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INFORMATIONAL FUNDAMENTALS OF THE MULTIPARAMETER DIFFERENTIAL PROTECTION OF BUSBAR GENERATORS AGAINST SINGLE LINE-TO-GROUND FAULTS

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The multiparameter differential protection of busbar generators against single line-to-ground faults (SLGF) is studied in accordance with information theory of protection. Such protection is based on the use of the individuality property of harmonic groups. Moreover, it controls many parameters of the higher harmonics of differential currents and is shown to have absolute selectivity. Given the properties of the harmonics of some groups, this perfection is achieved to maintain the aggregate information support of protection at a high level with SLGF in areas where the harmonics of other groups are insufficient. Depending on network parameters and modes, multiparameter differential protection does not require settings or adjustments. This advantage is provided by using relative characteristic values that are generated by the protection during operation. Such protection is sensitive due to a special active-adaptive recognition path, which can measure low-level harmonics against a background of the predominant component of the fundamental harmonic in the current.

Keywords: information signals of protection; information theory of protection; generator single line-to-ground fault; multiparameter differential generator protection.

The peculiarity of protection against single line-to-ground faults (SLGF) in the stator coil of busbar generators (hereinafter referred to as generators) is caused by the specificity of the generator network connection circuit. First, galvanic coupling with the network and other generators operating in parallel complicates the task of ensuring the selectivity of protection. Second, ground faults do not lead to remarkable changes in the phase currents of the generator being protected; thus, the necessary sensitivity of protection against SLGF is not achieved [1]. In such networks, algorithms based on the use of higher harmonics produced by the network are effective as information signals [2].

In [3], harmonics were proposed to be divided into groups (first, second, and zero), and the elements of each are characterized by a unique individuality property, which is manifested in the original nature of the dependence of their level on the SLGF location. The information content of harmonics of one group enriches the informational value of harmonics of another group by increasing the sensitivity and selectivity of protection. The use of the individuality property of harmonic groups is especially vital for protection against generator SLGF because it can fully reveal the potential of higher harmonics and thus can ensure the selectivity of detecting SLGF at any point on the generator stator coil.

This article presents a study on multiparameter protection against generator SLGF on the basis of the use of the individuality property of harmonic groups and by controlling the set of parameters of the higher harmonics of the differential current [4].

Protection is studied in the context of information theory of protection algorithms [1 – 5] in which cornerstone is the concept of an information signal. The information signal is understood to be the term of the electric quantity allocated by the protection and used by its algorithm. On this basis, the present study aims to analyze the information signals during the protection recognition task of network modes and the principles of the allocation and use of information signals during protection to assess its selectivity and sensitivity.

Analysis of information signals of protection. The information signals of the multiparameter differential protec-

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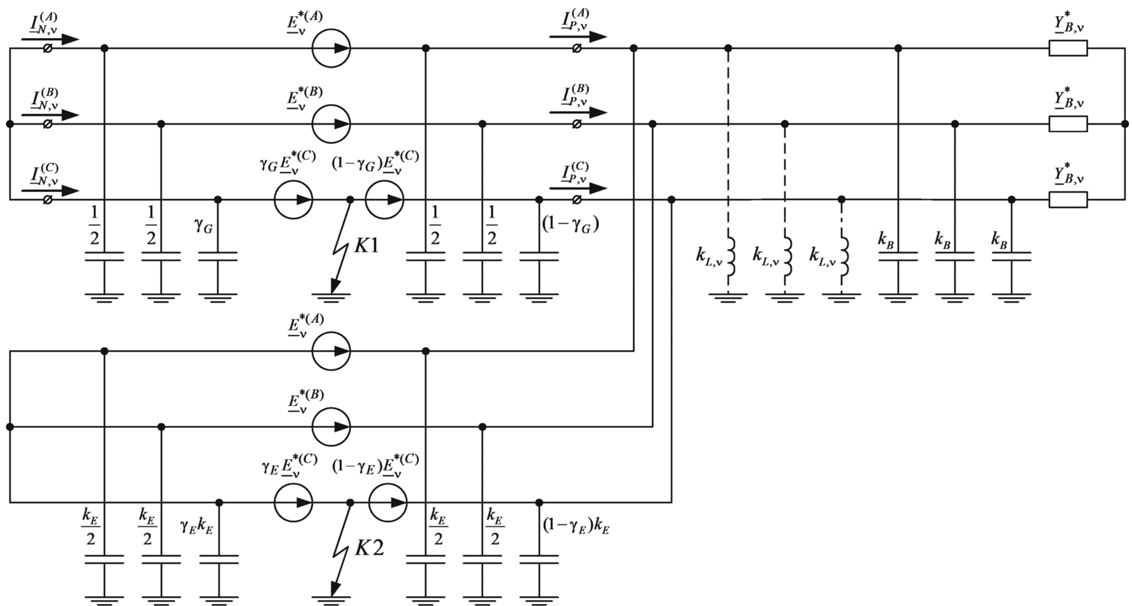

