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Sequence networks to the calculation of two-simultaneous faults at the same location

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ABSTRACT

The system of symmetrical components (012-system) can be used to simulate symmetrical and asymmetrical operation of power systems. However, the classical literature of Power Systems Analysis does not present one equivalent circuit in 012-system to two-simultaneous faults where there are a single-line-to-ground fault and a bolted line-to-line fault. This paper presents the equations and the new equivalent circuit mentioned. In addition, we present a comparison of results between the proposed approach and the output of the commercial software ANAFAS, which validates the methodology. We find evidence that the new equivalent circuit developed can substitute the equivalent circuits used to calculate a single line-to-ground fault and a bolted line-to-line fault.

Introduction

The system of symmetrical components can be used for the analysis of symmetrical and asymmetrical operation of power systems. Faults in general and in particular short-circuit currents are the most severe operating conditions in power systems. Hence, each of the different faults, e.g., single-phase-to-ground, three-phase, etc., can be represented by an equivalent circuit diagram in the ABC-system (system of phase components) and by this in the 012-system (system of symmetrical components) as well.

One of the most difficult problems in the solution of faulted networks is that involving two or more faults which occur simultaneously [1].

On the other hand, the need to improve service availability has increased the complexity of distribution network topology. Disconnected switches allow transferring loads to alternate sources under emergency conditions. Limitations on the rights of way make it necessary to use multicircuit overhead lines or single-circuit lines that run close to each other. As a result, simultaneous faults involving more than one circuit are becoming quite common. Typical causes which forces more than one fault at a single location include [2]:

- Multicircuit lines or lines sharing the same right of way.
- Switching operations.
- A stroke of lightning (thunderstorms).
- A man-caused accident.

The classical books of Power Systems Analysis [1,3,4] present the following equivalent circuits for two-simultaneous faults at the same location: Bolted three-phase (two-simultaneous bolted line-to-line fault), three-phase to ground (two-simultaneous line-to-line-to-ground fault) and line-to-line-to-ground (two-simultaneous line-to-ground fault). However, one common drawback of the Power Systems Analysis literature [1,3–5] is not presenting a procedure to derive an equivalent circuit to handle two-simultaneous faults of the type: single-line-to-ground fault and a bolted line-to-line fault (SLG-BLL-F). Furthermore, several other past and recent publications do not fill this gap as the references [6–15].

In Power Engineering, the specific topic about fault analysis receives much attention, as it is deeply important for the electric power industry. This importance is justified by the fact that fault analysis precedes power system protection studies. Take for example: when simultaneous faults occur on the transmission line, they have an effect on the operation of distance relays installed in the system. During faults, it is mandatory for the protection system to operate precisely. Therefore, if the simultaneous faults could be analyzed, it would be very useful [16]. Thus, it is important that also simultaneous SLG-BLL-F is studied.

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This paper provides the equations and a new equivalent circuit in the 012-system to a simultaneous SLG-BLL-F at the same location of the three-phase power system.

The paper is organized as follows: Firstly, a complete demonstration of the proposed equivalent circuit is presented. Secondly the equivalent circuit is validated. Numerical examples show step-by-step how to calculate a simultaneous SLG-BLL-F. Final conclusions and references are contained in this paper as well.

Equivalent circuit diagram in the 012-system

Whichever fault in the three-phase a.c. system has to be described by three independent conditions for the voltages, currents or combinations of both. Since any of the three phases can be arbitrarily labeled phase a, we do not consider single line-to-ground faults on other phases. The fault equations in the ABC-system are presented in the case of two-simultaneous faults where there are simultaneous SLG-BLL-F as follows.

$$V_a = z_f I_a; \quad I_b = -I_c; \quad V_b = V_c \tag{1}$$

where single-line-to-grounded fault impedance (SLGI) is z_f.

The transformation into the system of symmetrical components is carried out using the transformation matrices by Eqs. (2) and (3).

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \vec{a}^2 & \vec{a} \\ 1 & \vec{a} & \vec{a}^2 \end{bmatrix} \begin{bmatrix} V_{a_0} \\ V_{a_1} \\ V_{a_2} \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} V_{a_0} \\ V_{a_1} \\ V_{a_2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \vec{a} & \vec{a}^2 \\ 1 & \vec{a}^2 & \vec{a} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{3}$$

where $\vec{a} = 1 < 120^\circ$

The fault equations for the currents in the system of symmetrical components are

$$\begin{bmatrix} I_{a_0} \\ I_{a_1} \\ I_{a_2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \vec{a} & \vec{a}^2 \\ 1 & \vec{a}^2 & \vec{a} \end{bmatrix} \begin{bmatrix} I_a \\ -I_c \\ I_c \end{bmatrix} \tag{4a}$$

