Problem# 1

Ambient soil temperature = 25 ^{o}C
Conductor's normal operating Temp = 45 ^{o}C
Voltage = 400 V line to line (3-phase)
Current = 450 A
Cable type = PVC cables in a single conduit, buried in ground in single conduit
Cable length = 65 meter
Fault current = 5 kA for 1 second
Maximum voltage drop = 2.5 %

There are taken three considerations for calculating conductor size:

1. Current Carrying Capacity
2. Voltage drop along its length
3. Short Circuit temperature rise

Conductor Size as per Current Carrying Capacity

For current carrying capacity first circuit requirement are estimated, which is already given in problem. Then the required capacity is divided by different de-rating factors because tabulated current values are for standard condition and field condition are different. Conductor size is selected from the table for this final value of current.

Let us take following assumptions:

- There are two parallel conductors in each phase i.e. 2 circuits.
- Lets three single core PVC insulated copper cables in a single conduit. (total 6 cables for three phase)

Derating factor for putting group of conductor in the ground = 0.78 (from Table-25 AS /NZS 3008.1)
Derating factor for ambient soil temperature (25 degree centigrade) = 1.06 (from Table-27 AS /NZS 3008.1)

Overall derating factor = 0.78 x 1.06 = 0.826

Circuit requirement from a single cable = 450 / 2 = 225 A

Tabulated current capacity required = 225 / 0.826 = 272.13 A

From Table 20 of AS / NZS 3008.1,

Conductor size for 150 square-mm have 302 A.

Therefore, two parallel circuits of 150 squire – mm can be selected.

Conductor Size as per Voltage Drop less than 2.5 %:

As per AS/NZS 3008.1

Resistance of 150 sq-mm circular conductor multi-core cable at 45 ^{o}C temperature R= 0.139 Ω / km

AC Reactance of 150 sq-mm circular conductor multi-core cable X= 0.0868 Ω / km

Cable length L = 65m

Let us assume that load power factor = 0.8

Then,

Voltage drop $V = \frac{\sqrt{3}*I*(R*cos\Phi + X*sin\Phi)}{1000} * L = \frac{\sqrt{3}*450/2*(0.139*0.8 + 0.0868*\sin(cos^{-1}(0.8)))}{1000} * 65$ = 4.13V

For a 415 V system the drop is = 4.13/415*100 = 0.99 %, which is less than 2.5 % and acceptable.

Therefore, two 150 sq-mm conductor cable are acceptable.

Considering short circuit temperature rise

Short circuit energy which would cause the temperature rise = $\sqrt{I^2 * t}$

Minimum cross section of conductor for which temperature does not cross the limiting value = $\frac{\sqrt{I^2*t}}{K}$, where K = short circuit temperature rise constant.

For copper conductor, $K = 226\sqrt{ln\,(1 + \frac{\Theta_f - \Theta_i}{234.5 + \Theta_i})}$

Here, Θ_f = Limiting temperature = 160 ^{o}C, and

Θ_f = Initial temperature = Maximum operating temperature for conductor = 75°C

So, K = 111.329

Then Minimum cross section area of conductor = $\frac{\sqrt{(\frac{5000}{2})^2*1}}{111.392} = 22.44$ sq-mm,

which is quite less than selected conductor size and acceptable.

Therefore 2 single core copper cables of 150 sq-mm with PVC insulation for each phase, are selected to satisfy given requirements.

Problem# 2

Ambient air temperature = 40 ^{o}C
Conductor's normal operating Temp = 45 ^{o}C
Voltage = 400 V line to line (3-phase)
Current = 600 A
Let us assume Cable type = PVCsingle-core cables, and Cables are installed in free air in Cable Ladder
Cable length = 110 meter
Fault current = 32 kA for 1 second
Maximum voltage drop = 2.5 %

There are taken three considerations for calculating conductor size:

1. Current Carrying Capacity
2. Voltage drop along its length
3. Short Circuit temperature rise

Conductor Size as per Current Carrying Capacity

For current carrying capacity first circuit requirement are estimated, which is already given in problem. Then the required capacity is divided by different de-rating factors because tabulated current values are for standard condition and field condition are different. Conductor size is selected from the table for this final value of current.

