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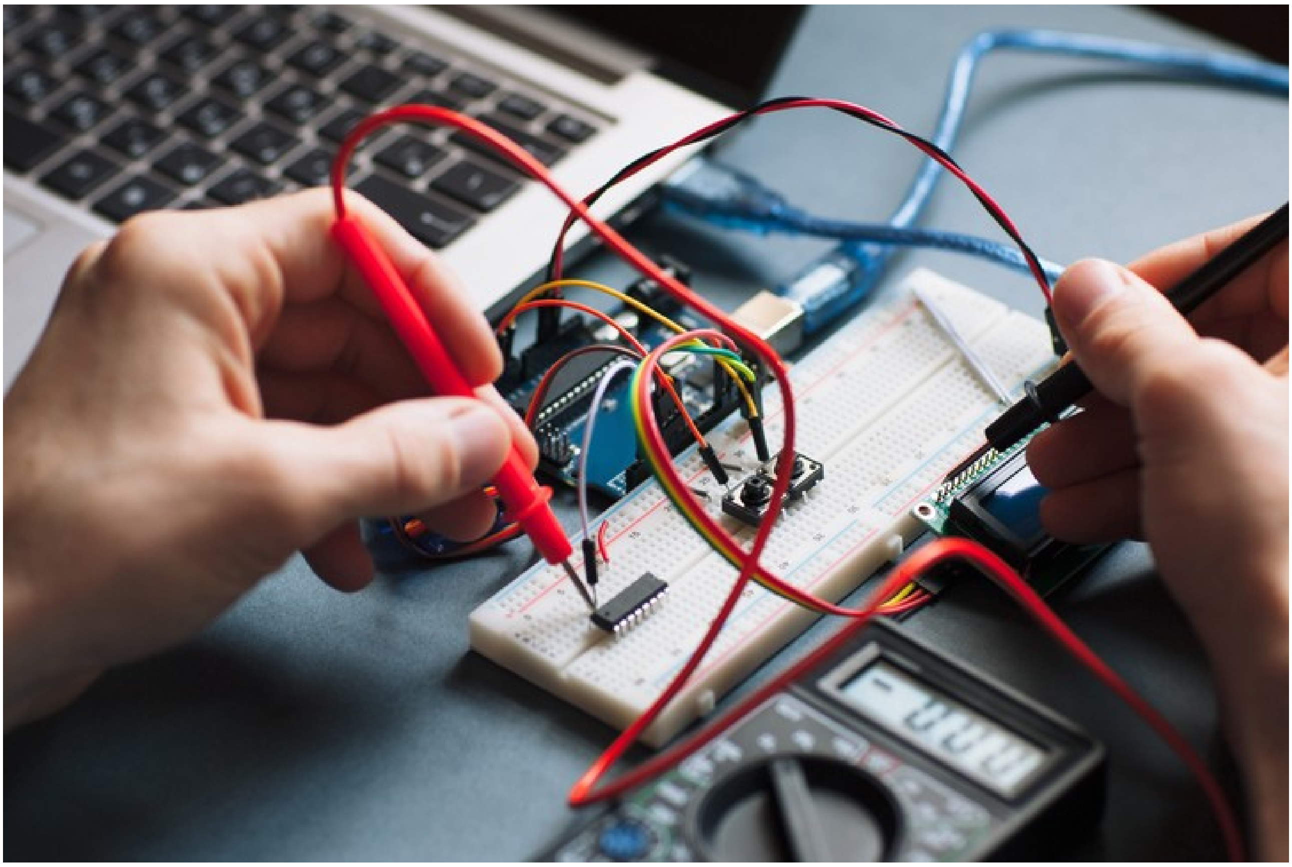


Topics

NAT10809003

Topics

1.1 Introduction: Revision – Impedance

Impedance

Impedance is the opposition to current in an a.c. circuit which results from a combination of resistance, inductive reactance and capacitive reactance in the circuit.

Impedance is defined as the ratio of the r.m.s. (Root means square) value of voltage to the r.m.s. value of current. The unit of impedance is ohms.

Impedance is calculated using this equation.

$$Z = \frac{V}{I}$$

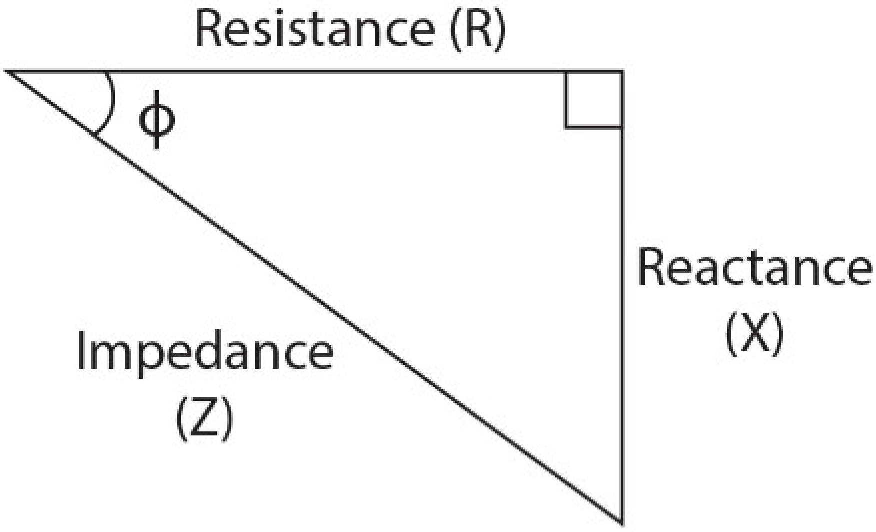
Where:

- Z = impedance in ohms (Ω)
- V = r.m.s. voltage in volts (V)
- I = r.m.s. current in amperes (A)

Impedance Triangle

An ‘impedance triangle’ is a graphical tool which helps to analyse the effects of resistors, capacitors and inductors in an a.c. circuit.

This diagram shows an impedance triangle, which is a right angled triangle with sides labeled Resistance (R), Reactance (X) and Impedance (Z). Trigonometry and Pythagoras’ Theorem are used to analyse these relationships.



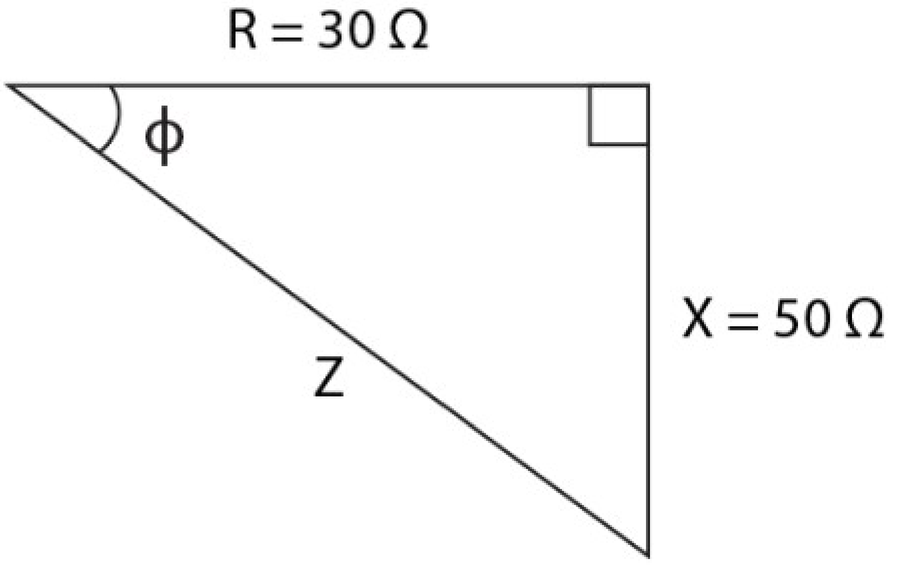
Points to note about the impedance triangle:

- Resistance is drawn horizontally.
- Reactance is drawn at right angles to the resistance (can be capacitive reactance, inductive reactance or a combination of both).
- Impedance is the hypotenuse of the triangle.
- Φ is the angle between the sides of the triangle representing resistance and impedance.

