© MAY 2026 | IRE Journals | Volume 9 Issue 11 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I11-1717867

# Analysis of Faults in an Electric Power System

ABBA M.O.[1], OMECHE A.A.[2], EZEMA, E.E.[3]

[1]*Dept of Electrical Engineering, Enugu State University of Science & Technology (ESUT), Enugu, Nigeria*

[2,3]*Department of Electrical/Electronic Engineering, Faculty of Engineering Madonna University, Nigeria.*

***Abstract- Electrical fault is an abnormal condition, caused by equipment failure, human errors and environmental conditions. These faults cause interruption to electric current flows, equipment damages and even death of humans, birds and animals. For example, a short circuit is a fault in which current bypasses the normal load. An open circuit fault occurs if a circuit is interrupted by some failures. In three phase systems, a fault may involve one or more phases and ground, or may occur only between phases. In a ground fault or earth fault, current flows into the earth. When fault occurs currents deviate from normal value. Bus impedance matrices are useful in the determination of these currents. This paper shows the analyses of a faulted power system using bus impedance matrices. The magnitudes of the currents during various fault conditions were determined for a particular power network. The results obtained show that the three-phase fault (symmetrical fault) has the highest fault current. These results enable the proper specification and optimal placing of circuit breakers for protection of the network.***

***Keywords— Power System, Faults, Symmetrical Component, Bus Impedance Matrix, Currents, Voltages.***

## I. INTRODUCTION

Under normal operating conditions, power system equipment or lines carry normal voltages and currents which results in a safer operation of the system. Fault in a transmission line is generally characterized as increase in phase current [1]-[4] (Anamika and Aleena, 2016), and could result in transient instability (Tan and Wang, 1997). A fault in a power distribution circuit could result in a costly power outage [5]. So, when fault occurs, it causes excessively high currents to flow, which can cause substantial damage or failure in electrical equipment and devices, and personal injuries. A large number of fires each year have been attributed to electrical failures in electrical equipment, appliances, and building wiring [6]-[7]. In a poly-phase system, a fault may affect all phases equally which is a "symmetrical fault". If only some phases are affected, the resulting "asymmetrical fault" becomes more complicated to analyze. The analysis of this type of fault is often simplified by using methods such as symmetrical component.

### 1.1 Symmetrical Faults

These are very severe faults and occur infrequently in the power system. This type of fault is defined as a simultaneous short-circuits across all three phases. These are also called balanced faults because it affects each of the three phases equally. They are of two types namely: (i) line-to-line-to-line-to ground (L-L-L-G) (Fig. 1) - it occurs due to insulation breakdown or short circuit between all the phases and earth, and (ii) line-to-line-to-line (L-L-L) - occurs due to insulation breakdown or short circuit between all the three phases. These are mainly due to wind swing on the transmission lines. Only 2-5 percent of system faults are symmetrical faults. If these faults occur, system remains balanced, but it is the most severe type of fault encountered [8]. Analysis of these faults is easy and usually carried by per phase basis. Three phase fault analysis or information is required for selecting set phase relays, rupturing capacity of the circuit breakers and rating of the protective switch gear. The estimation of the MVA rating required of a circuit breaker is usually made on the assumption that it must clear a 3-phase fault because, as that is generally the worst case, it is reasonable to assume that the circuit breaker can clear any other fault. Since the network remains balanced electrically, normal single-phase equivalent circuit is used for these calculations [9]-[10].