Fig. 1. Universal model of the generator network.

tion of generators against SLGF are the harmonics of currents of the transverse branches of the generator being protected. In the normal mode and with external SLGF, these currents include the phase-capacitive currents of the generator being protected. In the internal SLGF mode and damaged phase, a branch connects the generator winding to the ground, and numerous information signals are supplemented by a current in the location of the SLGF. The currents of the transverse branches are impossible to measure directly, but they can be determined through calculation as follows:

$$\underline{I}^{(\chi)}_{\Delta,\nu} = \underline{I}^{(\chi)}_{P,\nu} - {}^{(\chi)}_{N,\nu}, \quad (1)$$

where $\underline{I}^{(\chi)}_{N(P),\nu}$ is the complex effective value of the current of the νth harmonic of phase $\chi = \overline{A,B,C}$ of the generator being protected. Hereinafter, the lower indices N and P denote the currents from the neutral and phase terminals, respectively.

The information signals are analyzed for the normal mode of network operation and for SLGF modes in protected (internal SLGF) and equivalent (external SLGF) generators at different distances from their neutral terminals. The analysis tool is a universal network model (Fig. 1). In the universal model, the generator network is equivalent to the terminals of the generator being protected. All the network elements generating the harmonic under consideration are equivalent and considered in the universal model by an equivalent generator. Meanwhile, arc-suppression coils are considered by an equivalent reactor, whereas the remaining network elements are considered by an equivalent load.

The calculated equations for the parameters of the universal model, as well as the assumptions made, are considered in [5] as $\underline{I}^{*(\chi)}_{\nu}$, which is the relative complex effective value of the electromotive force of the νth harmonic of the phase χ; $\underline{I}^{*}_{B,\nu}$ is the relative complex longitudinal conductivity of the equivalent load phase at the νth harmonic; k_E and k_B are relative values of the transverse capacitances of the phases of the equivalent generator and equivalent load, respectively; $k_{L,\nu}$ is the relative conductivity of the phase of the equivalent arc-suppression coil at the νth harmonic; γ_G and γ_E are the relative electrical distances from the neutral to the SLGF location in the protected (*K1*) and equivalent (*K2*) generators, respectively.

In accordance with Eq. (1), the universal network model is transformed into the corresponding equivalent circuit on the basis of the considered network mode and the current harmonic analyzed. In the equivalent circuit, the electromotive force of the νth harmonic of the special phase of the protected generator and its own capacitive conductivity at the νth harmonic are taken as the base values of voltage and conductivity.

In consideration of the individuality property of the harmonic groups [3], analyzing the informational signals of protection for harmonics 3 and 5, which respectively represent the zero and second groups of harmonics, is enough; the findings can then be extended to another harmonic. The complex effective value of the intrinsic capacitive current of the generator being protected is taken as the basic value of the νth harmonic of the differential current $\underline{I}_{\text{base},\nu}$ at the corresponding harmonic,

$$\underline{I}_{\text{base},\nu} = j\nu\omega_1 C_G \underline{E}^{(f)}_{\nu}, \quad (2)$$

where ω_1 is the angular frequency of the fundamental harmonic, C_G is the transverse capacity of the generator being protected, and $\underline{I}^{(f)}_{\nu}$ is the complex effective value of the electromotive force of the νth harmonic of the special phase f. The damaged phase is taken as a special phase.

Analytical expressions for the calculation of the relative values of harmonics 3 and 5 of the differential currents of the protected generator [2, 3] in the considered operating modes of the generator network are summarized in Table 1.

In the normal mode, the levels of the same-name higher harmonics in the differential currents of all phases are equal. In addition, the level of harmonic 5 $(I^{(\chi)}_{\Delta,5})_{\rm norm}$ is completely determined by the intrinsic capacitive current of the protected generator, and the level of harmonic 3 $(I^{(\chi)}_{\Delta,3})_{\rm norm}$ is determined by the capacitive conductivities of the equivalent load k_B and the equivalent generator k_E (Fig. 2). The larger the capacitive conductivity of the equivalent load ($k_B \to \infty$), the closer the level of harmonic 3 of the differential phase current to the intrinsic capacitive current of the protected generator $[(I^{(\chi)}_{\Delta,5})_{\rm norm} \to 1/2]$.

