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Resource-Saving Current Protectors

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***Abstract*—Works on creation of resource-saving protections without the use of measuring current transformers with metal cores have been carried out since the 60s of the 20th century. To build relay protection without measuring current transformers, in this work inductance coils and reed switches, which were magnetic field sensors, were used. Magnetic fields created by the currents of the current-carrying phases of complete switchgear cells have their maximum values in the immediate vicinity near the center of these busbars. These maximum values of magnetic fields in the form of EMFs are picked up inductance coils and reed switches. The reed switch and the inductance coil are installed in the location of the switchgear panel where the maximum magnetic induction is present. The inductance coil is the sensing element of the resource-saving protection. The reed switch is the sensing and actuating element of the resource-saving protection. Inductance coils and reed switches were chosen because, in comparison with other magnetically controlled elements, they have advantages for relay protection, such as: reed switches, for example, do not require amplifiers for signal transmission; the signal transmission itself is carried out through control circuits, not through measuring circuits; reed switches and inductance coils do not need temperature compensation devices. Reed switches can simultaneously act as an analog-to-discrete converter, a measuring converter and a measuring protection device. Inductance coils perform the functions of measuring converter and measuring protection body. The research relates to the protection of high-voltage electrical installations.**

***Keywords*—inductance coil, reed switch, induction, current protection, resource saving**

I. INTRODUCTION

At the international conferences on large power systems (CIGRE), it has been repeatedly noted that one of the urgent tasks of modern electric power engineering is the development of relay protection without measuring current transformers with metal cores [1]. Such current transformers are metal-intensive, have significant weight and dimensional parameters and significant errors in transient modes [2–3]. At the same time, these current transformers are expensive. The problem becomes even more urgent in connection with the widespread introduction of microprocessor-based protections, since the reliability of their tripping or non-tripping in some cases is insufficient [4–5]. To solve this problem, it is necessary to use alternative resource-saving protections. It is also necessary to abandon the use of traditional measuring current transformers, as well as protections powered by these current transformers [4]. Creation of resource-saving relay protection devices on a different element base for various electrical installations against short circuits without the use of traditional measuring current transformers, which began in the second half of the last century, remains relevant to this day. In this regard, it is necessary to abandon the use of both the above-mentioned current transformers and protections based on them, from which they receive information. As an alternative, it is possible to consider protections on another element base - various magnetosensitive elements, such as Hall sensors, magnetoresistors, magnetodiodes, magnetotransistors, inductance coils, Rogowski coils and reed switches [6–13]. One of the most priority ways to build relay protection devices without current transformers with metal cores is the use of reed switches, which have advantages over other similar magnetosensitive elements [14–15].

Analyzing the published literature on the subject, it should be said that microprocessor-based relay protection devices are now widely introduced and used, the reliability of which is not higher than that of electromechanical or semiconductor devices. These devices are, among other things, vulnerable to hacker cyberattacks from the outside. These devices are powered by the aforementioned current transformers, which, for example, in combination with microprocessor-based devices, have a significant overall price tag.

In recent decades, a number of protections have been developed, the action of which is based on the actuation of a reed switch, installed near the current-carrying busbars of the electrical installation, from the magnetic field arising during a short circuit and creating a magnetomotive force sufficient for its actuation. Designs have also been developed to install reed switches and inductance coils inside the cells of complete switchgear [16–20]. These and other developments offer a completely new approach to the selection of element base and design of relay protection.

In this article as an alternative to traditional protections for various electrical installations are presented protections made with the use of reed switches and inductive coils. In the protections presented in this paper the effect of resource saving is undoubted, as such protections are tens and hundreds of times cheaper in cost and smaller in weight and dimensions than traditional protections with the mentioned measuring current transformers with metal cores.

II. MATERIALS AND METHODS

As is well known, overcurrent protection is triggered when the short-circuit current of the protected electrical installation exceeds its set maximum operating current. The overcurrent protection reacts to this short-circuit current by disconnecting the switchgear panel and thus the protected installation from the general electrical network. One of the alternative ways to

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detect such faults is the use of inductive coils and reed switches, instead of traditional current transformers with metal cores. In this connection it is necessary to consider the possibility of realization of current protections made on reed switches and inductive coils for protection of various electrical installations with voltage of 6-10 kV.

