Symmetrical component analysis of an unbalanced mine power distribution system in B^2-Spice

The paper describes the application method of symmetrical components for the analysis of unbalanced mine power distribution systems using B^2-Spice. The knowledge of symmetrical components is extremely useful for the study of unsymmetrical faults in three-phase power networks. The concept is also useful for studying the three-phase machine behaviour under unbalanced conditions. B^2-Spice is a general-purpose analog electrical and electronic circuit simulator. It is a powerful programme that is used to study the integrity of circuit designs and to predict circuit behaviour.

Keywords: *Mine distribution system; unbalanced faults; symmetrical components; sequence networks; B^2-Spice circuit simulator.*

Introduction

Various kinds of faults that occur in a power system can also be broadly classified into symmetrical faults and unsymmetrical faults. Symmetrical faults such as three-phase faults can be analyzed on a per-phase basis. Unsymmetrical faults such as line-to-ground and line-to-line faults, however, cannot be analyzed on a per-phase basis. In such cases, the method of symmetrical components is used to determine voltages and currents in all parts of a power system during unbalanced system conditions [1, 4]. Moreover, many protective relays operate from the symmetrical component quantities. Consequently, a good understanding of symmetrical components is very useful and an invaluable tool in power system protection [5, 6].

The method of symmetrical components

The analysis of a three-phase circuit in which phase voltages and currents are balanced (of equal magnitude in the three phases and displaced 120° from each other), and in which all circuit elements in each phase are balanced and symmetrical, is relatively simple since the treatment of a single-phase leads directly to the three-phase solution. The analysis by Kirchoff's laws is much more difficult, however, when the circuit is not symmetrical, as the result of unbalanced loads, unbalanced faults or short-circuits that are not symmetrical in the three phases. The method of symmetrical components is the technique generally adopted for calculating system voltages and currents in such circuits [7, 8].

Symmetrical component is an extremely useful technique for analyzing unbalanced 3-phase mine power systems. It involves a linear transformation from 3-phase components to a new set of components called symmetrical components. The advantage of this transformation is that for balance three-phase networks the equivalent circuit obtained for the symmetrical components, called sequence networks, are separated into three uncoupled networks. Furthermore, for unbalanced three-phase systems, the three sequence networks are connected only at the points of unbalance. As a result, sequence networks for many cases of unbalanced three-phase systems are relatively easy to analyze [9, 13].

The symmetrical component method permits systematic analysis and design of three-phase systems. Decoupling a

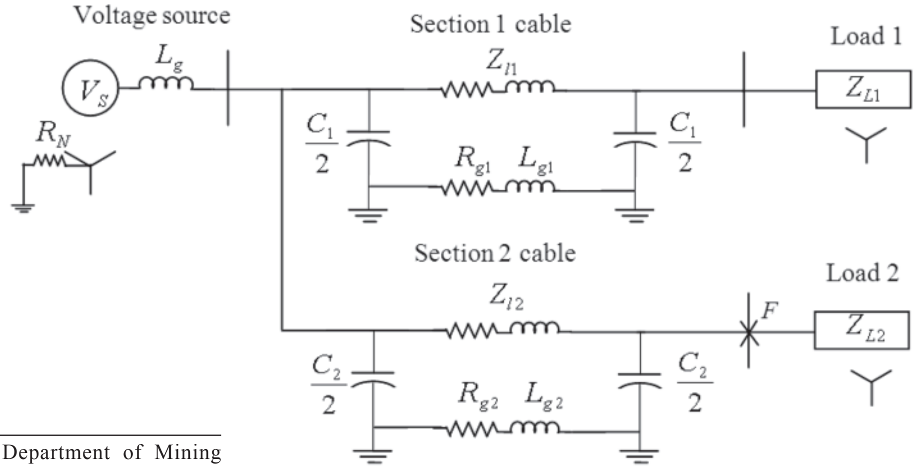

Fig.1 Single-line diagram of the distribution system.

