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Protection of complete switchgear against arc faults based on comparison of filter unbalance current

***Abstract**. The paper introduces protection of complete switchgear cells against arc faults which controls the ratio of the unbalanced currents of zero-sequence current filter and zero-sequence current transformer. The examples of its implementation on a semiconductor elements and software are given. The analysis of work in different modes and the methods for selecting settings and evaluating the sensitivity are proposed.*

Streszczenie.** W artykule opisano metodę zabezpieczania rozdzielnic elektrycznych przed wyładowaniami łukowymi bazująca na kontroli nierównowagi prądów filtru i transformatora zerowej kolejności faz. Zaproponowano rozwiązanie układowe i odpowiednie oprogramowanie.* ***Zabezpieczenie rozdzielnic elektrycznych przed wyładowaniami łukowymi bazujące na porównaniu prądu niezrównoważenia filtru

Keywords: complete switchgear cell, arc, unbalance current, ratio, amplification.
Słowa kluczowe:rozdzielnice elektryczne, wyładowanie łukowe, prąd niezrównoważenia.

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Introduction

Cells of complete switchgear (CCS) are widely used in the networks of 6-10 kV. The arcing fault is the most dangerous since it can cause significant damage [1, 2, 3, 4]. Known methods of arc detection are based on monitoring temperature and pressure in complete switchgear cells, density of charged particles, and heat radiation capacity. Such methods received very limited application because they have various drawbacks described in detail in [1]. The device [2] protects complete switchgear cells against ground arc faults but it does not reveal a phase-to-phase fault. The simplest and cheapest way of protecting against a phase to phase short circuit in a complete switchgear cell is overcurrent protection. But it has low speed. The low speed is also typical of undervoltage protection and devices that response to changes in a current waveform and voltage, as well as high-frequency components of current and voltage. Differential busbar protection disables a phase-to-phase fault only in the compartment of buses and breaker cells of a complete switchgear. They are not widely used in the networks of 6-10 kV [3]. Logical protection [4], recently produced by the Russian firm "Mechatronics", ensures fast tripping interphase arcing fault in the compartment of buses and circuit breakers. This protection is in the form of attachment to a traditional one; it is very simple and is performed using simple logic elements. At the same time short circuit in the compartment of transformers and cable harness, where they are most likely to occur, disables with a time-delay. In this paper, this disadvantage has been eliminated.

Principle of operation and selection of device settings

Protection is based on a comparison of unbalanced currents of zero sequence current filters and zero-sequence current transformer (ZSCT) and trip off the damaged connection when:

$$\frac{I_{\text{ub.ct}}}{k \cdot I_{\text{ub.zsct}}} \geq n \qquad (1)$$

where: $I_{\text{ub.ct}}$ и $I_{\text{ub.zsct}}$ – absolute values of unbalance currents of zero sequence currents filter and ZSCT; k – proportionality factor (amplification); n – setting of protection operation..

The factor k is chosen in case of an external three-phase short circuit (short circuit in the cable) $I_{\text{ub.ct}} = I_{\text{ub.zsct}}$,

$$k = \frac{I_{\text{ub.ct}}}{I_{\text{ub.zsct}}} \qquad (2)$$

Unbalance currents $I_{\text{ub.ct}}$ and $I_{\text{ub.zsct}}$ are calculated from the known formulas [7, 9]:

$$I_{\text{ub.ct}} = \frac{\varepsilon \cdot k_{\text{unf}} \cdot k_{\text{ap}} \cdot I_{\text{cab}}}{k_{\text{ct}}} \qquad (3)$$

$$I_{\text{ub.zsct}} = I^{*}_{\text{ub}} \frac{I_{\text{cab}}}{300} \qquad (4)$$

where: ε – error of current transformers; k_{unf} – factor of uniformity of current transformers; k_{ap} – factor of aperiodicity; I_{cab} – current in the cable; k_{ct} – current transformer transformation ratio; I^{*}_{ub} – unbalance current of zero-sequence current transformer when current 300 A flows through the cable [9].

