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Relay protection devices functionality comparative analysis

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ABSTRACT

With the development of technology, there has been an evolution in the electrical power industry, replacing conventional electromechanical relays with more advanced devices. Multifunctional microprocessor relay protection terminals became such innovations. This transition marked a new era in the field of monitoring and control of electrical systems. One of the strategic tasks of the energy sector is the comprehensive technical re-equipment and reconstruction of relay protection and automation systems with a focus on maximum automation of dispatch control operations. Solving this problem is impossible without the use of microprocessor devices. The purpose of this work is to conduct a comparative analysis of relay protection devices based on electromechanical relays, electronic components and microprocessor devices, review and compare their characteristics. The work presents the advantages and problems of using microprocessor-based relay protection and automation devices in modern substations. The stages of complexity of relay protection and automation systems from electromechanics to a digital substation are shown. The general trends in the formation of the concept of "Smart Grid" and the main directions for creating intelligent electrical power systems are considered.

Keywords: Generations of relay protection; microprocessor devices; digital substation; smart grid; Internet of Things

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INTRODUCTION. PROBLEM STATEMENT

Today, power disruptions such as blackouts can have a domino effect – a series of disruptions that can impact banking, communications, traffic and security. This is especially risky in winter, when homeowners may be left without heating. A smart grid will improve the resilience of the electricity system and make it more prepared for emergencies such as severe storms, earthquakes, solar flares and terrorist attacks. As a result of the operation of electric power systems (EPS), emergency situations inevitably arise that disrupt the normal operation of equipment and systems as a whole. The most dangerous among them are short circuits (SC). To localize damaged elements and prevent the development of accidents in EPS, relay protection (RP) devices are used, which play a decisive role in ensuring stable and safe operation and are an integral part of electrical automation.

Relay protection is a system of automatic devices created for the purpose of promptly detecting and separating damaged EPS components in the event of emergency situations. In the event of damage,the relay detects the damage zone and disconnects this zone from the EPS with subsequent restoration of normal operation of the remaining elements of the system without faults [1, 2].

Today, there are three element bases on which the operating relay protection devices are built: electromechanical, electronic and microprocessor (digital). Electromechanical means are the "oldest", and, according to rough estimates, currently their share in the EPS of Ukraine is more than 70% of the total number of installed RP systems. Electronic devices are not widely used due to a large number of shortcomings. The most modern are microprocessor (MP) relay protection and automation (RPA) devices. One of the strategic tasks of the energy sector is the comprehensive technical re-equipment and reconstruction of RPA systems with a focus on maximum automation of dispatch control operations. Solving this problem is impossible without the use of MP devices. The share of these devices increases significantly every year, and over time they will completely replace other element bases. For this reason, it is very important to know the principles of constructing MP RPA devices and be able to work with them: connect, configure and operate.

In addition to their main task – automatically shutting down power systems in case of emergency, MP terminals perform additional functions that are not found in other types of RP devices, such as electromechanical relays. These functions include the registration of emergency situations [3, 4], [5].

As a result of ongoing active hostilities on the territory of our country, as well as continuous missile attacks aimed at energy infrastructure facilities, the process of introducing MP RPA terminals is becoming one of the highest priorities. This will ensure the continuous operation of the EPS, which in turn helps to increase its efficiency and sustainability of operation.

LITERATURE OVERVIEW

Main characteristics of microprocessor devices

Ensuring reliable and trouble-free operation of electrical installations is closely related to increasing the technical level of RPA, the introduction of complex automation to manage normal, emergency and post-emergency operating modes, which is due to the continuity of the processes of production, distribution and consumption of electricity.

Currently, the main part of RPA circuits consists of electromechanical devices, most of which have been operating for more than 30 years. They are in a state of moral and physical deterioration, requiring annual routine maintenance.

Modern automated RPA systems operate on the basis of MP devices that combine many types of protection and emergency automation. One single RPA terminal is capable of performing many functions, the number of which can reach hundreds. Also, a significant feature of modern RPA devices is the ability to integrate them into an information network, which allows the implementation of the “Digital Substation” and “Smart Grid” concepts [6, 7].