© MAY 2026 | IRE Journals | Volume 9 Issue 11 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I11-1717867

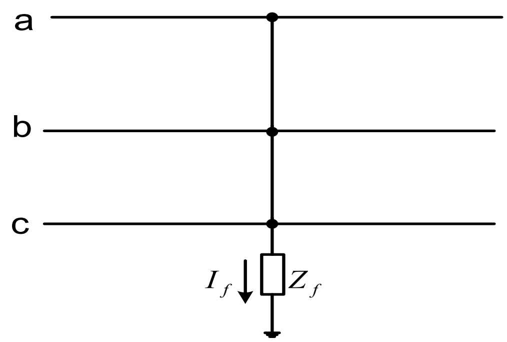


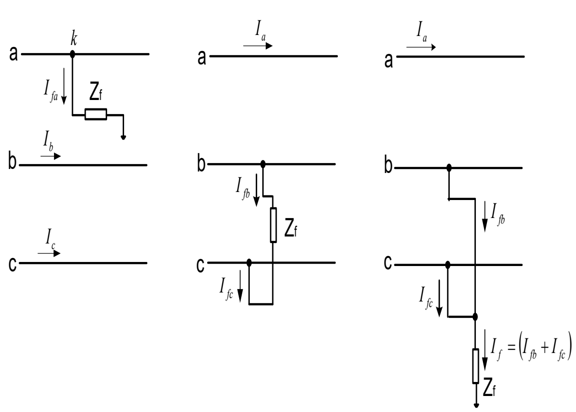
Fig. 1 Three-phase fault

1.2. Unsymmetrical Faults
These are very common and less severe than symmetrical faults. There are mainly three types namely:

(i) Single line-to-ground fault
It is also called a line to ground (L-G) fault (Fig. 2a). It mainly occurs due to insulation breakdown or short circuit between one of the phases and earth.

(ii) Line-to-line fault
It is also called line to line (L-L) fault (Fig. 2b). Line to line faults occur when two conductors make bare physical contact with each other or short circuited with each other.

(iii) Double line-to-ground fault
It is also called line to line to ground (L-L-G) fault (Fig. 2c) Two phases-to-ground faults occurs due to insulation breakdown between two phase and earth.




(a) (b) (c)

(a) L-G Fault, (b) L-L Fault, (c) L-L-G Fault
Fig. 2 Unsymmetrical Faults.

## II. ANALYSIS

It is important to determine the values of system voltages and currents during faulted conditions so that protective devices may be set to detect and minimize the harmful effects of such contingencies (Gross, 1979). Subtransient reactances of generators and motors are used to determine the initial current flowing on the occurrence of a short circuit. This current is used to select a circuit breaker for interrupting the fault current. The generators are represented by their no-load voltages in series with the subtransient reactances. Let us consider the system shown in Fig. 3 which shows a single line diagram of a power system in which two synchronous generators are connected through three-phase transformers to the transmission line. The ratings and reactances of the generators and transformers are:

Generators G1 and G2: 100MVA, 20KV;
$X_d'' = X_1 = X_2 = 20\%$ ; $X_0 = 4\%$; $X_n = 5\%$

Transformers T1 and T2: 100MVA, 20Y/345Y KV;
$X_1 = X_2 = X_0 = 8\%$

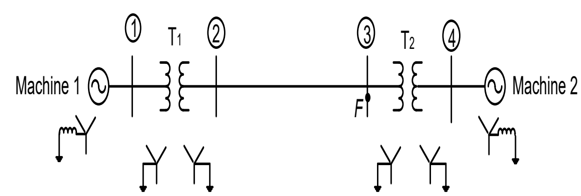
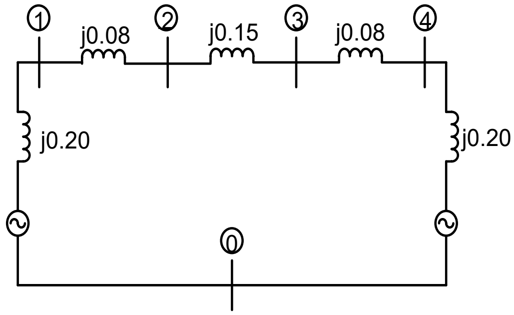



Fig. 3 Single-line diagram of a power system

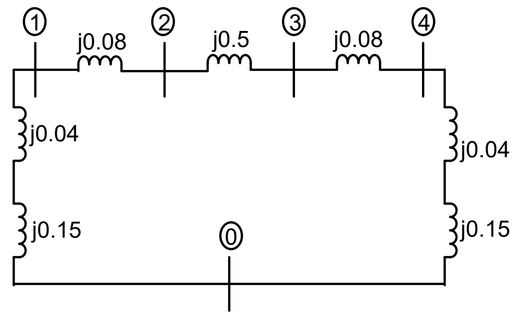
Both transformers are solidly grounded on two sides. The line reactance is and on a base of 100MVA and 345 kV in the transmission-line circuit, and the system is operating at nominal voltage.

