*

**For citation:** Shamsi Nasirov. Application of modern technologies to ensure operational reliability and safety in energy systems of Azerbaijan. *Power engineering: research, equipment, technology*. 2023; 25 (5): 83-90. doi:10.30724/1998-9903-2023-25-5-83-90.

# ПРИМЕНЕНИЕ СОВРЕМЕННЫХ ТЕХНОЛОГИЙ ДЛЯ ОБЕСПЕЧЕНИЯ ЭКСПЛУАТАЦИОННОЙ НАДЕЖНОСТИ И БЕЗОПАСНОСТИ В ЭНЕРГЕТИЧЕСКИХ СИСТЕМАХ АЗЕРБАЙДЖАНА

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***Резюме:*** *В настоящее время Азербайджан реализует крупномасштабные проекты по восстановлению инфраструктуры на территориях, недавно освобожденных от оккупации. Это включает, в частности, строительство новых современных электростанций и электрических сетей современного дизайна и высокой мощности. Это, в свою очередь, требует использования надежных и эффективных методов обеспечения безопасности и защиты этих систем от любых сбоев или повреждений. В связи с этим в данной статье рассматривается широкий круг вопросов по использованию современных технологий и разработок для защиты энергосистем, а также анализируются оптимальные концепции управления и защиты электросетей, которые наиболее подходят в местных условиях регионов, а также в масштабе энергетической системы всей страны.*

***Ключевые слова:*** *многофункциональные микропроцессорные устройства; современные технологии; киберугрозы; эксплуатационная надежность.*

**Для цитирования:** Насиров Ш. Применение современных технологий для обеспечения эксплуатационной надежности и безопасности в энергетических системах Азербайджана // Известия высших учебных заведений. ПРОБЛЕМЫ ЭНЕРГЕТИКИ. 2023. Т.25. № 5. С. 83-90. doi:10.30724/1998-9903-2023-25-5-83-90.

***Introduction***

Currently, Azerbaijan is implementing large-scale projects to restore infrastructure in the territories recently liberated from occupation. Among other things, this includes the construction of new power plants and electrical networks of modern design and high power. This, in turn, requires the application of reliable and effective safety methods and protection of these systems from any failures or damage.

Presently, there are multifunctional microprocessor devices that performing relay protection functions, simultaneously solving the problems of automating the control of electrical equipment. These include generator protection devices, motors, transformers, reactors, power lines, central control systems, etc. Relay protection devices are combined with sensors and integrated with communication devices. They are located as close as possible to the control object with significant savings on control cables. In addition to relay protection, the functions of recording emergency processes, identifying the place of damage, blocking switches, etc. are implemented.

Changing the management structure of the electric power industry and the processes of its reform requires 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 power system, regardless of ownership [1, 2]. Digitalization in the power industry allows to form large amounts of data about the state of connections, equipment at substations and the power system. The article [3] analyses the prospects of using methods based on multiple simulation, statistical processing of the results and machine learning in relay protection and automation of electrical networks.

At the same time, it is necessary to reconstruct and modernize systems using devices and systems based on the use of modern technologies.

In these conditions, it is necessary to have a wide range of alternative proposals for collection information based on modern multi-purpose technological process control systems and its integration with the automated control system of the enterprise, as discussed in [4]. At the same time, the problems of collecting information not only about the position of the equipment and the values of the mode parameters, but also the issues of maintenance, tasks of technical and commercial metering of electricity, registration of emergency events and processes, determining the location of damage, diagnostics of the main equipment, organization of a unified time system should be taken into account as much as possible [5, 6].

Multifunctional systems for collecting, processing and displaying information should also provide the task of outputting information to a modern control panel, including video screens for collective use. The study in [7] proves feasible using offline-computed parameters to implement a routine and emergency controls system for further transition to online software-based computing of steady states and transients.

The requirements for ensuring high structural and informational reliability of the system's operation are also obvious, as well as stringent requirements for the response time of the system. The latter is especially important in emergency situations when the response time of the personnel on duty to events can be reduced to 0.1 sec. A technique and a programming-computing suite (PCS) developed in the study [8] is aimed to estimate the effect of equipment reliability indices, schedules, and regular overhaul scopes on reliability and efficiency of combined heat and power plants

When introducing modern systems in the structure of the system operator, it is necessary to take into account the presence of a three-level (district, regional, central level) control system. In order to operate an electric power system without accidents, it is necessary to have complete and reliable information about the technological process.

