Resource-saving protections of power transformers against internal faults

Dauren Dzhambulovich Issabekov[1,*]

[1]Department of Electrical Power Engineering, Non-profit joint-stock company "Toraigyhrov University", Lomov str. 64, 140006 Pavlodar, Kazakhstan

Abstract. The paper presents the principle of operation of the developed gas protection and oil level control, the purpose of which is to protect power transformers from short circuits. The presented protections are made without using current transformers (CTs) and current relays with ferromagnetic cores, which are widely used in the power industry and have significant weight and size parameters and their high cost. The proposed protections are made with the use of magnetically controlled elements- reed switches. Protections with the use of reed switches can be used at the moment only as a backup to the traditional protections of power transformers, since there is no wide introduction into production of these protections and experience in their operation. At the same time it should be said that such protections are in no way inferior to traditional ones in terms of speed. The presented protections characterize a new approach in the implementation of relay protection and have a resource-saving effect. The resource-saving nature of these protections, applicable to virtually any type and voltage class of power transformers, lies in the use of reed switches, which are, both in cost and in weight and dimensions, an order of magnitude cheaper and smaller in size and weight than the above-mentioned CTs. The proposed protections are made in the form of devices with their installation inside the power transformers, as well as inside their expander tank..

1. Introduction

The issue of resource saving in the electric power industry, which has been repeatedly raised at international councils on large electrical systems of high voltage - SIGRE, remains relevant to the present day, including the implementation of resource-saving relay protection of power transformers against short circuits, without the use of expensive and having significant weight and dimensions of metal-intensive current transformers (CTs) and current relays with ferromagnetic cores [1–3]. To improve the reliability of traditional current protections, made on both electromechanical, semiconductor or microprocessor-based, it is advisable to apply duplication of protections, and to obtain the maximum effect it is necessary to duplicate the protection device itself and the current transducers themselves [4–5]. As an alternative to the use of CTs and the corresponding protections built with their use, it is possible to consider various magnetically controlled elements, such as Hall sensors, magnetoresistors, magnetodiodes, magnetotransistors, inductance coils, reed and Rogowski coils [6–13]. To build the relay protection of power transformers without the above-mentioned CTs, reed switches were chosen [12–13]. They were chosen due to the fact that in comparison with other similar magnetosensitive elements they have advantages, which are that the signal is transmitted not through measuring circuits, but through control circuits, at the same time they can perform the functions of analog-discrete and measuring transducer, as well as the measuring body of protection, while having a low cost and small weight parameters in comparison with CTs and current relays with ferromagnetic cores. Work on the development of resource-saving current protections without the use of CTs with ferromagnetic cores based on reed switches has been carried out since the 1960s. In recent decades, there are already a number of developed current protections using reed switches [14–19]. This paper presents and discusses the principle of operation of the developed gas protection, as well as oil level control offered in the form of devices.

[*]Corresponding author: Dauren_pvl2012@mail.ru

2. Resultative Methods

2.1 Implementation of protections made with reed switches

The main advantages of the reed switch when choosing it as an element base for protections with its use is: the ability to perform the functions of at the same time a fast-current relay and current transformer; control signal is transmitted by control circuits, not by measuring circuits; long service life. The fundamental factor for the use of reed switches in relay protection is the resource saving effect of protections based on them in comparison with the protections made on CTs with ferromagnetic cores. Reed switches are installed at a safe distance from the current-carrying phases of electrical installations according to the Rules for Electrical Installations [20]. Reed switches are widely used as an element base in various switches, relays and buttons. When it is affected by the magnetic field created by the current-carrying bus against which it is located, the ends of its contacts are magnetized to each other, closing the electrical circuit [12–13].

2.2 Gas protection of power transformers

The gas protection presented as a device consists of a body 1, an inspection window 2 with a first scale 3 placed on the same window 2, a tap 4 for taking a gas sample, a sealed cover 5, a cup 6 with a screw cap 7, first 8 and second 9 bushings, two first axes 10, first screw 11, oil-resistant gaskets 12, bolt-and-wrench joint 13, first 14, second 15 and third 16 flat plates fixed on the second axis 17, on the upper output of which the second screw 18 is fixed, three reciprocating springs 19, second scale 20, circular plate 21, three pairs of contacts to close 22.