From (2) and (3), assuming, as is customary k_{unf} = 0,5 (k_{unf} = 1) when the device is connected to uniformity (not uniformity) current transformers, k_{ap}=2 and ε=0,1 at the external three-phase short circuit, we obtain:

$$k_{0,5} = \frac{30}{k_{\text{ct}} \cdot I^{*}_{\text{ub}}} \qquad (5)$$

$$k_1 = 2k_{0,5} \qquad (6)$$

where $k_{0,5}$ и k_1 – values of factor k at k_{unf}=0,5 and k_{unf}=1, respectively.

From (1), (5) and (6) we find the maximum possible value of n at the external three-phase short circuit. In this case we accept the total error of calculations and implementing device with a margin of ± 10% (considered that the current obtained from filter of zero sequence currents may increase, and the current from a ZSCT decreases). After simple transformations n=1,22. With the stock we accept n=1,25. It is easy to show that for k_{unf}=1 ratio n has the same value.

Implementation and analysis

Figure 1 shows a principle scheme of a device based on a semiconductor element base. In normal operation of the system current is supplied to the rectifier inputs 12 through the filter 10 from the secondary winding transformer reactor 5, proportional to the current flowing through the neutral conductor current transformers 1, 2 and 3. To the inputs of the rectifier 13 through a filter 11 and amplifier 9, a gain factor of which is selected by (4a) or (4b), current flows from the secondary winding transformer reactor 6 proportional to the unbalance current flowing on the secondary winding 4 of ZSCT caused by an asymmetric arrangement of cable wires in its core. At the outputs of the rectifiers 12 and 13 currents are fed on a sensitive element 14 with no output signal since the ratio of these currents does not exceed the pickup setting (1)

In case of a three-phase short circuit in a point of M the relay of current 7, 8 picks up and the element of time of logical protection (it isn't shown in fig. 1) starts up. When there is no feed from electric motors current is supplied on inputs of the rectifier 12. This current is proportional to unbalance current of a three-transformer filter, it has a bigger value than in a normal mode, and current is not supplied to the outputs of a rectifier 13 since there is no current in the primary chain of ZSCT. Therefore current is supplied to the device 14 and is not supplied to the second one. Therefore (1) is carried out, and a shutdown signal is given to 16. In case when there is feed from electric motors (is not shown) current is supplied to rectifiers 12 and 13. Thus, current is lower on 13 rectifier output, compared to 12 rectifier input, since short circuit current from the system is higher than feed current from electric motors. Therefore, the reacting element 14 starts up, and the output relay 15 gives out a signal. The switch 16 is switched-off without endurance of time. Operation of the device in other modes is considered similarly.

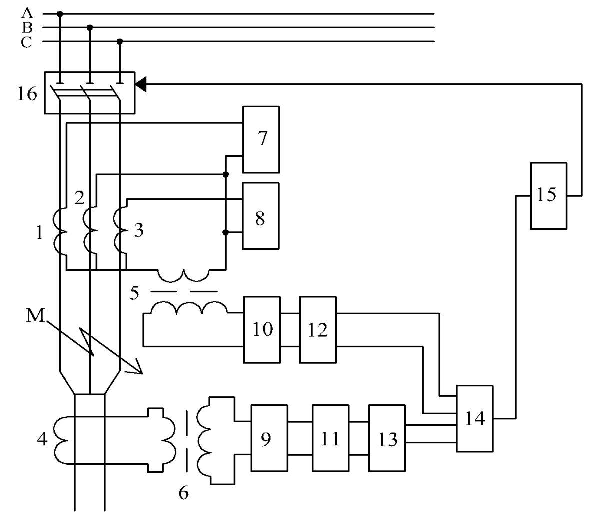

Fig.1. A schematic diagram of a protection device of complete switchgear cells against arc short circuits.

