Alternative Power Transformer Protections

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***Abstract*—The paper proposes to consider the principle of operation of alternative protections of power transformers against external and internal short circuits, having the effect of resource-saving materials used. The purpose of the work is to build the protection of power transformers made on a different element base and without the use of measuring current transformers (CT) with metal cores. The protections made with the use of inductive coils, which in current protections are a perceiving and an executive body, are presented for consideration. Protections with their use can be used as an alternative to conventional protections of electrical installations with the above-mentioned measures current transformers. The main result is the consideration of the following transformer protections: maximum current protection, longitudinal differential protection and gas protection. It should be noted that protections using inductance coils represent a new approach to the realization of relay protection. They are characterized by simplicity of execution, minimum consumables, convenience of operation, without the use of current and gas relays, current and voltage transformers with metal cores, which contain expensive steel, copper, high-voltage insulation and have significant weight and dimensional parameters, which meets the urgent problem of the electric power industry - resource saving.**

Keywords—maximum current, differential and gas protection, transformer, inductance coil

I. Introduction

The construction of relay protection without traditional current transformers with metal cores, as repeatedly noted at CIGRE committee meetings, is considered to be one of the fundamental unsolved problems of the electric power industry. Creation of resource-saving relay protection devices for various electrical installations, including power transformers against short circuits without the use of expensive and having significant weight and dimensions, metal-intensive current transformers (CT) with metal cores, started in the second half of the last century, remains relevant to this day [1; 2; 3]. Analyzing the situation and published literature on the subject, it should be said that microprocessor-based relay protection devices are now widely introduced and used, whose reliability is not higher than that of electromechanical or semiconductor devices, and which, among other things, have the so-called vulnerability to hacker cyberattacks from the outside [4–5]. These devices are powered by the aforementioned current transformers, which, for example, in combination with microprocessor-based devices, have a significant cost.

Various magnetosensitive elements such as Hall sensors, magnetoresistors, magnetodiodes, magnetotransistors, inductance coils, reed switches and Rogowski coils can be considered as an alternative to the use of CTs and corresponding protections. One of the most priority ways to create relay protection devices without the above-mentioned CTs and current relays with metal cores is the use of magnetically controlled contacts - reed switches and inductance coils [6–12]. This is one of the promising directions of solving this problem and creates prerequisites for the creation of advanced relay protection based on reed switches and inductance coils [12–13]. The principles of construction and some models of such current protections have already been developed [14–16].

II. Relevance and Scientific Significance

As it is known, overcurrent protection is triggered when the short-circuit current of the protected power transformer exceeds its set operating current. Maximum current protection and longitudinal differential protection respond to this fault by reacting to internal faults within the transformer, including inter-turn faults. Also, in the transformer, in the event of internal faults, oil vapors decompose and are released in the form of volatile compounds that rise up the transformer tank. In the event of a severe short circuit, there is a significant movement of gas mixtures that creates increased pressure towards the transformer expander. The formation of gases in the tank of a power transformer is a characteristic sign of a fault, which is the signal for triggering its gas protection. One alternative way to detect such faults is to use induction coils instead of traditional current transformers with metal cores. In this connection it is necessary to consider the possibility of realization of maximum current protection, longitudinal differential and gas protection of power transformer in the form of developed devices.

III. Current Protection Using Reed Switches and Inductive Coils

A reed switch (sealed contact) is used as an element base in various relays, buttons, switches, and so on [11-12]. When a reed switch is exposed to a magnetic field created by a current-carrying busbar, the ends of its contacts are magnetized and attracted to each other, closing an electric circuit. The inductance coil is widely used in various electrical devices: contactors, magnetic starters, various relays [13].The inductance coil is affected by the magnetic field from the

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current-carrying busbar of the electrical installation, near which it is installed, and an alternating voltage is induced in it, which is removed from the terminals of the inductance coil. In the presented maximum current protection and longitudinal differential protection of a power transformer, a reed switch, type MKA-50202, and inductance coils from an intermediate relay, type MKU-48, are used [18-19].

IV. Results

The result of solving the issue was the creation of alternative, having the effect of resource-saving materials of protection. This section consists of the presented maximum current protection, longitudinal differential protection and gas protection of power transformer, made in the form of devices.