Let us take following assumptions:

- There are two parallel conductors in each phase i.e. 2 circuits.
- Lets three single core PVC insulated copper cables in a single conduit. (total 6 cables for three phase)

Derating factor for putting group of conductor in cable ladder = 0.95 (from Table-23 AS /NZS 3008.1)
Derating factor for ambient air temperature (40 degree centigrade) = 0.88 (from Table-27 AS /NZS 3008.1)

Overall derating factor = 0.95 x 0.88 = 0.836

Circuit requirement from a single cable = 600 / 2 =300 A

Tabulated current capacity required = 300 / 0.836 = 358.85 A

From Table 20 of AS / NZS 3008.1, for 1 m/sec air,

Conductor size for 95 square-mm have 410 A.

Therefore, two parallel circuits of 95 squire – mm can be selected.

Conductor Size as per Voltage Drop across its length (which should not be more than 2.5 %)

As per AS/NZS 3008.1

Resistance of 95 sq-mm circular conductor multi-core cable at 45 ^{o}C temperature R= 0.214 Ω / km

AC Reactance of 95 sq-mm circular conductor multi-core cable X= 0.0904 Ω / km

Cable length L = 110 m

Let us assume that load power factor = 0.8

Then, Voltage drop $V = \frac{\sqrt{3}*I*(R*cos\Phi+ X*sin\Phi)}{1000} * L = \frac{\sqrt{3}*600/2*(0.214*0.8+ 0.0904*\sin(cos^{-1}(0.8)))}{1000} * 110$ = 12.88V

For a 415 V system the drop is = 12.88/415*100 = 3.10 %, which is more than 2.5 % and not acceptable.

Let us take 150 sq-mm conductors.

Resistance of 150 sq-mm circular conductor multi-core cable at 45 ^{o}C temperature R= 0.139 Ω / km

AC Reactance of 150 sq-mm circular conductor multi-core cable X= 0.0868 Ω / km

Then,

Voltage drop $V = \frac{\sqrt{3}*I*(R*cos\Phi+ X*sin\Phi)}{1000} * L = \frac{\sqrt{3}*450/2*(0.139*0.8+ 0.0868*\sin(cos^{-1}(0.8)))}{1000} * 110$= 6.98V

For a 415 V system the drop is = 4.13/415*100 = 1.68 %, which is less than 2.5 % and acceptable.

So, we can take two parallel 150 sq-mm cables in parallel.

Considering short circuit temperature rise

Short circuit energy which would cause the temperature rise = $\sqrt{I^2 * t}$

Minimum cross section of conductor for which temperature does not cross the limiting value = $\frac{\sqrt{I^2*t}}{K}$, where K = short circuit temperature rise constant.

For copper conductor, $K = 226\sqrt{ln\,(1 + \frac{\theta_f - \theta_i}{234.5 + \theta_i})}$

Here, θ_f = Limiting temperature = 160 ^oC, and

θ_f = Initial temperature = Maximum operating temperature for conductor = 75^oC

So, K = 111.329

Then Minimum cross section area of conductor = $\frac{\sqrt{(\frac{32000}{2})^2 * 1}}{111.392} = 143.63$ sq-mm,

Which is less than selected 150 sq-mm conductor and acceptable.

Therefore, two parallel single core copper cables of 150 sq-mm with PVC insulation for each pahse, are select to satisfy given requirements.

Problem# 3

A power system is operating at 1200kW at 0.825 PF, how much power factor correction is required to correct to 0.98. Show the power triangle and current before and after correction.

Given parameters:

Operating real power = 1200 kW

Existing Power Factor (PF) = 0.825

Corrected Power Factor (PF) = 0.98

Power Calculations:

Power variations are having frequency that is double of voltage and current frequency. Therefore, graphical representation of power is done as a separate power triangle which nothing but showing real power, reactive power and apparent power in complex plan. Calculation of the three powers is as below:

Before Correction:

Active Power

P = 1200 kW

Apparent Power

S = 1200 / 0.825 = 1454.54 kVA

Reactive Power

$$Q = \sqrt{S^2 - P^2} = \sqrt{1454.54^2 - 1200^2} = 822\ kVAR$$

After Correction:

Active Power

P = 1200 kW

Apparent Power

S = 1200 / 0.98 = 1224.48 kVA

Reactive Power

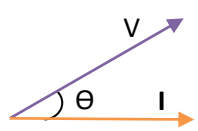
$$Q = \sqrt{S^2 - P^2} = \sqrt{1224.48^2 - 1200^2} = 243.62\ kVAR$$

As it is not clear in given problem that existing and desired power factor are lagging or leading.