Note: Φ is the angle of lead or lag between the voltage and the current in the circuit.

Worked example – Impedance triangle

A resistance of 30 ohms is connected in series with a reactance of 50 ohms, calculate the:



Impedance, Z

Phase angle, Φ

Impedance, Z

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

$$Z = \sqrt{(30^2 + 50^2)}$$

$$Z = \sqrt{(900 + 2500)}$$

$$Z = \sqrt{(3400)}$$

$$\underline{Z = 58.31\ \Omega}$$

b) Phase angle, Φ

$$\Phi = \cos^{-1}(0.52)$$

$$\underline{\Phi = 58.67°}$$

[precise answer (no rounding at intermediate steps) Φ = 59.04°]*

Topics

Capacitive Components in a.c. Circuits

Capacitors are generally connected into a.c. circuits for the purpose of changing the phase angle between the current and voltage in the circuit.

The two main uses for capacitors in a.c. circuits are listed in the following table.

Capacitive Components in a.c. Circuits	
Single-phase motor starting	• A capacitor is connected in series with the motor winding to increase the phase angle between the current and the supply voltage. • This improves the starting torque of the motor.
Power factor Correction (PFC) unit	• A capacitor bank can be connected in parallel with an inductive load in order to reduce the phase angle of the circuit, thereby reducing the line current.

Inductive Components in a.c. Circuits

Transformers, motor windings, discharge lighting ballasts, relay and contactor coils are all highly inductive loads when connected into a.c. circuits. Inductive loads cause the current to lag the supply voltage. In some circuits, inductors are installed for the purpose of current limiting because they have a low power loss.

Summary

- Impedance is the opposition to current in an a.c. circuit.
- Impedance is the combination of resistance, inductive reactance and/or capacitive reactance.
- The impedance triangle is a graphical tool for analysing the resistance, reactance and impedance of an a.c. circuit.
- In a series RC a.c. circuit, the current leads the voltage by some angle ($\Phi°$) between 0° and 90°.
- In a series RL a.c. circuit, the current lags the voltage by some angle ($\Phi°$) between 0° and 90°.
- Highly inductive a.c. loads includes transformers, motor windings, discharge lighting ballasts, relay and contactor coils.

Topics

1.2 AS/NZS 3000 Wiring Rules Requirements

Capacitors are often connected into a.c. circuits and equipment to achieve specific operating parameters. However, capacitors can introduce certain electrical hazards if they are not connected in accordance with the AS/NZS 3000 Wiring Rules. The requirements for capacitors connected into a.c. circuits are detailed in AS/NZS 3000:2018 Clause 4.15 Capacitors.

The following table outlines the requirements specified in AS/NZS 3000:2018 for the installation and protection of capacitors and in particular the requirements of clauses 4.15.2 and 4.15.3.

AS/NZS 3000:2007 Requirements for Capacitors – Clause 4.15 Capacitors		
Clause	**Sub-clause**	**Requirements**
4.15.2 Electrical Equipment	4.15.2.1	• Equipment and wiring connected to capacitors must be rated for the highest voltage, current or temperature that are likely to occur. • Also, adequate ventilation must be provided.
	4.15.2.2	• Circuit breakers, switches or contactors controlling capacitors must be suitably rated. • A suitable utilization category for contactors is AC-6b in accordance with AS60947.4.1.
4.15.3 Provision for discharge and control	4.15.2.3	connected to capacitors must have a current carrying capacity, not less than the greater of: • 135% of the capacitor

Topics

		rated current, or • the circuit breaker setting. For capacitors that are permanently connected into a motor circuit, the current carrying capacity must be not less than the greater of: • one-third the rating of the motor circuit conductors, or • 135% of the rated current of the capacitor.
	4.15.3.1	Capacitors with a capacitance greater than 0.5 µF must be provide with a permanent discharge path: • This is generally a resistor permanently connected across the capacitor terminals, or • The windings of a motor may provide this discharge path. • The discharge path must discharge the capacitor down to 50 V within the time specified • Capacitors rated up to and including 650 V, the discharge time is 1 minute. • Capacitors rate above 650 V, the discharge time is 5 minutes.

Summary

- AS/NZS 3000:2018, Clause 4.15 Capacitors, specifies the requirement for capacitors connected into a.c. circuits.
- Capacitors are connected into a.c. circuits to change the phase angle between the current and voltage.

Topics

1.3 Voltage Drop for Cables

The voltage drop of conductors can be calculated using impedance (reactance and resistance) values provided in AS/NZS 3008.1.1:2017 tables.

Tables 30 to 33 in AS/NZS 3008.1.1:2017 contain values of reactance (Xc) for the conductors of various types of cables. Reactance values are given in ohms per kilometre (Ω/km) at 50 Hz for various installation methods and insulation types.

Reactance Tables	
Cable type	**AS/NZS 3008.1.1:2017**
All cables except flexible cords, flexible cables, MIMS cables and aerial cables	Table 30
Flexible cords and flexible cables	Table 31
MIMS cables	Table 32
Aerial cables	Table 33

Tables 34 to 39 in AS/NZS 3008.1.1:2017 contain values of a.c. resistance (Rc) for the conductors of various types of cables. Resistance values are given in ohms per kilometre (Ω/km) at 50 Hz at various operating temperatures.

a.c. Resistance Tables	
Cable Type	**AS/NZS 3008.1.1:2017**
Single core cables	Table 34
Multicore cables with circular conductors	Table 35
Multicore cables with shaped conductors	Table 36
Flexible cords and flexible cables	Table 37
MIMS cables	Table 38
Aerial cables	Table 39

Calculating Conductor Impedance

To calculate conductor impedance, the a.c. resistance and reactance of the conductors should be calculated using values of Rc and Xc from the appropriate AS/NZS 3008.1.1:2017 table and the following equations:

$$X = \frac{X_c \times L}{1000}$$

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Where:

X = reactance of the conductor in ohms (Ω) => $X = X_c * L/1000$

R = resistance of the conductor in ohms (Ω) => $R = R_c * L/1000$

X_c = reactance in ohms per kilometre (Ω/km)

R_c = resistance in ohms per kilometre (Ω/km)

L = route length of the circuit conductors in metres (m)

These values of reactance and a.c. resistance must then be entered into the impedance equation:

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

Where:

Z = impedance of the conductor in ohms (Ω)

X = reactance of the conductor in ohms (Ω)

R = resistance of the conductor in ohms (Ω)

Calculating Voltage Drop

To calculate conductor voltage drop, the route length of the conductor, the load current and the impedance is required for the following equation:

$$\boxed{Vd = \frac{ILZc}{1000}}$$

Where:

Vd = voltage drop in cable, in volts (V

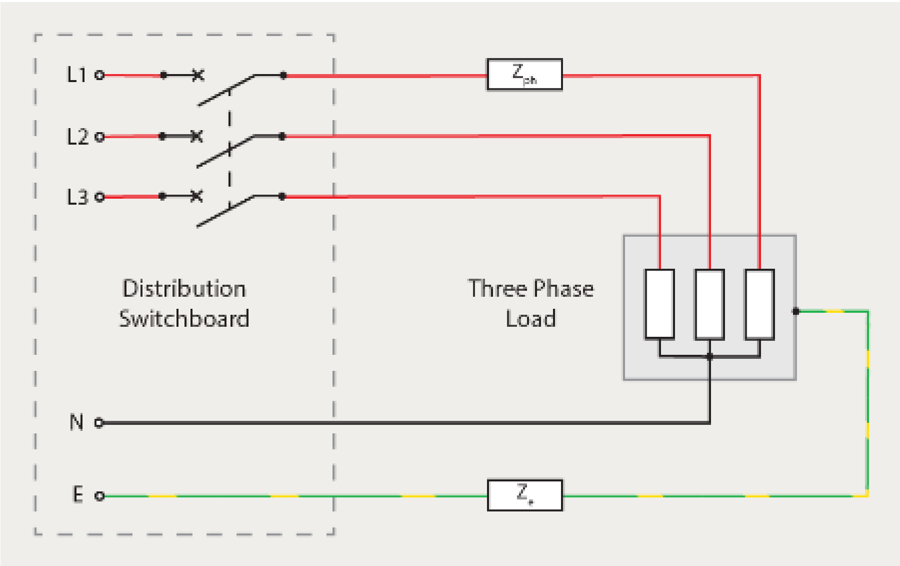
I = current flowing in cable, in amperes (A)

L = route length of circuit conductor in metres (m)

Z_c = impedance in ohms per kilometre (Ω/km)

Topics

Worked Example – Calculate Conductor Voltage Drop



Calculate the voltage drop of a 10 mm^2 active conductor of a 230 V final subcircuit that has a route length of 35 m. The circuit is wired in XLPE-SDI cables tied flat and touching on a perforated cable tray. The load current is 80 amperes.

Topics

The first step is to find the values of Xc from the applicable table in AS/NZS 3008.1.1:2017. In this case, Table 30 is selected based on the type of cable. Based on the installation method and the insulation type, Column 7 is selected for the active conductor.

The values of Xc = 0.129 Ω/km for the 10 mm^2 active conductor.

The next step is to find the values of Rc from the applicable table in AS/NZS 3008.1.1:2017. In this case, Table 34 is selected based on the type of cables. Based on the operating temperature and the conductor type, Column 5 is selected for the active and protective earthing conductors.

The values of Rc = 2.33 Ω/km for the 10 mm^2 active conductor.

The voltage drop of the active conductor can now be calculated, using the above VALUES OF Xc and Rc.:

$$\mathrm{Vd} = \frac{IL\sqrt{Rc^2 + Xc^2}}{1000}$$

$$\mathrm{Vd} = \frac{80 \ x\ 35\ x\ \sqrt{2.33^2 + 0.129^2}}{1000}$$

$$\mathrm{Vd} = \frac{6534}{1000}$$

$$\underline{\mathrm{Vd} = 6.53\ \mathrm{V}}$$

2.1 Power factor

Introduction

The power factor of an installation is an important parameter in the supply and utilisation of electricity. Poor power factor can result in higher current demands in an installation, requiring higher rated cables and equipment. This results in increased costs to the network provider and the consumer.

In some installations it is necessary to install power factor correction (PFC) equipment to ensure compliance with network provider requirements and to reduce energy costs.
This topic will help you develop your understanding of power factor, including the loads that cause low power factor, methods of improvement and associated network provider and Wiring Rules requirements.

Low Power Factor

A low power factor can cause an installation to become inefficient in the way that the voltage and current supplied to the load are utilised. Essentially, the lower the power factor, the more current is required to achieve the same power output at the load. This means that larger size conductors and higher rated equipment is required to handle the higher line currents.

The disadvantages of a low power factor include:

- Increased voltage drop in supply cables.
- Increased power losses.
- Increased demand on generating plants.
- Larger transmission and distribution transformers required.
- Larger conductors required.
- Higher current ratings required for switchgear and circuit protection.

Causes of Low Power Factor

The majority of electrical installations have a lagging power factor caused by inductive loads, which are more common than capacitive loads.

These loads can include:

- Motors
- Transformers
- Fluorescent lighting
- High intensity discharge (HID) lighting.

Effects of Load Power Factor

When compared to a circuit operating at unity ($\lambda = 1$), a circuit with a lagging power factor will have a higher voltage drop in the supply cables. This is due to the higher line currents flowing through the impedance of the supply cables (remember: $V = IZ$).

The effect of this increased voltage drop poses a problem to network providers, as the supply voltage needed at different installations varies, to a degree, depending on the installation's power factor.

AS/NZS 3008.1.1:2017 Electrical installations – Selection of cables Clause 4.5 illustrates how the load power factor can affect the value of supply voltage needed to maintain a given line voltage at the load. These effects are summarised below:

- The supply voltage is the phasor sum of the line voltage at the load and the voltage drop in the supply cables.
- Altering the power factor of the load changes the phase relationship between the line voltage and the voltage drop.
- When compared to unity power factor, a lagging power factor requires a larger supply voltage to maintain a given load voltage.
- When compared to a unity power factor, a leading power factor requires a smaller supply voltage to maintain a given load voltage.

Summary

- An installation operating at a low power factor requires a larger line current to supply the load compared to an installation operating at unity power factor.
- The power factor of the load will affect the voltage drop in the supply cables to the load.
- A load operating with a lagging power factor will cause a greater voltage drop in the supply cables compared to a load operating at unity power factor, or one with leading power factor.

2.2 Power factor improvement

Minimum Power Factor Levels

Local network providers set minimum and maximum limits for power factor in installations connected to their network. The minimum power factor for low voltage customers in Australia is 0.75 lag (Victoria), however in some jurisdictions the minimum is set at 0.8 – 0.9 lag. In some jurisdictions there is also a restriction on operating with a leading power factor, e.g. the NSW Service and Installation Rules state that 'The power factor of the installation must not become leading at any time'.

This allows the network provider to maintain the quality of the network supply and to avoid excessive loading and losses in network equipment.

Where the power factor is below the minimum specified level, the customer must install equipment to improve the installation's power factor. If this is not done, the customer can incur increased costs for their electricity or be disconnected.

Power Factor Improvement

As stated in Topic 2.1, most installations have a lagging power factor, as inductive loads such as motors are more common place than capacitive loads. In order to improve a lagging power factor, equipment that introduces capacitive reactance into the circuit can be installed to offset the excessive inductive reactance. This equipment includes:

- Capacitor banks
- Synchronous motors
- Static VAR compensators

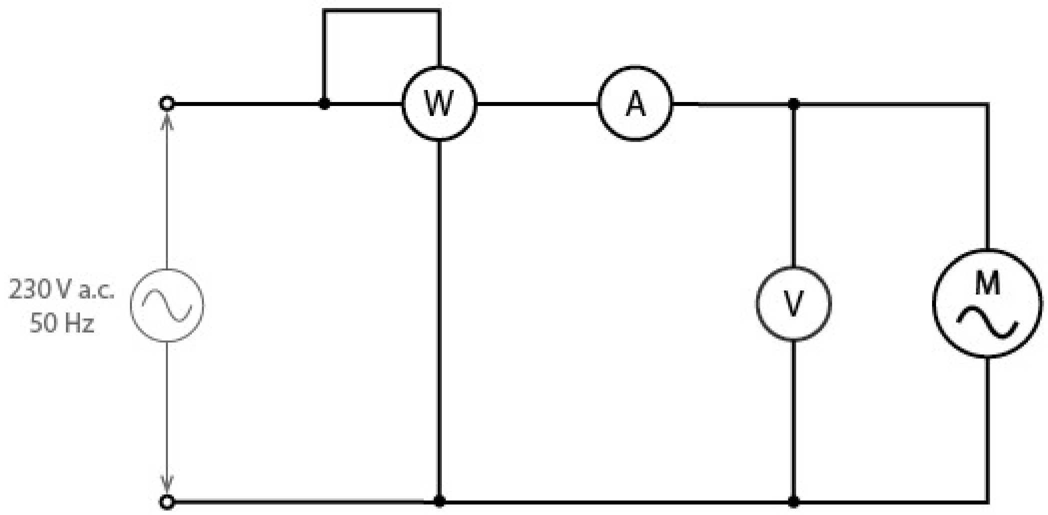
Topics

AS/NZS 3000 Requirements for Capacitors

As previously stated in Topic 1.1, AS/NZS 3000:2018 Clause 4.15 Capacitors outlines specific requirements for capacitors connected into a.c. circuits. These requirements apply equally to capacitors used for power factor correction.

