EARTHING SYSTEM & EARTH FAULT LOOP IMPEDANCE

PRESENT BY – U WIN MYINT
B.E (EP) 1977
National Counterpart (049)
Professional Engineer {Registration No. (0125)}
Asean Chartered Professional Engineer (Electrical)

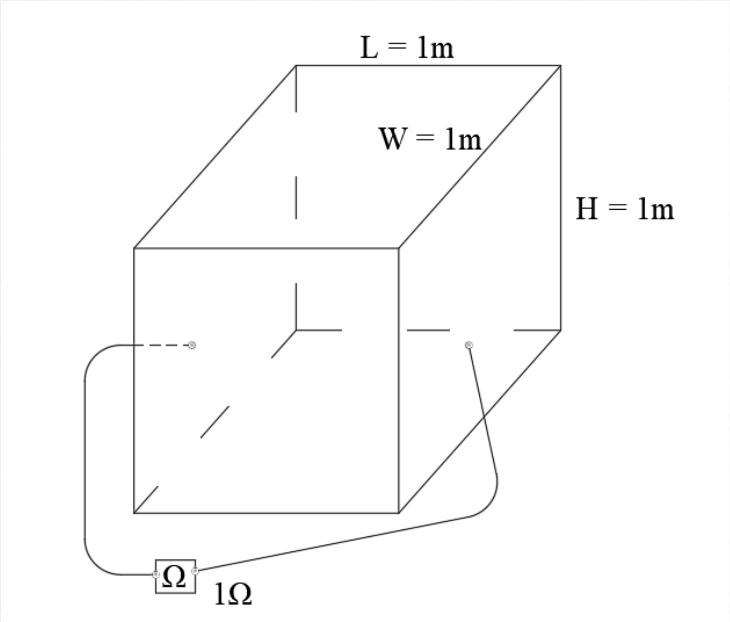
Date – 6th JULY, 2024
Location - MES

Course Outlines

1. Soil Resistivity and Assuming Earth is Zero Potential
2. Earth Fault Protection
3. Method of System Earthing
4. Installation Earthing
5. Neutral Earthing
6. TT Earthing System
7. TN-S Earthing System
8. Touch Voltage Concept
9. Comparison of Touch Voltage – TT & TN-S System
10. Exposed Conductive Part
11. Extraneous Conductive Part
12. Main Equipotential Bonding Conductor
13. Circuit Protective Conductors (CPC)
14. CPC for Final Circuit and Submains
15. Supplementary Bonding Conductor
16. Sizing of Main Earth Cable TT System
17. Sizing of Main Earth Cable TN-S System
18. Main Earth Bar

1. SOIL RESISTIVITY

Soil	Resistivity Ohm.m
Marshy Ground	2-2.7
Loam and Clay	4-150
Chalk	60-400
Sand	90-800
Peat	200Upward
Sandy Gravel	300-500
Rock	1000 Upward

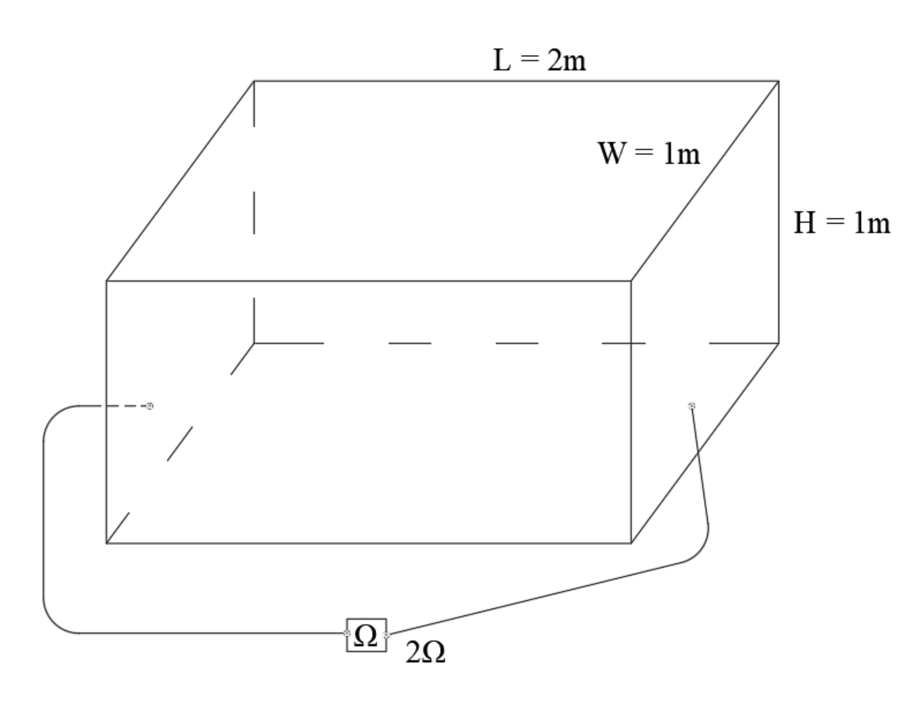


$$R = \frac{\rho \times L}{A}, \ \rho = 1\ \Omega\text{-m}$$

$$L = 1\ m$$

$$A = W \times H = 1m^2$$

$$R = \frac{1 \times 1}{1 \times 1} = 1\Omega$$

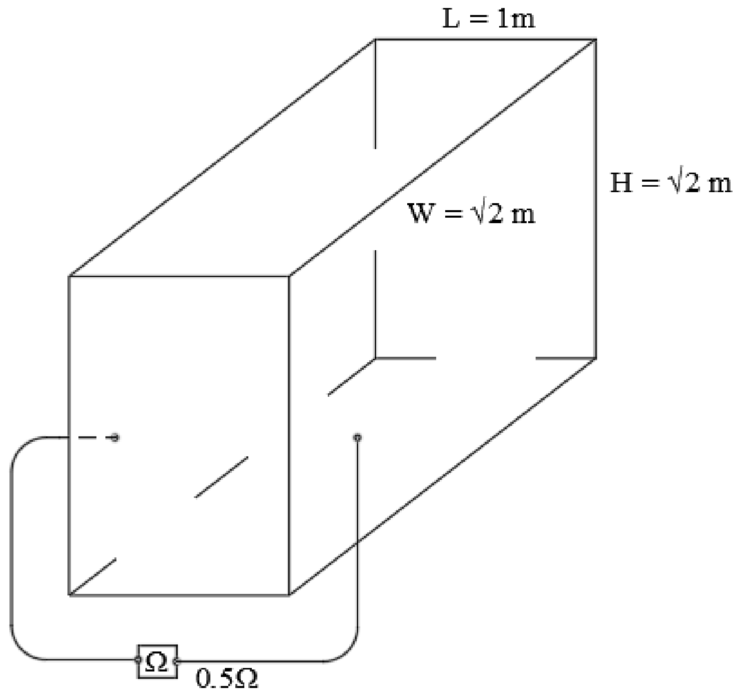


$R = \frac{\rho \text{ x } L}{A}$, $\rho = 1\ \Omega\text{-m}$

$L = 2$ m

$A = 1 \text{ x } 1 = 1m^2$

$R = \frac{1 \text{ x } 2}{1} = 2\Omega$



$R = \frac{\rho \times L}{A}$, $\rho = 1\ \Omega\text{-m}$

$L = 1\ m$

$A = \sqrt{2} \times \sqrt{2} = 2m^2$

$R = \frac{1 \times 1}{2} = 0.5\Omega$

$\rho = 1\ \Omega\text{-m}$

$L = 100\ m$

$A >> L$

$R = \frac{\rho \times L}{A} \approx \frac{10^5}{10^{10}} \approx 1 \times 10^{-5} \approx 0$

2. EARTH FAULT PROTECTION

- The earth is a huge conductor which can be considered to be at reference or zero potential.
- Human beings are normally in direct contact with this earth. Any metal parts which become charged with respect to earth may cause a hazard or “electric shock” if touched by a human body.
- The purpose of earthing is to link together all metalwork, except the live conductor, to the earth potential so that there is no excessive potential differences, either between different metal parts or between any metal parts and earth.

3. METHOD OF SYSTEM EARTHING

- An electric system can also be designed as an unearthed system, i.e. with the neutral of the system isolated from earth.
- During a line-to-earth fault, as the neutral of the system is unearthed, no fault current will flow from the system.
- The advantage of such an unearthed system is its ability to continue operations during a line-to-ground fault. It will not result in the automatic tripping of the circuit. Thus, the unearthed system offers an added degree of service continuity.

