Mounting Measuring Devices of Reed Switch Protection Near Conductors of Electrical Installations

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***Abstract.* The use of reed switches as measuring devices of relay protection is noted to solve the urgent problem of their construction without using current transformers. It is emphasized that the implementation of protection on reed switches is impossible without dedicated mounting near the conductors of electrical installations. It is noted that a number of models of such mounts have already been developed, while further advancement in this direction is required as well. Three new designs of measuring devices of protection are proposed for mounting reed switches near the busbars of cubicle switchboards arranged horizontally in a row, and near the busbars of bundled conductors located at the vertices of an equilateral triangle. The first mount differs from the known designs by the presence of a plate with reed switches, a plate with a scale and a rod with a thread and a handle. The second is a C-shaped platform with a support insulator, a case with a lid and a plate with reed switches. The third — with a double ear clamp and two pivoting bows with drum ratchets with reed switches. The strength of the third mount is assessed using the Pisarenko-Lebedev criterion, and a table with the calculation results of equivalent mechanical stresses in its clamp is given.**

Keywords: protection; reed switch; design; mount; busbar; conductor

I. Introduction

The problem of building relay protection devices without using current transformers was repeatedly emphasized at the CIGRE sessions [1, 2] as one of the still unsolved problems of the world electric power industry. At this stage, the Pavlodar State University named after S. Toraigyrov developed the principles [3-9] and certain protection devices [10-15], which have reed switches as measuring devices. More complex current protection devices as per [16-18] are currently in development and will be implemented in the nearest future. These devices require dedicated mounts allowing reed switches to be attached near phase conductors of the electrical installations at a safe distance from them, as well as the control of the protection response parameters. Several patented models of such mounts are known (for example, [19, 20]). However, research and development in this area still need much attention. This is because many different alternative layouts of electrical installations already exist and are developed differing from each other both in the arrangement of conductors and in their design, while most of these alternatives require their own unique mounts for attaching the measuring devices of protection circuits based on reed switches. This study considers the design of measuring devices of protection circuits developed by the authors for attaching reed switches near the buses of cubicle switchboards arranged horizontally in a row, and near the busbars of bundled conductors located at the tops of an equilateral triangle.

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II. Design of Measuring Device of Protection for Mounting Reed Switches Near the Busbars of Cubicle Switchboards

The measuring device [21] (Figure 1) contains plate 1 with reed switches 2 fixed on its first plane, plates 3, 4 and plate 5 with a scale, rod 6 (with thread 7 and handle 8), embedded into a hollow cylinder 9 by one end, while the other end is attached to the second plane of plate 1, parallel to its first plane. Bar 10 is fixed to plate 4 with two bolts 11. Hollow cylinder 9 is attached to bar 10. The first plane of plate 1 is located perpendicular to the cross-sectional plane of busbar 12 (Figure 2). Vertical slots 13 and 14 are located along the edges of plate 1 forming a rectangular quadrangle. Plate 3 enters slot 13, while plate 5 with a scale enters slot 14 (Figure 2). Reed switches 2 on plate 1 are installed at angles α, β, γ to the cross-sectional plane of busbar 12. Reed switch 2 serves as a sensing device for relay protection.

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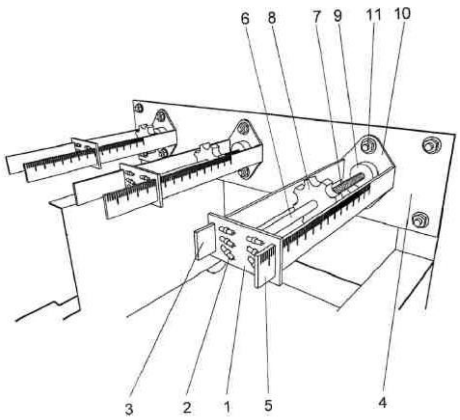


Fig. 1. Measuring device of protection circuit mounted in the compartments of cubicle switchboard (general layout) (part 1)

