IJIREEICE

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

Vol. 9, Issue 6, June 2021

DOI 10.17148/IJIREEICE.2021.9630

Fault Analysis

Rajdeep Chaudhary, Jatin Tayal, Prof. Vishal V. Mehtre

4th Year (Department of Electrical Engineering),

Bharati Vidhyapeeth College (Deemed to be University) College of Engineering, Pune-411043

I. INTRODUCTION

A fault in a power system or circuit is a failure which interferes with the normal flow of current.The faults are associated with abnormal change in current, voltage and frequency of the power systems.In general faults occur in power system networks due to insulation failure of equipments, flashover of lines initiated by a lightning stroke, or due to accidental faulty operation.
A fault is any abnormal condition in a power system. The steady state operating mode of a power system is balanced 3-phase a.c. .However, due to sudden external or internal changes in the system, this condition is disrupted.When the insulation of the system fails at one or more points or a conducting object comes into contact with a live point, a short circuit or a fault occurs nto contact with a live point, a short circuit or a fault occurs.

CAUSES OF POWER SYSTEM FAULTS:
The causes of faults are numerous, e.g.
Lightning
Heavy winds
Trees falling across lines
Vehicles colliding with towers or poles
Birds shorting lines
Aircraft colliding with lines
Vandalism
Small animals entering switchgear
Line breaks due to excessive loading

COMMON POWER SYSTEM FAULTS
Power system faults may be categorised as one of four types; in order of frequency of occurrence, they are:
· Single line to ground fault
· Line to line fault
· Double line to ground fault
· Balanced three phase fault
The first three types constitutes severe unbalanced operating conditions which involves only one or two phases hence referred to as unsymmetrical faults. In the fourth type, a fault involving all the three phases occurs therefore referred to as symmetrical (balanced) fault.

NEEDS OF FAULT CALCULATION:
When the fault occur in a part of power system, heavy current flows in that part of circuit which may cause permanent damage to the equipments.
❖ The selection of the circuit breaker depends on the current flowing immediately after the fault occurs.
❖ The estimation of these currents for various types of faults at various locations in the system is called fault calculation.
❖ The data obtained from fault calculations are also used to determine the settings of the relay which control the circuit breakers.

TYPES OF FAULTS:
The faults can be broadly classified into
a) Shunt faults (short circuit)
b) Series faults (open conductors)
❖ The shunt type of faults involves short circuit between conductor and ground or short circuit between two or more conductors. The shunt faults are characterized by increase in current and fall in voltage and frequency

IJIREEICE

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

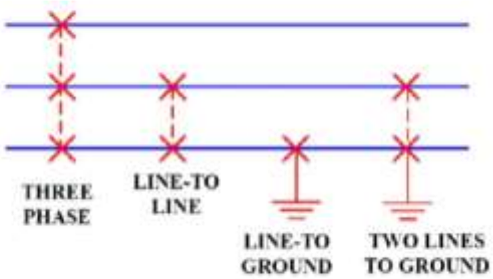
International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

