Selected problems of operation of synchronous generators in fuel-electric generating sets

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The paper presents possible use of synchronous generators, particularly of low power, in the generator sets of back-up supply of various objects. The calculations have been carried out with the help of the Mcad software, their selected results are presented and analyzed.

KEYWORDS: electrical machinery, synchronous machine

1. Introduction

The synchronous machines in so-called power application are used as generators or motors. The motors must be always connected to a power source, in practice it is always an electrical grid, while the generators must be provided with a device actuating them, that is serving as their drive. Synchronous generators are used mainly in power plants, where they are driven by steam or water turbines. At present the synchronous generators became important parts of so-called generating sets, where they are driven by fuel engines. The generating sets reckoned among the sources of back-up electric supply of various objects are more and more commonly used due, among others, to the fact that high buildings must be provided with the sources of back-up electric supply. The generating sets driven by fuel engines are not limited with regard to their power and operation time. Only sufficiently large fuel tank is necessary. Such sets are designed for nearly immediate operation after voltage failure in the network. The synchronous generators are universal in the sense that they are able to operate individually or in the electrical grid. According to the purpose of their use, their operating properties may vary. The synchronous generators in the power plants practically always operate in parallel with other generators and are connected to the electrical grid. On the other hand, the generators in the generating sets usually operate individually, without connection to electrical grid. In order to keep standard output parameters the independently operating generator must be provided with an effective control system of rotational speed and exciting current. The generator load depends solely on the parameters of the receivers connected thereto. The power of the propulsion engine must be so adjusted as to

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enable the speed controller to maintain constant power and rated voltage frequency, within the range of expected load of the generator with active power. The exciting current controller must be adjusted in such a way as to maintain the voltage at required value, irrespective of all variations of the generator load with active and reactive power. The synchronous generators operating in the network, after their synchronization, have a rotational speed corresponding to the network frequency. The excitation current is adjusted only prior to synchronization in order to set the voltage value. After the synchronization the change in the excitation current value affects only the reactive power transferred to the grid, which is a valuable advantage. In case of overexcitation, when the excitation current is sufficiently high, the inductive reactive power is fed to the grid. For low exciting current, i.e. in case of underexcitation, the capacitive reactive power is delivered to the grid. In most cases the synchronous generators connected to the grid operate in overexcitation state, i.e. the inductive reactive power is transferred to the network. Similar principles relate to the synchronous engines. In such cases the synchronous machines operate like capacitors, i.e. they serve as reactive power capacitors.

During autonomous (individual) mode the generator operation is determined by the propulsion engine and the receivers of various types – R, L or C. The receivers are usually connected to individually operating generators in 4-wire system, i.e. with a neutral wire. Such a way of connecting the receivers enables their operation in single- or three-phases design. The control system of excitation current allows to adjust the generator voltage. The control system of excitation current enables to stabilize the voltage values, i.e. to maintain its value irrespective of varying load. It should be noticed that in case of growing ohmic (resistive) and inductive load the excitation current should be increased, while for growing capacitive load the excitation current should be reduced. It is a well known phenomenon referred to as interaction of armature field. During operation of an independent generator the rotational speed controller of the propulsion engine has significant meaning, as it is decisive for the value of output voltage frequency of the generator. In case of any change in the generator load the speed controller must immediately stabilize the speed so as to keep constant voltage frequency. An asymmetric receiver gives rise to asymmetric state of the machine, adversely affecting the machine operation. For analysis of generator operation under asymmetric condition the use of untypical equations is necessary, that leads to the use of the method of symmetrical components.

2. Legal regulations

The operation conditions of the generators used in generating sets are in some detail described in several various standards and provisions. The regulation of the respective Minister provides that average frequency measured within 10 seconds

must fall in the range 50 Hz±1% for 95% of a week or 50 Hz+4%/-6% for 100% of a week, while during each week 95% results coming from 10-minute average r.m.s. values of the supply voltage should fall within the range ±10%. The standard related to the generating sets, except for the traction ones, states that the frequency characteristics in steady state depend, first of all, on the properties of the rotational speed controller of the engine. On the other hand, the characteristics under dynamical conditions depend on the properties of all the parts of the system. At the same time it is stated that characteristics of the generating set voltage depend mainly on the generator design and on appropriate voltage controller. In service limit values depend on the class of the requirements related to the generating set, divided into four groups: G1, G2,G3 or G4.

