Contents

CHAPTER ONE

1.0 FAULT

1.01 INTRODUCTION

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.

1.0.2 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

1.0.3 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.

1.04 EFFECTS OF POWER SYSTEM FAULTS

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

1.1 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.

1.2 SYMMETRICAL COMPONENTS

The majority of faults in power systems are asymmetrical. To analyse an asymmetrical fault, an unbalanced 3- phase circuit has to be solved. Since the direct solution of such a circuit is very difficult, the solution can be more easily obtained by using symmetrical components since this yields three (fictitious) single phase networks, only one of which contains a driving emf.

Since the system reactances are balanced the thee fictitious networks have no mutual coupling between them, a fact that is making this method of analysis quite simple.

1.21 General principles
Any set of unbalanced 3-phase voltages (or current) can be transformed into 3 balanced sets. These are:

1.   A positive sequence set of three symmetrical voltages (i.e. all numerically equal and all displaced from each other by $120^{0)}$ having the same phase sequence *abc* as the original set and denoted by V_{a1}, V_{b1}, V_{c1} as shown in the fig(1a)

V_{c1} V_{a1}

V_{b1}
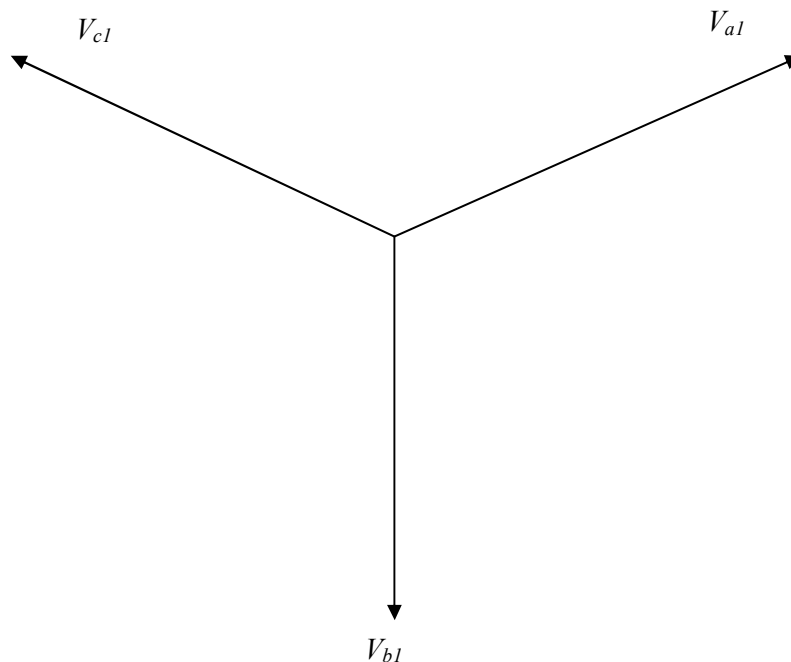
Fig. (a)

2.   A negative sequence set of three symmetrical voltages having the phase sequence opposite to that of the original set and denoted by V_{a2}, V_{b2}, V_{c2} as shown in fig(1b)

V_{a2}

V_{b2}

V_{c2}
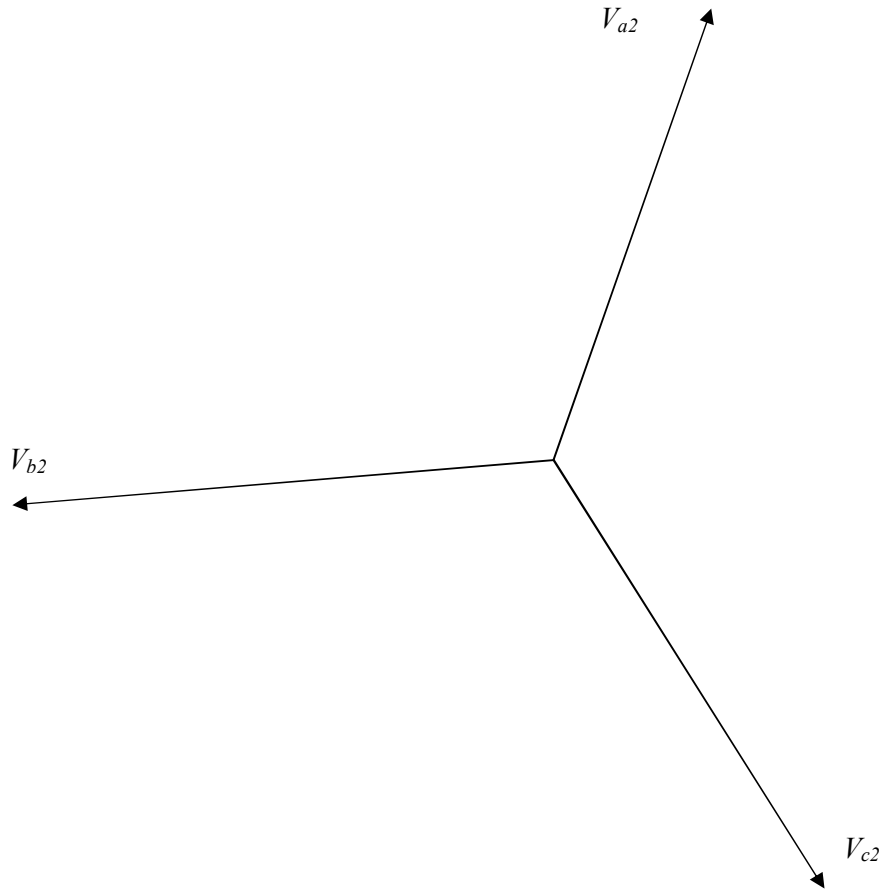
Fig. 1 (b)

3. A zero sequence set of three voltages, all equal in magnitude and in phase with each other and denoted by V_{a0}, V_{b0}, V_{c0} as shown in fig (1c) below:
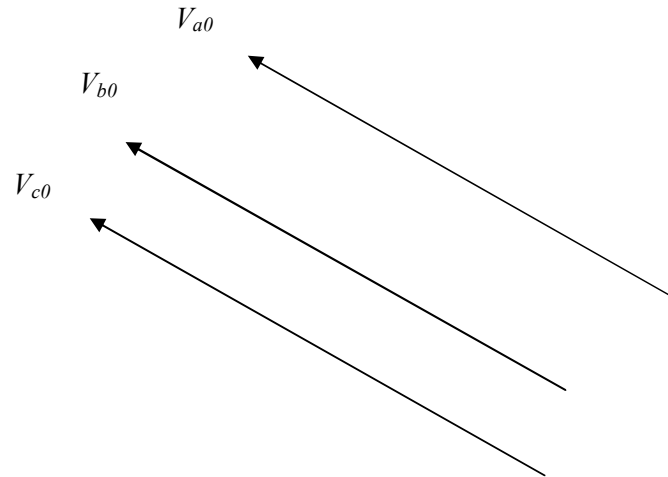
Fig. 1 (c)

The positive, negative and zero sequence sets above are known as symmetrical components.

Thus we have,

$V_a = V_{a1} + V_{a2} + V_{a0}$

$V_b = V_{b1} + V_{b2} + V_{b0}$

$V_c = V_{c1} + V_{c2} + V_{c0}$

The symmetrical components application to power system analysis is of fundamental importance since it can be used to transform arbitrarily unbalanced condition into symmetrical components, compute the system response by straightforward circuit analysis on simple circuit models and transform the results back to the original phase variables.

Generally the subscripts 1, 2 and 0 are used to indicate positive sequence, negative sequence and zero sequence respectively.

The symmetrical components do not have separate existence; they are just mathematical components of unbalanced currents (or voltages) which actually flow in the system.

1.2.2 The "a" operator

The operator õaö as used in symmetrical components is one in which when multiplied to a vector, rotates the vector through 120^0 in a positive (anticlockwise) direction without changing the magnitude.

The operator õaö is defined as $1\angle 120^0$

1.3 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.

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 I_{a1}, I_{a2} and I_{a0} are then inter-connected to represent the different fault conditions.

1.4 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 120^0.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.

CHAPTER TWO

2.0 SEQUENCE NETWORKS OF SYNCHRONOUS MACHINES

An unloaded synchronous machine having its neutral earthed through impedance, z_n, is shown in fig. 2(a) below.

A fault at its terminals causes currents I_a, I_b and I_c to flow in the lines. If fault involves earth, a current I_n flows into the neutral from the earth. This current flows through the neutral impedance Z_n.