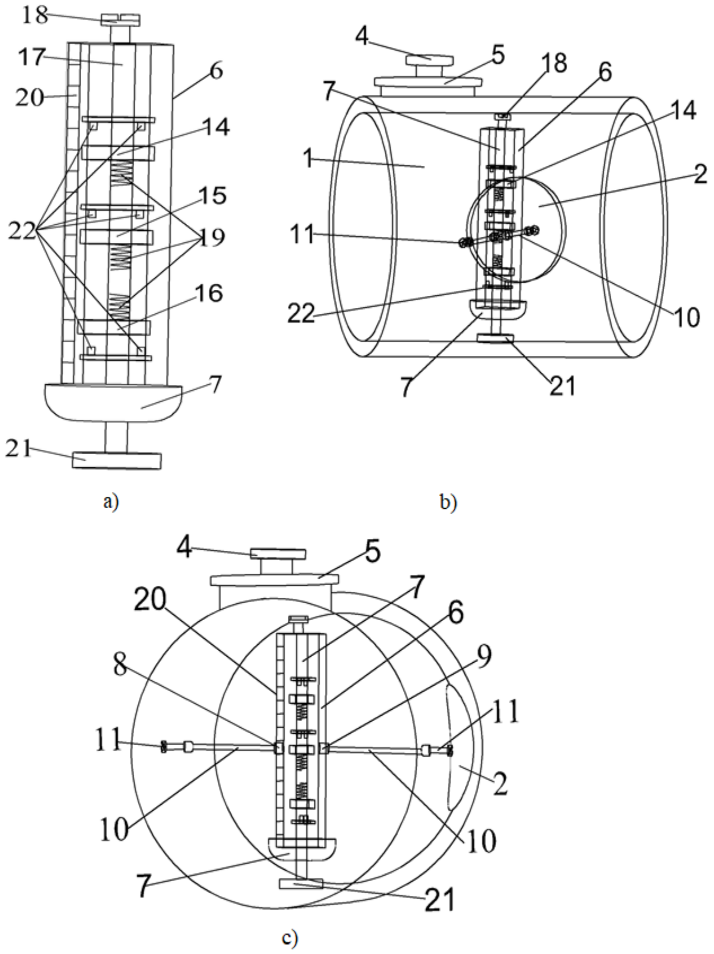


Fig. 1. Gas relay and its: a) rectangular beaker; b) front view; c) side view

The gas protection works in the following way. Before turning on the power transformer in operation, this device is screwed into the pipe section with the help of a bolt-and-wrench joint 13, having previously installed oil-resistant gaskets 12 on both sides of the housing 1, for the protrusions of the housing 1 (Fig.1b). Before opening the lid 5 of the housing 1, a rectangular-shaped beaker 6 is placed inside, with the first 14, second 15 and third 16 flat plates

 https://doi.org/10.1051/e3sconf/202343401041

installed inside it. For visual observation of the gas level in the body 1 there is an observation window 2 on one of the sides. The first 14, second 15 and third 16 flat plates mounted on the second axis 17 through reciprocating springs 19 (designed to limit the movement of these plates 14, 15 and 16 on the second axis 17) set in the cup 6, unscrewing the cover 7. After securing the glass 6 to the side walls of the housing 1 with the first 8 and second 9 of the bushing, screwed to one end of the first axis 10, the other end of these axes 10 is fixed with the first screws 11 to the housing 1 (Fig.1a). The round plate 21 is located on the outer bottom side of the cup 6, which also, as the first 14, second 15 and third 16 plates are fixed to the second axis 17. The distance between all plates (flat 14,15,16 and circular 21) is strictly fixed and corresponds to the volume of gas and oil filled in the gas relay when they pass through the pipeline to the expander. The first 14 and second 15 plates react to an increase in the level of gas and oil in the power transformer, and the third 16 to their decrease. The round plate 21 located on the outer bottom side of the cup 6 is the perception organ of the device, which reacts to the level of oil and gas in it. The necessary exit of the round plate 21 from the cup 6 is carried out by the second screw 18. The first 14, second 15 and third 16 flat plates are the executive body of the device and are designed for closing the first, second and third contacts.

In nominal load mode, and if there are no winding faults in the transformer windings, the round plate 21, and respectively the first 14 and second 15 flat plates do not go up, and the third 16 plate does not go down and respectively no signal, both to turn off the power transformer, and in the alarm circuit to the service personnel. With a small release of gases due to the short circuit of a small number of turns inside the transformer, the upper part of its tank is filled with gas (Fig. 2). This gas in small bubbles rises up through the pipeline to the expander and passes through this device, while the round plate 21 rising up, respectively, raises behind itself the second axis with the first 14, second 15 and third 16 flat plates fixed on it. The first plate 14 reaching the first pair of contacts closes between them, signaling a fault in the transformer in the alarm circuit to the operating personnel, that is, the transformer gas protection is triggered by the signal (Fig. 1a).