The drop of the frequency in case of a set of G1 class should not exceed 8%, in case of G2 class the limiting value amounts to 5% and 3% for G3-class. For a set of G4-class the frequency drop should be agreed between the manufacturer and customer. The voltage deviation under stead state, according to the set class, must not exceed ±10% in case of small units (up to 10 kVA) of G1 class and ±1% in the sets of G3-class. The voltage deviation for G4-class should be agreed between the manufacturer and customer.

In any case of generator operation the intensities of the armature currents should be checked, mainly for two reasons:
a)   to prevent exceedance above the rated current values;
b)   to prevent exceedance of the asymmetry degree index of currents ($I_2/I_1 < 0.1$) in case of asymmetric load, where I_2 is the symmetric negative-sequence current of the three-phase current system.

3. The calculation rules

Knowledge of the values of phase armature currents I_u, I_v, I_w allows to calculate the symmetric negative-sequence armature current (I_2) according to the formula (1):

$$I_2 = \frac{1}{3}(I_u + a^2 I_v + a I_w) \tag{1}$$

where a and a^2 are rotation operators while I_u, I_v, I_w are complex phase armature currents. The complex current has a form *I exp(-jφ)*.

During single-phase load the degree of asymmetry I_2/I_n depends on relative value of the loading current *(I_{obc}/I_n)*, since $I_2/I_n = 1/3$ *(I_{obc}/I_n + 0 + 0)*.

For three-phase asymmetric load the degree of asymmetry has usually less adverse impact than in case of single-phase load, since it depends on the load values of particular phases.

The standards stipulate that the generators should not be loaded with the current exceeding its rated level and that the ratio of positive-sequence current to

its rated value should not exceed 0.08 or 0.1. On the other hand, the ratio of negative- or zero-sequence current to the positive-sequence current should not exceed 0.05. Values of these indexes are calculated from the relationship (2):

$$I_1 = \frac{I_u + a^2 I_v + a I_w}{3} \qquad I_2 = \frac{I_u + a I_v + a^2 I_w}{3} \tag{2}$$

Analysis of operating conditions of a synchronous generator under asymmetric state may be carried out conveniently with the method of symmetrical components. It should be noticed that the synchronous generators, particularly the ones intended for use in the fuel-electric generating sets should be designed with a view to allow their asymmetric loading, however, to the extent defined by the regulations, i.e. keeping below 0.1 the ratio of symmetric negative-sequence current (I_2) to its rated value (I_n), called the asymmetry factor. Manufacturers of the generating sets communicate in their catalogues that the generators may be loaded asymmetrically, nevertheless, they do not inform how to define the admissible range of the asymmetric loads meeting the requirements of the relevant standards. Manufacturers of generating sets also do not inform to what extent the asymmetry of the currents affects asymmetry of the voltages. It should be noticed that the regulations also define the allowable indexes of voltage asymmetry.

During autonomous operation of a synchronous generator the rotational speed controller of the fuel engine is not always sufficiently quick and precise that often leads to deviation of the electromotive force from its rated value. Therefore, in the present paper it is taken into account that the frequency f may deviate from the rated frequency f_n. It is achieved by the coefficient $k_f = f/f_n$ included to the formulae.

The symmetric positive-, negative- and zero-sequence impedances of the receiver are calculated based on the formula (3):

$$\begin{pmatrix} Z_1(k_f) \\ Z_2(k_f) \\ Z_0(k_f) \end{pmatrix} = \frac{1}{3} \begin{pmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{pmatrix} \begin{pmatrix} Z_{zu}(k_f) \\ Z_{zv}(k_f) \\ Z_{zw}(k_f) \end{pmatrix} \tag{3}$$

Impedance of a synchronous generator for symmetric current components are written in the form (4):