V. Maximum Current Protection

Maximum current protection of a power transformer, presented as a design, contains in its composition inductance coils 1, taken from the relay MKU-48, without a core, movable 2 and fixed 3 platforms, stand 4 (fig. 1), voltage amplifier 5, measuring scale 6, which has a marking in centimeters to control the passage of distance coil inductance 1, equal to 70 cm. along the fixed platform 3, the first 7, second 8 and third 9 slots, automatic switch 10, micromotor 11 connected to the shaft with a thread 12, holder 13 with an internal thread with lugs 14, through which pass the running axles 15. The construction of maximum current protection is installed inside the cell, series KRU-2 [17;19]. The movable platform 2 and the fixed platform 3, the stand 4 is made of textolite, 0.5 cm thick. The micromotor 11 moves the movable platform 2, and together with it the fixed platform 3 with the help of the holder 13. The holder 13 moves up to the hollow cylinder 16. The beginning and ends of the traveling axles 15 are attached to the first 17 and second 18 strips. A micromotor 11 is attached to the first bar 17, and a hollow cylinder 16 is attached to the second bar 18. A movable platform 2 with three inductance coils 1 mounted on it, each opposite its phase (A, B, C), is fixed on the holder 13 (fig.2a). The outputs of the coils 1 are connected to the voltage amplifier 5 also of each phase (A, B, C) (fig. 2b). A microcontroller (not shown in the drawings) is used to regulate the movement of the inductance coils 1 by means of the micromotor 11 along the fixed platform 3 (from its left edge to its right edge). The number of revolutions of the micromotor 11 corresponds to the distance traveled and is set in the microcontroller program. The maximum current protection settings are changed by moving the movable platform 2 with inductance coils 1 along the slots 7, 8 and 9 of the stationary platform 3, relative to the busbars 19 by the micromotor 11. The movement of the movable platform 2 is controlled by the scale 6. The first 17 and second 18 bars are attached to the base 4, which is fixed to the frame 20 of the withdrawal cart of the switch, by means of support legs 21, the support legs 21 themselves being fixed to the base 4. The fixed platform 3 is fixed to the frame 20. Winding 22 of time relay 23 contact with time delay on closing 24, winding 25 of intermediate relay 26 with contact on closing 27, indicating relay 28, trip coil 29 of the circuit breaker of the electrical installation. Figure 1 shows the design of maximum current protection with remote selection of settings. Figure 2 shows: a) placement of the maximum current protection structure inside the switchgear cell; b) structural scheme for maximum current protection.

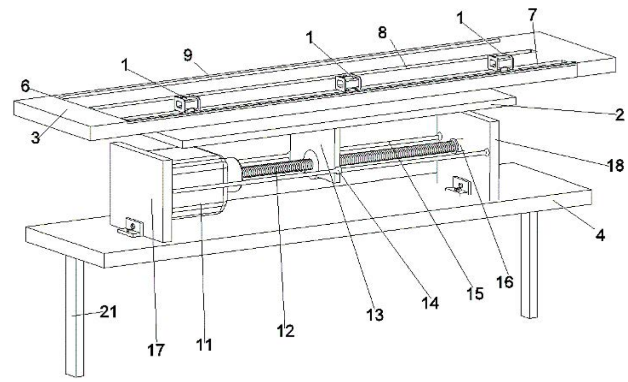
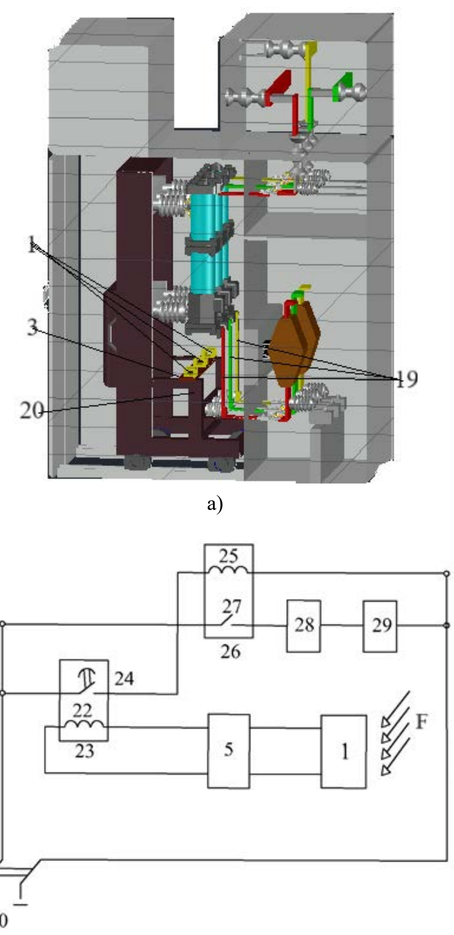