Single Phase Power Factor Measurement

This diagram show the meter arrangement for measuring the power factor of a 230 V a.c. single phase motor circuit, which can be used to measure the power factor of any single phase load.



The r.m.s. value of true power (P) is measured by the wattmeter. The apparent power (S) is determined by multiplying the voltmeter (V) and ammeter readings (A).

The power factor can be determined using this equation.

$$\lambda = \frac{P}{V \times I}$$

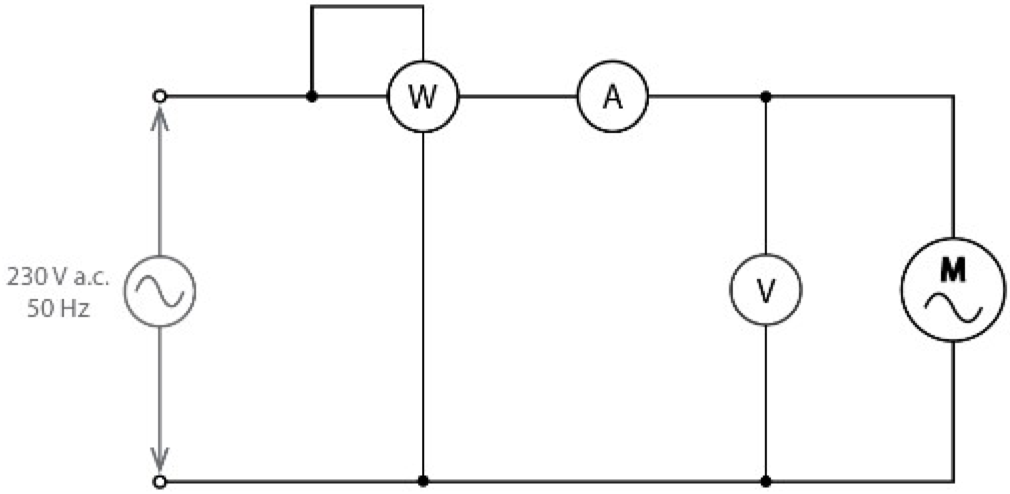
$\lambda = P/S \Rightarrow S = V * I \Rightarrow \lambda = P/V*I$

Where:

- λ = power factor (cos Φ) of the circuit
- P = true power in watts (W)
- V = load voltage in volts (V)
- I = load current in amperes (A)

Topics

Worked Example – Power Factor Calculations 1



Determine the power factor for the single phase motor circuit pictured above, given the following meter readings

$$\lambda = \frac{P}{S}$$

a) Wattmeter reading: 15.8 kW

b) Volmeter reading: 230 V

$$\lambda = \frac{P}{V \times I}$$

c) Ammeter reading: 84 A

1. Power factor, λ

$$\lambda = \frac{15800}{230 \times 84}$$

$$\lambda = \frac{15800}{19320}$$

$$\underline{\lambda = 0.82}$$

Worked Example – Power Factor Calculations 2

Topics

A 230 V 50 Hz, single phase lighting installation consists of high intensity discharge (HID) luminaries operating at a power factor of 0.52 lag.

If the total power of the installation is measured at 8.6 kW, determine the rating in kVAr, of a capacitor bank to be connected in parallel with the installation in order to correct the power factor to 0.9 lag.

$$S_{0.52} = \frac{P}{\lambda}$$

a) Apparent power ($S_{0.52}$) at $\lambda = 0.52$ lag

$$S_{0.52} = \frac{8600}{0.52}$$

$$\underline{S_{0.52} = 16538\ VA}$$

$$Q_{0.52} = \sqrt{}\,(16538^2 - 8600^2)$$

b) Reactive power ($Q_{0.52}$) at $\lambda = 0.52$ lag

$$\underline{Q_{0.52} = 14126\ \text{VAr}}$$

$$S_{0.9} = \frac{P}{\lambda}$$

c) Apparent power ($S_{0.9}$) at $\lambda = 0.9$ lag

$$S_{0.9} = \frac{8600}{0.9}$$

$$\underline{S_{0.9} = 9556\ VA}$$

$$Q_{0.9} = \sqrt{}\,(9556^2 - 8600^2)$$

d) Reactive power ($Q_{0.9}$) at $\lambda = 0.9$ lag

$$\underline{Q_{0.9} = 4166\ \text{Var}}$$

$$Q_C = Q_{0.52} - Q_{0.9}$$

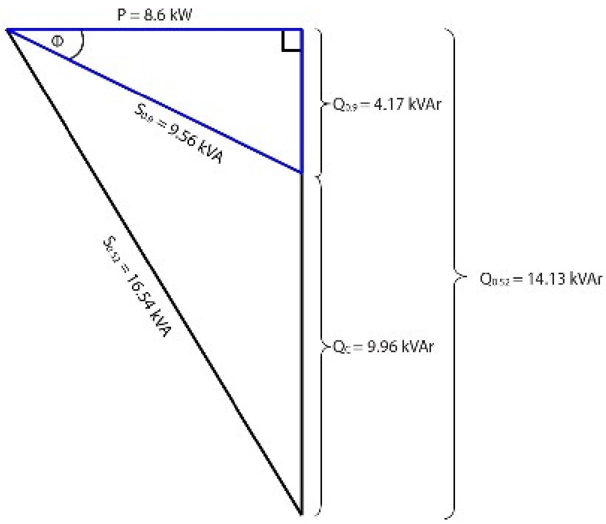
$$Q_C = 14126 - 4165$$

e) kVAr rating of capacitor bank, Q_C

$$\underline{Q_C = 9961\ \text{VAr}}$$

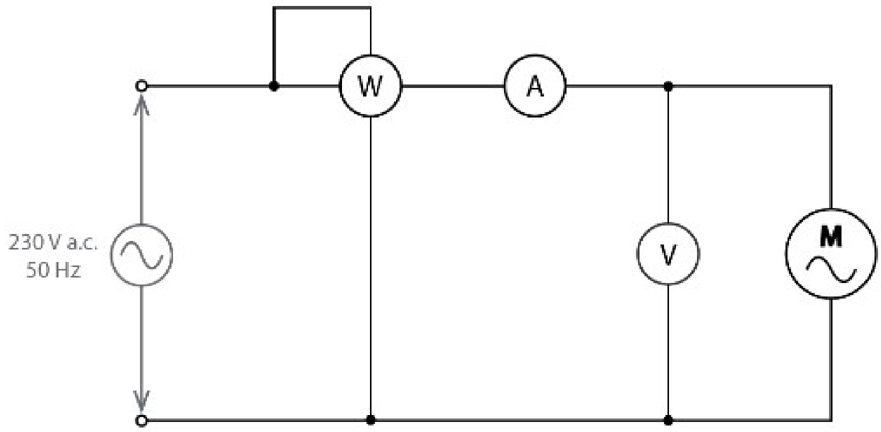
[Topics]

f) Power triangle



Topics

Worked Example – Power Factor Calculations 3



At full load, the single phase motor pictured above draws a line current I_L of 16 A at 0.71 lag. Determine the value of shunt capacitance required to improve the power factor to 0.95 lag.