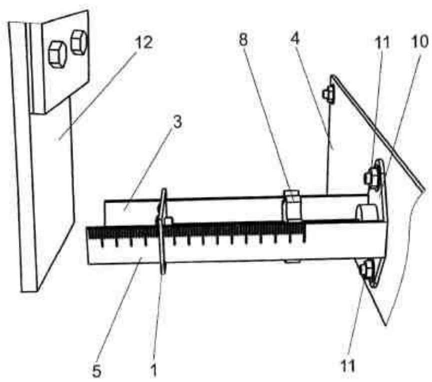


Fig. 2. Measuring device located close to the busbar

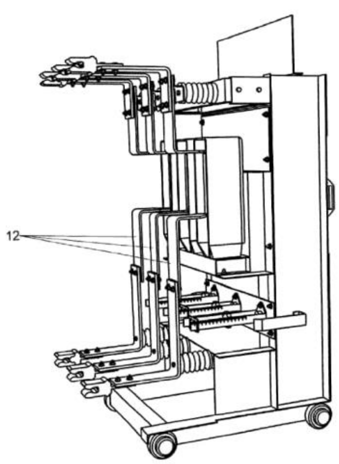


Fig. 3. Cubicle switchboard with the proposed measuring device (isometric view)

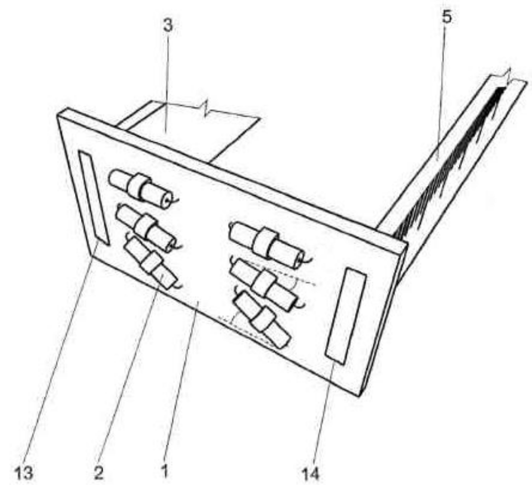


Fig. 4. Layout of a plate with reed switches

To find the correct parameters of short circuit protection (SC), the plate shall be moved parallel to the busbars (by changing the distance from them) and one of six reed switches shall be used. In the horizontal plane, movements are performed by turning handle 8, which moves plate 1 within slots 13 and 14 (Figure 4). During adjustment, the distance from plate 1 to busbar 12 is determined by the scale printed on plate 5. The reed switches are installed at angles α, β, γ, , which values are calculated theoretically to fine-tune the protection parameters.

All movements are done manually. All parts of the measuring device are made of dielectric material.

III. Design of the Measuring Device of Protection Circuit for Mounting Reed Switches Near Flat and U-Shaped Busbars of Cubicle Switchboards

The mount (Figure 5) includes C-shaped platform 1, attached to busbar 2. Support insulator 3 is fixed to platform 1. Case 4 with lid 5 is installed on insulator 3. The case includes plate 6 with reed switches 7 attached to it.

The measuring device works as follows. The protection tripping current in busbar 2 is calculated (Figure 5). Then, taking into account the distance from busbar 2 to reed switches 7 fixed on plate 6, one of the reed switches 7 with the required magnetomotive actuation force is selected. Next, the measuring device is fixed using C-shaped platform 1 on U-shaped busbar 2, and a connecting cable is connected to the contacts of selected reed switch 7. The other cable end is connected to the logical part of the protection circuit (not shown in Figure 5

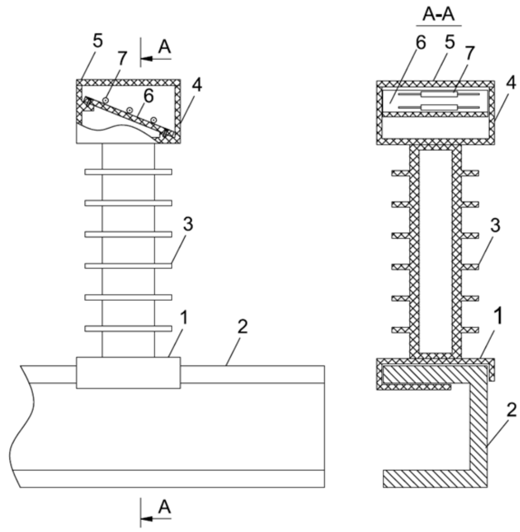


Fig. 5. Measuring body scheme

). In this case, the dimensions of support insulator 3 are such that plate 6 with reed switches 7 fixed on it, installed in case 4, is located at a safe distance from busbar 2. During a short circuit, the current in busbas 2 and the magnetic field created by it increases, which leads to reed switch 7 tripping, and a signal is transmitted via the connecting cable to the logical part of the protection circuit.

