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Resource-Saving Current Protections for Electrical Installations

Dauren D. Issabekov
Department of Electrical Power Engineering
Toraighyrov University
Pavlodar, Kazakhstan
Dauren_pvl2012@mail.ru

Olzhas M. Talipov
Department of Electrical Engineering and Automation
Toraighyrov University
Pavlodar, Kazakhstan
talipov1980@mail.ru

***Abstract*—It is presented that one of the urgent problems of modern power engineering is the construction of current protections of electrical installations that do not use current transformers with ferromagnetic cores. It is shown that magnetically controlled elements-hercone and inductance coil can be used to build such protections, installing them near current-carrying busbars of electric installation, as they have important advantages for relay protection in comparison with other magnetically controlled elements: they do not require amplifiers for signal transmission, signal transmission is performed by control circuits, not by measuring ones, they do not need temperature influence compensation devices, can simultaneously perform the functions of an analog-digital converter, a measuring transducer and a measuring protection device. New schemes of current protections of electrical installations on reed switches and inductance coils, including with fault control, connected to cells of complete switchgear (switchgear), with the effect of resource-saving materials. Their properties and principle of operation are considered. For the considered current protections, new schemes of their implementation are presented, which confirms the possibility of building current protections for various electrical installations connected to the cells of complete switchgears, with the installation of reed and inductance coils inside them.**

Keywords—reed switch, inductance coil, maximum current protection, current cutoff, electrical installation

I. INTRODUCTION

Due to their simplicity and high reliability, overcurrent protections such as overcurrent protection (overcurrent protection) and overcurrent trip have become widely used in industrial plants for short-circuit protection of electrical installations 6-35 kV. Traditionally, they receive information about the current in the phase of the protected installation, like most other protections [1, 2] from current transformers (CTs) with ferromagnetic cores.

These current transformers have a number of well-known drawbacks [3, 4], because of which it was repeatedly noted at the International Councils on Large Electric High Voltage Systems (CIGRE), for example [5], that one of the current tasks of power industry is the development of relay protection without the above mentioned CTs. Works to eliminate these drawbacks, to create new currency converters, as well as resource-saving protections that do not use current transformers ferromagnetic cores, started in the middle of the last century, such as Rogowski coils [6, 7], magnetoresistors [8, 9], Hall sensors [9], galvanomagnetic elements [10], magnetodiodes [11], magnetotransistors [11] and reed switches [12, 13] continue to this day [14-16].

To build current protections without traditional current transformers, magnetically controlled hermetically sealed contacts - reed and inductance coils were chosen [12–17].

II. RELEVANCE AND SCIENTIFIC SIGNIFICANCE

As is known, the maximum current protection trips when the current of the protected electrical installations exceeds the set operating current and reacts to external faults of electrical installations.

One alternative way to detect this type of fault is to use inductance coils and reed switches instead of traditional current transformers with metal cores. In this connection it is necessary to consider the realization of maximum current protection of high-voltage electrical installations in the form of devices.

III. METHOD

The aim of the study is to create alternative current protections for the protection of high-voltage electrical installations, such as maximum current protection implemented on reed switches and inductance coils, without using current transformers and current relays with metal cores for these protections. The main factor is the refusal to use metal-intensive, bulky and expensive current transformers and current relays.

Main tasks: to achieve the goal it is necessary to develop a maximum current protection for the protection of various high-voltage electrical installations.

IV. IMPLEMENTATION OF CURRENT PROTECTIONS WITH REED AND INDUCTANCE COILS

In such protections, the reed and the inductance coil act simultaneously as a current sensor and as a measuring body of the protection and react to the magnetic field created by the currents in the phases of the electrical installation. For example, a reed switch actuates (closes its previously open contacts) if the induction of the magnetic field acting along its contacts reaches the actuation value, i.e. there is the so-called magnetomotive force of actuation of the reed switch, which is determined in the factory by the control winding with a certain length wound on the reed switch, as well as taking into account the magnetic permeability of air. To perceive the magnetic field, the reed and the inductor coil can be mounted near the current-carrying busbars [16].

In this work we consider the variant of their mounting at a safe distance, because then there is no need for special measures to ensure safety, the probability of their breakdown is much less, while it is easier and more accurate to regulate their triggering parameters (this is done by changing the distance h from the reed and inductance coil to the current-carrying bus).