$$I_R = I_L \times \lambda$$

a) I_R at full load

$$I_R = 16 \times 0.71$$

$$\underline{I_R = 11.36\ A}$$

$$I_X = \sqrt{(I_L^2 - I_R^2)}$$

b) I_X at 0.71 lag

$$I_X = \sqrt{(16^2 - 11.36^2)}$$

$$I_X = \sqrt{(256 - 129.05)}$$

$$\underline{I_X = 11.27\ A}$$

$$\lambda = \frac{I_R}{I_L}$$

c) I_L at 0.95 lag

$$I_L = \frac{I_R}{\lambda}$$

$$I_L = \frac{11.36}{0.95}$$

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$$I_X = \sqrt{(I_L^2 - I_R^2)}$$

d) I_X at 0.95 lag

$$I_X = \sqrt{(11.96^2 - 11.36^2)}$$

$$I_X = \sqrt{(143 - 129.05)}$$

$$I_X = 3.74\ A$$

$$I_{XC} = I_{X(0.71)} - I_{X(0.95)}$$

e) Capacitor current, I_{XC}

$$I_{XC} = 11.27 - 3.74$$

$$\underline{I_{XC} = 7.53\ A}$$

$$X_C = \frac{V}{I_{XC}}$$

f) Capacitive reactance, XC

$$X_C = \frac{230}{7.53}$$

$$\underline{X_C = 30.54\ \Omega}$$

$$X_C = \frac{1}{2 \times \pi \times f \times C}$$

g) Capacitance, C

$$C = \frac{1}{2 \times \pi \times f \times X_C}$$

$$C = \frac{1}{2 \times \pi \times 50 \times 30.54}$$

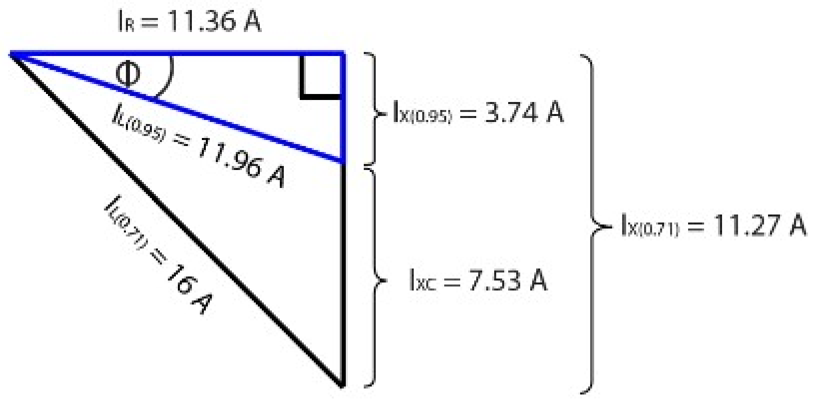
$$C = \frac{1}{9596}$$

$$\underline{C = 104.21\ \mu F}$$

[precise answer (no rounding at intermediate steps) C = 104.23 µF]*

Topics

h) Phasor diagram



The exercise above is to find the shunt capacitance required to improve the power factor to an acceptable power factor lag.

To do this the following steps was required:

Ir at full load	=>	ir = IL x λ
Ix at 0.71 lag	=>	Ix = √ (IL^2 - Ir^2)
IL at 0.95 lag	=>	IL = Ir / λ
Ix at 0.95 lag	=>	Ix = √ (IL^2 - Ir^2)
Capacitor current, I xc	=>	Ixc = Ix(0.71) - Ix(0.95)
Capacitive reactance, xc	=>	Xc = V / I xc
Capacitive, C	=>	Xc = 1/(2 * pi * hz * C)

Summary

- Local network providers set the minimum level of power factor for an installation in their jurisdiction.
- When an installations power factor falls below the minimum level, power factor correction equipment must be installed.
- Power factor correction equipment adds a capacitive reactance to an installation to offset the lagging power factor created by inductive loads.
- The power factor of an installation can be calculated by using a wattmeter, voltmeter and ammeter to measure the load power, voltage and current.

Topics

3.1 Function of neutral conductors

Introduction

Three phase, low voltage installations are supplied via four conductors—three line conductors and a neutral conductor. Three phase four-wire systems enable the connection of both three phase balanced loads and single phase loads, such as lighting, socket outlet circuits, fixed appliances and motors, etc.

The connection of a diverse range of single phase loads across a three phase supply may cause the three phase system to be unbalanced, which requires the neutral conductor to carry the out-of-balance current.

This topic will help you develop your understanding of three phase four-wire systems. You will learn about the functions of the neutral conductor, the adverse effects of a high impedance neutral conductor, the voltage drop in unbalanced circuits and the AS/NZS 3000:2018 requirements for neutral conductors.

In a balanced three phase system the load impedances are equal, the phasor sum of the line currents is zero, and a neutral conductor is not required.

In an unbalanced three phase system the neutral conductor is necessary and provides several critical functions to ensure the correct operation of the three phase system.

The functions of the neutral conductor in an unbalanced system, are:

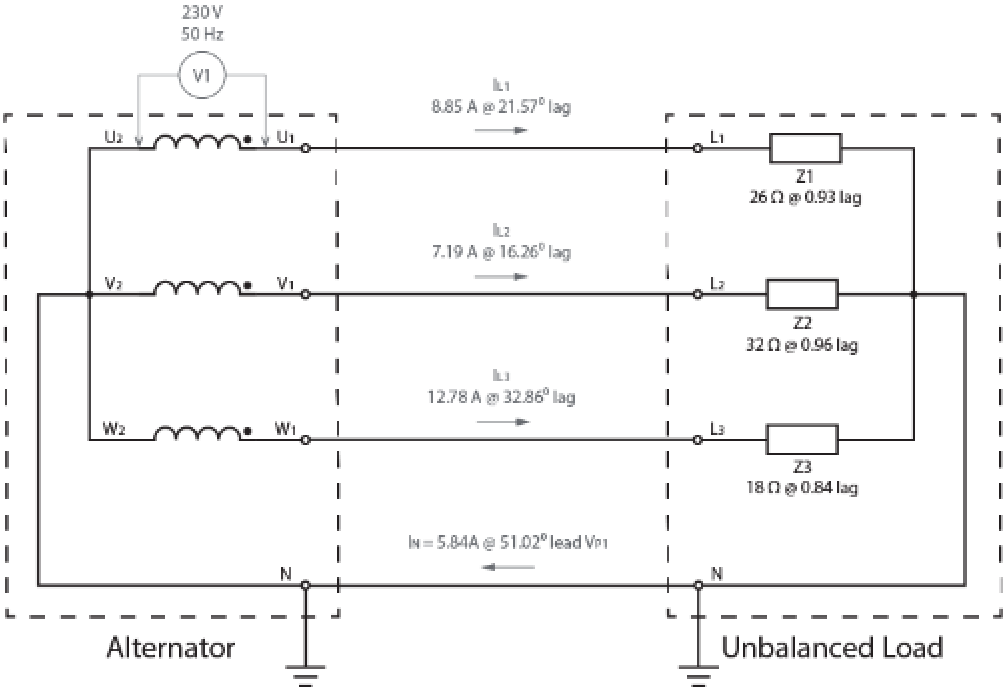
- To carry the out-of-balance line currents.
- To maintain the phase voltage across each load at equal values.
- To act as the combined protective earth neutral (PEN) conductor in the MEN (multiple earth neutral) system, i.e. to complete the earth fault loop.
- To ensure correct operation of circuit protective devices in the event of an earth fault (MEN system).
- To carry 3rd harmonic currents produced in circuits with non-linear loads.
- To enable connection of single phase equipment.