Another typical feature of modern RPA is the use of open logic. This technology is a visual-symbolic programming language based on logical circuits, which allows you to subsequently change the device software algorithms. In other words, the user has the opportunity to configure the device’s software parameters for specific tasks [8, 9], [10].

When switching to a new element base, it is not the principles of operation of the relay automation that change, but only its functionality expands, which makes operation more convenient. It is for these reasons that outdated electromechanical and microelectronic relays are being replaced by MP devices.

Modern are microprocessor relay protection and automation terminals are one of the most complex electronic devices used for energy needs. For their effective use and reliable operation, deep knowledge is required not only in theory, but also in the circuitry of RPA systems.

Stages of development of relay protection and automation systems from electromechanics to digital substation

Circuitry, logical part (algorithms) and calculation of settings are the three main segments that are present regardless of the element base in RPA systems. However, their shares are different.

In electromechanics the logic of the operation of RPA algorithms is clear directly from the circuit diagram; a small percentage of it is hidden in the relays themselves. However, the circuits of the relays themselves are mostly simple, and the algorithms for their operation are obvious. Thus, RP in electromechanics is clear and understandable when studied.

In conventional digital terminals, the circuit diagram is reduced and simplified, and complex logical connections are transferred inside the digital device. The number of algorithms implemented in one device is increasing sharply.

Manufacturing personnel who work with MP terminals must be familiar with all aspects of electromechanics, as well as the rules for working with logic circuits. In addition, he must understand the specifics of using digital devices, such as the purpose of discrete inputs, rules for working with software, operational power supply of the terminal, electromagnetic compatibility (EMC), etc. In this case, higher standards are imposed on the qualifications of personnel than when using electromechanical systems.

A digital substation is a key element of smart energy, where the organization of all information flows when solving problems of monitoring, analysis and control is carried out in digital form, and the parameters of such transmission are determined by a single electronic project file [11, 12]. A local area network (LAN) based on Ethernet technology is used as the main data transmission medium within a digital substation, and the communication protocols described by the IEC 61850 standard are used [13]. The main characteristics of such a substation are the intellectualization of primary equipment, a developed communication network and automation of operation and control [14].

In the concept of a digital substation based on IEC 61850 standards, the circuitry is reduced almost completely, and the logical part is expanded. Understanding of the system deteriorates due to a lack of visualization, while the degree of abstraction in the presentation of information becomes excessive. The functions of the RP are autonomous and not tied to specific equipment; they are implemented in a virtual model of the substation. Operating such equipment requires specialists of a higher level than those who deal with conventional MP RPA terminals. They must have knowledge of a modern substation with MP RPA and IEC 61850 transport protocols.

Modern substation automation system based on IEC 61850 is an established technology for providing smart grid infrastructure in the transmission system, but continuous development is required to realize this. As utilities turn to IEC61850 to upgrade or expand existing substations, as well as introduce new digital substations, the foundation is laid for smooth integration of the whole system. With this development, advanced energy management and asset management within a smart transmission network can be achieved. The stages of development of relay protection and automation systems from electromechanics to digital substation are shown in Fig. 1.

The basics of RPA are the same for standard relay protection and for digital substations, since IEC 61850 does not introduce any significant innovations in this aspect. The scope of the IEC 61850 standard is communication systems inside a substation.

Despite the benefits of IEC 61850 digitization, a number of cybersecurity vulnerabilities were included in the system, such as lack of authentication and encryption of GOOSE (Generic Object-Oriented Substation Event) messages, which could allow messages to be intercepted and change the state of the circuit breaker in the substation and lead to an outage electricity or even the loss of life [12].

Knowledge of various cyberattack techniques, as well as applicable, possible and state-of-the-art defense mechanisms can enable researchers to effectively study them and improve various methods to combat new forms of cyberattacks on power systems [16].

During the evolution of RPA, the main changes occurred in circuitry, where it moved from the use of bulky relay systems based on visually understandable elements to compact devices capable of connecting to the information network of a digital substation, like a regular computer.

Modern directions in controlling the modes of electric power systems

In recent years, the demand for energy has increased sharply due to the rapid expansion of various industries and significant development of society. This process was accompanied by a rethinking of approaches to energy consumption and production [17, 18].