With an external SLGF, the level of any of the harmonics of the phase differential current is determined only by the intrinsic capacitive current of the protected generator and depends on the damage location. Moreover, the harmonic 3 level $(I^{(\chi)}_{\Delta,3})_{\rm ext}$ becomes identical in all phases (Fig. 3*a*) and decreases as the SLGF location approaches the middle of the equivalent generator winding. In a special phase, the nature of the dependence of harmonics 3 $(I^{(f)}_{\Delta,3})_{\rm ext}$ and 5 $(I^{(f)}_{\Delta,5})_{\rm ext}$ of currents from the SLGF location is identical. In adjacent phases, the level of harmonic 5 of the current $(I^{(\sigma)}_{\Delta,5})_{\rm ext}$ alters the nature of its variation and grows with the increase in the distance of the SLGF from the neutral of the equivalent generator; thus, more than the level of the corresponding harmonic remains in a particular phase $(I^{(f)}_{\Delta,5})_{\rm ext}$ (Fig. 3*a*).

With internal and external SLGF, the levels and nature of the dependencies of the information signals $I^{(\sigma)}_{\Delta,3}$ and $I^{(\sigma)}_{\Delta,5}$ in the intact phases from the location of SLGF are equal

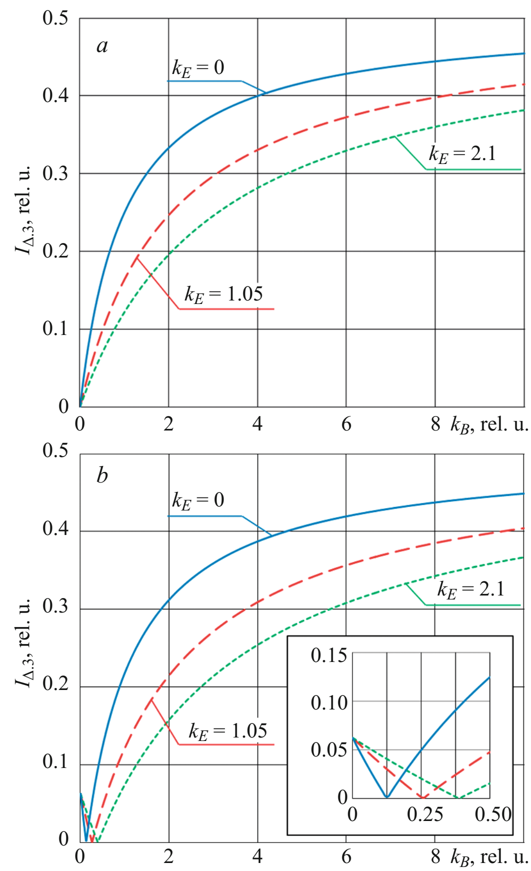

Fig. 2. Level of harmonic 3 of the differential current of the protected generator in the normal mode of the network: *a*, with isolated neutral ($k_R = 0$); *b*, with compensated neutral ($k_R = 1$).

(Fig. 3). However, *with internal SLGF* in the damaged phase, the level of harmonic 5 of the current $(I^{(f)}_{\Delta,5})_{\rm int}$ increases with the increase in the distance of SLGF from the neutral of the generator being protected; moreover, the level of harmonic 3 $(I^{(f)}_{\Delta,3})_{\rm int}$ is equal to zero with an SLGF in the middle part of

TABLE 1. Higher Harmonics of the Differential Currents of the Phases of the Protected Generator in the Normal and External and Internal SLGF Modes