Topics

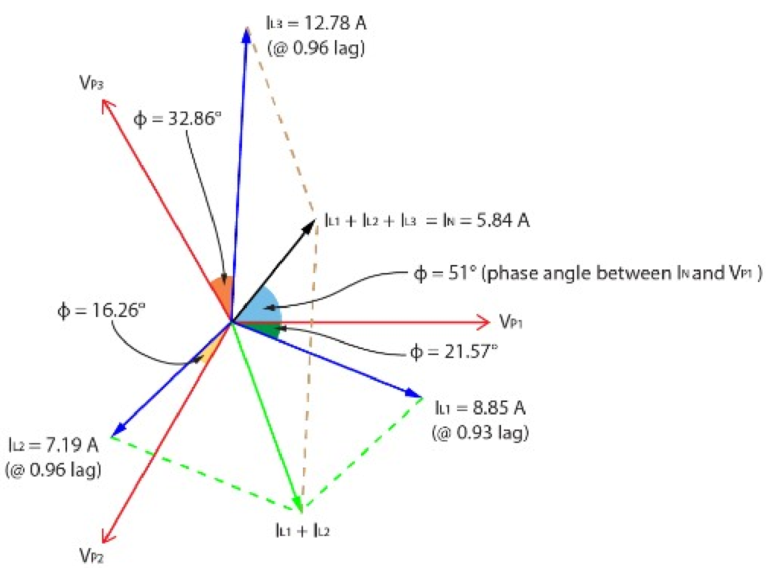
Neutral Current

In a three phase system with unbalanced loads, the current in the neutral conductor is the phasor sum of the unbalanced line currents.

This diagram shows a three phase alternator supplying a three phase unbalanced load, where the neutral conductor current, IN = 5.84 A.

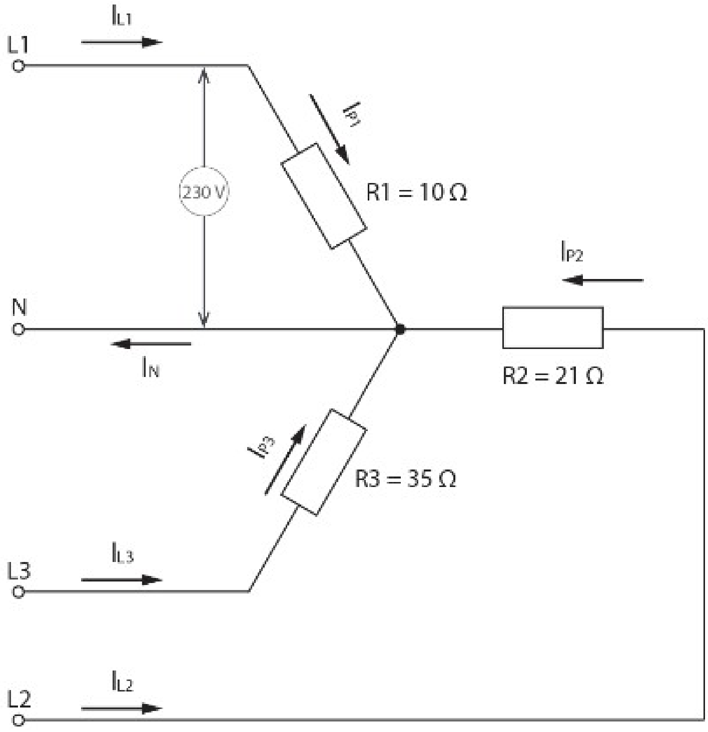


The phasor diagram for the unbalanced circuit shows that the neutral current is the phasor sum of the line currents IL1, IL2 and IL3.



Topics

Worked Example – Neutral Current in an Unbalanced Star Connected System



This diagram shows a three phase *unbalanced* star connected resistive load, determine:

a) Phase current, I_{P1}

b) Phase current, I_{P2}

c) Phase current, I_{P3}

d) Neutral current, I_N

$$I_{P1} = \frac{V_P}{R_1}$$

a) Current, I_{P1}

$$I_{P1} = \frac{230}{10}$$

$$\underline{I_{P1} = 23.0\ A}$$

Topics

b) Current, I_{P2}

$$I_{P2} = \frac{V_P}{R_2}$$

$$I_{P2} = \frac{230}{21}$$

$$\underline{I_{P2} = 10.95\ A}$$

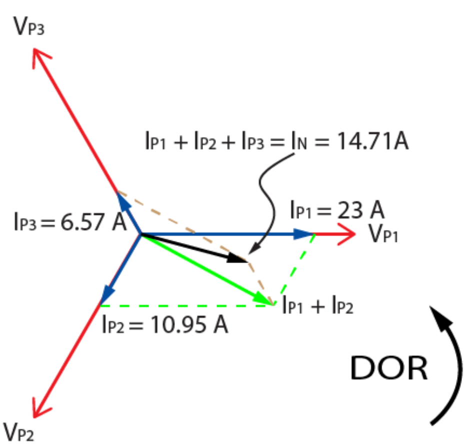
c) Current, I_{P3}

$$I_{P3} = \frac{V_P}{R_3}$$

$$I_{P3} = \frac{230}{35}$$

$$\underline{I_P = 6.57\ A}$$

d) Neutral Current, I_N (by phasor addition)



Topics

Effect of High Impedance Neutral Conductor

A high impedance in the main neutral conductor in a MEN installation can lead to hazardous conditions which can affect the safe operation of the installation.

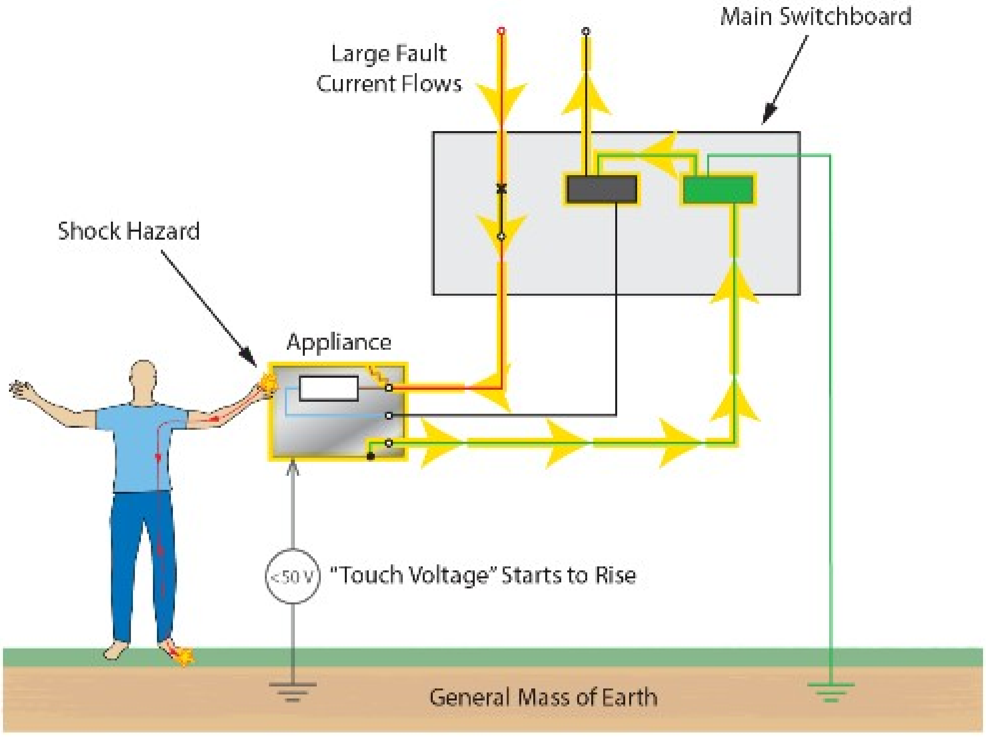
As noted above, the supply neutral conductor is part of the earth fault loop in a MEN installation.

If an earth fault occurs in an installation with a high impedance main neutral conductor, the fault current will be below the mean tripping current of the protection device. The result is that the protection device will not trip in the required time, and a potentially fatal touch voltage may exist between exposed conductive parts and earth for as long as the circuit remains energised.

In this diagram an earth fault in the appliance has caused a large fault current to flow, creating a shock hazard. As the fault current flows, the touch voltage at the appliance starts to rise.