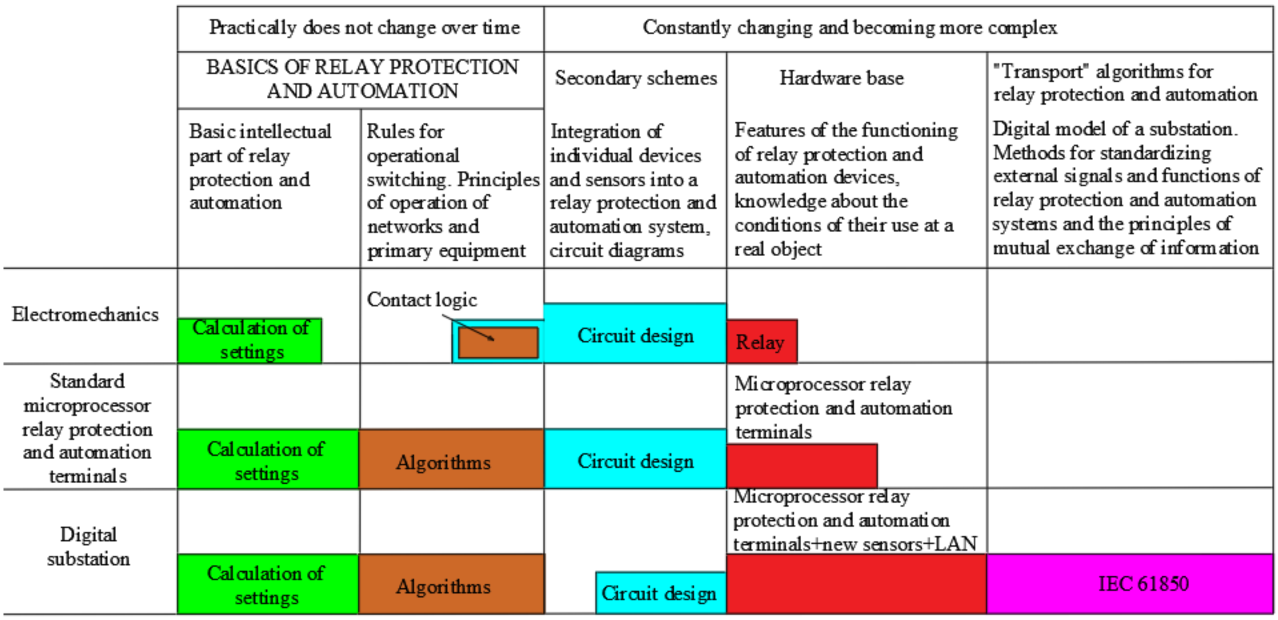

Fig. 1. **Stages of development of relay protection and automation systems from electromechanics to digital substation.**
***Source*: compiled by the [15]**

According to the US Energy Information Administration's (EIA) International Energy Outlook 2021 (IEO2021), if current policy and technological trends continue global energy consumption and energy-related carbon dioxide emissions will rise through 2050 as a result of population and economic growth. Despite long-term improvements in energy efficiency, by 2050 global energy consumption in the baseline scenario will increase by almost 50% compared to 2020 [19]. In terms of energy consumption, climate change at the global level has increased the need for the use of electric devices to reduce gasoline consumption and greenhouse gas emissions in all economic sectors [20, 21], [22, 23].

This created significant pressure on energy consumption and required the implementation of automated systems that ensure tight integration of system components, which in turn facilitated the use of innovative technologies, including response to changes in demand [24, 25], [26].

There has been a significant change in energy production. The main driver of this transformation has been the increasing share of renewable energy sources. Traditionally, the energy industry has relied on fossil fuels such as coal, oil and gas. Due to growing environmental concerns and the sharp decline in the cost of renewable energy, there is an irresistible trend to gradually replace traditional fossil energy with renewable and clean energy [27]. These changing dynamics reflect a desire for sustainability and reduced environmental impact.

With the development of solar, wind, hydropower and other renewable technologies, large-scale implementation of these methods in energy production has become possible [28, 29], which has contributed to the diversification of the energy portfolio of many countries and reducing dependence on unstable markets and prices for fossil fuels.

