2024 International Ural Conference on Electrical Power Engineering (UralCon)

Alternative Protections on Inductance Coils

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***Abstract*—In the article the authors present the principle of operation of alternative maximum current protection (MCP) and protection against power cable earth faults. The purpose of these protections is the protection of high-voltage electrical installations, voltage 10-35kV from short circuits. These protections are performed without the use of current relays and current transformers (CTs) with metal cores widely used in the electric power industry, which have significant weight and dimensional parameters and high price cost. The proposed protection is made with the use of inductive coils, which have a number of known advantages for relay protection in comparison with CTs and other magnetosensitive elements and the possibility of their installation in the magnetic field created by the current-carrying busbar of the cell of the complete switchgear and closed switchgear. Protections with their application can be used instead of traditional current protections for various electrical installations, but at the same time by their technical and economic characteristics are not inferior to them. To expand the range of relay protection, the presented protections characterize an innovative approach in relay protection by using inductance coils. The resource-saving nature of these protections lies in the use of inductive coils, which are, both in terms of cost and weight and dimensional parameters, an order of magnitude cheaper and smaller in size and weight than the aforementioned CTs. The proposed protections are carried out in the form of structures with their installation inside the cells of complete switchgears and closed switchgears, voltage 10 and 35 kV.**

Keywords—current protection, inductance coil, cell, resource saving

I. Introduction

The issue of resource saving in the electric power industry has been raised many times at international conferences on large power systems (CIGRE), remaining relevant for relay protection without the use of expensive and having significant weight and dimensional parameters of metal-intensive current transformers and current relays with metal cores [1–3]. In view of the fact that traditional current protections made both on electromechanical and microprocessor bases still use measuring current transformers with metal cores of their power supply, it is necessary to use alternative protections instead of these protections [4–5]. As an alternative to the application of CTs and corresponding protections, it is possible to consider the various magnetosensitive elements, such as Hall sensors, magnetoresistors, magnetodiodes, magnetotransistors, inductance coils and reed switches [6–13]. Works on creation of resource-saving current protections without CTs with metal cores have been carried out since the 60s of the last century [9–10]. To build relay protection of electrical installations without the above-mentioned CTs, the authors chose inductance coils [14]. They were chosen due to the fact that in comparison with other magnetosensitive elements they have the advantages that they can perform the functions of a measuring transducer, as well as the measuring body protection, have a low price cost and small weight-size parameters in comparison with CTs and current relays with metal cores. For the last decades, there is a number of developed current protections on inductance coils. This paper considers the principle of operation of alternative protections of 10 and 35 kV electrical installations, made in the form of devices.

II. Purpose of the Study

The aim of the research is to create alternative shields, instead of traditional current shields, to protect various electrical installations. Electrical installations can be power transformers, power lines and electric motors. Such protection is realized on inductance coils, without the use in its composition of measuring transformers of current and current relay with metal cores. The main factor is the elimination of the use of metal-intensive, cumbersome and expensive traditional measuring current transformers and current relays.

Main objectives: to achieve the goal, it is necessary to develop alternative shields, including differential ones, to protect various electrical installations.

III. Inductance Coils from Relay KL-25

Let's consider as an example the parameters of the inductance coil (winding without metal core) from a common intermediate relay, type KL-25 [15–16]. This inductance coil was used in the research and construction of alternative current protections.

Intermediate relay KL-25 Un~220V has found wide application in the schemes of relay protection, telemechanics and automation, working on alternating current, with voltage 220 V. Time of operation of the relay itself, from the moment of supply of nominal alternating voltage to the relay coil to the moment of closing of closing contacts - not more than 0,06 sec. Time from the moment of EMF appearance on the relay coil and from the moment of its detection on its terminals is 0,02 sec. The operating temperature range of the ambient air at which the inductance coil operates is from minus 20 to plus 55 °C. The coil of the intermediate relay KL-25 withstands 1,1 on for a long time. The environment is non-explosive, containing no conductive dust, aggressive gases and vapors in concentrations destroying the coil insulation. The place of

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installation of the inductance coil inside the switchgear cubicle is protected against splashes of water, oils, emulsions and other liquids, as well as against direct exposure to solar radiation. Developed alternative current protection devices based on inductive coils are presented below.

