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A.V. Neftisov[1] , A.Zh Sarinova[2], O.M Talipov[3], L. N Kirichenko[4]., I. M. Kazambaev[5]
[1,2,3,4,5]Astana IT University, Republic of Kazakhstan, Nur-Sultan
Toraighyrov University, Republic of Kazakhstan, Pavlodar
S.Seifullin Kazakh AgroTechnical University
Republic of Kazakhstan, Nur-Sultan.

POSSIBILITY OF BUILDING MICROPROCESSOR RELAY PROTECTION DEVICES ON OPEN ARCHITECTURE

The article analyzes the structure of relay protection devices of various designs. Based on the Unified Electric Power System of the Republic of Kazakhstan prediction on the electric energy balance the plan to increase the generation of electricity due to the commissioning of new capacities was revealed In addition, the international market of the energy sector and a preliminary forecast for the total demand for energy separeted into the declared scenarios and the scenario of sustainable development of electricity generation, cumulative average annual growth rate, electric capacity by countries, continents and regions were studied. It is determined that the type of power generation system and the fuel used affect the features of building and updating relay protection systems. The hypothesis of the study is the replacement of existing closed solutions on the market of relay protection systems with open hardware and software, which allow developing and applying then various power supply systems, including FPGAs. Within the framework of the study, solutions for building a microprocessor relay on an open architecture were proposed: a block diagram and a developed laboratory stand "relay protection microprocessor on an Arduino board"; «Relay protection microprocessor using FPGA». Comparative data on the characteristics of the boards are presented, where the FPGA board is more effective in all respects. The program was developed in the Quartus Prime 21.1 Lite Edition environment. Based on the results of the work, it can be noted that aim of the further research will be the expansion of the microprocessor relay protection devices based on an open architecture use.

Keywords: relay protection, open architecture, FPGA, microprocessor protection, FPGA, automation, control

Introduction

Relay protection is a type of automation of the power system, without which its normal operation is impossible. Relay protection devices (RP) are designed to detect and disable damage to electrical installations and usually contain a measuring (MP) and logical part (LP) and an output organ (VO) (Figure 1) [1].

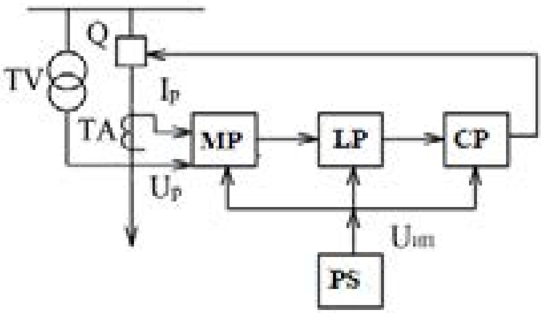

Figure 1– Typical structure of relay protection devices

The measuring part (MP) receives information about the state of the object using devices such as measuring current transformers (CT), voltage transformers (VT) or contactless sensors. However, currently most relay protections use measuring transformers [2]. Moreover, if a relay is used, the state of the protected object is described by discrete signals, then due to the microprocessor, information is received in the form of an analog signal, which expands the protection functionality [3].

The main elements of digital relay protection are the following functional blocks: analog AC inputs, elements for digital signal processing, digital inputs, digital outputs, human-machine interface (HMI), system interface, functional interface [4].

Digital relay protection devices for various purposes have a lot in common, and their block diagrams are very similar (Figure 2). It should be noted that in a real relay protection device, several microprocessors can be used, each of which will be engaged in solving a separate fragment of a common task in order to ensure high performance. For example, 7-10 microprocessors working in parallel are used in complex relay protection devices [5].

The main elements of digital relay protection are the following functional blocks: analog AC inputs, elements for digital signal processing, digital inputs, digital outputs, functional control keyboard, display, service interface, system interface, functional interface [4].