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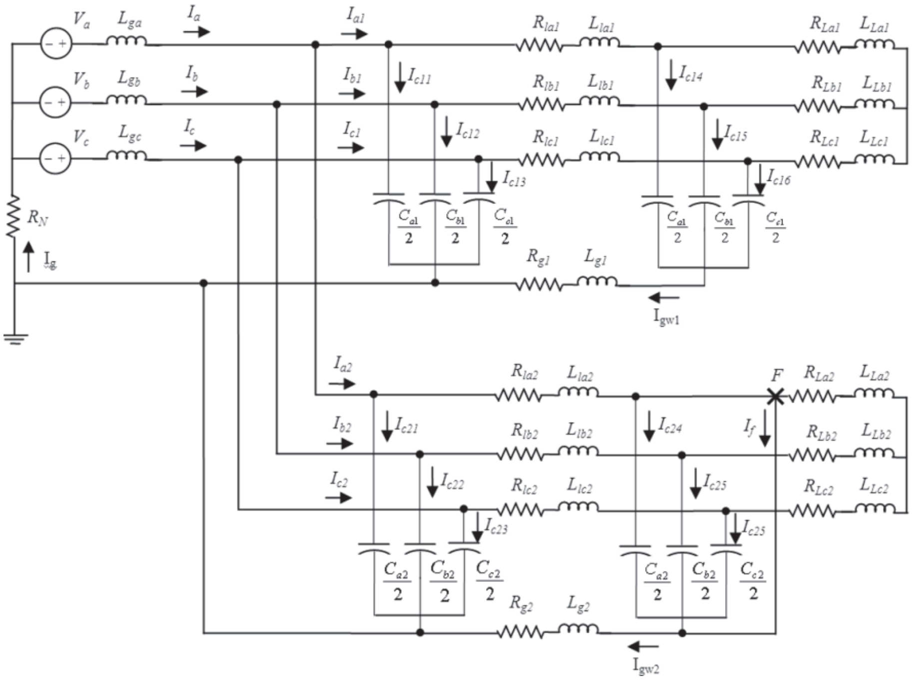

Fig.2 Three-phase circuit diagram of the distribution system

TABLE 1: SUMMARY OF RESULTS FOR THE THREE-PHASE AND SEQUENCE NETWORK SIMULATION MODELS

Component	3-Phase system model value (A)	Sequence network model value (A)
I_a	63.97∠−17.28°	63.93∠−17.32°
I_b	46.14∠−150.38°	46.13∠−150.39°
I_c	40.25∠−274.90°	40.26∠−274.90°
I_{a1}	28.18∠−40.22°	28.18∠−40.21°
I_{b1}	27.70∠−149.34°	27.70∠−149.35°
I_{c1}	23.68∠−274.29°	23.69∠−274.29°
I_{a2}	39.57∠−1.17°	39.51∠−1.24°
I_{b2}	18.45∠−151.93°	18.45∠−151.94°
I_{c2}	16.57∠−275.74°	16.57∠−275.75°
I_{c11}	0.01∠124.99°	0.01∠124.44°
I_{c12}	2.49∠−63.31°	2.49∠−63.32°
I_{c13}	2.54∠−122.99°	2.53∠−123.08°
I_{c14}	≈ 0	≈ 0
I_{c15}	2.49∠−63.37°	2.49∠−63.36°
I_{c16}	2.53∠−122.95°	2.53∠−122.95°
I_{c21}	≈ 0	≈ 0
I_{c22}	1.25∠−63.31°	1.25∠−63.30°
I_{c23}	1.27∠−122.99°	1.27∠−122.98°
I_{c24}	≈ 0	≈ 0
I_{c25}	1.25∠−63.31°	1.25∠−63.31°
I_{c26}	1.27∠−122.93°	1.27∠−122.92°
I_g	24.47∠−4.00°	24.41∠−4.08°
I_f	27.64∠24.26°	27.57∠24.21°
I_{gw1}	4.36∠−93.51°	4.36∠−93.49°
I_{gw2}	26.70∠20.09°	26.63∠20.05°

detailed three-phase network into three simpler sequence networks reveals complicated phenomena in more simplistic terms. Sequence network results can then be superimposed to obtain three-phase results. The application of symmetrical components to unsymmetrical fault studies is indispensable [14, 15].

Description of mine distribution system

Figs.1 and 2 show the single-line diagram and equivalent three-phase circuit diagram of a simple mine distribution system with a line-to-ground fault. A three-phase voltage source supplies power to two sections, each through a π-equivalent representation of cables. Loads have been represented by series resistance and inductance in each phase and connected in wye. The source and load impedances have been transferred to the distribution voltage level. The source neutral is resistance grounded which is a standard practice in US mines [16, 18]. Location of the fault has been indicated by the letter F in the two power system diagrams.