Fig. 1. Design of maximum current protection with remote selection of settings.



a)

b)

Fig. 2. Positioning of the maximum current protection structure inside the switchgear panel a); structural scheme of maximum current protection b)

Maximum current protection works as follows. The inductance coil 1 connected to the voltage amplifier 5 is placed directly opposite the current-carrying busbar 19 of its phase, at the minimum safe distance from it according to the Rules for

Electrical Installations, equal to 120 mm [20]. To change the maximum current protection settings, the movable platform 2 and the coils 1 located on its move each along its slot 7, 8 and 9 (left or right) of the fixed platform 3.

In this case, for example, the coil 1 installed opposite its phase "A" is moved along the slit 7 of the fixed platform 3 to the hollow cylinder 16 by means of the micromotor 11, reaching the end point equal to 70 cm of the measuring scale 6. For the coils 1 of the other two phases "B" and "C", the situation is the same, each moving along its slots 8 and 9 of the fixed platform 3 to the hollow cylinder 16, reaching also the end point equal to 70cm of the measuring scale 6.

In the rated load mode, a current not exceeding the maximum operating current flows through the transformer to be protected, connected to the complete switchgear cell, and a magnetic field acts on the inductance coil 1, the induction value of which is insufficient to trigger the maximum current protection. Parameters in the voltage amplifier 5 are adjusted so that it is triggered only when the voltage at its terminals of about 3V, and at a voltage value less than this, the maximum current protection to disconnect the electrical installation does not trip.

When a short-circuit occurs at the outputs of the protected electrical installation, the current in the current-carrying busbars 19 increases, and consequently the value of the magnetic flux becomes greater than the maximum current protection tripping current (shown by arrows in figure 2b). Therefore, the inductive coil 1 reacts to this change in the magnetic field, as a result of which it induces an increased value of the electromotive system, for example, of the order of 3V, then it, coming to the voltage amplifier 5, through it is increased to a value equal to U = 220 V and is fed to the outputs of the winding 22 of the time relay 23. As a result, this relay 23 triggers a contact with a time delay equal to 0.02s. on closing 24 and sends a potential "+" coming from the circuit breaker 10 to the first terminal of the winding 25 of the intermediate relay 26. Relay 26 is triggered by means of the indicating relay 28 and sends potential "+" through its contact on closing 27 to the first lead of the trip coil 29 of the circuit breaker of the electrical installation. As a result, the electrical installation to be protected is disconnected. The tripping of the maximum current protection is detected by the indicating relay 28. The presence of a micromotor 11 with a programmable microcontroller makes it possible to remotely move the coil 1 and thereby change the setting of the maximum current protection, relative to the location of the current busbar 19.

VI. Longitudinal Differential Protection of the Transformer

The longitudinal differential protection of a power transformer is in the form of a device and operates as follows, with its elements set up according to the sequence shown below. Each current conducting busbar 1 of the block-module switchgear bay CSG-110kV (indoor switchgear) and ComSG-10kV (switchgear) of the K-63 series, in compliance with the minimum allowable distance, according to the safety regulations (Electrical equipment rules), which is equal to 700 and 120 mm, should have the pillar 2 attached to it with the first group of inductance coil IC (1-3) on the CSG-110kV and the second group of inductance coil IC (4-6) 3 (fig. 3a, b) [20;21]. The pillar is fixed to the busbar 1. Prior to installation of the inductance coil IC 3 in the switchgear bays CSG-110kV and ComSG-10kV, two factors should be considered: maximum parameters of the magnetic field induced by the busbar 1 (In the regions with the highest magnitude of magnetic induction) and the convenience of placing the induction coil IC 3 (fig.3a, b).