Thus depending on the type of fault, one or more of the line currents may be zero.
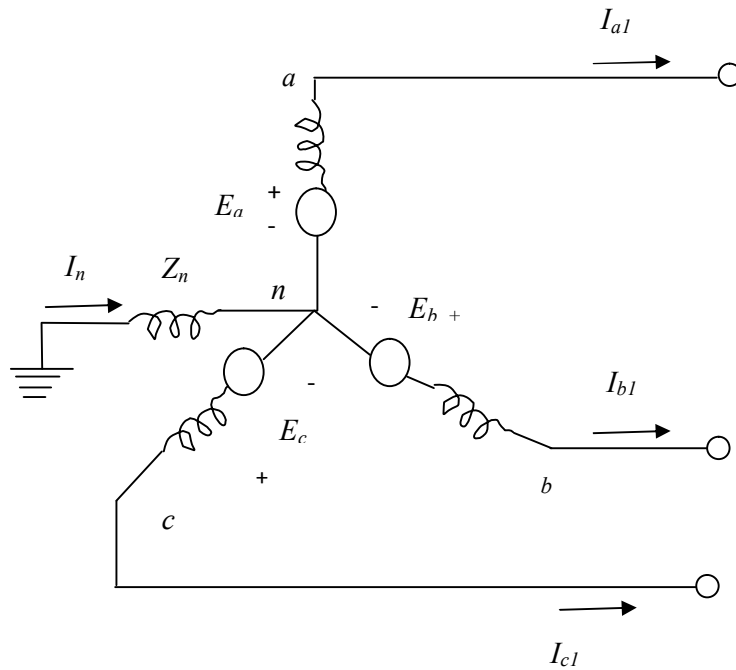
Fig.2 (a)

2.0.1 Positive sequence network

The generated voltages of a synchronous machine are of positive sequence only since the windings of a synchronous machine are symmetrical.

The positive sequence network consists of an emf equal to no load terminal voltages and is in series with the positive sequence impedance Z_1 of the machine. Fig.2 (b) and fig.2(c) shows the paths for positive sequence currents and positive sequence network respectively on a single phase basis in the synchronous machine. The neutral impedance Z_n does not appear in the circuit because the phasor sum of I_{a1}, I_{b1} and I_{c1} is zero and no positive sequence current can flow through Z_n. Since its a balanced circuit, the positive sequence N

The reference bus for the positive sequence network is the neutral of the generator.

The positive sequence impedance Z_1 consists of winding resistance and direct axis reactance. The reactance is the sub-transient reactance $X\ddot{o}_d$ or transient reactance $X\o_d$ or synchronous reactance X_d depending on whether sub-transient, transient or steady state conditions are being studied.

From fig.2 (b) , the positive sequence voltage of terminal a with respect to the reference bus is given by:

$V_{a1} = E_a - Z_1 I_{a1}$
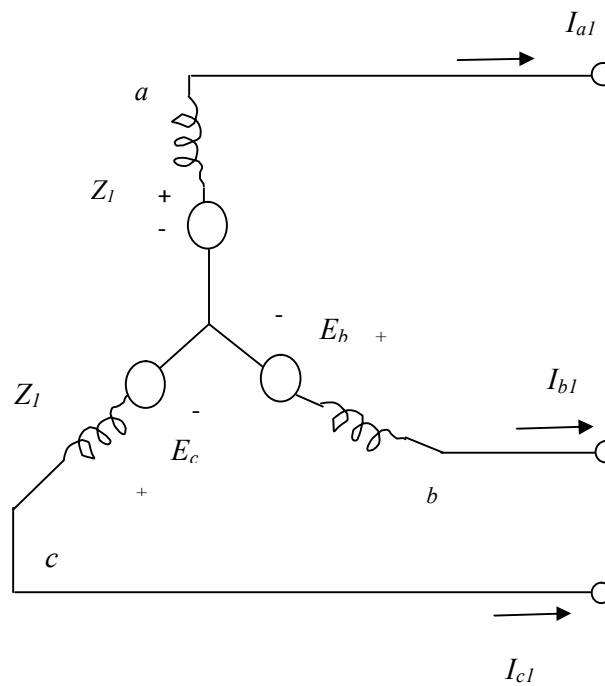
Fig.2 (b)
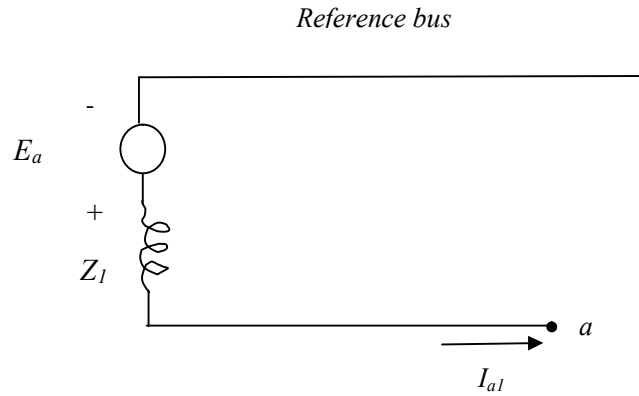
Fig.2(c)

2.02 Negative sequence network

A synchronous machine does not generate any negative sequence voltage. The flow of negative sequence currents in the stator windings creates an mmf which rotates at synchronous speed in a direction opposite to the direction of rotor, i.e., at twice the synchronous speed with respect to rotor.

Thus the negative sequence mmf alternates past the direct and quadrature axis and sets up a varying armature reaction effect. Thus, the negative sequence reactance is taken as the average of direct axis and quadrature axis sub-transient reactance, i.e.,

$X_2 = 0.5 \ (X''_d + X''_q)$.

It not necessary to consider any time variation of X_2 during transient conditions because there is no normal constant armature reaction to be effected. For more accurate calculations, the negative sequence resistance should be considered to account for power dissipated in the rotor poles or damper winding by double supply frequency induced currents.

The fig.2 (d) and fig.2 (e) shows the negative sequence currents paths and the negative sequence network respectively on a single phase basis of a synchronous machine.

The reference bus for the negative sequence network is the neutral of the machine. Thus, the negative sequence voltage of terminal a with respect to the reference bus is given by:

$V_{a2} = -Z_2 I_{a2}$

I_{a2}

a

Z_2

Z_2

Z_2

b

I_{b2}

c

I_{c2}

Fig.2 (d)

Reference bus

Z_2

a

I_{a2}
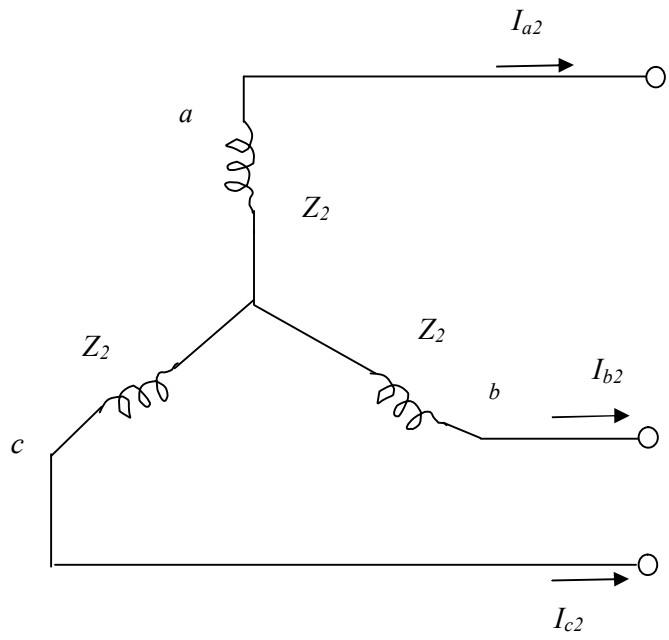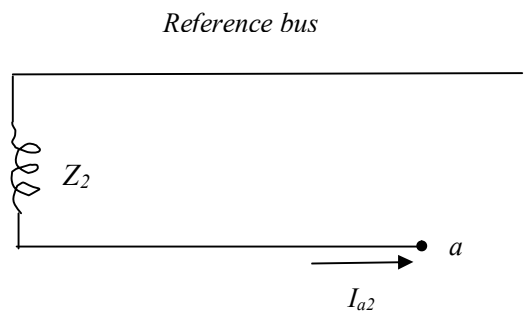
Fig.2 (e)

2.0.3 Zero sequence network

No zero sequence voltage is induced in a synchronous machine. The flow of zero sequence currents in the stator windings produces three mmf which are in time phase. If each phase winding produced a sinusoidal space mmf, then with the rotor removed, the flux at a point on the axis of the stator due to zero sequence current would be zero at every instant.

When the flux in the air gap or the leakage flux around slots or end connections is considered, no point in these regions is equidistant from all the three óphase windings of the stator.

The mmf produced by a phase winding departs from a sine wave, by amounts which depend upon the arrangement of the winding.

The zero sequence currents flow through the neutral impedance Z_n and the current flowing through this impedance is $3I_{a0}$.

Fig.2(f) and fig.2(g) shows the zero sequence current paths and zero sequence network respectively, and as can be seen, the zero sequence voltage drop from point a to ground is - $3I_{a0}Z_n$ ó$I_{a0}Zg_0$ where Z_{g0} is the zero sequence impedance per phase of the generator.

