Analysis of asymmetrical operating conditions of a power system for different models of synchronous generators

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Abstract. In the paper, the waveforms of the output quantities of different mathematical models of a synchronous generator operating in a power system (PS) are compared. In the investigations, it was assumed that the PS consisted of a generating unit (including, among others, a synchronous generator) connected to a bus by a high voltage transmission line. The disturbances of the steady state in the form of symmetrical and asymmetrical short-circuits in a selected place of the transmission line were considered. In the generator model, the subtransient asymmetry was taken into account. The XT and RL models of the synchronous generator when assuming different input and output quantities of the system were investigated.

1 Introduction

Short-circuits are the most common faults occurring in a power system (PS). Most often they are asymmetrical short-circuits. They cause many unfavorable phenomena, i.a. in synchronous generators. It causes the necessity to limit the duration of asymmetrical conditions [1, 2, 3, 4].

Due to the difficulty in modeling asymmetrical operating conditions, symmetrical short-circuits are mainly analyzed in simulation investigations. Specialist simulation software often does not allow to modify of ready-made PS element models, to access all the model internal signals, to select a solver, and to fully and deeply analyze of the system work. Therefore, it seems necessary to conduct research aimed at simulation of the disturbance waveforms of selected quantities for different asymmetries occurring in the PS [2, 3, 4].

The aim of the paper is to compare the disturbance waveforms of selected quantities for a two-phase short-circuit to earth and a three-phase short-circuit.

2 The PS mathematical model

As part of the research, a mathematical model of the PS was developed in the Matlab-Simulink environment. It consists of a generating unit model (which includes, among others, a synchronous generator model determined in the axial coordinate system d, q, 0) connected to a bus by a high voltage transmission line. The subtransient asymmetry of the generator was taken into account, while the phenomenon of saturation of the generator magnetic cores was neglected. It was assumed that the generator operated with an ungrounded neutral point. The equations of the presented models of the generator can be transformed so that the selected axial components of the stator currents or voltages are the input quantities of the model and the other components are the output quantities. The following generator models were considered in the analyses: GENROU model [5] with current inputs, not including stator transformation voltages, and RL (2, 2) models [5] with voltage inputs and current inputs, taking into account stator transformation voltages.

When analyzing asymmetrical operating conditions of the PS, it is convenient to express the equations of stator currents and voltages, transmission line and bus with the use of phase quantities. Then the Park transformation is used to relate the quantities in the axial (d, q, 0) coordinate system to those in the phase (A, B, C) coordinate system [2, 5].

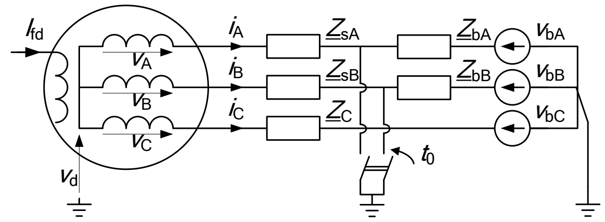

Fig. 1. Diagram of the PS for short-circuits to earth.

Fig. 1 shows a diagram of the analyzed PS for short-circuits with earth. Symbols in the figure : i_j – generator stator currents, v_j – generator stator voltages, v_{bj} – bus voltages, $\underline{Z}_j$, $\underline{Z}_{sj}$, $\underline{Z}_{bj}$ – complex impedances of the transmission line (phase quantities, j = A, B, C), I_{fd} – generator field current, v_d – voltage between the neutral points of the generator and the bus, t_0 – instant of the disturbance occurrence.

The transformation voltages were omitted in the transmission line equations, so the appropriate algebraic relations between the currents and voltages were determined. Depending on the used generator model, currents or voltages are given by: for healthy phases:

$$i_j\left(t+\Delta t_j\right)=\frac{v_j(t)+v_d(t)-v_{bj}(t)}{\left|\underline{Z}_j\right|},\quad \Delta t_j=\frac{\varphi_j}{2\pi}\frac{1}{f},\qquad \text{(1a)}$$

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$$\text{or} \quad v_j(t) = i_j(t + \Delta t_j) \cdot |\underline{Z}_j| - v_d(t) + v_{bj}(t), \tag{1b}$$

for phases with short-circuit to earth:

$$i_j(t + \Delta t_j) = \frac{v_j(t) + v_d(t)}{|\underline{Z}_{sj}|}, \tag{1c}$$

$$\text{or} \quad v_j(t) = i_j(t + \Delta t_j) \cdot |\underline{Z}_{sj}| - v_d(t), \tag{1d}$$

where: φ_j – phase angles of the appropriate transmission line impedances, $f = 50$ Hz. Additionally:

$$i_A(t) + i_B(t) + i_C(t) = 0. \tag{1e}$$

3 Exemplary calculations

Simulation calculations were carried out for long-term three-phase short-circuits and two-phase short-circuits to earth (in phases A and B). For example, the short-circuits in the transmission line at a distance of 66% of the line length from the generating unit were considered. It was assumed that in the steady state before the short-circuit the generator was loaded with active power $P_0 = 0.1$ p.u. and reactive power $Q_0 = 0.05$ p.u.