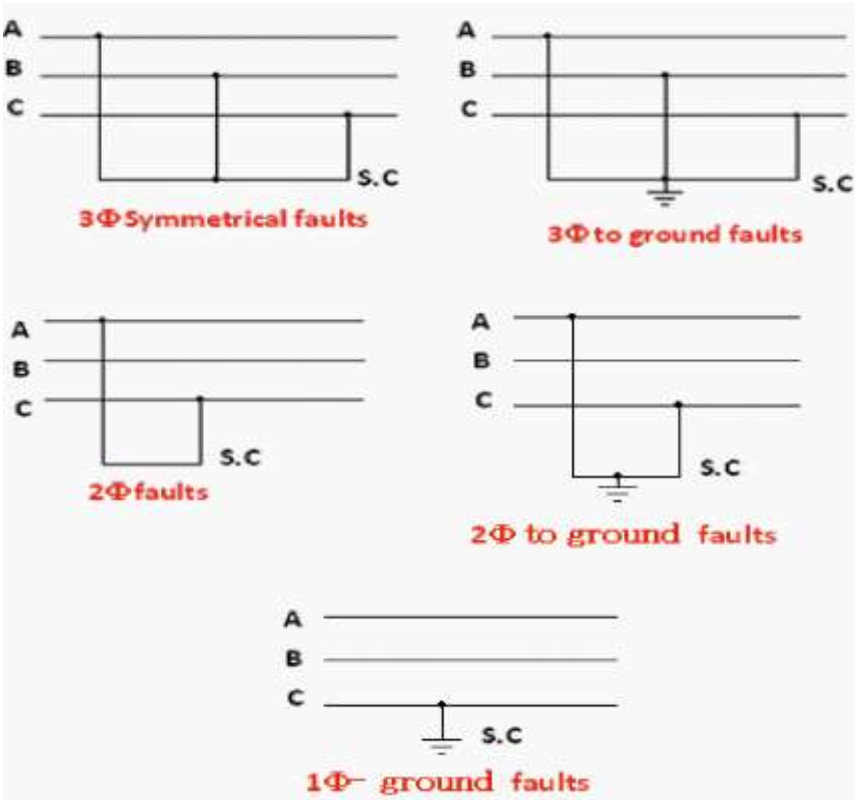
Vol. 9, Issue 6, June 2021

DOI 10.17148/IJIREEICE.2021.9630

❖ The series faults may occur with one or two broken conductors which creates open circuits. The series faults are characterized by increase in voltage and frequency and fall in current in the faulty phase.

II. TYPES OF FAULTS (CONT.)





Occurrence of faults in the power systems in the order of increasing is as follows:

➢ 3-Phase fault - 5%
➢ Double line to ground fault - 10%
➢ Line to line fault - 15%
➢ Single line to ground fault - 70%

The various faults in the order of increasing severity are as follows:--

➢ Open conductor fault
➢ L-G fault
➢ L-L fault
➢ L-L-G fault
➢ 3-Ø fault

That fault on the power system which gives rise to symmetrical current (i.e. equal fault currents in the lines with 1200 displacement) is called a symmetrical fault.

IJIREEICE

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

Vol. 9, Issue 6, June 2021

DOI 10.17148/IJIREEICE.2021.9630

❖ The symmetrical fault occurs when all the three conductors of a 3-Ø line are brought together simultaneously into a short circuit condition.

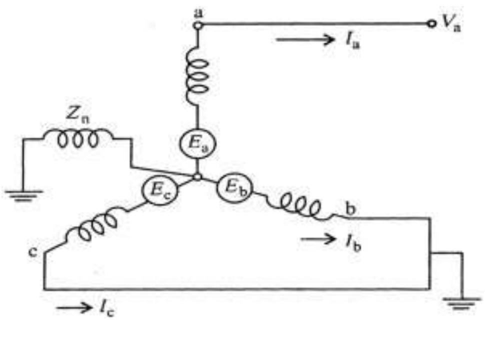
3-phase Fault:-
Va=Vb=Vc
Ia+Ib+Ic=0
❖ The Symmetrical fault conditions are analyzed on per phase basis using Thevenin's Theorem or Bus Impedance Matrix...

III. SEQUENCE COMPONENTS

An unbalanced system of 'n' related vectors can be resolved into 'n' system of balanced vectors called Symmetrical components of original vectors.
❖ In a Three phase system, the three unbalanced vectors either Va, Vb, Vc or Ia, Ib, Ic can be resolved into three balanced system of vectors. The vectors of the balanced system are called Symmetrical components of the original system
❖ The symmetrical components of Three Phase system are as follows:
Positive Sequence Components
Negative Sequence Components
Zero Sequence Components

Sequence Components (contd...).....!
1. Positive sequence components:
✓ Equal in magnitude
✓ 120 degrees phase angle exists with same phase sequence of original vectors
✓ occurs before and after fault
Importance: Relay and circuit breaker operates on positive sequence components
2. Negative sequence components:
✓ Equal in magnitude
✓ 120 degrees phase angle exists with opposite phase sequence of original vectors
✓ Occurs only during fault
Importance: Synchronous Generator is protected from unbalanced condition by using negative sequence relay.
3. Zero sequence components:
✓ Equal in magnitude, No phase difference
✓ Occurs only when neutral is grounded and fault occurred with grounded
Importance: zero sequence components are used in the calculation of leakage Flux.