AS/NZS 3000:2018 Clause 1.5.5.3 Protection by automatic disconnection of supply, sets a limit on the value of Touch Voltage, and specifies the maximum disconnection times for equipment connected to 230/400 V supplies, which are:

- 0.4 s for final sub-circuits supplying socket outlets, hand-held Class I equipment and portable equipment intended for manual movement.
- 5 s for other circuits.



Topics

Voltage Drop in Unbalanced Circuits

AS/NZS 3000:2018 Wiring Rules requires that the voltage drop at any point in an installation must not exceed 5% of the nominal supply voltage.

AS/NZS 3008:1.1:2017 Electrical installations—Selection of cables, Section 4, provides values of VC (voltage drop in mV/A.m at 50 Hz) which are used for determining the voltage drop in various cable types and sizes in different installation conditions.

In unbalanced three phase circuits, the calculation of voltage drop must consider both the voltage drop in the heaviest loaded active conductor, plus the voltage drop in the neutral conductor due to the neutral current.

AS/NZS 3008.1.1:2017 Clause 4.6, provides guidance for determining voltage drop in unbalanced multi-phase circuits, specifically:

When determining the voltage drop in sub-mains supplying a three phase unbalanced load:

- If the load is *intermittent* or *inconsistent*, the calculation should be performed using the *three phase value of* V_C and the value of current in the *heaviest loaded phase*.
- If the unbalance load is *consistent*, the voltage drop can be determined from the phasor sum of the voltage drop in the heaviest loaded phase and the voltage drop in the neutral, using the *single phase values of* V_C.

Summary

- In unbalanced three phase systems, the neutral conductor:
  - Carries the out-of-balance line currents.
  - Maintains the phase voltages at equal values.
  - Acts as a combined PEN conductor in the MEN system.
  - Ensures correct operation of the protective device in the event of an earth fault.
  - Carries the third harmonic current produced by non-linear loads.
  - Enables connection of single phase loads.
  - The neutral current is the phasor sum of the unbalanced line currents.
- A high impedance neutral conductor:
  - Can limit the fault current to less than the instantaneous trip current of the protective device.
  - Could allow a potentially fatal touch voltage to appear between exposed conductive parts and earth.
  - AS/NZS 3008.1.1:2017 Clause 4.6, provides guidance for determining voltage drop in unbalanced three phase circuits.

Topics

3.2 Neutral conductors

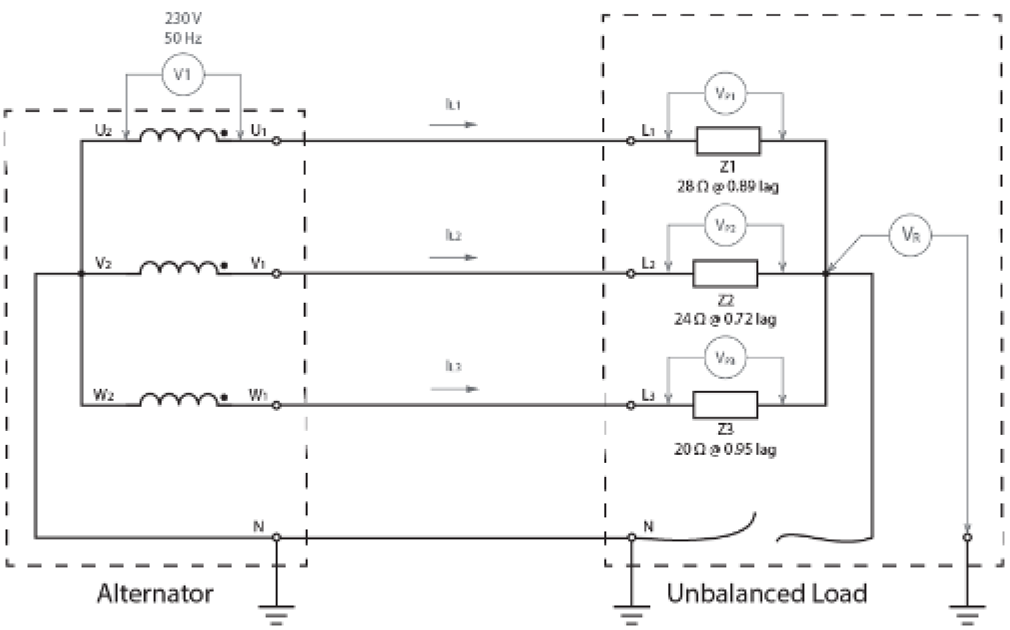
Effects of Broken/Disconnected Neutral Conductor

This diagram shows a three phase alternator supplying a three phase unbalanced load, in which the neutral conductor has been disconnected or is broken.

The effects of a broken neutral conductor, include:

- An increase in the line/phase currents.
- Unequal phase voltages.
- An increase in the voltage between the load star point and earth.

Note: the phase voltage at the alternator is unaffected by a broken neutral at the load.

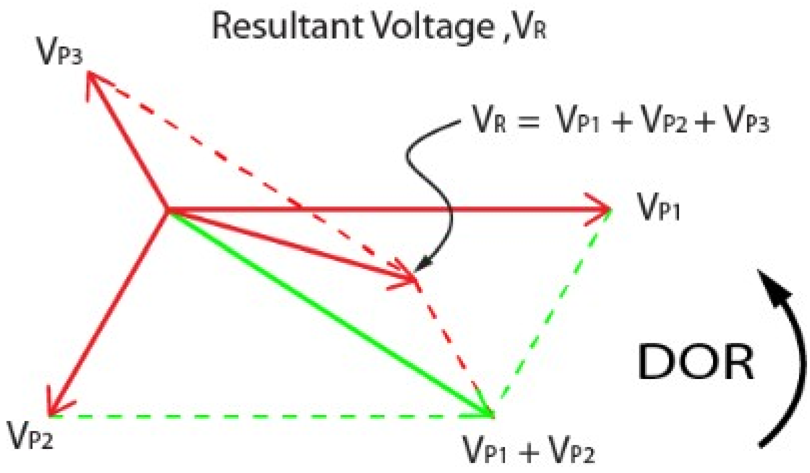


Topics

This phasor diagram shows the unequal phase voltages caused by the broken neutral conductor.

The resultant voltage (V_R) is the voltage measured between the load *star point* and earth.

The broken/disconnected neutral creates unstable phase voltages in an unbalanced system because the load star point is disconnected from the zero reference point provide by the earth connection.



Summary

- The effects of a broken or disconnected neutral in an unbalanced three phase system includes:
    - Increased load phase currents.
    - Unequal phase voltages.
    - Increase in the star point voltage above earth potential.
    - The voltage at the alternator is unaffected by a broken neutral conductor.

3.3 Australian standards requirements

AS/NZS 3000:2018 Wiring Rules Requirements

The following table outlines the requirements for the selection and installation of neutral conductors specified in AS/NZS 3000:2018.

AS/NZS 3000:2018 Requirements for Neutral Conductors	
Clause	**Requirement**
1.4.84 (Definitions)	The definition of a *neutral conductor*.
2.2.1.3 (Common neutral)	Requirements for the arrangement of *two or more circuits* using a *common* neutral conductor.
2.3.2.1.2 (Isolation of conductors)	Requirements for *switching* a neutral conductor that forms part of an a.c. system.
3.5.2 (Neutral conductor size)	Requirements for determining the *minimum size* of neutral conductors.
3.16 (ESR system)	Requirements for *PEN conductors* used as part of an ESR system.
8.3.7.1 (Polarity)	Requirements for *verifying* that the neutral conductors in an installation *have not been transposed* with other conductors.

Size of the Neutral Conductor

AS/NZS 3000:2018 Clause 3.5.2 states the requirements for determining the size of the neutral conductor.