Let us assume that exist both power factors are lagging.

Then, Power factor correction required = 0.98 – 0.825 = 0.155 (capacitive)

Figure **1** and Figure 2, shows the power triangle and current directions before and after power factor correction.



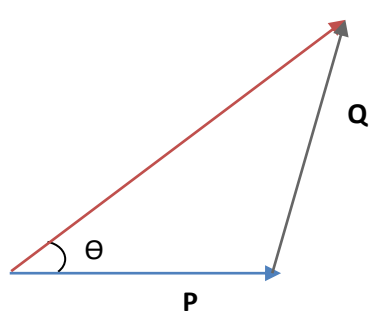
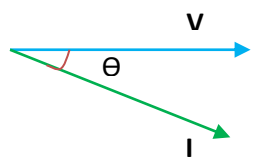


Figure 1: *Power Triangle and Current before power factor correction*



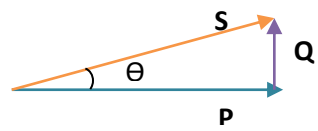


Figure 2: *Power Triangle and Current after power factor correction*

Problem# 4

How many levels of lightning protection are there and what is their efficiency?

Describe the principle of Faraday cage.

Levels of Lightning Protection and their efficiency:

There are four (I to IV) Lightning Protection Levels (LPL) are there with four types of relevant protection measures for the design of Lightning Protection System.

All lightening protection standards advice that it is not possible to achieve a 100% protection of a structure. Several Lightning Protection Levels (LPL) are defined according to the probability that lightning strikes the protected area. This probability is calculated taking into account the minimum values of the lightning peak current that define the Rolling Sphere radius.

Lightening Protection Level (LPL)	Efficiency (ē)
LPL I	**0,95 < ē < 0,98**

LPL II	**0,90 < ē < 0,95**
LPL III	**0,80 < ē < 0,90**
LPL IV	**0 < ē < 0,80**

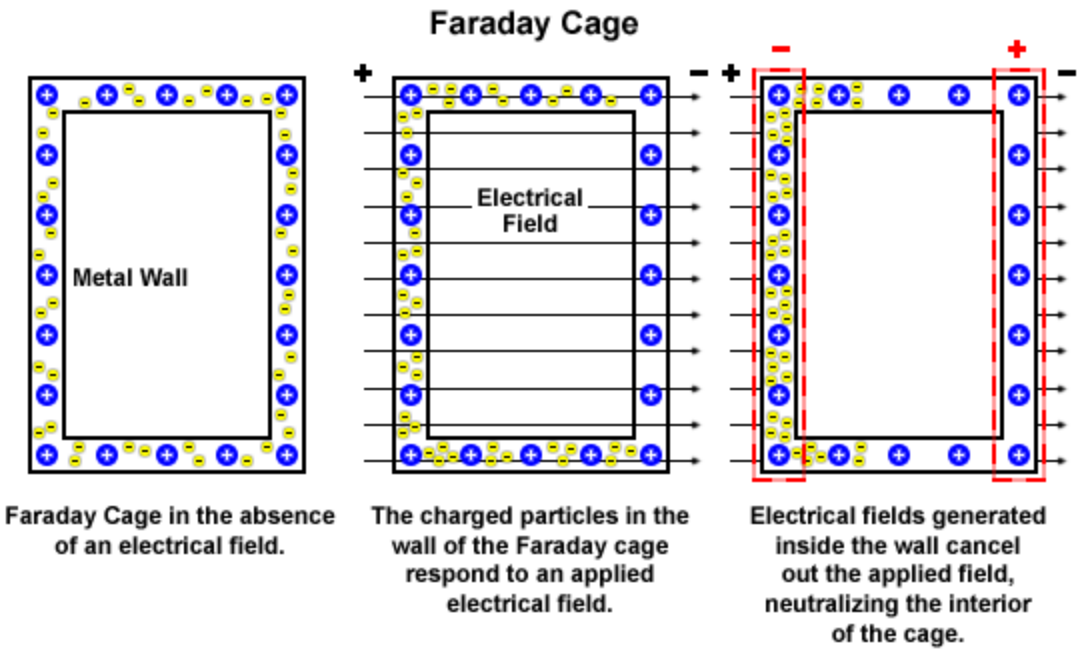
Principle of Faraday Cage:

A Faraday cage is an enclosed conducting shell. It can be a solid conducting shell or a shell made of wire mesh; the important thing is that it completely encloses a region.

