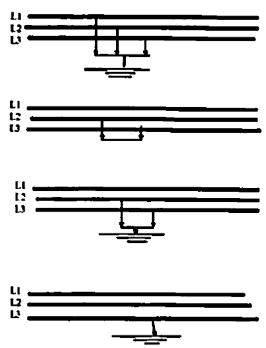
16. SHORT CIRCUIT CALCULATION

Goal

- To Appreciate the use of Ohmic and MVA Methods for Symmetrical Short Circuit Calculation

Types of Fault in a 3 phase network

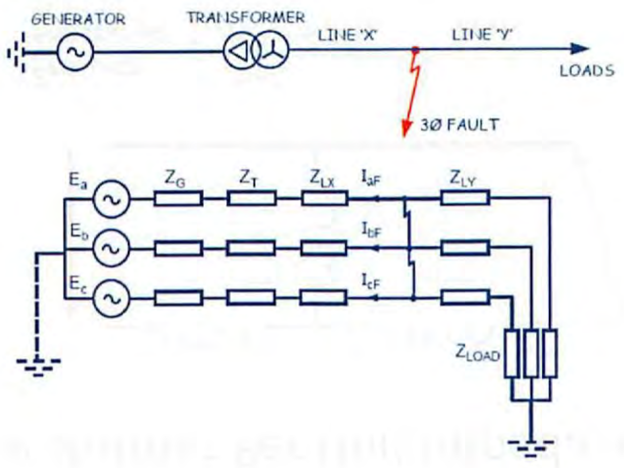
- Three-phase fault with or without earth (5%)
- Phase-to- phase clear of ground (10 – 15%)
- Tow-phase-to-earth fault (10 – 20%)
- Phase-to-earth fault (65 – 70%)
- Fault Incident:
  85% of faults are overhead line.
  50% of these are due to lightning strikes.



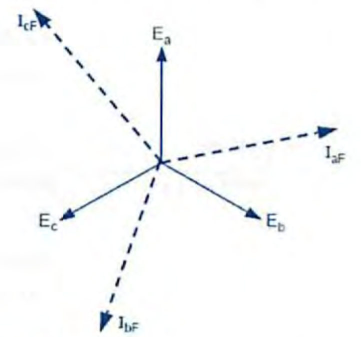
3 PHASE FAULTS

- A 3-ph fault affects the three-phase network symmetrically. They rarely occur. All three conductors are equally involved and carry the same rms short-circuit current. There is the need to use only one conductor for the calculation.
- It is valid because the system is maintained in a balanced state during fault.
- Voltages are equal and 120° apart.
- Currents are equal and 120° apart.
- Power system plant symmetrical:-
  - ➢ Phase impedance equal
  - ➢ Mutual impedance equal
  - ➢ Shunt admittances equal
- Causes:
  - ➢ System energization with maintenance earthing clamps still connected.
  - ➢ 1ø faults developing into 3ø faults. Etc.

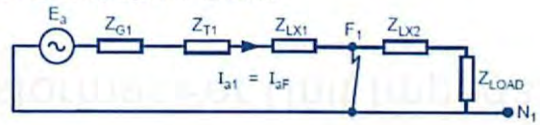
3 PHASE FAULTS



3 PHASE FAULTS

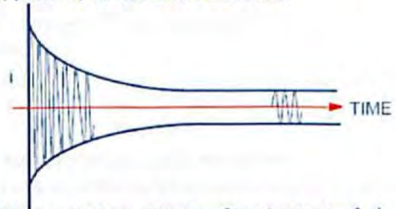


Positive Sequence (Single Phase) Circuit :-



GENERATOR SHORT CIRCUIT CURRENT

The AC Symmetrical component of the short circuit current varies with time due to effect of armature reaction.



Magnitude (RMS) of current at any time t after instant of short circuit :

$$I_{ac} = (I'' - I')e^{-t/Td''} + (I' - I)e^{-t/Td'} + I$$

where :

I'' = Initial Symmetrical S/C Current or Sub-transient Current $= E/X_d'' \approx 50ms$

I' = Symmetrical Current a Few Cycles Later $\approx 0.5s$ or Transient Current $= E/X_d'$

I = Symmetrical Steady State Current $= E/X_d$

Over View of Per Unit System For Short Circuit Calculation

- Per- Unit Notations. It is used to simplify calculations on system with more than two voltages. (The V are eliminated)

  It can be seen by inspection of any power system diagram that:

  a. several voltage levels exist in a system

  b. it is common practice to refer to plant MVA in terms of per unit or percentage values

  c. transmission line and cable constants are given in ohms/km

- Before any system calculations can take place, the system parameters must be referred to 'base quantities' and represented as a unified system of impedances in either, percentage, or per unit values.

- Per-unit analysis is based on "normalized" representations of the electrical quantities (i.e., voltage, current, impedance, etc.). The per-unit equivalent of any electrical quantity is dimensionless. It is defined as the ratio of the actual quantity in units (i.e., volts, amperes, ohms, etc.) to an appropriate base value of the electrical quantity.
  - Per Unit (p.u) value = Actual value / Base value

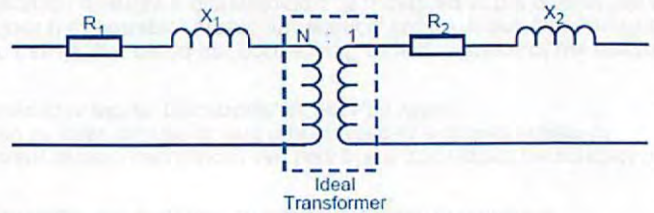
Formulae used in Per-Unit Short Circuit Calculations

- The base quantities are:
  three-phase power in MVA (MVA rating of largest item or 100MVA) It is constant thought at all voltages
  the line voltage in kV. Fixed at one part and it is transferred through the transformers to obtain base voltages of the other part of the system.

The following Equations are used in Per- Unit Calculation:

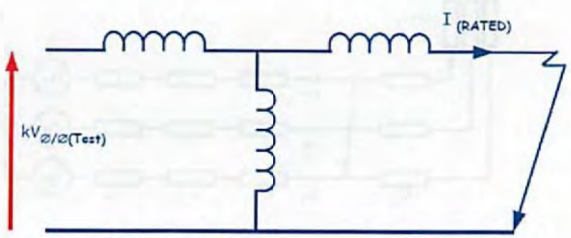
- $I_{p.u} = I_{actual} / I_{base}$
- $S_{p.u} = S_{actual} / S_{base}$
- $V_{p.u} = V_{actual} / V_{base}$
- Base Current (kA), $I_b = MVA_{b\,(3\varnothing)} / \{1.732 \times kV_{b\,(L\text{-}L)}\}$
- Base Impedance (Ohm) $Z_b = (kV)^2_{(L\text{-}L)} / MVA_{b\,3\varnothing}$
- $Z_{p.u}^{(new)} = Z_{p.u}^{(old)} \times [MVA_b^{(N)} / MVA_b^{(old)}] \times [kV_b^{(old)} / kV_b^{(new)}]^2$

Referring Impedances



Consider the equivalent circuit referred to :-

Transformer Per Unit Impedance



$Z_{PER\ UNIT}$ = Z p.u.

$Z_{PERCENTAGE}$ = 100 x Z p.u.

Z p.u. = Z_a/Z_b = Z_{actual}/Z_{base}

Transformer Per Unit Impedance

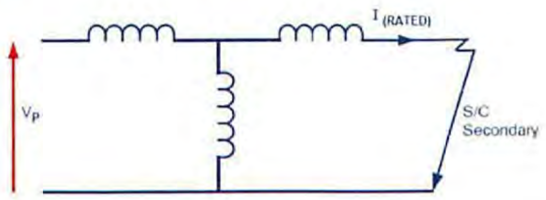
$$Za = \frac{kV_{\varnothing/\varnothing(TEST)}}{\sqrt{3}\,.\,I_{(RATED)}}$$

$$Zb = \frac{kV_{\varnothing/\varnothing(RATED)}^{\;2}}{MVA_{(RATED)}} = \frac{kV_{\varnothing/\varnothing(RATED)}^{\;2}}{\sqrt{3}\,.\,kV_{\varnothing/\varnothing(RATED)}\,.\,I_{(RATED)}}$$

$$= \frac{kV_{\varnothing/\varnothing(RATED)}}{\sqrt{3}\,.\,I_{(RATED)}}$$

$$Zp.u. = \frac{Za}{Zb} = \frac{kV_{\varnothing/\varnothing(TEST)}}{kV_{\varnothing/\varnothing(RATED)}}$$

Transformer Percentage Impedance



Increase V_P until I_{RATED} flows in secondary.

$$Z_{(PERCENTAGE)} = \frac{V_P}{V_{(RATED)}} \times 100\%$$

$$Z_{p.u.} = \frac{V_P}{V_{(RATED)}}$$

Transformer Percentage Impedance

- If ZT = 5%

  with Secondary S/C 5% V (RATED) produces I (RATED) in Secondary.

  ∴ V (RATED) produces $\frac{100 \times I\,(RATED)}{5}$

  = 20 x I (RATED)

- If Source Impedance ZS = 0

  Fault current = 20 x I (RATED)

  Fault Power = 20 x kVA (RATED)

- ZT is based on I (RATED) & V (RATED)

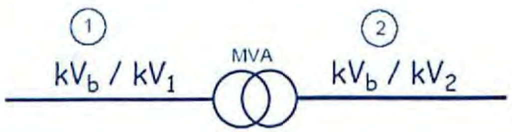
  i.e. Based on MVA (RATED) & kV (RATED)

  ∴ is same value viewed from either side of transformer.

Transformer Percentage Impedance

Per unit impedance of transformer is same on each side of the transformer.

Consider transformer of ratio kV_1 / kV_2



Actual impedance of transformer viewed from side 1 = Z_{a1}

Actual impedance of transformer viewed from side 2 = Z_{a2}

Transformer Percentage Impedance

$$Z_{p.u.1} = \frac{Z_{a1}}{Z_{b1}} = Z_{a1} \times \frac{MVA}{kV_1^2}$$

$$Z_{p.u.2} = \frac{Z_{a2}}{Z_{b2}} = Z_{a2} \times \frac{MVA}{kV_2^2}$$

but $$Z_{a2} = Z_{a1} \times \frac{kV_2^2}{kV_1^2}$$

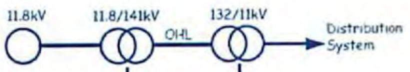
$$\therefore \quad Z_{p.u.2} = Z_{a1} \times \frac{kV_2^2}{kV_1^2} \times \frac{MVA}{kV_2^2}$$

$$= Z_{a1} \times \frac{MVA}{kV_1^2}$$

$$= Z_{p.u.1}$$

Transformer Base Voltage Selection

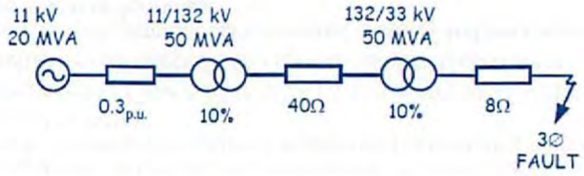
Base voltage on each side of a transformer must be in the same ratio as voltage ratio of transformer.



