#15

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EE740

SHORT CIRCUIT STUDIES

6. Short circuit study as an engineering tool:

- The main objective of the short-circuit study is to determine the interrupting capability required for circuit breakers at each switching location. For this type of application, the maximum currents the breaker may be exposed to during the three phase balanced faults on each side of the breaker need to be determined.

- For protective relaying design it is necessary to determine voltages and currents for balanced and unbalanced faults at many locations in the system.

Short circuit problem formulation:

Assumptions:

1) Normally, all shunt elements including loads and line charging are neglected. Loads may be represented with constant load impedance models.

2) Each generator is represented by a constant voltage behind its subtransient reactance.

3) All tap changing transformers are assumed to be at their nominal tap settings.

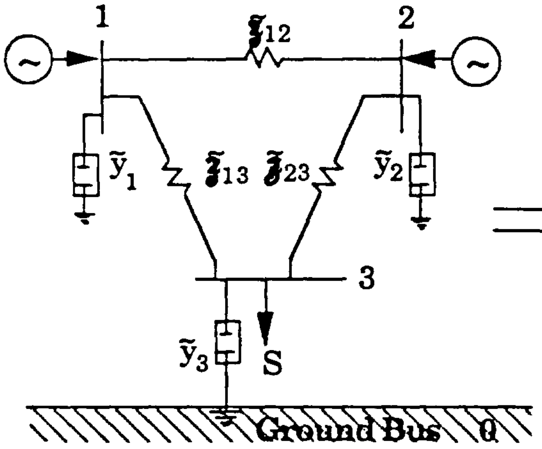
4) Balanced transmission lines are assumed. For a balanced three-phase fault only positive sequence network is excited. For an unbalanced fault, all three sequence networks may be excited.

5) The negative and positive sequence impedance networks are normally assumed equal and coupling between adjacent circuits is taken into account in the zero sequence network only.

6) All voltages behind the generator reactances are assumed equal in magnitude and phase angle (normally one per unit). Therefore, no current is flowing in any portion of the network prior to the fault.

Balanced 3 - ϕ Fault Analysis:

Assuming balanced three-phase fault on a balanced three-phase system and using the above assumptions, we will have:



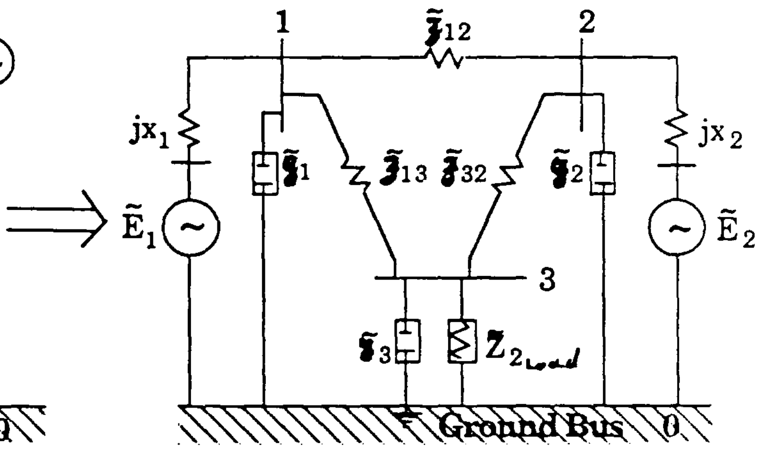
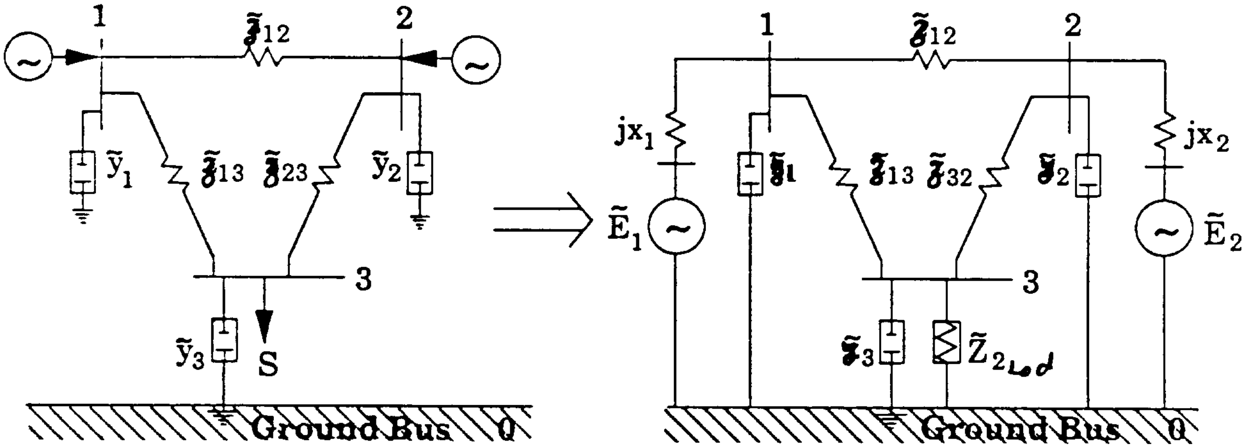


Fig 1: Single line diagram of a three-phase system.

Fig 2: Positive sequence impedance network representation of a power system for 3-ϕ analysis.

Comments:

- Fig 2 shows the complete model of a power system including the shunt elements and loads. Note that $Z_2 = \frac{(V_2)^2}{P_2 - jQ_2}$.
- The model given by Fig. 2 can be simplified by removing the shunt elements and load. This will make Z_{BUS} calculation easier.