Harmonic current	Special phase ($\chi = f$)	Adjacent phases ($\chi = \sigma$)
$(\underline{I}^{(\chi)}_{\Delta,3})_{\rm norm}$	$\frac{1}{2} - \frac{1+k_E}{2(1+k_E+k_B)(1-k_{R,3})}$	
$(\underline{I}^{(\chi)}_{\Delta,5})_{\rm norm}$	$-1/2$	$-\underline{a}^{5\lambda}/2$
$(\underline{I}^{(\chi)}_{\Delta,3})_{\rm ext}$	$\gamma_E - 1/2$	
$(\underline{I}^{(\chi)}_{\Delta,5})_{\rm ext}$	$\gamma_E - 1/2$	$\gamma_E - \underline{a}^{5\lambda}/2$
$(\underline{I}^{(\chi)}_{\Delta,3})_{\rm int}$	$(1-\gamma_G)[3(1+k_E+k_B)(1-k_{R,3})-1]-1-3k_E/2$	$\gamma_G - 1/2$
$(\underline{I}^{(\chi)}_{\Delta,5})_{\rm int}$	$-\gamma_G[3(1+k_E+k_B)(1-k_{R,5})-1]-1/2$	$\gamma_G - \underline{a}^{5\lambda}/2$

Note. $\underline{I}^{(\chi)}_{\Delta,\nu}$ is the complex effective value of the νth harmonic of the differential current of the phase χ; $k_{R,\nu} = k_R/\nu^2$ is the degree of compensation of the capacitive current of the network at the νth harmonic; k_R is the degree of compensation of the capacitive current of the network on the fundamental harmonic; $\underline{a} = e^{j120°}$ is the complex rotation operator; $\lambda = 1$ for the leading phase ($\sigma = f + 1$); $\lambda = 2$ for the lagging phase ($\sigma = f - 1$); norm, int, and ext are indices corresponding to the normal and internal and external SLGF modes, respectively.

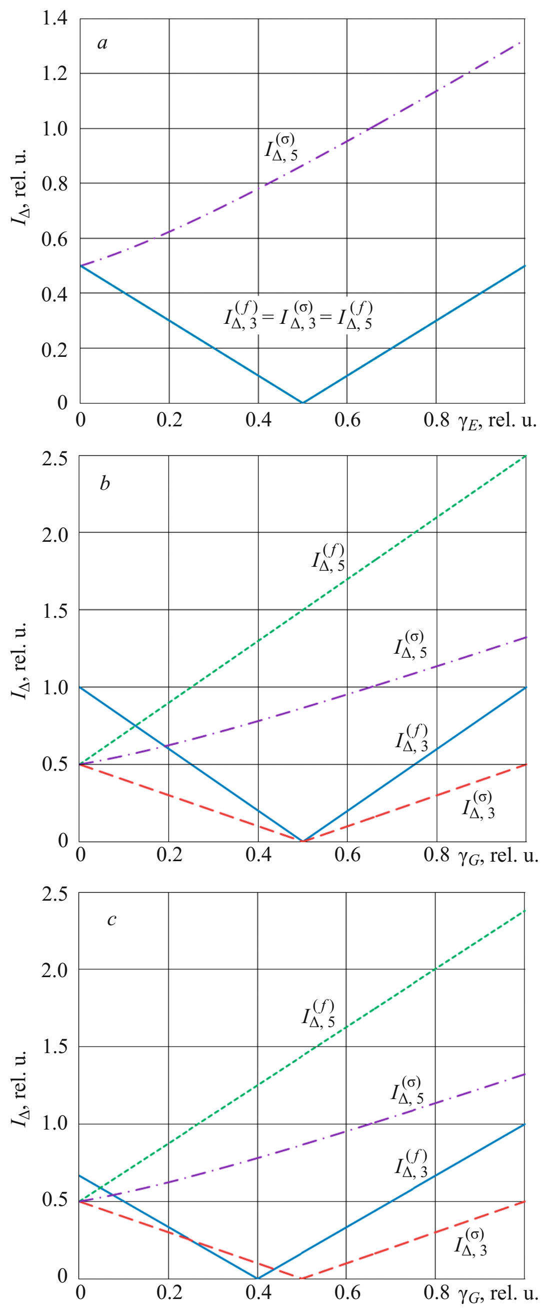

Fig. 3. Harmonic levels of the differential currents of the phases of the generator being protected, depending on the SLGF location with the minimum network capacity ($k_E = 0$, $k_B = 0$): *a*, external SLGF mode; *b*, internal SLGF mode in the network with isolated neutral ($k_R = 0$); *c*, internal SLGF mode in the network with compensated neutral ($k_R = 1$).