Fig.3 shows the three sequence networks of the power system connected to represent the single-line-to-ground fault condition. Drawing positive-, negative- and zero-sequence networks has been carried out using standard symmetrical component analysis techniques. While constructing the symmetrical component circuit, determination of the path for zero-sequence current is not always straight forward. While drawing the zero-sequence network, it must be kept in mind that an ungrounded-wye or a Δ-connection offers infinite impedance to zero-sequence current. Also, if the neutral point of a wye is grounded through an impedance Z_n, $3Z_n$ is placed between the neutral point and ground in the zero-sequence network diagram.

Subsequently, the three-phase power system and sequence network models were constructed in B^{2}Spice. In constructing the models, the following values for the system elements were used:

Ulility source

V_a = 7200/0°V

V_b = 7200/- 120°V

V_c = 7200/- 240°V

$L_{ga} = L_{gb} = L_{gc}$ = 20.626 mH

R_N = 288 Ω

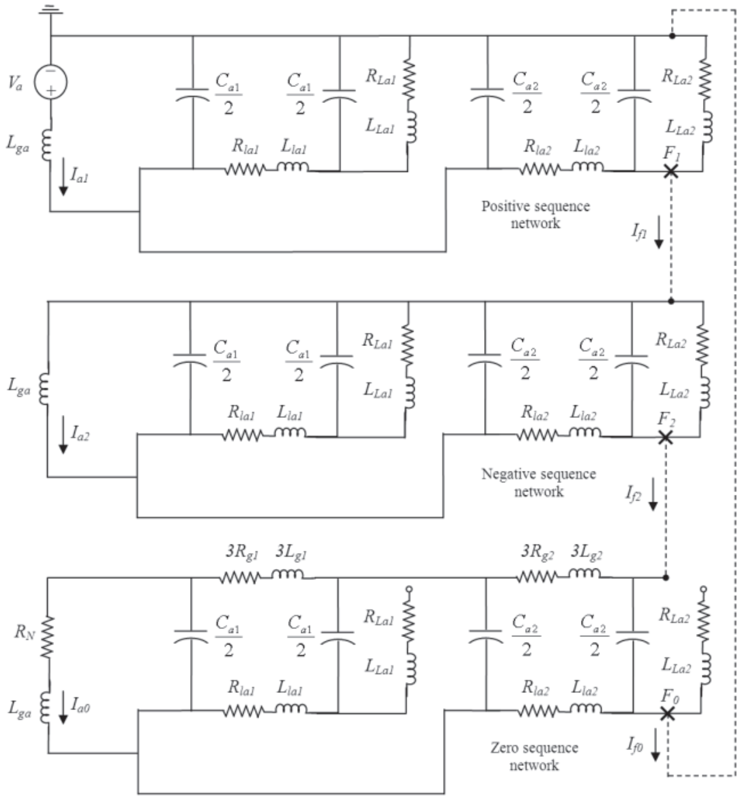

Fig.3: Connection of sequence networks for the mine distribution system with a line-to-ground fault