The analog signal converter lowers the value of the current from current (TA) and voltage (TV) transformers and changes it to digital. The converted signal is proceeded by control unit (CU), RAM, ROM, PROM and as the result the digital outputs module activates the control part, which trips the circuit breaker (Q). Through the digital inputs module, the CU monitors the state of the control part and, therefore, the state of the circuit breaker

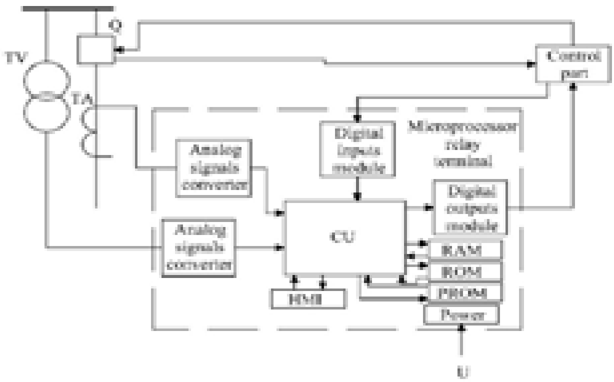

Figure 2 – Block diagram of a digital relay protection device

Materials and methods

At this stage of development, the domestic relay protection market needs to update existing relay protection systems, as well as the introduction of new solutions that can meet the needs of the market.

According to the order of the Ministry of Energy of the Republic of Kazakhstan No. 16 dated 14.01.2022, electricity production will increase to 131.7 billion by 2028. kW due to the introduction of new capacities, including stations with renewable energy sources (RES). Figure 3 shows the forecast balance of electric energy of the Unified Electric Power System of the Republic of Kazakhstan for the period 2022–2028.

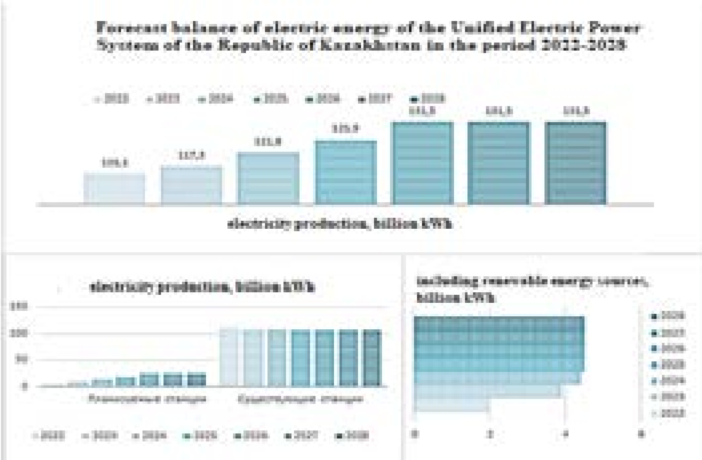

Figure 3 – Forecast balance of electric energy of the Unified Electric Power System of the Republic of Kazakhstan for the period 2022–2028

From 2022 to 2028, it is planned to reduce the load by 4 % on existing stations. Electricity production at the expense of stations that are planned to be put into operation by 2028 will increase from 4.6 billion. kWh. (2022) up to 25.6 billion. kWh. (2028), including by increasing electricity generation at renewable energy facilities by 64 % by 2025 and maintaining this volume until 2028.

Figure 4 shows a diagram of the projected balance of electric power for 2022-2028 due to the introduction of new capacities. The commissioning of new capacities includes the reconstruction and expansion of current facilities, as well as the construction of new power plants.

From 2022 to 2028, it is planned to increase the capacity of the Unified Electric Power System of the Republic of Kazakhstan by introducing new capacities 5 times in the western zone (from 167 MW/hour in 2022 to 820 MW/hour in 2028), 7 times in the northern zone (from 263 MW/hour in 2022 to 1849 MW/hour for 2028) and 7.8 times in the southern zone (from 79 MW/hour for 2022 to 623 MW/hour for 2028) [6].

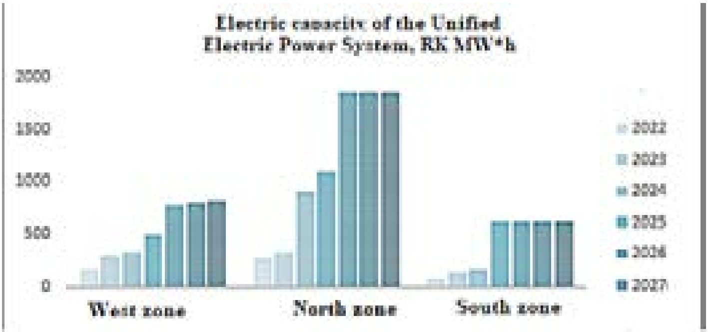

Figure 4 – Forecast balance of electric capacity of the Unified Electric Power System of the Republic of Kazakhstan per hour by zones due to the introduction of new capacities.