While implementing systems for collecting, transferring and displaying information, the relevant general issues for all companies in the industry are:

- ensuring the functions of reliability and survivability of the system,
- use of industry unified standards for information exchange protocols,
- providing a convenient and advanced human-machine interface, primarily for monitoring and control in real time.

Cyber threats present an increasing danger to energy facilities. It is necessary to ensure the cybersecurity of automatic control systems, such as relay protection devices (RPA), mode control (RC) and emergency control (EC) devices, automated control systems. In the article [9], the authors propose a methodological approach to the analysis of the structure of automatic means of regime and emergency control from the point of view of their influence on the reliability and survivability of power systems, taking into account the known cybersecurity threats. Authors of paper [10] analysed methodological and modelling developments on the study of energy security problems and describes the features and new challenges in the research of energy security at present, highlighting the need to develop modern methods, models and tools.In this regard, this article considers a set of aspects of the use of modern technologies and developments for the protection of power systems and provides the qualitative analysis of the optimal concepts of management and protection of electrical networks, which are most suitable in the local conditions of the regions, and have a theoretical and practical importance of developing the global energy system in Azerbaijan.

*Materials and methods*

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 (Shusha, Zangilan, Fizuli, Jebrail, Lachin, Kelbajar, Khojavend, Gadrut, Aghdam, Gubadli, as well as in Khankendi, Khojaly, etc.) 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 still appear in the supply of electrical energy at times. The appearance of these intervals is accompanied by accidents in the power system.

Analysis of emergency processes in the power system leads to the need, first of all, to analyze the reliability of the power system as a whole, and the reliability of all its constituent elements.

The growth of the unit capacity of the power system (300-400 MVA), the presence of extended power lines of 330-500 kV, necessary for the transportation of power from the excess part of the system to the deficit, branching the network of 110 kV, leads:

- to an increase in short-circuit currents and powers
- difficulties in ensuring the stable operation of the system,
- increase in frequent emergency events, including the possibility of complex (cascade) accidents.

One of the ways to comprehensively solve prevention problems is to carry out control without shutting down the equipment using measurement methods carried out at operating voltage. Methods of control under voltage, in addition to improving the effectiveness of prevention, can also provide the accumulation of data for assessing the reliability of equipment.

With a reduction in the monitoring period, the probability of timely detection of defects increases and, consequently, the likelihood of emergency equipment failures decreases. It is especially important to carry out frequent monitoring during operation, when the likelihood of such failures is high.

Base on monitoring the factors causing a decrease in the reliability of electrical equipment and elements in the power system identified as follows:

- damage of isolation
- lightning strike
- the severity of the weather
- touching foreign bodies
- various types of short circuits
- security is not working properly
- broken overhead power lines, open loop
- broken cable
- damage to the switching devices of the second side
- damage to the connecting cables
- heating of linear dividers
- errors of technical personnel during repair and operation
- errors made during the project

- overload
- corrosion of the grounding circuit of the support
- corrosion of supporting metal structures
- gaps in bolted connections of anchor supports

As per significant risk factors, the energy system of Azerbaijan is divided into 4 zones for lightning damage and pollution:

1.Apsheron Peninsula, Caspian Sea Region
lightning strike, on average 0 ÷ 20 hours, higher pollution
2.Kura, Araz, Salyan, Mugan
lightning strike, on average 20 ÷ 30 hours, average pollution
3.Karabakh plain, Sheki, Guba-Gusar, Tovuz, Shamkir, Ganja
lightning strike, on average 30 ÷ 50 hours, average pollution
4.Agstafa, Oguz, Gabala
lightning strike, on average 50 ÷ 100 hours, low pollution

All this requires special measures aimed at ensuring the necessary level of reliability. Under the reliability of the power system (or its elements), it is necessary to understand its ability to perform its task while reducing the main functioning in static and dynamic modes, within acceptable limits.

The main means of improving reliability are:

- reservation
- application of high-quality materials, structures and manufacturing technology,
- strict compliance with the rules of technical operation of equipment,
- 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.

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.

**Table 1**

Failure flow / recovery time

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

**Источник: Составлено авторами Source: compiled by the author.*

For power transmission lines it is necessary to take into account the coefficient of unstable failures [11]. 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 |

**Источник: Составлено авторами Source: compiled by the author.*

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 [12].