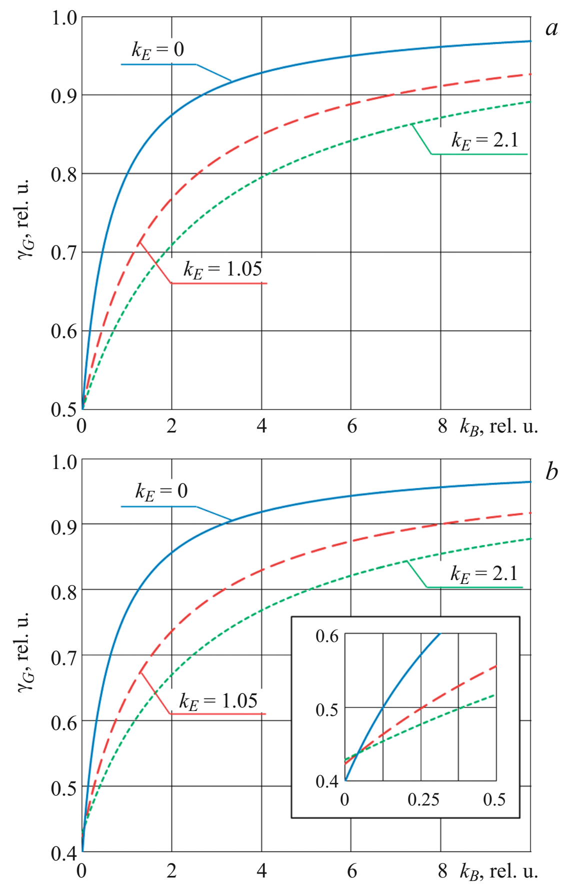

Fig. 4. Graphs of the dependence of the distance to the internal SLGF location (where the level of the harmonic 3 of the differential current of the damaged phase of the protected generator is zero) on the network capacity: *a*, with isolated neutral ($k_R = 0$); *b*, with compensated neutral ($k_R = 1$).

the winding and its growth when removed from it. The harmonic 5 level of the differential current of the damaged phase $(I_{\Delta,5}^{(f)})_{\text{int}}$ with SLGF near the neutral is determined only by the capacitive conductivity of the generator being protected. When the SLGF location is removed from the neutral, it depends increasingly on the capacitive conductivities of the equivalent generator and the load.

The level of the harmonic 3 of the differential current of the damaged phase $(I_{\Delta,3}^{(f)})_{\text{int}}$ with SLGF near the neutral of the protected generator depends on the value of the capacitive conductivities of the equivalent generator and the load and grows with its increase; with SLGF on the phase terminals, it depends only on the capacitive conductivities of the generators. Therefore, with an increase in the capacitive conductivity of the equivalent load k_B, the SLGF location where the level of the harmonic 3 of the differential current of the damaged phase is zero $[(I_{\Delta,3}^{(f)})_{\text{int}} = 0]$ is displaced toward the phase terminals of the protected generator ($\gamma_G > 1$) (Fig. 4).

The neutral grounding mode of the network does not fundamentally affect the distribution of higher harmonics of currents in the network (Fig. 3) but changes only slightly the harmonics of the differential current of the damaged phase depending on internal SLGF location.

The analysis of information signals (Fig. 3) shows that with SLGF in the central part of the winding, where the harmonics of the zero group have a low-level, the harmonics of the first (second) group undertake information support to recognize the network operating mode. Given this property of harmonics, the protection of the generator against SLGF can recognize the operating mode of the network by comparing the same-name harmonics of the differential currents of the phases.

Analysis of the principle of action of protection. In the multiparameter differential protection against SLGF in the generator stator winding [4], the harmonic levels of the emergency components of the differential currents of the phases are controlled.

$$\underline{\xi}_{\nu}^{(\chi)} = \underline{I}_{\Delta,\nu}^{(\chi)} - (\underline{I}_{\Delta,\nu}^{(\chi)})_{\text{pr}}, \quad (3)$$

where "pr" is an index indicating the network operation mode preceding the SLGF.

For each νth harmonic, a characteristic value ζ_{ν} is formed as the ratio of the maximum and median of the effective values of the phase-controlled quantities of Eq. (3) of the corresponding harmonic.

$$\zeta_{\nu} = \frac{\max(\xi_{\nu}^{(A)}, \xi_{\nu}^{(B)}, \xi_{\nu}^{(C)})}{\text{mid}(\xi_{\nu}^{(A)}, \xi_{\nu}^{(B)}, \xi_{\nu}^{(C)})}. \quad (4)$$

The characteristic value ζ_{ν} is compared with the corresponding response threshold $\zeta_{\text{th},\nu}$. Therefore, general protection has many triggering channels, which form an individual feature of SLGF for each νth harmonic.

$$s_{\nu} = \begin{cases} 1, \zeta_{\nu} \geq \zeta_{th,\nu}; \\ 0, \zeta_{\nu} < \zeta_{th,\nu}. \end{cases} \quad (5)$$

A common feature of SLGF protection

$$S = \underset{\nu=3,5,\ldots}{W} s_{\nu} \quad (6)$$

is formed by the disjunction of individual features of SLGF in accordance with Eq. (5).