The evolution in energy production is therefore not only economic, but also an important step towards a more sustainable and environmentally friendly future.

In addition, the tendency to use decentralized and distributed generation plays an important role in the new approach to energy generation [30, 31], [32, 33]. All these challenges have prompted the electric power industry to transform its power grids from legacy to smart.

In recent decades, the idea of an intelligent energy system known as a Smart Grid has been actively discussed and developed abroad. It is presented as an innovative idea for the development of the electric power industry in the future [34, 35], [36]. Intelligent power networks, called Smart Grid, are a modernized version of conventional networks through the use of modern automation and communication systems that provide two-way exchange of both energy and information, with the help of which it is possible to automatically increase efficiency, reliability, economic benefits, and also ensure the sustainability of processes power generation and distribution in real time [37, 38].

In other words, Smart Grid is a digital technology that provides two-way communication between a utility and its customers, as well as monitoring of power lines, which is what makes the grid “smart”.

The main challenges of smart grids when using conventional automation systems were connecting a huge number of devices, quickly managing them and continuously monitoring them. Moreover, the integration of remote and isolated objects required quite significant financial costs [39].

In addition to providing real-time communication across all systems, from generation and transmission to distribution and end-users, smart grids introduce new capabilities, technologies and various monitoring equipment that constantly monitors, checks and fully controls the entire system. The need for such infrastructure has brought the concept of Internet of Things (IoT) [40] into the existing network.

The IoT is becoming an increasingly important and widespread concept in today's world. It covers a wide range of devices, ranging from smart thermostats and fitness trackers to industrial sensors and medical devices. The main idea of IoT is to allow devices to collect and exchange data over the Internet, thereby creating smarter and more efficient systems [41].

With the increasing availability of high-speed Internet and the development of wireless communication technologies, IoT has received new impetus for development. Devices can now communicate in real time, opening the door to improving many areas of life. For example, smart cities use IoT to manage transport infrastructure [42], optimize energy consumption [43], and improve safety [44].

However, as the number of connected devices increases, additional challenges arise. Data security becomes critical as attackers may attempt to hack into devices and gain access to sensitive information. Privacy concerns also arise as a large amount of user data is collected and analyzed to improve the functionality of devices [45].

However, the prospects for IoT remain exciting. With the development and adoption of new technologies such as 5G and the advancement of security standards, IoT has the potential to change the way we interact with all aspects of our lives, making them more efficient, convenient and intelligent.

Internet of Things has also added the ability to use cloud computing, which eliminates the dependence on local infrastructure for storing, processing and analyzing data, thereby increasing system uptime, in addition to increasing data security and overall system availability, while accessing data in the cloud simultaneously from many workstations increases flexibility [46].

Expected benefits from implementing Smart Grid [47] include:

- improved security;
- faster restoration of power supply after power failures;
- more efficient power transmission;
- increased integration of large-scale renewable energy systems;
- improved integration of customer and owner power generation systems, including renewable energy systems;
- lower operating and management costs for utilities and ultimately lower energy costs for consumers;
- reducing peak demand, which will also help reduce electricity tariffs.

The development of Smart Grid entails a profound restructuring of the market for electricity and energy services.

Before the emergence of the Smart Grid concept, electrical networks, as well as energy systems in general, were designed with a centralized and hierarchical structure. This meant that in such a network there were only two large classes of devices – sources and consumers of electrical energy. In such networks, the transmission of electrical energy was carried out only from sources to consumers.

The implementation of Smart Grid requires the abandonment of traditional hierarchical architectures of automation systems and the transition to architectures in which intelligent control devices interact both horizontally and vertically, and have certain autonomy when making decisions with elements of artificial intelligence [48].

THE AIM OF THE RESEARCH

The purpose of this work is to conduct a comparative analysis of relay protection and automation devices based on electromechanical relays, electronic components and MP devices, review and compare their functionality.

GENERAL PROVISIONS

As follows from the analysis of literary sources, the leaders in the production of MP RPA terminals are the European concerns Siemens, ABB, Schneider Electric. Digital protection products produced by these organizations are distinguished by high technical characteristics and versatility.