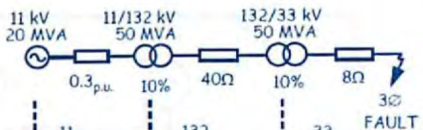
Incorrect selection of kV_b	11.8kV	132kV	11kV
Correct selection of kV_b	$\frac{132 \times 11.8}{141}$ = 11.05kV	132kV	11kV
Alternative correct selection of kV_b	11.8kV	141kV	$\frac{141 \times 11}{132}$ = 11.75kV

Example

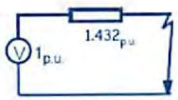
Calculate the fault currents in 11KV, 132KV and 33KV system for the three phase fault shown



Example



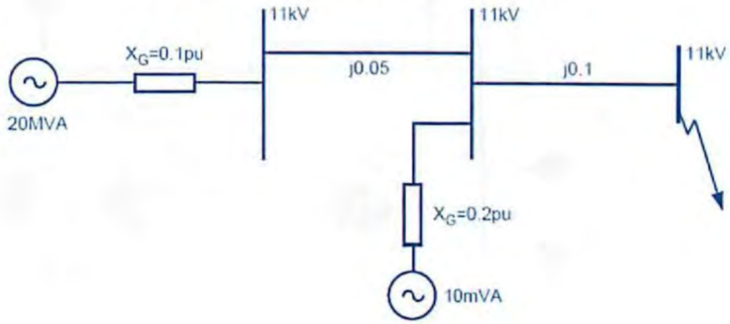
kV_b	11	132	33
MVA_b	50	50	50
$Z_b = \frac{kV_b^2}{MVA_b}$	2.42 Ω	348.5 Ω	21.8 Ω
$I_b = \frac{MVA_b}{\sqrt{3} kV_b}$	2624 A	219 A	875 A
$Z_{p.u.}$	$0.3 \times \frac{50}{20} = 0.75_{pu}$; 0.1_{pu}	$\frac{40}{348.5} = 0.115_{pu}$	0.1_{pu} ; $\frac{8}{21.8} = 0.367_{pu}$



$I_F = \frac{1}{1.432} = 0.698 p.u.$

$I_{11kV} = 0.698 \times I_b$
$= 0.698 \times 2624 = 1832A$
$I_{132kV} = 0.698 \times 219 = 153A$
$I_{33kV} = 0.698 \times 875 = 611A$

Parallel Generators



If both generator voltages are equal, they can be thought of as resulting from the same ideal source - thus the circuit can be simplified.

Parallel Generators

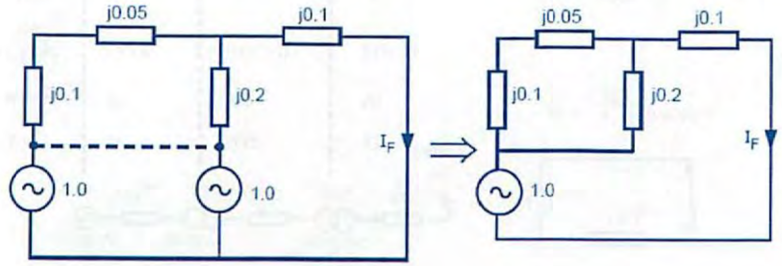


Illustration on Per-Unit Calculation

One Line Diagram and its Equivalent Impedance Diagram

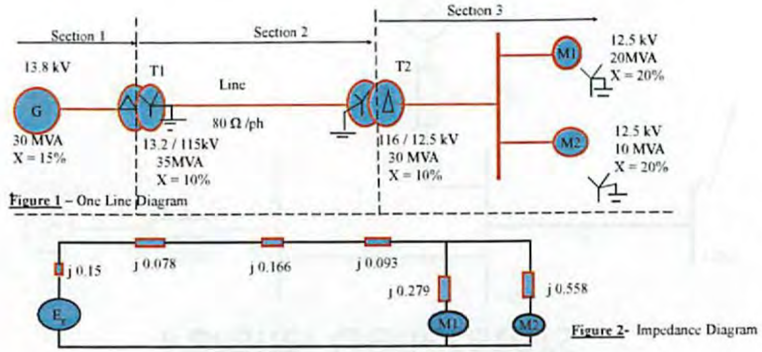


Figure 1 – One Line Diagram

Figure 2- Impedance Diagram

Illustration on Per-Unit Calculation

Conversion and Calculation of new Per- Unit reactance (X p.u)

- Base kV 13.8
- Base MVA 30
- Base Voltage for section 1 - 13.8 kV
- Base Voltage for section 2 - (13.8 / 13.2) x 115 = 120.23 kV
- Base Voltage for section 3 - (120.23 /116) X 12.5 = 12.96 kV
- 3ø Generator
  No conversion , hence X p.u = 15%
- Transformer 1
  X p.u = 0.1x (30 / 35) x [13.2 / 13.8]^2 = 0.078 p.u
- Transmission Line
  X base = (120.23)^2 / 30 = 481.84 Ω / ph
  X p.u = 80 / 481.84 = 0.166 p.u
- Transformer 2
  X p.u = 0.1x (30 / 30) x [12.5 / 12.96]^2 = 0.093 p.u
- Motor 1
  X p.u = 0.2x (30 / 20) x [12.5 / 12.96]^2 = 0.279 p.u
- Motor 2
  X p.u = 0.2x (30 / 10) x [12.5 / 12.96]^2 = 0.558 p.u

MVA METHOD FOR 3 PHASE SHORT CIRCUIT CALCULATION

- The MVA Method is recognized and widely acceptable by industry in calculating power system short circuits where the reactance of all circuit components far exceeds resistance producing a consistently high X/R ratio throughout the system.
- There is no need to convert to an MVA base or worry about voltage levels
- It is a useful method to obtain an estimate value of fault current
- Combined MVA of components connected in series and parallel are calculated using the following formulas:
- series: MVA1, 2 = MVA1 X MVA2 / (MVA1 + MVA2)
- parallel: MVA1, 2 = MVA1 + MVA2
- As can be seen from the formulae above, series MVA's are being calculated same as resistances in parallel. Parallel MVA combinations are done same as resistances in series.
- MVA diagram undergoes same reduction process as impedance diagram, only that MVA values are used instead of per unit impedances or reactances.

MVA METHOD FOR 3 PHASE SHORT CIRCUIT CALCULATION

- The MVA method is a modification of the Ohmic method where the impedance of a circuit equals the sum of the impedances of components constituting the circuit.
- In practice, the MVA method is used by separating the circuit into components and calculating each component with its own infinite bus as shown in figures *1* and *2* below:

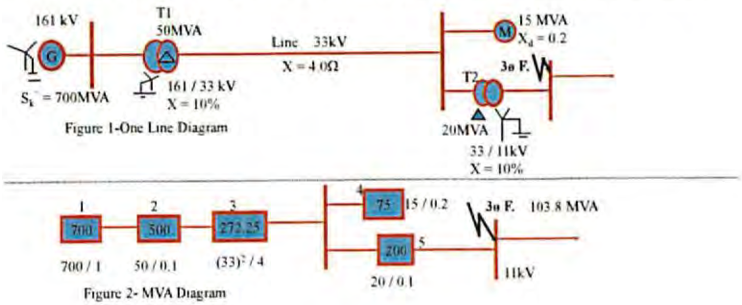


Figure 1-One Line Diagram

Figure 2- MVA Diagram

MVA METHOD FOR 3 PHASE SHORT CIRCUIT CALCULATION

- In our example:
  MVA's 1& 2 are in series
  - MVA (1&2) = (700 x 500) / (700 + 500) = 291.67

  MVA's (1&2) & 3 are in series
  - MVA = (291.67 x 272.25) / (291.67 + 272.25) = 140.81

  MVA's (1,2&3) // MVA 4
  - MVA at the point = 140.81 + 75 = 215.81

  MVA's (1,2,3&4) in series with MVA 5
  MVA at the Fault point = (251.81 x 200) /(251.81 + 200) = 103.802
  Considering Voltage Factor of 1.1, MVA = 103.802 x 1.1 = 114.18

  - 3Ø I_{SC} =MVA /(1.732 x U_n) =114.18 /(1.732 x 11) = 5.99 kA

CALCULATION OF 3 PHASE FAULT USING %/MVA SYSTEM METHOD

Let Consider the same Single Line Diagram used in the case of MVA Method

- Hence the % / MVA of the various component are as follows:

  - Source Network reactance X =(1.1 x 100%)/ S_K'' =110 / 700 = 0.157% /MVA

  - Transformer 1 $X_T = U_k / S_r$ = 10 / 50 = 0.2% /MVA

  - Line X_L = [X(Ω) x 100%]/ U^2_n = 4 x100 /(33)² = 0.367% /MVA

  - Transformer 2 $X_T = U_k / S_r$ = 10 / 20 = 0.5% /MVA

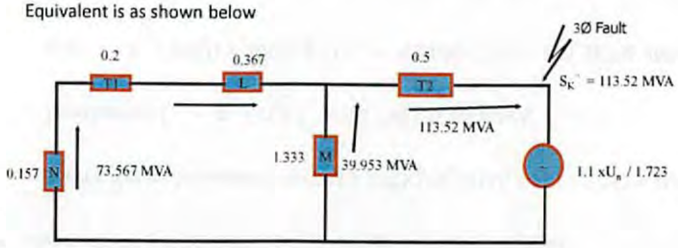
  - Motor $X_M = X_d / S_r$ = 20 / 15 = 1.333% / MVA

Table for Short Circuit Calculation

Component	X (% / MVA)	1 / X (MVA /%)	S'_K (MVA)
1. 161 Network	0.157		73.567
2. Transformer 1	0.200		-
3. Line	0.367		-
4. (1,2 & 3) in series	0.724	1.381	-
5. Motor	1.333	0.750	39.953
6. 4. // 5.	0.469	2.131	-
7. Transformer 2	0.500		-
8. Fault Location	0.969		113.52

CALCULATION OF 3Ø FAULT USING %/MVA SYSTEM METHOD

Equivalent is as shown below



- Hence $S_K'' = 1.1 \times 100\% / X_K = 110 / 0.969 = 113.52$ MVA
  3Ø I = 113.52 / (1.732 x 11) = 5.958 kA

  Contribution by Motor = (0.750 / 2.131) x 113.52 = 39.953 MVA

  Contribution from NETWORK through Transformer 1
  = (1.381 / 2.131) x 113.52 = 73.567 MVA

29

CONCLUSION

- In very large and complex network systems computer programs are used for short circuit analysis.
- In ECG Network, ASPEN software is used for short circuit analysis.