Protection is not intended for operation with multiphase faults. Therefore, it is taken out of operation by the signal of actuation of the starting element of the second stage of the maximum current protection of the generator or when the level of the fundamental harmonic exceeds the direct sequence current, for example, a twofold value of the nominal current of the generator.

Protection triggering settings. In accordance with Eqs. (4) and (5), protection is triggered if, for any of the harmonics, the controlled quantity of Eq. (3) in one phase is greater than that in other phases by a specified number of times, as determined by setting ζ_{ν}.

Here, the controlled values of Eq. (3) in the phases of the protected generator in the normal and external and internal SLGF modes are analyzed. We proceed from the assumption that the previous mode of the network is in normal mode; then

$$(\underline{I}_{\Delta,\nu}^{(\chi)})_{\text{pr}} = (\underline{I}_{\Delta,\nu}^{(\chi)})_{\text{norm}}. \quad (7)$$

In consideration of Eq. (7), the calculated expressions of the harmonics of the controlled quantities of Eq. (3) in various network operation modes are summarized in Table 2.

According to Table 2, the same-name harmonics of the controlled currents of all phases are equal to zero in the normal mode and equal to each other in the external SLGF mode. Thus, the protection becomes theoretically devoid of excessive triggering in the normal and external SLGF modes for any

$$\zeta_{\text{th},\nu} > 1. \quad (8)$$

With internal SLGFs, the level of the controlled value of the νth harmonic of Eq. (3) in the damaged phase exceedingly multiplies the controlled value level of the corresponding harmonic in the intact phase. The repetition factor

$$K_{\nu} = 3(1 + k_E + k_B)(1 - k_{R,\nu}) - 1 \quad (9)$$

is equal to the total transverse conductivity of the entire network, except for the capacitive conductivity of the damaged phase of the protected generator. Hence, considering Eqs. (4)

TABLE 2. Higher Harmonics of the Emergency Components of the Differential Phase Currents of the Protected Generator in the Normal and External and Internal SLGF Modes

Emergency component	Special phase ($\chi = f$)	Adjacent phases ($\chi = \sigma$)
$(\underline{I}_3^{(\chi)})_{\text{norm}}$	0	
$(\underline{I}_5^{(\chi)})_{\text{norm}}$	0	
$(\underline{I}_3^{(\chi)})_{\text{ext}}$	$\gamma_E - 1 + \frac{1 + k_E}{2(1 + k_E + k_B)(1 - k_{R,3})}$	
$(\underline{I}_5^{(\chi)})_{\text{ext}}$	γ_E	
$(\underline{I}_3^{(\chi)})_{\text{int}}$	$-K_{\nu}\left[\gamma_G - 1 + \frac{1 + k_E}{2(1 + k_E + k_B)(1 - k_{R,3})}\right]$	$\gamma_G - 1 + \frac{1 + k_E}{2(1 + k_E + k_B)(1 - k_{R,3})}$
$(\underline{I}_5^{(\chi)})_{\text{int}}$	$-\gamma_G K_{\nu}$	γ_G

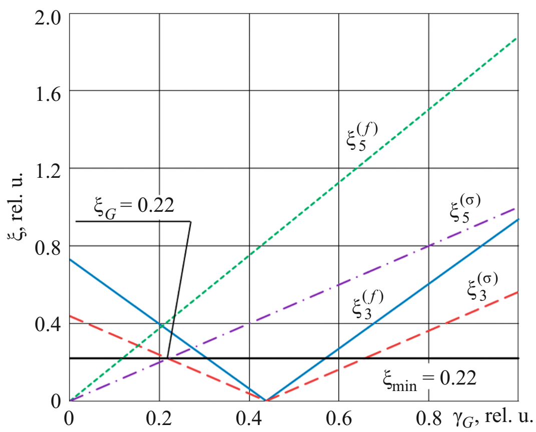

Fig. 5. Levels of the controlled values of Eq. (3) of the damaged and intact phases of the protected generator for harmonics 3 and 5 in the calculated mode of the network with compensated neutral.