This hollow conducting shell will have no electric field inside, even when placed in a very strong external electric field because the charges on the conducting surface rearrange themselves until the electric field inside is zero. A Faraday cage also works in reverse. If there is a strong electric field inside, the field outside the cage will be zero.

This Faraday cage effect causes Faraday cages to act as shields for strong electric fields or other electrical effects. In addition electromagnetic waves consist of oscillating electric and magnetic fields. Therefore Faraday cages effectively shield electromagnetic waves or electromagnetic radiation as long as the holes in the wire mesh are significantly smaller than the wavelength of the electromagnetic waves.

For this reason Faraday cages are sometimes called Faraday shields.



Problem# 5

Describe what is meant by the following: (i) IP22, (ii) IP44, and (iii) IP65

IP (Ingress Protection) Rating for Equipment and Enclosures and it's followed by two digits. A two-digit number (as specified in Australian Standards AS60529 and EN60529) is used to provide an IP Rating to a piece of electronic equipment or to an enclosure for electronic equipment.

The two digits represent different forms of environmental influence:

The first digit represents protection against ingress of solid objects

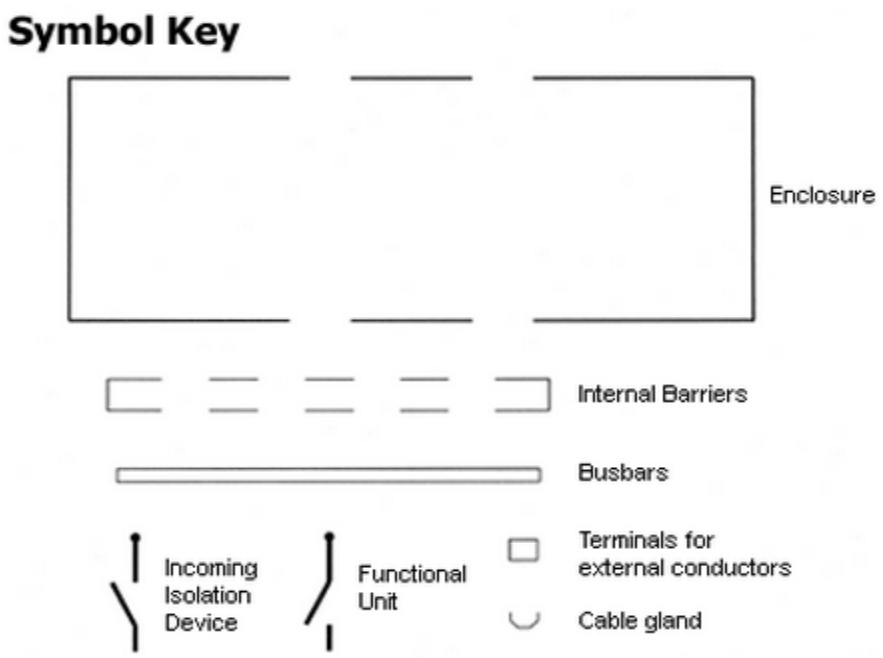
The second digit represents protection against ingress of liquids

Protection Level	First Digit (Protection against ingress of solids)	Second Digit (Protection against ingress of liquids)
IP22	Protected against solid objects over 12mm e.g. hands, large tools	Protected against direct sprays of water up to 15° from vertical.

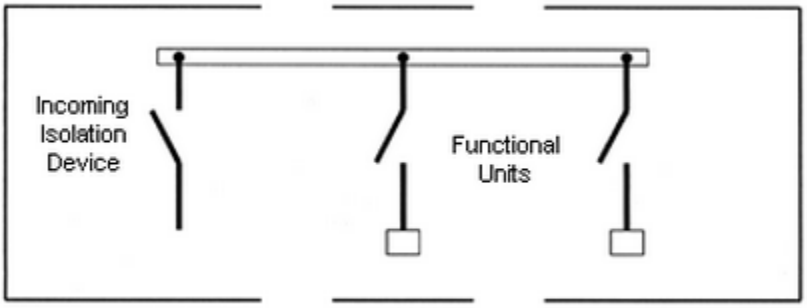
IP44	Protected against solid objects over 1.0mm e.g. wires	Protected against water sprayed from any direction. Limited ingress permitted.
IP65	Totally protected against dust ingress.	Protected against low pressure water jets from any direction. Limited ingress permitted.