III. Principle Circuit of the Reed Switch Current Protection

After reed switch actuation (its open contacts close), a signal (positive potential from a supply source) from its contacts passes through a two-phase circuit shown in Fig. 1 [13,19]. A two-phase two reed switch circuit means that reed switches functioning as supervisory and executive bodies are mounted in front of two current-carrying phases A and C. The reed switch protection responds to all phase-to-phase sort circuits, both two– (AB, BC, and AC) and three–phase (ABC).

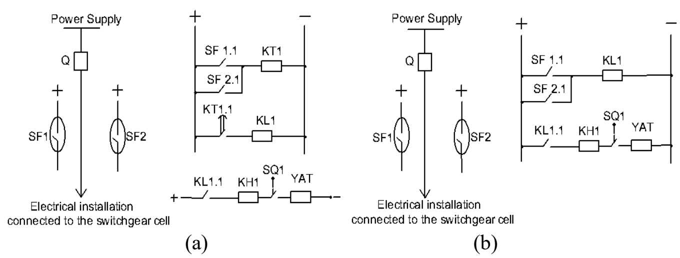

Fig. 1. Diagram of a two-phase two reed switch protection: (a) time delay overcurrent protection; (b) instantaneous overcurrent protection.

The presented current protection functions as follows. It operates under the effect of a magnetic flux F produced by the current in the busbars acting on reed switches SF1 and SF2 (Fig. 1). This device can be mounted in switchgear cells of 6–10 kV in voltage and a closed-type switchgear of 35–110 kV in voltage at the point where the magnetic flux F is maximal. The device functions as an overcurrent protection and a current cutoff.

If a short circuit occurs in electrical installations connected to cells of a 6–10 kV switchgear and a 35–110 kV closed-type switchgear, the current in the current-carrying busbars of a cell increases and the magnetic flux also becomes greater than under the protection operation current. Therefore, reed switches SF1 and SF2 mounted at a safe distance (at least 120 mm) from their current-carrying buses A and C, according to the Rules for Electrical Installation Mounting, respond to the change in the magnetic field the MMF of the reed switches is adjusted to [21]. This is a fundamental factor when designing a current protection based on reed switches.

When this device functions as an overcurrent protection, a voltage equal to, e.g., U = 220 V from a current source (not shown in the diagram) is supplied to the first output of the winding of time relay KT1 from contacts SF1.1 or SF2.1 of reed switch SF1 or SF2 when it actuates (Fig. 1a). Relay KT1 operates, and its contact KT1.1, with a time delay of, e.g., 0.02 s, sends positive potential, arrived from a DC source, to the first terminal of the coil of intermediate relay KL1. Relay KL1 actuates and supplies positive potential through its contact for closing KL1.1 and to indicating relay KH1 through limit switch SF1 to the first terminal of trip coil YAT of the cell breaker. As a result, the protected electrical installation is switched off. The operation of the overcurrent protection is fixed by indicating relay KH1. The second terminal of the winding of time relay KT1, intermediate relay KL1, and the trip coil YAT of the cell breaker are connected to the negative pole of the DC source.

When the device functions as a current cutoff, the voltage U = 220 V from the current source is supplied to the first terminal of the coil of intermediate relay KL1 from contacts SF1.1 or SF2.1 of reed switch SF1 or SF2 when it actuates (Fig. 3b). Intermediate relay KL1 activates and supplies positive potential with the help of its closing contact KL1.1 to indicating relay KH1. From this relay, positive potential is supplied through limit switch SF1 to the first output of trip coil YAT of the switchgear cell breaker. As a result, the protected electrical installation connected to the cell is switched off. The operation of the current cutoff is fixed by indicating relay KH1. The second terminal of the coil of intermediate relay KL1 and trip coil YAT of the cell breaker are connected to the negative pole of the DC source.

Current which flows through the protected electrical installation connected to the switchgear cell under the rated load mode does not exceed its maximal operating current [17,18]. Reed switches SF1 or SF2 are affected by a magnetic field, the induction of which is insufficient to trigger the current cutoff and overcurrent protection.