THREE-SEQUENCE IMPEDANCES AND SEQUENCE NETWORKS
Positive sequence currents give rise to only positive sequence voltages, the negative sequence currents give rise to only negative sequence voltages and zero sequence currents give rise to only zero sequence voltages, hence each network can be regarded as flowing within in its own.
network through impedances of its own sequence only.In any part of the circuit, the voltage drop caused by current of a certain sequence depends on the impedance of that part of the circuit to current of that sequence.



IJIREEICE
ISSN (Online) 2321-2004
ISSN (Print) 2321-5526
International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering
Vol. 9, Issue 6, June 2021
DOI 10.17148/IJIREEICE.2021.9630

The impedance of any section of a balanced network to current of one sequence may be different from impedance to current of another sequence.The impedance of a circuit when positive sequence currents are flowing is called impedance, When only negative sequence currents are flowing the impedance is termed as negative sequence impedance.With only zero sequence currents flowing the impedance is termed as zero sequence impedance.
The analysis of unsymmetrical faults in power systems is carried out by finding the symmetrical components of the unbalanced currents. Since each sequence current causes a voltage drop of that sequence only, each sequence current can be considered to flow in an independent network composed of impedances to current of that sequence only.
The single phase equivalent circuit composed of the impedances to current of any one sequence only is called the sequence network of that particular sequence.The sequence networks contain the generated emfs and impedances of like sequence. Therefore for every power system we can form three- sequence network s. These sequence networks, carrying current Ia1, Ia2 and Ia0 are then inter-connected to represent the different fault conditions.

PHYSICAL SIGNIFICANCE OF SEQUENCE COMPONENTS:-
This is achieved by considering the fields which results when these sequence voltages are applied to the stator of a 3-phase machine e.g. an induction motor.
If a positive sequence set of voltages is applied to the terminals a, b, c of the machine, a magnetic field revolving in a certain direction will be set up. If now the voltages to the terminals band c are changed by interchanging the leads to terminals b and c, it is known from induction motor theory that the direction of magnetic field would be reversed. It is noted that for this condition, the relative phase positions of the voltages applied to the motor are the same as for the negative sequence set.Hence, a negative sequence set of voltages produces a rotating field rotating in an opposite direction to that of positive sequence.
For both positive and negative sequence components, the standard convention of counter clockwise rotation is followed.The application of zero sequence voltages does not produce any field because these voltages are in phase and the three -phase windings are displaced by 1200 .The positive and the negative sequence set are the balanced one. Thus, if only positive and negative sequence currents are flowing, the phasor sum of each will be zero and there will be no residual current.
However, the zero sequence components of currents in the three phases are in phase and the residual current will be three times the zero sequence current of one phase. In the case of a fault involving ground, the positive and negative sequence currents are in equilibrium while the zero sequence currents flow through the ground and overhead ground wires.

SEQUENCE IMPEDANCES OF TRANSMISSION LINE
The positive and negative sequence impedances of linear symmetrical static circuits do not depend on the phase sequence and are, therefore equal. When only zero sequence currents flow in the lines, the currents in all the phases are identical. These currents return partly through the ground and partly through overhead ground wires.
The magnetic field due to the flow of zero sequence currents through line, ground and round wires is very different from the magnetic field due to positive sequence currents. The zero sequence reactance of lines is about 2 to 4 times the positive sequence reactance.