The reed switch is used as an element base in various relays, buttons, switches and other electrical devices [12]. The inductance coil is also widely used in various electrical devices: contactors, magnetic starters, various relays [18].

Under the influence of a magnetic field on the reed switch, created by a current-carrying bus or a permanent magnet - as in the gas protection of a power transformer, the ends of its contacts are magnetized in opposite ways and, bending, are attracted to each other, closing the electrical circuit. Figure 1 shows the common types of reed switches used [18]. The presented maximum current and gas protection of the power transformer uses reed switches, type KM-1.

The inductance coil is also affected by a magnetic field from the current-carrying bus of the electrical installation, and at the same time, an alternating voltage is removed from its terminals. In the presented longitudinal differential protection of the power transformer, inductance coils from an intermediate relay, type MKU-48 AC, are used. Figure 2 shows the inductance coil of an intermediate relay, type MKU-48

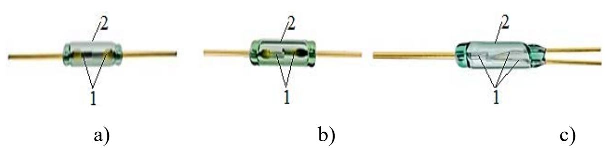

Fig. 1. Types of reed switches. a, b - closing, type MKA-20101 and KM1; c - switching, type MKC 27103: 1 - reed switch contacts; 2 - glass flask.

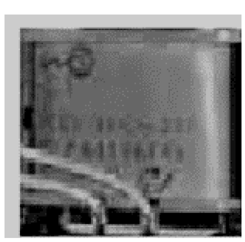

Fig. 2. Appearance of the inductance coil of the intermediate relay MKU – 48.

Current protection with a functional diagram on a reed switch or inductance coil consists of the following elements (fig.3): 1 - reed switch or inductance coil, 2 - pulse expander (amplifier), 3 - time relay, 4 - intermediate relay [17]. In this case, the time relay in some protections may not be used.

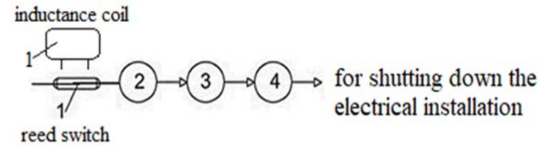

Fig. 3. Functional diagram of current protection on a reed switch or inductance coil.

When the reed switch is located at a safe distance h, for example, from the busbar of phase A in the plane of its cross section [18], and without taking into account the influence of the remaining phases, according to the Biot–Savart–Laplace law, the reed switch operates at an induction equal to [19, 20]:

$$B_{PA} = I_{PA}\cos\varphi\mu_0/2\pi h = I_C\,\omega_C\mu_0/L_C = F_C\mu_0/L_C = H_{PA}\mu_0, \quad (1)$$

where I_{PA}, H_{PA} and B_{PA} are the minimum values of the current in the current-carrying bus, the strength and induction of the magnetic field, at which the reed switch is activated; ω_C - the number of turns of the inductance coil; L_C - the length of the inductance coil; μ_0 – magnetic permeability of air equal to μ_0=4π·10-7 H/m.

However, in this way, the operating current I_{PA} is determined in electrical installations for direct and single-phase alternating current. In three-phase electrical installations, the operation current I_{PA} data already depends on the type of short circuit itself. And in this regard, a magnetic field with induction acts on the reed switch or inductance coil, which are located at distances L_A, L_B and L_C from current-carrying tires [19, 20]:

$$B = \mu_0/2\pi(I_A\cos_{\alpha A}/L_A + I_B\cos_{\alpha B}/L_B + I_C\cos_{\alpha C}/L_C), \quad (2)$$

where α_A, α_B, α_C is the angle between the vector B_A, B_B, B_C of the induction of magnetic fields created by currents I_A, I_B, I_C of three phases A, B, C and the axis of the reed switch itself or the inductance coil.

Since the principle of operation of current protection on reed switches or inductors remains the same as that of traditional protection, it should not work when electric motors self-start [19, 20]:

$$I_{PA} \geq I_{OP.MAX}\cdot k_{OFF}\cdot k_{SELF}, \quad (3)$$

where $I_{OP.MAX}$ – is the maximum operating current in the current-carrying bus under consideration; k_{OFF} and k_{SELF} are the detuning factor and the self-starting factor of the electric motor.