ABB offers the following series of digital devices for control and protection in medium voltage networks (6-35 kV): feeder – REF601, REJ601; generator – REG615; busbar – REB611; motor – REM601, REM611; transformer – RET615.

The current generation of digital protection devices from Siemens is the SIPROTEC 5 product line. Depending on the type of protection, the following types of devices are offered: current protection – 7SJ81; power line protection – 7SA82; transformer protection – 7UT82; motor protection – 7SK82; generator protection – 7UM85; busbar protection – 7SS85.

For medium voltage distribution networks, the offer of MP RPA terminals from Schneider Electric is the Easergy P5 line, used to protect: cable and overhead power lines; supply and outlet connections of distribution devices; transformers. An overview of the Easergy P5 series devices is shown in Fig. 2.

One of the main advantages of MP terminals compared to old-style protections is their compactness. For example, to implement protection, automation, and control of equipment on a 35 kV line, previously it was necessary to install a complex circuit that included many electromechanical relays that barely fit on one relay panel. Thanks to the compact size of MP protection terminals (Fig. 3), two such terminals can be placed on one relay protection panel.

When using MP RPA terminals, there is no need to install additional measuring instruments, since the protective device independently displays information, for example, about the load on line phases or other electrical parameters.

Another important advantage of MP RPA terminals is the convenience of monitoring the operating mode of equipment, including the prompt elimination of emergency situations. On the front panel of the terminal there are LED indicators with labels indicating their functions.

To indicate operating modes, old-style protections used signal (indicating) relays called “blinkers”. When emergency situations occurred, it was necessary to check each of the indicator relays, which very often had an inconvenient relative position, while returning the relay to its original position (the “acknowledgement” procedure) had to be performed individually.

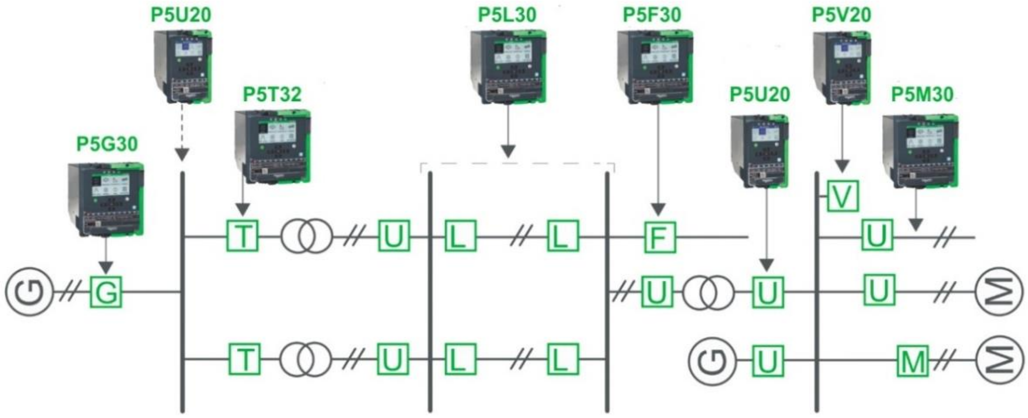

Fig. 2. **Overview of Schneider Electric Easergy P5 series devices, where the letters indicate the following protections:**
G – generator; T – transformer; U – universal; L – lines; F – feeder;
V – frequency and voltage; M – motor
***Source*: compiled by the [5]**

a b c

Fig. 3. **Appearance of microprocessor terminals for relay protection and automation from leading European manufacturers:**
a – Relion series (ABB)
***Source*: compiled by the [3];**
b – Siprotec 5 Series (Siemens)
***Source*: compiled by the [4];**
c – Easergy Series (Schneider Electric)
***Source*: compiled by the [5]**

The LEDs on the terminal are placed in a vertical or horizontal row, which makes it convenient to monitor possible deviations – just look at the corresponding terminal. In addition, the convenience is that to "acknowledgement" the LEDs on the terminal you only need to press one button. This advantage is especially valuable in the event of a major fault in a substation, when many protective devices are activated simultaneously. In such a situation, it is enough to go to each terminal, record the state of the LEDs and press the button. In contrast to electromechanical protection, where it is necessary to spend much more time fixing the state of each indicating relay and returning it to its original position, that is, "acknowledge".