We can observe a similar trend in the international energy sector market, which is confirmed by the 2020 international forecast of the US Energy Information Administration, according to which by 2040, according to the scenario of the stated policy, electricity generation will grow to 40094 TWh, which is 1.48 times more than in 2019 (26619 TWh) [7]. Figure 5 shows a preliminary forecast for total energy demand by scenario.

The type of power generation system, the type of fuel used also affects the features of the construction of relay protection systems. The average annual growth rate of RES will be 5.1%. In turn, according to the sustainable development scenario, the share of RES by 2040 will be 72 % with an average annual growth rate of 6.7 %. The largest share will be wind energy (25 % and 39 %), solar photovoltaic system (15 % and 22%), respectively, according to the scenarios of the declared policy and sustainable development. [7].

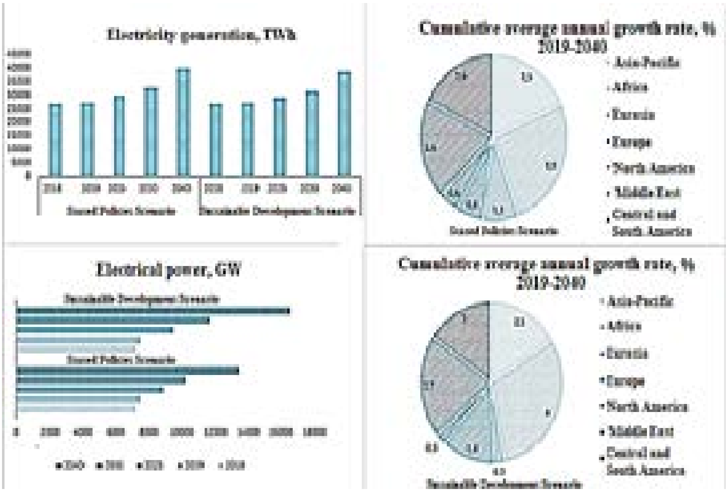

Figure 5 – Forecast for total electricity demand by scenario

An increase in the share of renewable energy sources, in turn, will lead to the need for the operation of relay protection systems in the presence of various types of generation systems.

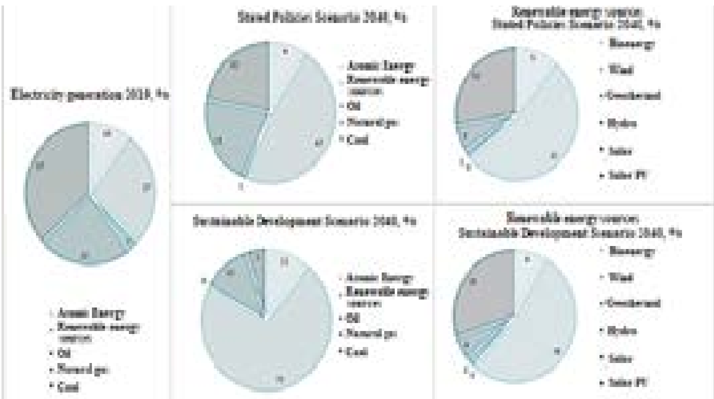

Figure 6 – Forecast of energy production from 2019 to 2040 by scenario

As a result of an increase in the amount of global electricity generation due to the growing demand for electricity, an increase in renewable substation automation capacities, as well as an increase in modification in the manufacturing industry, the market for protective relays and relay protection systems is expected to grow in developing countries in Asia, the Middle East and Africa. According to the forecast of the company Market Research Future (MR. FR), the global protective relay market will reach 7.11 billion US dollars by 2027, compared with a market volume of 2.79 billion US dollars in 2020, with an average annual growth rate of 7.57% during the forecast period (Figure 7) [8].

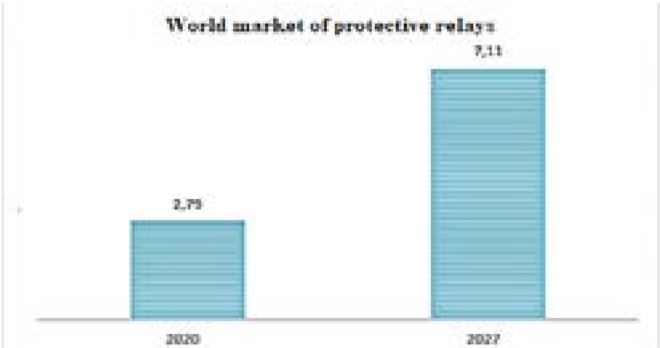

Figure 7 – World market of protective relays

At the moment, the main players in the global market of protective relays, as well as other circuit protection devices, are ABB, General Electric, Siements, Eaton and Schneider Electric [9].