Since the current in the zero sequence network is I_{a0} this network must have an impedance of $3Z_n + Z_{g0}$. Thus,

$Z_0 = 3Z_n + Z_{g0}$

The zero sequence voltage of terminal a with respect to the reference bus is thus:

$V_{a0} = -I_{a0}Z_0$

Fig.2 (f)

Reference bus
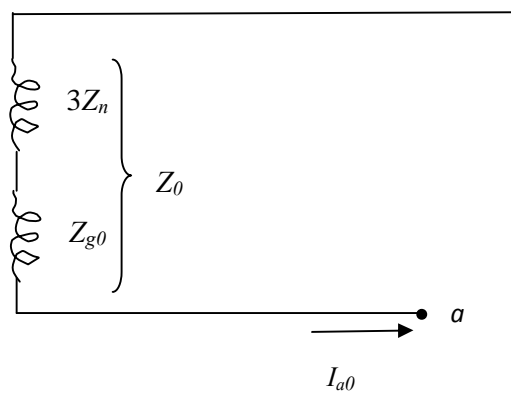
Fig.2 (g)
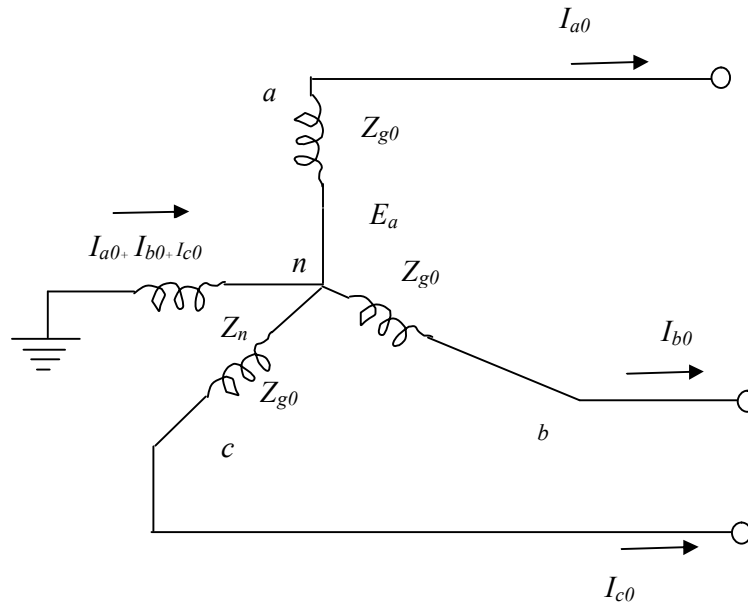
2.1 SEQUENCE IMPEDANCES OF TRANSMISSION LINE

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.

2.2 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.

2.3 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 Z_n appears as $3Z_n$ in the zero sequence network.

- The three sequence networks are independent and are interconnected suitably depending on the type of fault.

2.4 UNSYMMETRICAL FAULTS

The basic approach to the analysis of unsymmetrical faults is to consider the general situation shown in the fig.3.0 which shows the three lines of the three- phase power system at the point of fault.

The general terminals brought out are for purposes of external connections which simulate the fault. Appropriate connections of the three stubs represent the different faults, e.g., connecting stub `a' to ground produces a single line to ground fault, through zero impedance, on phase `a'. The currents in stubs b and c are then zero and Ia is the fault current.

Similarly, the connection of stubs b and c produces a line to line fault, through zero impedance, between phases b and c, the current in stub a is then zero and I_b is equal to Ic. The positive assignment of phase quantities is important. It is seen that the currents flow out of the system.

The three general sequence circuits are shown in fig.3.1 (a). The ports indicated correspond to the general 3- phase entry port of fig.3.1. A suitable inter- connection of the three- sequence networks depending on the type fault yields the solution to the problem.

The sequence networks of fig.3.1 (a) can be replaced by equivalent sequence networks of fig.3.1 (b) . Z_0, Z_1 and Z_2 indicate the sequence impedances of the network looking into the fault
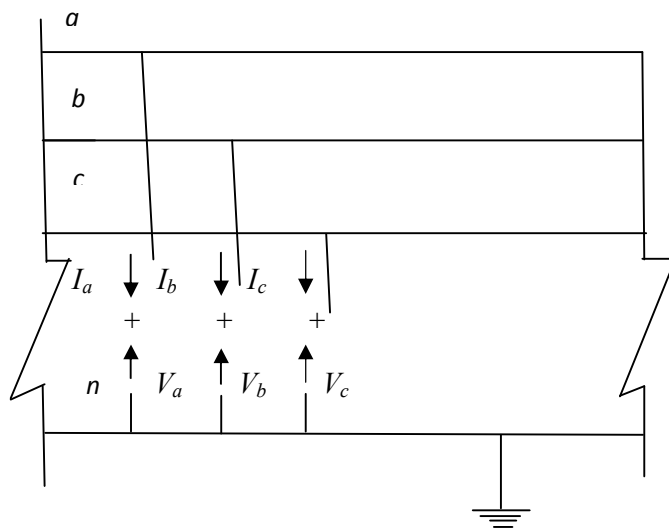
Fig.3.0 General 3- phase access port
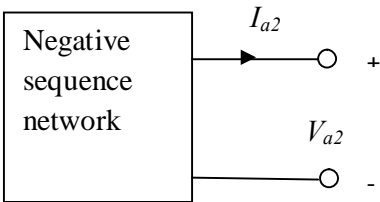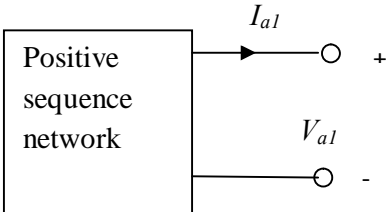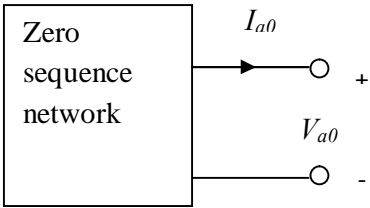
General sequence networks   Equivalent sequence networks
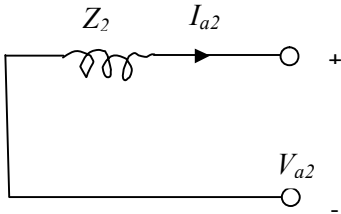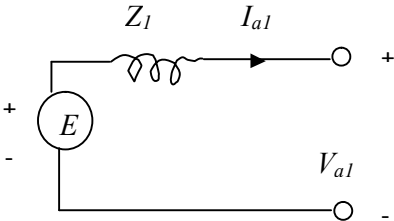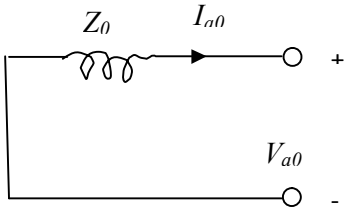
Fig.3.1 (a)   Fig.3.1 (b)

2.4.1 SINGLE LINE TO GROUND FAULT

The termination of the three- phase access port as shown in fig. 3.2 brings about a condition of single line to ground fault through a fault impedance Z_f.

Typically Z_f is set to zero in all fault studies. I include Z_f in the analysis for the sake of generality. The terminal conditions at the fault point give the following equations:

$I_b = 0$

$I_c = 0$

$V_a = I_a Z_f$
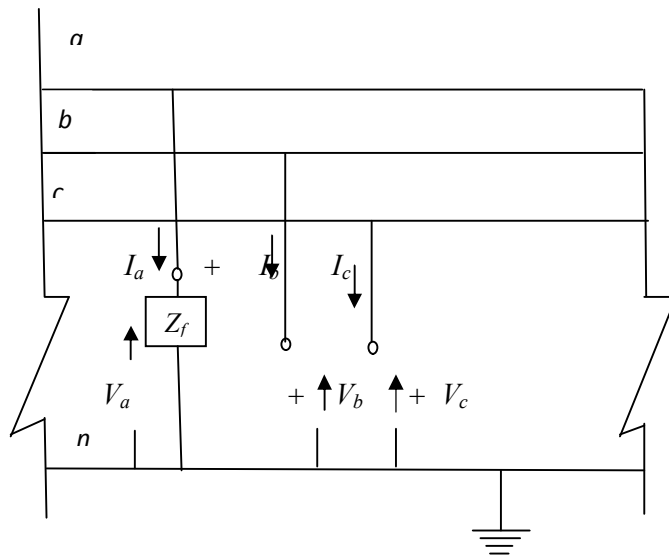
Fig. 3.2

Connections of sequence networks for a single line to ground fault and its simplified equivalent circuit are shown in the fig. 3.3(a) and fig. 3.3 (b) below:

General sequence networks
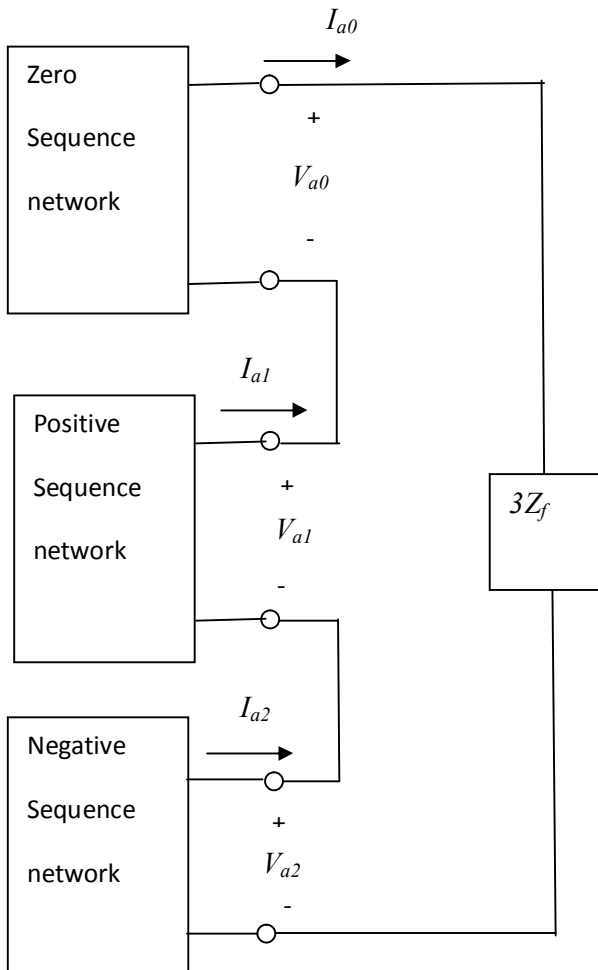
Equivalent sequence networks
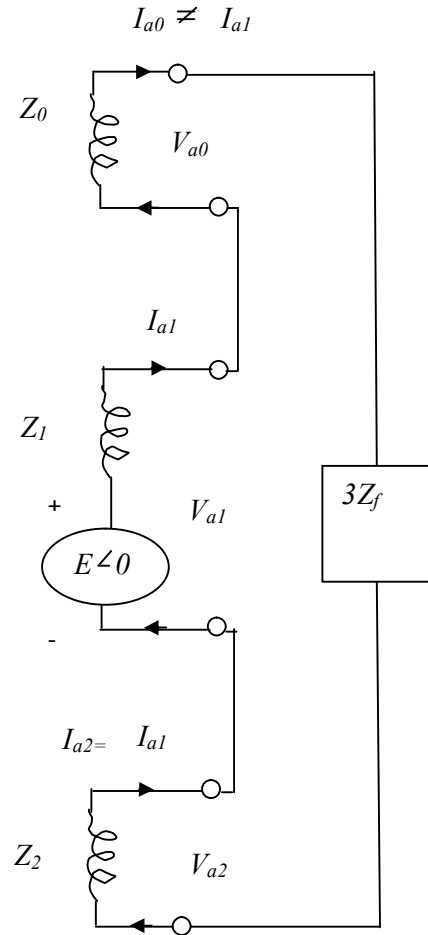
Fig.3.3 (a)

Fig.3.3 (b)

2.4.2 LINE TO LINE FAULT

The termination of the three- phase access port as in the fig.3.4 below simulates a line to line fault through a fault impedance Z_f .
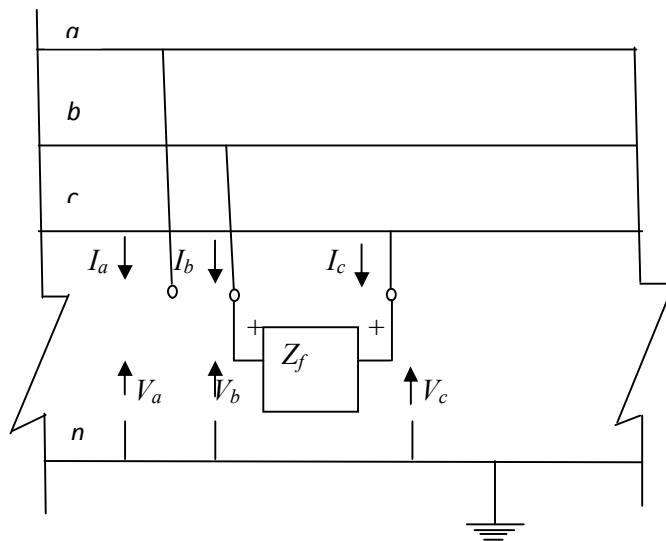
Fig. 3.4

The terminal conditions at the fault point give the following equations,

$I_a = 0$

$I_b = -I_c$

$V_b = V_c + Z_f I_b$

$I_b = -I_c = I_{a0} + a^2 I_{a1} + a I_{a2}$

Connection of sequence networks for a line to line fault and its simplified equivalent circuit are shown in the fig.3.5 (a) and fig.(b) below.

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General sequence networks
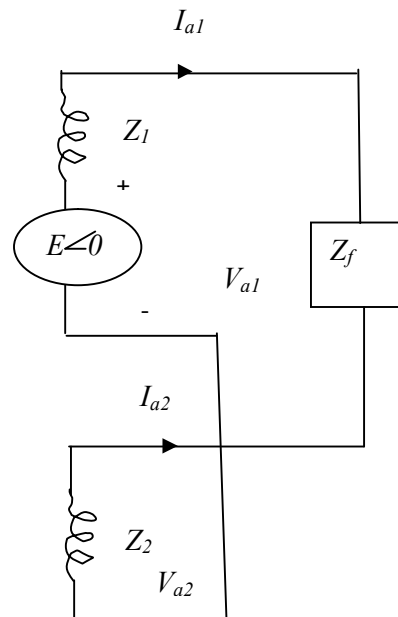
Fig. 3.5 (a)   Fig.3.5 (b)

2.4.3 DOUBLE LINE TO GROUND FAULT

The termination of the three- phase access port as shown in fig.3.6 simulates a double line to ground fault through fault impedance Z_f.

The terminal conditions at the fault point give the following equations,

$$I_a = 0$$

$$V_b = V_c = (\ I_b + I_c\ ) Z_f$$

a

b

c

I_a ↓ I_b ↓ I_c ↓

+   +
Z_f

↑V_a ↑V_b ↑V_c

n
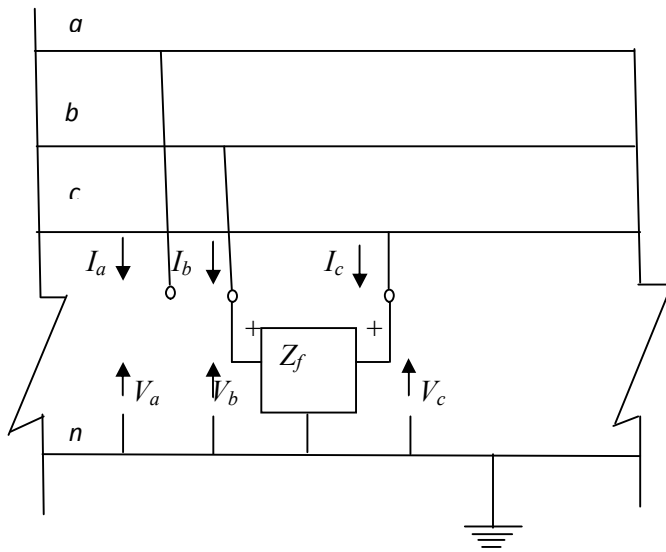
Fig. 3.6

The sequence networks and the equivalent circuit are shown by the Fig.3.7 (a) and Fig. 3.7 (b) below

Fig. 3.7(a)

Fig.3.7 (b)

2.5 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.

CHAPTER THREE

3.0 THE BUS IMPEDANCE MATRIX

3.0.1 INTRODUCTION

Since the actual power systems are very large, network reduction method can only be used to solve very small systerms.Therefore a systematic procedure suitable for digital computer calculations is necessary.

System studies can be carried out using Y_{bus} or Z_{bus}. Y_{Bus} is used for load flow computations, but for fault calculations (short circuit studies) , the use of Z_{bus} is preferable.

3.0.2 THE ALGORITHM FOR FORMULATING THE COMPLEX Z_{bus} IMPEDANCE MATRIX

This is described in terms of modifying an existing bus impedance matrix designated as $[Z_{bus}]_{old}$. The new modified matrix is designated as $[Z_{bus}]_{new}$.

The network consists of a reference bus and a number of other buses. When a new element having self impedance z_s is added, a new bus may be created if the new element is a tree branch or a new bus may not be created if the new element is a link.

Each of these two cases can be subdivided into two cases so that z_s may be added in the following ways:

1.   Adding z_s from a new bus to reference.

2.   Adding z_s from a new bus to an old bus.

3.   Adding z_s from an old bus to reference.

4.   Adding z_s between two old buses.

The case of addition of z_s to create two new buses simultaneously has been carefully avoided by properly selecting the order in which the elements are added.

Therefore, for my case, bus zero was taken as the reference bus and then the following procedure was adhered to:

1.   A branch was added from a new bus to a reference bus zero.

2.   A branch was then added from a new bus to an existing bus.

3.   A link was finally added between two old buses to generate the complex bus impedance matrix by method of building algorithms.