In general, all MP RPA terminals have a similar generalized structure, as well as principles for constructing working interfaces. Thus, having experience and competence in working with some of them, the process of mastering new ones becomes much more simplified.

Functional features of microprocessor relay protection devices

If MP devices are used to protect the line, then when the circuit breaker is disconnected from the protection system or when the automation is operating, the internal memory of the device stores information about the moment of operation, the name of the activated protection or automation element on the line, and also records electrical parameters in the periods before the accident occurred, during the time of the accident and after its completion. Thanks to this functionality, it is possible to accurately reconstruct the course of events, which becomes critically important when serious accidents occur. Registration of emergency situations is carried out within a few milliseconds, and this, when analyzing the operation of protective devices, allows you to correctly determine the sequence of their operation, as well as draw a conclusion about the compliance of the operation of the protective mechanisms with the specified settings and conditions. Event records are stored by the device in its non-volatile memory.

The protection terminal has a self-diagnosis function and also monitors the operation of incoming and outgoing circuits, which allows you to quickly identify faults. In the case of using electromechanical protection, disturbances in the operation of these devices often go unnoticed, and their malfunctions are often discovered only when the protection system is not functioning correctly or completely fails.

In the MP protective device, changing the protection response settings is done in the menu by selecting the required values. In this case, you can organize several sets of parameters and easily switch between them, which turn out to be very convenient when you need to temporarily change the setpoint values.

One of the additional advantages of MP terminals is the ability to integrate them with the supervisory control and data acquisition (SCADA) system, which allows substation maintenance personnel to monitor the status of switching devices, load and bus voltage, and remotely control equipment directly from the central command post.

Modern RPA devices combine the functions of RP, measurement, regulation and control of an electrical installation in one system. As part of automated process control systems of energy facilities, they act as final devices for collecting information.

Analysis of the functionality of relay protection devices based on electromechanical relays and microprocessor devices

This analysis requires an assessment and comparison of the characteristics, advantages and disadvantages of electromechanical relays and MP devices.

Electromechanical relays

They are traditional relay protection devices operating on the basis of the physical principles of electromagnetism and mechanics. They include contacts, springs and electromagnets that respond to changes in the electrical parameters of the network. They are used in a variety of electrical circuits to provide reliable protection and control.

Advantages:

• simplicity and reliability: electromechanical relays are attractive due to their simplicity of design, which ensures their understanding by engineers and technicians;

• interference resistance: these devices exhibit a certain level of immunity to electromagnetic interference and voltage variations, making them valuable in situations where the electrical grid is not very stable.

Disadvantage:

• limited speed and accuracy: electromechanical relays have limited actuation speed and response time, which may not be sufficient to provide protection against fast events such as short circuits;

• maintenance required: relays require periodic maintenance and calibration to ensure reliable functionality. Due to the mechanical nature of their component parts, they are subject to wear and may require replacement over time;

• limited capabilities: complex modern power supply systems may require more complex protection algorithms that are difficult or impossible to implement using electromechanical relays.

Microprocessor relay protection devices

With the advent of new technologies in electronics and information technology, MP devices RP have become available that provide greater flexibility and an expanded range of functions.

Advantages:

• high accuracy and speed: MP devices have the ability to perform data processing with increased speed and accuracy, which facilitates the implementation of complex protection algorithms and quickly respond to events;

• flexibility and customization: it is possible to customize protection settings to suit unique system requirements, which becomes important for adapting to a variety of operating conditions;

• integration and control: MP devices easily integrate with other automation, monitoring and control systems, which allows you to achieve a deeper level of control over the operation of the power supply system.

Disadvantage:

• high cost: the use of MP devices involves investing in electronic components and software, which may entail increased costs compared to the use of electromechanical relays;

• non-repairability: if a functional unit fails, it can only be replaced as a whole;

• dependence on electronic components: MP devices may become vulnerable when problems or defects occur in electronic components;

• for programming, configuring and maintaining MP devices, specialists with appropriate qualifications are required;

• the possibility of deliberate remote influences on MP relay protection in order to disrupt its normal functionality;

• moreover, MP RPA terminals from different manufacturers cannot be used interchangeably due to the lack of a uniform standard for equipment.