30

17. UNSYMMETRICAL OR UNBALANCED FAULTS CALCULATIONS

UNBALANCED FAULTS

- Unbalanced Faults may be classified into SHUNT FAULTS and SERIES FAULTS
- SHUNT FAULTS

➢ Line to Ground
➢ Line to Line
➢ Line to Line to Ground

❑ SERIES FAULTS

➢ Single phase open circuit
➢ Double phase open circuit

CAUSES OF UNBALANCE FAULTS

❑ CAUSES OF SHUNT FAULTS

➢ Insulation Breakdown
➢ Lightning Discharges
➢ Mechanical Damage

❑ CAUSES OF OPEN CIRCUIT FAULTS

➢ Broken Conductor
➢ Operation of Fuses
➢ Mal-operation of single phase CB

❑ During Unbalanced Faults, symmetry of system is lost. Hence single phase representation is no longer valid for the fault analysis.

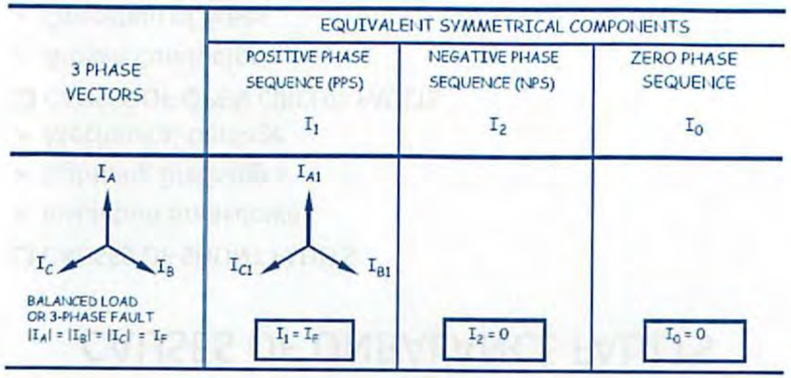
Analysis of Unbalanced Faults

- Unbalanced faults are analysed using :-

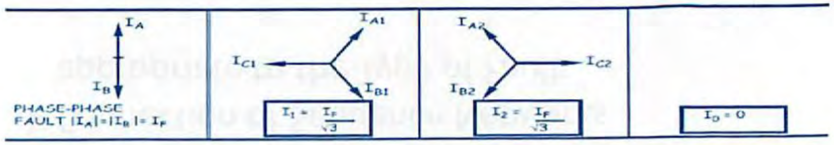
➢ Symmetrical Components
➢ Equivalent Sequence Networks of the Power System
➢ Connection of Sequence Networks appropriate to the Type of Fault

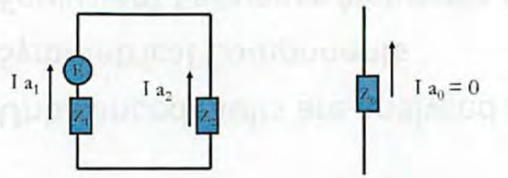
Sequence Components for a three Phase Fault

Any 3 phase system of vectors may be represented as the sum of 3 sets of symmetrical vectors :-



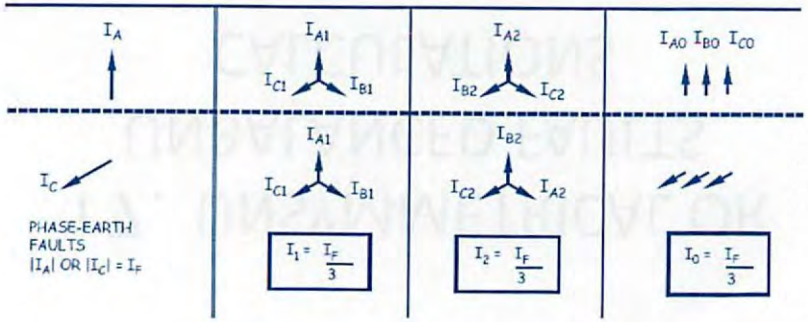
Sequence Components for a Phase to Phase Fault





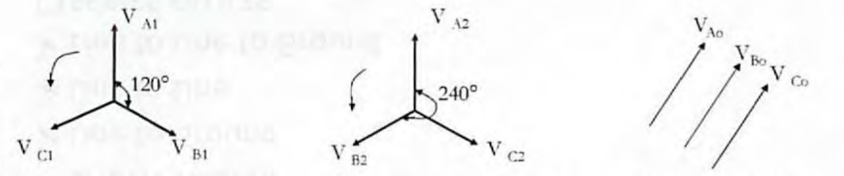
Sequence Network Interconnection for phase to phase fault

Sequence Components for a Phase to Earth Fault



Unbalanced 3-phase system of voltages

- This can be resolved into :-



Positive Sequence Phasors   Negative Sequence Phasors   Zero Sequence Phasors

Symmetrical Components and Sequence Components

Phase ≡ Positive + Negative + Zero

$V_A = V_{A1} + V_{A2} + V_{A0}$

$V_B = V_{B1} + V_{B2} + V_{B0}$

$V_C = V_{C1} + V_{C2} + V_{C0}$

$V_{B1} = a^2V_{A1}$ $V_{B2} = aV_{A2}$ $V_{B0} = V_{A0}$

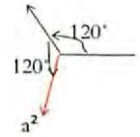
$V_{C1} = aV_{A1}$ $V_{C2} = a^2V_{A2}$ $V_{C0} = V_{A0}$

Operators

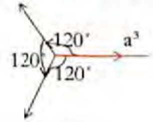
Symmetrical Components utilize a unit vector "a"
Properties of Unit Vector "a"

- a = 1<120˚ = -o.5+j0.866

- a^2 = 1<240˚ = -0.5-j0.866



- a^3 = 1



- 1 +a + a^2 = 1 + 1<120˚ + 1<240˚ = 0

Converting from phase value to sequence components

$V_A = V_{A1} + V_{A2} + V_{A0}$

$V_B = V_{B1} + V_{B2} + V_{B0} = a^2V_{A1} + aV_{A2} + V_{A0}$

$V_C = V_{C1} + V_{C2} + V_{C0} = aV_{A1} + a^2V_{A2} + V_{A0}$

Add V_A, V_B, V_C vectorially

$$V_A = V_{A1} + V_{A2} + V_{A0}$$
$$V_B = a^2V_{A1} + aV_{A2} + V_{A0}$$
$$V_C = aV_{A1} + a^2V_{A2} + V_{A0}$$

$$V_A + V_B + V_C = 0 + 0 + 3V_{A0}$$

$$\therefore V_{A0} = 1/3\,(V_A + V_B + V_C)$$

Converting from phase value to sequence components

Add V_A, aV_B, a^2V_C vectorially

$$V_A = V_{A1} + V_{A2} + V_{A0}$$
$$aV_B = V_{A1} + a^2V_{A2} + aV_{A0}$$
$$a^2V_C = V_{A1} + aV_{A2} + a^2V_{A0}$$

$$V_A + aV_B + a^2V_C = 3V_{A1} + 0 + 0$$

$$\therefore V_{A1} = 1/3\,(V_A + aV_B + a^2V_C)$$

Add V_A, a^2V_B, aV_C vectorially

$$V_A = V_{A1} + V_{A2} + V_{A0}$$
$$a^2V_B = aV_{A1} + V_{A2} + a^2V_{A0}$$
$$aV_C = a^2V_{A1} + V_{A2} + aV_{A0}$$

$$V_A + a^2V_B + V_C = 0 + 3V_{A2} + 0$$

$$\therefore V_{A2} = 1/3\,(V_A + a^2V_B + aV_C)$$

Symmetrical Components

$$V_A = V_{A1} + V_{A2} + V_{A0}$$
$$V_B = a^2V_{A1} + aV_{A2} + V_{A0}$$
$$V_C = aV_{A1} + a^2V_{A2} + V_{A0}$$

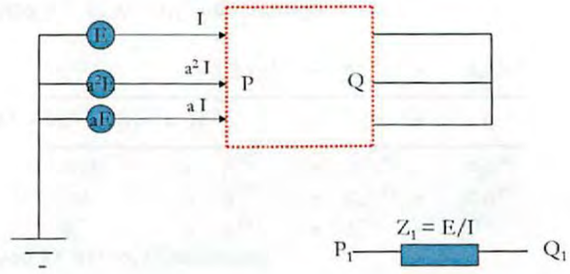
$$I_A = I_{A1} + I_{A2} + I_{A0}$$
$$I_B = a^2I_{A1} + aI_{A2} + I_{A0}$$
$$I_C = aI_{A1} + a^2I_{A2} + I_{A0}$$

$$V_{A1} = 1/3\{V_A + aV_B + a^2V_C\}$$
$$V_{A2} = 1/3\{V_A + a^2V_B + aV_C\}$$
$$V_{A0} = 1/3\{V_A + V_B + V_C\}$$

$$I_{A1} = 1/3\{I_A + aI_B + a^2I_C\}$$
$$I_{A2} = 1/3\{I_A + a^2I_B + aI_C\}$$
$$I_{A0} + 1/3\{I_A + I_B + I_C\}$$

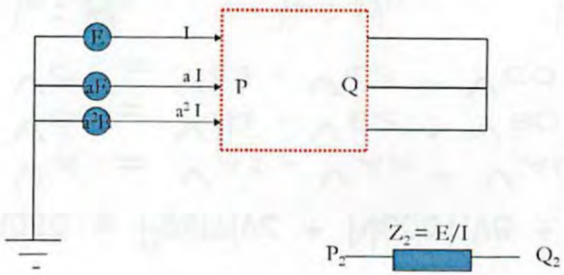
Phase Sequence Equivalent Circuits

Positive Sequence Impedance



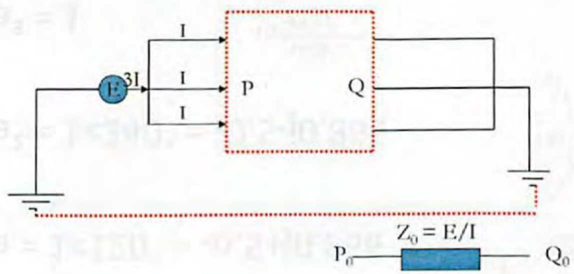
Phase Sequence Equivalent Circuits

Negative Sequence Impedance
For static non-rotating plant :- Z2= Z1



Phase Sequence Equivalent Circuits

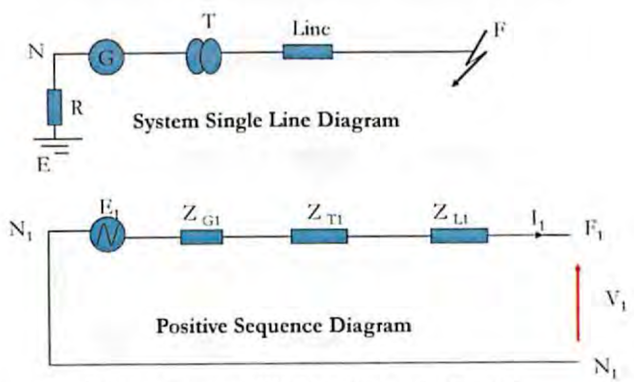
Zero Sequence Impedance



Sequence Networks

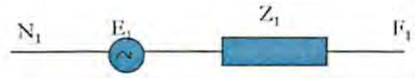
- +ve, -ve and zero sequence networks are drawn for a 'reference' phase. This is usually taken as the 'A' phase.
- Faults are selected to be 'balanced' relative to the reference 'A' phase.
  e.g. For Ø/Earth faults, we consider an A-Earth fault
  For Ø/Ø faults, we consider a B-C fault
- Sequence network interconnection is the simplest for the reference phase.