However, formula (3) cannot be used, since the reed switch and the inductance coil react to the magnetic flux, and not to the current flowing in the current-carrying bus. The reed switch is triggered by induction B equal to [20]:

$$B = B_P = F_P\mu_0/L_C, \quad (4)$$

The sensitivity coefficient k_{SENS} of protections made on reed switches is determined, as well as for traditional protections on current transformers with ferromagnetic cores according to formula 5:

$$k_{SENS} = I_{SC.MIN} / I_{PA} , \quad (5)$$

where $I_{SC.MIN}$ – is the minimum short circuit current, I_{PA} – is the protection operation current.

At the same time, this sensitivity coefficient for current protection made on reed switches in case of damage at the end of the protected section should have a coefficient equal to $k_{SENS} \geq 2$, and at the end of the reserve section $k_{SENS} \geq 1.6$, since the magnitude of the reed switch actuation current I_{PA} can be 30% more than the rated current, due to the installation error of the reed switch itself.

And for the reed switch and the inductance coil, the sensitivity coefficient is determined by the formula [20]:

$$k_{SENS} = B_{SC.MIN} / B_{PA} , \quad (6)$$

where $B_{SC.MIN}$ – is the induction of the magnetic field created by the minimum short-circuit current flowing in the current-carrying busbars of the protected connection and at the installation point of the reed switch or inductance coil.

If the protection on the reed switches has the required sensitivity to short circuits, then the reed switch is selected from reference books with a trip induction equal to [20]:

$$B_{P.S} = F_P \mu_0 / L_C \approx B_{PA.S}, \quad (7)$$

And the inductance coil is selected with a trip induction equal to:

$$B_{P.C} = U / 2\pi f S \omega_K \approx B_{PA.C}, \quad (8)$$

where: U – voltage of alternating current; f– is the frequency of the alternating current; ω_C – the number of turns of the coil; S – is the cross-sectional area of the coil.

V. MAXIMUM OVERCURRENT PROTECTION AND OVERCURRENT TRIP OF ELECTRICAL INSTALLATIONS

Long Maximum current protection and overcurrent shutdown of electric installations, presented in the form of device, contains inductance coil 1 with two paired leads, connected to the first (A1)2 and the second (A2)3 voltage amplifiers, which amplify the voltage taken from the leads of inductance coil 1 to the required value. The first voltage amplifier 2 is connected to the winding 4 of time relay 5, a constant current source 6, from the pole "+" of which the positive potential comes to the contact with time delay for closing 7 of time relay 5, to which is connected the first terminal of winding 8 of the first intermediate relay 9. The positive potential of the pole "+" DC source 6 goes to the contact closure 10 first intermediate relay 9, which in turn is connected to the first terminal of the first indicator relay (KH) 11, and with it to the first terminal of the coil turn off (YAT) 12 circuit breaker electrical installation. The second voltage amplifier 3 is connected to the coil 13 second intermediate relay 14, a DC current source 6, with the pole "+" positive potential is fed to the contact closure 15 second intermediate relay 14, which in turn is connected to the first terminal of the second indicator relay 16, and from it to the first terminal of the coil turn off (YAT)12 switch of the electrical installation. The second terminal of the winding 8 of the first intermediate relay 9 and shutdown coil (YAT)12 are connected to the pole "-" of the direct current source 6 (fig.4).

The principle of operation of these protections is based on the impact of the magnetic flux F (shown by arrows), created by the current of the current-carrying bus of the protected electrical installation on the inductor coil 1 (fig.4). The device, which is a set of protection, can be installed in the cells of a complete switchgear (switchgear), closed switchgear (closed switchgear) and in the closed busducts for each phase at the point where there is a maximum value of magnetic flux.

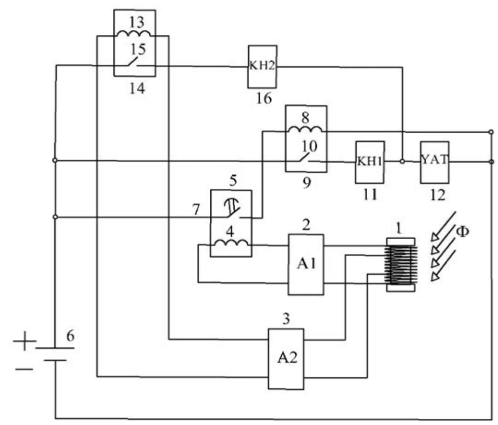

Fig. 4. Functional Scheme of maximum current protection and overcurrent cutoff of electrical installations.