IV. Alternative Resource-Saving Current Protection

The realization of this protection is based on the tank circuit breaker, type C-35-630-10 [17]. For electrical installations with nominal voltage U = 35 kV. it is necessary to develop a design of maximum current protection, installed inside the tank circuit breaker and allowing longitudinal and transverse movement of inductance coils, thereby realizing the choice of protection settings, by adjusting the distance from the inductance coils to the current-carrying rod of the circuit breaker. Maximum current protection, presented as a structure, contains a plate 1 on the outer side of which three inductance coils 2,3,4, current-carrying rod 5 of the circuit breaker 6 are fixed (Fig. 1a, b). The outputs of coils 2, 3, 4 are connected to the input of the voltage amplifier 7, and the output of the amplifier 7 is connected to the winding 8 of the time relay 9, to the contact for closing 10 with a time delay which is connected to the winding 11 of the intermediate relay 12, the contact for closing 13 of the relay 12 is connected to the input of the indicator relay 14 (Fig. 1c). The output of the indicator relay 14 is connected to the input of the trip coil 15 of the circuit breaker 6 of the electrical installation. The output of the trip coil 15 of the circuit breaker 6 is connected to the minus potential of the DC source 16. The plate coils 1 is fixed inside the casing 17, which in its upper part is fixed to the central axis 18, and on the sides by means of lugs 19 to the side axes 20 (Fig.1a). The central axis 18 is rigidly connected to the first end of the rotating shaft 21. The side axles 20 in the upper part are attached to the cover 23 of the switch 6 (Fig. 1b) by means of bushings 22. On the cover 23 for fastening and fixing of the cover 17 there is a first strip 24 with a longitudinal hole 25, the second strip 26 is located in the first 24, on the second end of the rotating shaft 21 there is a valve 27. A handle 28 is mounted on the second strip 26. Horizontal 29 and vertical 30 scales are arranged on the first bar 24. Inlets of the casing 17 and the first strip 24 are sealed with gaskets 31 (Fig.1, a). Current protection works as follows. To select the required tripping set point, transverse or longitudinal movement of the plate 1 coils 2,3,4 relative to the rod 5 (Fig.1a, b) is carried out. In this case, one of the coils is used for one protection, the other two coils are necessary for realization of other protections, for example, maximum current protection with a different time delay or current cutoff. Longitudinal movement of the plate 1 coils relative to the rod 5 is carried out by turning the valve 27 clockwise or counterclockwise, while the plate 1 coils moves up or down relative to the cover 23 of the circuit breaker 6 (Fig. 1a, b). Transverse movement of the same plate 1 coils relative to the rod 5 is carried out by moving the second bar 26 by means of the knob 28 along the longitudinal hole 25, thereby bringing the coils closer or farther away relative to the rod 5. The required distance from the plate 1 coils 2, 3, 4 at its longitudinal or transverse movement relative to the rod 5 is determined by the horizontal 29 and vertical 30 scales applied to the first bar 24 (Fig. 1a).

Before installing the design of current protection in the tank of the circuit breaker 6, the necessary hole in the first bar 24 is drilled in its cover 23 (Fig. 1b). Through this hole, enter the casing 17 with the plate 1 coils 2,3,4 installed inside it, and then fix the first bar 24 on the cover 23 itself (Fig.1a, b). At the same time, the necessary distance from the rod 5 to the coils 2,3,4 and the angle at which they should be located in relation to the magnetic field force lines created by the current in the current-carrying rod 5 are also calculated. The casing 17 with the plate 1 installed inside it is installed parallel to the rod 5 and is located in the upper part of the switch tank 6. In normal operation mode, the current flowing through the stubble 5 does not exceed the normal operating value and the magnetic field acts on the coils 2,3,4, the induction value of which is insufficient for them to produce a voltage value equal to 5V and in this regard, the current protection does not trip (Fig. 1b).