IV. Design of Measuring Device of Protection for Mounting Reed Switches Near the Busbars of Bundled Conductors of Different Shape

A. Measuring body scheme

The measuring body [22] contains two reed switches, a double ear clamp, two identical adjustment assemblies in the form of pivoting bows connected to the movable part of fixed hinges, which are rigidly fixed with on double ear clamps. A drum ratchet with a catch hook and a locking screw is flexibly attached to the end of each bow. Each ratchet has a reed switch inside, fixed with a clamp, which in turn is fixed with mounting bolts. The double ear clamp is fixed with a bolt and nut in the support insulator groove, which is attached to the busbar of the bundled conductor with a sheath.

To trip the reed switch attached near the busbar, a magnetomotive force F_{tr} is required, which is created by the current I_{tr} in the busbar. If reed switch 1 is located (Figure 6) at a distance h from busbar 2 in the plane N, parallel to the bus (Δabc is located on the plane N), then the following is true in accordance with the Biot-Savart-Laplace law:

$$I_{tr} = H_{tr} / g, \tag{1}$$

where I_{tr} and H_{tr} are the minimum values of the current in busbar 2 and magnetic field strength created by this current, at which the reed switch is triggered (H_{tr} is directed along the reed switch contacts); g — coefficient describing the location of the reed switch relative to busbar 2, expressed via h , m , γ .

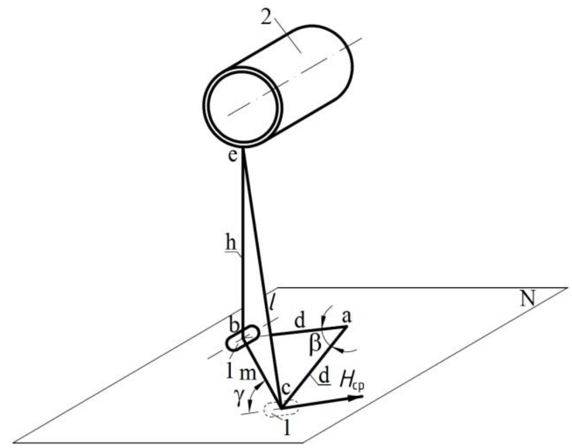
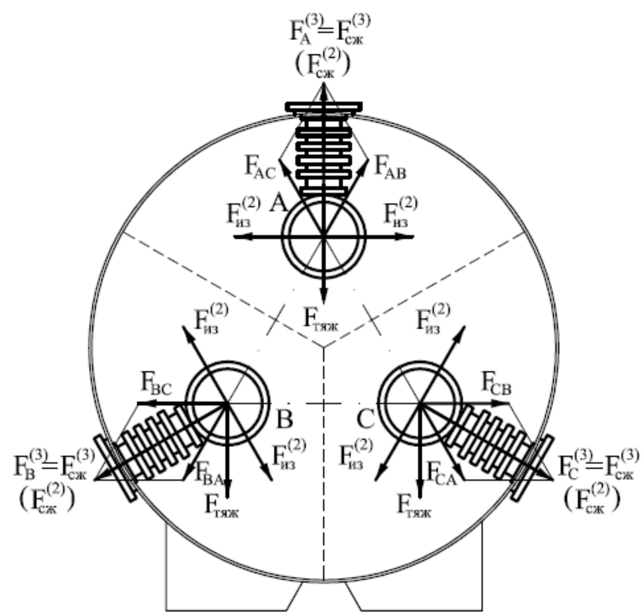


Fig. 6. Diagram for determining the magnetomotive force acting on a reed switch



$F_{из}$	F_{bend}
$F_{тяж}$	F_{gr}
$F_{сж}$	F_{comp}

Fig. 7. Forces acting on the busbars of the bundled conductor

$$g = \frac{h\cos\gamma}{h^2 + m^2}, \tag{2}$$

where $m = \sqrt{2d^2 - 2d^2 \cos\beta}$ is the distance of reed switch movement due to change in the pivoting bow position; d — the chord of the bow; β — the angle of bow rotation; γ — the angle between m and the longitudinal axis of the reed switch.

Figure 6 shows two positions of reed switch 1 — at $m = 0$ (solid line) and $m \neq 0$ (dashed line). The minimum of the corresponding current function as pwe (1) determines the coordinates of reed switches, where they have the maximum sensitivity.