3.1 A THREE BUS POWER SYSTEM NETWORK

A 3-bus system characterised by the following parameter values was used for the analysis:

Input data (Impedances in per- unit)

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

CHAPTERT FOUR

4.0 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 fault were executed using a Matlab environment to generate results for the analysis:

4.0.1 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.

4.0.2 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.

4.0.3 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.

4.0.4 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.

4.1 Z BUILD CODE

The zero sequence impedances and the positive sequence impedances for the network were computed using the zbuild code where the positive and the negative sequence impedances were treated to be the same as indicated by the programs specifications.The network data for the various sequence impences i.e the sequence network of its thevenin∅s equivalent was obtained as below:

The above sequence network was the run using the zbuild code to form the complex bus impedance matrix by the method of building algorithm.

4.2 RESULTS
The following results were obtained after simulation of the codes using a matlab environment:

4.2.1 The complex bus impedance matrix

Zbus1 =

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

4.2.2 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-------

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
2	3	1.5190	0.0000	0.0000
3	F	3.7975	0.0000	0.0000

4.2.3 Line-to-line fault analysis

Line-to-line fault at bus No. 1

Total fault current =   5.9726 per unit

Bus Voltages during the fault in per unit

Bus	-------Voltage Magnitude-------		
No.	Phase a	Phase b	Phase c
1	1.0000	0.5000	0.5000
2	1.0000	0.5541	0.5541
3	1.0000	0.5080	0.5080

Line currents for fault at bus No. 1

| From | To | -----Line Current Magnitude---- | | |
Bus	Bus	Phase a	Phase b	Phase c
1	F	0.0000	5.9726	5.9726
2	1	0.0000	1.9112	1.9112
2	3	0.0000	0.5973	0.5973
3	1	0.0000	0.5973	0.5973

Line-to-line fault at bus No. 2

Total fault current =   5.9726 per unit

Bus Voltages during the fault in per unit

| Bus | -------Voltage Magnitude------- | | |
No.	Phase a	Phase b	Phase c
1	1.0000	0.5541	0.5541
2	1.0000	0.5000	0.5000
3	1.0000	0.5218	0.5218

Line currents for fault at bus No. 2

| From | To | -----Line Current Magnitude---- | | |
Bus	Bus	Phase a	Phase b	Phase c
1	2	0.0000	1.9112	1.9112
1	3	0.0000	0.5973	0.5973

2	F	0.0000	5.9726	5.9726
3	2	0.0000	0.5973	0.5973

Line-to-line fault at bus No. 3

Total fault current =   3.9365 per unit

Bus Voltages during the fault in per unit

Bus	-------Voltage Magnitude-------		
No.	Phase a	Phase b	Phase c
1	1.0000	0.6128	0.6128
2	1.0000	0.6364	0.6364
3	1.0000	0.5000	0.5000

Line currents for fault at bus No. 3

From	To	-----Line Current Magnitude----		
Bus	Bus	Phase a	Phase b	Phase c
1	3	0.0000	2.3619	2.3619
2	1	0.0000	0.3149	0.3149
2	3	0.0000	1.5746	1.5746
3	F	0.0000	3.9365	3.9365

4.2.4 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	-------Voltage Magnitude-------		
No.	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	To	-----Line Current Magnitude----		
Bus	Bus	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

Double line-to-ground fault at bus No. 2

Total fault current =   9.4414 per unit

Bus Voltages during the fault in per unit

Bus   -------Voltage Magnitude-------

No.   Phase a   Phase b   Phase c

1   0.8411   0.2894   0.2894

2   0.8155   0.0000   0.0000

3   0.8269   0.1835   0.1835

Line currents for fault at bus No. 2

From   To   -----Line Current Magnitude----

Bus   Bus   Phase a   Phase b   Phase c

1   2   0.6727   2.0868   2.0868

1   3   0.2203   0.6482   0.6482

2   F   0.0000   7.6129   7.6129

3   2   0.2203   0.6482   0.6482

Double line-to-ground fault at bus No. 3

Total fault current =   3.2609 per unit

Bus Voltages during the fault in per unit

Bus   -------Voltage Magnitude-------

No.   Phase a   Phase b   Phase c

1   1.0109   0.4498   0.4498

2   0.9402   0.5362   0.5362

3   1.1413   0.0000   0.0000

Line currents for fault at bus No. 3

From   To   -----Line Current Magnitude----

Bus   Bus   Phase a   Phase b   Phase c

1   3   0.0000   2.5565   2.5565

2   1   0.1848   0.4456   0.4456

2   3   0.0000   1.7043   1.7043

3   F   0.0000   4.2608   4.2608

4.2.5 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   Voltage   Angle

No.   Magnitude   degrees

1   0.0000   0.0000

2   0.2759   0.0000

3   0.1034   0.0000

Line currents for fault at bus No. 1

From	To	Current	Angle
Bus	Bus	Magnitude	degrees
G	1	4.0000	-90.0000
1	F	6.8966	-90.0000
G	2	2.8966	-90.0000
2	1	2.2069	-90.0000
2	3	0.6897	-90.0000
3	1	0.6897	-90.0000

Balanced three-phase fault at bus No. 2

Total fault current =   6.8966 per unit

Bus Voltages during fault in per unit

Bus	Voltage	Angle
No.	Magnitude	degrees
1	0.2759	0.0000
2	0.0000	0.0000
3	0.1724	0.0000

Line currents for fault at bus No. 2

From Bus	To Bus	Current Magnitude	Angle degrees
G	1	2.8966	-90.0000
1	2	2.2069	-90.0000
1	3	0.6897	-90.0000
G	2	4.0000	-90.0000
2	F	6.8966	-90.0000
3	2	0.6897	-90.0000

Balanced three-phase fault at bus No. 3

Total fault current =   4.5455 per unit

Bus Voltages during fault in per unit

Bus No.	Voltage Magnitude	Angle degrees
1	0.4091	0.0000
2	0.4545	0.0000
3	0.0000	0.0000

Line currents for fault at bus No. 3

From Bus	To Bus	Current Magnitude	Angle degrees
G	1	2.3636	-90.0000
1	3	2.7273	-90.0000
G	2	2.1818	-90.0000
2	1	0.3636	-90.0000
2	3	1.8182	-90.0000
3	F	4.5455	-90.0000

4.3 DISCUSSION

Computation of fault currents in power system is best done by computer. Computer formulation of the impedance matrix was accomplished by programming the four modifications presented in chapter three. Care was taken to avoid the new- bus to new-bus modification, which requires infinite entries into [Z]. This situation was avoided in two ways; the buses were numbered to avoid the problem; a fictitious large impedance was inserted from one of the new buss to reference that was taken as bus zero, to change its status to an old bus in the next step. Complete modification was done using the old-bus- to new- bus method.

The procedure was followed in duplicate for the sequences since same values were used for positive- and negative- sequence impedances.

 In most fault calculation techniques, prefault, or load, component of current is neglected usually on the assumption that currents throughout the system are zero prior to the fault, this is almost never strictly true; however the error produced is small, since the fault currents are generally much larger than the load currents. The load currents and the fault currents are almost 90^0 displaced in phase from each other, making their sum more closely equal to the large component than would have been the case if the currents were in phase. Besides, selecting precise values for all prefault currents is somewhat speculative, since there is no way of predicting what the loaded state of the system is when a fault occurs.

4.4 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.

4.5 RECOMMENDATIONS

The local power generating companies e.g. KenGen and power transmission and distribution companies e.g. KPLC should establish a fully - fledged faults analysis department in their institutions to entrench and implement modern computerised methods of electrical power systems fault analysis that would provide more accurate data that can be used to size and set protective devices adequately.

For purposes of future work, the following should be given due attention:

1.   Incorporate computer monitoring software for fault detection

2.   More work to be done on the analysis so that it can reflect the post fault security of a system.

3.   Computerised technique on interfacing of fault detection application and protection systems e.g. circuit breakers needs to be studied to improve the switching speed of our protective devices.

4.   There is need to focus on the relevance of the fibre optics technology to fault studies so as to to have our fault analysis softwares embedded in the communication link for efficient customer notification services by KPLC on fault occurrences.