- for positive-sequence $\quad Z_{g1}(k_f) = R_{g1} + 1 j k_f X_{g1}$

- negative-sequence $\quad Z_{g2}(k_f) = R_{g2} + 1 j k_f X_{g2} \tag{4}$

- and zero-sequence $\quad Z_{g0}(k_f) = R_{g0} + 1 j k_f X_{g0}$

With the help of equivalent schemes of the synchronous machines for particular symmetrical components the equation of voltage equilibrium may be

written in the form of a matrix $(E) = (Z)*(I)$. Particular terms of the matrix are presented in the equation (5)

$$\begin{pmatrix} E_1(k_f,k_{u1}) \\ E_2(k_f,k_{u2}) \\ E_0(k_f,k_{u0}) \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \begin{pmatrix} I_1(k_f,k_{u1},k_{u2},0) \\ I_2(k_f,k_{u1},k_{u2},0) \\ I_0(k_f,k_{u1},k_{u2},0) \end{pmatrix} \tag{5}$$

In the equation (4) E_1, E_2, and E_0 are the electromotive forces for symmetrical components, while I_1, I_2, and I_0 are the currents of particular symmetrical components, respectively.

In the matrix (E) of the electromotive forces the coefficients k_{u1}, k_{u2}, and k_{u0} are included, that enable presentation of particular components of the electromotive forces as functions of the reference electromotive force E_{wn}, according to equation (6):

$$\begin{pmatrix} E_1(k_f,k_{u1}) \\ E_2(k_f,k_{u2}) \\ E_0(k_f,k_{u0}) \end{pmatrix} = \begin{pmatrix} E_{wn}(k_f,k_{u1}) \\ E_{wn}(k_f,k_{u2}) \\ E_{wn}(k_f,k_{u0}) \end{pmatrix} \tag{6}$$

E_{wn} is the electromotive force induced in armature winding for rated excitation current I_{wn} and rated frequency $(k_r = 1)$, calculated from the equation (7):

$$E_{wn}(k_f) = U_n + I_n Z_{g1}(k_f) \tag{7}$$

The coefficients k_{u1}, k_{u2}, and k_{u0} enable to carry out the simulation computation of particular symmetrical components corresponding to any EMF values enforced by the excitation current. It is usually assumed that the calculation is carried out for asymmetric load of internally symmetrical generator. Therefore, the electromotive forces of negative- and zero-sequence are equal to zero, i.e. $E_2 = 0$ and $E_0 = 0$. Such an assumption is adopted in the present paper.

The impedance matrix (Z) includes the equations (5), while the values defined by the equation (8) should be attributed to particular terms:

$$\begin{pmatrix} Z_{g1}(k_f)+Z_0(k_f) & Z_2(k_f) & Z_1(k_f) \\ Z_1(k_f) & Z_{g2}(k_f)+Z_0(k_f) & Z_2(k_f) \\ Z_2(k_f) & Z_1(k_f) & Z_{g0}(k_f)+Z_0(k_f) \end{pmatrix} \tag{8}$$

Inversed transformation of the matrix $(E) = (Z)*(I)$ provides the matrix of the currents of symmetrical components $(I_s) = (M)*(E_s)$ (equation (9)) as functions of the exciting current, i.e. of the electromotive force E_{wn}:

$$\begin{pmatrix} I_1(k_f,k_{u1},k_{u2},k_{u0}) \\ I_2(k_f,k_{u1},k_{u2},k_{u0}) \\ I_0(k_f,k_{u1},k_{u2},k_{u0}) \end{pmatrix} = \begin{pmatrix} M_{11}(k_f) & M_{12}(k_f) & M_{13}(k_f) \\ M_{21}(k_f) & M_{22}(k_f) & M_{23}(k_f) \\ M_{31}(k_f) & M_{32}(k_f) & M_{33}(k_f) \end{pmatrix} \begin{pmatrix} E_{wn}(k_f,k_{u1}) \\ E_{wn}(k_f,k_{u2}) \\ E_{wn}(k_f,k_{u0}) \end{pmatrix} \frac{1}{D(k_f)}$$

$$\tag{9}$$

Knowledge of the currents of symmetrical components is necessary with a view to calculate the values of currents flowing in particular phases and, additionally, to estimate allowable asymmetric load of the generator based on the asymmetry factor.