Problem# 6

Provide a sketch showing a from1 and form3 & form4a construction.

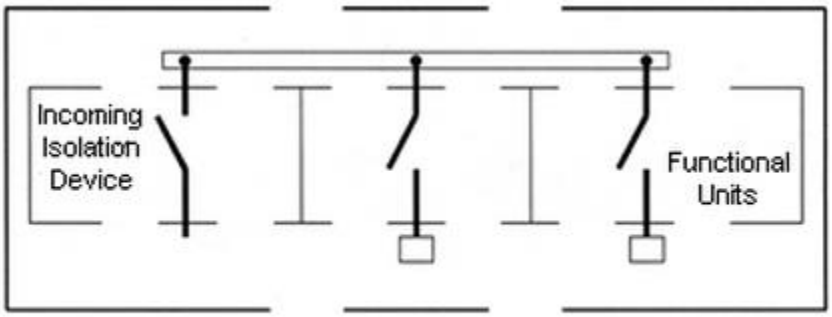


- **Form1:**



No internal separation - This form construction is rarely used.

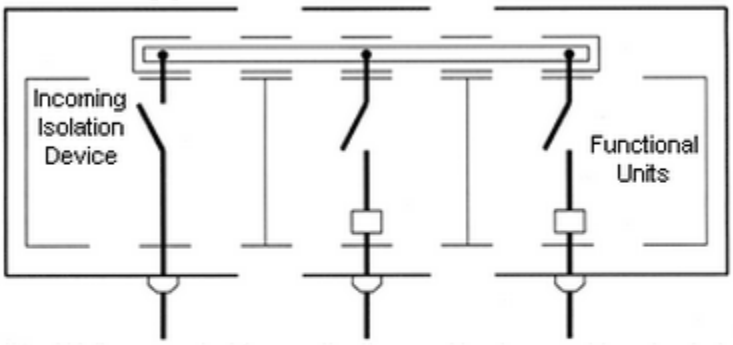
- ## Form 3a :



Functional Units separated from each other, terminals, and busbars, but terminals NOT separated from busbars.

- ## Form 4a (Type1 and 2, Type3):

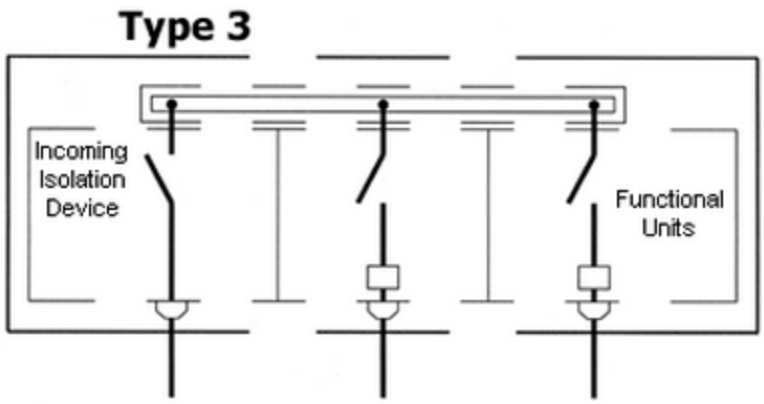
Type 1 and 2



Functional Units separated from eath other, and busbars, cables glanded elsewhere. Terminals associated with Functional Units, to be located in the same compartment as the Functional Unit.

Type 1 - Separation by insulated coverings.

Type 2 - Separation by metallic, or non-metallic rigid barriers.



Functional Units separated from each other, and busbars, cables glanded on the Functional Unit compartment. Terminals associated with Functional Units to be located in the same compartment as the Functional Unit.
Separation by metallic, or non-metallic rigid barriers.