In this paper the voltages at the buses and currents flowing in the lines for the different kinds of fault at bus 3 have been determined.

2.1. Sequence Networks
These are shown in Fig. 4




(a) Positive-sequence network




(b) Zero-sequence network

Fig. 4 Sequence Networks

Note that negative-sequence network is the same as the positive-sequence network with the machines omitted.

2.2. Impedance Matrices
(i) Positive–sequence network bus impedance matrix.
The Bus impedance matrix (Zbus) of the network in Fig. 4a is:

$$Z_{bus}^{(1)} = \begin{bmatrix} j0.1437 & j0.1211 & j0.0789 & j0.0563 \\ j0.1211 & j0.1696 & j0.1104 & j0.0789 \\ j0.0789 & j0.1104 & j0.1696 & j0.1211 \\ j0.0563 & j0.0789 & j0.1211 & j0.1437 \end{bmatrix} \quad (1)$$

$$Z_{bus}^{(2)} = Z_{bus}^{(1)} \quad (2)$$

(ii) Zero–sequence network bus impedance matrix.
The Bus impedance matrix (Zbus) of the network in Fig. 4b is:

$$Z_{bus}^{(0)} = \begin{bmatrix} j0.1553 & j0.1407 & j0.0493 & j0.0347 \\ j0.1407 & j0.1999 & j0.0701 & j0.0493 \\ j0.0493 & j0.0701 & j0.1999 & j0.1407 \\ j0.0347 & j0.0493 & j0.1407 & j0.1553 \end{bmatrix} \quad (3)$$

2.3. Calculation of fault currents
(i) Symmetrical fault – Three-phase fault occurring at bus 3

Generally, when the three-phase fault occurs on bus k of a large-scale network, the fault current is given as:

$$I_f = \frac{V_f}{Z_{kk}^{(1)}} \quad (4)$$

Where $V_f$ is the pre-fault voltage at the buses. It is normally taken as equal to the rated/base voltage, i.e. $V_f$ = 1.0 p.u. $Z_{kk}^{(1)}$ is the reactance per phase of the whole system reduced to a single reactance.

Thus, fault current into bus 4 is:

$$I_f = \frac{V_f}{Z_{33}^{(1)}} = \frac{1.0}{j0.1696} = -j5.8962 \text{ p.u.}$$

Current flowing in line 1-to-2 is:

$$I_{12} = \frac{V_1 - V_2}{Z_b} = \frac{0.5349 - 0.3488}{j0.08} = j2.326$$

So, the all the line currents are:

$$I = \begin{bmatrix} 0 & -j2.3256 & 0 & 0 \\ j2.3256 & 0 & -j2.3256 & 0 \\ 0 & j2.3256 & 0 & j3.5714 \\ 0 & 0 & -j3.5714 & 0 \end{bmatrix}$$

It can be observed that the sum of the currents flowing in lines 2-to-3 and 4-to-3 equals –j5.897 p.u. as obtained previously.

(ii) Unsymmetrical Faults
A convenient method of analyzing unbalanced operation (unsymmetrical faults) is through symmetrical components, where the three-phase voltages (and currents) which may be unbalanced are

© MAY 2026 | IRE Journals | Volume 9 Issue 11 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I11-1717867

transformed into three sets of balanced voltages (and currents) called symmetrical components (Nagrath and Kothari, 1994).