In Table 1 shows a comparison of the characteristics of electromechanical relays and MP devices.

Electromechanical relays are ideal for small protection systems where there are few components and high reliability is required. MP devices allow to use more complex and flexible protection algorithms, easily integrate them into automated systems, and also more accurately configure protection parameters.

The choice between these types of devices depends on the specific requirements of the protection system:

– if it is necessary to ensure high accuracy, complex protection algorithms and integration with other systems, then MP devices are preferable;

– if reliable protection is required when using simple circuits, then the use of electromechanical relays can be considered.

In modern RPA systems, a combination of electromechanical relays and MP devices is common, which helps to combine the advantages of both approaches: accuracy, flexibility and the ability to integrate MP devices, and the high reliability of electromechanical relays.

Table 1. **Comparison of characteristics of electromechanical relays and microprocessor devices**

No.	Parameter	Electromechanical relays	Microprocessor devices
1	Principle of operation	Based on the use of contacts and electromagnets. When the parameters of the electrical network change, the relay mechanism reacts to the electromagnetic field by switching contacts	They work based on algorithms specified by the program. The microprocessor processes data from sensors and makes decisions in accordance with the specified parameters
2	Speed reaction	Limited by mechanical processes, the rate of reaction is limited by the time required to move the mechanism	Provides high processing and response speeds through fast calculations, making them effective in rapidly changing environments.
3	Flexibility and customization	Limited in customization of parameters and functionality, their ability to change is limited by mechanical design.	They have high configuration and programming flexibility. Protection parameters, time delays and operating logic can be easily changed
4	Complexity of protection algorithms	Can provide basic protection algorithms, but are limited in implementing complex algorithms such as differential protection or harmonic analysis	Allows the implementation of a wide range of complex algorithms, including differential and harmonic analysis, as well as integrated monitoring and diagnostic functions
5	Reliability	Reliable, can withstand temporary overloads. However, with age and wear of mechanisms and contacts, their reliability may decrease	Depends on the reliability of electronic components. May be subject to malfunctions due to overvoltages, electromagnetic interference, or software errors
6	Integration and Remote Control	Typically, do not have built-in integration and remote control capabilities	Easily integrated into control, monitoring and diagnostic systems, which allows you to remotely configure and monitor their operation
7	Maintenance	Require periodic calibration and maintenance for reliable operation	Requires technical support and software updates

***Source*: compiled by the authors**

Promoting the Smart Grid concept is a complex and large-scale process that requires changes at various levels of the energy system. This concept involves the use of modern technologies and innovations aimed at improving the efficiency, reliability and sustainability of the electric power industry.

In addition, the Smart Grid creates new opportunities for electricity market participants such as utility companies, consumers and equipment suppliers. They can actively participate in managing their energy consumption and provide energy balancing and management services.

Thus, the implementation of the Smart Grid concept is not only a technical challenge, but also a strategic opportunity to modernize the energy industry, improve the efficiency and sustainability of the entire system.

Already today the world is realizing that it is impossible to quickly move to the ideal (reference) Smart Grid model.

The Smart Grid will consist of millions of parts and controls, computers, power lines, new technologies and equipment. It must be taken into account that it takes some time to improve all technology components, install the necessary equipment and thoroughly test all systems. All this preliminary improvement is only the first stage before the full launch. The gradual rollout of the Smart Grid concept will occur in stages over the next decade, and perhaps even a little more.

It should be remembered that the initial implementation of Smart Grid will not happen instantly, but will be carried out in successive steps. The process will be similar to evolution, with each stage representing an important building block in building a smarter, more efficient energy grid.

However, it is worth noting that once Smart Grid reaches full functionality, it can be expected to impact our way of life, work, leisure and learning as much as the Internet has. This transformation will be a consequence of the cumulative impact of smart technologies on the energy sector. Just as the Internet has changed the way we interact and share information, the Smart Grid will be able to reformat the way we produce, distribute and consume energy. This can lead to more efficient use of resources, reduced environmental impacts and the creation of new opportunities for innovation and development.