- However, as the system is unearthed and no fault current flows during a line-to-ground fault, the faulty phase will then take the earth voltage.
- As a result, the magnitude of the voltage between each healthy line to earth is equal to the line-to-line voltage. This causes a rise in voltage on the other two healthy phases of approximately √3 of the voltage between each phase to ground.
- In other words, the other two phase conductors throughout the entire system are subjected to 73% overvoltage. This additional voltage stress may produce insulation breakdown in the circuits, especially machine windings and other voltage sensitive equipment.

4. INSTALLATION EARTHING

The earthing for electrical installations and electrical equipment are to meet the following objectives:

- To maintain, as close as possible, the voltage on the exposed-conducive parts of electrical equipment and electrical appliances at “Earth Potential” so as to provide protection against electric shock.

- To enable the phase to earth fault current to flow and return safely to its source via a properly designed low impedance path, so that the protection devices can operate expeditiously for automatic disconnection to cut-off the electricity supply.

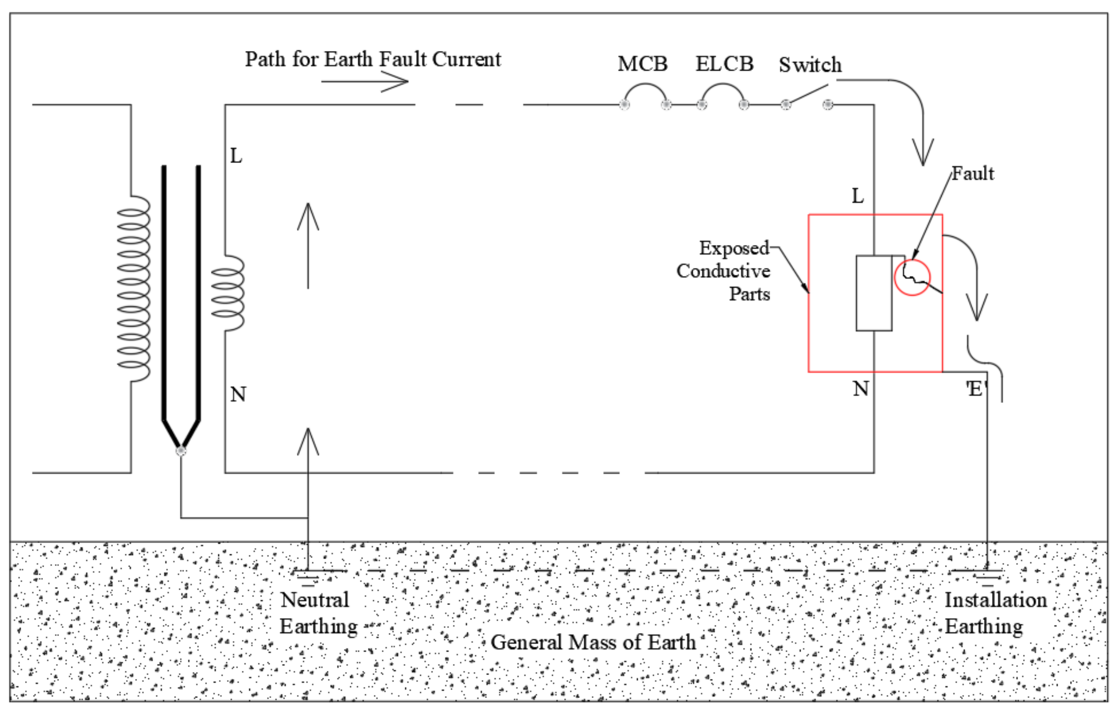


Figure (4.1)

5. NEUTRAL EARTHING

The earthing for the star point (or Neutral point) of the star windings of a H.V/L.V distribution transformer (DY11) are to meet the following objectives:

a) To maintain, as close as possible, the voltage on the neutral point and neutral conductors of the electrical installation at “Earth Potential”.

b) To enable the safe return of phase to earth fault current to the star point (or Neutral point) of the star windings of the distribution transformer.

6. TT EARTHING SYSTEM

a) TT earthing system is used when consumers receive electricity supply at 400V/230V.

b) As the distribution transformer is installed on the power supply company side, Neutral earthing electrode system is installed at the power supply company's substation.

All exposed-conductive parts of an installation are connected to an earth electrode which is electrically independent of the source earth.

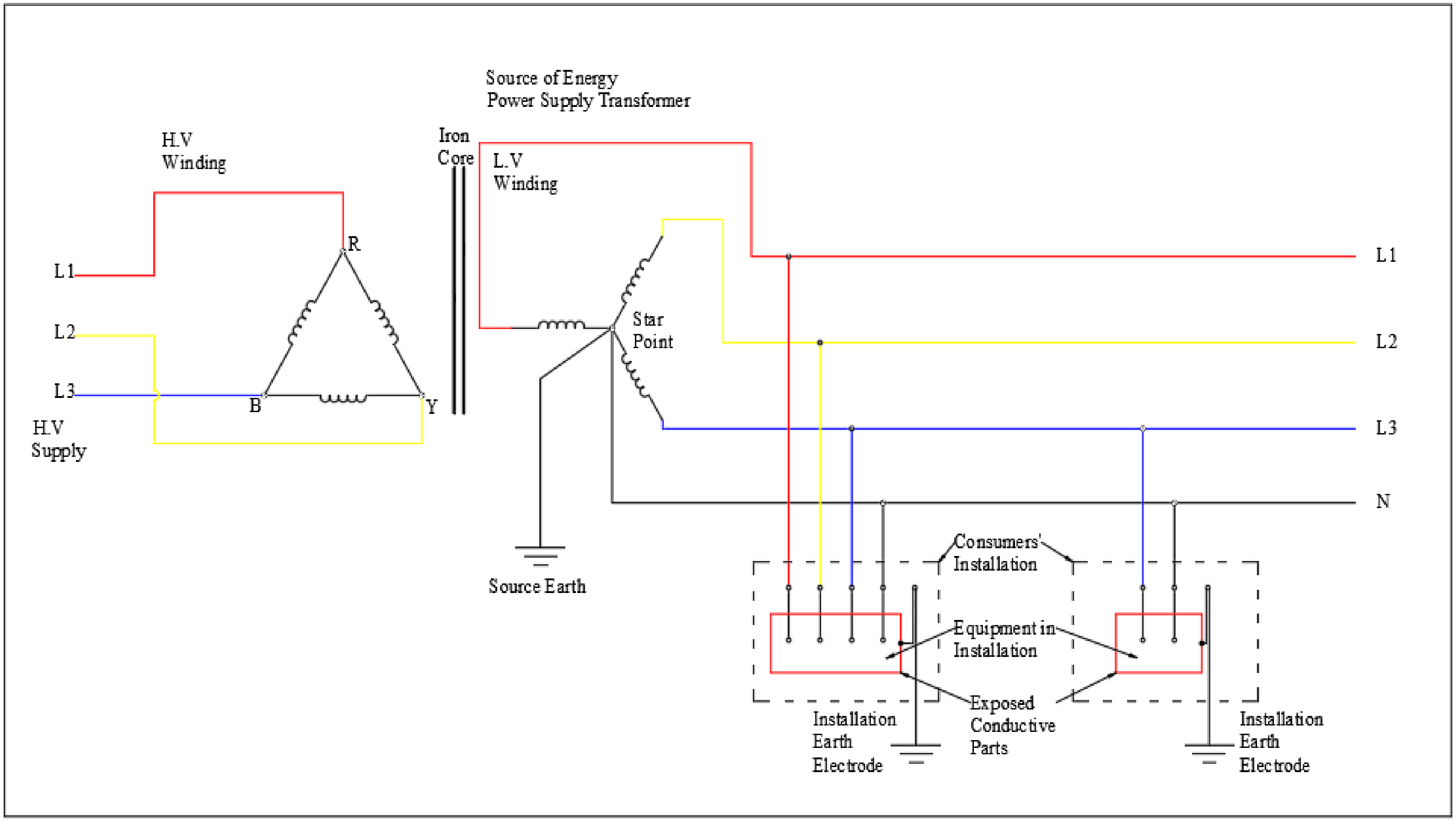


Figure 6.1 TT Earthing System

c) Earth fault loop impedance of TT earthing system as shown in figure 6.2 is given as