Positive Sequence Diagram



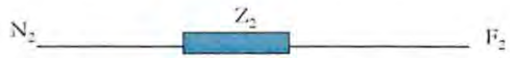
V_1=Positive sequence PH-N voltage at fault point
I_1=Positive sequence phase current flowing into F_1
$V_1=E_1-I_1(Z_{G1}+Z_{T1}+Z_{L1})$

Positive Sequence Diagram



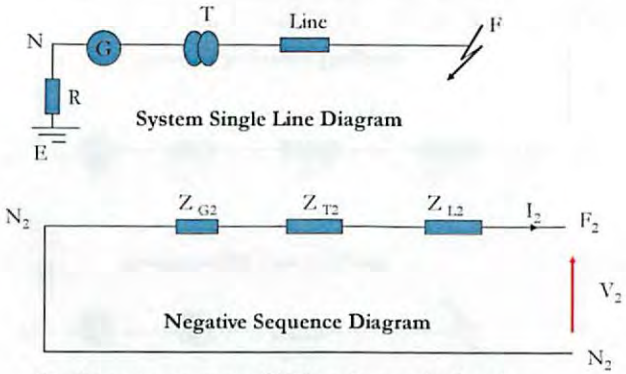
- 1. Start with neutral point N1
  -All generator and load neutrals are connected to N1
- 2. Include all source voltages:- Phase-neutral voltage
- 3. Impedance network:- Positive sequence impedance per phase
- 4. Diagram finishes at fault point F1

Negative Sequence Diagram



- Start with neutral point N_2
  -All generator and load neutrals are connected to N_2
- No voltages included
  -No negative sequence voltage is generated!
- Impedance network
  -Negative sequence impedance per phase
- Diagram finishes at fault point F_2

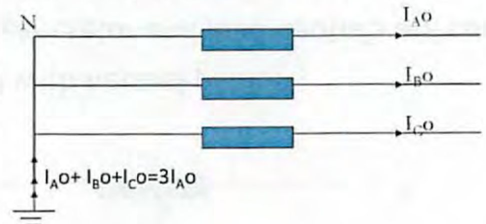
Negative Sequence Diagram



V_2=Negative sequence PH-N voltage at fault point
I_2=Negative sequence phase current flowing into F_2
$V_2 = -I_2 (Z_{G2} + Z_{T2} + Z_{L2})$

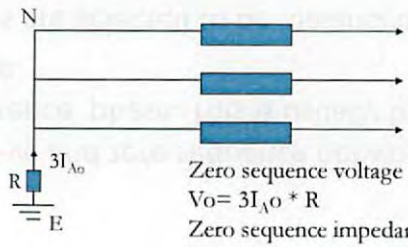
Zero Sequence Diagram

- For "In Phase" (Zero Phase Sequence) currents to flow in each phase of the system, there must be a fourth connection (this is typically the neutral or earth connection).



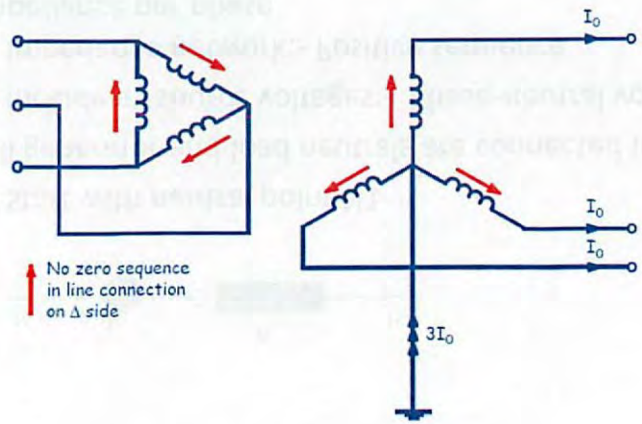
Zero Sequence Diagram

Resistance Earthed System :-



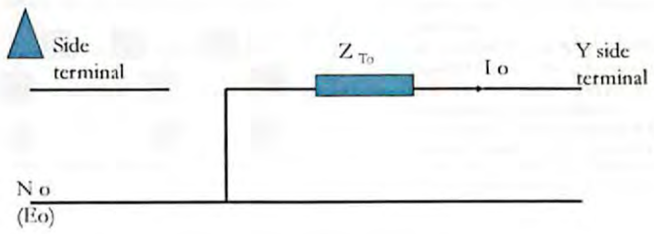
Zero sequence voltage between N & E is given by
$V_O = 3I_AO * R$
Zero sequence impedance of neutral to earth path
$Z_O = V_O / I_{Ao} = 3R$

Zero Sequence Equivalent "D y" Transformer"

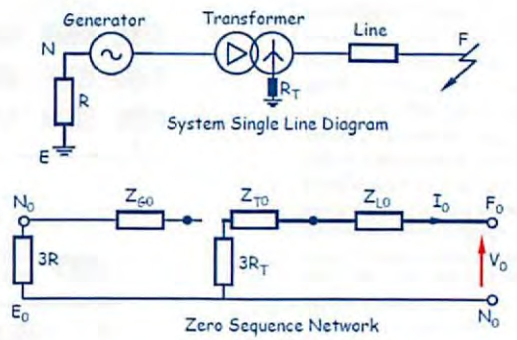


Zero Sequence Equivalent "D y" Transformer

Thus, Equivalent single phase zero sequence diagram is as shown:-



Zero Sequence Equivalent Circuits

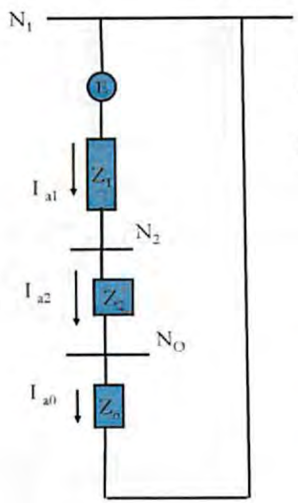


V_0 = Zero sequence PH-E voltage at fault point

I_0 = Zero sequence current flowing into F_0

$V_0 = -I_0 (Z_{T0} + Z_{L0})$

Sequence Network Interconnection for a Phase - Earth Fault



$I_{fg} = I_{a1} + I_{a2} + I_{ao}$

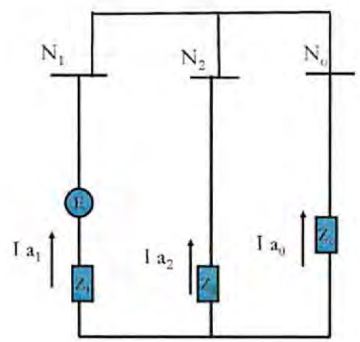
$I_{a1} = I_{a2} = I_{ao} = E / (Z_1 + Z_2 + Z_o)$

$I_{fg} = 3 * E / (Z_1 + Z_2 + Z_o)$

$E = V_{L-N}$

$$I_{fg} = \frac{3 * V_{L-N}}{Z1 + Z2 + Z0}$$

Sequence Network Interconnection for Phase – Phase - Earth Fault



$I_{a1} = E / (Z_1 + (Z_o Z_2 / (Z_o - Z_2))$

$I_{a2} = -(Z_o * I_{a1}) / (Z_2 + Z_o)$

$I_{ao} = -(Z_2 * I_{a1}) / (Z_2 + Z_o)$

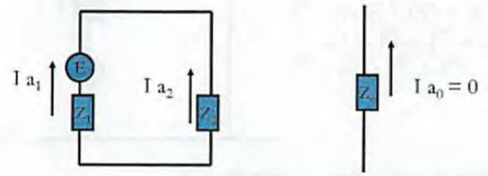
$I_a = I_{ao} + I_{a1} + I_{a2}$

$I_b = I_{ao} + a^2 I_{a1} + a I_{a2}$

$I_c = I_{ao} + a I_{a1} + a^2 I_{a2}$

Sequence Network Interconnection for Phase - Phase Fault

- $I_{a1} = E / (Z_1 + Z_2)$
  $I_{a2} = -I_{a1}$
  $I_b = I_{ao} + a^2 I_{a1} + a I_{a2} = (a^2 - a) E / (Z_1 + Z_2)$
  $I_c = I_{ao} + a I_{a1} + a^2 I_{a2} = (a - a^2) E / (Z_1 + Z_2)$



Sequence Network Interconnection for phase to phase fault

MVA METHOD FOR SINGLE PHASE TO GROUND FAULT CALCULATION

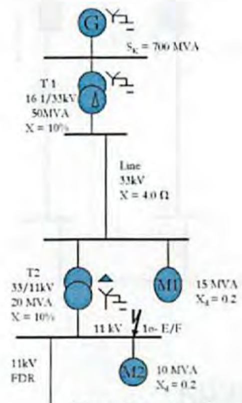


Figure 1: One Line Diagram

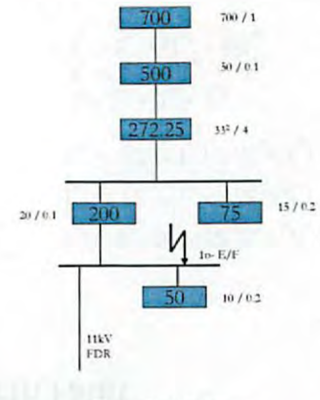


Figure 2: MVA Diagram

MVA METHOD FOR SINGLE PHASE TO GROUND FAULT CALCULATION

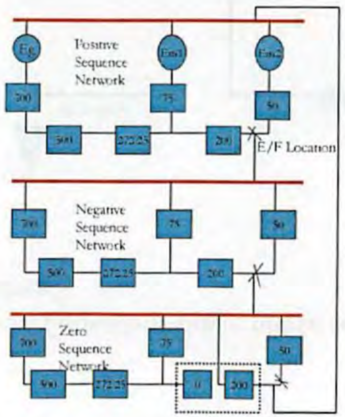


Figure 3: MVA Sequence Diagram for Positive, Negative and Zero Sequence Network in SC MVA quantities

- MVA sequence diagram beside shows all components of positive, negative and zero sequence networks in SC MVA quantities. The connection shown illustrates single phase to ground fault at the 11 kV bus.
- The 3ø fault up to the 11kV bus as calculated in the previous presentation is 103.802 MVA.
- NB: The previous presentation had no motor at the 11kV bus.
- Hence with a second motor at the bus, the total 3ø MVA will be:
- Total MVA = 103.802+50 = 153.802
- Since the positive sequence fault is equal to negative sequence fault, $MVAX_1 = MVAX_2$ = 153.802
- The zero sequence fault MVA, however, must be calculated, and its MVA value then is combined with the positive and negative MVA values.
- In this example, for a fault on the 11 kV bus, only the transformer and motor 2 contribute to zero sequence MVA as shown in the diagram.