When a short circuit occurs in the protected electrical installation, the current in its current-carrying bus increases and the inductor coil 1, installed at a safe distance from this current-carrying bus (at a distance of 12 cm) according to the Rules of Electrical Installation (REI) reacts to changes in the magnetic field, and in it is induced an increased value of electromotive force (EMF) [18] (fig.4)

For the maximum current protection function the first paired pin of the inductor coil 1 is used, and for the current cutoff function the second paired pin of the inductor coil 1 is used. Due to the fact that the value of the voltage removed from the leads of inductance coil 1 when the device performs the function of maximum current protection has a maximum value of about 5 V, it is increased with the first voltage amplifier (A)2 to a value equal to U = 220 V and is fed to the leads of winding 3 of time relay 4. As a result, this relay triggers a contact with time delay (0,02s.) on closure 6 and sends the potential "+" coming from the DC source 5 to the first terminal of the winding 7 of the first intermediate relay 9. This relay 9 is triggered, sends a potential "+" through its contact to close 10 to the first terminal of the trip coil (YAT)12 circuit breaker of the electrical installation. As a result, the protected electrical installation is disconnected. The tripping of the overcurrent protection is detected by the first indicating relay (KH1)11.

When the device performs the function of current cutoff, the value of the removed voltage from the terminals of the inductor coil 1 has a value of about 3V, then it increases with a second voltage amplifier (A)3 to a value equal to U = 220 V and fed to the first terminal winding 13 second intermediate relay 14.

As a result, the second intermediate relay (KL)14, after tripping, applies a "+" potential to the first terminal of the trip coil (YAT)12 of the circuit breaker of the electrical installation via its contact on closure 15. As a result the protected electrical installation is disconnected. The tripping of the current cut-off is detected by the second indicating relay (KH2)16 (fig.4).

In normal operation of the electrical installation, the parameters in the voltage amplifiers 2 and 3 are adjusted so that they are triggered only when a voltage of about 3–5 V appears on their terminals, and when the voltage is less than this, the maximum current protection and current cutoff to disconnect the electrical installation do not operate.

VI. Maximum current protection of electrical installations

The maximum current protection for electrical installations, represented in the form of a device contains a reed switch 1 with switching 2, 3 and opening 4 contacts, the control winding 5 of reed switch 1, current-carrying bus 6, a source of direct-current source 7, control unit 8, first 9, second 10 and third 11 pointer relay, the first 12 and second 13 time relay, the first 14 and second 15 of intermediate relay, trip coil 16 breaker of electrical installation, opener 17 second intermediate relay (KL)15 (fig.5).

The maximum current protection works as follows. In normal operation at the reed switch 1 closing contact 3 does not work, because it is configured not to operate when the maximum load current flowing in the conductive bus 6 of the electrical installation. Therefore, overcurrent protection does not operate and there is no signal on the output of the first time relay 12 (fig.5).

When a short circuit in the protected electrical installation at the reed switch 1 under the influence of current flowing in the current bus 6 is greater than the maximum, simultaneously breaking contact 4 and the closing contact 3, while the closing contact 3 sends a signal to the input of the first time relay 12.

The first time relay 12, triggered, counts down time equal to 0.02 s and sends a signal to the input of the first intermediate relay 14. This relay 14, triggered, through the break contact 17 of the second intermediate relay 15 sends a signal through a second indicator relay 10 to the trip coil 16 of the circuit breaker of the electrical installation. When the opening contact 4 reed contact 1 triggers the first pointer relay 9 due to loss of power. The first 9 and the second 10 pointer relays send a signal about triggering of the protection to the service personnel, and as a result the protected electrical installation is disconnected. In this case, if after the first indicator relay 9 does not return to its original state - does not fall out the blinker "On", it indicates a sticking switching 2 and closing 3 contacts of reed switch 1, and the attendant must replace this reed switch 1 for serviceable (fig.5).

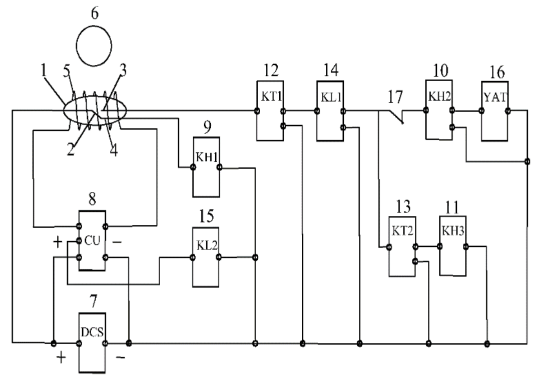

Fig. 5. Maximum current protection structure scheme.

