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New filters for symetrical current components

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ABSTRACT

Negative- and zero-sequence-current filters based on inductance coil and magnetically operated switch with control winding without the use of current transformers are considered. The technique is presented for the calculation of coordinates of the points where the inductance coil and magnetically operated switch should be mounted for the cases of triangle and parallel arrangements of conductors of three phases of an electrical installation. The main unit for mounting the inductance coil and magnetically operated switch with the control winding near the electrical installation phases conductors is described. The relations for the parameters of filter components are derived. An example of the calculation of these parameters is given.

1. Introduction

Construction of relay protection (RP) without current transformers (CTs) was repeatedly mentioned as an urgent problem at International Conferences on Large Electric Systems (of CIGRE) [1,2]. The use of magnetosensitive elements is one of the ways of the problem solution. Works on the creation of RP on the basis of inductance coils (IC) [3,4], Hall sensors [5], magnetically operated sealed switches (MOS) [6] began in the 1970–80s; later on, magnetic transistors [7] and Rogowski coils [2] were suggested. A preferable RP version will be chosen after the completion of the works and from the operation experience of RP with the above listed sensors. However, most works are far from over. We have selected MOS and IC, since MOSs are commonly used in engineering [8,9] and have some advantages important for RP [6,8,10], and ICs have been used in RP for a long time, including like CTs [4]. This work is devoted to the design of MOS- and IC-based systems capable of operating as filters of symmetrical current components, which are widely used in RP, without the use of CTs.

2. Negative-sequence-current filter (NSCF) in the case of triangle arrangement of phases

The NSCF without CTs suggested includes (Fig. 1) MOS 1 with control winding 2, amplifier 3, phase rotation circuit 4 (PRC), adjusting resistor 5, and IC 6. The MOS and IC are mounted in the magnetic filed of currents IA, IB, and IC in conductors of phases A, B, and C of the electrical installation so as their longitudinal axes are in a plane perpendicular to the conductor axes.

The MOS serves an output relay of the filter; it switches contacts (is actuated) when the induction $\underline{B}_{LA}^{\Sigma}$ of the total magnetic fields, which act along the longitudinal axis of the MOS at the point M—MOS's center of gravity, becomes sufficient for producing magneto-motive force (MMF) F of MOS actuation, i.e., $F\mu_0/l = \underline{B}_{LA}^{\Sigma}$, where l is the coil length of the manufacturer's IC. It is clear that the MOS reacts to I_2, if $\underline{B}_{LA}^{\Sigma} = K_1 I_2$ (K_1 is the coefficient of proportionality). It is obvious that

$$\underline{B}_{LA}^{\Sigma} = \underline{B}_{LA}^{MOS} + \underline{B}_{LA}^{WIND},$$

where $\underline{B}_{LA}^{MOS}$ и $\underline{B}_{LA}^{WIND}$ are the inductions of the magnetic fields (acting along the MOS longitudinal axis) produced by the currents of the electrical installation phases and current in winding 2.

Hence, for the MOS to serves an output relay of NSCF, the device parameters and MOS and IC coordinates near the electrical installation phases should be selected so as to ensure the equality

$$\underline{B}_{LA}^{\Sigma} = \underline{B}_{LA}^{MOS} + \underline{B}_{LA}^{WIND} = K_1 \underline{I}_2 \quad (1)$$

Derivation of the device parameters and MOS and IC coordinates. Let represent $\underline{I}_2$ in Eq. (1) as [11]

Abbreviations: CT, current transformers; IC, inductance coils; MOC, magnetically operated sealed switch; NSCF, negative sequence current filters; ZSCF, zero sequence current filters; NSC, negative sequence current; EMF, electromotive force; FRS, phase rotation circuit; DSC, direct sequence currents

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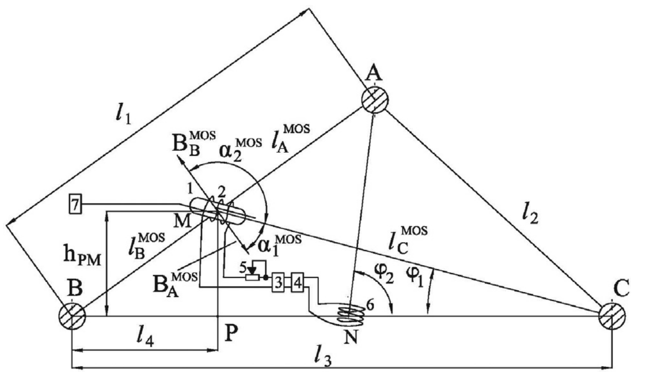

Fig. 1. NSCF in the case triangle arrangement of the electrical installation phases.

$$3\underline{I}_2 = (\underline{I}_A - \underline{I}_B) + (\underline{I}_B - \underline{I}_C)\cdot e^{-j\cdot 60} \quad (2)$$

where $\underline{I}_A$, $\underline{I}_B$, and $\underline{I}_C$ are the total current in the phases A, B, and C; $e^{-j\cdot 60}$ is the complex number that characterizes the counterclockwise 60-degree phase shift.