The adjustment of I_{av} is carried out as follows. By rotating the movable part of the hinge, for example, using a reversible screwdriver, the pivoting bow is displaced out of the groove of the support insulator by an angle β (Figure 6) in the plane N.. After extending the bow, the drum ratchet located on the bow becomes accessible for adjustment. The ratchet rotates reed switch 1 (Figure 6) by the calculated angle γ in the plane N after the locking screw of the catch hook is unscrewed (after the operation the latter is returned to its original position and the screw is tightened).

B. Strength assessment for the mount

To assess the strength, various criteria can be used, for example, those presented in [23, 24]. We will use the generalized Pisarenko–Lebedev criterion [23], which allows to obtain fairly reliable results for various materials in both plastic and brittle states, and therefore is widely used [25].

Depending on the relative position of the busbars and insulators, the latter are exposed to the electrodynamic forces of interaction between the busbars, which are critical during the short-circuit current surge. Two-phase and three-phase short circuits shall be considered when assessing the phase interaction. When the phases are located at the vertices of an equilateral triangle (Figure 7), all busbars are in the same conditions. For instance, let us consider a phase C, forces F_{CA} and F_{CB} of which act on its busbar (caused by currents in the busbars with a three-phase short circuit), or only one of them (two-phase short circuit). In the case of a three-phase short circuit, the resulting force $F_C^{(3)}$ creates a compressive force $F_{comp}^{(3)} = F_C^{(3)}$ on the insulator. In the case of a two-phase short circuit, the resulting force of F_{CA} or F_{CB}, creates bending $F_{bend}^{(2)} = 0.5F_C^{(2)}$ and compressive $F_{comp}^{(2)} = \frac{\sqrt{3}}{2} F_C^{(2)}$ forces on the insulator (Figure 7). Also, the insulator is affected by the gravity force F_{grav} created by the busbar mass, which is ignored further, since this force is less than 1% of the magnitude of electrodynamic forces. The clamp of the proposed measuring device, installed in the insulator groove, is affected by the sliding friction force $F_{fr} = kF_{comp}$ caused by the compressive force F_{comp} (where k is the sliding friction coefficient for the insulator rubber shell sliding over the clamp material), as well as part of the bending force F_{bend} (since the force F_{bend} applied to the insulator top is much greater than the force applied to the clamp due to distribution of F_{bend} along the insulator). Let us assume that the clamp is affected by F_{bend} in full scale, which creates a margin of safety. Since the clamp is made of PLA plastic with a density of 1.25 g/cm^3, then the following is true as per [26]: $k = 0.1$.

During a two-phase short-circuit, the forces $F_{bend}^{(2)}$ and $F_{fr}^{(2)}$ create primary mechanical stresses $\sigma_1^{(2)} = \sigma_{bend}^{(2)}$ and $\sigma_2^{(2)} = \sigma_{fr}^{(2)}$. in the clamp. Then, according to the criterion from [23], the equivalent stress $\sigma_{eq}^{(2)}$ is determined by the expression:

$$\sigma_{eq}^{(2)} = \chi\sqrt{\left(\sigma_1^{(2)}\right)^2 + \left(\sigma_2^{(2)}\right)^2 - \sigma_1^{(2)}\sigma_2^{(2)}} + \\ + (1-\chi)\sigma_1^{(2)} \leq \sigma_{\max}, \tag{3}$$

where χ is the material plasticity coefficient ($\chi = 1$ for PLA); $\sigma_{\max}$ — the maximum permissible stress in the material for the proposed device ($\sigma_{\max} = 58\,MPa$ for PLA plastic).

With a three-phase short circuit, the force $F_{fr}^{(3)}$ creates mechanical stress $\sigma_1^{(3)} = \sigma_{fr}^{(3)}$, in the clamp, and the strength condition has the following form:

$$\sigma_{eq}^{(3)} = \sigma_1^{(3)} \leq \sigma_{\max}. \tag{4}$$

If inequalities (3) and (4) are satisfied, the design of the measuring device can be assumed to have sufficient strength.