The degree of the current asymmetry is determined based on:

a) the rate of negative-sequence to positive-sequence current,

$$KI_{21} = \frac{\left|I_2(k_f, k_{u1}, k_{u2}, k_{u0}\right|}{\left|I_1(k_f, k_{u1}, k_{u2}, k_{u0}\right|} \tag{10}$$

and

b) the rate of negative-sequence current to its rated value,

$$KI_{2/n} = \frac{\left|I_2(k_f, k_{u1}, k_{u2}, k_{u0}\right|}{I_n} \tag{11}$$

Particular terms of admittance M in equation (9) are calculated based on the formulae:

$$M_{11}(k_f) = (Z_{g2}(k_f) + Z_0(k_f))(Z_{g0}(k_f) + Z_0(k_f)) - Z_1(k_f)Z_2(k_f)$$

$$M_{12}(k_f) = Z_1(k_f)^2 - Z_2(k_f)(Z_{g0}(k_f) + Z_0(k_f))$$

$$M_{13}(k_f) = Z_2(k_f)^2 - Z_1(k_f)(Z_0(k_f) + Z_{g2}(k_f))$$

$$M_{21}(k_f) = Z_2(k_f)^2 - Z_1(k_f)(Z_0(k_f) + Z_{g0}(k_f))$$

$$M_{22}(k_f) = (Z_0(k_f) + Z_{g1}(k_f))(Z_0(k_f) + Z_{g0}(k_f)) - Z_1(k_f)Z_2(k_f)$$

$$M_{23}(k_f) = Z_1(k_f)^2 - Z_2(k_f)(Z_0(k_f) + Z_{g1}(k_f))$$

$$M_{31}(k_f) = Z_1(k_f)^2 - Z_2(k_f)(Z_0(k_f) + Z_{g2}(k_f))$$

$$M_{32}(k_f) = Z_2(k_f)^2 - Z_1(k_f)(Z_0(k_f) + Z_{g1}(k_f))$$

$$M_{33}(k_f) = (Z_0(k_f) + Z_{g1}(k_f))(Z_0(k_f) + Z_{g2}(k_f)) - Z_1(k_f)Z_2(k_f)$$

$$D(k_f) = D_1(k_f) + D_2(k_f) + D_3(k_f)$$

where

$$D_1(k_f) = (Z_0(k_f) + Z_{g1}(k_f))(Z_0(k_f) + Z_{g2}(k_f))(Z_0(k_f) + Z_{g0}(k_f))$$

$$D_2(k_f) = -Z_1(k_f)Z_2(k_f)[3Z_0(k_f) + (Z_{g1}(k_f) + Z_{g2}(k_f) + Z_{g0}(k_f))]$$

$$D_3(k_f) = Z_1(k_f)^3 + Z_2(k_f)^3$$

The standards stipulate that the generators should not be loaded with the current exceeding its rated level and that the rate of positive-sequence current to its rated value should not exceed 0.08 or 0.1. On the other hand, the rate of negative- or zero-sequence current to the positive-sequence current should not exceed 0.05. Values of these indexes are calculated from the relationship I_2/I_n less than 0.1 and I_2/I_1 less than 0.05.

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$$\frac{\left| I_2(k_f, k_{u1}, k_{u2}, k_{u0} \right|}{\left| I_1(k_f, k_{u1}, k_{u2}, k_{u0} \right|}$$

The voltage asymmetry factor can best be calculated from the formula (12), including only the values of inter-phase voltage

$$k_{nu} = \sqrt{6 \frac{U_{uv}^2 + U_{vw}^2 + U_{wu}^2}{(U_{uv} + U_{vw} + U_{wu})^2} - 2} \tag{12}$$

During computation of the current symmetrical component the phase currents of the load should be substituted together with the φ angles corresponding thereto, since the I_2 value is affected not only by the modules of particular phase currents but also by their angular shifts.

Better calculation accuracy is obtained when the value of negative-sequence current is computed with the use of complex impedances of the receivers Z_u, Z_v, and Z_w, that should be known.

The equivalent impedances of the load connected to particular phases u, v, w of the armature winding are written in the form (13), where the k_f coefficient is included:

$$Z_{zu}(k_f) = R_{zu} + jk_f X_{zu}$$
$$Z_{zv}(k_f) = R_{zv} + jk_f X_{zv} \tag{13}$$
$$Z_{zw}(k_f) = R_{zw} + jk_f X_{zw}$$

The reactance values must be given for the rated frequency.