IV. Resource-Saving Overcurrent Protection Device

This device contains a start button 1 with the first 2 and second 3 closing contacts and with the third 4 and fourth 5 opening contacts (Fig. 2a) [19]. It also includes reed switch 6 with control winding 7 and with closing contact 8, inductive coil 9, current-carrying bus 10, constant operating current source 11 with positive and negative poles, intermediate relay 12 with control winding 13 and with first 14 and second 15 closing contacts, time relay 16 with a control winding 17 and with a time delay contact for closing 18, voltage amplifier (A) 19, signal lamp 20, alternating current source 21 with the first and second terminal, circuit breaker trip coil (YAT) 22 (Fig. 2 b). The first core 23 of the closing contact 8 of the reed switch 6, as well as the first lead of the closing time contact 18 of the time relay 16 is connected to the potential "+" of the constant operating current source 11. The first lead of the control winding 17 of the time relay 16 is connected to the second core 24 of the closing contact 8 of the reed switch 6.

The second lead of the contact with a time delay on closing 18 of the time relay 16 is connected to the first lead of the control winding 13 of the intermediate relay 12, the first leads of the first 14 and the second 15 contacts for closing which are connected to the potential "+" source of direct operating current 11, and to the second leads of these contacts 14 and 15 are connected through the second closing 3 and fourth opening 5 contacts of the button "Start" 1 the first lead of the signal lamp 20 and trip coil (YAT) 22 of the switch. The control winding 7 of the reed switch 6 is connected to the output of the

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voltage amplifier (A) 19, to the first input of which is connected to the first lead of the inductive coil 9, in front of which is installed the first opening contact 4 of the "Start" button 1, also with parallel in this circuit is connected the first lead of the alternating current source 21, which supplies the first phase signal through the first closing contact 2 of the "Start" button 1 [20]. To the second input of the voltage amplifier (A) 19 is connected the second lead of the inductance coil 9, in whose circuit is connected in parallel the second lead of the alternating current source 21, which supplies the second phase signal continuously. The second lead of the control windings 13 and 17 of the intermediate relay 12 and the timer relay 16 and the trip coil (YAT) 22 of the circuit breaker, as well as the second lead of the signal lamp 20 are connected to the potential "-" of the constant operating current source 11.

The device works as follows. The principle of operation of the device is based on the effect of magnetic flux F (shown by arrows), created by the current in the current-carrying bus 10 on the inductive coil 9 (Fig. 2b). Voltage amplifier (A) 19 amplifies the voltage taken from the terminals of the inductive coil 9 to the desired value.

In normal operation, when the maximum load current flows in the current-carrying bus 10, the value of the voltage applied to the inductive coil 9 is insufficient and, accordingly, no signal from the inductive coil 9 is received at the input of the voltage amplifier (A) 19.

In the event of a short circuit in the protected electrical installation, the current in the current-carrying busbar 10 increases, and the inductive coil 9 reacting to the change in the induction of the magnetic field induces an increased voltage value. Because of the fact that this value of voltage U, taken from the terminals of the inductance coil 9 is small (about 3-5 V), it is increased by a voltage amplifier (A) 19 to U = 220 V. and is fed to the control winding 7 reed switch 6 (Fig. 2b). As a result, a magnetic flux F is created in the control winding 7 of the reed switch 6, acting on it. This reed switch 6 actuating closes the first 23 and the second 24 contact cores and sends potential "+" from the source of direct operating current 11 to the first terminal of the control winding 17 of the time relay 16. Then the contact with time delay on closing 18 of the time relay 16 counting the time delay equal to 0,02 s. triggers and supplies to the first terminal of the control winding 13 of the intermediate relay 12 the potential "+" from the source of direct operating current 11. Intermediate relay 12 triggering closes the first 14 and second 15 contacts, with the potential "+" from the second contact to close 15 comes through the fourth disconnecting contact 5 of the button "Start" 1 to the first lead of the trip coil (YAT) 22 of the circuit breaker. As a result, the protected electrical installation is disconnected (Fig. 2).