This second time relay 13 when activated sends a signal to the third indicator relay 11, signaling the operation of the self-diagnostic circuit of the device to the operating personnel. If any element of the device is damaged, there is no test signal at the output of the first intermediate relay 14 and the third indicator relay 11 is not triggered. If at the same time the indicator relay 11 does not return to its original state - the blinker "On" fell out, it indicates a sticking of switch 2 and close 3 contacts of reed switch 1. If the first time relay 12 and the first intermediate relay 14 do not switch on, this indicates a sticking of the switching 2 and opening 4 contacts of the reed switch 1. In both cases the service personnel, paying attention to the fallen out blinkers of the first 11, second 12 and third 13 of the indicator relay replaces the failed reed switch 1 with a serviceable one.

VII. Maximum current protection with minimum voltage lockout

The Maximum current protection with minimum voltage locking, designed as a device, contains a first 1, second 2 and third 3 inductance coil, where the first 1 is connected to the leads of the first voltage amplifier (A1)4, and the second 2 to the second voltage amplifier (A2)5 (fig.6a). The first 4 and second 5 voltage amplifiers amplify the voltage taken from the outputs of the first 1 and second 2 inductor coils to the required voltage. The third inductor coil 3, consisting of primary and secondary windings, is wound on a current-carrying bus 6, in which the output of the secondary winding is connected to the input of the second inductor coil 2 (fig.6b). The first inductance coil 1 is located in the cable compartment of the K-63 series switchgear panel and opposite to the current-carrying busbar 6, and the second inductance coil 2 is located in the relay cabinet of this panel [21]. The output of the first voltage amplifier 4 is connected to the winding 7 of the first intermediate relay 8, and the output of the second voltage amplifier 5 is connected to the winding 9 of undervoltage relay 10, DC source 11, from pole "+" positive potential is fed to the contact to open 12 relay 10, to which is connected first winding 13 second intermediate relay 14. The closure contact 15 of the first intermediate relay 8 is connected to the closure contact 16 of the second intermediate relay 14, which in turn is connected to the winding 17 of the time relay 18. The positive potential pole "+" DC source 11 comes to the contact with time delay on closing 19 of the time relay 18, which in turn is connected to the indicator relay (KH) 20, and with it to the first terminal of the coil turn off (YAT)21 circuit breaker electrical installation. The second terminal winding: 13 second intermediate relay 14, 17 time relay 18 and shutdown coil (YAT)21 are connected to the pole "-" DC power source 11 (fig.6a).

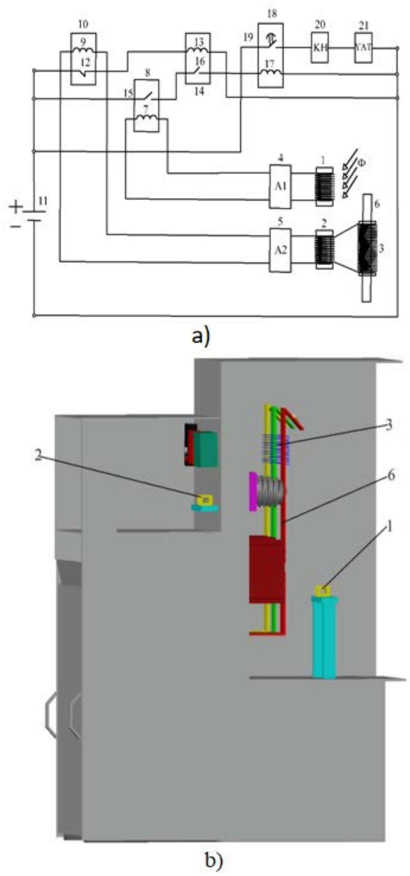

Fig. 6. Maximum current protection with blocking of the minimum voltage:(a) functional scheme; (b) placement of elements of the maximum current protection with blocking of the minimum voltage inside the cell of the complete switchgear

The principle of operation of the maximum current protection at the time of short circuit on the protected electrical installation is based on the effect of magnetic flux F (shown by arrows), created by the current-carrying bus 6 to the first inductor coil 1 and the removal of the secondary voltage from the secondary winding of the third coil 3 and supply it to the second inductor coil 2 (fig.3a). This device is a set of protection, which can be installed in the cells of a complete switchgear, closed switchgear and in closed current conduits for each phase in a separate set. The first inductor coil 1 is installed in front of the current-carrying busbar 6 and in the place where there is a maximum value of magnetic flux (fig.6b).