The formulae allow for the use of relative values related to apparent reference impedance determined by the formula (14):

$$Z_{odn} = \frac{|U_n|}{|I_n|} \tag{14}$$

where U_n is the rated phase voltage while I_n – the rated armature current.

In order to keep the asymmetry factor below 0.1 at asymmetric two-phase load the phase currents must not exceed $0.3I_n$ for equal phase shifts corresponding to rated value of $cos\varphi$. For such values of the load current and unequal phase angles the asymmetry factor will vary and shall depend on in which phase the phase shift angle φ deviates from its rated value. For example, if in one of the phases the angle varies from $\varphi = 0$ to $\varphi = 2\varphi_n$, the asymmetry factor changes from 0.07 to 0.15. In case the load currents exceed $0.3I_n$ the asymmetry factor may grow even to 0.36.

Under asymmetric three-phase load the currents of particular phases may be so adjusted as to keep the asymmetry factor below 0.1.

Once the phase currents are given by the formulae (15):

$$I_u(k_1) = I_n k_1 e^{1j\left(-\theta_n 2\frac{\pi}{3}\right)}$$

$$I_v(k_2,k_4) = I_n k_2 e^{1j\left[-\left(\theta_n k_4 2\frac{\pi}{3}\right)-\left(2\frac{\pi}{3}\right)\right]}$$

$$I_w(k_3) = I_n k_3 e^{1j\left[-\left(\theta_n 2\frac{\pi}{3}\right)-\left(4\frac{\pi}{3}\right)\right]}$$

(15)

in which the current and phase shift angle values may be controlled by k_1, k_2, k_3, and k_4 coefficients, the asymmetry factor k_i will change as is shown in Figs 1 and 2.
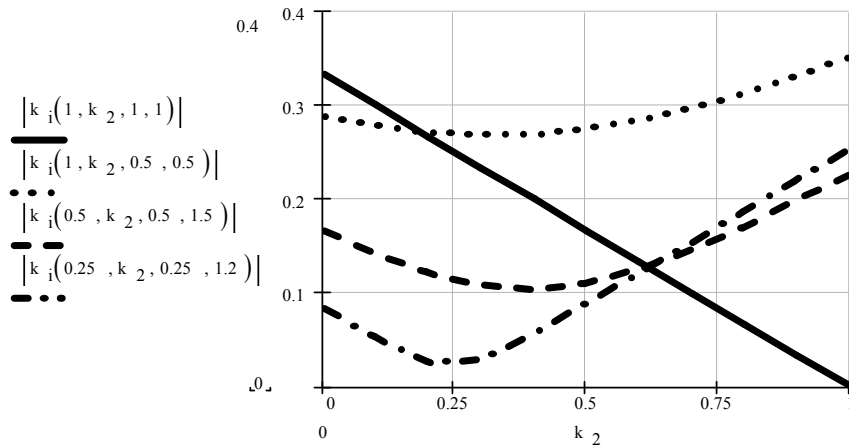

Fig. 1. The effect of current intensity variations of the second phase *(k₂)* on the asymmetry factor for various phase current and phase shift values
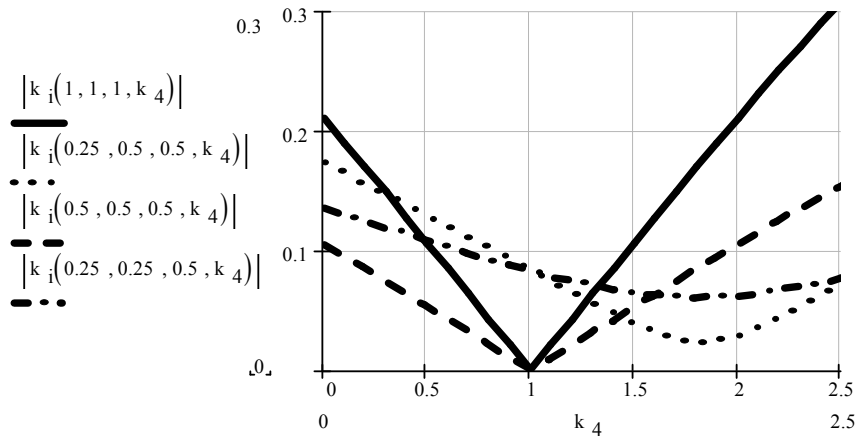

Fig. 2. The effect of phase shift angle variations *(k₄)* on the asymmetry factor for various phase current values

In the formula determining the asymmetry factor $k_i = I_2(k_1,k_2,k_3,k_4)/I_n$ the first term in the bracket is related to the u phase current, the second one to v phase current, the third one to w phase current, and the fourth to the phase shift angle in v phase.