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:

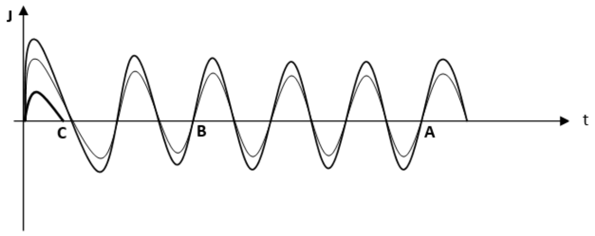


**Fig. 1.** Relay response in case of short-circuit current

**Источник: Составлено авторами Source: compiled by the author.*

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

$T_a$ 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 [13 - 15].

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.

***Results***

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, [16, 17].

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 [18-20].

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.

***Conclusions***

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 in order 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 kind.
- 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

## Reference


1. B.V. Papkov, P.V. Ilyushin, A.L.Kulikov, *Reliability and efficiency of modern power supply*, Nizhny Novgorod: Scientific and Publishing Center "XXI Century", (2021)
2. B.V. Papkov, A.I. Kulikov, P.V. Ilyushin, *Problems of reliability of modern power supply,* Publishing house "Infra-Engineering", (2021)
3. L. Anton, P. Pavel, V. Vladimir, *Improving the recognition of operating modes in intelligent electrical networks based on machine learning methods.* E3S Web of Conferences 216, 01034 (2020)
4. A.N. Antamoshin, O.V. Bliznova, A.V. Bobov, *Intellectual control systems of organizational and technical systems*, M.: RiS, (2016)
5. Y.Z. Tsypkin, *Relay automatic systems*, "Nauka", (2017)
6. Yu.A. Barabanov, *Microprocessor devices of relay protection and automation of distribution networks*, ( 2015)
7. P. Ilyushin, *Automated control of distributed generation enabled power districts,* E3S Web of Conference 139, 01035 (2019)
8. V.N. Bazhenov, E.I. Sokol, O.G. Grib, V.G. Sychenko, A.A. Danilov, Yu.V. Vladimirov, D.A. Gapon, S.V. Shvets, T.S. Jerusalemova, N.V. Rudevich, *Calculation of relay protection and automation systems in the electric power industry,* Kharkov: FOP Panov V.N., (2017)
9. Osak, D. Panasetsky, E. Buzina, *Analysis of the emergency control and relay protection structures approached from the point of view of EPS reliability and survivability by taking into account cybersecurity threats,* Conference 139, 01029 (2019

10. N. Pyatkova, V. Rabchuk. *Energy security problems and features of its research at the present stage*, E3S Web of Conferences 25, 01007 (2017)

11. E. F. Makarov., *Reference book on electric networks 0,4-35 kV and 110-1150 kV*. Monogr. Volume 1, Energiya - M., (2018)

12. Siemens smart process instrumentation tutorials for scaling and calibration. 2015

13. A.N. Aleksandrovskaya, *Avtomatika*, M.: Academia, (2018)

14. V.V. Ovchinnikov, *Architecture of distributed information and computing microprocessor systems*, M.: Energoatomizdat, (2017)

15. Florentina Magda Enescu, Nicu Bizon, *SCADA Applications for Electric Power System*, Springer International Publishing, (2017)

16. Mini S. Thomas, John Douglas McDonald. *Power System SCADA and Smart Grids*, CRC Press, (2020)

17. G.F. Kovalev, L.M. Lebedeva, *Reliability of Power Systems*. Springer, (2019)

18. D. Krupenev, *Determination of Critically Objects of Electric Power Systems from the Position of Energy Security*, E3S Web of Conferences. Vol.58, (2018)

19. N. Beresneva, N. Pyatkova, *Choosing of the FEC critical objects in model researches of energy security problems and its features*, E3S Web Conf. Volume 58, (2018)

20. N. Pyatkova, N. Beresneva, A. Edelev. *Research of critical energy infrastructures taking into account energy security*, E3S Web Conference. Vol. 25, (2)

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*Шифр научной специальности: 2.4.5. «Энергетические системы и комплексы»*

***Получено*** ***24.10.2023 г.***

***Отредактировано*** ***30.10.2023 г.***

***Принято*** ***26.11.2023 г.***