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TABLE I. RESULTS OF CALCULATION OF EFFORTS AND EQUIVALENT STRESSES IN THE CLAMP

Conductor type	$F_{bend}^{(2)}$	$F_{fr}^{(2)}$	$F_{fr}^{(3)}$	$\sigma_1^{(2)}$	$\sigma_2^{(2)}$	$\sigma_{eq}^{(2)}$	$\sigma_{eq}^{(3)} = \sigma_1^{(3)}$
	N			*MPa*			
Without phase-to-phase barriers							
ШЗК-0.4-1600(2000)-51	6562	1137	1502	5.8	1	5.4	1.3
ШЗК-1.0-1600(2000)-81	16554	2867	3788	14.5	2.5	13.4	3.3
ТЗК-6-1600-81	7019	1216	1606	6.2	1.1	5.7	1.4
ТЗК-10-1600-128	14807	2565	3389	13	2.3	12	3
ТЗК-10-2000-128	13479	2335	3085	11.8	2	10.9	2.7
ТЗК-10-3150-128	30440	5272	6966	26.7	4.6	24.7	6.1
ТЗК-10-3200-128	23579	4084	5396	20.7	3.6	19.2	4.7
ТЗК-10-4000-170	53692	9300	12287	47.1	8.2	43.6	10.8
ТЗК-15-1600(2000)-81	9370	1623	2144	5	0.9	4.6	1.1
ТЗК-15-4000-81	13730	2378	3142	7.3	1.3	6.7	1.7
ТЗК-15-4000-128	34289	5939	7846	18.1	3.1	16.8	4.1
With phase-to-phase barriers							
ТЗКР-1-3000-128	9000	1559	2060	7.9	1.4	7.3	1.8
ТЗКР-6-1600-81	1790	310	409	1.6	0.3	1.5	0.4
ТЗКР-6-2000-81	1752	304	401	1.5	0.3	1.4	0.4
ТЗКР-10-1600-81	1689	293	387	1.5	0.3	1.4	0.3
ТЗКР-10-2000-128	3846	666	880	3.4	0.6	3.1	0.8
ТЗКР-10-3150-128	7028	1217	1608	6.2	1.1	5.7	1.4
ТЗКР-10-4000-170	10318	1787	2361	9.1	1.6	8.4	2.1

According to the methods recommended by GOST [27], calculations were made of the resulting forces at two-phase and three-phase short circuits, forces $F_{bend}^{(2)}$, $F_{comp}^{(2)}$, $F_{comp}^{(3)}$, $F_{fr}^{(2)}$, $F_{fr}^{(3)}$, as well as the primary $\sigma_1^{(3)}$, $\sigma_1^{(2)}$, $\sigma_2^{(2)}$ and equivalent $\sigma_{eq}^{(3)}$, $\sigma_{eq}^{(2)}$ stresses in the clamp for all bundled conductors produced in the Russian Federation without phase-to-phase barriers.

Table 1 shows the results of these calculations using the properties of conductors produced by Moselectroschit JSC [28] (as per specifications, conductors produced by other companies have the same properties). The analysis of the obtained results showed that the proposed design of the measuring device has the required strength (the worst result is $\sigma_{пр} / \sigma_{экв} \geq 1.33$).

The structural strength of the measuring device for conductors with phase-to-phase barriers (shown in Figure 7 by dashed lines) is estimated in the same way as discussed above. In this case, it is assumed that the barriers reduce the electrodynamic forces of interaction between the busbars by a factor of 3–4 [29]. The calculation results for equivalent stresses $\sigma_{eq}^{(2)}$ and $\sigma_{eq}^{(3)}$ in the clamp for bundled conductors with phase-to-phase barriers show that the proposed design of the measuring device has sufficient strength (the ratio $\sigma_{\max} / \sigma_{eq} \geq 6.9$ in the worst case).

The assessment of the thermal stability of the mount can be neglected, since the duration of the short circuit is insignificant (few seconds) and the heat released in the busbar is almost entirely spent on heating the conductor [30] and does not have enough time to be transferred to the environment.

V. CONCLUSIONS

The proposed designs of measuring devices of protection circuits allow to attach the reed switches at a safe distance from busbars of cubicle switchboards arranged horizontally in a row, and from busbars of bundled conductors located at the tops of an equilateral triangle. Also, these mounts provide the ability to adjust the tripping parameters of the protection based on reed switches, which is achieved by installing the reed switches at the required location by moving them in the horizontal or vertical planes, or by installing several reed switches in the plane perpendicular to the busbar. The design of the measuring device with a double ear clamp and two pivoting bows is of a particular practical interest, as it has an increased strength when its clamp is exposed to mechanical stresses and can be used in electrical installations of all types, which have support insulators.

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