(a) Single line-to-ground fault occurring on phase A at bus 3 on Fig. 1, the symmetrical components of the current out of the system and into the fault are:

$$I_{fa}^{(0)} = I_{fa}^{(1)} = I_{fa}^{(2)} = \frac{V_f}{Z_{33}^{(1)} + Z_{33}^{(2)} + Z_{33}^{(0)} + 3Z_f} \quad (5)$$

where

$I_{fa}^{(0)}$, $I_{fa}^{(1)}$ and $I_{fa}^{(2)}$ are zero-sequence, positive-sequence and negative-sequence current respectively

$$I_{fa}^{(0)} = \frac{1.0\angle 90^o}{j(0.1696 + 0.1696 + 0.1999)} = -j1.8549\, p.u.$$

$$I_{fa} = 3I_{fa}^{(0)} = -j5.5648 \;\; p.u.$$

Current out of machine G1

$$\begin{bmatrix} I_{g1a} \\ I_{g1b} \\ I_{g1c} \end{bmatrix} = \begin{bmatrix} 10828\angle -90^o \\ 4492\angle -90^o \\ 4492\angle -90^o \end{bmatrix}$$

Current out of machine G2:

$$\begin{bmatrix} I_{g2a} \\ I_{g2b} \\ I_{g2c} \end{bmatrix} = \begin{bmatrix} 25320\angle -90^o \\ 15590\angle -90^o \\ 15590\angle -90^o \end{bmatrix}$$

Current flow in line 1 to 2:

$$\begin{bmatrix} I_{1a} \\ I_{1b} \\ I_{1c} \end{bmatrix} = \begin{bmatrix} 325.4539\angle -90^o \\ 41.8327\angle 90^o \\ 41.8327\angle 90^o \end{bmatrix}$$

Current flow in line 2 to 3:

$$\begin{bmatrix} I_{2A} \\ I_{2B} \\ I_{2C} \end{bmatrix} = \begin{bmatrix} 325.45\angle -90^o \\ 41.83\angle 90^o \\ 41.83\angle 90^o \end{bmatrix}$$

Current flow in line 4 to 3

$$\begin{bmatrix} I_{4a} \\ I_{4b} \\ I_{4c} \end{bmatrix} = \begin{bmatrix} 605.88\angle -90^o \\ 41.83\angle -90^o \\ 41.83\angle -90^o \end{bmatrix}$$

Fault current is:

$$I_f = \begin{bmatrix} I_{2A} \\ I_{2B} \\ I_{2C} \end{bmatrix} + \begin{bmatrix} I_{4a} \\ I_{4b} \\ I_{4c} \end{bmatrix} = \begin{bmatrix} 931.33\angle 270^o \\ 0 \\ 0 \end{bmatrix}$$

(b) double-line to ground fault - phase-b and phase-c are assumed shorted to ground at bus (3) :

$$I_{fa}^{(1)} = \frac{V_f}{Z_{33}^{(1)} + \left[\frac{Z_{33}^{(2)}\left(Z_{(33)}^{(0)} + 3Z_f\right)}{Z_{33}^{(2)} + Z_{33}^{(0)} + 3Z_f}\right]}. \quad (6)$$

$$= \frac{1.0}{j0.1696 + \frac{j0.1696xj0.1999}{j0.1696 + j0.1999}} = -j3.8266\, p.u$$

$$I_{fa}^{(2)} = -I_{fa}^{(1)}\left[\frac{Z_{33}^{(0)}}{Z_{33}^{(2)} + Z_{33}^{(0)}}\right] \quad (7)$$

$= j2.0704$ p.u.

$$I_{fa}^{(0)} = -I_{fa}^{(1)}\left[\frac{Z_{33}^{(2)}}{Z_{33}^{(2)} + Z_{33}^{(0)}}\right] \quad (8)$$

$= j1.7563$ p.u.