At the rapid release of gases, resulting from the short circuit of a significant number of turns inside the transformer, the upper part of its tank is filled with a large volume of gas. This gas rushes up the pipeline to the expander (Fig. 2b). The gas together with the oil passing through the gas protection device, raising the round plate 21 upwards, it in turn raises behind itself the second axis with the first 14, second 15 and third 16 flat plates fixed on it.

The first plate 14 reaching the first pair of contacts, as well as the second plate 15 reaching the second pair of contacts close between them, simultaneously signaling both the fault and the power transformer tripping circuit. The gas protector responds to the signal and to the tripping of the transformer (Fig.1a). This process occurs as follows. Raising up the first plate 14 closes its (first) pair of contacts, having a certain stroke margin due to the reciprocating spring 19, it is compressed and at the same time the second plate 15 also rising up, closes its (second) pair of contacts to close. After switching off the transformer's gas protection, the gas is inspected and taken from the housing 1 by means of the tap 4, placed on the cover 5.

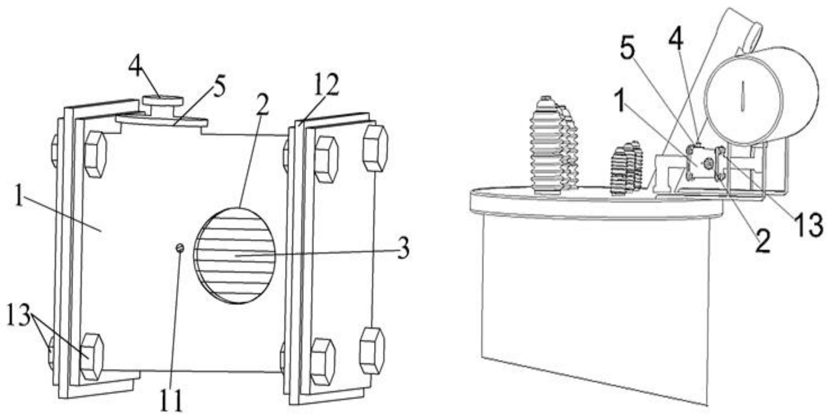


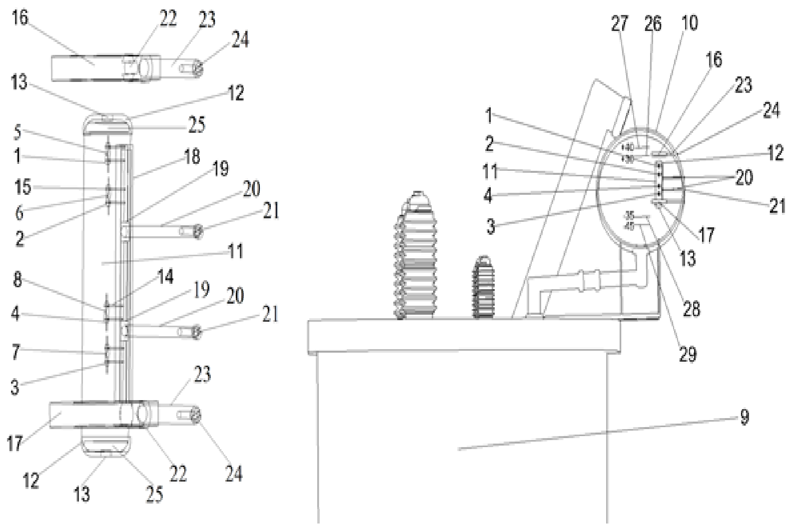
Fig. 2. Gas relay: a) its general view; b) fixing it in the transformer pipe section

When the oil level in the power transformer decreases, this level also decreases in the gas protection device, while the round plate 21 goes down and the second axis with the three flat plates 14, 15 and 16 fixed on it goes down with it. The third plate 16 reaches the third pair of contacts and closes them with each other, signaling a fault in the transformer to the operating personnel. The gas protection of the power transformer is triggered by the signal (Fig.2b).