1
z̃12
2
ỹ1
z̃13
z̃23
ỹ2
3
ỹ3
S
Ground Bus
0
1
z̃12
2
jx1
jx2
z̃1
z̃13
z̃32
z̃2
Ẽ1
Ẽ2
3
z̃3
Z̃2Lod
Ground Bus
0

Three-phase fault

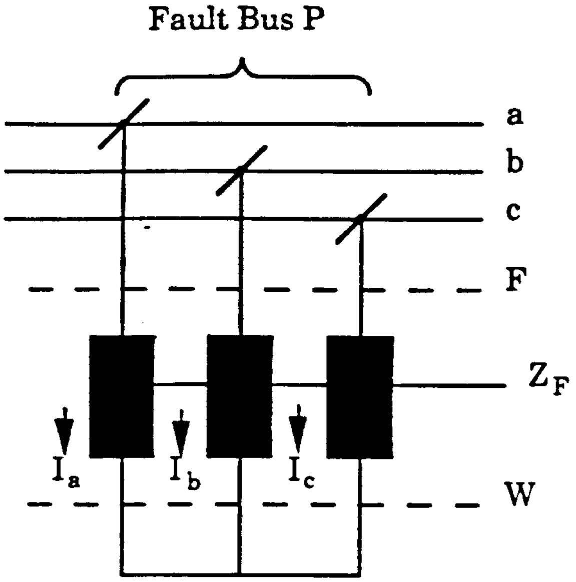


Fig. 2

"1" $\xrightarrow{\text{same}}$ (+)

"2" $\rightarrow$ (-)

"0" $\rightarrow$ (0)

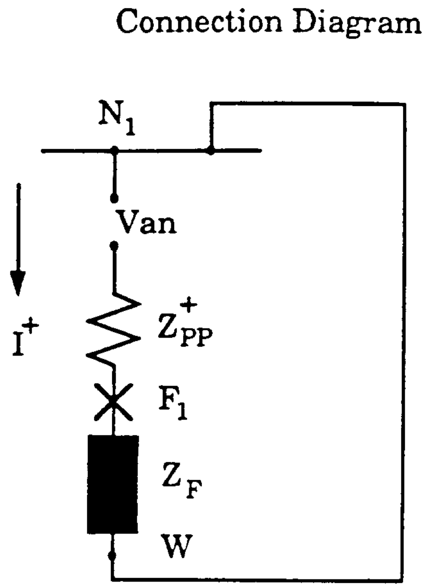


Fig. 1

$$\underset{\text{positive sequence}}{\mathbf{Z}_{bus}} = \begin{array}{cc} & \begin{array}{ccc} \phantom{Z_{11}} & p & \phantom{Z_{1n}} \end{array} \\ \begin{array}{c} \\ p \\ \\ \end{array} & \left[\begin{array}{ccc} Z_{11} & Z_{1p} & Z_{1n} \\ Z_{p1} & Z_{pp} & Z_{pn} \\ Z_{n1} & Z_{np} & Z_{nn} \end{array}\right] \end{array}$$

Single-line to ground fault
at bus p

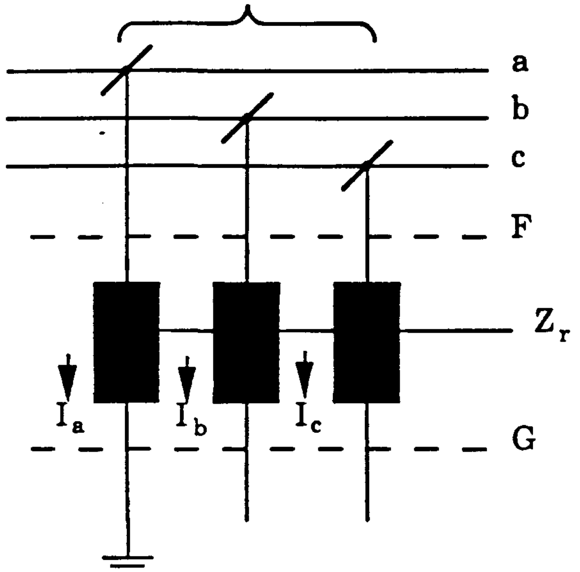


Fig. 1

"1" ----→ (+)
"2" ----→ (-)
"0" ----→ (0)