MVA METHOD FOR SINGLE PHASE TO GROUND FAULT CALCULATION

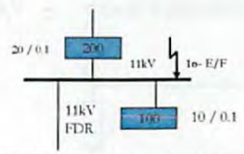


Figure 4: Zero sequence Power circuit Diagram.

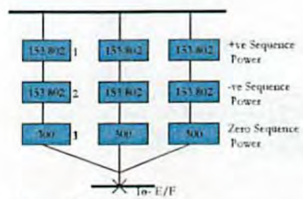


Figure 5: Line to Fault Power

- The delta primary of the transformer blocks any zero sequence power flowing from the system and across the transformer
- MVAX0 T_2=MVAX$_1$ T_2= MVAX$_2$ T_2= 200
  as the transformer zero sequence reactance equals its positive and negative reactance.
- the zero sequence reactance of the motor is about 1/2 of its positive sequence reactance.
- Hence MVAXo, M_2 = 10 / 0.1 = 100 MVA,
- Total zero sequence fault power is
- MVAXo T_2+ MVAXo M_2 = 200 + 100 = 300
- Considering Figure 5 and taking 1 circuit.
- MVA(1,2) = 153.802 / 2 =76.901
- MVA(1,2-3)= (76.901x300)/(76.901+300) =61.21
- Hence MVA(1ø-E/F) = 3x 61.21 = 183.632
- I (E/F)=183.632 x 1000 /(1.73 x11)
- =9638.18A

MVA METHOD FOR DOUBLE PHASE TO GROUND FAULT CALCULATION

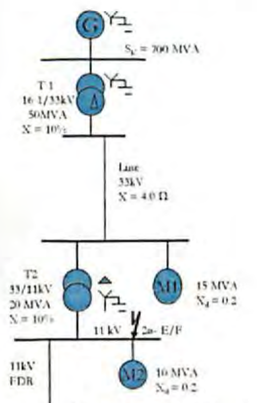


Figure 1: One Line Diagram

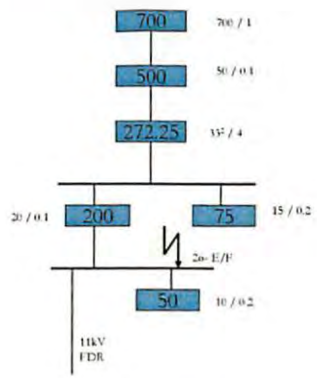
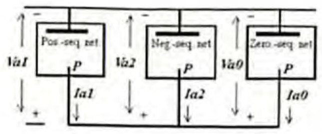
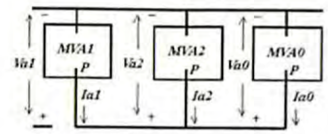


Figure 2: MVA Diagram

MVA METHOD FOR DOUBLE PHASE TO GROUND FAULT CALCULATION



- Figure 1



- Figure 2

- The connection of the sequence networks to simulate unsymmetrical double phase to ground fault is shown in Figure 1.
- The sequence networks are indicated schematically by rectangles enclosing a heavy line to represent the reference bus of the network and a point marked *P* to represent the point in the network where the fault occurs.
- The positive sequence network contains emfs that represent the internal voltages of the machines.

MVA METHOD FOR DOUBLE PHASE TO GROUND FAULT CALCULATION

- If the emfs in a positive sequence network are replaced by short circuits, the impedance between the fault point *P* and the reference bus is the positive sequence impedance Z1 in the equation developed for faults on a power system and is the series impedance of the Thevenin equivalent of the circuit between *P* and the reference bus.
- When the other sequence networks are interconnected with the positive system network, the current flowing out of the network is Ia1 and the reference bus is Va1.
- Since the reciprocal of positive sequence impedance Z1 is the short circuit MVA1 at unit voltage which flows through the sequence to a fault, we can replace the sequence network of Figure1 with the corresponding MVA1, 2, 0 sequence equivalents, and use these to derive MVA equations for double phase to ground fault calculations.
- The resulting MVAF and I_F for the two phase to ground fault are then calculated.

MVA METHOD FOR DOUBLE PHASE TO GROUND FAULT CALCULATION

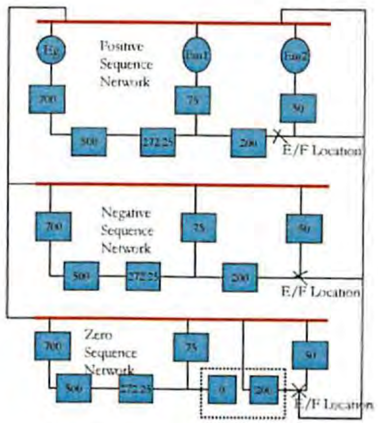


Figure 3 MVA Sequence Diagram for Positive, Negative and Zero Sequence Network in SC MVA quantities

- MVA sequence diagram beside shows all components of positive, negative and zero sequence networks in SC MVA quantities. The connection shown illustrates two phase to ground fault at the 11 kV bus.
- The 3ø fault up to the 11kV bus as calculated in the previous presentation is 103.802 MVA.
- The previous presentation had no motor at the 11kV bus.
- Hence with a second motor at the bus, the total 3ø MVA will be:
- Total MVA = 103.802+50 = 153.802
- Since the positive sequence fault is equal to negative sequence fault, $MVAX_1 = MVAX_2$ = 153.802
- The zero sequence fault MVA, however, must be calculated, and its MVA value then is combined with the positive and negative MVA values.
- In this example, for a fault on the 11 kV bus, only the transformer and motor 2 contribute to zero sequence MVA

MVA METHOD FOR DOUBLE PHASE TO GROUND FAULT CALCULATION

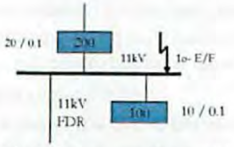


Figure 4: Zero sequence Power circuit Diagram.

- The following formulae are used for the calculation of 2ø to ground fault for equal X/R ratio.
- $MVAX_1 = MVA_1 \times (MVA_2 + MVAo) / (MVA_1 + (MVA_2 + MVAo))$
- $MVAXo = MVAX_1 \times MVAo / (MVAo + MVA_2)$
- $MVAF = 3 \times MVAXo$
- $I(2ø\text{-}E/F) = MVAF \times 1000 / (1.73 \times kV)$
- The delta primary of the transformer blocks any zero sequence power flowing from the system and across the transformer
- $MVAXo\ T_2 = MVAX_1\ T_2 = MVAX_2\ T_2 = 200$ as the transformer zero sequence reactance equals its positive and negative reactance.
- the zero sequence reactance of the motor is about 1/2 of its positive sequence reactance.
- Hence $MVAXo, M_2 = 10 / 0.1 = 100$ MVA,
- Total zero sequence fault power MVAo is
- $MVAXo\ T_2 + MVAXo\ M_2 = 200 + 100 = 300$
- Hence to get 2ø-E/F Power; the formulae beside are used.
- $MVAX_1 = 153.802(153.802+300)/(153.802+153.802+300) = 114.87$
- $MVAXo = 114.87 \times 300 / (300+153.802) = 75.94$
- Hence $MVA(2ø\text{-}E/F) = 3 \times 75.94 = 227.82$
- $I(E/F) = 227.82 \times 1000 / (1.732 \times 11)$
- $= 11957.2A$

18. SYSTEM PROTECTION AND CONTROL

1

ECG, VRA Generation and Distribution Systems

- An electric power system consists of four principal components:
- Generation: the production of electricity
- Transmission: the system of lines and accessories that transport the electricity from the generating plants to the bulk supply stations.
- Sub-Transmission: the system of lines and accessories that transport the electricity from the bulk supply stations to the Distribution Sub stations
- Distribution: the system of lines that connect the individual customer to the electric power system.

2

Transmission Lines Properties

- Resistance
- Inductance
- Capacitance
- Conductance

3

Introduction to power system simulator

- The power system simulator is a device built to represent a real power system and designed to carry out experiments and research work. The ECG power simulator was designed and built by Terco Limited from Sweden.
- The Terco Power System Simulator is divided in five modules;
- Power plant module
- Transmission line and distribution module
- Receiving substation module
- Power factor correction module
- Load module

4

Power system simulator

- The cubicles are labeled C1, C2-------------C12.
- The front plates are labeled from top to bottom as K5, K9, K13, to K17.
- The desk front plate is labeled from J21, J25 to J29.
- The simulator is equipped with the under-listed important units;
- The logic blocking unit- it uses a microprocessor to determine the logical sequence of operation of the simulator. For example it helps to determine if and isolator can be operated or not.
- The channel measuring unit-All channels are easily adapted for measuring AC, DC or mixed quantities.
- The digital instruments-The simulator contains a number of LCDs and line-to-line or line-to-neutral voltages can be selected with the help of a selector switch.
- Emergency switch- An emergency switch is situated at the front of cubicle 1 and anyone involved in an experiment and system operation must know how to operate it.