Section 1 cable

$R_{la1} = R_{lb1} = R_{lc1} = 0.63\ \Omega$

$L_{la1} = L_{lb1} = L_{lc1} = 0.928$ mH

$C_{a1} = C_{b1} = C_{c1} = 0.5468\ \mu F$

$R_{g1} = 0.80\ \Omega$

$L_{g1} = 0.928$ mH

Section 2 cable

$R_{la2} = R_{lb2} = R_{lc2} = 0.315\ \Omega$

$L_{la2} = L_{lb2} = L_{lc2} = 0.464$ mH

$C_{a2} = C_{b2} = C_{c2} = 0.2734\ \mu F$

$R_{g2} = 0.40\ \Omega$

$L_{g2} = 0.464$ mH

Load 1

$R_{La1} = R_{Lb1} = R_{Lc1} = 200\ \Omega$

$L_{La1} = L_{Lb1} = L_{Lc1} = 0.398$ mH

Load 2

$R_{La2} = R_{Lb2} = R_{Lc2} = 300\ \Omega$

$L_{La2} = L_{Lb2} = L_{Lc2} = 0.597$ mH

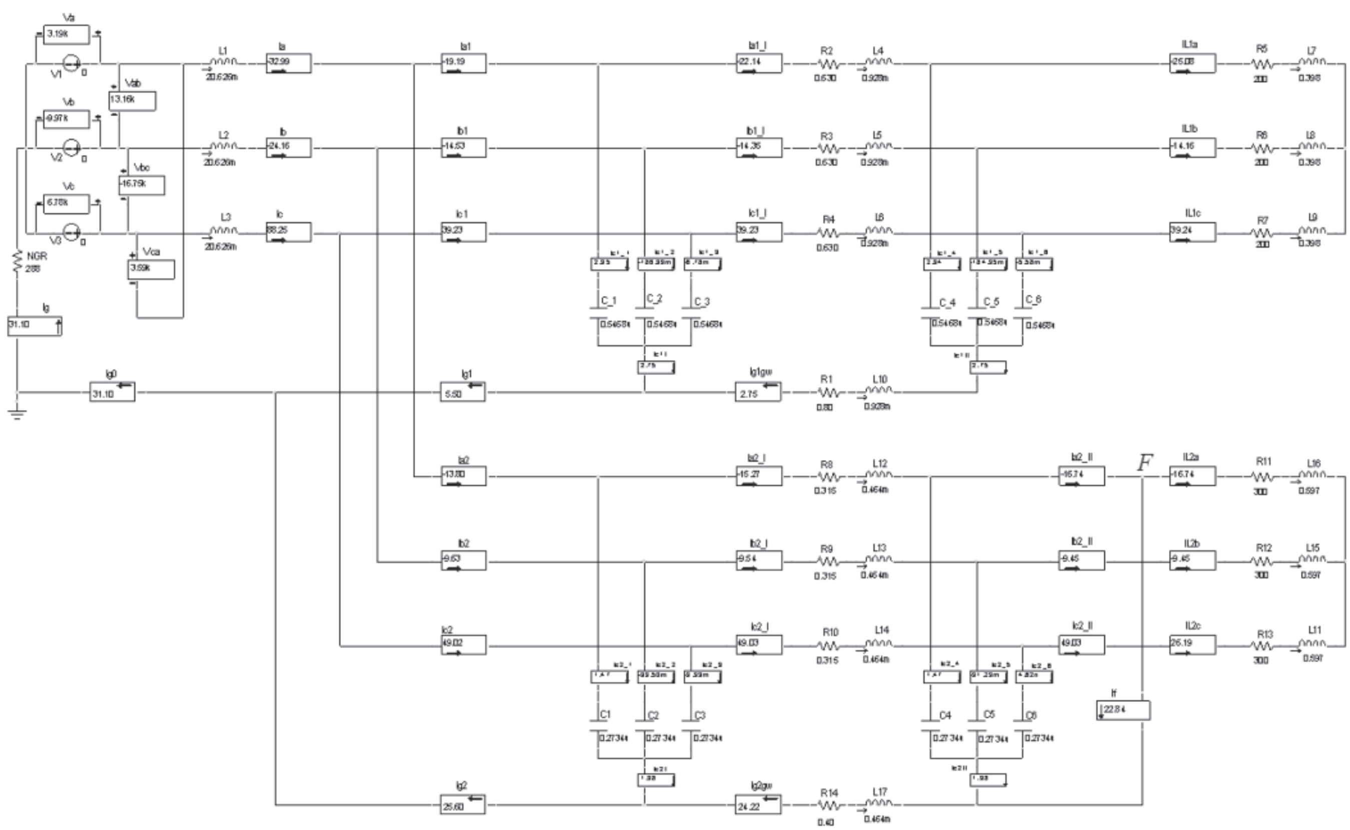

Fig.4: Three-phase circuit model of the mine distribution system with a bolted line-to-ground fault at F constructed in B^2-Spice