At a short circuit on the outgoing connections from the circuit breaker 6, the current flowing through the rod 5 exceeds the current triggering protection, and given that the value of the voltage removed from the coil terminals 2, 3, 4 has a maximum value of 5V, it is increased by a voltage amplifier 7 to a value equal to U = 220 V and is fed to the outputs of the winding 8 relay, 9 (Fig. 2b, c). As a result, the relay 9 triggers the contact with time delay on closing 10, equal to 0,02s. and sends potential "+" coming from the source of direct current 16 to the first terminal of winding 11 of relay 12. The intermediate relay 12, having tripped, supplies the potential "+" through its closing contact 13 to the first terminal of the indicating relay 14, and for it to the input of the trip coil 15 of the circuit breaker of the electrical installation. As a result, the protected electrical installation is disconnected (Fig. 2c).

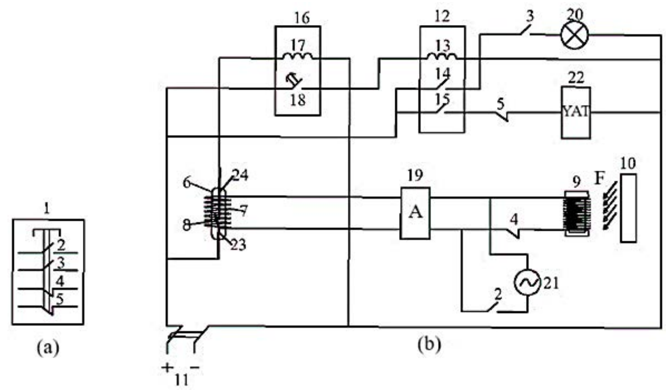


Fig. 2. Principle diagram of resource-saving overcurrent protection device

In order to exclude failure of the device operation, its serviceability is monitored by means of a test signal - by briefly pressing the "Start" button 1, at that its first 2 and second 3 contacts close, and the third 4 and fourth 5 contacts open. When contact 2 of this button 1 is closed, the first phase signal is supplied, and the second phase signal comes continuously from the alternating current source 21 to the input of the voltage amplifier (A) 19. The signal output from the voltage amplifier (A) 19 goes to the control winding 7 of the reed switch 6. As a result, this reed switch 6 triggering closes its first 23 and second 24 contact cores closing contact 8 between themselves and coming from the source of direct operating current 11 potential "+" through them comes to the first terminal of the control winding 17 of the time relay 16.

Contact with a time delay on closing 18 timer relay 16 counting time delay equal to 0.02 s. triggers and the output signal from it goes to the first terminal of the control winding 13 of the intermediate relay 12, which closes its first 14 and second 15 contacts, transmitting through the second closing contact 3 of the "Start" button 1 an impulse to the first terminal of the signal lamp 20, which lights up signaling the serviceability of this device. In this scheme, when pressing the same button "Start" 1, when opening the third contact 4, the signal from the inductive coil 9 to the voltage amplifier (A) 19 is not received, and when opening the fourth contact 5 there is no signal coming from the potential "+" of the source of direct operating current 11 to the first lead of the trip coil (YAT) 22, as a result of which the switch of the electrical installation remains on all the time.

Fault diagnosis of the device is performed by pressing the "Start" button 1 when receiving the duty shift by the substation (power station) operating personnel, or taking into account the load graph of the connected electrical installation - during its minimum period. The device with the use of inductive coil allows to realize overcurrent protection with diagnostics of its elements fault by means of test signal supply, without using bulky weight and dimensional parameters and expensive cost current transformers with metal cores, that as a result gives the possibility of device realization for realization of overcurrent protection for any electrical installations.

V. Current Protection Device

The current protection device contains a reed switch 1 with switching 2, closing 3 and opening 4 contacts [19]. The device also includes the control winding 5 of the reed switch 1, current-carrying bus 6, constant operating current source 7, control unit 8, first 9, second 10 and third 11 indicating relays, first 12 and second 13 time relays, first 14 and second 15 intermediate relays, trip coil 16 of the switch of the electrical installation and opening contact 17 of the second intermediate relay 15 (Fig. 3).