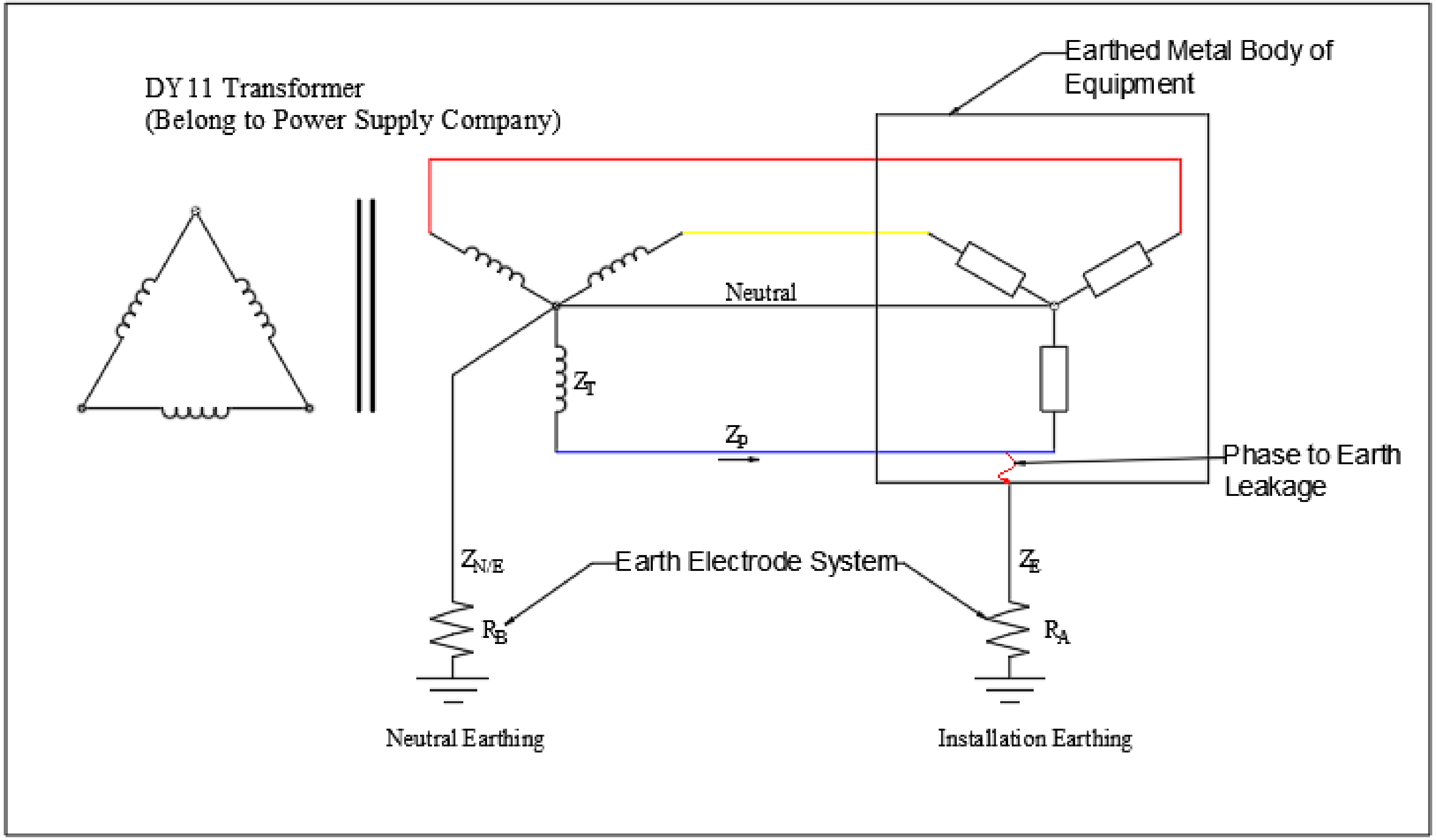


Figure 6.2 TT Earthing System

$$\mathbf{Z_{ELFI} = Z_T + Z_P + Z_E + (R_B + R_A) + Z_{N/E}}$$
$$\mathbf{\approx (R_B + R_A)}$$

where

Z_T =Transformer winding impedance

Z_P =Phase conductor's impedance

Z_E =Earth conductor's impedance

$Z_{N/E}$=Neutral to Earth conductor impedance

R_A=Installation earth electrode resistance

R_B=Neutral earth electrode resistance

Note:

Earth Fault Loop Impedance is defined as the total impedance in the path of the phase to earth fault current.

Therefore, $I_{E/F} = \frac{V_{ph}}{Z_{EFLI}}$

$$= \frac{V_{ph}}{Z_T + Z_P + Z_E + (R_A + R_B) + Z_{N/E}}$$

$$= \frac{V_{ph}}{R_A + R_B}$$

$$I_{E/F} = \frac{230V}{R_A + R_B} = \frac{230V}{1\Omega + 1\Omega} = 115A \text{ to } 120A$$

If $R_A = R_B = 1\Omega$

& $I_{E/F} = \frac{230V}{R_A + R_B} = \frac{230V}{0.1\Omega + 0.1\Omega}$ = 1150A to 1200A

If $R_A = R_B = 0.1\Omega$

As the phase to earth fault current has to pass through the two electrode systems in TT system, the Earth fault current $I_{E/F}$ is limited by R_A & R_B.

d) As a result of the flow of earth leakage current and earth fault current to the electrode system, there would be an earth potential rise may be as high as 120V:

$I_{E/F} \times R_A = 120A \times 1\Omega = 120V$

(or)

$I_{E/F} \times R_A = 1200A \times 0.1\Omega = 120V$

7. TN-S EARTHING SYSTEM

a) TN-S earthing system is used when the consumers receive electricity supply at high voltage (33kV, 11kV or 6.6kV) supply in Myanmar.

b) As the distribution transformers are installed on the consumer side, system neutral earthing and installation earthing (i.e. safety earthing for consumer's electrical equipment) share the same electrode system.

The protective conductor (PE) is the metallic covering of the cable supplying the installations or a separate earth conductor.

All exposed-conductive parts of an installation are connected to this protective conductor via the main earthing terminal of the installation.