Therefore,

$$I_a = 3I_{a_0} \tag{4b}$$

$$I_{a_1} = -I_{a_2} + 2I_{a_0} \tag{4c}$$

and for the voltages

$$\begin{bmatrix} V_{a_0} \\ V_{a_1} \\ V_{a_2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \vec{a} & \vec{a}^2 \\ 1 & \vec{a}^2 & \vec{a} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_b \end{bmatrix} \tag{4d}$$

Therefore,

$$V_{a_1} = V_{a_2} \tag{4e}$$

The fault conditions as per Eqs. 4(a)–(4e) can only be realized by a series–parallel connection of the positive-, negative- and zero-sequence component. The equivalent circuit diagram in the system of symmetrical components is outlined in Fig. 1. The positive-, negative- and zero-sequence component are represented by impedances Z_1, Z_2 and Z_0, with $Z_0 = z_0 + 3z_f$. Where z_0 is the zero sequence impedance network.

The currents and voltages of the system of symmetrical components are then calculated as

$$I_{a_1} = \frac{E_1(4Z_2 + Z_0)}{D}; \quad I_{a_2} = -\frac{E_1 Z_0}{D}; \quad I_{a_0} = \frac{2E_1 Z_2}{D} \tag{5a}$$

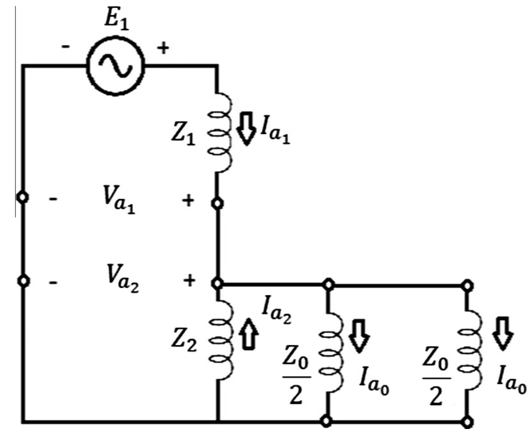

Fig. 1. Equivalent circuit diagram in the 012-system to simultaneous SLG-BLL-F.

$$V_{a_1} = E_1 - Z_1 I_{a_1}; \quad V_{a_2} = -Z_2 I_{a_2}; \quad V_{a_0} = -2V_{a_1} + 3z_f I_{a_0} \tag{5b}$$

where

$D = Z_2 Z_0 + Z1(4Z2 + Z0)$

Validating the circuit developed

Fault currents calculation is a key factor in determining the tap settings of protection relays for many practical applications.

The commercial software Simultaneous Fault Analysis (ANAFAS), developed by the Electric Energy Researches Center (CEPEL) – Brazil, was used just for verification of the fault currents and voltages calculation.

Consider the modified Example 3.1 of the reference [1]. The Thevenin voltage at bus C is $E_1 = 1.0$ (pu). The simple power system shown in Fig. 2, consists of a generator, transformer, transmission line, load transformer, and load. Consider simultaneous SLG-BLL-F at bus C with a SLGI of 4 ohms.

The following data concerning the system is known: Generator: 25 MVA, 10 kV, $x = 0.125$ pu, connected Y-grounded. T1: 30 MVA, 10–20 kV, $x = 0.105$, connected Δ—Y-grounded. Line: $Z = 2 + j4$ ohm. T2: 20 MVA, 5–20 kV, $x = 0.05$, connected Y—Δ. Load: static (constant z) load of 10 + j5 MVA at 5 kV.

Solution

According to reference [1], the impedances (pu) calculated are: $Z_1 = 0.1287 + 0.3059j$; $Z_2 = Z_1$; $z_f = 0.2$; $Z_o = 0.1 + 0.27j + 3z_f = 0.7 + 0.27j$.

Now, we may synthesize phase currents and phase voltages both in pu. We calculate the phase currents and the phase voltages to the equivalent circuit using Eqs. (5a), (5b) and (2).

Table 1 shows the results obtained to simultaneous SLG-BLL-F at bus C.

The results from equivalent circuit and the results from ANAFAS can be seen to be much closer. Therefore, the equivalent circuit proposed can be considered as validated.

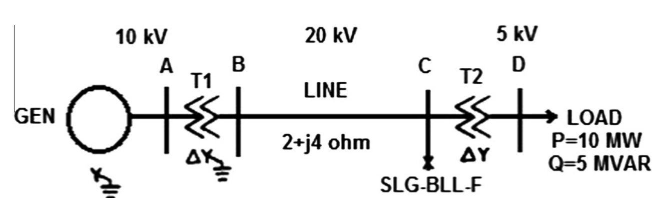

Fig. 2. Power system.