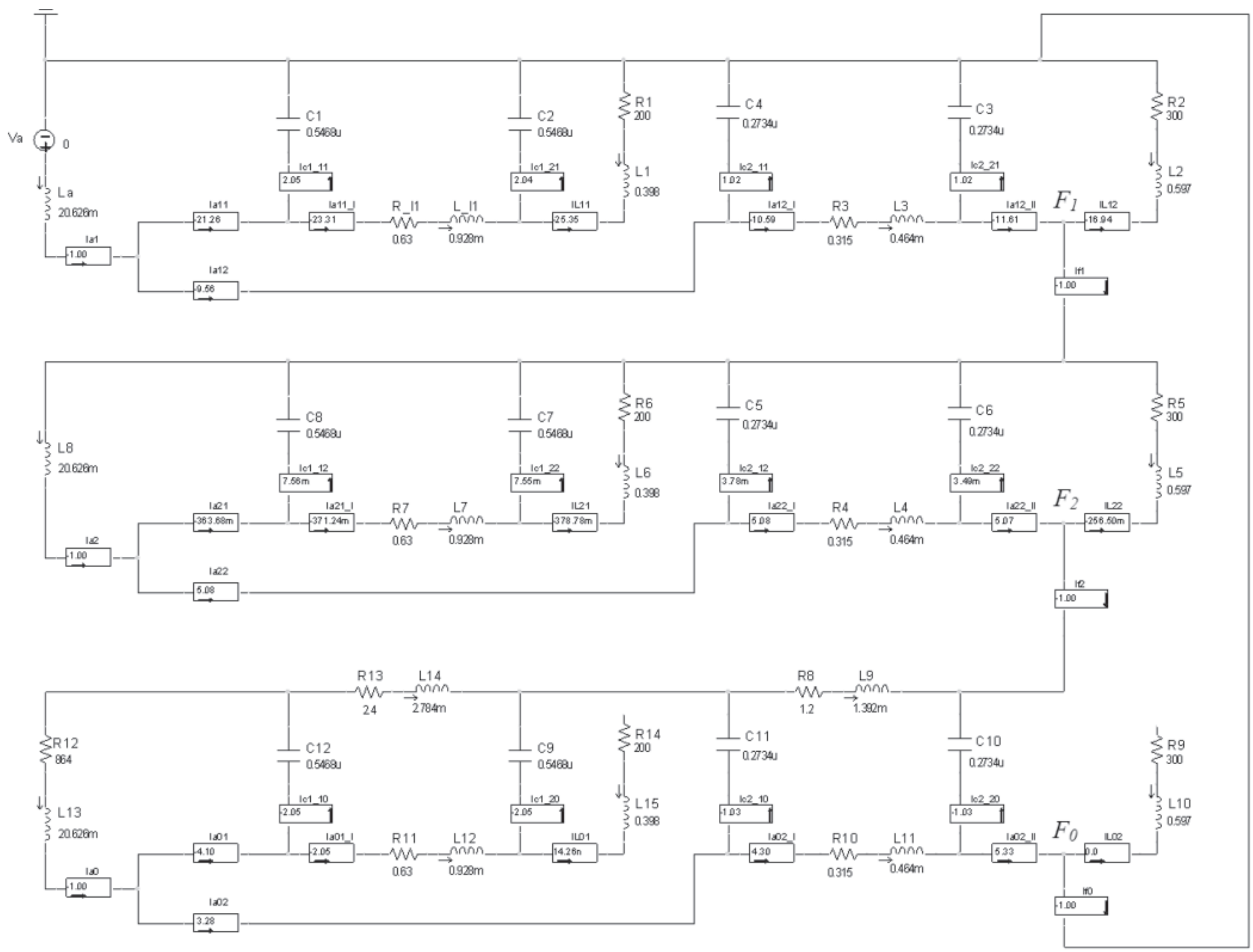

Fig.5: Sequence network model of the mine distribution system with a bolted line-to-ground fault at F constructed in B^2-Spice

The three-phase and sequence network simulation models constructed in B^2-Spice have been shown in Figs.4 and 5. Table 1 displays a summary of simulation results for the two circuit models.

For the three-phase circuit model of Fig.4, the system currents were measured directly from the simulation, whereas standard symmetrical component equations were used to calculate the system current from the sequence network model of Fig.5. From the results shown in Table 1, we observe that the values obtained for various system quantities in the two cases are nearly identical. This verifies that the sequence network model constructed is an equivalent representation of the three-phase mine distribution system model.

Conclusion

The method of symmetrical components was used in the present research to determine system voltages and currents in all parts of an unbalanced mine power distribution system. Symmetrical component analysis of an unbalanced two section mine power distribution system with a line-to-ground fault was presented in this paper. The system voltages and currents obtained for the three-phase simulation model and corresponding sequence network simulation model were found to be identical in the present research, thus verifying the approach. Using similar approach, it is possible to carry out fault analysis of faulted mine power distribution system of any possible size.

References

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