This representation has been chosen to exclude the effects of magnetic fields produced by zero-sequence-currents to the MOS and IC. When decomposing the phase currents into symmetrical components, the zero-sequence-currents are co-directed in all the phases and compensate each other when subtracting.

Eqs. (1) and (2) show that MOS 1 reacts to current I_2, if the device parameters and MOS and IC coordinates provide for the fulfillment of equations

$$\underline{B}_{LA}^{MOS} = K_1(\underline{I}_A - \underline{I}_B)/3 \quad (3)$$

$$\underline{B}_{LA}^{WIND} = K_1(\underline{I}_B - \underline{I}_C)e^{-j\cdot 60}/3 \quad (4)$$

The induction $\underline{B}_{LA}^{MOS}$ is produced by currents of all the phases; therefore, according to the Biot–Savart–Laplace law and accounting that MOS is affected by the magnetic field of currents of all the three phases,

$$\underline{B}_{LA}^{MOS} = \frac{\mu_0 \underline{I}_A}{2\pi l_A^{MOS}}\cos\alpha_1 + \frac{\mu_0 \underline{I}_B}{2\pi l_B^{MOS}}\cos\alpha_2 + \frac{\mu_0 \underline{I}_C}{2\pi l_C^{MOS}}\cos\alpha_3 = \\ = \underline{B}_A\cos\alpha_1 + \underline{B}_B\cos\alpha_2 + \underline{B}_C\cos\alpha_3 \quad (5)$$

where $\underline{B}_A$ ($\underline{B}_B$ and $\underline{BC}$) is the induction of the magnetic field produced by the current $\underline{I}_A$, ($\underline{I}_B$ and $\underline{I}_C$) at the point M; α_1 (α_2 and α_3) is the angle between the longitudinal axis of MOS and $\underline{B}_A$ ($\underline{B}_B$ and $\underline{B}_C$); l_A^{MOS}, l_B^{MOS}, and l_C^{MOS} are the distances from the conductors of phases A, B, and C, respectively, to the point M; μ_0 is the vacuum permeability; π is the ratio of a circle's circumference to its diameter, π = 3,14.

The analysis of Eqs. (3) and (5) shows that condition (3) fulfils if

$$K_1 = \frac{\mu_0}{2\pi l_A^{MOS}}\cos\alpha_1^{MOS} = -\frac{\mu_0}{2\pi l_B^{MOS}}\cos\alpha_2^{MOS} \\ \text{and} \quad \frac{\mu_0}{2\pi l_C^{MOS}}\cos\alpha_3^{MOS} = 0 \quad (6)$$

As for condition (4), its fulfillment is supported by corresponding coordinates of IC, the amplification coefficient K_A of amplifier 3 (Fig. 1), and calculations of the angle β_{PRC} of phase angle circuit (4). The induction $\underline{B}_{LA}^{WIND}$is produced by the current I_{out} in control winding 2; I_{out} is produced by the electro-motive force (EMF) E at the leads of IC 6, and E is produced by the flux Φ (produced by the currents of the three phases) with the magnetic induction $\underline{B}_{LA}^{IC}$acting along the longitudinal axis of IC. Finally,

$$\underline{B}_{LA}^{WIND} = K_2\underline{B}_{LA}^{IC} \quad (7)$$

The formulas that connect all these parameters, as well as the coefficient K_2, are well known and are given in Appendix A.

Let us note that the induction $\underline{B}_{LA}^{IC}$is represented by similar formulas (with the corresponding angles and distances, denoted below by the superscript IC); l_A, l_B, l_C, α_1, α_2, and α_3 below mean values different from the above considered and proper for each filter, as well as the parameters of their components.