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APPENDIX A

MATLAB CODES

Z_{bus} *IMPEDANCE MATRIX*

```
% This program forms the complex bus impedance matrix by the method
% of building algorithm.  Bus zero is taken as reference.




function [Zbus] = zbuild(linedata)
nl = linedata(:,1); nr = linedata(:,2); R = linedata(:,3);
X = linedata(:,4);
nbr=length(linedata(:,1)); nbus = max(max(nl), max(nr));
for k=1:nbr
   if R(k) == inf | X(k) ==inf
   R(k) = 99999999; X(k) = 99999999;
   else, end
end

ZB = R + j*X;
Zbus = zeros(nbus, nbus);
tree=0;  %%%%new
% Adding a branch from a new bus to reference bus 0
  for I = 1:nbr
  ntree(I) = 1;
     if nl(I) == 0 | nr(I) == 0
        if nl(I) == 0      n = nr(I);
        elseif nr(I) == 0  n = nl(I);
        end
           if abs(Zbus(n, n)) == 0   Zbus(n,n) = ZB(I);tree=tree+1; %%new
           else Zbus(n,n) = Zbus(n,n)*ZB(I)/(Zbus(n,n) + ZB(I));
           end
           ntree(I) = 2;
     else,end
  end

% Adding a branch from new bus to an existing bus
while tree < nbus  %%% new

  for n = 1:nbus
    nadd = 1;
    if abs(Zbus(n,n)) == 0
      for I = 1:nbr
        if nadd == 1;
           if nl(I) == n | nr(I) == n
```

```
        if nl(I) == n      k = nr(I);
        elseif nr(I) == n  k = nl(I);
        end
          if abs(Zbus(k,k)) ~= 0
              for m = 1:nbus
                 if m ~= n
                 Zbus(m,n) = Zbus(m,k);
                 Zbus(n,m) = Zbus(m,k);
                  else, end
               end
               Zbus(n,n) = Zbus(k,k) + ZB(I); tree=tree+1; %%new
               nadd = 2;  ntree(I) = 2;
            else, end
         else, end
       else, end
     end
   else, end
end


end  %%%%%new

% Adding a link between two old buses
 for n = 1:nbus
    for I = 1:nbr
       if ntree(I) == 1
         if nl(I) == n | nr(I) == n
           if nl(I) == n      k = nr(I);
           elseif nr(I) == n k = nl(I);
           end
        DM = Zbus(n,n) + Zbus(k,k) + ZB(I) - 2*Zbus(n,k);
           for jj = 1:nbus
           AP = Zbus(jj,n) - Zbus(jj,k);
              for kk = 1:nbus
              AT = Zbus(n,kk) - Zbus(k, kk);
              DELZ(jj,kk) = AP*AT/DM;
               end
            end
          Zbus = Zbus - DELZ;
          ntree(I) = 2;
       else,end
      else,end
    end
 end
```

Double- Line- Ground fault

% The program dlgfault is designed for the double line-to-ground
% fault analysis of a power system network. The program requires

% the positive-, negative- or zero-sequence bus impedance matrices,
% Zbus1 Zbus2,and Zbus0. The bus impedances matrices may be defined
% by the user, obtained by the inversion of Ybus or it may be
% determined either from the function Zbus = zbuild(zdata)
% or the function Zbus = zbuildpi(linedata, gendata, yload).
% 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.

function dlgfault(zdata0, Zbus0, zdata1, Zbus1, zdata2, Zbus2, V)

if exist('zdata2') ~= 1
zdata2=zdata1;
else, end
if exist('Zbus2') ~= 1
Zbus2=Zbus1;
else, end

nl = zdata1(:,1); nr = zdata1(:,2);
nl0 = zdata0(:,1); nr0 = zdata0(:,2);
nbr=length(zdata1(:,1)); nbus = max(max(nl), max(nr));
nbr0=length(zdata0(:,1));
R0 = zdata0(:,3); X0 = zdata0(:,4);
R1 = zdata1(:,3); X1 = zdata1(:,4);
R2 = zdata2(:,3); X2 = zdata2(:,4);

for k = 1:nbr0
   if R0(k) == inf | X0(k) == inf
   R0(k) = 99999999; X0(k) = 999999999;
   else, end
end
ZB1 = R1 + j*X1; ZB0 = R0 + j*X0;
ZB2 = R2 + j*X2;

if exist('V') == 1
   if length(V) == nbus
   V0 = V;
   else, end
else, V0 = ones(nbus, 1) + j*zeros(nbus, 1);
end

fprintf('\nDouble line-to-ground fault analysis \n')
ff = 999;

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```
while ff > 0
nf = input('Enter Faulted Bus No. -> ');
while nf <= 0 | nf > nbus
    fprintf('Faulted bus No. must be between 1 & %g \n', nbus)
    nf = input('Enter Faulted Bus No. -> ');
    end
fprintf('\nEnter Fault Impedance Zf = R + j*X in ')
Zf = input('complex form (for bolted fault enter 0). Zf = ');
fprintf(' \n')
fprintf('Double line-to-ground fault at bus No. %g\n', nf)
a =cos(2*pi/3)+j*sin(2*pi/3);
sctm = [1   1   1; 1 a^2  a; 1 a  a^2];

Z11 = Zbus2(nf, nf)*(Zbus0(nf, nf)+ 3*Zf)/(Zbus2(nf, nf)+Zbus0(nf, nf)+3*Zf);
Ia1 = V0(nf)/(Zbus1(nf,nf)+Z11);
Ia2 =-(V0(nf) - Zbus1(nf, nf)*Ia1)/Zbus2(nf,nf);
Ia0 =-(V0(nf) - Zbus1(nf, nf)*Ia1)/(Zbus0(nf,nf)+3*Zf);
I012=[Ia0; Ia1; Ia2];
Ifabc = sctm*I012; Ifabcm=abs(Ifabc);
Ift = Ifabc(2)+Ifabc(3);
Iftm = abs(Ift);

fprintf('Total fault current = %9.4f per unit\n\n', Iftm)
fprintf('Bus Voltages during the fault in per unit \n\n')
fprintf('   Bus    -------Voltage Magnitude-------  \n')
fprintf('   No.   Phase a    Phase b    Phase c  \n')

for n = 1:nbus
Vf0(n)= 0 - Zbus0(n, nf)*Ia0;
Vf1(n)= V0(n) - Zbus1(n, nf)*Ia1;
Vf2(n)= 0 - Zbus2(n, nf)*Ia2;
Vabc = sctm*[Vf0(n); Vf1(n); Vf2(n)];
Va(n)=Vabc(1); Vb(n)=Vabc(2); Vc(n)=Vabc(3);
fprintf(' %5g',n)
fprintf(' %11.4f', abs(Va(n))),fprintf(' %11.4f', abs(Vb(n)))
fprintf(' %11.4f\n', abs(Vc(n)))
end
fprintf(' \n')
fprintf('Line currents for fault at bus No.  %g\n\n', nf)
fprintf('   From    To     -----Line Current Magnitude---- \n')
fprintf('   Bus     Bus    Phase a    Phase b    Phase c  \n')
for n= 1:nbus
  for I = 1:nbr
    if nl(I) == n | nr(I) == n
      if nl(I) ==n      k = nr(I);
      elseif nr(I) == n  k = nl(I);
      end
        if k ~= 0
        Ink1(n, k) = (Vf1(n) - Vf1(k))/ZB1(I);
        Ink2(n, k) =  (Vf2(n) - Vf2(k))/ZB2(I);
```

```matlab
              else, end
          else, end
      end
    for I = 1:nbr0
      if nl0(I) == n | nr0(I) == n
        if nl0(I) ==n      k = nr0(I);
        elseif nr0(I) == n  k = nl0(I);
        end
          if k ~= 0
          Ink0(n, k) =  (Vf0(n) - Vf0(k))/ZB0(I);
            else, end
      else, end
    end
    for I = 1:nbr
      if nl(I) == n | nr(I) == n
        if nl(I) ==n      k = nr(I);
        elseif nr(I) == n  k = nl(I);
        end
          if k ~= 0
          Inkabc = sctm*[Ink0(n, k); Ink1(n, k); Ink2(n, k)];
          Inkabcm = abs(Inkabc); th=angle(Inkabc);
            if real(Inkabc(2)) < 0
            fprintf('%7g', n), fprintf('%10g', k),
            fprintf(' %11.4f', abs(Inkabc(1))),fprintf(' %11.4f', abs(Inkabc(2)))
            fprintf(' %11.4f\n', abs(Inkabc(3)))
            elseif real(Inkabc(2)) ==0 & imag(Inkabc(2)) > 0
            fprintf('%7g', n), fprintf('%10g', k),
            fprintf(' %11.4f', abs(Inkabc(1))),fprintf(' %11.4f', abs(Inkabc(2)))
            fprintf(' %11.4f\n', abs(Inkabc(3)))
            else, end
          else, end
      else, end
    end
    if n==nf
    fprintf('%7g',n), fprintf('        F'),
    fprintf(' %11.4f', Ifabcm(1)),fprintf(' %11.4f', Ifabcm(2))
    fprintf(' %11.4f\n', Ifabcm(3))
    else, end
end
resp=0;
  while strcmp(resp, 'n')~=1 & strcmp(resp, 'N')~=1 & strcmp(resp, 'y')~=1 & strcmp(resp,
'Y')~=1
  resp = input('Another fault location? Enter "y" or "n" within single quote -> ');
  if strcmp(resp, 'n')~=1 & strcmp(resp, 'N')~=1 & strcmp(resp, 'y')~=1 & strcmp(resp,
'Y')~=1
  fprintf('\n Incorrect reply, try again \n\n'), end
  end
  if resp == 'y' | resp == 'Y'
  nf = 999;
  else ff = 0; end
```

end   % end for while

Line- Ground fault