and (5), protection is theoretically sensitive to internal SLGFs for any

$$\zeta_{th,\nu} < K_\nu. \quad (10)$$

The level of monitored values of Eq. (3) generally depends on the capacity of the network; thus, from the point of view of ensuring the sensitivity of protection, the calculated mode is the operation of the network with minimum capacitive conductivity ($k_E = 0$, $k_B = 0$). In this case, the multiplicity of the controlled values in the damaged and intact phases according to Eq. (9) is minimal and equal to

$$K_{\nu,\min} = 2 - 3k_{R,\nu}. \quad (11)$$

The degree of compensation of the capacitive current of the network $k_{R,\nu}$ depends on the neutral grounding mode. For a network with isolated neutral ($k_{R,\nu} = 0$), the coefficients of multiplicity K_ν by Eq. (9) are equal for all harmonics. Furthermore, considering Eqs. (8), (10), and (11), the settings $\zeta_{th,\nu}$ under the condition of operation in accordance with Eq. (5) must be in the following range:

$$1 < \zeta_{th,\nu} < 2. \quad (12)$$

In the network with compensated neutral, the degree of compensation of the capacitive current is $0 < k_{R,\nu} < 1$ and decreases with the increase in harmonic number. Assuming that the SLGF current of the fundamental harmonic is fully compensated ($k_R = 1$), we obtain the values of the compensation coefficients for the remaining harmonics $k_{R,3} \approx 0.11$, $k_{R,5} = 0.04$, $k_{R,7} \approx 0.02$. In this case, according to Eqs. (8), (10) and (11), the values of the settings $\zeta_{th,\nu}$ should be in the following ranges:

$$1 < \zeta_{th,3} < 1{,}66;\ 1 < \zeta_{th,5} < 1{,}88;\ 1 < \zeta_{th,7} < 1{,}94. \quad (13)$$

On the basis of the neutral mode of the network at the stage of protection design, the values of the operation thresholds $\zeta_{th,\nu}$ are recommended to be equal to the values of the middle of the ranges according to Eqs. (12) and (13).

Calculation of protection sensitivity. Table 2 shows that the controlled values are reduced to zero when the SLGF is located at certain points of the stator winding of the generator. Therefore, with SLGF, the controlled quantities of Eq. (3) experience a considerable influence of measurement errors in a certain neighborhood of these points; therefore, the protection may have a false response. To avoid such situations, protection should block the operation in the νth channel with a reduced level of the controlled values of Eq. (3) to the current of the accurate operation at the νth harmonic ($\xi_{\min,\nu}$).

$$\xi_\nu^{(\chi)} < \xi_{min,\nu}. \quad (14)$$

As a result, a dead band appears in the region of small values of controlled quantities for each harmonic channel. Moreover, its location within the stator winding of the generator is different for the harmonics of the zero and first (second) groups (Fig. 5).

The levels of the controlled quantities of Eq. (3) for the harmonics of the first and second groups are equal to zero at the SLGF in the neutral of the generator and increase as the SLGF location approaches the phase terminals of the generator. This circumstance explains the location of the dead band for the harmonic channels of the first and second groups near the neutral of the generator being protected.

The levels of the controlled values for the harmonics of the zero group are zero with SLGF in the middle part of the generator winding and increase as SLGF approaches its terminals. When the level of the controlled quantity is equal to zero, the location of the SLGF depends largely on the relative capacitive conductivity of the equivalent load and is close to the phase terminals of the generator for networks with high capacitive conductivity. In the design mode of the network with compensated neutrals ($k_E = 0$, $k_B = 0$, $k_R = 1$), the dead band for the harmonics of the zero group is located in the middle part of the stator winding. With an increase in the capacitive conductivity of the equivalent load, the dead band becomes narrow and shifts toward the generator phase terminals.

The width of the dead band is determined by the level of the controlled value in the intact phase because it is less than the corresponding value of the damaged phase. By considering the equations for the controlled quantities in the intact phase together with the internal SLGF (Table 2) and Eq. (14), the limits of the dead band of the protection for harmonic 3

$$0.44 - \xi_{\min,3} < \gamma_G < 0.44 + \xi_{\min,3} \quad (15)$$

and harmonic 5

$$0 \le \gamma_G < \xi_{\min,5} \tag{16}$$

can be determined.