The inductance coil IC 3 should be placed perpendicular to the plane of the busbar 1 cross section. Next, the circuit breaker 4 on the protection panel 5 is switched on and the first contact cores 6 of the reed switch 7 receive a positive (plus) potential (fig. 3c).

The working principle of the longitudinal differential protection device of the power transformer 8 is based on the comparison of the voltage value of the transformer windings and the busbar 1, according to the traditional longitudinal differential protection. The power transformer 8 (fig.4) stands between the inductance coil groups IC 3 (1-3) and IC3 (4-6), which are installed on the current conducting busbars 1 of the ZRU-110kV and ComSG-10kV switchgear bays. The groups have the same parameters and are placed on the three-phase busbar. For example, each “A” phase of CSG-110kV and ComSG-10kV has one (two, in total) inductance coil IC (1-4), while the other two busbar 1 phases “B” and “C” have IC (2-5) and IC (3-6), respectively.

The impact of the magnetic fluxes F induced by the busbar 1 of the switchgear bays CSG-110kV and ComSG-10kV on the inductance coil IC 3 is shown by the arrows (fig. 5c). Since the parameters of the observed voltage on the output of the inductors 3 is insignificant, the voltage amplifier A9 (1-6) increases the value till the required level. If needed, it is possible to use pillar 2 for moving the inductance coil IC 3 with respect to the busbar 1 plane. If necessary, it is possible by means of the stand 2 to move the inductance coils IC 3 relative to the plane of the current-carrying bus 1, thereby making an additional selection (adjustment) of the triggering settings of the longitudinal differential protection (fig. 3a, b).

Under normal working conditions of the transformer 8 the parameters of the protection system are set by the resistors R10 (1-6) such that the voltages U_1 and U_2 are equal in magnitude. Meanwhile, the device should react only to the internal short circuits inside the transformer 8 and ignore the external short circuits outside the transformer (fig. 3c). In case of a short circuit in the power transformer 8, the current flowing in the busbar 1 increases and the inductors IC3, which react to the change in magnetic field around the busbar 2, incite voltage of a certain level (fig 3a,b). Since the level of the voltage, which is measured at the output of the inductance coil induction coil 3, is low (around 20–25 B), the voltage amplifier A9 (1-6) is used to raise it till U=220V and send it to the first output of the control winding 11 of the reed switch 7 (fig. 3c). As a result, the voltages U1 and U2 of the inductors 3 installed in the switchgear bays CSG-110kV and ComSG-10kV become different in magnitude. Furthermore, due to the different polarity of U_1 and U_2, the currents, which flow in the control windings 11 of the reed switch 7 and create the magnetic flux acting on these reed switches, will also be different (fig. 3c). If the voltage difference between U_1 and U_2 reaches the level of the reed switches 7 triggering, the magnetic field of the control winding 11 creates the conditions under which the reed switch closes the first contact core 6 and the second contact core 12 through the closing contact 13. A "+" signal is sent from the circuit breaker 4 on the first output of winding 14 of intermediate relay 15. Relay 15 has the first output of winding 17 of intermediate relay 18 connected to its closing contact 16. If the relay trips, it sends a signal to trip coil (YAT) 19 of the circuit breaker of transformer 8.