However, it is worth noting that all available solutions on the market are closed, not involving development and modernization, that is, they do not allow changing algorithms, but only with the possibility of engineering settings, filling in setpoints, for example during start-up and commissioning.

At the present stage of the development of the industry and the development of digital technologies, the direction of open hardware has been developed, which is computer and electronic hardware, created as well as open software (software) [10]. A feature of the open architecture is the principle of openness of equipment made according to drawings, diagrams, layouts of printed circuit boards, source code in HDL (hardware description language), descriptions of materials and other logical programming languages.

Advantages over closed solutions in comparison with open equipment may be the following factors [11]:

- Innovation. The design of open equipment provides cost savings due to the repeated use of components, short terms of product release to the market and quality improvement due to the principle of free access.

- Democratization. Open hardware design processes are available to all users without licensing costs.

- Security. Information security is achieved by hiding design features that are a trade secret, but attackers can find and exploit weaknesses of computer systems. [12].

Open hardware solutions are used in various industries: telecommunications, automation systems, as well as in relay protection devices.

There is a device for differential protection built on FPGA [13]. The algorithm of operation is implemented using Modelsim software, and then on FGPA using Quartus prime software. The device was programmed so that it could distinguish between internal and external faults.

The FPGA board used in this study is an Altera DE2-115 board, which is equipped with Cyclone IV E (EP4CE115F29C7), where the relay algorithm is programmed.

To test the effectiveness of the proposed FPGA-based digital differential protection scheme, MATLAB software is used to perform the in-the-loop (FIL) operation.

A large-scale model of a wind farm connected to the grid has also been developed in MATLAB/Simulink to test the proposed protection scheme, which is shown in Figure 8.

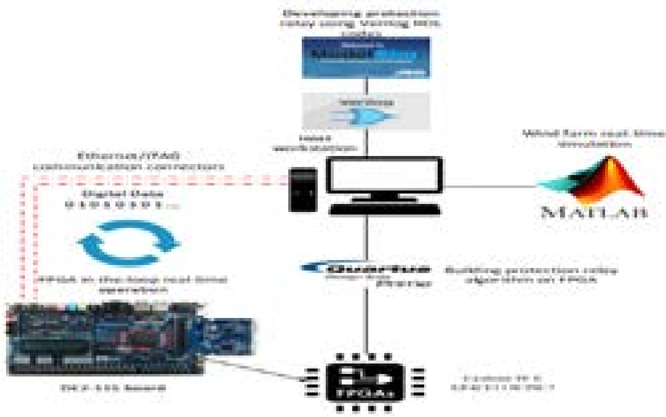

Figure 8 – Large-scale model

In [14], a digital relay on the FPGA is proposed. All relay submodules have been developed in VHDL and can be easily ported to various development environments.

The resistance relay was implemented on the Xilinx Virtex-7 XC7VX485T FPGA, using Xilinx ISE 14.1 tools for synthesis and implementation of the architecture.

Results and discussion

The solution of building a microprocessor relay on an open architecture is possible on the basis of an Arduino using an ATmega328 microprocessor. The algorithm of operation is implemented in the software Arduino IDE 1.8.19. Microprocessor relay protection is made in the form of a reed switch 1, on which an inductor coil 2 is wound (Figure 10). Trigger 3 K155LA3 is used to eliminate the contact rattle. The ATmega328P board is accepted as the logical part 4. Information about the short-circuit current is displayed on the display 5 of the LCD1602 model. The output body of the microprocessor relay protection is made in the form of an output relay 6. To test the device, a linear auto transformer and an oscilloscope 7 AKIP-4115 were used.

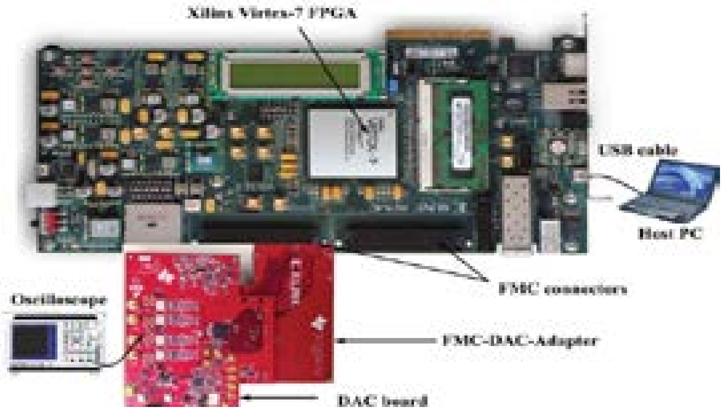

Рисунок 9 – Реле сопротивления на Xilinx Vertex-7

The measurement of the short circuit current is carried out thanks to the Arduino IDE 1.8.19 program. The algorithm of operation consists in measuring the time when the reed switch 1 contact is in a closed state.