In the event of a short circuit on the protected installation, the current in its current-carrying bus 6 increases, and the first 1 and third 3 inductors react to changes in the magnetic field, with the first inductor coil 1 set at a safe distance under the Rules for Electrical Installations (REI) from this bus 6, and as a result on the first inductor coil 1 and on the secondary winding of the third inductor coil 3 is induced voltage applied to the second

induction coil 2 (fig.3a; b). Due to the fact that the values of the removed voltage from the leads of the first 1 and second 2 coils of inductors have small values, the order of 5 and 1V, they are raised with the first 4 amplifier to 220V, and with the second 5 amplifier to a value equal to U=100V. After this voltage data from the first voltage amplifier 4 fed to the coil 7 first intermediate relay 8, and from the second amplifier 5-to the winding 9 of the minimum voltage relay 10 (fig.6a).

As a result, the first intermediate relay 8 triggered contact closure 15, sending a potential "+" coming from a DC source 11 to the contact to close 16 second intermediate relay 14, from which the potential "+" comes on the winding 17 time relay 18. After the positive potential of the pole "+" of the direct current source 11 comes to the contact with time delay for closing 19 of the time relay 18. At the same time with the first intermediate relay 8 the undervoltage relay 10 is activated, the contact 12 opens, as a result the winding 7 of the second intermediate relay 14 loses power and the relay is triggered. From the contact with time delay (KT) on closing 19 of the time relay 18 the positive potential of the pole "+" DC source 11 comes to the indicator relay (KH) 20, which after triggering the potential "+" to the first terminal of the coil turn off (YAT) 21 circuit breaker of the electrical installation. As a result, the protected electrical installation is disconnected (fig.3a). The second output: the windings13 second intermediate relay 14; windings 17 time relay 18 and trip coil (YAT)21 are connected to the pole "-" DC source 11 (fig.6a).

In normal operation of the electrical installation, the parameters in the first 4 and second 5 voltage amplifiers are adjusted so that they are triggered only when a voltage of 5V and 1V appears on their terminals, and at voltage values less than this, the device to shut down the electrical installation does not work.

VIII. Conclusion

Considering the presented current protections of electrical installations, it should be said that the maximum current protection and current cutoff perform current protection of electrical installations with the use of inductance coil. Inductance coil performs the functions of a combined current relay, which implements the maximum current protection and current cutoff. The maximum current protection of the electrical installations allows the remote control of the serviceability of its elements, by automatically sending a test signal with simultaneous control of the sticking of the reed contacts. The maximum current protection with minimum voltage blocking is realized by using the first and second inductance coils, and the third inductance coil, consisting of primary and secondary windings, wound on a current-carrying busbar, serves as a voltage transformer. The second inductance coil is designed to increase the sensitivity of the protection. This maximum current protection is carried out with two starting organs: the first and the second inductance coil, as in conventional maximum current protection with the same starting organs, only current and minimum voltage.

Presented current protections of electrical installations fully meet the issues of relay protection, such as cybersecurity - complete immunity to cyber attacks, due to the lack of internet connection; do not use in their composition current and voltage transformers with ferromagnetic cores, containing in their composition expensive steel, copper and high voltage insulation, the new approach to the implementation of current protections for various electrical installations of any voltage rating class using reed switches and inductance coils is a completely new approach in the implementation of current protections for various electrical installations with any voltage rating class.

From the above it becomes clear that the presented current protections made on reed switches and inductance coils in comparison with traditional protections using current transformers and current relays with ferromagnetic cores are several times cheaper and smaller in price and weight-size parameters. However, at present these current protections have not yet found wide application in electric power industry due to the fact that they have not yet been widely implemented in production, i.e. there are no statistical data on these protections, but the future of electric power industry is undoubtedly behind these types of protections. As repeatedly noted at international conferences on large power systems CIGRE, the construction of relay protection without traditional current transformers with ferromagnetic cores is considered one of the fundamentally unsolved problems of modern power engineering. And, just so, one of the promising directions of solving this problem is the creation of resource-saving relay protections on reed switches and inductance coils, which have known advantages over other magnetically controlled elements.