5

PST

6

Introduction to SCADA system

- SCADA- Supervisor Control and Data Acquisition
- The SCADA functions include;
- Data acquisition
- Monitoring and event processing
- Control functions
- Time tagged data
- Disturbance data collection and analysis
- Reports and calculations

7

SCADA

8

Generator action

- Induction: Transfer of electric energy from one circuit to another without electric connection
- Electromagnetic induction: Transfer of electric energy by magnetic field
- Electromagnetic induction occurs when there is a relative movement between conductor and a magnetic field

9

Generator action

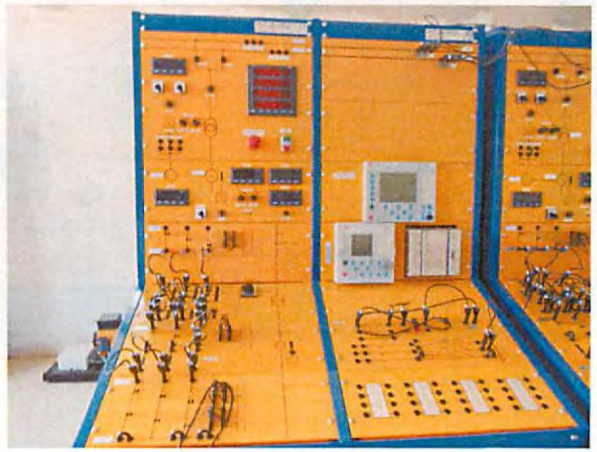
- AC generator consist of a loop of wire rotating in a magnetic field
- The loop of wire is called armature
- The magnetic field is called field
- The armature is turned by a prime mover
- The armature windings are connected to load
- The field windings create the magnetic field

10

Generator action

- The armature loop is connected to slip rings
- As the armature rotates in the field, voltage is created
- The stronger the field the higher the voltage
- AC voltage is controlled by varying the current in the DC field windings
- Frequency is controlled by the speed of rotation

11



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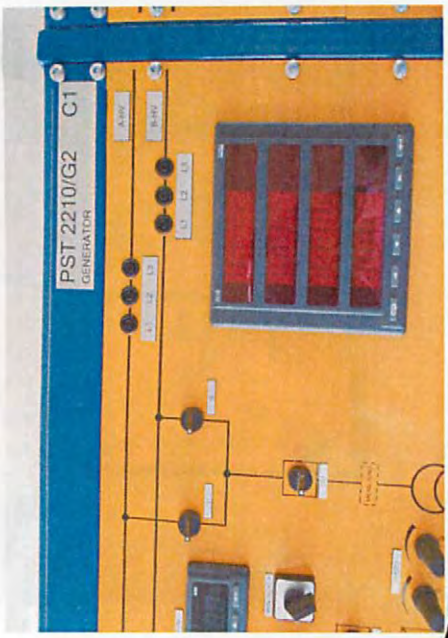
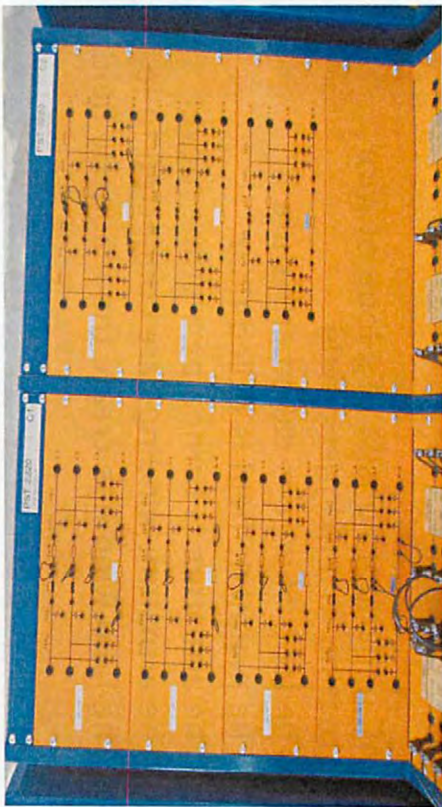
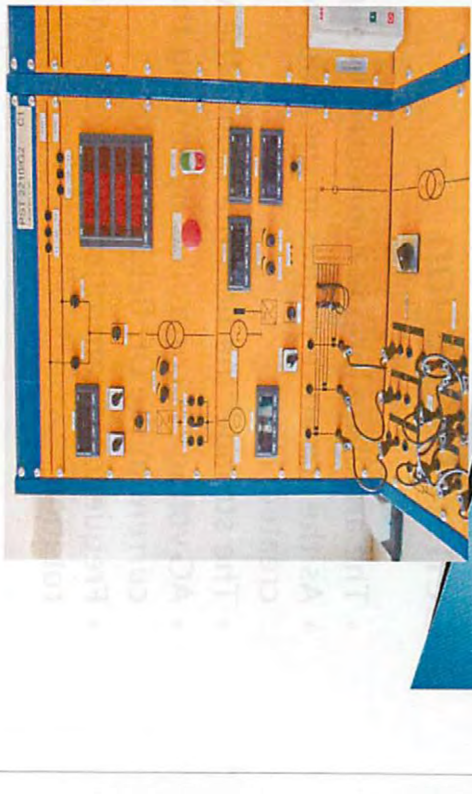