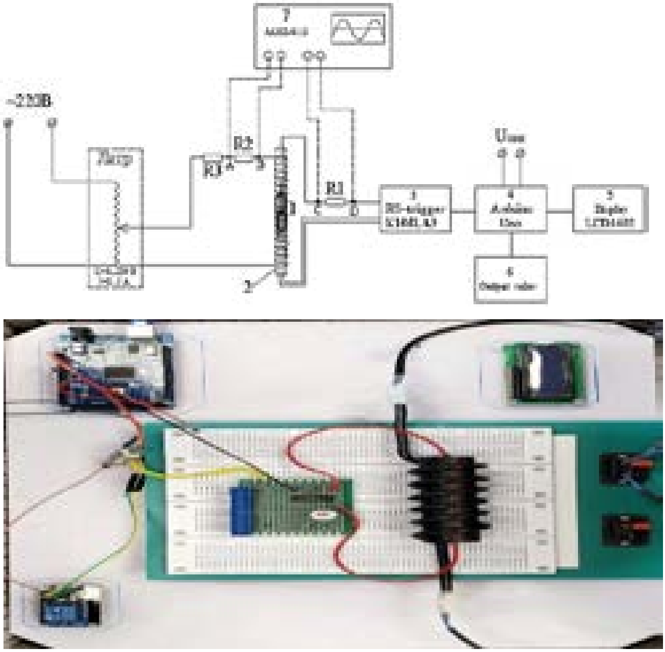

Figure 10 – Structure of the microprocessor relay protection device on Arduino

The Arduino solution, however, has its drawbacks. For example, interference is quite easily applied to the board. Low productivity, and therefore relatively long processing of information. To eliminate these shortcomings, an FPGA with an open architecture of the ALTERA Cyclone IV EP4CE6E22C8N model is proposed to replace the Arduino ATmega328. Comparative characteristics of the proposed prototype and the known one are presented in Table 2 [15, 16].

Reed switch 1, as in the previous device, is connected by a contact to the RS-trigger K155LA4, which performs the function of an anti-rattling circuit, with an output connected to the Cyclone IV FPGA board 3. The result of short circuit detection is the operation of the output relay 4, and the current value is output via the display 5.

Table 2 – Comparative characteristics of microprocessor boards

Position	Arduino ATmega328p	ALTERA Cyclone IV
Clock frequency	16 MHz	402 MHz
SRAM	2 Kb	from 9 Kb
Built-in memory	16 Kb	6.3 Mb

The proposed device is similar in structure to a traditional microprocessor relay protection. However, instead of a traditional terminal, an FPGA is used (Figure 11).

The short circuit current is generated using a linear autotransformer (LATR) and an inductor (CI) 2 and resistors R2 and R3. The values of the currents and the duration of the closed state of the reed switch contacts 1 are determined using an oscilloscope 7 AKIP-4115.

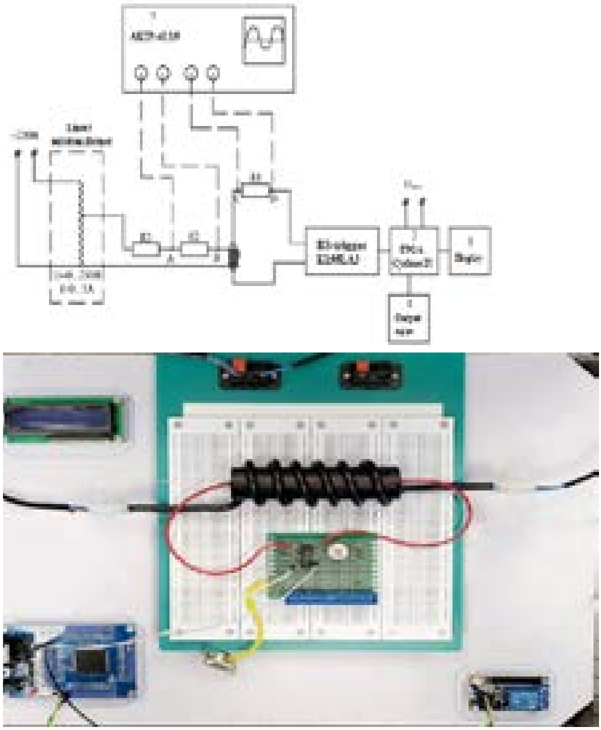

Figure 11 – Microprocessor relay protection using FPGA

The short circuit current is determined according to the program developed in the Quartus Prime 21.1 Lite Edition environment. A fragment of this code is written as follows