Induction $\underline{B}_{LA}^{WIND}$ (7) should coincide with $\underline{B}_{LA}^{WIND}$ (4); therefore,

$$K_1(\underline{I}_B - \underline{I}_C)e^{-j\cdot 60}/3 = K_2\underline{B}_{LA}^{IC} \quad (8)$$

Let us consider Eq. (8) as an equation in terms of K_A and β_{PRC} which enter into K_2 (see Section A). The right part of the equation should be proportional to the difference ($\underline{I}_B$ - $\underline{I}_C$) to be reduced to it (otherwise, the equation turns out to be undetermined). For $\underline{B}_{LA}^{IC} = K_3(\underline{I}_- \underline{I}_C)$, where K_3 is the coefficient of proportionality, it is sufficient to satisfy conditions similar to (6):

$$K_3 = \frac{\mu_0}{2\pi l_B^{IC}}\cos\alpha_2^{IC} = -\frac{\mu_0}{2\pi l_C^{IC}}\cos\alpha_3^{IC} \\ \text{and} \quad \frac{\mu_0}{2\pi l_A^{IC}}\cos\alpha_1^{IC} = 0 \quad (9)$$

Substituting K_1 from Eq. (6), K_2 from Eq. (A.3), and K_3 into Eq. (8) and transforming, we derive an equation, from which β_{PRC} and then K_A can be found: $\beta_{PRC} = 30^\circ + \varphi$, since real multipliers are in one part of the equation, and multipliers represented by e in powers that include φ, β_{PRC}, -60°, and -90° are in another part.

The MOS and IC should be mounted at the points M and N on the plane ABC (Fig. 1), which is perpendicular to the axes of the electrical installation phase conductors, and satisfy safety requirements for conditions (6) and (9) to fulfill. They fulfill strictly if the MOS and IC are centered at sides AB and BC.

For the convenience of mounting the MOS at the point M, the length of the segment l_4 (Fig. 1) and height PM = h_{PM} in the triangle BMC should be determined. The interphase distances l_1, l_2, and l_3 known at any arrangement are considered as initial data. Then, using the aspect ratio in the triangles ABM, ACM, and MBC, after simple transformations, we derive

$$a)\ l_4 = \frac{l_1^2 + l_3^2 - l_2^2}{4l_3}, \qquad b)\ h_{PM} = \frac{\sqrt{4l_1^2 l_3^2 - (l_1^2 + l_3^2 - l_2^2)^2}}{4l_3}.$$

After fixing MOS 1 and IC 6 at the points M and N with the use of corresponding constructions [12], MOS 1 and IC 6 are rotated so as their longitudinal axes coincide with the straight lines passing through the points M and C and N and B.

Let us consider NSCF operation. During two-phase shorts (SC), negative-sequence currents $\underline{I}_{A2}$, $\underline{I}_{B2}$, and $\underline{I}_{C2}$ run through the electrical installation phase conductors. They are representable as $\underline{I}_{A2} = I_2 e^{j0^0}$, , and $\underline{I}_{C2} = I_2 e^{-j120^0}$($e^{j0}$, e^{j120}, and e^{-j120} are the complex numbers, which correspond to the clockwise 0- and 120-degree and counterclockwise 120-degree phase shifts). Let substitute them in Eq. (2) instead of $\underline{I}_A$, $\underline{I}_B$, and $\underline{I}_C$. Then Eqs. (1) and (3) with accounting for Eqs. (4) and (6) imply $\underline{B}_{LA}^{\Sigma} = \mu_0(\cos\alpha_1^{MOS1}/l_A^{MOS1})\underline{I}_2/2\pi$, MOS 1 acts, switches the contacts on, and feds a signal to actuator 7 (see Fig. 1). Zero-sequence currents $\underline{I}_{A0} = \underline{I}_{B0} = \underline{I}_{C0}$ run through the conductors of phases A, B, and C of the faulty electrical installation during SC. However, as seen from Eqs. (3) and (4), if $\underline{I}_{A0}$, $\underline{I}_{B0}$, and $\underline{I}_{C0}$ are substituted for $\underline{I}_A$, $\underline{I}_B$, and $\underline{I}_C$, then $\underline{B}_{LA}^{\Sigma} = 0$, and they affect neither MOS no IC. During two-phase and single-phase SC, positive-sequence currents $\underline{I}_{A1}$, $\underline{I}_{B1}$, and $\underline{I}_{C1}$ also run through the phase conductors. But the field produced by them affects neither MOS with winding no IC. It is easily seen if substituting $\underline{I}_{A1} = I_1 e^{j0^0}$, $\underline{I}_{B1} = I_1 e^{-j120^0}$, and $\underline{I}_{C1} = I_1 e^{j120^0}$into Eq. (2) for $\underline{I}_A$, $\underline{I}_B$, and $\underline{I}_C$. Thus, a signal at the exit of the filter suggested is generated only in the case of faults of the electrical installation accompanied by $\underline{I}_2$ currents.

3. Zero-sequence-current filter (ZSCF) in the case of triangle arrangement of phase conductors

Zero-sequence-current filter (ZSCF) [13] in the case of triangle arrangement of phase conductors can be constructed on the basis of a MOS without IC. Let us show this. Eq. (5) implies that $\underline{B}_{LA}^{MOS} = 3K_4\underline{I}_0$, if