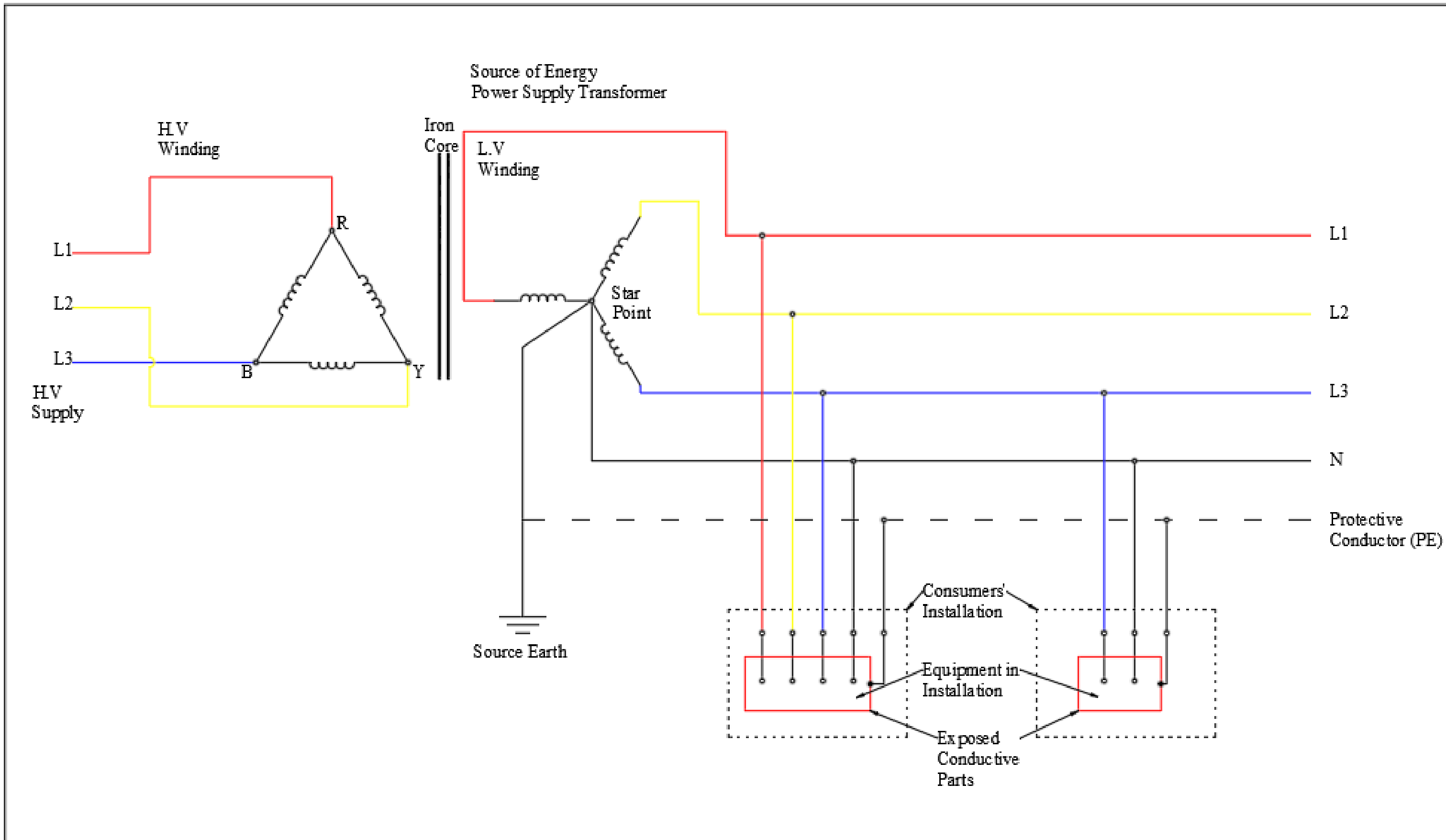


Figure 7.1 (a) TN-S Earthing System

c) Earth fault loop impedance of TN-S earthing system does not include any of the earth electrode system;

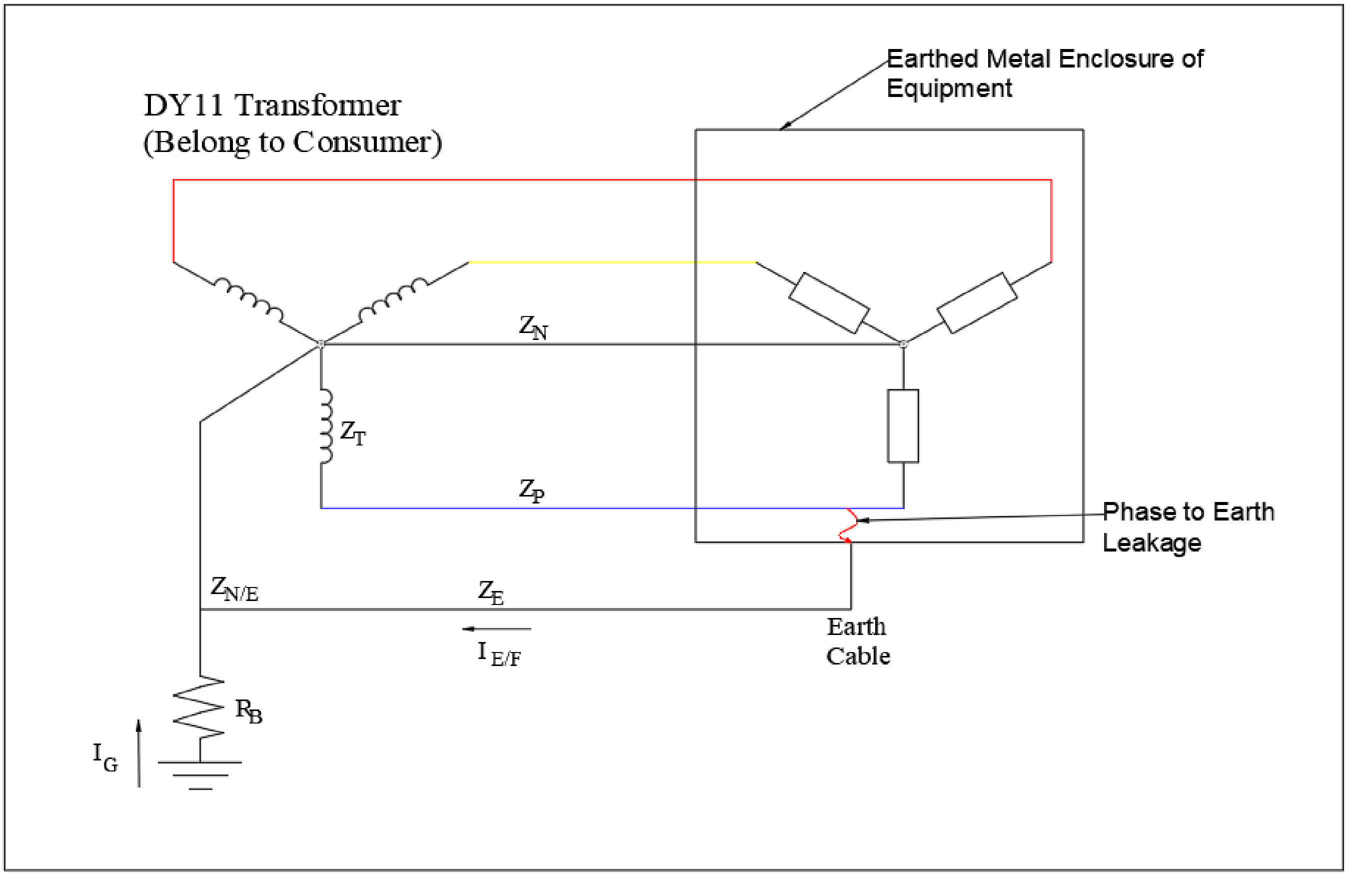


Figure 7.1 (b) TN-S Earthing System

$\mathbf{Z_{ELFI} = Z_T + Z_P + Z_E + Z_{N/E}}$

where

Z_T =Transformer winding impedance

Z_P =Phase conductor's impedance

Z_E =Earth conductor's impedance

$Z_{N/E}$=Neutral to Earth conductor impedance

Note that earth electrode resistance R_B for neutral earthing is not included in the $\mathbf{Z_{ELFI}}$ formula.

Therefore, Phase to Earth Fault current,

$$I_{E/F} = \frac{V_{ph}}{Z_{EFLI}}$$

$$= \frac{V_{ph}}{Z_T + Z_P + Z_E + Z_{N/E}}$$

Ground Potential rise or Earth Potential rise at earth electrode terminal = $I_g x R_B = 0 Volt$

Ground Potential rise or Earth Potential rise at metal enclosure= $I_{E/F}$ x Z_E

8. TOUCH VOLTAGE CONCEPT

a) Two forms of electric shocks are recognized:
   i. Direct Contact
   ii. Indirect Contact

b) The touch voltage concept is concerned with "Indirect Contact". It is used to determine the magnitude of voltage to which the person at risk would be subjected to in the event of an earth fault occurring in an installation.

c) One often hears or reads the statement that provided an item of electrical equipment is properly earthed, it is not possible for a person to receive an electric shock in the event of a fault.

The touch voltage concept shows that such a statement to be totally incorrect.

d) The connection of all exposed conductive parts to Earth terminal of the installation leads to the creation of ‘touch voltage’ in the event of an earth fault and hence, to the shock risk.

e) The protective measure is automatic disconnection of supply. In the event of an earth fault, the speed of disconnection should be such that if the person at risk experiences an electric shock, it will not be a harmful one.

9. COMPARISON OF TOUCH VOLTAGE – TT & TN-S SYSTEM

Example 9.1

TT Earthing System

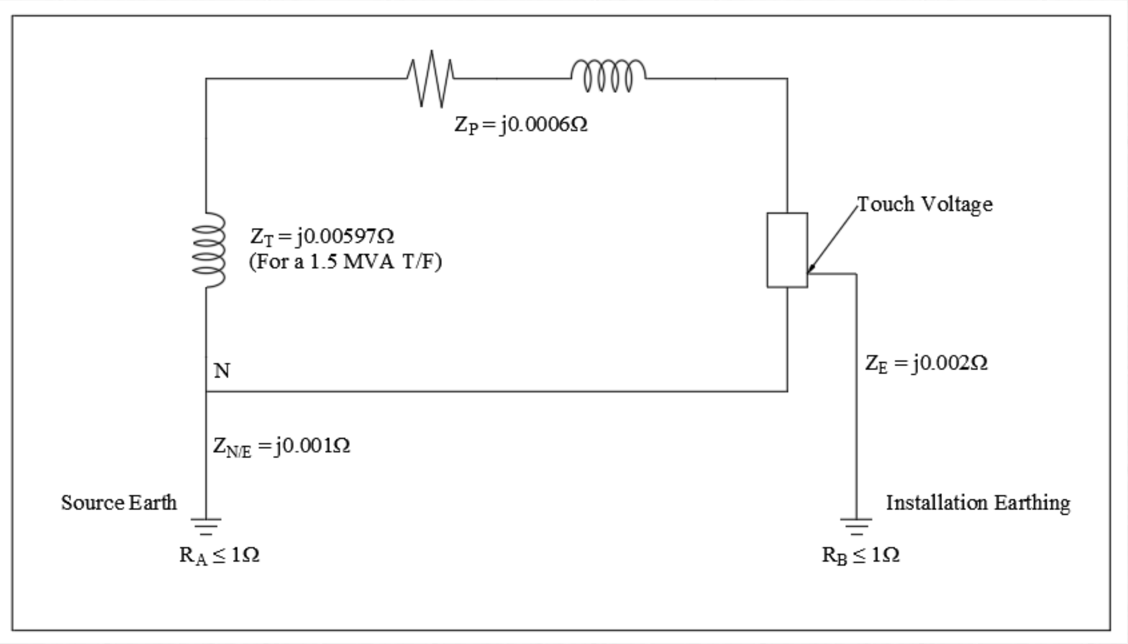


Figure 8.1 (a)