SEQUENCE IMPEDANCES OF TRANSFORMERS
A power system network has a number of transformers for stepping up and stepping down the voltage levels.
A transformer for a 3-phase circuit may consist of three single phase transformers with windings suitably connected in star or delta or it may be a 3-phase unit.
Modern transformers are invariably three-phase units because of their lower cost, lesser space requirements and higher efficiency. The positive sequence impedance of a transformer equals its leakage impedance. The resistance of the windings is usually small as compared to leakage reactance.
For transformers above 1 MVA rating, the reactance and impedance are almost equal. Since the transformer is a static device, the negative sequence impedance is equal to the positive sequence impedance.
The zero sequence impedance of 3-phase units is slightly different from positive sequence impedance. However the difference is very slight and the zero sequence impedance is also assumed to be the same as the positive sequence impedance.
The flow of zero sequence currents through a transformer and hence in the system depends greatly on the winding connections. The zero sequence currents can flow through the winding connected in star only if the star point is grounded. If the star point isolated zero sequence currents cannot flow in the winding. The zero sequence currents cannot flow in the lines connected to a delta connected winding because no return path is available for these zero sequence currents. However, the zero sequence currents caused by the presence of zero sequence voltages can circulate through the delta connected windings.

IJIREEICE

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

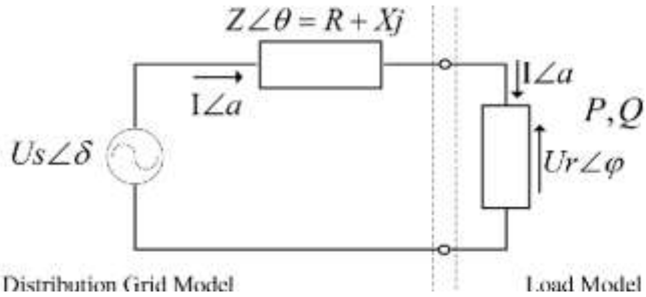
International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

Vol. 9, Issue 6, June 2021

DOI 10.17148/IJIREEICE.2021.9630

IV. THEVENIN'S EQUIVALENT CIRCUIT

Thevenin's theorem states that any linear network containing any number of voltage sources and impedances can be replaced by a single emf and an impedance. The emf is the open circuit voltage as seen from the terminals under consideration and the impedance is the network impedance as seen from these terminals. This circuit consisting of a single emf and impedance is known as Thevenin's equivalent circuit.



The calculation of fault current can then be very easily done by applying this theorem after obtaining the open circuit emf and network impedance as seen from the fault point.

FORMATION OF SEQUENCE NETWORKS

A power system network consists of synchronous machines, transmission lines and transformers. The positive sequence network is the same as the single line reactance diagram used for the calculation of symmetrical fault current. The reference bus for positive sequence network is the system neutral. The negative sequence network is similar to the positive sequence network except that the negative sequence network does not contain any voltage source. The negative sequence impedances for transmission line and transformers are the same as the positive sequence impedances. But the negative sequence impedance of a synchronous machine may be different from its positive sequence impedance.
Any impedance connected between a neutral and ground is not included in the positive and negative sequence networks because the positive and the negative sequence currents cannot flow through such impedance. The zero sequence network also does not contain any voltage source. Any impedance included between neutral and ground becomes three times its value in a zero sequence network.

The following are the summary of the rules for the formation of sequence networks:-

· The positive sequence network is the same as single line impedance or reactance diagram used in symmetrical fault analysis. The reference bus for this network is the system neutral.
· The generators in power system produce balanced voltages. Therefore only positive sequence network has voltage source. There are no voltage sources in negative and zero sequence networks.
· The positive sequence current can cause only positive sequence voltage drop. Similarly negative sequence current can cause only negative sequence voltage drop and zero sequence current can cause only zero sequence voltage drop.
· The reference for negative sequence network is the system neutral. However, the reference for zero sequence network is the ground. Zero sequence current can flow only if the neutral is grounded.
· The neutral grounding impedance Zn appears as 3Zn in the zero sequence network.
· The three sequence networks are independent and are interconnected suitably depending on the type of fault.