Current out of machine G1

$$\begin{bmatrix} I_{g1a} \\ I_{g1b} \\ I_{g1c} \end{bmatrix} = \begin{bmatrix} 4252.7.1\angle 90^o \\ 9294.7\angle 128.7^o \\ 9294.7\angle 51.3^o \end{bmatrix}$$

Current out of machine G2:

$$\begin{bmatrix} I_{g2a} \\ I_{g2b} \\ I_{g2c} \end{bmatrix} = \begin{bmatrix} 15056\angle 90^o \\ 5845\angle 90^o \\ 5845\angle 90^o \end{bmatrix}$$

Current flow in line 1 to 2

$$\begin{bmatrix} I_{1a} \\ I_{1b} \\ I_{1c} \end{bmatrix} = \begin{bmatrix} 39.6\angle -90^o \\ 362.8\angle 158.3^o \\ 362.8\angle 21.7^o \end{bmatrix}$$

Current flow in line 2 to 3:

$$\begin{bmatrix} I_{2A} \\ I_{2B} \\ I_{2C} \end{bmatrix} = \begin{bmatrix} -j39.6 \\ -337.04 + j134.26 \\ 337.04 + j134.26 \end{bmatrix} = \begin{bmatrix} 39.6 - \angle 90^o \\ 362.8\angle 158.3^o \\ 362.8\angle 21.7^o \end{bmatrix}$$

Current flow in line 4 to 3:

$$\begin{bmatrix} I_{4a} \\ I_{4b} \\ I_{4c} \end{bmatrix} = \begin{bmatrix} j39.6 \\ -517.60 + j306.61 \\ 517.60 + j306.61 \end{bmatrix} = \begin{bmatrix} 39.6\angle 90^o \\ 601.6\angle 149.35^o \\ 601.6\angle 30.64^o \end{bmatrix}$$

Current flow to bus 3:

$$\begin{vmatrix} I_{2A} \\ I_{2B} \\ I_{2C} \end{vmatrix} + \begin{bmatrix} I_{4a} \\ I_{4b} \\ I_{4c} \end{bmatrix} = \begin{bmatrix} I_{3a} \\ I_{3b} \\ I_{3c} \end{bmatrix} = \begin{bmatrix} 0 \\ -854.64 + j440.86 \\ 854.64 + j440.86 \end{bmatrix}$$

Thus, the fault current to ground is, from (7):

$$I_f = I_{3b} + I_{3c}$$

$$= -854.64 + j440.86 + 854.64 + j440.86$$

$$= j881.72 = 881.72\angle 90^o$$

(c) line-to-line fault – short circuit between phase-b and phase-c at bus 3:

$$I_{fa}^{(1)} = -I_{fa}^{(2)} = \frac{V_f}{Z_{kk}^{(1)} + Z_{kk}^{(2)} + Z_f} \quad (9)$$

$$\frac{V_f}{Z_{33}^{(1)} + Z_{33}^{(2)}} = -j2.9485\ p.u$$

$$I_{fa} = I_{fa}^{(1)} + I_{fa}^{(2)} = 0 \quad (10)$$

$$I_{fb} = a^2 I_{fa}^{(1)} + a I_{fa}^{(2)} \quad (11)$$

$$= (-5.107 + j0)\ p.u.$$

Current out of machine G1;

$$\begin{bmatrix} I_{g1a} \\ I_{g1b} \\ I_{g1c} \end{bmatrix} = \begin{bmatrix} 0\angle 90^o \\ 5814\angle 180^o \\ 5814\angle 0^o \end{bmatrix}$$

Current out of machine G2:

$$\begin{bmatrix} I_{g2a} \\ I_{g2b} \\ I_{g2c} \end{bmatrix} = \begin{bmatrix} 0\angle 0^o \\ 8928.6\angle 180^o \\ 8928.6\angle 0^o \end{bmatrix}$$

Current flow in line 1 to 2:

$$\begin{bmatrix} I_{1a} \\ I_{1b} \\ I_{1c} \end{bmatrix} = \begin{bmatrix} 0\angle -90^o \\ 337\angle 180^o \\ 337\angle -0^o \end{bmatrix}$$

Current flow in line 2 to 3:

$$\begin{bmatrix} I_{2A} \\ I_{2B} \\ I_{2C} \end{bmatrix} = \begin{bmatrix} 0\angle 90^o \\ 337\angle 180^o \\ 337\angle 0^o \end{bmatrix}$$