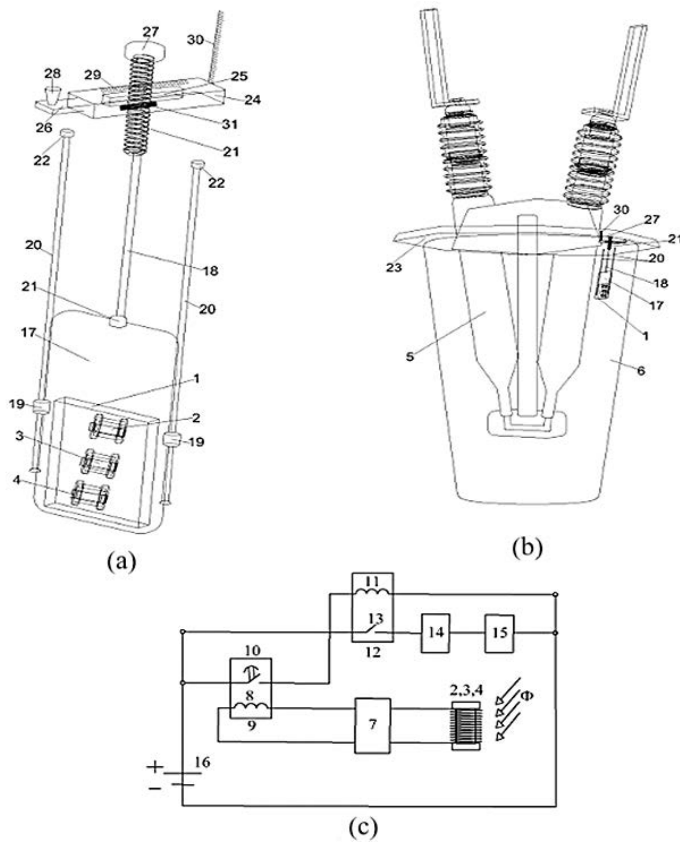
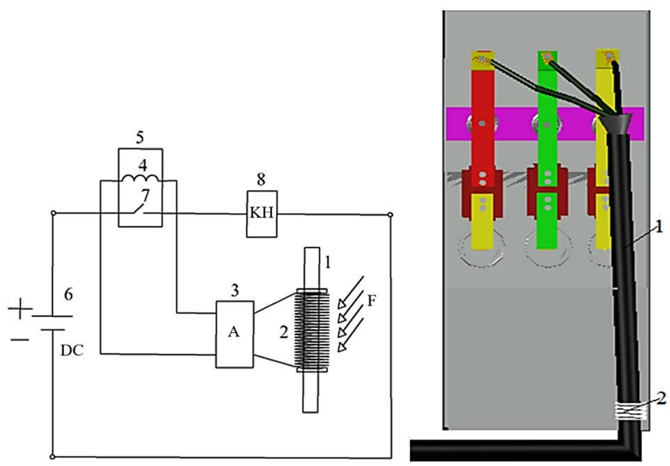


Fig. 1. Alternative resource-saving current protection: (a) design; (b) location of the current protection structure inside the circuit breaker tank; (c) structural diagram of current protection

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. 1b, 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. 1c).

V. Alternative Resource Saving Protection from Ground Closures

The principle of operation of this protection is based on the impact of magnetic fluxes F, created by the current that takes place when the power cable 1 (connecting the cell of the complete switchgear with the electrical installation) is shorted to earth and flows through one of its current-carrying conductors to the winding 2, wound closely on this cable 1, on its outer side (Fig. 2 a). Winding 2, winding on the power cable 1 is installed in the cell of the complete switchgear in the same place where the traditional cable current transformer with a metal core was installed, only instead of it (Fig. 2 a, b). This example shows the placement of winding 2, wound on the cable 1 in the cable compartment of the cell of the complete switchgear, series K-63 [18].