ZEROES SEQUENCE NETWORKS OF TRANSFORMERS (CONT..):--

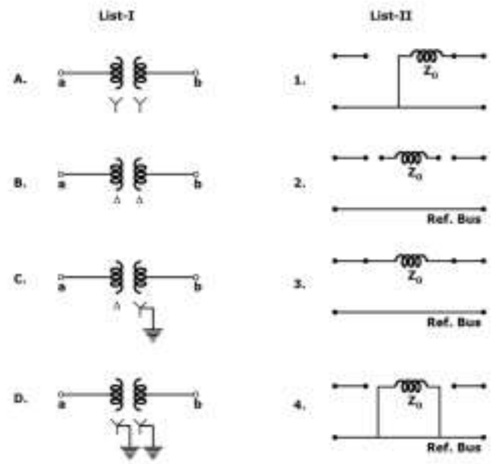
IJIREEICE

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

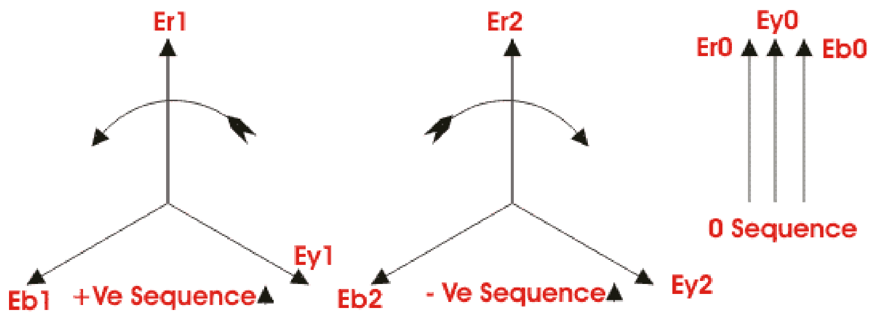
International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

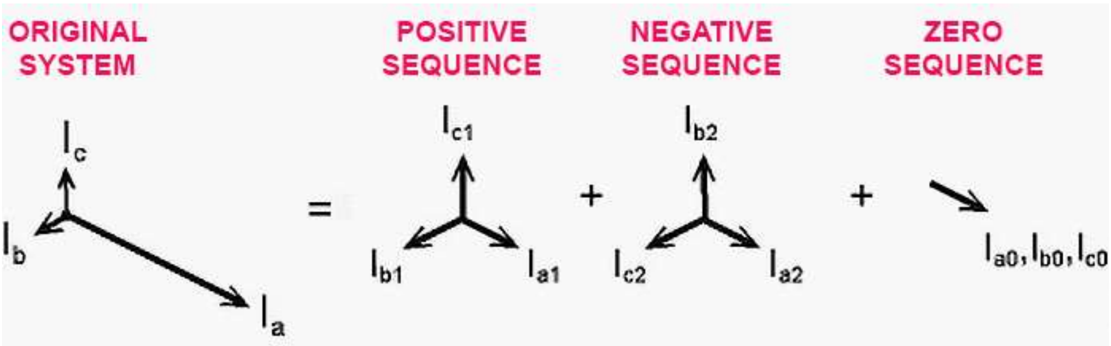
Vol. 9, Issue 6, June 2021

DOI 10.17148/IJIREEICE.2021.9630



These are lists of zeroes sequence of networks of transformers.





in above fig. shown described the phasor diagram of postive sequence, negative sequence and zero sequence.

V. UNSYMMETRICAL FAULT ANALYSIS

❖ The faults on the power system which give rise to unsymmetrical fault currents (i.e. unequal fault currents in the lines with unequal phase displacement) are known as unsymmetrical faults.

❖On the occurrence of an unsymmetrical fault, the currents in the three lines become unequal and so there is a phase displacement among them.

❖ There are three ways in which unsymmetrical faults may occur in a power system

➢Single line-to-ground fault (L-G)

➢Line-to-line fault (L-L)

➢Double line-to-ground fault (L-L-G)

CONT..:--

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

Vol. 9, Issue 6, June 2021

DOI 10.17148/IJIREEICE.2021.9630

Case (a): Without fault impedance
Let us assume an L-G fault occurs on phase-a as shown below
The boundary conditions are
Va =0; Ib=0; Ic=0
The fault current is If=Ia
Faults may lead to fire breakout that consequently results into loss of property, loss of life and destruction of a power system network. Faults also leads to cut of supply in areas beyond the fault point in a transmission and distribution network leading to power blackouts; this interferes with industrial and commercial activities that supports economic growth, stalls learning activities in institutions, work in offices, domestic applications and creates insecurity at night.
All the above results into retarded development due to low gross domestic product realised.It is important therefore 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.