Similar approach may be applied to variations of the modules and angle shifts in case of impedances of particular phases. Once the phase impedances are given by the formulae (16)

$$Z_{odbu}(k_1) = Z_{odn}k_1 \exp j\varphi_n$$
$$Z_{odbv}(k_2,k_4) = Z_{odn}k_2 \exp j\varphi_n k_4 \qquad\qquad (16)$$
$$Z_{odby}(k_3) = Z_{odn}k_3 \exp j\varphi_n$$

in which the coefficients k_1, k_2, k_3 enable changing the impedance values and k_4 controls the v-phase shift angle, such a description allows to analyze the impact of particular load parameters on phase currents and voltages and on current and voltage asymmetry factors. It allows also to calculate the capacity of rated power utilization of the generator.

Table 1 presents selected simulation results of the impact of various types of receiver asymmetry on characteristic output values of the generator. The coefficients $k_1, k_2,$ and k_3 characterize relative impedance values of particular phases. On the other hand, k_4 depicts variations of the v-phase shift angle. The reference impedance Z_{odn} is defined according to the equation 2. The angle φ_n corresponding to the rated value $cos\varphi_n = 0.8$ is adopted as a reference phase shift angle. All the current and voltage values are related to their rated levels.

The load parameters adopted as standard ones are so selected as to prevent exceedance of the rated current value (I_n) in any phase and, at the same time, to keep the current asymmetry factor below its allowable value (0.1). Other values of the load serve as a comparison of the values occurring under various load cases with reference to standard values. The standard asymmetric load specified in the second row of Table 1 may be adopted as a standard one. It is the load of the asymmetry degree, for which the asymmetry factor is equal to the allowable value of 0.1, without exceedance of the rated current in the most loaded phase and with phase shifts of the receiver impedance corresponding to the rated value $cos\varphi_n = 0.8$. The simulation results presented above allow to notice that the higher resistance of the receiver, the lower the asymmetry factor

According to Table 1 the asymmetry factor equal to the ratio of symmetric negative-sequence to positive-sequence voltage does not exceed 0.03, taking into account the voltage asymmetry considered during the calculations, hence legal requirements related to the Class 3 receivers are met. In case of the receivers of Class 1 and 2 this factor should not exceed 0.01 and 0.02, respectively. For the considered type of asymmetry the deviations of the phase voltages practically do not exceed the level allowed by the regulations, i.e. ±10%.

Relative values of the capacity of rated power utilization of the generator for particular rows of Table 1 are presented in Table 2.

Table 1. Simulation of the effect of receiver asymmetry on the values of the generator output values

Receiver parameters				Generator output values							
k_u	k_v	k_w	k_4	I_u	I_v	I_w	I_2/I_1	U_u	U_v	U_w	U_2/U_1
1.0	1.0	1,0	1.0	1,0	1.0	1.0	0.0	1.0	1.0	1.0	0.0
1.00	1.25	1.61	1.0	1.003	0.825	0.655	0.1	1.003	1.032	1.055	0.016
1.00	1.25	1.61	0.674	1.024	0.857	0.670	0.049	1.024	1.072	1.078	0.007
1.00	1.25	1.61	1.326/ 0.674	1.005	0.816	0.664	0.181	1.005	1.020	1.070	0.029
1.00	1.25	1.61	0.022	1.003	0.878	0.657	0.072	1.003	1.098	1.580	0.011
1.00	1.25	1.11	0.022	1.022	0.876	0.916	0.159	1.002	1.094	1.016	0.026

Table 2. Relative values of capacity of rated power utilization of the generator

Row position of Table 1	1	2	3	4	5	6
Capacity of power utilization	1.00	0.85	0.938	0.834	0.969	1.044