PST 2210/G2 C1
GENERATOR

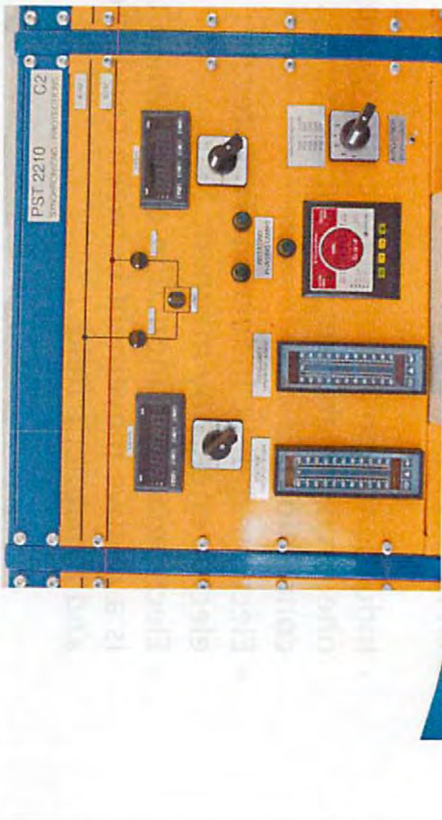
14


PST 2220 C1

16

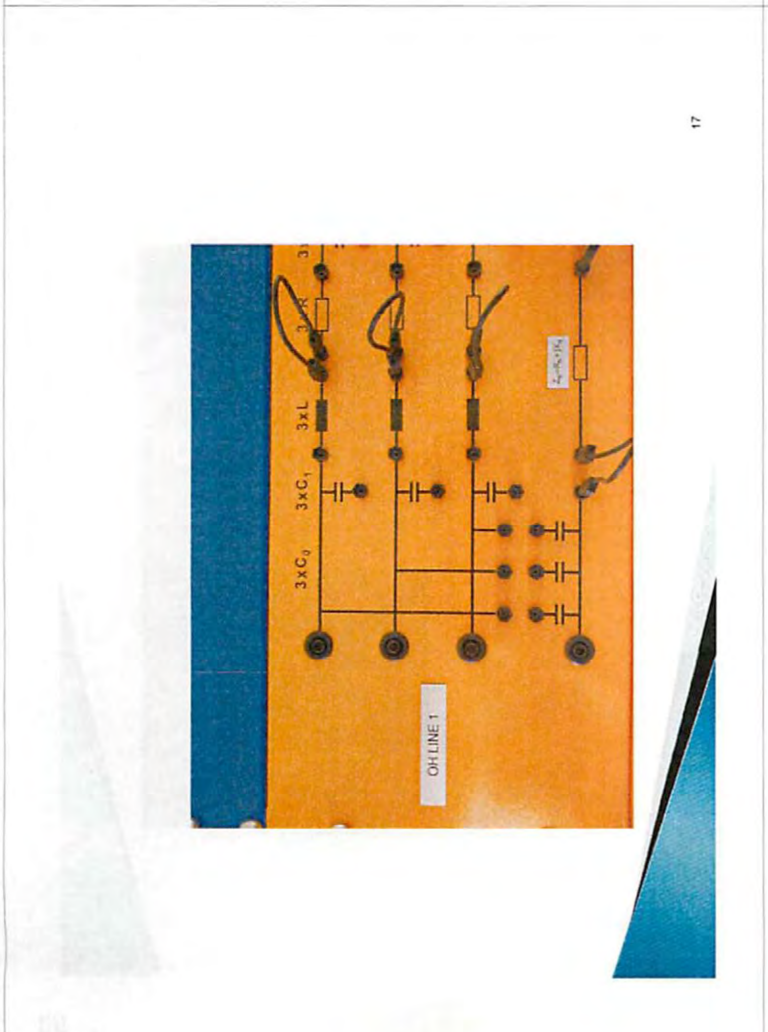

PST 2210/G2 C1

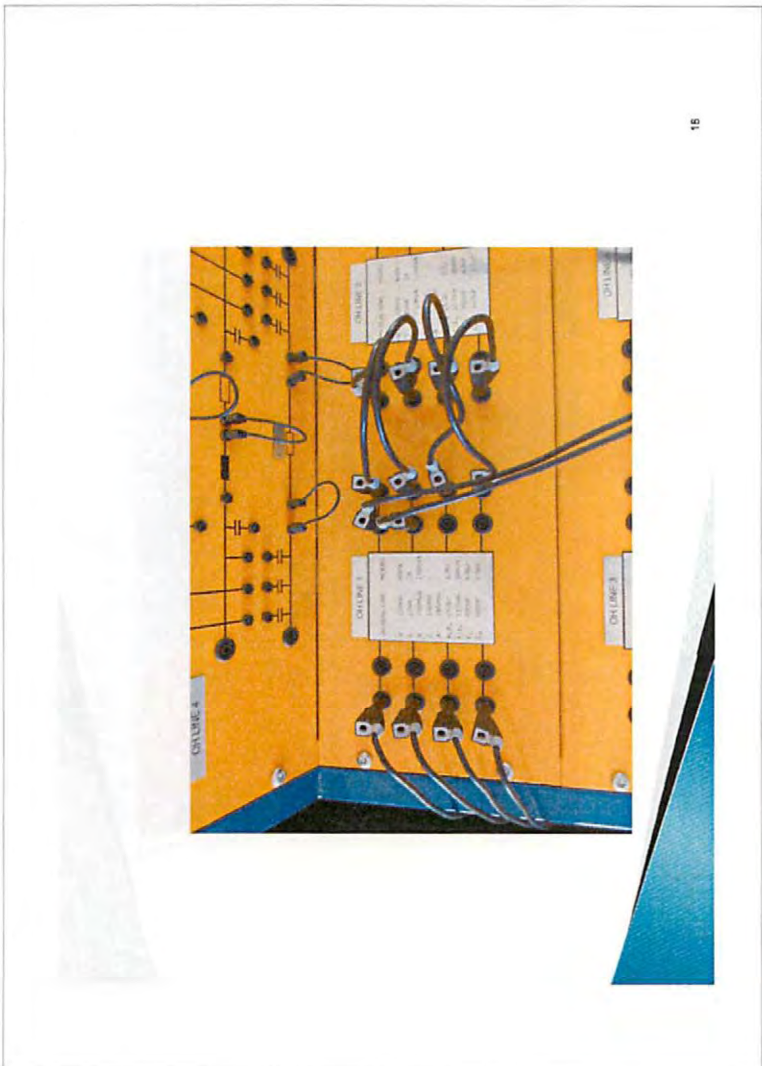
13

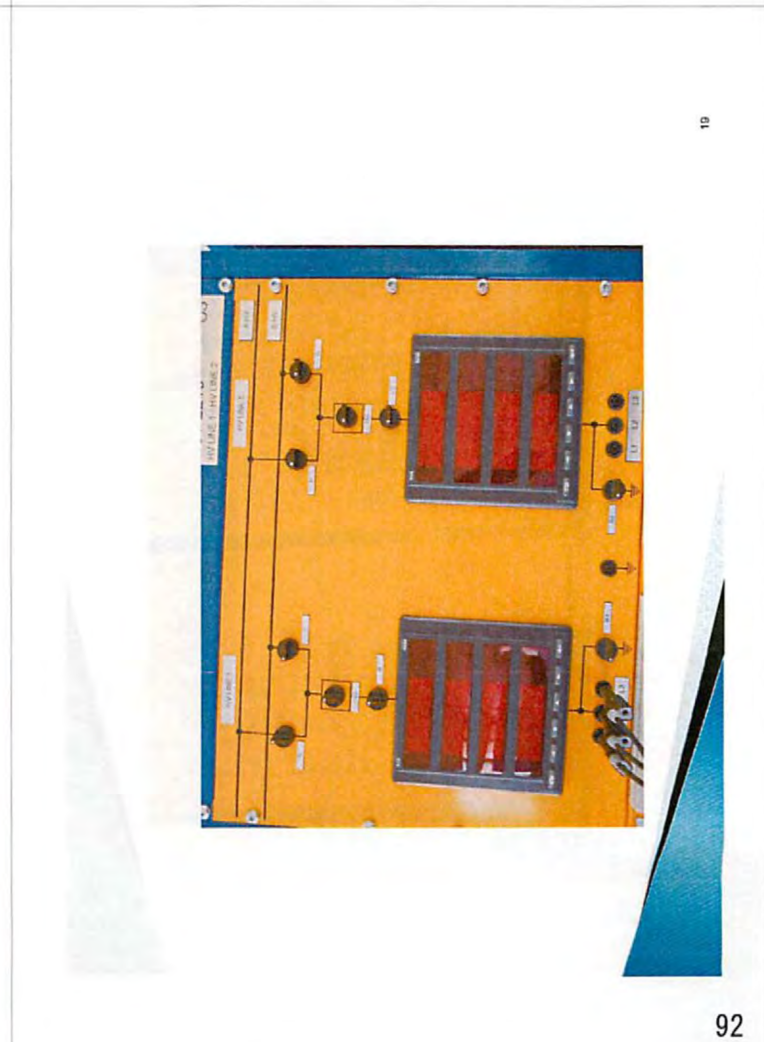

PST 2210 C2
SYNCHRONISING PROTECTIONS

15

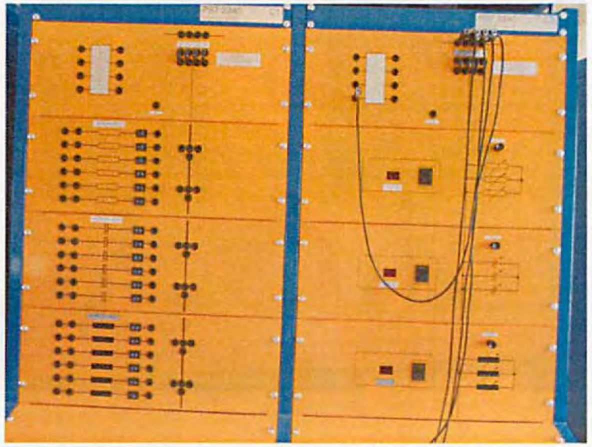
91


OH LINE 1
3 x L
3 x C1
3 x C0
17


OH LINE 4
OH LINE 3
18


19

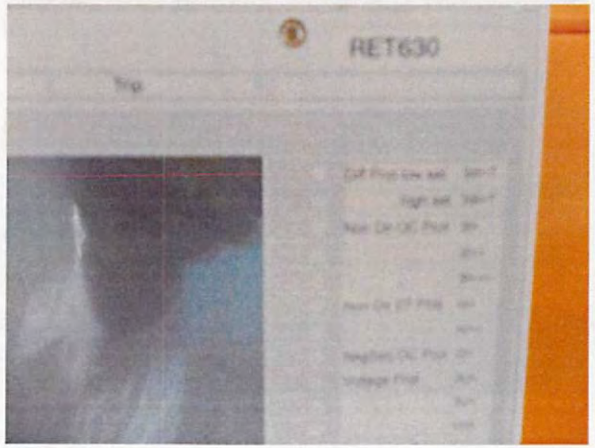

20



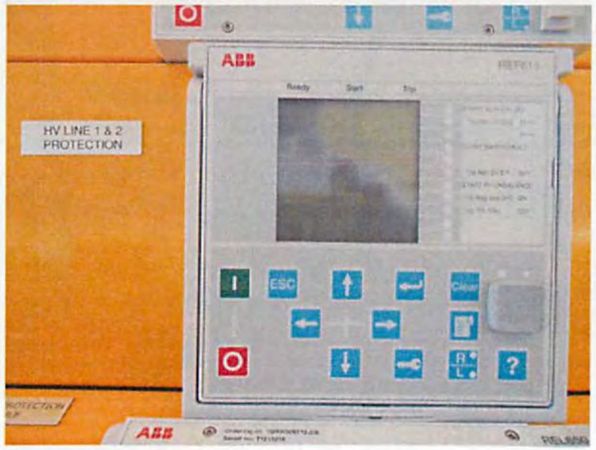
21


ABB
RET630
Ready
Start
Trip
ESC
Clear

22


RET630
Trip

23


HV LINE 1 & 2
PROTECTION
ABB
Ready
Start
Trip
ESC
Clear

24

19. POWER SYSTEM PROTECTION & CONTROL TRAINING

PROTECTIVE RELAY SETTINGS

1

Objectives

- Importance of protective relay settings.
- Work flow of generating protective relay settings.
- Demonstration of generating protective relay settings for a radial network.

2

Importance of Relay Settings

Ensure maximum benefit of installed protection system

- Detect and isolate faults from power system
- Prevent damage to power system equipment
- Limit system interruption to faulty section of power network
- Protect personnel, public and animals

Work Flow of Protective Relay Settings

1. Collate data on power system to be protected.
   - Single Line Diagram (SLD) of power network
   - Short Circuit Duty/Ratings of all Installed Generators or Power Grid
   - Short Circuit Duty/Rating of all Installed Power Transformers
   - Parameters of Installed Feeders – length and conductor type
   - Installed instrument transformer ratings
   - Protective relays installed on various sections of power system

4

Work Flow of Protective Relay Settings

2. Model the power system using appropriate software.

3. Fault Calculations/Simulations

   - Determine short circuit currents at various points of power system

4. Relay Settings

   - Maximum power flow, allowable overloading of power system components
   - Time coordination – selectivity, speed

5

Work Flow of Protective Relay Settings

5. Finalization of Relay Settings

   - Protective relays at various points selectively coordinated to clear faults

6. Documentation of Relay Settings.

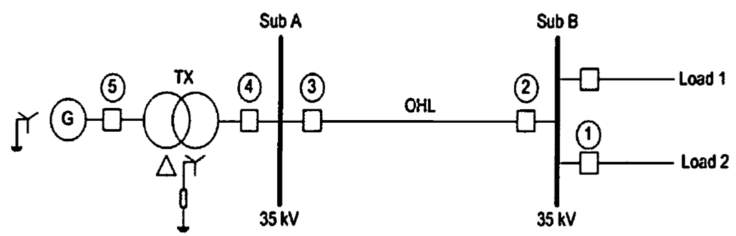
7. Implementation of Relay Settings.

8. Monitoring and Review.

6

Practical Protective Relay Settings

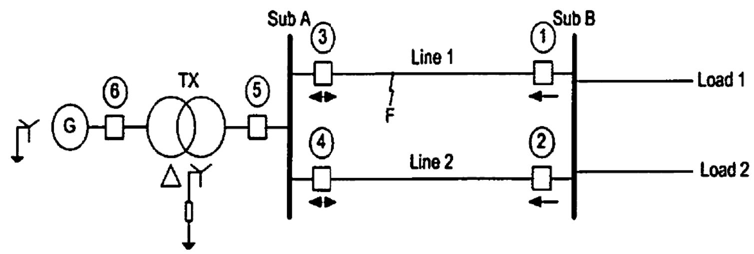
Case Study 1



7

Practical Protective Relay Settings

Case Study 2



8

7) Result of the Questionnaire for Trainees` Supervisors (Feb. 2015)

Training Course for Technicians of ECG “Maintenance Techniques for Power Equipment and Implementation Procedure” (1)

Result of the Questionnaire for Trainees` Supervisors

Training Course for Technicians of ECG "Maintenance Techniques for Power Equipment and Implementation Procedure (July 2014)

3 months after the completion of the course, the Questionnaire was sent to the supervisors of the trainees. Result of the Questionnaire is shown below.

1. Effectiveness of the Training Course from the view of supervisors of the trainees

   90% of the supervisors answered that they recognized the effectiveness of the Training Course.

   From this fact we can judge that the Training Course was implemented effectively enough to enhance techniques of ECG technicians.

2. Improvement points pointed out by the supervisors

(1) Safety consciousness is improved.

(2) The schedule management of the job is improved.

(3) The meeting before the job and information sharing come to be performed.

(4) The operating time of job is shortened.

(5) The job attitude and responsibility are improved.

3. Items to be added to the Training pointed out by the supervisors

   Switching and operations procedures for HV and LV networks

   As for the above-mentioned indication, there are an operating procedure for safety and a procedure of the switching operation in High/ Low voltage power system.

   The former was dealt with in the training course but the latter remained in generalities.

   Therefore, I would like to discuss with C/P how to teach the switching operation in High/ Low voltage power system by following the standard and know-how of ECG.

4. Other requests to the Training course

(1) To increase the implementation number of the Training course

(2) To increase the number of trainees

5. Conclusion

   Judging from the result of the Questionnaire for Trainees` Supervisors, we can conclude that the Training Course was implemented effectively enough to enhance techniques and knowledge of ECG technicians.