Connection Diagram
Single line to ground fault

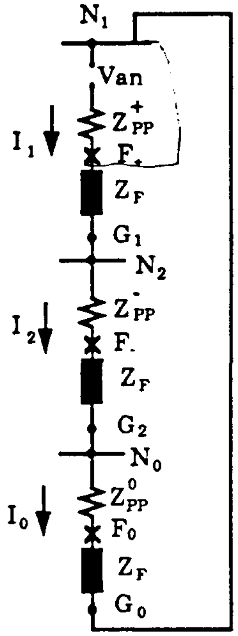


Fig. 2

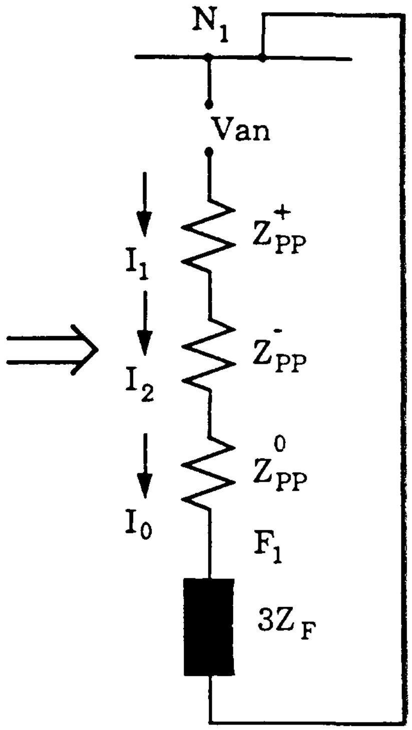


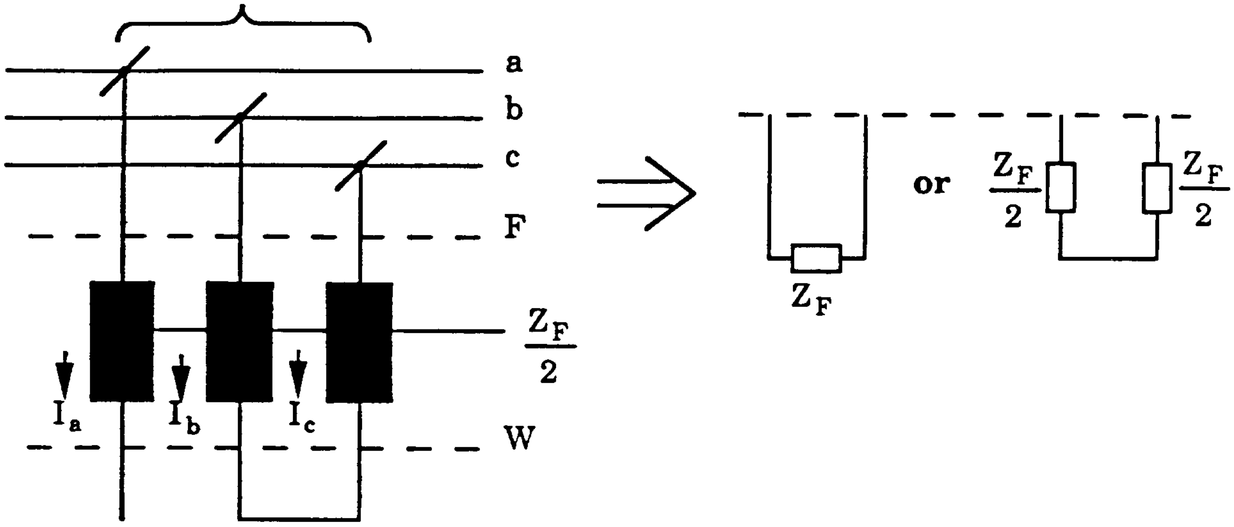
Fig. 3

$$\mathbf{Z}_{\text{bus}\,(1)} = \begin{array}{c} \\ 1 \\ p \\ n \end{array} \begin{array}{ccc} 1 & p & n \\ \left[\begin{array}{c} Z_{11} \\ \vdots \\ Z_{n1} \end{array}\right. & \begin{array}{c} \cdots \\ Z_{pp} \\ Z_{np} \end{array} & \left.\begin{array}{c} Z_{1n} \\ \vdots \\ Z_{nn} \end{array}\right] \end{array}$$

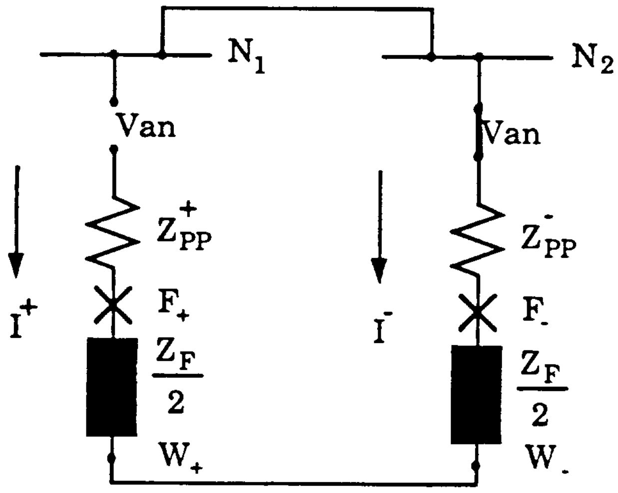
$$\mathbf{Z}_{\text{bus}\,(2)} = \begin{array}{c} \\ 1 \\ p \\ n \end{array} \begin{array}{ccc} 1 & p & n \\ \left[\begin{array}{c} Z_{11} \\ \vdots \\ Z_{n1} \end{array}\right. & \begin{array}{c} \cdots \\ Z_{pp} \\ Z_{np} \end{array} & \left.\begin{array}{c} Z_{1n} \\ \vdots \\ Z_{nn} \end{array}\right] \end{array}$$

$$\mathbf{Z}_{\text{bus}\,(0)} = \begin{array}{c|ccc} & 1 & p & n \\ \hline 1 & Z_{11} & Z_{1p} & Z_{1n} \\ p & Z_{p1} & Z_{pp} & Z_{pn} \\ n & Z_{n1} & Z_{np} & Z_{nn} \end{array}$$