As it was noticed before, oscillations of engine rotational speed occur very often. In consequence, the frequency of the induced electromotive force is subject to oscillations too. Therefore, observation of the effect of frequency variation on output parameters of the generator is of large practical importance. Fig. 3 presents the effect of frequency variations on the current asymmetry factor for various asymmetry types and varying excitation current, while in Fig. 4 the impact of frequency variation on the currents flowing in particular phases is shown, for a selected asymmetry and selected excitation current. The presented charts show that small frequency variations only insignificantly affect the output generator parameters.
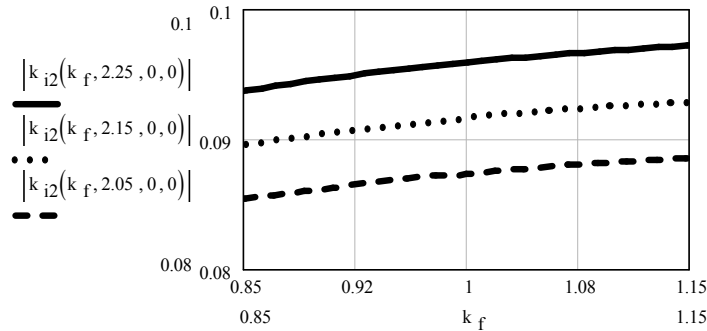

Fig. 3. The pattern of k coefficients vs. the excitation current

4. Selected computation results

The calculations have been carried out for a 250 kVA ~400 V generator. Table 3 specifies the phase current and voltage values as well as the ratio of negative- to positive-sequence voltage as a function of the excitation current.

Table 3. The voltage and current values for various values of the excitation current

k_f	The first phaze		The second phaze		The three phase		U_2/U_1
	A	U/U_n	A	U/U_n	A	U/U_n	
0,95	222,4	0,963	226,4	0,980	219,9	0,952	0,018
1,00	228,1	0,985	238,7	1,003	239,2	0,973	0,019
1,05	232,5	1,007	237,2	1,027	229,4	0,993	0,020

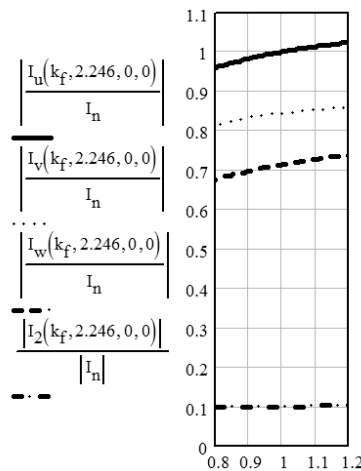Figure 4 presents the current patterns as functions of the excitation current.

Fig. 4. The patterns of phase currents and symmetric negative-sequence current as functions of the excitation current

5. Conclusions

Comparison of the simulation results of various asymmetric states is a difficult task, as the standards stipulate no allowable current load in particular windings, providing instead only the requirements imposed on the negative-sequence value. The most characteristic simulation results of asymmetrical loads of small power generator are specified. It was shown that the requirements defined by applicable regulations related to asymmetric loads are so inaccurate that despite meeting the provisions related to allowable value of the ratio of symmetric negative-sequence current to its rated value, various current flows

may be induced in the generator windings. These flows are conducive to various power loss values in the windings and, in consequence, their various heating intensities. Taking into account that for a three-phase load the value of $I_2/I_n = 0.1$ ratio depends on many variables, it is difficult to predict for what current values in particular windings the required value of the ratio may be achieved. Hence, the requirement of keeping the total power loss in the windings below their rated levels seems to be necessary. The only case that may be considered easy to define may be the one of asymmetric single-phase load for which the $I_2/I_n = 0.1$ ratio occurs for the loading current equal to 0.3 of the rated armature current. Nevertheless, although such a case complies with the provisions, the generator is then obviously under loaded.

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[5] ROZPORZĄDZENIE MINISTRA GOSPODARKI I PRACY z dnia 20 grudnia 2004 r. W sprawie szczegółowych warunków przyłączenia podmiotów do sieci elektroenergetycznej, ruchu i eksploatacji tych sieci.