(a) (b)

Fig. 2. Alternative resource-efficient protection against earth faults: (a) structural diagram; (b) placement of winding 2 around the power cable 1, in the cable compartment of the complete switchgear cell.

When power cable 1 is shorted to ground, the current one of its conductors increases, as a result of which winding 2 reacts to changes in the magnetic field and an increased value of electromotive force is induced in it (Fig. 2a). Due to the fact that the value of this removed voltage from the terminals of winding 2 has a value of the order of 2 V, it is increased by means of a voltage amplifier (A) 3 to a value equal to U=220 V and is fed to the terminals of winding 4 of intermediate relay 5. As a result, the intermediate relay 5 is triggered and its contact 7 closes, giving the potential "+" coming from the DC source 6 to the indicating relay 8, which fixes the operation of protection against earth faults.

When flowing through the power cable 1 rated load current, as well as with three and two-phase short circuits in it, the parameters in the voltage amplifier 3 are adjusted so that it does not trip on the occurrence on its terminals of voltage values characteristic of these modes (different from 2V), but reacts only on the occurrence on its terminals of voltage equal to 2V. Accordingly, when the voltage value is different from 2V, this protection does not trip the electrical installation connected to the cell (Fig. 2a,b).

Advantages of the device. The absence of current relay and cable current transformer with metal cores in this protection, which are used in the traditional protection, which contain expensive copper and steel in their composition and also have significant weight and size parameters, meets the actual issue of relay protection - resource saving of used materials and represents a new approach in the implementation of ground fault protection for any electrical installations connected to the cell of the complete switchgear, in the form of an alternative to the traditional protection.

VI. Alternative Differential Protection of an Electric Motor

The design of differential protection of the electric motor contains inductance coils 1, consisting of the first and second groups: IC1-3 and IC4-6 (Fig.3a). The first group of inductance coils (IC1-3) 1 is located opposite the current-carrying busbars 2 in the busbar compartment 3 of the switchgear cell 4 and fixed by means of the first clamps 5 with the first screw-nut connection 6 on the plate 7 (Fig.3b, 4a). The second group of inductance coils (IC4-6) 1 is also located inside the electric motor 8 and is fixed by means of the second clamps 9 with the second screw-and-wrench connection 10 of the leads of its stator windings 11 (Fig.4b, c). To the six voltage amplifiers (A_1-A_6) 12 are connected the leads of inductance coils 1, and the voltage amplifiers 12 themselves are connected to the microcontroller (M) 13 (Fig.3b). The input of the microcontroller (M)13 is connected to the "plus" and "minus" poles of the circuit breaker 14, and to its output is connected the first lead of the winding 15 of the intermediate relay 16. To the closing contact 17 of the intermediate relay 16, connected to the "plus" pole of the circuit breaker 14, the first lead of the trip coil 19 of the circuit breaker 20 (Fig. 4a) is connected by means of the indicating relay 18 (Fig. 4a) [19]. Voltage amplifiers 12, intermediate relay 16 and indicating relay 18 are located in the relay cabinet 21 of the cell 4.