```
% The program lgfault is designed for the single line-to-ground
% fault analysis of a power system network. The program requires
% the positive-, negative- and zero-sequence bus impedance matrices,
% Zbus1 Zbus2,and Zbus0.The bus impedances matrices may be defined
% by the user, obtained by the inversion of Ybus or it may be
% determined either from the function Zbus = zbuild(zdata)
% or the function Zbus = zbuildpi(linedata, gendata, yload).
% 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.
```

```
function lgfault(zdata0, Zbus0, zdata1, Zbus1, zdata2, Zbus2, V)
if exist('zdata2') ~= 1
zdata2=zdata1;
else, end
if exist('Zbus2') ~= 1
Zbus2=Zbus1;
else, end
nl = zdata1(:,1); nr = zdata1(:,2);
nl0 = zdata0(:,1); nr0 = zdata0(:,2);
nbr=length(zdata1(:,1)); nbus = max(max(nl), max(nr));
nbr0=length(zdata0(:,1));
R0 = zdata0(:,3); X0 = zdata0(:,4);
R1 = zdata1(:,3); X1 = zdata1(:,4);
```

```
R2 = zdata1(:,3); X2 = zdata1(:,4);

for k=1:nbr0
    if R0(k)==inf | X0(k) ==inf
    R0(k) = 99999999;  X0(k) = 99999999;
    else, end
end
ZB1 = R1 + j*X1;  ZB0 = R0 + j*X0;
ZB2 = R2 + j*X2;

if exist('V') == 1
    if length(V) == nbus
    V0 = V;
    else, end
else,  V0 = ones(nbus, 1) + j*zeros(nbus, 1);
end
fprintf('\nLine-to-ground fault analysis \n')
ff = 999;
while ff > 0
nf = input('Enter Faulted Bus No. -> ');
while nf <= 0 | nf > nbus
    fprintf('Faulted bus No. must be between 1 & %g \n', nbus)
    nf = input('Enter Faulted Bus No. -> ');
    end
fprintf('\nEnter Fault Impedance Zf = R + j*X in ')
Zf = input('complex form (for bolted fault enter 0). Zf = ');
fprintf(' \n')
fprintf('Single line to-ground fault at bus No. %g\n', nf)
a =cos(2*pi/3)+j*sin(2*pi/3);
sctm = [1   1   1; 1 a^2  a; 1 a  a^2];
Ia0 = V0(nf)/(Zbus1(nf,nf)+Zbus2(nf, nf)+ Zbus0(nf, nf)+3*Zf); Ia1=Ia0; Ia2=Ia0;
I012=[Ia0; Ia1; Ia2];
Ifabc = sctm*I012;
Ifabcm = abs(Ifabc);
fprintf('Total fault current = %9.4f per unit\n\n', Ifabcm(1))
fprintf('Bus Voltages during the fault in per unit \n\n')
fprintf('    Bus    -------Voltage Magnitude------- \n')
fprintf('    No.   Phase a    Phase b    Phase c \n')

for n = 1:nbus
Vf0(n)= 0 - Zbus0(n, nf)*Ia0;
Vf1(n)= V0(n) - Zbus1(n, nf)*Ia1;
Vf2(n)= 0 - Zbus2(n, nf)*Ia2;
Vabc = sctm*[Vf0(n); Vf1(n); Vf2(n)];
Va(n)=Vabc(1); Vb(n)=Vabc(2); Vc(n)=Vabc(3);
fprintf(' %5g',n)
fprintf(' %11.4f', abs(Va(n))),fprintf(' %11.4f', abs(Vb(n)))
fprintf(' %11.4f\n', abs(Vc(n)))
end
fprintf(' \n')
```

```
fprintf('Line currents for fault at bus No.  %g\n\n', nf)
fprintf('   From    To    -----Line Current Magnitude----  \n')
fprintf('   Bus    Bus    Phase a    Phase b    Phase c  \n')
for n= 1:nbus
  for I = 1:nbr
    if nl(I) == n | nr(I) == n
      if nl(I) ==n       k = nr(I);
      elseif nr(I) == n  k = nl(I);
      end
        if k ~= 0
        Ink1(n, k) = (Vf1(n) - Vf1(k))/ZB1(I);
        Ink2(n, k) =  (Vf2(n) - Vf2(k))/ZB2(I);
        else, end
    else, end
  end
  for I = 1:nbr0
    if nl0(I) == n | nr0(I) == n
      if nl0(I) ==n       k = nr0(I);
      elseif nr0(I) == n  k = nl0(I);
      end
        if k ~= 0
        Ink0(n, k) =  (Vf0(n) - Vf0(k))/ZB0(I);
        else, end
    else, end
  end
  for I = 1:nbr
    if nl(I) == n | nr(I) == n
      if nl(I) ==n       k = nr(I);
      elseif nr(I) == n  k = nl(I);
      end
        if k ~= 0
        Inkabc = sctm*[Ink0(n, k); Ink1(n, k); Ink2(n, k)];
        Inkabcm = abs(Inkabc); th=angle(Inkabc);
          if real(Inkabc(1)) > 0
          fprintf('%7g', n), fprintf('%10g', k),
          fprintf(' %11.4f', abs(Inkabc(1))),fprintf(' %11.4f', abs(Inkabc(2)))
          fprintf(' %11.4f\n', abs(Inkabc(3)))
          elseif real(Inkabc(1)) ==0 & imag(Inkabc(1)) < 0
          fprintf('%7g', n), fprintf('%10g', k),
          fprintf(' %11.4f', abs(Inkabc(1))),fprintf(' %11.4f', abs(Inkabc(2)))
          fprintf(' %11.4f\n', abs(Inkabc(3)))
          else, end
        else, end
    else, end
  end
  if n==nf
  fprintf('%7g',n), fprintf('        F'),
  fprintf(' %11.4f', Ifabcm(1)),fprintf(' %11.4f', Ifabcm(2))
  fprintf(' %11.4f\n', Ifabcm(3))
  else, end
```

```
end
resp=0;
   while strcmp(resp, 'n')~=1 & strcmp(resp, 'N')~=1 & strcmp(resp, 'y')~=1 & strcmp(resp,
'Y')~=1
   resp = input('Another fault location? Enter ''y'' or ''n'' within single quote -> ');
   if strcmp(resp, 'n')~=1 & strcmp(resp, 'N')~=1 & strcmp(resp, 'y')~=1 & strcmp(resp,
'Y')~=1
   fprintf('\n Incorrect reply, try again \n\n'), end
   end
   if resp == 'y' | resp == 'Y'
   nf = 999;
   else ff = 0; end
end    % end for while
%Ink0
%Ink1
%Ink2
```

Line- line fault

```
% The program llfault is designed for the line-to-line
% fault analysis of a power system network. The program requires
% the positive- and negative-sequence bus impedance matrices,
% Zbus function Zbus = zbuildpi(linedata, gendata, yload).
% 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.


function llfault(zdata1, Zbus1, zdata2, Zbus2, V)
if exist('zdata2') ~= 1
zdata2=zdata1;
else, end
if exist('Zbus2') ~= 1
Zbus2=Zbus1;
else, end

nl = zdata1(:,1); nr = zdata1(:,2);
R1 = zdata1(:,3); X1 = zdata1(:,4);
R2 = zdata2(:,3); X2 = zdata2(:,4);
ZB1 = R1 + j*X1;  ZB2 = R2 + j*X2;
nbr=length(zdata1(:,1)); nbus = max(max(nl), max(nr));
```

```
if exist('V') == 1
   if length(V) == nbus
   V0 = V;
   else, end
else,  V0 = ones(nbus, 1) + j*zeros(nbus, 1);
end
fprintf('\nLine-to-line fault analysis \n')
ff = 999;
while ff > 0
nf = input('Enter Faulted Bus No. -> ');
while nf <= 0 | nf > nbus
    fprintf('Faulted bus No. must be between 1 & %g \n', nbus)
    nf = input('Enter Faulted Bus No. -> ');
    end
fprintf('\nEnter Fault Impedance Zf = R + j*X in ')
Zf = input('complex form (for bolted fault enter 0). Zf = ');
fprintf(' \n')
fprintf('Line-to-line fault at bus No. %g\n', nf)
a =cos(2*pi/3)+j*sin(2*pi/3);
sctm = [1   1   1; 1 a^2  a; 1 a  a^2];
Ia0=0;
Ia1 = V0(nf)/(Zbus1(nf,nf)+Zbus2(nf, nf)+Zf); Ia2=-Ia1;
I012=[Ia0; Ia1; Ia2];
Ifabc = sctm*I012;
Ifabcm = abs(Ifabc);
fprintf('Total fault current = %9.4f per unit\n\n', Ifabcm(2))
fprintf('Bus Voltages during the fault in per unit \n\n')
fprintf('   Bus   -------Voltage Magnitude-------  \n')
fprintf('   No.   Phase a     Phase b     Phase c  \n')

for n = 1:nbus
Vf0(n)= 0;
Vf1(n)= V0(n) - Zbus1(n, nf)*Ia1;
Vf2(n)= 0 - Zbus2(n, nf)*Ia2;
Vabc = sctm*[Vf0(n); Vf1(n); Vf2(n)];
Va(n)=Vabc(1); Vb(n)=Vabc(2); Vc(n)=Vabc(3);
fprintf(' %5g',n)
fprintf(' %11.4f', abs(Va(n))),fprintf(' %11.4f', abs(Vb(n)))
fprintf(' %11.4f\n', abs(Vc(n)))
end
fprintf(' \n')
fprintf('Line currents for fault at bus No.  %g\n\n', nf)
fprintf('   From    To     -----Line Current Magnitude---- \n')
fprintf('   Bus     Bus    Phase a     Phase b     Phase c \n')

for n= 1:nbus
  for I = 1:nbr
    if nl(I) == n | nr(I) == n
      if nl(I) ==n      k = nr(I);
      elseif nr(I) == n  k = nl(I);
```