Figure 2 shows a block diagram of the device algorithm of the microprocessor. A setting of protection n, factors k_{unf}, k_{ct} and current I^*_{ub} is introduced. Instant values of three phase currents of i_A, i_B, i_C of accession and current $i_{ub.zsct}$ are processed in parallel. After digital filtering vectors I_A, I_B, I_C and the absolute value $I_{ub.zsct}$ of the specified currents have been found. Absolute value of current $I_{ub.ct}$ has been calculated. Value of k_{unf} is checked. If k_{unf}=0,5, then value of $k_{0,5}$ is calculated. If k_{unf} =1, Then – k_1. Then the inequality (1) is checked at the received coefficient of strengthening. A shutdown switch signal is given.

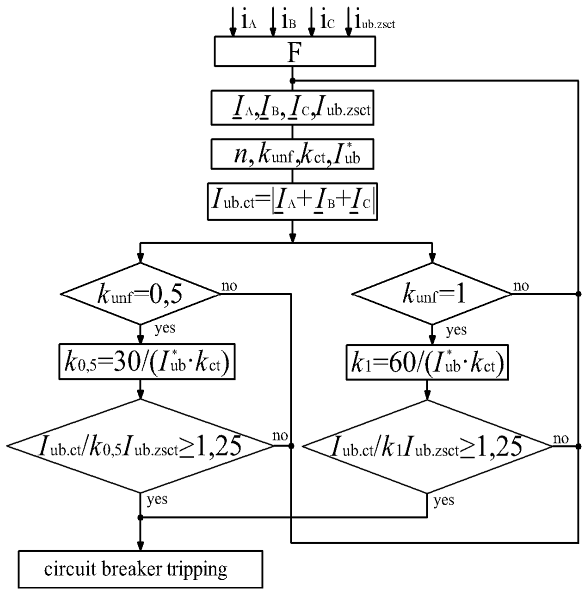

Fig. 2. A schematic diagram of a protection device of complete switchgear cells against arc short circuits.

Sensitivity and area of protection

As a rule [7], sensitivity of protection against interphase short circuits is estimated by a sensitivity factor k_s. In this case for current protection k_s is equal to the relation of the minimum current of short circuits – $I_{cs.min}$ to current of operation of protection, and for high-speed protection $k_s \geq 2$. Arguing similarly, for offered protection at interphase short circuits it is necessary to have

$$\frac{n^{cs}_{min}}{n} \geq 2 \tag{7}$$

where n^{cs}_{min} – minimum possible value of the relation of $I_{ub.zsct}$ to $k\cdot I_{ub.zsct}$ at two-phase short circuits in a protected zone.

We will note that n^{cs}_{min} has different values depending on what loading feeds the cable departing from a protected cell of complete switchgear. The matter is that if the cable doesn't feed electric motors, at two-phase short circuits in a point of M (fig. 1) between considered transformers current, then current in a secondary coil of ZSCT is absent. Thus it is considered, as usual it is accepted, that current is equal in a free phase to zero. Then (7) it is carried out at any sizes of current of short circuits. If the cable feeds the electric motors, current in a secondary coil of TTNP is proportional to current of feed of I_{cf}, and it can appear that (5) isn't carried out. We will find at what $I_{cs.min}$ it is carried out. We define n^{cs}_{min} from (1) at k_{unf} =0,5 and k_{unf} =1, using (3), (4) and (5), (6), and we substitute in (7). We mean thus that in (3) $I_{cab}= I^{(2)}_{min}$ ($I^{(2)}_{min}$ – the minimum current of two-phase short circuits), and in (4) – $I_{cab}= I_{cf}$ =0,9I_{stc} (I_{stc} – starting current of the engine) [10], and the device reduces $I^{(2)}_{min}$ and increases I_{cf} by 10%. After simple transformations we will receive (irrespective of size k_{unf}):

$$I^{(2)}_{min} \geq 2{,}75 \cdot I_{stc} \tag{8}$$

Conclusion

Protection provides shutdown without time endurance of arc interphase short circuits in a compartment of current transformers and cable harness of a complete switchgear cell. It is always sensitive to specified short circuits if a switchgear cable departing from a cell doesn't bear motive loading. Otherwise, demanded sensitivity is provided if the minimum current of two-phase short circuits is 2,75 times higher than starting current of electric motors.

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