4. Line-to-line fault at bus P

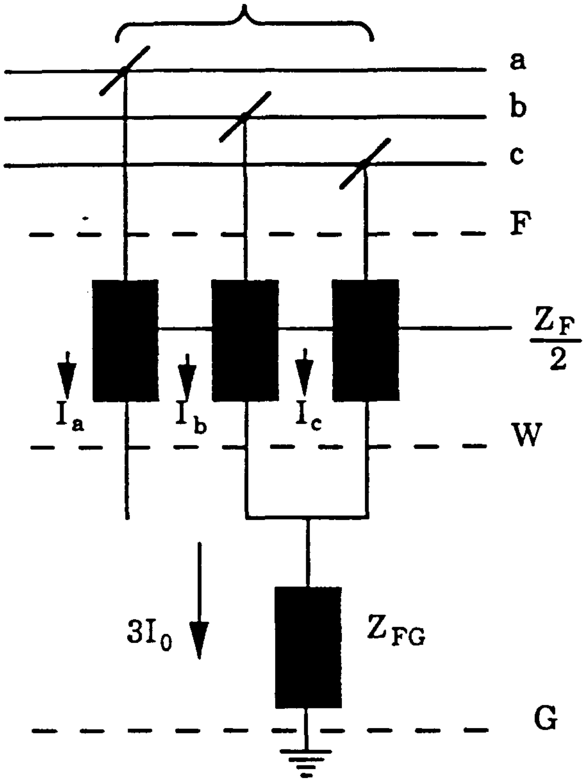


Connection Diagram



$$\mathbf{Z}_{bus(1)} = \begin{array}{c} \\ 1 \\ p \\ n \end{array} \begin{array}{c} \begin{array}{ccc} 1 & p & n \end{array} \\ \left[\begin{array}{ccc} Z_{11} & \cdots & Z_{1n} \\ \vdots & Z^{+}_{pp} & \vdots \\ Z_{n1} & Z_{np} & Z_{nn} \end{array}\right] \end{array} \qquad \mathbf{Z}_{bus(2)} = \begin{array}{c} \\ 1 \\ p \\ n \end{array} \begin{array}{c} \begin{array}{ccc} 1 & p & n \end{array} \\ \left[\begin{array}{ccc} Z_{11} & \cdots & Z_{1n} \\ \vdots & Z^{-}_{pp} & \vdots \\ Z_{n1} & Z_{np} & Z_{nn} \end{array}\right] \end{array}$$

Double line-to-line-to-ground fault at bus P

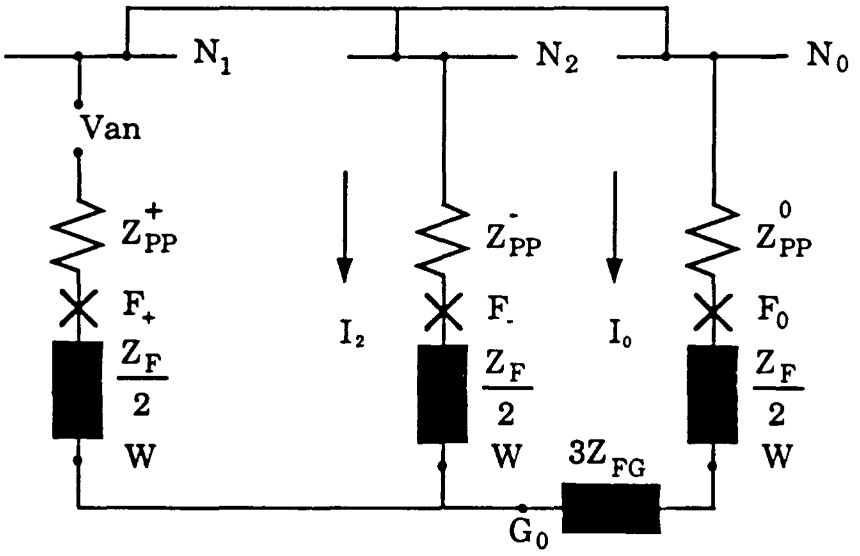


$$Z_{bus(1)} = \begin{array}{c|ccc|} & 1 & p & n \\ 1 & Z_{11} & Z_{1p} & Z_{1n} \\ p & Z_{p1} & \overset{+}{Z}_{pp} & Z_{pn} \\ n & Z_{n1} & Z_{np} & Z_{nn} \end{array}$$

$$Z_{bus(2)} = \begin{array}{c|ccc|} & 1 & p & n \\ 1 & Z_{11} & Z_{1p} & Z_{1n} \\ p & Z_{p1} & Z_{pp} & Z_{pn} \\ n & Z_{n1} & Z_{np} & Z_{nn} \end{array}$$

$$Z_{bus(0)} = \begin{array}{c|ccc|} & 1 & p & n \\ 1 & Z_{11} & Z_{1p} & Z_{1n} \\ p & Z_{p1} & \overset{0}{Z}_{pp} & Z_{pn} \\ n & Z_{n1} & Z_{np} & Z_{nn} \end{array}$$

Connection Diagram



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Problem: Consider a typical power system given below:

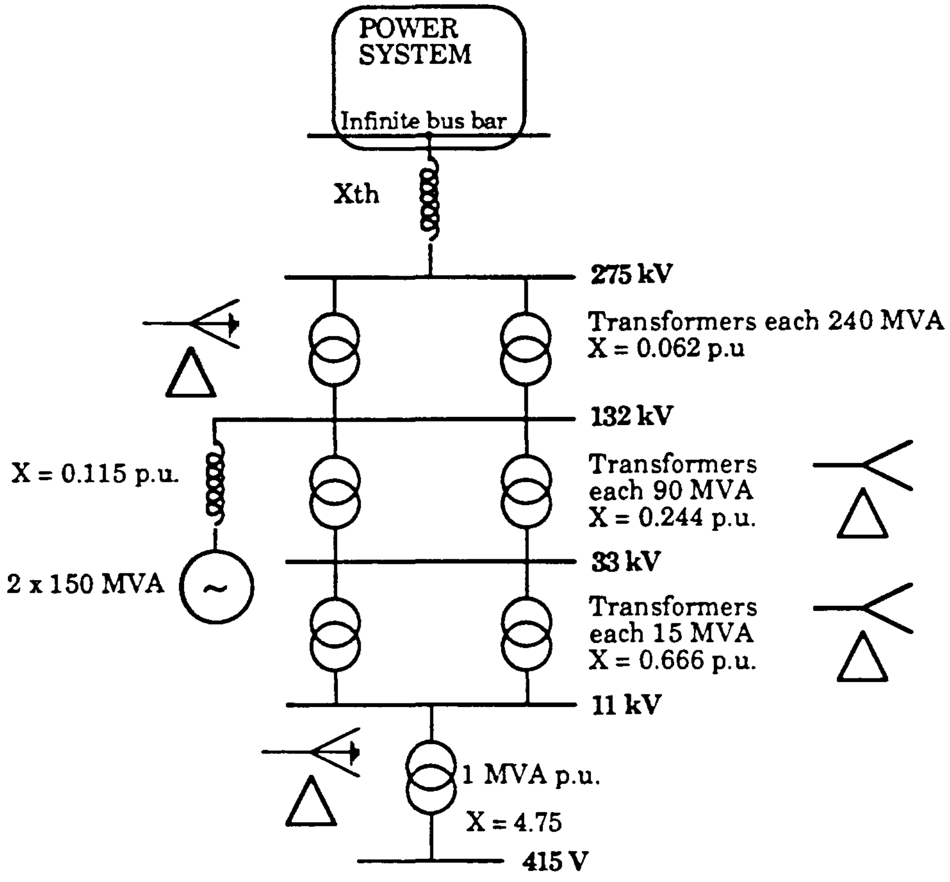


Figure 1: Typical transmission system. All reactances on a 100 MVA base

X_{th} = 0.01 when the maximum number of generators is in service.

X_{th} = 0.015 when the minimum number of generators is in service.

Compute the following:

1) The short circuit capacity of 415 volt bus when all transformers are is in service, but generator G_1 is not in service. Assume that the maximum number of generators is in service.
2) The short circuit capacity of 415 volt bus when all transformers and the generator G_1 are in service. Assume, also, that the maximum number of generators is in service.

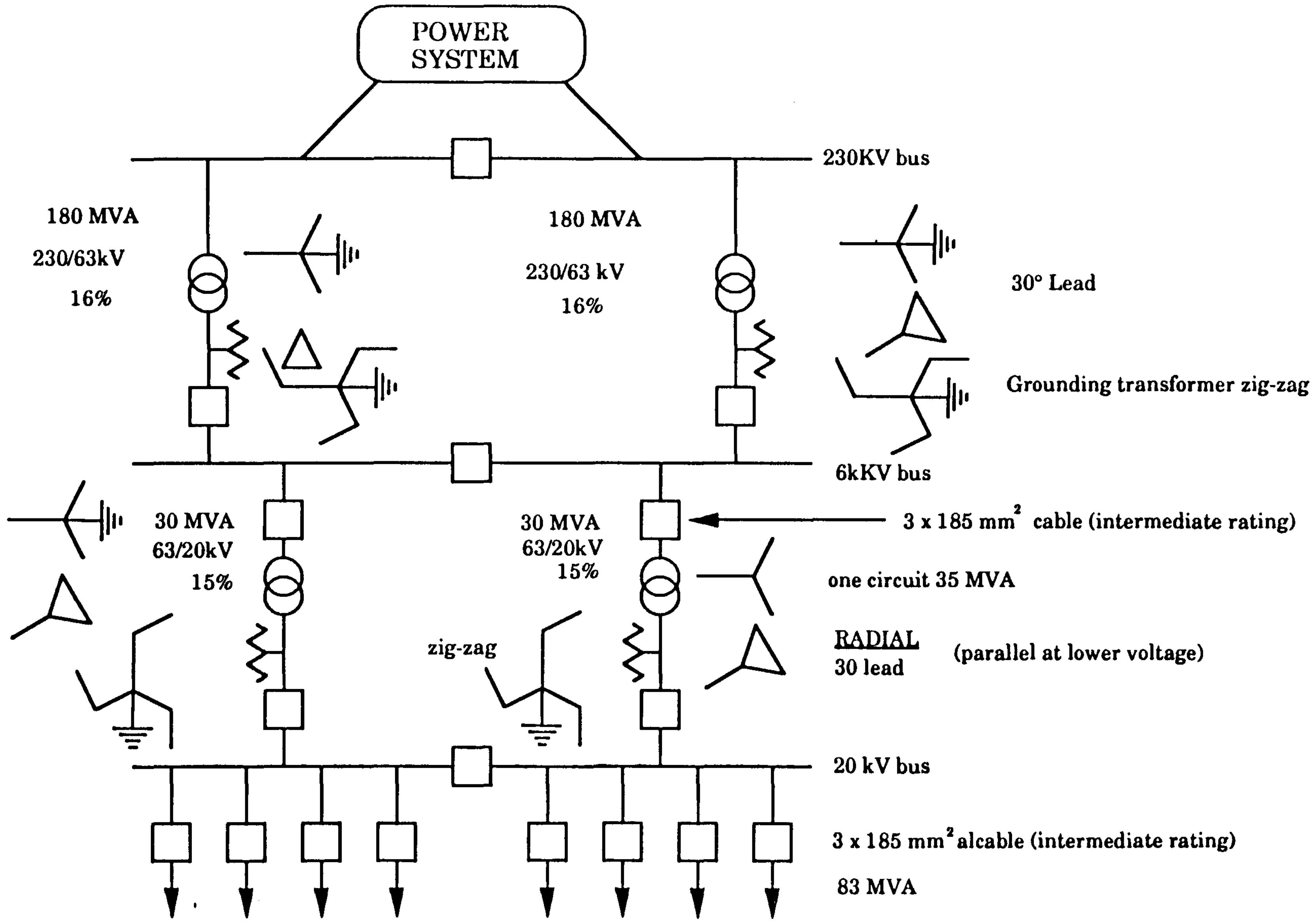
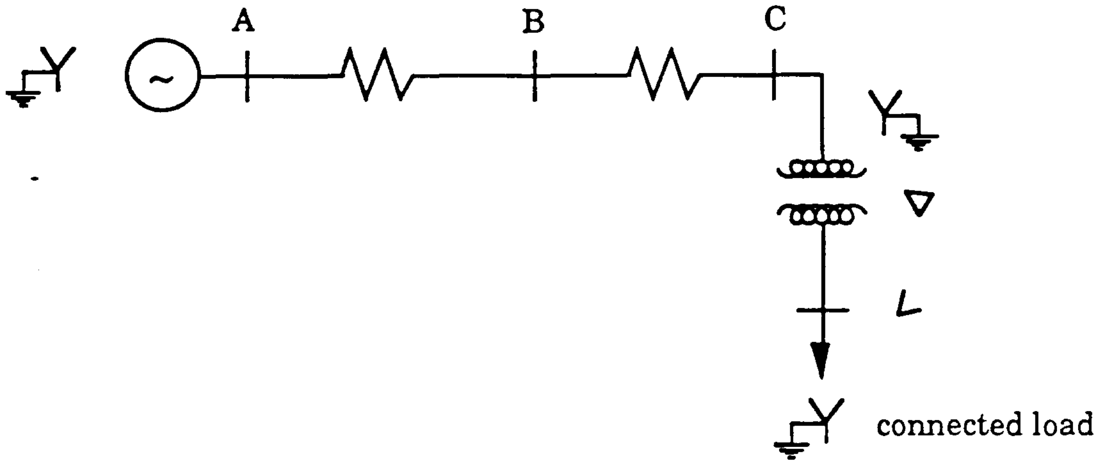