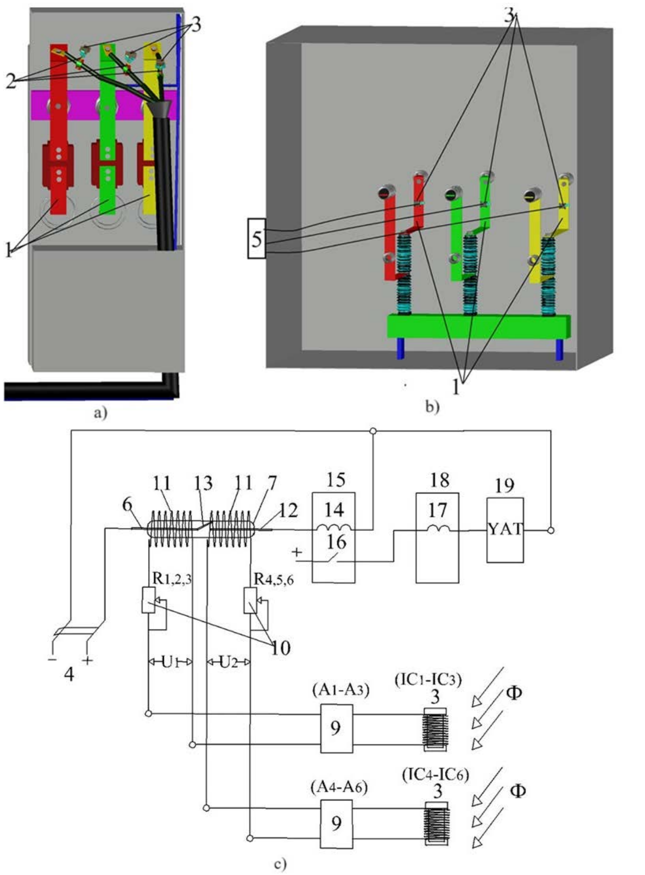


Fig. 3. The arrangement of the inductance coil in switchgear bays of ComSG-10kV a) and CSG-110kV b); the block diagram of the differential protection of power transformers c)

The trip coil is placed in the switchgear bay CSG-110kV. As a result, the protected power transformer 8 is disconnected from the network (fig. 4).

VII. Gas Protection of the Transformer

The gas protection of the power transformer on reed switches is designed as a device and works as follows. Before switching on the transformer 1, the device's body should be attached by its left and right ribs to the cut section 2 of pipeline (fig. 5a, c). The cut section 2 of the pipeline connects the transformer tank to conservator tank 3 by the means of bolts and nuts. Also, during the installation of the device oil resistant gaskets should be present on both sides of the device body 4 to obtain greater impermeability. Opening the sealed cover 5 with observation window 6 of the body 4 beforehand, a trip switch cylinder 7 with two reed switches 8 and 9 inside should be installed in the body 4 (fig. 5a, b). In order to install the reed switches inside the trip switch cylinder, the cover caps 10 and 11 should be removed and the reed switches need to be fixed on the holders 12 using the clamps 13. Next, the trip switch cylinder should be fixed to the body 4 using screws 14 on the axes 15. Axes 15 are fixed on the sides of the trip cylinder 7 using first 16 and second collar 17. Reed switch 9 balanced by the counterbalance cylinder 18 is in the lower part of the body 4, where it.

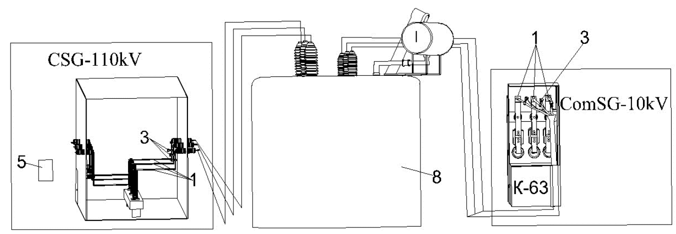


Fig. 4. Connection diagram of the longitudinal differential protection device.