The construction operates as follows, with its elements installed according to the sequence described below. Inside the busbar compartment 3 of the cell 4, on the plate 7, in compliance with the minimum permissible distance according to the Rules for Electrical Installations, equal to 12 cm. (for electrical installations with voltage U=6-10 kV) fix by means of the first clamps 5 and with the help of the first screw-nut connection 6 the first group of inductance coils (IC1-IC3)1, located perpendicular to the plane of the cross-section of current-carrying busbars 2 (Fig.3a, 4a) [20]. To install the second group of inductance coils (IC4-IC6)3 inside the motor stator winding mountings 8 is fixed by means of the second clamps 9 and by means of the second screw-nut connection 10 to the leads of its stator windings11 (Fig.4b,c). For the input of the six voltage amplifiers (A_1-A_6)12 are connected to the outputs of the inductance coils 1, and the voltage amplifiers 12 are connected to the microcontroller (M)13 (Fig. 3b). The input of the microcontroller (M) 13 is connected to the "plus" and "minus" poles of the circuit breaker 14, and to its output is connected the first lead of the winding 15 of the intermediate relay 16. To the closing contact 17 of the intermediate relay 16, connected to the "plus" pole of the circuit breaker 14, the first lead of the trip coil 19 of the circuit breaker 20 is connected by means of the indicating relay 18 (Fig. 3b). Voltage amplifiers 12, intermediate relay 16 and indicating relay 18 are located in the relay cabinet 21 of cell 4 (Fig. 4a).

Before installing and fixing the inductance coils (IC1-IC6)1 opposite the current-carrying busbars 2 and on the leads of stator windings 11, they are installed in the points of maximum values of the magnetic field induced induced by each current-carrying busbar 2 and stator winding (on the leads) 11, as well as taking into account the convenience of placing the inductance coils 1 (Fig.4a, b). Further, the circuit breaker 14 is switched on and the potential "plus" is applied to the contact 17 of the intermediate relay 16 (Fig.3b).

The principle of operation of the claimed device is based on comparison of magnetic field induction values. The protected zone is the area between two groups of inductance coils (IC1-IC3 and IC4-IC6) 1 having the same parameters. The effect of magnetic fluxes F created by currents in current-carrying busbars 2 and in stator windings 11 on inductance coils (IC1-3 and IC4-6) 1 is shown by arrows (Fig. 3b). Voltage amplifiers (A_1-A_3 and A_4-A_6) 12 amplify the value of voltage taken from the terminals of inductance coils 1 to the required value.

At short circuit inside the protected electric motor 8, the current in its stator windings 11 increases and inductance coils 1 react to the change of magnetic field induction, i.e. an increased value of voltages is induced in them (Fig. 4b). Due to the fact that these values of voltages taken from the terminals of inductance coils 1 are smaller (not more than 2V), they are increased by means of voltage amplifiers (A_1-A_3 and A_4-A_6)12 up to the required value, maximum equal to U=220V (Fig.3b). In this case, the voltage amplifiers (A_1-A_3 and A_4-A_6)12 will have different values of voltage U_1 and U_2, for example, 180V and 210V, i.e. not equal to each other, because they are connected to different groups of inductance coils 1. The difference of the two voltage values is the basis for the action of the claimed motor differential protection device 8. These voltage values differ from each other in the same way as, for example, the current values in a conventional longitudinal differential protection. These voltage values are received by the microcontroller (M)13, which, according to the program loaded therein, processes them and outputs a "plus" signal to the first terminal of the winding 15 of the intermediate relay 16. Then relay 16, having triggered, gives the potential "plus" through its contact on closing 17 of the indicating relay 18, and with it this potential goes to the first lead of the trip coil 19 of the circuit breaker 20 (Fig. 4a). As a result, the protected electric motor 8 is disconnected from the mains (Fig.4c).

In normal operation of the protected electric motor voltage values A_1 and A_2 are initially set so that they coincide in magnitude, that is, they are equivalent and the circuit of this device does not react to internal short circuits within the current-carrying busbars 2 busbar compartment 3 cell 4 and stator winding 11 electric motor 8 (Fig. 4).