Figure 2: A typical power system

Problem. 3 Consider the power system given below:



Given:

$Z_{G(1)} = Z_{G(2)} = j0.10$ p.u , $Z_{G(0)} = j0.05$ p.u
$Z_{AB(1)} = Z_{AB(2)} = j0.2$ p.u , $Z_{AB(0)} = j0.4$ p.u
$Z_{BC(1)} = Z_{BC(2)} = j0.2$ p.u , $Z_{BC(0)} = j0.4$ p.u
$Z_{Trans(1)} = Z_{Trans(2)} = Z_{Trans(0)} = j0.05$ p.u
$V_L = 0.9\angle\underline{-4.0}$ p.u $S_{Load} = 1 + j0.5$ p.u

For a single-line to ground fault at bus B, compute the following:

1) The fault currents flowing from bus A and bus C to bus B (faulted bus) when the load is ignored.
2) The same as part 1), but take the load into consideration.
3) The same as part 1), but assume the generator is not grounded.

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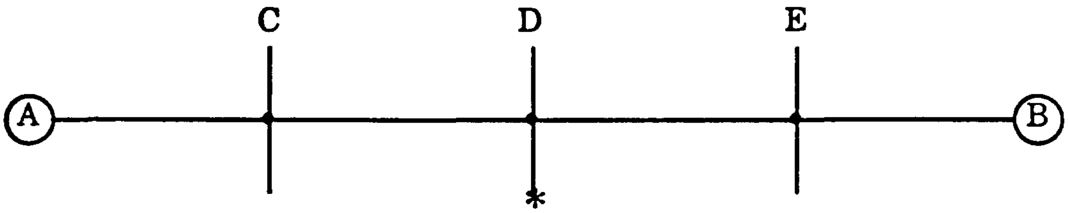
Problem Consider the power system given below.



Generator A:

$$X''_G(1) = 0.25, X''_G(2) = 0.15, X''_G(0) = 0.03 \text{ p.u}$$

Generator B:

$$X''_G(1) = 0.2 \;, X''_G(2) = 0.12, X''_G(0) = 0.02 \text{ p.u}$$

Transmission line C - D: $Z_{(1)} = Z_{(2)} = j0.08$. $Z_{(0)} = j0.14$

Transmission line D - E: $Z_{(1)} = Z_{(2)} = j0.06$. $Z_{(0)} = j0.12$

All values are given in per unit and MVA base of 100.

Compute:

a) Assume generators are wye connected and ungrounded and then compute the single-line-to-ground-fault current and actual phase volatages (i.e. V_a, V_b, V_c in p.u) of buses C, D and E.

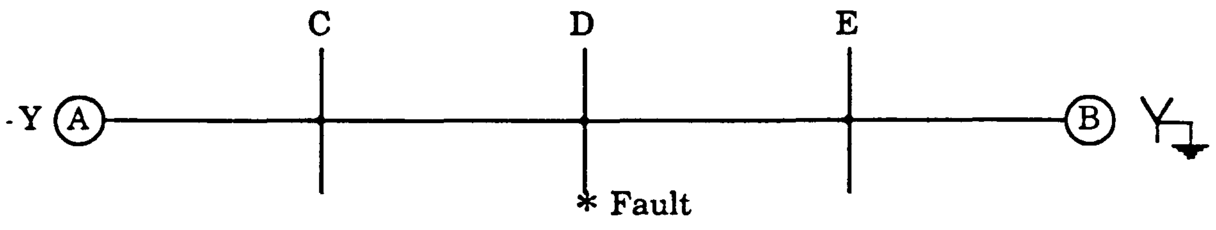
b) Assume generator A is wye connected and ungrounded, and generator B is wye connected and grounded, then compute the single-line-to-ground fault current and actual phase voltages (i.e. V_a, V_b, V_c in p.u) of buses C, D, and E.