Fig. 2 shows the waveforms of the generator stator current i_A (in relative units). Table 1 presents the distributions of amplitudes of the current harmonics in phase A and the field current in the steady state of the short-circuit. The percentage values of higher harmonics with significant amplitudes with respect to the first harmonic for the stator quantities and to the constant component for the generator field current are given. The reference values in relative units are given in brackets.

Table 1. Amplitudes of harmonics in the analyzed waveforms.

h	2-phase short-circuit			3-phase short-circuit		
	GEN-ROU	RL(2,2) voltage input	RL(2,2) current input	GEN-ROU	RL(2,2) voltage input	RL(2,2) current input
Current in phase A I_A, %						
1	100 (1.1051 p.u.)	100 (1.5498 p.u.)	100 (1.2149 p.u.)	100 (0.3768 p.u.)	100 (0.3977 p.u.)	100 (0.3977 p.u.)
3	9.3144	19.208	17.584	0.0002	0.0018	0.0018
5	0.1987	0.3055	0.2507	0.0001	0.0006	0.0006
Field current I_{fd}, %						
0	100 (0.6157 p.u.)	100 (0.6376 p.u.)	100 (0.6547 p.u.)	100 (0.5348 p.u.)	100 (0.5593 p.u.)	100 (0.5593 p.u.)
2	51.225	73.917	48.01	0.001	0.0062	0.0062
4	1.1062	1.0665	0.6127	0.0005	0.0031	0.0031

4 Conclusion

Based on the performed investigations one can state that:

– In the steady state before the disturbance, the waveforms of all the analyzed quantities are identical for all the models used.

– For the 3-phase short-circuit, almost identical waveforms were obtained for both variants of the RL (2, 2) generator model. The results obtained for the GENROU model differ slightly from the others, there are no fast changes in the amplitude in the initial moments after the short-circuit. Despite taking into account the subtransient asymmetry of the generator, only the first harmonic is practically present in the steady short-circuit waveforms of the stator current and only the constant component occurs in the field current waveforms.

a)

b)

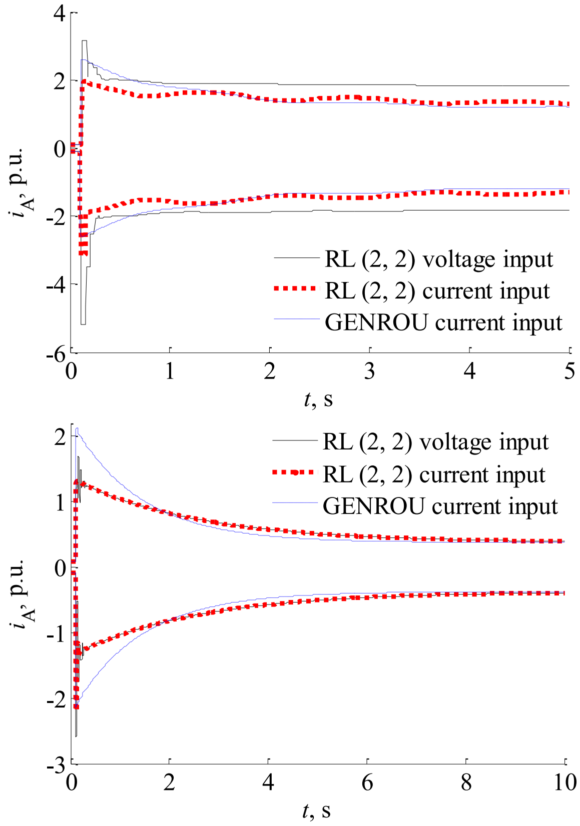

Fig. 2. Envelopes of the current in phase A for 2-phase short-circuit to earth (a) and 3-phase short-circuit (b).

– For the 2-phase short-circuit, the waveforms obtained for individual models differ to some extent. In the short-circuit currents, in addition to the basic harmonic, there are odd harmonics with significant amplitudes. In the steady state, in the generator field current there are: constant component, second harmonic and higher even harmonics.

References

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