```
       end
          if k ~= 0
          Ink0(n, k) = 0;
          Ink1(n, k) = (Vf1(n) - Vf1(k))/ZB1(I);
          Ink2(n, k) =  (Vf2(n) - Vf2(k))/ZB2(I);

          Inkabc = sctm*[Ink0(n, k); Ink1(n, k); Ink2(n, k)];
          Inkabcm = abs(Inkabc); th=angle(Inkabc);
             if real(Inkabc(2)) < 0

           fprintf('%7g', n), fprintf('%10g', k),
            fprintf(' %11.4f', abs(Inkabc(1))),fprintf(' %11.4f', abs(Inkabc(2)))
            fprintf(' %11.4f\n', abs(Inkabc(3)))
            elseif real(Inkabc(2)) ==0 & imag(Inkabc(2)) > 0
            fprintf('%7g', n), fprintf('%10g', k),
            fprintf(' %11.4f', abs(Inkabc(1))),fprintf(' %11.4f', abs(Inkabc(2)))
            fprintf(' %11.4f\n', abs(Inkabc(3)))
            else, end
          else, end
     else, end
   end
   if n==nf
   fprintf('%7g',n), fprintf('        F'),
   fprintf(' %11.4f', Ifabcm(1)),fprintf(' %11.4f', Ifabcm(2))
   fprintf(' %11.4f\n', Ifabcm(3))
   else, end
end
resp=0;
   while strcmp(resp, 'n')~=1 & strcmp(resp, 'N')~=1 & strcmp(resp, 'y')~=1 & strcmp(resp,
'Y')~=1
   resp = input('Another fault location? Enter "y" or "n" within single quote -> ');
   if strcmp(resp, 'n')~=1 & strcmp(resp, 'N')~=1 & strcmp(resp, 'y')~=1 & strcmp(resp,
'Y')~=1
   fprintf('\n Incorrect reply, try again \n\n'), end
   end
   if resp == 'y' | resp == 'Y'
   nf = 999;
   else ff = 0; end
end   % end for while
```

Balanced Three- phase fault

```
% The program symfault is designed for the balanced three-phase
% fault analysis of a power system network. The program requires
% the bus impedance matrix Zbus. Zbus may be defined by the
% user, obtained by the inversion of Ybus or it may be
% determined either from the function Zbus = zbuild(zdata)
% or the function Zbus = zbuildpi(linedata, gendata, yload).
```

```
% 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.function symfault(zdata,
Zbus, V)

nl = zdata(:,1); nr = zdata(:,2); R = zdata(:,3);
X = zdata(:,4);
nc = length(zdata(1,:));
  if nc > 4
  BC = zdata(:,5);
  elseif nc ==4, BC = zeros(length(zdata(:,1)), 1);
  end
ZB = R + j*X;
nbr=length(zdata(:,1)); nbus = max(max(nl), max(nr));
if exist('V') == 1
   if length(V) == nbus
   V0 = V;
   else, end
else,  V0 = ones(nbus, 1) + j*zeros(nbus, 1);
end
fprintf('\Three-phase balanced fault analysis \n')
ff = 999;
while ff > 0
nf = input('Enter Faulted Bus No. -> ');
   while nf <= 0 | nf > nbus
   fprintf('Faulted bus No. must be between 1 & %g \n', nbus)
   nf = input('Enter Faulted Bus No. -> ');
   end
fprintf('\nEnter Fault Impedance Zf = R + j*X in ')
Zf = input('complex form (for bolted fault enter 0). Zf = ');
fprintf(' \n')
fprintf('Balanced three-phase fault at bus No. %g\n', nf)

If = V0(nf)/(Zf + Zbus(nf, nf));
Ifm = abs(If); Ifmang=angle(If)*180/pi;
fprintf('Total fault current = %8.4f per unit \n\n', Ifm)
%fprintf(' p.u. \n\n', Ifm)
fprintf('Bus Voltages during fault in per unit \n\n')
fprintf('  Bus    Voltage      Angle\n')
fprintf('  No.    Magnitude    degrees\n')

for n = 1:nbus
   if n==nf
   Vf(nf) = V0(nf)*Zf/(Zf + Zbus(nf,nf)); Vfm = abs(Vf(nf)); angv=angle(Vf(nf))*180/pi;
   else, Vf(n) = V0(n) - V0(n)*Zbus(n,nf)/(Zf + Zbus(nf,nf));
   Vfm = abs(Vf(n)); angv=angle(Vf(n))*180/pi;
```

```
      end
   fprintf('   %4g',  n), fprintf('%13.4f', Vfm),fprintf('%13.4f\n', angv)


end


fprintf('  \n')


fprintf('Line currents for fault at bus No.  %g\n\n', nf)
fprintf('    From    To    Current    Angle\n')
fprintf('    Bus    Bus   Magnitude  degrees\n')


for n= 1:nbus
    %Ign=0;
    for I = 1:nbr
      if nl(I) == n | nr(I) == n
        if nl(I) ==n      k = nr(I);
        elseif nr(I) == n  k = nl(I);
        end
         if k==0
          Ink = (V0(n) - Vf(n))/ZB(I);
          Inkm = abs(Ink); th=angle(Ink);
            %if th <= 0
            if real(Ink) > 0
            fprintf('    G   '), fprintf('%7g',n), fprintf('%12.4f', Inkm)
            fprintf('%12.4f\n', th*180/pi)
            elseif real(Ink) ==0 & imag(Ink) < 0
            fprintf('    G   '), fprintf('%7g',n), fprintf('%12.4f', Inkm)
            fprintf('%12.4f\n', th*180/pi)
            else, end
         Ign=Ink;
         elseif k ~= 0
          Ink = (Vf(n) - Vf(k))/ZB(I)+BC(I)*Vf(n);
          %Ink = (Vf(n) - Vf(k))/ZB(I);
          Inkm = abs(Ink); th=angle(Ink);
          %Ign=Ign+Ink;
          %if th <= 0
           if real(Ink) > 0
              fprintf('%7g', n), fprintf('%10g', k),
              fprintf('%12.4f', Inkm), fprintf('%12.4f\n', th*180/pi)
              elseif real(Ink) ==0 & imag(Ink) < 0
              fprintf('%7g', n), fprintf('%10g', k),
              fprintf('%12.4f', Inkm), fprintf('%12.4f\n', th*180/pi)
              else, end
           else, end
      else, end
    end

if n==nf
fprintf('%7g',n), fprintf('         F'),  fprintf('%12.4f', Ifm)
fprintf('%12.4f\n', Ifmang)
```

```
 else, end
end
  resp=0;
  while strcmp(resp, 'n')~=1 & strcmp(resp, 'N')~=1 & strcmp(resp, 'y')~=1 & strcmp(resp,
'Y')~=1
  resp = input('Another fault location? Enter ''y'' or ''n'' within single quote -> ');
  if strcmp(resp, 'n')~=1 & strcmp(resp, 'N')~=1 & strcmp(resp, 'y')~=1 & strcmp(resp,
'Y')~=1
  fprintf('\n Incorrect reply, try again \n\n'), end
  end
  if resp == 'y' | resp == 'Y'
  nf = 999;
  else ff = 0; end
end   % end for while
```

NETWORK CODE

```
zdata1=[0      1      0       0.25
        0      2      0       0.25
        1      2      0       0.125
        1      3      0       0.15
        2      3      0       0.25];


 zdata0=[0      1      0       0.40
         0      2      0       0.1
         1      2      0       0.3
         1      3      0       0.35
         2      3      0       0.7125];

   zdata2=zdata1;
   Zbus1=zbuild(zdata1)
   Zbus0=zbuild(zdata0)
   Zbus2=Zbus1;
   symfault(zdata1,Zbus1)
   lgfault(zdata0, Zbus0, zdata1, Zbus1, zdata2, Zbus2)
   llfault(zdata1, Zbus1, zdata2, Zbus2)
   dlgfault(zdata0,Zbus0,zdata1,Zbus1,zdata2,Zbus2)
```