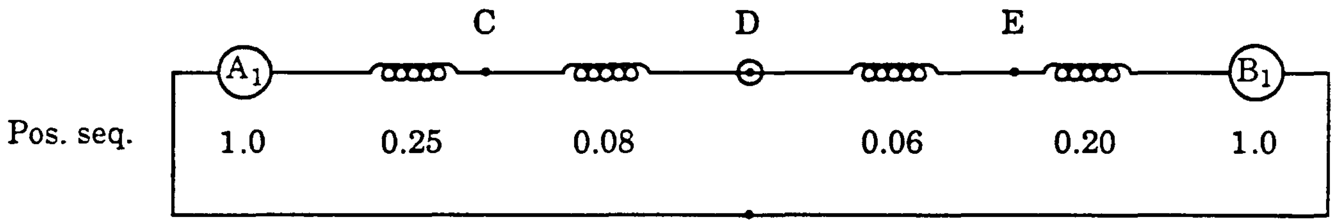
Hint:

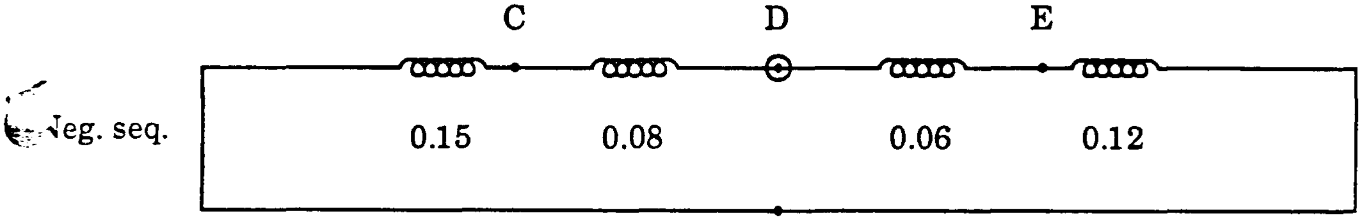
$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} V_0 \\ V_1 \\ V_2 \end{bmatrix}$$

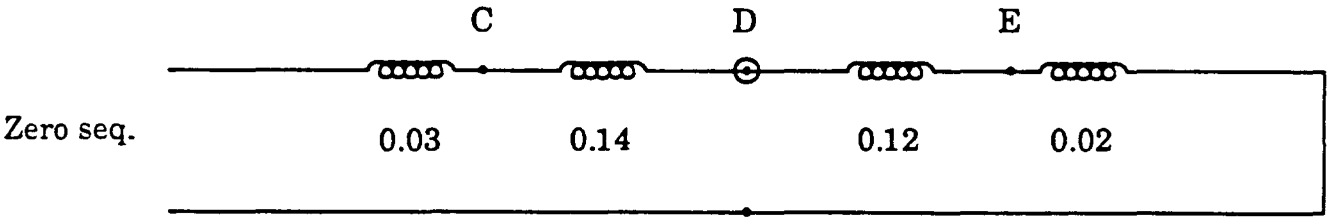
Special problem

Single line to ground fault.







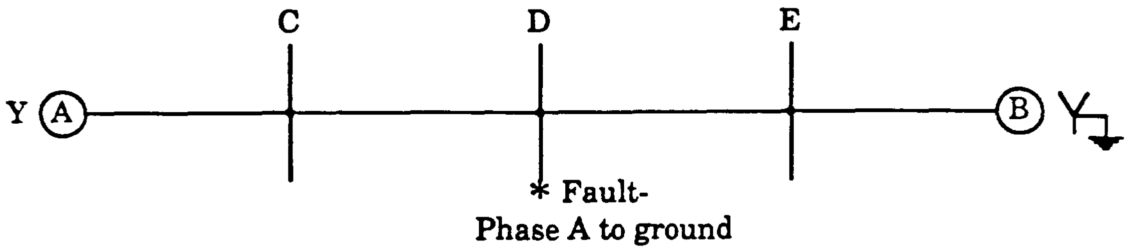


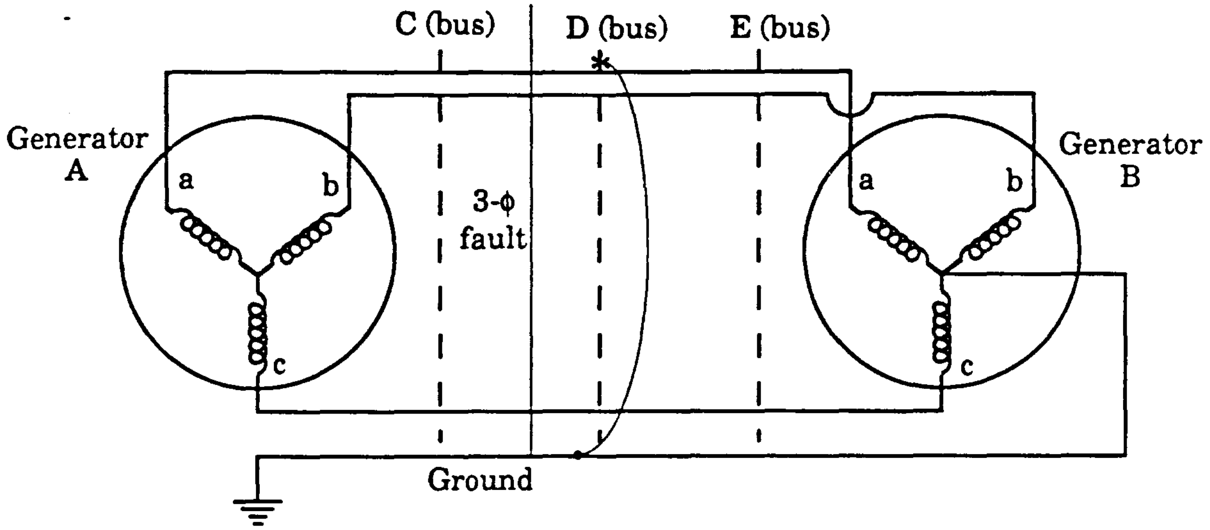
For a single phase to ground fault at bus D compute:

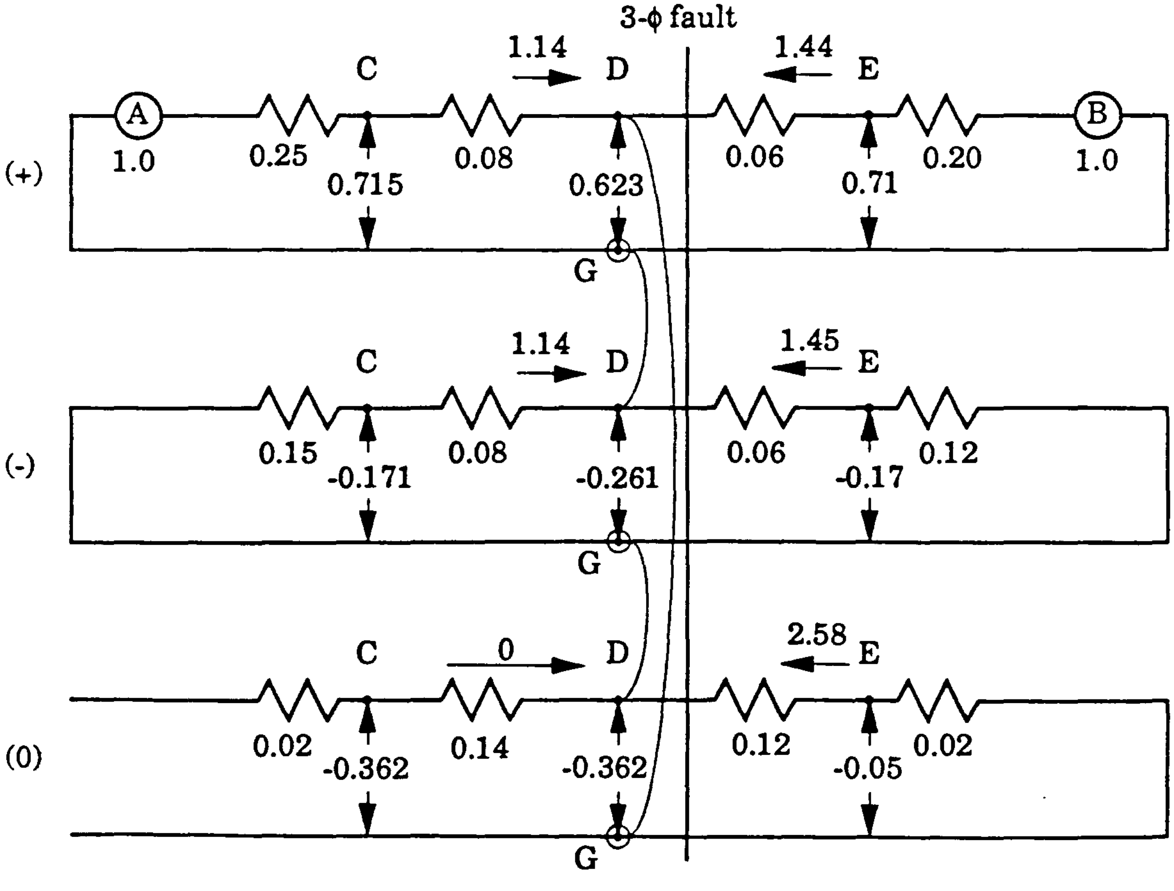
a) Find the actual phase voltages at the three buses. Show the phasor diagrams.

b) Find the actual generator line currents.

c) Compare the currents in (b) with those for a three-phase fault at bus D.


C
D
E
Y
A
B
* Fault-
Phase A to ground


C (bus)
D (bus)
E (bus)
Generator
A
a
b
c
3-ϕ
fault
Generator
B
a
b
c
Ground


3-ϕ fault
(+)
1.14
1.44
C
D
E
A
B
1.0
0.25
0.715
0.08
0.623
0.06
0.71
0.20
1.0
G
(-)
1.14
1.45
C
D
E
0.15
-0.171
0.08
-0.261
0.06
-0.17
0.12
G
(0)
0
2.58
C
D
E
0.02
-0.362
0.14
-0.362
0.12
-0.05
0.02
G

Algorithm for calculations of balanced and unbalanced fault currents.

Step 1: Build the positive sequence $\mathbf{Z}_{bus}$ matrix with reference to ground.

Step 2: Build the negative sequence $\mathbf{Z}_{bus}$ matrix. This is normally the same as the positive sequence.

Step 3: Build the corresponding zero sequence $\mathbf{Z}_{bus(0)}$ matrix.

Step 4: For specified fault types, connect the appropriate network sequences and compute the voltage and current flow at the faulted bus.