2.3 Checking the oil level in the power transforme

Oil level control, presented in the form of a device contains reed switches 1,2,3 and 4 with open contacts 5,6,7 and 8 (Fig.3 a), the transformer tank 9, the expansion tank 10, the transparent bulb 11 with four reed switches installed inside it, closed at both ends with covers 12, the covers themselves have slots 13 for screwing off and tightening the covers 12 with screwdrivers, holders 14 with installed on them clamps 15, necessary for fastening the reed switches 1,2,3 and 4. Holders 14 are one with a transparent flask 11, the upper 16 and lower 17 permanent magnets, these magnets 16 and 17 are located above and below the transparent flask 11, on its two sides, relative to the maximum and minimum oil level mark in the expansion tank 10, the level of movement 18 transparent flask 11, bushings 19, set at the level of movement 18 of the transparent flask 11, which includes one end of the first two axes 20. These axes at the other end are fixed to the wall of the expansion tank 10 with the first screws 21, necessary for fixing the transparent bulb 11 to the expansion tank 10 and ensure the movement of the transparent bulb 11 inside the expansion tank 10, relative to the upper 16 and lower 17 permanent magnets, which with the brackets 22, connected to the second axes 23 are fixed to the wall of the expansion tank 10 with the second screws 24. Transparent bulb 11 for ease of maintenance is located inside the expansion tank 10 closer to the edge of one of its sides (Fig. 3a) and seals on both sides of the application of oil-resistant gaskets 25, installed between the lid 12 and the body of the transparent flask 11. There are marks on the expansion tank 10, On the expansion tank 10 there are marks corresponding to the initial 26 with positive temperature $+30^0C$ and limit 27 with temperature $+40^0C$ to the maximum and initial 28 with negative temperature $–35^0C$ and limit 29 with temperature $–45^0C$ to the minimum mark of oil in the power transformer tank 9 (fig. 3 б)

The transformer oil level control works as follows. In the initial position the device is located in the space between the oil level and the top of the expansion tank 10 inside it, with the upper 16 and lower 17 permanent magnets not touching, and the lower end of the transparent bulb 11 touches the oil level (Fig.3a). If the oil level in the tank of the power transformer 9 changes, if it rises or falls, respectively, changes the oil level in the expansion tank 10, the transparent bulb 11 mounted on the first two axes 20, through the bushings 19, moves up or down along the level of movement 18, and together with it move, located inside it reed switches 1, 2, 3 and 4.



a) b)

Fig. 3. Transformer oil level control, a); placement of the oil level control device inside the transformer expansion tank, b)

Before you turn on the power transformer in the work, first unscrew the covers 12 transparent bulb 11 inside it install four reed switches 1, 2, 3 and 4 on the holders 14 with clamps 15 (Fig.3a). After that, to the wall of the expansion tank 10 with the first 21 and second 24 screws, previously installed on both sides of the transparent bulb 11 oil-resistant gaskets 25, screw it with the first two screws 21 through the first two axes 20 to the wall of the expansion tank 10, as well as the top 16 and bottom 17 with permanent magnets 22, through the second axis 23 and with the second 24 screws, also to the wall of the tank 10 (Fig. 3b). Reed switches 1 and 2 are located in the upper part, and reed switches 3 and 4 in the lower part of the transparent bulb 11, while initially they are not in the magnetic field of the upper 16 and lower 17 permanent magnets and respectively contacts 5,6,7 and 8 reed switches 1,2,3 and 4 are not closed [12;13]. The location of the top 16 and bottom 17 permanent magnets corresponds to the maximum and minimum oil level mark in the expansion tank 10, respectively the oil level in the tank of the power transformer 9. If

the oil level in the tank of the power transformer 9 corresponds to the nominal level, the contacts 5, 6, 7 and 8 of the reed switches 1, 2, 3 and 4 remain open and there is no signal for a failure or for switching off the power transformer.
When the oil level in the tank of the power transformer 9, due to an increased load or an increase in ambient temperature, respectively, increases the oil level in the expansion tank 10 to the maximum mark (Fig. 3b). In this case, the oil inside the expansion tank 10 lifts up the transparent bulb 11 along the displacement level 18, reaching the initial level 26 with a positive temperature of . Reed switch 1 passes through the top 16 permanent magnet and falls under the influence of its magnetic field, as a result of its contact 5 closes and sends a signal to the sound and light alarm circuit about the increase in the oil level in the tank of the power transformer 9. As the oil level in the tank of the power transformer 9 continues to rise, the transparent bulb 11 continues to rise up, reaching the limit level 27 with a positive temperature .In this case, the reed switch 2 also passes through the top 16 permanent magnet and falls under the influence of its magnetic field, contact 6 reed switch 2 closes and as a result, it gives a signal in the circuit of switching off the power transformer from the mains.
When the oil level in the tank of the power transformer 9 decreases, the oil level in the expansion tank 10 also decreases and reaches the minimum mark (Fig. 3b). With a decrease in the oil level in the expansion tank 10 the transparent bulb 11 goes down along the level of displacement 18 reaching the initial level 28 with a negative temperature of C. Reed switch 3 passes through the bottom 17 of the permanent magnet and falls under the influence of its magnetic field, contact 7 of the reed switch 3 closes and sends a signal in the chain of audio and light alarm on lowering the oil level in the tank of the power transformer 9. As the oil level in the tank of the power transformer 9 decreases further, the transparent bulb 11 continues to go down, reaching the limit level 29 with a negative temperature of C. As a result, the reed switch 4 also passes through the bottom 17 permanent magnet and falls under the influence of its magnetic field, the contact 8 of the reed switch 4 closes and sends a signal to the circuit to turn off the power transformer from the mains.
The effect of the gas protection device lies in the simplicity of its operation, its light weight, the minimum of used parts, thus eliminating significant economic costs than when implementing the same transformer gas protection using traditional gas relays.
The oil level control device is characterized by the absence of the use of pointer, glass flat and tubular oil indicator, thus responding to the urgent issue of relay protection - resource saving, and the use of reed switches, which are characterized by such characteristics as: ease of operation, low weight, long service life and above-the number of reed switch actuations), low cost and the ability to operate at ambient temperatures from - 60^0C to + 125^0C together allow to use this device to monitor the oil level in the power transformer.