The ability of specialists to correctly calculate the operation parameters of relay protection and automation systems and configure them increases the reliability of operation and safety of operation of electrical equipment. That is why it is important, even at the stage of studying at a higher educational institution, to gain not only theoretical knowledge, but also practical skills in working with modern equipment. To achieve this goal, laboratory training stands are used [49].

Research conducted during the training process, aimed at mastering the skills of working with MP protection terminals, is extremely appropriate for graduates of universities with electrical engineering specialties.

The use of modern trends in creating experimental stands for testing digital protection makes this research even more relevant and practical.

An original and accessible approach to teaching using visual displays adds to the value of this approach to this work.

CONCLUSIONS

1. Electromechanical relays undoubtedly played an important role in the electrical power industry, but they had certain limitations: they were relatively single-functional and required manual configuration for different scenarios. In addition, they are subject to wear and tear, which necessitates their constant (regular or periodic) maintenance.

2. When deciding on the transition from electromechanical relays to microprocessor-based relay devices, one should take into account the requirements for the system, its complexity, response speed and level of integration. In some cases, the combined use of these two types of devices makes it possible to achieve an optimal balance between the reliability and functionality of the protection system.

3. Today, MP devices replace traditional relay protection, combining the functions of protection, automation, control and alarm. Their use increases the sensitivity of protection and reduces response time, which reduces damage from power outages. It is also possible to create automated substation control systems and their integration with upper-level automated process control systems. This opens up prospects for the use of MP terminals as the main relay protection devices in electrical networks for further progress towards the ideal Smart Grid model.

4. Effective selection of MP RPA equipment for a substation requires optimization of costs and efficiency. It is necessary to take into account the initial and total costs of servicing MP RPA terminals for 10 years. It is also important to consider the costs of software updates and specialist services from the manufacturer.

5. The widespread use of digital (microprocessor)-based RP and its advantages over traditional RP require additional research to determine which functionality of MP terminals should be used. Existing relay protection and automation training stands, although they allow you to learn how to use the equipment, do not provide sufficient flexibility when upgrading and unlocking the full potential of MP terminals. Thus, the development of modern experimental stands for testing MP terminals becomes an urgent task. These stands should be available in order to improve the quality of acquired knowledge and practical skills in working with MP protection terminals for graduates of universities with electrical engineering specialties.

6. An important part of the Smart Grid is also education and awareness of consumers. The main advantage of Smart Grid is the integration of IoT and cloud computing. This technology links energy use to the environment, which increases consumer awareness and supports sustainable development and environmental protection.

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Порівняльний аналіз функціональних можливостей пристроїв релейного захисту

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АНОТАЦІЯ

З розвитком технологій відбулася еволюція у сфері електроенергетики, що замінила звичні електромеханічні реле на більш досконалі пристрої. Такими інноваціями стали функціональні мікропроцесорні термінали релейного захисту. Цей перехід позначив нову епоху у сфері контролю та управління електричних систем. Одним із стратегічних завдань енергетики є комплексне технічне переозброєння та реконструкція систем релейного захисту та автоматики з орієнтацією на максимальну автоматизацію операцій диспетчерського управління. Вирішення цього завдання неможливе без використання мікропроцесорних пристроїв. Метою даної роботи є проведення порівняльного аналізу пристроїв релейного захисту, заснованих на електромеханічних реле, електронних компонентах та мікропроцесорних пристроях, огляд та порівняння їх характеристик. У роботі наведено переваги та проблеми використання мікропроцесорних пристроїв релейного захисту та автоматики на сучасних підстанціях. Показано етапи ускладнення систем релейного захисту та автоматики від електромеханіки до цифрової підстанції. Розглянуто загальні тенденції формування концепції «Розумної мережі» (Smart Grid) та основні напрями створення інтелектуальних електроенергетичних систем.

Ключові слова: покоління релейного захисту; мікропроцесорні пристрої; цифрова підстанція; інтелектуальна мережа; інтернет речей

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