Earth Fault Loop Impedance is

$Z_S = Z_T + Z_P + Z_E + (R_B + R_A) + Z_{N/E}$

$\approx (R_B + R_A) \approx (1+1)\Omega$

Therefore, $I_{E/F} = \frac{230}{(1+1)\Omega}$ =120A

Therefore, Touch Voltage = $I_{E/F} \times (Z_E + R_B)$ = 120A x 1Ω

= 120V

Example 9.2

TN-S Earthing System

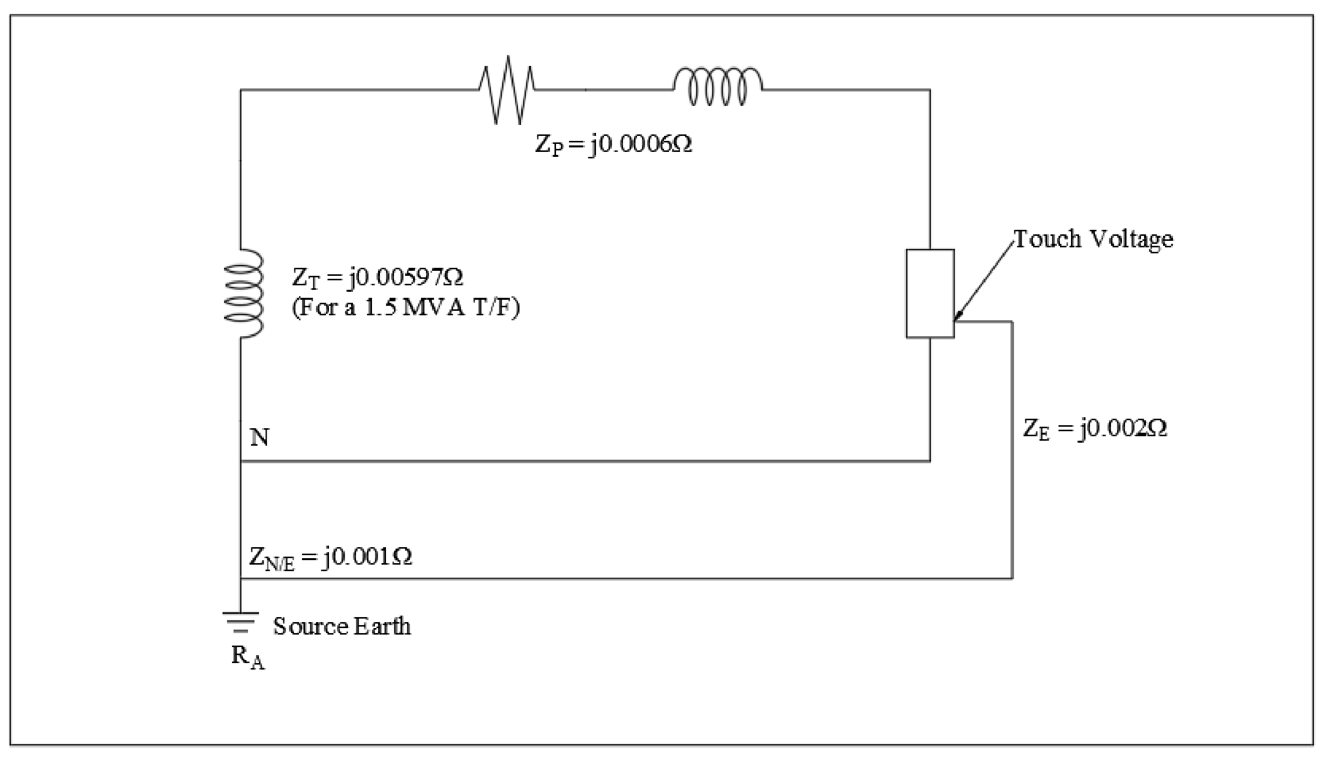


Figure 8.1 (b)

Earth Fault Loop Impedance is

$Z_S = Z_T + Z_P + Z_E + Z_{N/E}$

$= j(0.00597 + 0.0006 + 0.002 + 0.001) = j0.00957$

Therefore, $I_{E/F} = \frac{230}{0.00957} = 24033\ A$

Touch Voltage = $I_{E/F} \times (Z_E) = 24033A \times 0.002\Omega$

$= 48V$

10. EXPOSED CONDUCTIVE PART

Exposed Conductive Part is defined as a conductive part of electrical equipment which can be touched and which is not a ‘Live’ part but which may become live under fault conditions.

Exposed conductive parts of electrical installation essentially include:

i. Metallic Enclosure of electrical equipment & electrical appliances
ii. Metallic Enclosure of electrical Switchboard (MB & SB) & Distribution Boards (DB)

iii. Metallic cable tray & cable trunking

- Connection of cable tray & cable trunking are considered as <u>earthing</u> for electrical safety and not <u>bonding</u>.