BALANCED THREE PHASE FAULT:-
This type of fault occurs infrequently, as for example, when a line, which has been made safe for maintenance by clamping all the three phases to earth, is accidentally made alive or when, due to slow fault clearance, an earth fault spreads across to the other two phases or when a mechanical excavator cuts quickly through a whole cable. It is an important type of fault in that it results in an easy calculation and generally, a pessimistic answer. The circuit breaker rated MVA breaking capacity is based on 3- phase fault MVA. Since circuit breakers are manufactured in preferred standard sizes e.g. 250, 500, 750 MVA high precision is not necessary when calculating the 3- phase fault level at a point in a power system. The system impedances are also never known accurately in three phase faults.

ANALYSIS:-
Fault analysis was done by technical computer method using the theory of symmetrical components.The fault impedance Zf was taken as zero. The following describes how the program codes that were developed for each type of faultwere executed using a Matlab environment to generate results for the analysis:-

LINE-GROUND FAULT:--
The program prompts the user to enter the faulted bus number and the fault impedance Zf. The prefault bus voltages are defined by the reserved Vector V. The array V may be defined or it is returned from the power flow programs lfgauss, lfnewton, decouple or perturb. If V does not exist the prefault bus voltages are automatically set to 1.0 per unit. The program obtains the total fault current, bus voltages and line currents during the fault.

LINE-LINE FAULT:--
The program prompts the user to enter the faulted bus number and the fault impedance Zf. The prefault bus voltages are defined by the reserved Vector V. The array V may be defined or it is returned from the power flow programs lfgauss, lfnewton, decouple or perturb. If V does not exist the prefault bus voltages are automatically set to 1.0 per unit. The program obtains the total fault current, bus voltages and line currents during the fault.

DOUBLE-LINE-GROUND FAULT:--
The program prompts the user to enter the faulted bus number and the fault impedance Zf. The prefault bus voltages are defined by the reserved Vector V. The array V may be defined or it is returned from the power flow programs lfgauss, lfnewton, decouple or perturb. If V does not exist the prefault bus voltages are automatically set to 1.0 per unit. The program obtains the total fault current, bus voltages and line currents during the fault.

SYMMETRICAL FAULT (BALANCED THREE - PHASE FAULT):--
The program prompts the user to enter the faulted bus number and the fault impedance Zf. The prefault bus voltages are defined by the reserved Vector V. The array V may be defined or it is returned from the power flow programs lfgauss, lfnewton, decouple or perturb. If V does not exist the prefault bus voltages are automatically set to 1.0 per unit. The program obtains the total fault current, the postfault bus voltages and line currents.

BUS CODE	Z0	Z1
0 1	0.0 0.40	0.0 0.25
0 2	0.0 0.10	0.0 0.25
1 2	0.0 0.30	0.0 0.125
1 3	0.0 0.35	0.0 0.15
2 3	0.0 0.7125	0.0 0.25

The complex bus impedance matrix:-
Zbus1 =

IJIREEICE

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

Vol. 9, Issue 6, June 2021

DOI 10.17148/IJIREEICE.2021.9630

0 + 0.1450i 0 + 0.1050i 0 + 0.1300i
0 + 0.1050i 0 + 0.1450i 0 + 0.1200i
0 + 0.1300i 0 + 0.1200i 0 + 0.2200i
Zbus0 =
0 + 0.1820i 0 + 0.0545i 0 + 0.1400i
0 + 0.0545i 0 + 0.0864i 0 + 0.0650i
0 + 0.1400i 0 + 0.0650i 0 + 0.3500i