Training Course for Technicians of ECG "Maintenance Techniques for Power Equipment and Implementation Procedure (June 2014)
Result of the Questionnaire for Trainees` Supervisors (3 months after the completion of the course)

	(1)Improvement of trainees` job	(Improvement points)	(2) if any additional issues of the course	(3)if any requests to the course
P-1	No(re-assigned)			
P-2	Yes	—planning of job schedule —job commitment and attitude towards the job —submission of maintenance data and technical information —preventive maintenance	—Switching and operations procedures for bolt HV and LV networks	—other member of the section should be considered in the course.
P-3	Yes	—supervisory roles	—encompass all aspect of maintenance techniques	—training course should be conducted twice
P-4	Yes	—more safety conscious —discuss the job well with his team	-training should be conducted continuously	—training to sharpen his supervisory skills
P-5	Yes	—planning of job schedule —safe way of handling tools	—more personnel	—more frequently
P-6	Yes	—prompt preparation and leave —ability to analyze issues —good personnel relationship	—Switching and operations procedures for bolt HV and LV networks	—other member of the section should be considered in the course.
P-7	Yes	—technical abilities in solving serious problems —quick responses to fault or any duties —access information due to the computer programme	—more practical than theory	—a vehicle for 24 hours patrol
P-8	Yes	—confident on the job —safety precautions —contribution effectively toward work	-new technology on the job market	—tools, equipment and materials to the enhancement of the job - training should be organized frequently for all staff
P-9	Yes	—safety on the job —two days in house training —gate tail talks before work —importance of safety ,request for insolation	-new technology on the job market	—tools, equipment and materials to the enhancement of the job
P-10	Yes	—quick responses to fault intervention —more safety conscious	none	—refresher courses to keep up to date with current live line technologies

Answer to the Questionnaire

The Questionnaire (Interview) to the Supervisor of the Trainee
(Around three months after training course)

Name: Agyare Bediako Title: Senior Technician Engineer
Name of the Trainee: Samuel Acquah (P-1)
Training Course for Technicians of ECG
"Maintenance Techniques for Power Equipment and Implementation Procedure"

(1) Can you find some improvement in the trainee's job after receiving the training course?
- Not really. The trainee was re assigned after the training. Unfortunately, the other team members were sent to the training school for live line training.

If yes, please describe his (or her) improvement.

(2) If you find some additional issues to the training course above, please describe.
- From the report he gave, the program will be beneficial to the company but has not been put into practice.

(3) If you have any requests to the training course above, please describe.
- I recommend that a new person should be selected for the training.

Thank you very much for your Cooperation.

The Questionnaire (Interview) to the Supervisor of the Trainee

(Around three months after training course)

Name: Monister Kroateng Title: Senior Technician Engineer

Name of the Trainee: Gershon K. Asiedu (P-2)

Training Course for Technicians of ECG

"Maintenance Techniques for Power Equipment and Implementation Procedure"

(1) Can you find some improvement in the trainee's job after receiving the training course?

- He has improved on the skills of his job scheduled.
- His commitment and attitude towards the job as a maintenance staff has also improved.

If yes, please describe his (or her) improvement.

- Data or technical information submitted from the field on maintenance has improved.
- He undertook a preventive maintenance exercise on LV fuses, where he replaced old fuses with new fuses on part of Tuba and radio feeders. He also corrected weak jumper and separators around Maccarthy Hills and Odorcor.

(2) If you find some additional issues to the training course above, please describe.

- Switching and operations procedures for bolt HV and LV networks.

(3) If you have any requests to the training course above, please describe.

- Other members of the section should be considered in this training.

Thank you very much for your Cooperation.

The Questionnaire (Interview) to the Supervisor of the Trainee

(Around three months after training course)

Name: Rendy Adjalolo Title: Electrical Engineer

Name of the Trainee: Paul Kumah (P-3)

Training Course for Technicians of ECG

"Maintenance Techniques for Power Equipment and Implementation Procedure"

(1) Can you find some improvement in the trainee's job after receiving the training course?

- Yes

If yes, please describe his (or her) improvement.

- Improvement in his supervisory roles. A typical case was when he supervised a shutdown maintenance at the Top BSP, Eastern region for about four (4) hours before the arrival of the maintenance engineer.

(2) If you find some additional issues to the training course above, please describe.

- Reports submitted by the trainee suggested that the training encompasses all aspects of maintenance practices/ techniques and therefore has improved the maintenance culture in the region.

(3) If you have any requests to the training course above, please describe.

- It is hoped that such training courses be conducted twice yearly with the introduction of modern maintenance of equipment techniques and application of on-line diagnostic instruments and equipment.

Thank you very much for your Cooperation.

The Questionnaire (Interview) to the Supervisor of the Trainee

(Around three months after training course)

Name: Victor Aryee　　Title: Principal Technician Engineer

Name of the Trainee: Prince Oduro Anim (P-4)

Training Course for Technicians of ECG

"Maintenance Techniques for Power Equipment and Implementation Procedure"

(1) Can you find some improvement in the trainee's job after receiving the training course?

- Yes

If yes, please describe his (or her) improvement.

- He has become much more safety conscious.
- He discusses the job well with the team before leaving to site and put more emphasis on technique as a way of improved working procedure.
- He delivers the work well ahead of time.

(2) If you find some additional issues to the training course above, please describe.

- I will suggest that continued training programme of this mature work help make him a better technical personnel and master in his field.

(3) If you have any requests to the training course above, please describe.

- A training to sharpen his supervisory skills over the six workers he is controlling.
-

Thank you very much for your Cooperation.

The Questionnaire (Interview) to the Supervisor of the Trainee

(Around three months after training course)

Name: George Aryetey Title: Senior Technical Engineer

Name of the Trainee: Effah Mensah Emmanuel (P-5)

Training Course for Technicians of ECG

"Maintenance Techniques for Power Equipment and Implementation Procedure"

(1) Can you find some improvement in the trainee's job after receiving the training course?

- Yes

If yes, please describe his (or her) improvement.

- He has been contributed immensely in planning towards maintenance of the network and the safe way of handling tools during work.

(2) If you find some additional issues to the training course above, please describe.

- More personnel should be given such training.

(3) If you have any requests to the training course above, please describe.

- It should be frequently organised.

Thank you very much for your Cooperation.

The Questionnaire (Interview) to the Supervisor of the Trainee

(Around three months after training course)

Name: Raymond Dey Afesi   Title: Principal Technician Engineer

Name of the Trainee: Kenneth Assan (P-6)

Training Course for Technicians of ECG

"Maintenance Techniques for Power Equipment and Implementation Procedure"

(1) Can you find some improvement in the trainee's job after receiving the training course?

- Yes

If yes, please describe his (or her) improvement.

(i) Prompt preparation to do work or leave for field

(ii) Ability to analyze issues

(iii) Good personnel relationship others

(2) If you find some additional issues to the training course above, please describe.

- Switching and operations procedures for bolt HV and LV networks.

(i) The course made him think fast delegate when necessary

(3) If you have any requests to the training course above, please describe.

- Other members of the section should be considered in this training.

- None

Thank you very much for your Cooperation.

The Questionnaire (Interview) to the Supervisor of the Trainee
(Around three months after training course)

Name: Samuel Amponsah Title: Senior Technician Engineer
Name of the Trainee: Moro Hakuna (P-7)
Training Course for Technicians of ECG
"Maintenance Techniques for Power Equipment and Implementation Procedure"

(1) Can you find some improvement in the trainee's job after receiving the training course?
- Yes

If yes, please describe his (or her) improvement.
1. I can see maximum improvement in his technical abilities in solving serious problems.
2. He can quick responses to fault or any other duties assigned to him.
3. He can easily access information due to the computer programme which has been designed fro daily activities logging.

(2) If you find some additional issues to the training course above, please describe.
- The training should be more practical rather than theory.

(3) If you have any requests to the training course above, please describe.
- A vehicle which can contain all gang members should be given to the overhead lines gang to enable them discharge duties such as 24 hours patrol of the network and also discharge their work professionally.

Thank you very much for your Cooperation.

The Questionnaire (Interview) to the Supervisor of the Trainee

(Around three months after training course)

Name: Ray K. Cudugbe Title: Work Superintendent

Name of the Trainee: Deffor Atsu Edem (P-8)

Training Course for Technicians of ECG

"Maintenance Techniques for Power Equipment and Implementation Procedure"

(1) Can you find some improvement in the trainee's job after receiving the training course?

- Yes

If yes, please describe his (or her) improvement.

- He is confident on the job.
- He Always adhere to safety precautions.
- He contributes effectively towards work and the team as whole.

(2) If you find some additional issues to the training course above, please describe.

- The training programme should be periodic as new technology on the job market is mobbing very fast.

- It talks too long a time for such programmes to be organised.

(3) If you have any requests to the training course above, please describe.

- Tools, equipment and materials for the enhancement of the job would be welcome.
- The training should be organised frequently for all staff.

Thank you very much for your Cooperation.

The Questionnaire (Interview) to the Supervisor of the Trainee

(Around three months after training course)

Name: Godwin Amenuvo Title: Senior Technical Engineer

Name of the Trainee: Seth C. Martey (P-9)

Training Course for Technicians of ECG

"Maintenance Techniques for Power Equipment and Implementation Procedure"

(1) Can you find some improvement in the trainee's job after receiving the training course?

- Yes

If yes, please describe his (or her) improvement.

a. He has inculcated the habit of safety on the job at site.

b. He has organised a two day in house training with his direct reports on the programme.

c. He has been having gate tail talks with his direct report before work starts.

d. He has implored into his reports the importance of safety , request for insolation, and the reason of requesting for permit before work starts.

(2) If you find some additional issues to the training course above, please describe.

- The training programme should be periodic as new technology on the job market is mobbing very fast.

(3) If you have any requests to the training course above, please describe.

- Tools, equipment and materials for the enhancement of the job would be welcome.

Thank you very much for your Cooperation.

The Questionnaire (Interview) to the Supervisor of the Trainee

(Around three months after training course)

Name: Anthony Appiah Acquaye　　　Title: Principal Technician Engineer

Name of the Trainee: Matthew Yaw Aboagy (P-10)

Training Course for Technicians of ECG

"Maintenance Techniques for Power Equipment and Implementation Procedure"

(1) Can you find some improvement in the trainee's job after receiving the training course?

- Yes

If yes, please describe his (or her) improvement.

- Quick response to fault intervention

  More safety conscious

(2) If you find some additional issues to the training course above, please describe.

- No

(3) If you have any requests to the training course above, please describe.

- There should be regular refresher courses to keep the trainees up to date with current live line technologies

Thank you very much for your Cooperation.