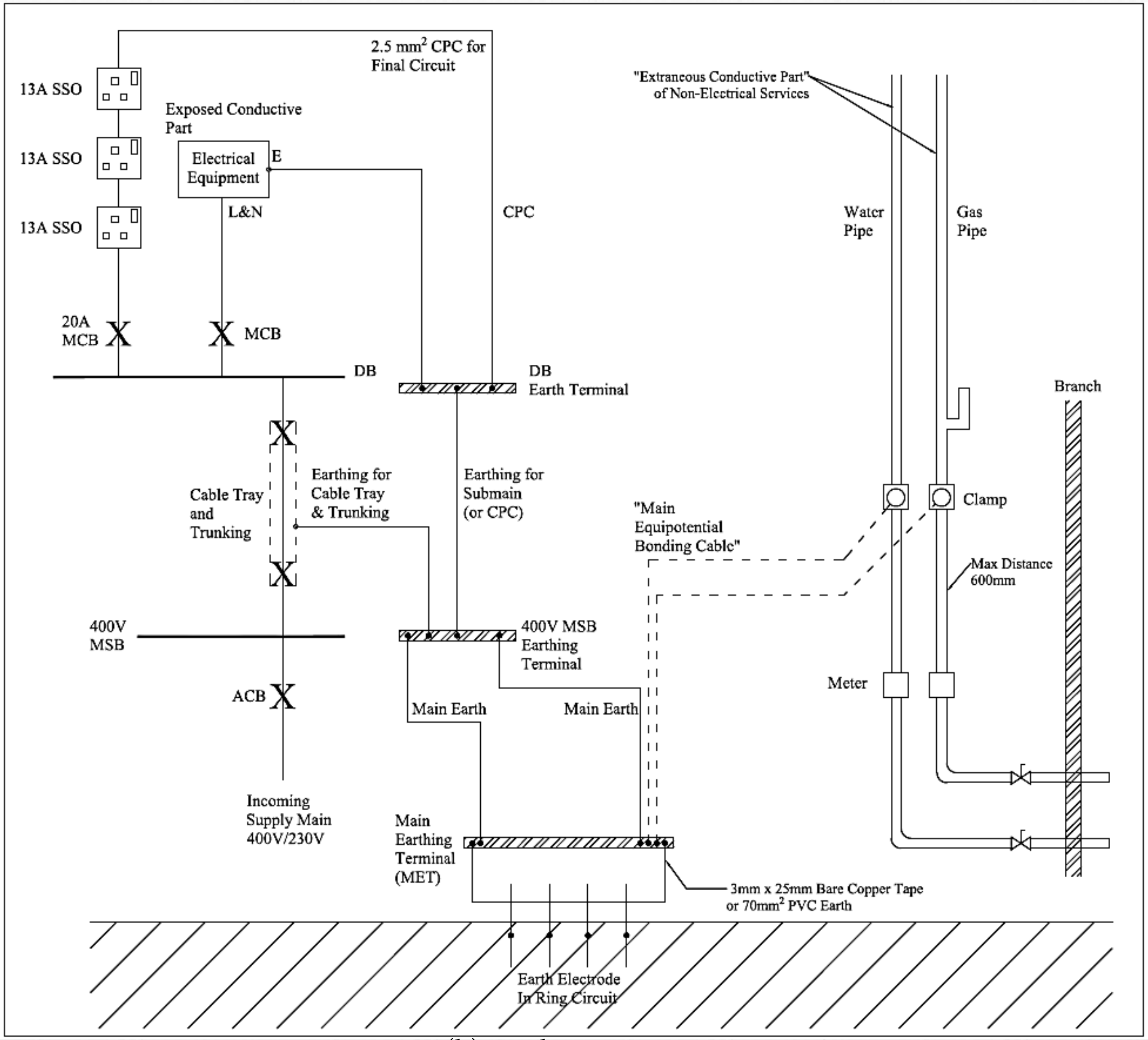


Figure 10.1 (b) Earthing Arrangement TT System

11. EXTRANEOUS CONDUCTIVE PART

Extraneous conductive part is defined as a conductive part of non-electrical services which does not form part of the electrical installation, but is likely to introduce an earth potential.

Extraneous Conductive Parts in the buildings include non-electrical services such as:

i. Water pipes & gas pipes
ii. Air-conditioning ducting
iii. Fire protection, wet risers and sprinkler piping

As there extraneous conductive parts form a separate earthing system in the building and introduce an earth potential, it is possible that a person could simultaneously touch the exposed conductive part and the extraneous conductive part which may introduce a potential difference especially when the electrical equipment develops a fault and becomes ‘live’ or partially ‘live’.

12. MAIN EQUIPOTENTIAL BONDING CONDUCTOR

- To eliminate or minimize the potential difference that may exit between exposed conductive part and extraneous conductive part.
- A bonding conductor is used to connect the extraneous conductive part such as a water pipe & gas pipe to the Main Earthing Terminals(MET) of the electrical system to create an equipotential zone.
- This is known as main equipotential bonding as shown in Figure 12(b).

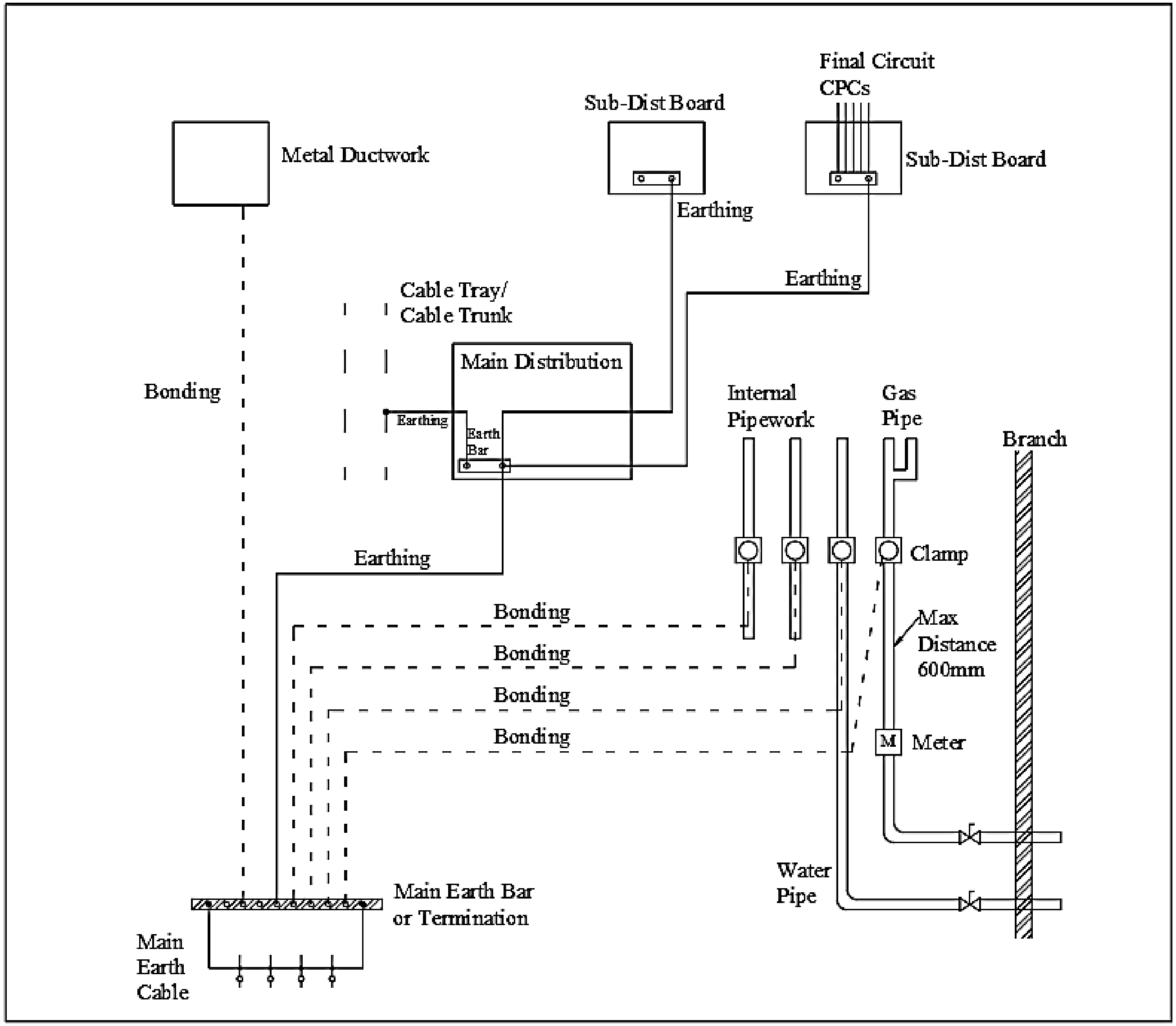


Figure 12(a) Earthing & Main Equipotential Bonding

13. CIRCUIT PROTECTIVE CONDUCTORS (CPC)

Circuit protective conductor (CPC) is defined as a protective conductor connecting exposed-conductive-parts of electrical equipment to the main earthing terminal.

Size of earth cable on circuit protective conductors (S mm^2) may be determined by the formula given as follows:

$$K^2S^2 \geq I_{E/F}^2\, t \quad \text{(OR)} \quad S = (I_{E/F}\sqrt{t}) / K$$

where: S is the nominal cross-sectional area of the conductor in mm^2.

$I_{E/F}$ is the value in amperes (r.m.s. for a.c.) of fault current for a fault of negligible impedance, which can flow through the associated protective device, due account being taken of the current limiting effect of the circuit impedances and the limiting capability of that protective device.

t is the operating time of the disconnecting device in seconds corresponding to the fault current/amperes.

k is a factor taking account of the resistivity, temperature coefficient and heat capacity of the conductor material, and the appropriate initial and final temperatures.