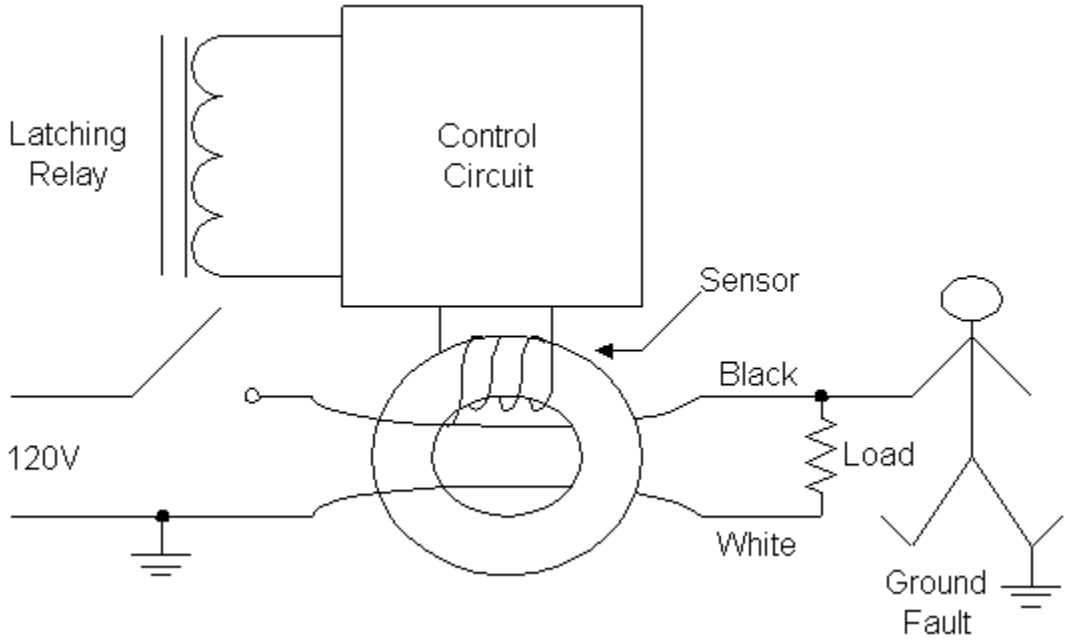
Problem# 7

An RCD can be defined as, A mechanical switching device or association of devices intended to cause the opening of the contacts when the residual current attains a given value under specified conditions'. An RCD is a protective device used to automatically disconnect the electrical supply when an imbalance is detected between live conductors. In the case of a single-phase circuit, the device monitors the difference in currents between the phase and neutral conductors.

In a healthy circuit, where there is no earth fault current or protective conductor current, the sum of the currents in the phase and neutral conductors is zero. If a phase to earth fault develops, a portion of the phase conductor current will not return through the neutral conductor. The device monitors this difference, operates and disconnects the circuit when the residual current reaches a preset limit, the residual operating current. RCDs are used to provide protection against the specific dangers that may arise in electrical installations including:

- protection against indirect contact
- supplementary protection against direct contact

- protection against fire and thermal effects



As shown in Figure blow, when the phase and neutral (black and white wires) currents are same, RCD core would have not any magnetic flux and no voltage will be sent to Control Circuit. But as soon as there is a phase to ground fault such a human touching phase wire, it would generate voltage in control winding. Control Circuit will detect the fault condition and signal will be given to latching relay coil to be opened. It would save human from the potential danger.

Problem# 8

Earth loop impedance is the path followed by fault current when a fault occurs between the phase conductor and earth, i.e. "earth fault loop". Fault current is driven round the loop by the supply voltage. The higher the impedance, the lower the fault current will be and the longer it will take for the circuit protection to operate.

To make sure the protection operates fast enough; the loop impedance must be low. Every circuit must be tested to make sure that the actual loop impedance does not exceed that specified for the protective device concerned. It is recommended that the Earth loop impedance test be done first. This test, done at the distribution board, gives the loop impedance of the circuit, excluding the installation.