To ensure the sensitivity of protection against SLGF at any point of the stator winding of the generator, the dead bands according to the harmonics of the first (second) [Eq.(15)] and zero [Eq. (16)] groups must not intersect. Eqs. (15) and (16) reveal that the requirements for sensitivity of protection can be provided for various combinations of the values $\xi_{\min,\nu}$ of individual harmonics. For example, when using harmonics 3 and 5 in protection, having an effective current of no more than 22% of the base value [Eq. (2)] of the corresponding harmonic (i.e., $\xi_{\min,\nu} < 0.22$) for each of these harmonics is enough.

Working with intermittent arc faults (IAF). IAFs are characterized by repetitive transient processes in the network with a high level of rapidly decaying high-frequency free components in electrical quantities [6]. The ratios of the levels of free components in the controlled quantities of Eq. (3) of the damaged and intact phases at external and internal IAFs are similar to those for harmonics. Therefore, the protection also retains sensitivity and selectivity in IAF. The decay time of the free component currents is short and can be less than 1 msec; thus, IAF detection in digital relay protection and automation requires an increased sampling frequency (more than 4000 Hz).

The sign of SLGF [Eq. (6)] appears periodically during IAF; therefore, an additional channel is provided in the protection that controls the frequency and number of its occurrences. To adjust nonrepeating transient processes in the electric network (e.g., those caused by the equipment switching action), the protection acts for the generation shedding with a time delay, whose value is usually equal to 0.5 sec.

Thus, the multiparameter protection of the generator against SLGF becomes sensitive and selective in all network operation modes while ensuring proper measurement accuracy of higher harmonics in differential currents.

Isolation of information signals. The input protection signals are either currents $i_{N(P)}^{(\chi)}(t)$, measured near the inputs and neutrals of all the generator phases or differential currents

$$i_{\Delta}^{(\sigma)}(t) = i_P^{(\sigma)}(t) - i_N^{(\sigma)}(t), \tag{17}$$

where t is continuous time.

The use of differential currents as input signals in analog form according to Eq. (17) is preferable because it improves the conditions for the recognition of the information signals of higher harmonics by Eq. (1). This phenomenon is explained by the fact that in differential currents according to Eq. (17), the level of the component of the load currents is theoretically equal to zero, thus increasing the ratio of the levels of higher and fundamental harmonics and improving the conditions for the analog-to-digital conversion (ADC) of currents according to Eq. (17).

The advantage of measuring differential currents according to Eq. (17) can be fully implemented only if the same type of current transformers is installed on the neutral side and phase terminals of the generator. In the absence of this possibility, the differential current is calculated in the protection by the digitized phase currents $i_{N(P)}^{(\chi)}(k)$ (k is the number of counts of the electrical quantity at a discrete time $t_k = kT_s$, T_s is the sampling period of the electrical quantity).

If the sources of higher harmonics are synchronous generators, then harmonic 3 is most significant among the harmonics of the zero group, and harmonics 5 or 7 are most significant among the harmonics of the second or first group, respectively, depending on the design aspects of the generator [7]. Therefore, harmonics 3, 5, and 7 should generally be controlled in the protection. If the network comprises sources of harmonics of a higher order (for example, equipment based on power electronics with nonlinear characteristics), then the information basis of protection can be expanded to increase sensitivity at the expense of the harmonics of such sources.

Estimates of information signals contain errors that result from errors in the measurement paths, including current transformers and ADCs [8]. The presence of errors in the estimates of information signals affects the sensitivity and selectivity of protection and is considered using the parameter $\xi_{\min,\nu}$ at implementation stage of protection in a particular device.

The levels of higher harmonics are substantially lower than that of the fundamental harmonic of the current, and the frequency of the generator network varies widely; thus, the estimation of information signals requires the use of contemporary methods of digital signal processing [9] and adaptive structural analysis [10 – 12]. For the multiparameter differential protection of the generator against SLGF, a special active-adaptive ADC path [13] that recognizes the weak terms of an electrical quantity with high accuracy has been developed under conditions of structural uncertainty [14].

CONCLUSIONS

1. Based on the use of the plurality of harmonics of the network currents, the multiparameter differential protection of the busbar generator against SLGF has absolute selectivity. This perfection is achieved due to the properties of the harmonics of some groups to maintain the aggregate informational support of protection at a high level at SLGF in zones where the level of harmonics of other groups is insufficiently high.

2. Depending on parameters and network modes, protection does not have settings and adjustments. This advantage is ensured by using the relative characteristic values formed by the protection during operation.

3. The high sensitivity of protection is provided by a special active-adaptive recognition path that can measure low-level harmonics against a background of the predominant component of the fundamental harmonic in the current.

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