13.(a) Table 3.7 Values of k for calculation of the effects of fault current

Conductor	Insulation	Q_1 ˚C	Q_F ˚C	k
Copper	PVC	70	160	115
	PVC*	70	140	103
	PVC	30	160	143
	PVC*	30	140	133
	Rubber	85	220	134
	XLPE	90	250	143
Aluminium	PVC	70	160	76
	PVC	30	160	95
Steel	PVC	30	160	52
Bare Copper	-	30	200	159
Bare Aluminium	-	30	200	105

*For conductors larger than $300mm^2$

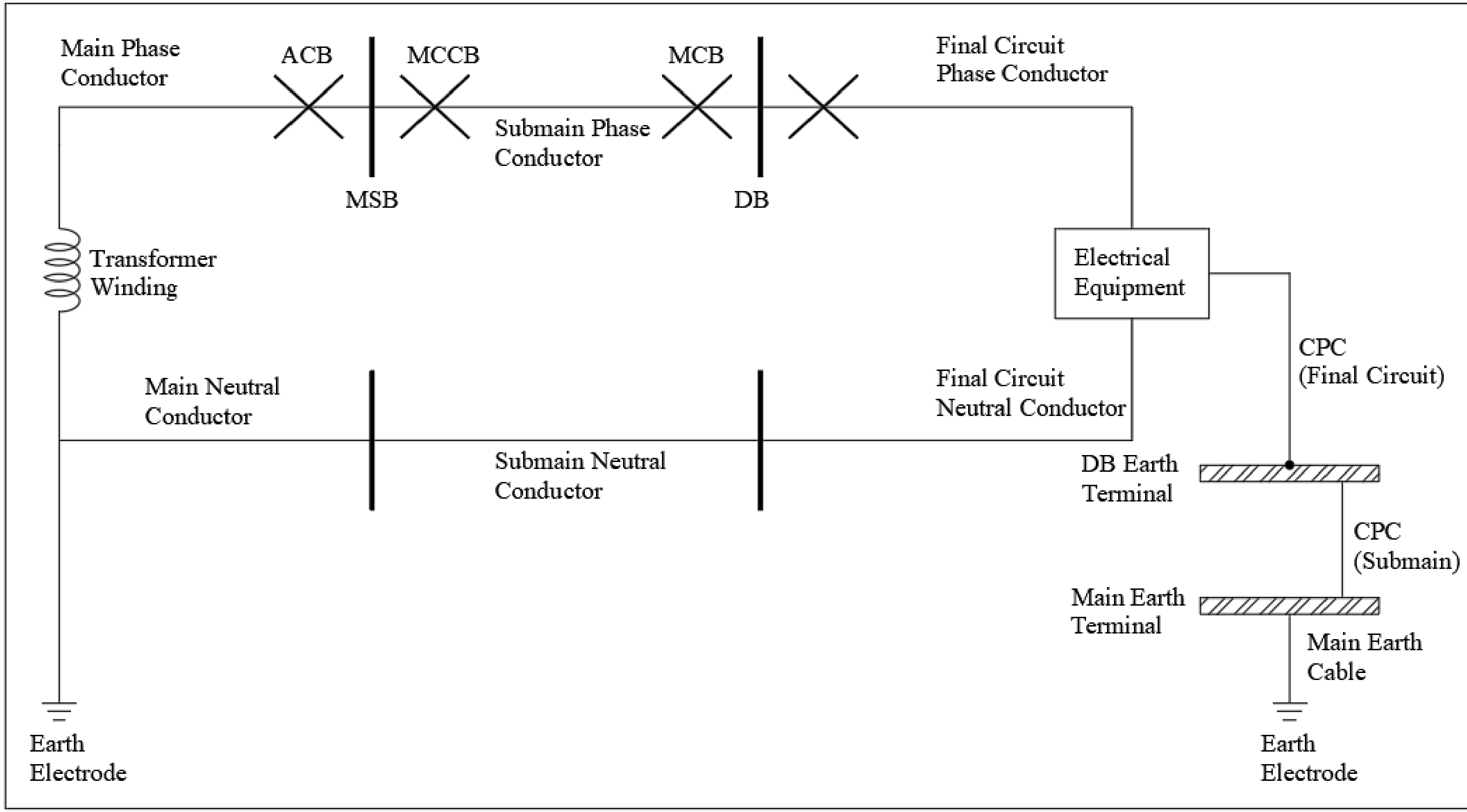


Figure 13(b) CPC and Main Earth Cable in a TT Earthing System

14. CPC FOR FINAL CIRCUIT AND SUBMAINS

Size of CPC in Relation to the Size of Phase Conductor

Phase conductor size (S), mm^2	Minimum CPC size, mm^2
$S \leq 16$	S
$16 < S \leq 35$	16
$S > 35$	S/2

Minimum cross-sectional area of CPC in relation to cross-sectional area of phase conductors

15. SUPPLEMENTARY BONDING CONDUCTOR

Supplementary bonding may be required at locations of increased electric shock risk as shown in Figure.

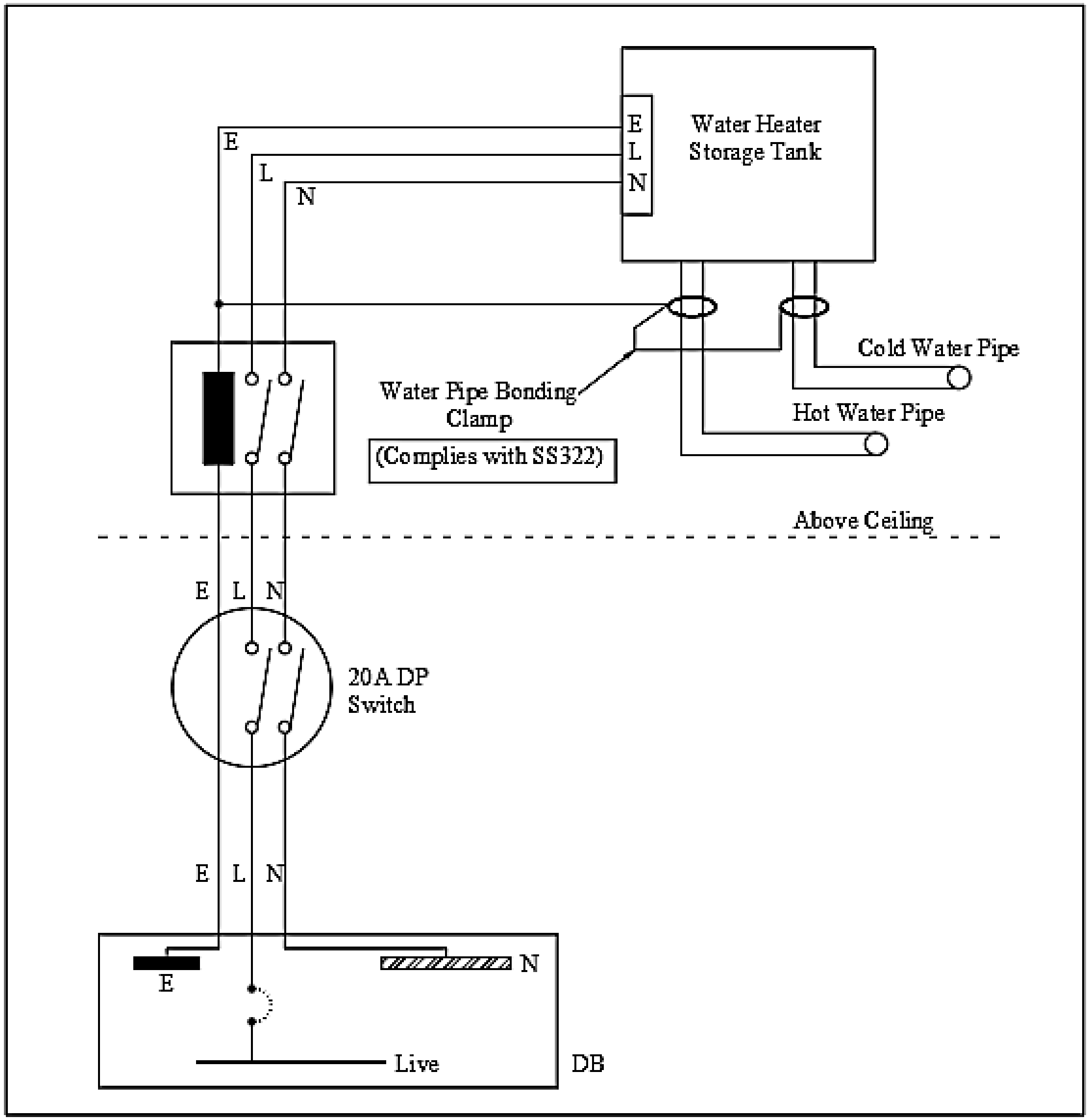


Figure 15 (a) Supplementary bonding of hot water pipe of water heater

Table 1 – Cross sections for equipotential bonding conductors

	Main equipotential bonding	Supplementary equipotential bonding	
Normal		between two bodies	1 x cross section of the smaller protective conductor
		between a body and an extraneous conductive part	0.5 x cross section of the protective conductor
Minimum	6 mm^2	with mechanical protection	2.5 mm^2 Cu or equivalent conductivity
		without mechanical protection	4 mm^2 Cu or equivalent conductivity
Possible limit	25 mm^2 Cu or equivalent conductivity	–	–