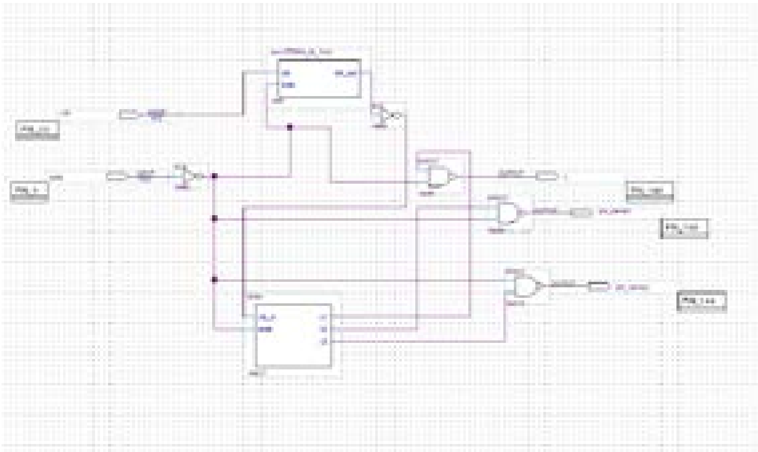

Figure 12 – Block diagram in FBD language

According to the diagram in Figure 12, PIN_23 with the name clk, performs the function of a pulse generator with a frequency of 27 MHz. It is connected to the PIN_1 input with the name sub, to the reed switch contact. Thus, when the reed switch is triggered, the block (conv27MHz_to_1 ms) converts a pulse with a frequency of 27 MHz into a pulse with a frequency of 100 Hz. The Timer block starts counting only after the reed switch is triggered. If the reed switch has been closed for 7 milliseconds, then a trip current equal to 342.3 A is selected. In the case when the reed switch is closed for 8 milliseconds or more, the FPGA selects the tripping current equal to 390.7, otherwise the setpoint is selected equal to 369.8 A. The FPGA performs a calculation according to which the value of the measured tripping current is displayed on the display, and simultaneously sends a signal to the output relay, which, when triggered, turns off the switch.

Conclusion

The assessment of electricity production, as well as the dynamics of the introduction of new capacities, shows that there is a need for relay protection devices.

There are isolated attempts to implement relay protection devices on FPGAs.

According to known data, their parameters meet the requirements. Microprocessor relay protection devices can be designed on the basis of open hardware platforms, however, it will be possible to talk about the application only after studies of the devices being developed, as well as experimental and industrial operations.

Further research will be aimed at building a solution on STM32. In the future, it is necessary to study the functioning of devices based on FGPA, STM32 and a well-known solution on the market.

Appreciation

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** А. В Нефтисов[1]., А. Ж, Саринова[2] О. М Талипов[3], Л. Н. Кириченко[4], И. М. Казамбаев[5]*

[1,2,3,4,5]Astana IT University, Қазақстан Республикасы, Нұр-Сұлтан қ.;
Торайғыров университеті, Қазақстан Республикасы, Павлодар қ.;
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АШЫҚ АРХИТЕКТУРАДА МИКРОПРОЦЕССОРЛЫ РЕЛЕ ҚОРҒАУ ҚҰРЫЛҒЫЛАРЫН ҚҰРУ МҮМКІНДІГІ