The device operates as follows. In normal operation mode, the reed switch 1 does not actuate the closing contact 3, because it is configured not to actuate when the maximum load current of the electrical installation flows in the conductive busbar 6. Therefore, the current protection does not operate and there is no signal at the output of the first time relay 12.

In case of a short circuit in the protected electrical installation of the reed switch 1 under the action of the current flowing in the conductor busbar 6 is greater than the maximum current, simultaneously actuate the opening contact 4 and closing contact 3, with the closing contact 3 gives a signal to the input of the first time relay 12 (Fig. 3). The first time relay 12, having tripped, counts down the time delay equal to 0.02 s and gives a signal to the input of the first intermediate relay 14. This relay 14 having tripped, through the opening contact 17 of the second intermediate relay 15 signals through the second indicating relay 10 to the trip coil 16 of the circuit breaker of the electrical installation. When the opening contact 4 of the reed switch 1 is actuated, the first indicator relay 9 is actuated due to loss of power. The first 9 and the second 10 indicating relays signal the operation of the protection to the service personnel, and as a result, the protected electrical installation is disconnected. In this case, if after that the first indicator relay 9 does not return to the initial state - does not fall out blinker "On", it indicates sticking switching 2 and closing 3 contacts of reed switch 1, and service personnel need to replace this reed switch 1 for a serviceable one.

In order to ensure reliable operation of the current protection device, its serviceability is continuously monitored by means of a test signal. This control is performed by means of the control unit 8. This block 8 contains a microprocessor (not shown in the drawing), which, with the help of a program written in it, carries out with a preset time delay (90 s.) the supply of direct operating current to the control winding 5 of the reed switch 1. After that, the closing 3 and opening contact 4 of the reed switch 1 are triggered (the test signal appears). At the same time trigger the first pointer 9 (because it loses power) and the second intermediate relay 15, powered from the control unit 8, this relay 15 opens its contact 17, as a result, the trip coil of the circuit breaker 16 does not receive a signal to trip. When the closing contact 3 of the reed switch 1 triggers the first time relay 12 with a time delay equal to 0.02 s, then the output signal from this time relay 12 goes to the first intermediate relay 14, it triggers and signals the second time relay 13, which has a time delay equal to 0.03 s. This second time relay 13, having tripped, gives a signal to the third indicating relay 11, signaling the operation of the self-diagnostic circuit of the device to the service personnel. If any element of the device is damaged, the output of the first intermediate relay 14 has no test signal and the third indicating relay 11 does not operate.

If at the same time the indicating relay 11 does not return to the initial state - the blinker "On" has fallen out, it indicates sticking of the switching 2 and closing at 3 contacts of the reed switch 1. In the case of not turning on the first time relay 12 and the first intermediate relay 14, it indicates the 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 blinkers of the first 11, second 12 and third 13 indicating relays replace the failed reed switch 1 for a serviceable one.

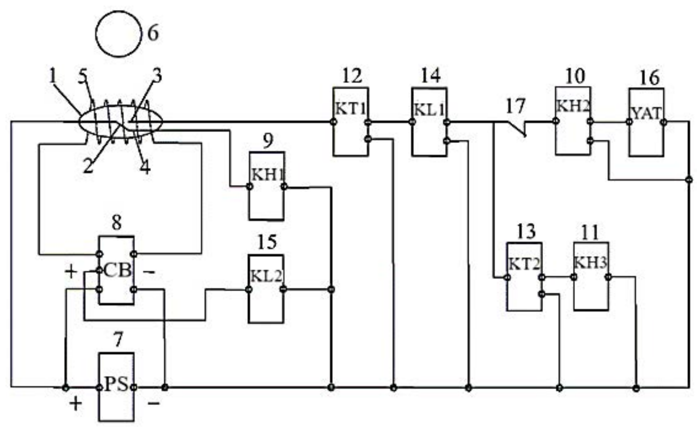


Fig. 3. Functional diagram of the current protection device

The current protection device makes it possible to carry out remote control of its operability by means of automatic transmission of a test signal with simultaneous monitoring of the sticking of the reed switch contacts; corresponds to relay protection issues such as cyber security: complete non-conformity to cyber attacks, due to lack of Internet connection; does not use bulky weight and expensive current transformers with metal cores, which makes it possible to use this device for current protection of any electrical installation.