16. SIZING OF MAIN EARTH CABLE - TT SYSTEM

(i) At the Main Switchboard

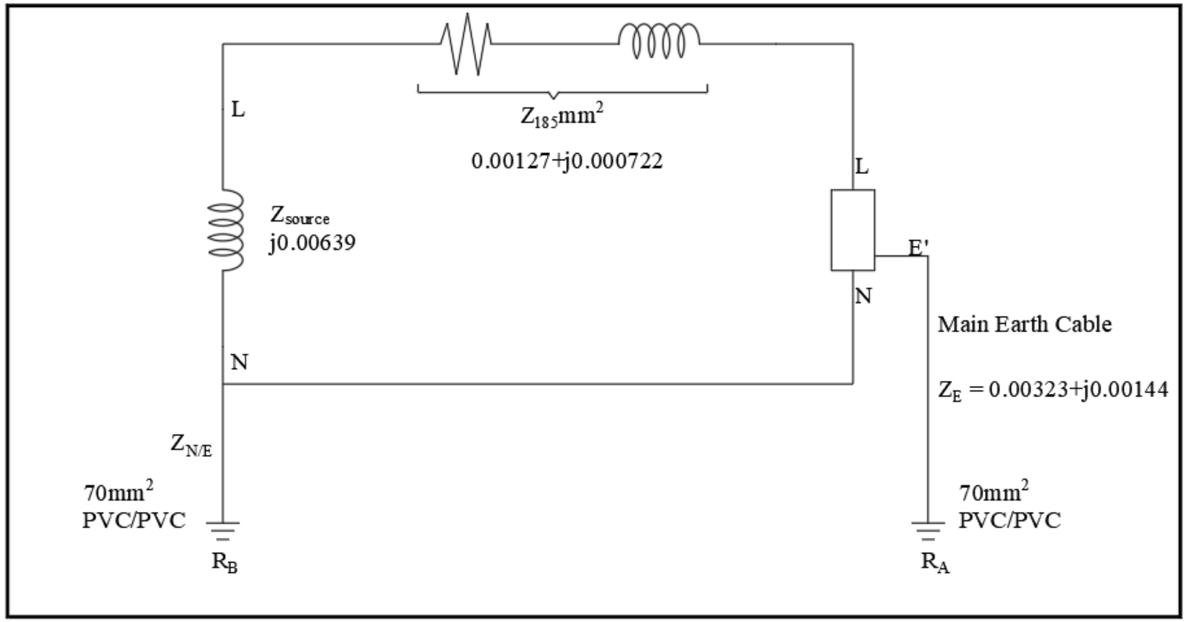


Figure 16.1

Earth Fault Loop Impedance = $Z_{source} + Z_T + Z_P + Z_E + Z_{N/E}$

Where $Z_{source} = 0.00639\Omega$

$Z_{185} = 0.00127 + j0.000722$

$Z_E = Z_{70} = 0.00323 + j0.00144$

Therefore, Z_{source} approx. R_A+R_B

If $R_A = R_B = 1\ \Omega$, $Z_{EFLI} = 1+1 = 2\ \Omega$

$$I_{E/F} = \frac{400V/\sqrt{3}}{2\Omega} \text{ approx. } 120A$$

If $R_A = R_B = 0.1\ \Omega$, $Z_{EFLI} = 0.1+0.1 = 0.2\ \Omega$

$$I_{E/F} = \frac{400V/\sqrt{3}}{0.2\Omega} \text{ approx. } 1200A$$

(ii) Main Earth Cable Sizing

$K^2 S^2 > I_{E/F}^2$ t and $S > \frac{I_{E/F}\sqrt{t}}{K}$

Assuming t = 1sec, $S > \frac{1200\sqrt{1}}{159}$ = 7.6 mm^2

where K = 159 for bare copper tape

Assuming t = 3sec, $S > \frac{1200\sqrt{3}}{159}$ = 13.1 mm^2

Therefore, bare copper tape of 3 mm x 25 mm = 75mm^2 is selected.

(iii) Protection Against Indirect Contact by Automatic Disconnection of Supply

As $I_{E/F}$ may be as low as 120A to 1200A, it may not be sufficient to cause the overcurrent protection device (i.e. MCB, MCCB or overcurrent relay) to operate.

Therefore for TT earthing system, the code of practice for electrical installations recommended that Residual Current Device is preferred for protection against indirect contact.

17. SIZING OF MAIN EARTH CABLE – TN-S SYSTEM

(i) Total Earth Fault Loop Impedance

$Z_{EFLI} = + Z_T + Z_{500} + Z_E + Z_N$

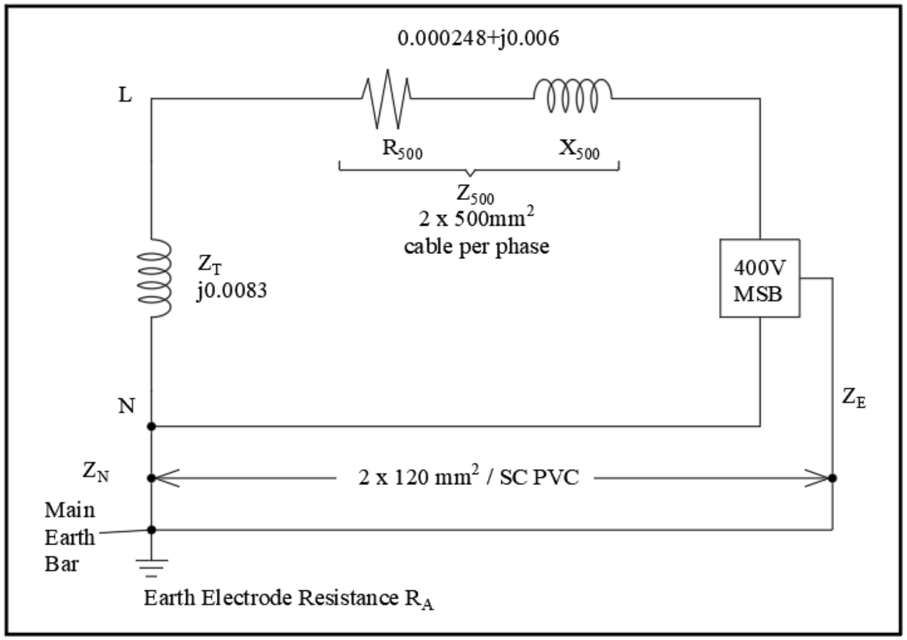


Figure 17.1

Earth Electrode Resistance R_A is not included because it is not in the earth fault loop path.

$Z_T = j0.0083\ \Omega$

$Z_{500} = 0.000248 + j0.0006\ \Omega$

2 x 1C 120mm^2 cable,

$Z_N + Z_E = (0.001848 + j0.001732)\ \Omega$

$Z_{EFLI} = (j0.0083\ \Omega) + (0.000248 + j0.0006) + (0.001848 + j0.001732)$

$= 0.002096 + j0.01063$

Therefore, $I_{E/F} = \frac{230V}{0.01084} = 21.22kA$

(b) For K = 143, t = 1 sec & $I_{E/F}$ = 21.22 kA

The minimum cable size which is able to withstand the thermal stress for 1 second is

Therefore, $S = \frac{I\sqrt{t}}{K} = \frac{21.22 \; x \; 10^3 x \; 1}{143}$

$= 148 \text{ mm}^2$

Since S = 148 mm^2 which is smaller than 2 x 120 mm^2, the main earth cable at (2 x 120 mm^2) is able to withstand the thermal stress for 1 sec.

18. MAIN EARTH BAR

The cross-sectional area of the Main Earth Bar of the switchboard is calculated from the formula:

$$k^2S^2 > I^2t \quad \text{OR} \quad S > I\sqrt{t}/k$$

where S = C.S.A in mm^2

I = r.m.s. value of A.C. fault current

t = operating time of the disconnecting device, in seconds

k = Thermal constant for material of conductor

The method for calculation and appropriate k values can be obtained from Annex B of Singapore Standard SS 482: Part 1:2000 for switchboard.

Example 18.1

With a short time withstand current of 50kA for 3 seconds and k=176 for bare copper conductor the calculated size is 492 mm^2. A copper bare of 50mm x 10mm is selected and installed at the bottom part of the cubicle for bonding to every sections of the cubicles, connection of incoming and outgoing protective conductors.

$$S > \frac{50 \text{ x } 10^3 \text{ x } \sqrt{3}}{176} = 492 \text{ mm}^2$$

Therefore, 50mm x 10mm bare copper bar is selected.

thank you!