Жұмыста әртүрлі конструкциялардың релелік қорғаныс құрылғыларының құрылымы талданады. Қазақстан Республикасының Бірыңғай электр энергетикалық жүйесінің электр энергиясының болжамды балансы негізінде жаңа қуаттарды іске қосу есебінен электр энергиясын өндіруді арттыру жоспарланып отырғаны анықталды. Сондай-ақ, энергетикалық сектордың халықаралық нарығы және мәлімделген сценарийлер мен елдер, континенттер және аймақтар бойынша тұрақты даму сценарийі бойынша бөлінген энергияға жалпы сұраныстың алдын ала болжамы зерттелді: электр энергиясын өндіру, жиынтық орташа жылдық өсу қарқыны. Электр сыйымдылығы. Энергияны өндіру жүйесінің түрі және қолданылатын отын релелік қорғаныс жүйелерін құру және жаңарту ерекшеліктеріне әсер ететіні анықталды. Зерттеудің гипотезасы релелік қорғаныс жүйелері нарығындағы қолданыстағы жабық шешімдерді ашық аппараттық және бағдарламалық қамтамасыз етумен ауыстыру болып табылады, бұл оны әртүрлі электрмен жабдықтау жүйелерінде, соның ішінде FPGA-да әзірлеуге және қолдануға мүмкіндік береді. Зерттеу аясында ашық архитектурада микропроцессорлық реле құру шешімдері ұсынылды: блок-схема *және «Arduino тақтасындағы релелік қорғаныс микропроцессоры» әзірленген зертханалық стенд; «FPGA қолданатын релелік қорғаныс микропроцессоры». Тақталардың сипаттамалары бойынша салыстырмалы деректер ұсынылған, мұнда FPGA тақтасы барлық жағынан тиімді. Бағдарлама Quartus Prime 21.1 Lite Edition ортасында әзірленді. Жүргізілген жұмыстардың нәтижелері бойынша алдағы зерттеулер ашық архитектура негізіндегі микропроцессорлық релелік қорғаныс құрылғыларын қолдануды кеңейтуге бағытталатынын атап өтуге болады.*

Кілтті сөздер: релелік қорғаныс, ашық архитектура, FPGA, микропроцессорлық қорғау, FPGA, автоматтандыру, басқару.

**А. В Нефтисов[1], А. Ж. Саринова[2] О. М. Талипов[3], Л. Н Кириченко[4], И. М. Казамбаев[5]*
[1,2,3,4,5]Astana IT University, Республика Казахстан, г. Нур-Султан;
Торайгыров университет, Республика Казахстан, г. Павлодар;
Казахский агротехнический университет имени С. Сейфуллина, Республика Казахстан, г. Нур-Султан
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ВОЗМОЖНОСТЬ ПОСТРОЕНИЯ МИКРОПРОЦЕССОРНЫХ УСТРОЙСТВ РЕЛЕЙНОЙ ЗАЩИТЫ НА ОТКРЫТОЙ АРХИТЕКТУРЕ

В работе проанализирована структура устройств релейной защиты различного исполнения. На основе прогнозного баланса электрической энергии Единой электроэнергетической системы Республики Казахстан, выявлено что планируется увеличение генерации электроэнергии за счёт ввода новых мощностей. Также исследован международный рынок энергетического сектора и предварительный прогноз на общий спрос на энергию в разбивке по заявленному сценариям и сценарию устойчивого развития в разрезе стран, материков и регионов: выработке электроэнергии, совокупному среднегодовому темпу роста, электрической мощности. Определено, что тип системы генерации электроэнергии и используемое топливо влияет на особенности построения и обновления систем релейной защиты. Гипотезой исследования является замена имеющихся закрытых решений на рынке систем релейной защиты на открытое аппаратное и программное обеспечение, позволяющее разработать и применять его в различных системах энергоснабжения, в том числе *на ПЛИС. В рамках исследования предложены решения построения микропроцессорного реле на открытой архитектуре: структурная схема и разработанный лабораторный стенд «микропроцессор релейной защиты на плате Arduino»; «микропроцессор релейной защиты с применением ПЛИС». Представлены сравнительные данные по характеристикам плат, где по всем параметрам эффективным является плата ПЛИС. Разработка программы выполнялась в среде Quartus Prime 21.1 Lite Edition. По результатам работы можно отметить, что дальнейшие исследования будут направлены на расширение применения микропроцессорных устройств релейной защиты на базе открытой архитектуры.*

Ключевые слова: релейная защита, открытая архитектура, ПЛИС, микропроцессорная защита, ПЛИС, автоматизация, управление.