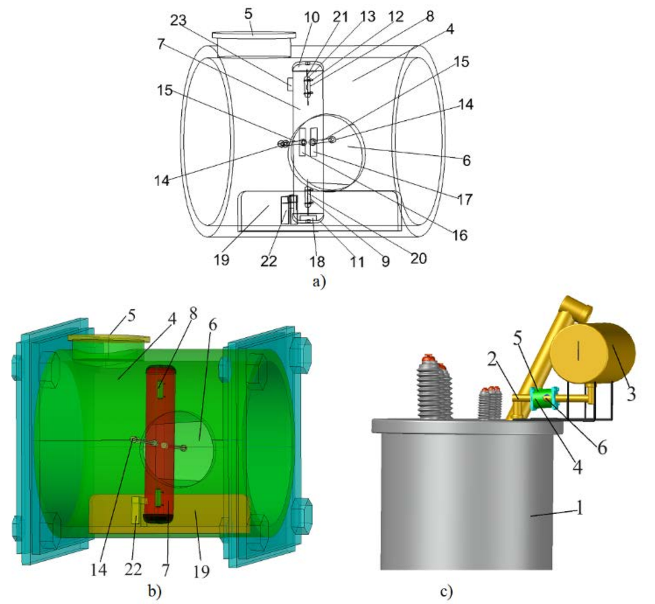


Fig. 5. Power transformer gas protection device a, b) and its fastening in the pipeline cut c).

Counterbalance cylinder 18 pulls reed switch 9 to the lower part of the body 4. In this position reed switch 9 is on the plane of the permanent magnet's 19 cross section, hence, the reed switch contact 20 is closed. If there are no faults in the tank of the transformer, the contact 20 remains closed and no fault signal is sent (fig. 5a).

In the nominal load mode inside the tank of power transformer 1 there are no winding shorts in the windings and, accordingly, there is no gas formation. The contact 20 of the reed switch 9 remains closed. Since the reed switch is normally closed and is connected to the alarm circuit in such a way that there is no alarm signal in the circuit. At the same time, contact 21 of the reed switch 8 is open and the protection system does not trigger (fig. 5a).

Short circuit in a small number of turns causes gas formation. The gas starts to fill the upper part of the transformer tank. Small bubbles of the gas rise up the pipe 2 into the conservator tank 3 (fig. 5c). On its way, the gas passes through the Buchholz relay and the trip switch cylinder 7 starts to spin inside the body 4 affected by the gas flow direction. After that, reed switch 9 steps out of the permanent magnet's 19 cross section plane and its contact 20 is open. This event sends a fault signal to the alarm circuit (fig. 5a) and the protection system reacts.

In case of a short circuit of a large number of turns, a more rapid formation of gases occurs. Larger volume of gas fills the upper part of the tank of the transformer 1. The stream of gas flows to the conservator tank 3 through the pipe 2 (fig. 5c). The gas and the oil pass through the Buchholz relay and turn the trip switch cylinder 7. The cylinder spins 180˚ around its axis in the opposite direction till the bar 22. The function of the bar 22 is to save the cylinder from complete flips (fig. 5a). Then, the cylinder with a buffer 23 attached touches the bar 22. The buffer 23 is needed to mitigate the collision of the cylinder 7 and the bar 22. The reed switch 9 steps out of the permanent magnet's 19 cross section plane and its contact 20 opens. Open contacts initiate a fault signal indicating a fault present in the transformer 1. At the same time, the reed switch 8 enters the permanent magnet's 19 cross section plane and its contact 21 closes. In this case, a signal is sent to the circuit that switches off the transformer 1. After the transformer's shutting down the counterbalance cylinder 18 levels out the trip switch cylinder 7, which returns to its initial position (fig. 5a). The protection system is now ready for further work.

When the oil level in the power transformer decreases, the oil level in the device's body 4 decreases, too. The cylinder 7 moves down along the displacement indicator 23 that is visible in the observation window 6. In the same manner, the reed switch 9 steps out of the permanent magnet's 19 cross section plane and its contact 20 opens. A fault signal is sent to the alarm circuit (fig. 5a). All structural elements of the device are made of lightweight, durable, thermo- and oil- resistant plastic and printed by a 3D printer. The only exception is the body 5 and the screws 14, which are made of non-magnet materials.

VIII. Conclusion

The presented protections are characterized by simple implementation, minimal material consumption, ease of operation and react to all external and internal short circuits in power transformers. At the same time these protections do not use current and gas relays, measuring current and voltage transformers with metal cores, so widely used for traditional protections, which contain expensive steel, copper and high-voltage insulation, as well as have significant weight and size parameters. All of the above corresponds to the actual task of relay protection - resource saving, which makes it possible to significantly reduce the economic costs required to create such protections already at the initial stage. Resource saving also eliminates the need to use a gas relay and oil flow regulator. Maximum current protection made with the use of micromotors allows remote selection of the operating set point of protection.

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