Line-to-ground fault analysis:-

Single line to-ground fault at bus No. 1
Total fault current = 6.3559 per unit
Bus Voltages during the fault in per unit
Bus -------Voltage Magnitude-------
34
No. Phase a Phase b Phase c
1 0.0000 1.0414 1.0414
2 0.4396 0.9510 0.9510
3 0.1525 1.0108 1.0108

Line currents for fault at bus No. 1
From To -----Line Current Magnitude----
Bus Bus Phase a Phase b Phase c
1 F 6.3559 0.0000 0.0000
2 1 2.2564 0.2225 0.2225
2 3 0.6780 0.0424 0.0424
3 1 0.6780 0.0424 0.0424
Single line to-ground fault at bus No. 2
Total fault current = 7.9708 per unit
Bus Voltages during the fault in per unit
Bus -------Voltage Magnitude-------
No. Phase a Phase b Phase c
1 0.2972 0.9401 0.9401
2 0.0000 0.9319 0.9319
3 0.1896 0.9355 0.9355

Line currents for fault at bus No. 2
From To -----Line Current Magnitude----
Bus Bus Phase a Phase b Phase c
1 2 1.9827 0.5679 0.5679
1 3 0.6111 0.1860 0.1860
2 F 7.9708 0.0000 0.0000
3 2 0.6111 0.1860 0.1860
Single line to-ground fault at bus No. 3
Total fault current = 3.7975 per unit
Bus Voltages during the fault in per unit
Bus -------Voltage Magnitude-------

No. Phase a Phase b Phase c
1 0.4937 1.0064 1.0064
2 0.6139 0.9671 0.9671
3 0.0000 1.0916 1.0916

Line currents for fault at bus No. 3
From To -----Line Current Magnitude----
Bus Bus Phase a Phase b Phase c
1 3 2.2785 0.0000 0.0000
2 1 0.5190 0.2152 0.2152

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

Vol. 9, Issue 6, June 2021

DOI 10.17148/IJIREEICE.2021.9630

2 3 1.5190 0.0000 0.0000
3 F 3.7975 0.0000 0.0000

Double line-to-ground fault analysis:

Double line-to-ground fault at bus No. 1

Total fault current = 5.8939 per unit

Bus Voltages during the fault in per unit

Bus No.	-------Voltage Magnitude------- Phase a	Phase b	Phase c
1	1.0727	0.0000	0.0000
2	0.9008	0.3756	0.3756
3	1.0196	0.1322	0.1322

Line currents for fault at bus No. 1

From Bus	To Bus	-----Line Current Magnitude---- Phase a	Phase b	Phase c
1	F	0.0000	6.6601	6.6601
2	1	0.2063	2.2302	2.2302
2	3	0.0393	0.6843	0.6843
3	1	0.0393	0.6843	0.6843

Balanced three-phase fault analysis:

Balanced three-phase fault at bus No. 1

Total fault current = 6.8966 per unit

Bus Voltages during fault in per unit

Bus No.	Voltage Magnitude	Angle degrees
1	0.0000	0.0000
2	0.2759	0.0000
3	0.1034	0.0000

VI. CONCLUSION

The fault analysis codes were able to generate accurate results based on the input data defined by the theory of symmetrical components. It was noted that only symmetrical fault analysis can reveal the post fault bus voltages while the unbalanced faults analysis can only generate results for total fault current, bus voltages and line currents during the fault. Therefore the project can be regarded as successfully done.

REFRENCES

[1]. Singh, L.P. Advanced power system analysis and Dynamics. Wiley, New York,1983.
[2]. Neuenswander, John R .Modern Power Systems. International Textbook Co.,Scranton, PA1971.
[3]. El- Abiad, A.H. "Digital Calculation of Line- to- ground short Circuits by matrixmethods." AIEE Trans.PAS-79.323, 1960.
[4]. Weedy, B.M. Electrical Power systems.3d ed. Wiley, New York, 1979.
[5]. Anderson, Paul M. Analysis of faulted power systems. Iowa State Press, Ames,1973.
[6]. Brown, H.E. and C.E. Person, short Circuit Studies of Large Systems by the impedance Matrix method, Proc. PICA, 1967, p.335.
[7]. Stevenson series "Elements of power systems".