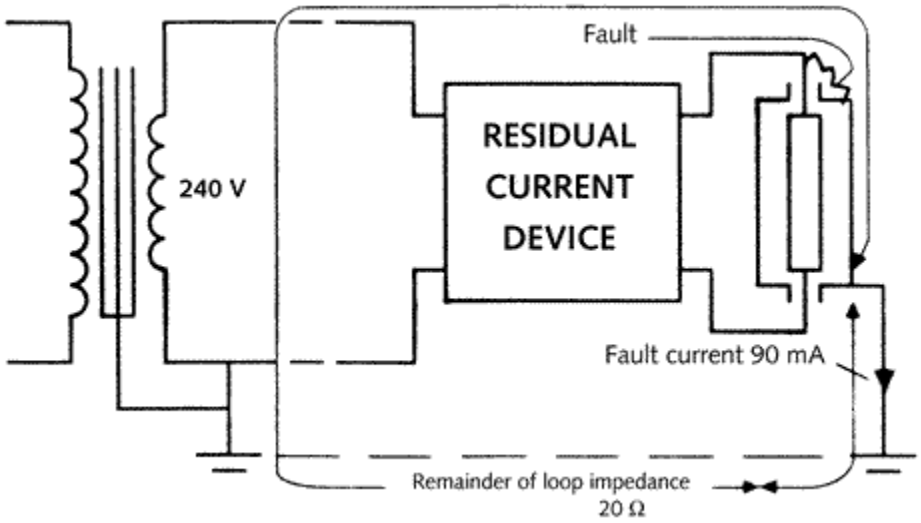


Figure above show an Earth fault occurred at phase wire. If a 90 mA current flows from fault to Earth. Then for a 20 Ohm resistance potential of Earth will be 1.8V (=0.09 x 20). But if Earth loop impedance is high, let us say 1000 Ohm. Then earth voltage will be 90V (=0.09 x 1000), which is a dangerous voltage.

Therefore higher the impedance of Earth Loop will result in:

- Low fault current, so no fault detected from protection devices.
- High voltage of earth

Problem# 9

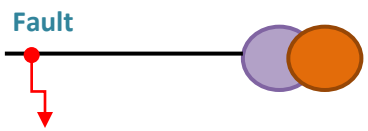
Calculate the fault level at each of the following,

(i) Fault level on HV side is 175MVA

(ii) Transformer 2,000 kVA 11kV/400V with 4.25% impedance

(iii) 90m 3No 400mm2 XLPE/PVC cables per phase

(i) Fault level on HV side is 175MVA

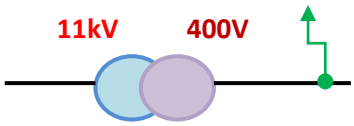


Fault MVA level = 175 MVA
Voltage = 11kV
If fault level current = y kA

Then $\sqrt{3} * 11\ kV * y\ kA = 175\ MVA$

y = $\frac{175}{\sqrt{3} * 11} = 9.185\ kA$

(ii) Transformer 2,000 kVA 11kV/400V with 4.25% impedance



MVA Capacity = 2 MVA

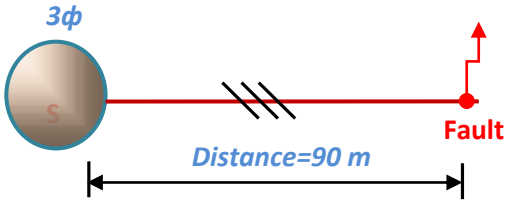
Fault MVA = $\frac{2}{4.25/100} = 47.05\ MVA$

If fault level current = x kA

Then $\sqrt{3} * 11\ kV * x\ kA = 47.05$

x = $\frac{47.05}{\sqrt{3} * 11} = 2.26\ kA$

(iii) 90m 3No 400mm2 XLPE/PVC cables per phase



For a 3 phase system fault level current in each phase = $\frac{Vphase}{Z}$
Where Vphase = Phase Voltage and Z = Line Impedance

Vphase = $\frac{400}{\sqrt{3}}$ **= 230.94 V**

Z = $\sqrt{R^2 + X^2}$

Lets assign conductor temperature = 75 DegC (maximum operating temp.)
Then for 400 mm2 copper conductor Rs = 0.063 Ω/km

R = Rs x $\frac{90}{1000}$ **= .063 x 0.09 = 0.00567 = 5.67 mΩ and**

Xs = 0.074 Ω/km

So X = 0.074 x $\frac{90}{1000}$ **= 0.074 x 0.09 = 6.66 mΩ**

Z = $\sqrt{0.00567^2 + 0.00666^2} = 38.25\ \mu\Omega$

Fault Current in each Phase = $\frac{230.94}{38.25*10^{-6}} = 6.03 * 10^6\ Amp$