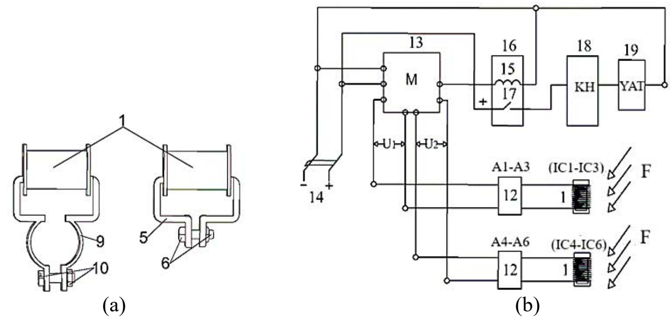


Fig. 3. Alternative differential protection of electric motor: (a) inductance coils with clamps; (b) structural scheme of differential protection

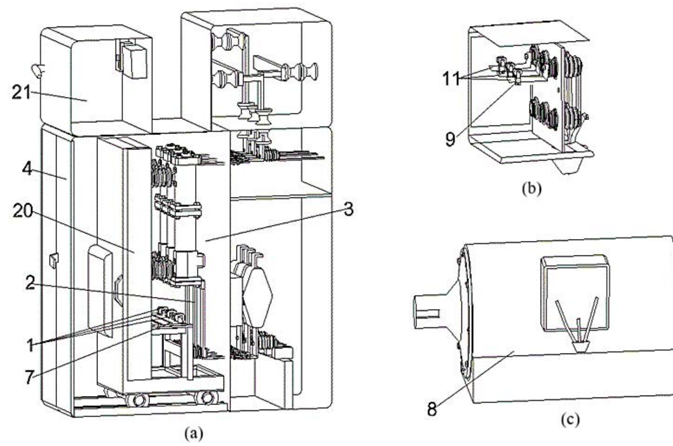


Fig. 4. Complete distribution cell and protected electric motor: placement of inductance coils in the busbar compartment of the cell (a) and inside the electric motor (b); protected electric motor (c)

VII. Alternative Current Protection

The construction of current protection contains a coil inductance 1, connected to a voltage amplifier (A)2, which amplifies the value of voltage taken from the terminals of the coil inductance 1 to the required voltage and connected to the winding 3 of the time relay 4, a source of direct current 5, from the pole "+" of which positive potential goes to the contact with a time delay on closing 6 of the time relay 4, to which is connected the first terminal of the winding 7 of the intermediate relay 8, the positive potential of the pole "+" goes to the contact on closing 9 of the intermediate relay 8, which in turn is connected to the first terminal of the indicator relay 10, and for it to the first terminal of the winding of the trip coil (YAT) 11 of the switch of the electrical installation. The second winding lead 7 of the intermediate relay 8 and the trip coil (YAT) 11 are connected to the pole "-" DC source 5 (Fig. 8).

The principle of operation of the construction is based on the impact of magnetic fluxes F (shown by arrows), created by current current busbar protected electrical installation of the inductance coil 1 (Fig. 5). This design is a set of protection, can be installed in the cells of the complete distribution and closed switchgear, as well as in closed current conduits, both for all three phases in one set, and for each phase of a separate set, in the place where there is a maximum value of magnetic fluxes.

When a short circuit in the protected electrical installation, the current in its current-carrying busbars increases and inductive coil 1, installed at a safe distance from these current-carrying busbars in accordance with the Rules of Electrical Installations reacts to changes in the magnetic field, and it is induced an increased value of EMF (Fig. 5). Due to the fact that the value of this voltage removed from the terminals of the inductance coil 1 has a value of about 5 V, it is increased by means of a voltage amplifier (A) 2 to a value equal to U = 220 V. This increased voltage is applied to the terminals of winding 3 of time relay 4. As a result, the closing contact 6 of this relay 4 is triggered, with a time delay equal to 0.02s. Further from this contact potential "+" coming from the source of direct current 5 comes to the first terminal of winding 7 of the intermediate relay 8. The intermediate relay 8, having tripped, sends potential "+" through its contact for closing 9 to the first lead of the trip coil 11 of the circuit breaker of the electrical installation. As a result, the electrical installation to be protected is disconnected. The tripping of the current protection is detected by the indicating relay (KH) 10.