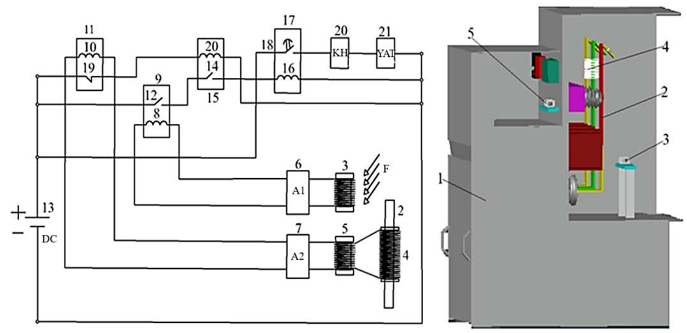
VI. Alternative over Current Current Protection of Electrical Installations with Minimum Voltage Blocking

Principle of operation. Considering the short-circuit mode on the protected electrical installation connected to the cell 1 complete switchgear, series K-63 it should be said that the main factor is the impact of magnetic flux F (shown by arrows), created by the current of the current-carrying busbar 2 on the first 3 and second 4 inductance coils, and the second coil 4 has primary and secondary windings, wound on the current-carrying busbar 2 and performs the function of a measuring voltage transformer, by analogy, as in the usual conventional protection [18, 20]. At the same time, the secondary voltage is removed from the secondary winding of the second coil 4 and fed to the third inductance coil 5 (Fig. 4 a). This device is a protection set, which can be installed in the cells of a complete switchgear, closed switchgear, in closed current conduits and can be mounted as a separate set for each phase. The first inductance coil 3 is installed opposite the current-carrying busbar 2 and in the place where there is a maximum value of magnetic flux (Fig. 4 b). The first 3 and the third 5 inductance coils are installed on a dielectric base in the cell 1, series K-63, with the first coil 3 in the cable compartment and the second coil 5 in the relay cabinet of the cell. In the event of a short circuit in the protected electrical installation, the current in its current-carrying busbar 2 increases, and the first 3 and second 4 inductance coils react to changes in the magnetic field, whereby the first inductive coil 3 is installed at a safe distance equal to 12 cm. from the given busbar 2 according to the Rules for Electrical Installations [21].

As a result, an electromotive force is induced in the first inductive coil 3 and on the secondary winding of the second inductance coil 4, which is fed to the third inductance coil 5 (Fig. 4 a, b).Due to the fact that the values of the removed electromotive force from the terminals of the first 3 and second 4 inductance coils have small values, of the order of 3 and 1V, they are increased by means of the first voltage amplifier (A1) 6 to 220V, and by means of the second voltage amplifier (A2) 7 to a value equal to U=100V. After that, these voltage values from the first voltage amplifier 6 are fed to the winding 8 of the first intermediate relay 9, and from the second amplifier 7 to the winding 10 of the minimum voltage relay 11 (Fig. 4 a). As a result, the first intermediate relay 9 triggers the closing contact 12, sending the potential "+" coming from the DC source 13 to the closing contact 14 of the second intermediate relay 15, from which this potential "+" comes to the winding 16 of the time relay 17. Afterwards, the positive potential of the "+" pole of the DC source 13 goes to the time delayed closing contact 18 of the time relay 17. In this case, simultaneously with the first intermediate relay 9, the minimum voltage relay 11 is actuated, at which the contact 19 opens, as a result of which the winding 20 of the second intermediate relay 15 loses power and this relay is actuated. From the contact with a time delay on closing 18 of the time relay, 17 positive potential "+" pole of the DC source 13 goes to the indicating relay (KH) 20, which triggers the potential "+" to the first lead of the trip coil (YAT) 21 of the circuit breaker of the electrical installation. As a result, the protected electrical installation is disconnected (Fig.4 a). The second output: windings 20 of the second intermediate relay 15; windings 16 of the timer relay 17 and trip coil (YAT) 21 are connected to the "-" pole of the DC source 13 (Fig.4 a).