3. Conclusions

The presented protections with their structural parts, made of heat-resistant, durable and lightweight plastic, type "PLA", printed on a 3D printer meet the current issue of relay protection - resource-saving materials, thereby significantly reducing the economic costs of their layout and allowing the use of considered protections for application for power transformers of any type, power and voltage class, implemented on reed switches.

Acknowledgment

The work was supported by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan (grant № AP14972954).

References

1. Dyakov A.F. «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, № 4, pp. 7-16, April 2004.
2. Kazansky V.E., Current transformers in relay protection circuits, Moscow: Energiya, 1969.
3. Kazansky V.E., Measuring current transducers in relay protection, Moscow: Energoatomizdat, 1988.
4. Andreev V.A., Relay protection and automation of power supply systems: a textbook for universities, ed. 4th, ref. and add., Moscow: Higher school, 2006.
5. Shneerson E.M., Digital relay protection, Moscow: Energoatomizdat, 2007.
6. Kozhovich L.A., Bishop M.T. «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. Kozhovich L.A., Bishop M.T. «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. Kotenko G.I., Magnetoresistors, Moscow: Energy, 1972.
9. Kobus A., Tushinsky J., Hall sensors and magnetoresistors / per. from polish, B.I. Tikhonova, K.B. Macidonian; ed. O.K. Khomeriki, Moscow: Energy, 1971.
10. Ovcharenko N.I., Doroguntsev V.G., Bass E.I., Budkin V.V., Application of galvanomagnetic elements in relay protection and automation, Moscow: Energy, 1966.
11. Egiazaryan G.A., Stafeev V.I., Magnetodiodes, magnetotransistors and their applications, Moscow: Radio and communication, 1987.
12. Dikovskiy Ya.M., Kapralov I.I., Magnetically controlled contacts, Moscow: Energy, 1970.
13. Karabanov S.M., Maisels R.M., Shoffa V.N., Magnetically operated contacts (reed switches) and products based on them, Dolgoprudny: Publishing House Intellect, 2011.
14. Patent No. 34420 of the Republic of Kazakhstan. Installation for the study of the electromagnetic field inside a complete switchgear / Isabekov D.D.; publ. 26.06.2020.
15. Patent № 2743483 of the Russian Federation. Current protection device for cells of complete switchgears / D.D. Isabekov, V.I. Polishchuk, K.V. Baratova; publ. 19.02.21.
16. Patent № 2779908 of the Russian Federation. Device for overcurrent protection of electrical installations / D.D. Isabekov, V.N. Goryunov, E.P. Zhilenko; publ. 15.09.2022.
17. Patent № 2780820 of the Russian Federation. Device for preventing an overhead crane from crossing the limit positions / D.D. Isabekov, V.I. Polischuk, K.Y. Postoyankova; publ. 04.10.2022.
18. Patent №2678189 of the Russian Federation. Device for current protection of electrical installations / D.D. Isabekov, M.Y. Kletsel, K.I. Nikitin, B.E. Mashrapov; publ. 24.01.2019.
19. Issabekov D.D., Kletsel M.Ya., Zhantlesova A.B., Mayshev P.N., Mashrapov B.E. «New filters for symetrical current components» // Electrical Power and Energy Systems. – 2018. – №101. – pp. 85-91.
20. Rules for Arrangement of Electrical Installations (PUE), seventh edition, the date of introduction, Moscow: 01.01.2003.