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G. G. Zhabalova[1], O. N. Onishchenko[2], S. N. Кamarova[3], O. N. Lelikova[4]
[1,2,3,4]Karaganda Industrial university, Republic Kazakhstan, Temirtau

RECONSTRUCTION OF THE ASH AND SLAG REMOVAL SYSTEM IN CHP-2 OF JSC «ARSELORMITTAL TEMIRTAU»

This article discusses the modernization of the ash and slag removal system at CHPP-2 of JSC «ArcelorMittal Temirtau», the transition from the wet method of cleaning ash and slag to a more technologically advanced dry one. The long-term use of the hydraulic ash and slag removal system (GZSHU) has led to the accumulation of a huge amount of ash, which is subsequently not used. A comprehensive replacement of wet cleaning equipment for dry cleaning is considered. The wet method offers quenching with water (in this case, up to 1 % of the thermal efficiency of the TP-81 boiler unit is lost), followed by the use of drag pumps and the removal of ash and slag through the hydraulic ash removal channels to the ash dump.

In the future, this ash cannot be used. During dry ash and slag removal, extinguishing with water is not used, but a pneumatic system for removing combustion products is used. Ash from gas cleaning plants through a system of pneumatic chamber pumps and intermediate hoppers is fed through ash pipelines to a silo warehouse. The use of this technology allows minimizing the harmful impact on the environment by reducing groundwater pollution with pulp, reducing the area of ash dumps, reducing water consumption by the station, using ordinary types of steel in pipeline systems, and reducing the cost of equipment maintenance.

Keywords: boiler, slag, ash and slag removal, dust preparation, hydraulic ash removal, fuel, coal, ash.

Introduction

Today, ash disposal is an urgent problem. Up to 30 million tons of ash and slag waste is generated annually in Kazakhstan, most of which is sent to giant dumps and is not used in any way.

In order to use ash and slag, it must be turned into a commodity, it is necessary to modernize the ash and slag removal system operating at the coal-fired CHPP-2, replacing the wet method with a more technologically advanced dry one.

The long-term use of the hydraulic ash and slag removal system (GZSHU) has led to the accumulation of a huge amount of ash, which is subsequently not used.

The toxicity of ash and slag hydromass consists in the release of alkali, which enters directly into the ground, contaminating groundwater. Obvious environmental consequences are complemented by economic ones [1].

Materials and methods

The hydraulic ash removal system is designed to remove ash and slag from the bunkers of the boiler unit and transport them outside the station territory (ash dump).

In the boiler shop of CHPP-2 in JSC «ArcelorMittal Temirtau» two pump rooms are installed, to which process water is supplied from the circulation conduit №7 through valves with a diameter of 400 to the pump room №1,2 and from the circulation conduit №8 through a valve with a diameter of 600 additionally to the pump room branch №2. Clarified water is supplied from the GTS workshop to the CHPP-2 boiler shop through the JET filter located inside building of the bager pump house №2. The filter is cut off by two valves with a diameter of 400 [2].

The filter is equipped with a bypass line through a valve with a diameter of 300. Further, after the filter, the clarified water collector before entering the boiler shop is divided into two flows into pump rooms №1 and №2. One pipeline enters to pump room №2 through a valve with a diameter of 300, the other pipeline, passing through the workshop №1 along row D at elevation 4m in the area of DV-4B through a sectional valve with a diameter of 400, enters the suction in pump room №1 through a valve with a diameter of 400. Pump room №1 is mounted at the permanent end of the boiler shop.

In the distribution manifold of pump room No. 1, the suctions of flushing pumps NSV No. 1,2 and irrigation pumps NOV No. 1,2,3 and washing of boilers NOK No. 3 crash into the distribution manifold. Pump room No. 2 is mounted between queues No. 1 and 2. Suctions of flushing pumps NSV No. 3,4 and irrigation pumps NOV No. 4,5,6 and washing of boilers NOK No. 2 crash into the distribution manifold of the pump room. Heads NSV No. 1-4 through valves supply water to a common collection manifold of flush water with a diameter of 325x8, mounted along row D. From it, through a pipeline with a diameter of 159x4mm, water is supplied to the incentive nozzles of the GZU channels, the ShZU channel, slag baths, through a pipeline with a diameter of 133x4mm on flushing nozzles of trays (collecting collectors for water seals) of electrostatic precipitators, on irrigation units of ring emulsifiers of boilers TP-81 No. 1-4. In the DV-4B area of the flush manifold, a sectional valve with a diameter of 300 was mounted. In the area of

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Торайғыров университеті
140008, Павлодар қ., Ломов к., 64, 137 каб.

«Toraighyrov University» баспасы
Торайғыров университеті
140008, Павлодар қ., Ломов к., 64, 137 каб.
67-36-69
E-mail: kereku@tou.edu.kz
www.vestnik-energy.tou.edu.kz