In normal operation, connected to the cell 1 of the complete switchgear electrical installation, the parameters in the first 6 and second 7 voltage amplifiers are adjusted so that they are triggered only when the voltage at their terminals equal to 3 and 1 V, and at voltage values less than these, the alternative maximum current protection to disconnect the electrical installation is not triggered.

Advantages of the device. The absence of the use in this protection of current and voltage measuring transformers with metal cores, which contain expensive steel, copper and high-voltage insulation, as well as significant weight and dimensional parameters, meets the actual issue of relay protection - resource saving of the materials used and is one of the alternative ways of realizing the maximum current protection, performed with the use of inductive coils.



(a) (b)

Fig. 4. Alternative overcurrent protection with minimum voltage blocking: (a) structural diagram; (b) placement of its elements in the cell of a complete switchgear cubicle

VII. Conclusions

The conducted research on the application of resource-saving current protection devices for electrical installations connected to the cells of the complete switchgear has shown the possibility of creating new resource-saving current protection on inductive coils and reed switches. They meet the requirements of relay protection, while having the effect of resource-saving materials used. The developed devices have shown their efficiency, as the protection reacts to all types of inter-phase short circuits (two-phase and three-phase), which take place in electrical installations connected to the cells of switchgears. It is recommended to install the developer resource-saving current protection devices for protection of electrical installations with voltage U=6–10 kV, connected to the cells of complete switchgears.

Environmental effect, which consists in saving both the extraction of non-ferrous and ferrous metals from the earth's surface and their further processing at metallurgical plants. As a result, the load on power generation by power plants and on non-ferrous and ferrous metal consumption in the production of traditional measuring current transformers is simultaneously reduced. The tasks of environmental protection and reduction of harmful emissions of production are solved; reduced, or even complete absence of heat and power consumption for the production of traditional current transformers due to their uselessness for power supply of relay protection devices. At the same time, the emission of harmful substances into the air atmosphere of the planet decreases and as a result, various human pathologies and diseases related to ecology are reduced. At the same time, the number of healthy and able-bodied population increases, which is undoubtedly a powerful personnel and social effect.

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References

[1] A. F. Dyakov, “Electric power industry in the world at the beginning of the XXI century,” based on the materials of the 39th session of CIGRE, Paris, Energy abroad, 4-5, pp. 44–45, 2004..

[2] V. E. Kazansky, Current transformers in relay protection circuits. - Moscow: Energiya, p.184, 1969, [Online] Available: https://www.studmed.ru/kazanskiy-v-e-transformatory-toka-v-shemah-releynoy-zaschity_c5273ca1e5e.html

[3] Sverdlovsk Plant of Current Transformers. [Online] Available: https://www.cztt.ru/catalog/transformatory-toka/transformatory-toka-naruzhnoy-ustanovki/opornye1/10-kv-1/tol10iii/

[4] J. V. Andreev, “Relay protection and automatics of power supply systems,” 4th ed.; Higher School: Moscow, Russia, 2008, p. 608, [Online] Available: https://www.elec.ru/library/nauchnaya-i-tehnicheskaya-literatura/andreev-relejnaya-zashita/

[5] E. M. Shneerson, Digital relay protection, Moscow: Energoatomizdat, 2007, https://www.elec.ru/library/nauchnaya-i-tehnicheskaya-literatura/cifrovaya-relejnaya-zashita/

[6] V. Gurevich, Electrical relay. Device, principle of operation and application, SOLON-PRESS, p. 688, 2011, https://www.elec.ru/library/nauchnaya-i-tehnicheskaya-literatura/gurevich-elektricheskie-rele/

[7] A. Kobus, and J. Tushinsky, “Hall sensors and magnetoresistors,” per. from Polish V.I. Tikhonova, K. B. Makedonsky; ed. O. K. Khomeriki, Moscow: "Energy", 1971, https://www.studmed.ru/kobus-a-tushinskiy-ya-datchiki-holla-i-magnitorezistory_08ef7f3d7b0.html#google_vignette

[8] G. I. Kotenko, Magnetoresistors, L: Energy, 1972, https://www.studmed.ru/kotenko-gi-magnitorezistory_3bed601fad0.html (accessed on 10 February 2024).