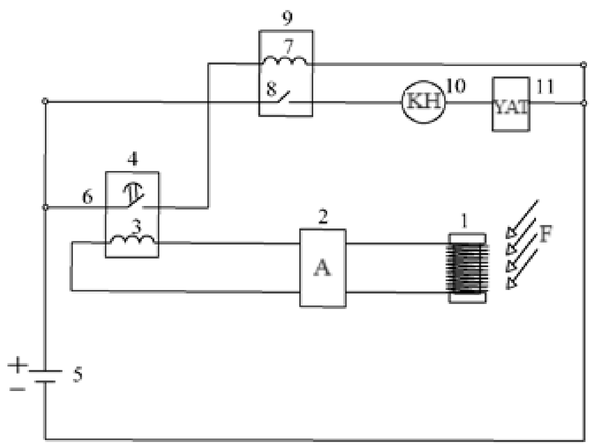


Fig. 5. Functional scheme of current protection

In normal operation of the electrical installation, the parameters in the voltage amplifier 2 are adjusted so that it is tripped only when the voltage exceeding 5 V appears on its terminals. If the voltage value is less than this, the current protection will not trip the installation.

Construction advantages. Absence of current relays and current transformers with metal cores, which contain expensive steel, copper and high-voltage insulation, as well as significant weight and dimensional parameters, meets the current issue of relay protection - resource saving. This construction is a completely new approach to the realization of current protection for various electrical installations with any class of rated voltage, realized on an inductive coil.

VIII. Conclusions

Alternative resource-saving current protections with the designs presented for their implementation, which do not use built-in and remote current transformers and current relays with metal cores, which have a high cost and weight-dimensional parameters, meet the current task of the electric power industry - saving the resources of the materials used. For example, the design of an alternative resource-saving current protection carries out longitudinal and transverse regulation of the distance from the inductive coils to the current-carrying rod, which makes it possible to select the settings of the protection settings and use it to implement the protection of electrical installations with a voltage of U = 35. kV.

«Alternative resource-saving current protection», «Alternative resource-saving current protection against ground faults», «Alternative differential protection of electric motors» and «Alternative current protection» have shown their effectiveness, since the protections respond to all types of short circuits, both phase-to-phase, single-phase, and inter-turn faults occurring in electrical installations connected to switchgear cells. The developed devices are recommended to be installed to protect electrical installations with voltage U=6, 10 and 35 kV, connected to cells of complete switchgears with voltage of 6-10 kV, as well as to cells of closed switchgears with voltage of 35 kV. Absence of use in such protections of remote and built-in traditional measuring current transformers with metal cores, possessing high price cost and weight-size parameters, meets the urgent issue of electric power industry - resource saving of used materials. This issue now and in the future has significant priorities in the electric power industry. All constructive elements of the investigated and considered alternative devices and protection constructions are made of lightweight and durable plastic, type "PLA", printed on a 3D printer and without the use of any metal parts.

The application of these protections will ensure:

In accordance with the strategically important task set by the international committee on large energy systems of CIGRE, according to which it is recommended to phase out the use of measuring current transformers with metal cores. The resource-saving effect consists in the reduction of costs for the realization of current protection, which eventually leads to an increase in the material income of the world power industry and the world community as a whole, by an amount greater than the initial cost of the layout of this protection;

The impact of the expected results on the development of the main scientific direction (relay protection and automation) and related areas of science and technology is the development of resource-saving relay protection without the use of traditional measuring current transformers.

Scientific and technical effect is that these protections are not inferior to the existing traditional current protections, made with the use of traditional measuring current transformers.

Economic effect:

- presented protections perform the functions of measuring current protection transformer, possessing resource saving, consisting in minimize initial material costs and subsequently in minimum annual costs of their operation;
- development of competitive relay protection of the future, reduction of production costs of such protection, namely, produced at stations and consumed electricity substations of enterprises, increase in labor

productivity, due to the reduction of time for the production of such protective devices in comparison with the cost and time spent on the creation of traditional current protection.

ACKNOWLEDGMENT

This research was funded by the Committee on Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant № AP14972954).

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