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REFERENCES

[1] V. A. Andreev, Relay Protection and Automation of Power Supply Systems: A Textbook for Universities, 4th ed. Moscow: Higher School, 2006.

[2] E. M. Shneerson, Digital Relay Protection. Moscow: Energoatomizdat, 2007.

[3] V. E. Kazansky, Current Transformers in Relay Protection Circuits. Moscow: Energiya, 1969.

[4] V. E. Kazansky, Measuring Current Transducers in Relay Protection. Moscow: Energoatomizdat, 1988.

[5] A. F. Dyakov, "Power industry of the world at the beginning of the XXI century (based on the material of the 39th session of CIGRE, Paris)," Energy Abroad, no. 4, pp. 7-16, April 2004.

[6] L..A. Kozhovich and M. T. Bishop, "Modern relay protection with current sensors based on the Rogowski coil," Modern Trends in the Development of Relay Protection and Automation of Power Systems: Collection of Articles. Report Int. Scientific and Technical Conf. Moscow: Scientific and Engineering Information Agency, pp. 39-48, September 2009.

[7] L. A. Kozhovich and M. T. Bishop, "Experience in operating differential protection of power transformers using the Rogowski coil," Modern Trends in the Development of Relay Protection and Automation Systems of Power Systems: Collection of Articles. Report Int. Scientific and Technical Conf. Moscow: Scientific and Engineering Information Agency, pp. 49-59, September 2009.

[8] G. I. Kotenko, Magnetoresistors. Moscow: Energy, 1972.

[9] A. Kobus, J.Tushinsky, and O. K. Khomeriki, eds., Hall Sensors and Magnetoresistors. Moscow: Energy, 1971.

[10] N. I. Ovcharenko, V. G. Doroguntsev, E. I. Bass, and V. V. Budkin, Application of Galvanomagnetic Elements in Relay Protection and Automation. Moscow: Energy, 1966.

[11] G. A. Egiazaryan and V. I. Stafeev, Magnetodiodes, Magnetotransistors and their Applications. Moscow: Radio and Communication, 1987.

[12] S. M. Karabanov, R. M. Maisels, and V. N. Shoffa, Magnetically Operated Contacts (Reed Switches) and Products Based on them. Dolgoprudny: Publishing House Intellect, 2011.

[13] Ya. M. Dikovskiy and I. I. Kapralov, Magnetically Controlled Contacts. Moscow: Energy, 1970.

[14] D. D. Issabekov, "Multipurpose power system protection set that provides constant remote serviceability control," 2022 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM), Sochi, Russian Federation, 2022, pp. 35-39, doi: 10.1109/ICIEAM54945.2022.9787128.

[15] D. D. Isabekov, M. Ya. Kletsel, B. E. Mashrapov, and D. T. Amrenova, "Reed-switch-based relay protection without current transformers," Russian Electrical Engineering, no. 4, pp. 247-253, 2022, doi: 10.3103/S1068371222040058.

[16] M. Ya. Kletsel, A. B. Zhantlesova, P. N. Mayshev, B. E. Mashrapov, and D. D. Issabekov, "New filters for symetrical current components," Electrical Power and Energy Systems, no. 101, pp.. 85-91, 2018, doi: 10.1016/j.ijepes.2018.03.005.

[17] E. I. Bass, Automation Protection Relay Coils. Moscow: Energy, 1974, 80 p.

[18] Joint Stock Company "Ryazan Plant of Metalloceramic Devices." [Online]. Available: www.rmcip.ru

[19] Order of the Minister of Energy of the Republic of Kazakhstan. Rules for the device of electrical installations of the Republic of Kazakhstan: approved by the Ministry of Energy of the Republic of Kazakhstan. March 20, 2015, № 230.

[20] L. A. Bessonov, "Theoretical bases of electrical engineering," in the book: Electromagnetic Field, 9th ed. Moscow: Gardariki, 2001, 317 p.

[21] Complete Distribution Device with Voltage 6÷10 kV. KRU K-63, Technical Information. Novosibirsk: OOO Siberian Plant Electroshield, 2015. [Online]. Available: https://sibelz.ru/wp-content/uploads/2019/03/KRU_K-63-tehnicheskaya-informatsiya.pdf.