[9] G. A. Egiazaryan and V. I. Stafeev, Magnetodiodes, magnetotransistors and their applications, Moscow: Radio and communication, 1987, https://rusneb.ru/catalog/010003_000061_95d9b22e8ac5758361f9267d39c39f9d/

[10] I. M. Sirota, Schemes of induction measurement of currents in three-phase high-voltage circuits, Moscow: Electricity, №4, pp. 22–24, 1967, https://www.booksite.ru/elektr/1967/1967_4.pdf

[11] 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, 2009, http://retro-rzia.ru/up/konferencii/RZA_2009/04_RZA_s_datchikami_toka_Rogovskogo.pdf

[12] L. A. Kozhovich and M. Bishop, “Modern protection relay with current sensors based on the Rogowski coil,” Modern trends in the development of relay protection and automation of power systems, in: Proc. CIGRE, Moscow, Sept. 7–10, 2009. https://energyland.info/files/library/092009/2ff8a8be3a4831831f87f66415086f7f.pdf

[13] 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, [Online] Available: https://search.rsl.ru/ru/record/01004905317

[14] D. D. Issabekov, “Multipurpose power system protection set that provides constant remote serviceability control,” Collection of Papers of 2022 International Conference on Industrial Engineering, 2022. pp. 35–39. doi: 10.1109/icieam54945.2022.9787128

[15] D. D. Issabekov, “Resource-saving protections of power transformers against internal faults,” E3S Web of Conferences 434, 01041, ICECAE, pp. 35–39, 2023. [Online] Available: https://doi.org/10.1051/e3sconf/202343401041

[16] D. Issabekov and S. Issenov, Alternative Resource-Saving Current Protections for Electric Motors, Proceedings - 2024 International Russian Smart Industry Conference, SmartIndustryCon 2024, 2024, pp. 19–24, DOI: 10.1109/SmartIndustryCon61328.2024.10515681

[17] K. I. Doroshev, Complete switchgears 6-35 kV, Moscow: Energoizdat, p. 376, 1982, [Online] Available: https://www.elec.ru/library/nauchnaya-i-tehnicheskaya-literatura/doroshev-kru-6-35-kv/

[18] Complete distribution device with voltage 6-10 kV. KRU K-63, Technical information, Open public association Siberian plant “Electroshield”, Novosibirsk, 2015, [Online] Available: https://sibelz.ru/wp-content/uploads/2019/03/KRU_K-63-tehnicheskaya-informatsiya.pdf

[19] Joint Stock Company “Ryazan Plant of Metalloceramic Devices” [Online] Available: www.rmcip.ru, http://www.rmcip.ru/reeds/product/id/19, http://www.rmcip.ru/files/catalogue/mka_502021.pdf

[20] Relay MKU–48. JSC “Irkutsk Relay Plant,” [Online] Available: https://irzirk.ru/catalog/element/rele_mku_48s_ra4500136_ra0450002_tu/

[21] 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, № 230, 2015, [Online] Available: https://adilet.zan.kz/rus/docs/V1500010851

[22] Voltage regulator with digital display. [Online] Available: https://satu.kz/p99283690-regulyator-napryazheniya

[23] Product catalog Joint Stock Company „Cheboksarsky Electroapparatny Zavod,” Joint Stock Company. [Online] Available: https://shop.cheaz.ru/catalog/163/36699/

[24] Time relay ST3PR (RVL-22D) AC220V. Characteristics and description. [Online] Available: https://satu.kz/p66421479-rele-vremeni-st3pr.html

[25] MiCOM P120/P121/P122/P123 Schneider Electric maximum current relay, [Online] Available: https://www.se.com/kz/ru/download/document/P12x_RU_T_G86/.

[26] N. D. Rogalyov, A. D. Zubkova, et. al. Economics of Power Engineering, Textbook for Universities, MPEI Publishing House, Moscow, 2005.

[27] S. L. Kuzhekov, P. I. Okley, and G. S. Nudelman, “Analysis of a set of requirements to relay protection in order to assess its efficiency,” Electric power stations 2, pp. 43–48, 2010.