Current flow in line 4 to 3:

$$\begin{bmatrix} I_{4a} \\ I_{4b} \\ I_{4c} \end{bmatrix} = \begin{bmatrix} 0\angle 0^o \\ 517.6\angle 180^o \\ 517.6\angle -0^o \end{bmatrix}$$

Fault current is:

$$I_f = \begin{bmatrix} I_{2A} \\ I_{2B} \\ I_{2C} \end{bmatrix} + \begin{bmatrix} I_{4a} \\ I_{4b} \\ I_{4c} \end{bmatrix} = \begin{bmatrix} 0\angle 0^o \\ 854.64\angle 180^o \\ 854.64\angle 0 \end{bmatrix}$$

The bar chart in Fig. 5 shows the contrast in the magnitudes of the fault currents of the different types of fault.

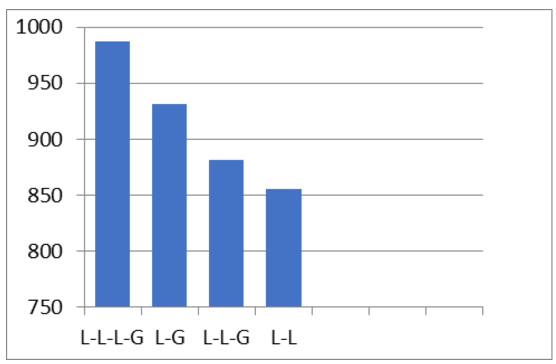



Fig. 5. Bar Chart showing the magnitudes of current of different faults

## III. CONCLUSION

The bus impedance matrix is systematic and be easily adopted on a digital computer for practical networks of large size. An important feature of the method is that, having computed the Zbus, we can easily obtain all the required short circuit data for a fault on any bus. That is, for a fault at any point on the power system, the bus impedance matrices can be formulated and applied to calculate the voltages and currents at any points in the system. The Magnitude of the currents at the faulted bus is 987A, 931A, 881A and855A for three-phase fault, L-G fault, L-L-G fault, L-L fault and respectively. Since the three-phase (L-L-L-G) fault current is the most severe, i.e., it has the highest magnitude (987A), it is used to properly specify circuit breakers to be applied in protecting the system against the flow of such currents. The circuit breaker rated breaking capacity must also be equal to, or greater than, the 3-phase fault level (approximately 590MVA).

REFERENCES

[1] Anamika Y. and Aleena S, "A Finite-State Machine-Based Approach for Fault Detection and Classification in Transmission Lines", Electric Power Components Systems, 44(1):43-59, 2016.

[2] Tan Y.L. and Wang Y., "Design of series and shunt Facts controller using adaptive nonlinear coordinated design techniques", IEEE Trans. on Power Syst. vol. 12: 1374-1379, 1997..

[3] Tan Y.L., "Investigation into the cause of failure of 22kV PILC cable", ASCE J. Perform. Constructed Facilities, vol. 12(3): 162-165, 1998.

[4] Tan, Y.L. (2002), "Damage of a Distribution Transformer due to Through-Fault Currents: An Electrical Forensics Viewpoint", IEEE Transactions on Industry Applications, vol.38 (1): 29-33.

[5] Wanjing Xiu and Yuan Liao, "Optimal Fault-Location Estimation in Distribution Systems with Distributed Generations", Electric Power Components Systems, 44(3):241-251, 2016.

[6] Hadi Saadat, "Power System Analysis", Tata McGraw Hill, 2002.

[7] Weedy, B.M., "Electric Power Systems", John Wiley & Sons, London, 1975.

[8] Gross, C. A., "Power System Analysis", John Wiley and Sons, New York, 1979.

[9] Nagrath, I.J. and Kothari, D.P, "Power System Engineering", Tata McGraw-Hill, New Delhi, 2002.

[10] John J. Grainger John J. and Stevenson, William D. Jr., "Power System Analysis", McGraw-Hill, Inc., 1994.