The minimum size of the neutral conductor in an installation is affected by the following installation conditions:

- The maximum demand of the installation/final sub-circuit.
- The presence of third harmonic currents.
- The size of the associated active conductors.
- How evenly the single phase loads are distributed across the three phase supply.
- The method of cable installation

Summary

- The size of the neutral conductor must be determined in accordance with AS/NZS 3000:2007 Clause 3.5.2.
- The size of the neutral conductors is affected by:
    - The maximum demand.
    - The presence of 3rd harmonic currents.
    - The size of the associated active conductors.

Topics

- The distribution of single phase loads across the three phase supply.
- The method of installation.

4.1 Harmonics

Introduction

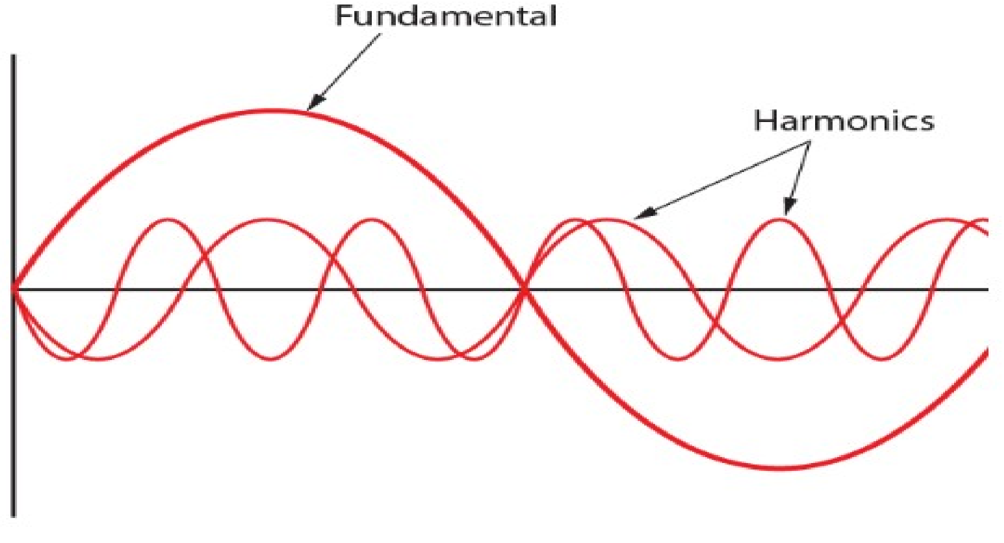
A sine wave is the fundamental wave shape for voltage and current in the electricity supply and distribution network. The advantage of a sine wave is that it is the only a.c. waveform that can be transformed and keep its shape. In Australia, the frequency is set at 50 Hz, and power station designers and operators strive to ensure that the frequency and sine wave shape remains stable.

Harmonics are additional a.c. waveforms that are superimposed on the supply system that distort the wave shape of the fundamental. This can have a detrimental effect on the electricity network and cause resonance in a.c. circuits. The first part of this topic explores the causes, effects and solutions to harmonic distortion.

In the second part you will learn about resonance. Resonance occurs in a.c. circuits when the inductive reactance equals the capacitive reactance. It can affect the operation of a circuit and cause the current in parts of the circuit to increase to dangerous levels and the voltage across inductive and capacitive components to increase above the supply voltage.

'Harmonics' are sinusoidal waveforms having frequencies which are multiples of the fundamental 50 Hz waveform. In an ideal a.c. power system, the frequency of the supply and the sinusoidal wave shape remains stable. In a practical a.c. power system, the 50 Hz waveform is actually a combination of the fundamental waveform and a number of harmonic waveforms.

This diagram shows a 50 Hz waveform with two additional harmonic waveforms.



Topics

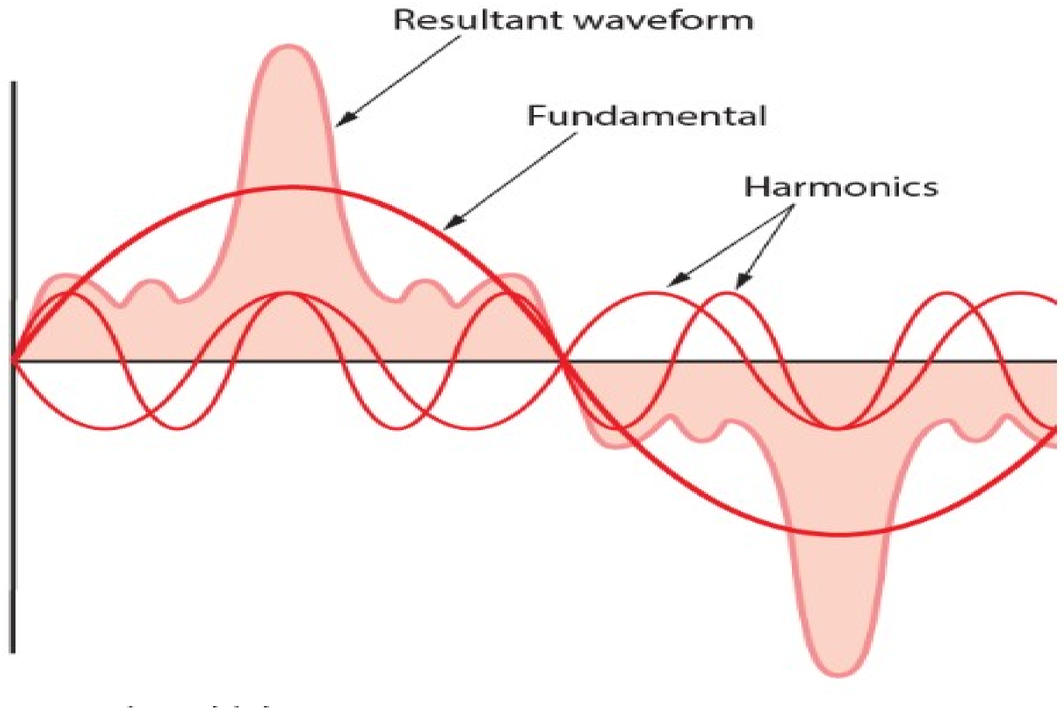
Effects on Fundamental Frequency

Harmonic frequencies distort the fundamental wave shape of voltage and current so that they no longer have a sinusoidal shape.

The combined effect of all harmonics in a power system is called the ‘total harmonic distortion’ (THD).

This diagram shows the resultant waveform when two harmonics are added to the fundamental waveform. The resultant waveform is the sum of the instantaneous values of each waveform, i.e. the fundamental and the two harmonics.

If an infinite number of harmonics were added to the fundamental waveform, the resultant waveform will be a square wave.



Harmonic Multiples

Harmonic frequencies occur as multiples of the fundamental frequency and are classified as ‘odd’ or ‘even’.

The resultant waveforms produced by odd harmonics are ‘symmetrical’, and include:

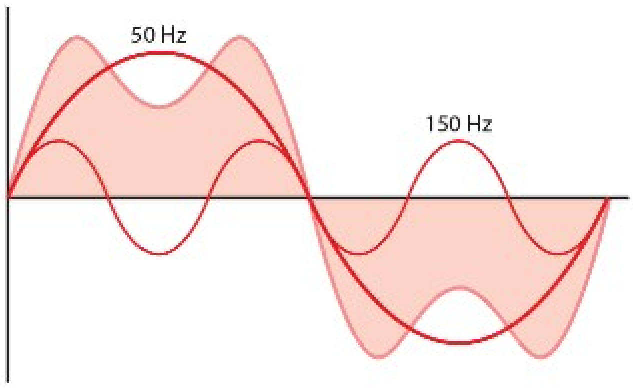
- 3rd harmonic – 3 times 50 Hz = 150 Hz
- 5th harmonic – 5 times 50 Hz = 250 Hz
- 7th harmonic – 7 times 50 Hz = 350 Hz
- 9th harmonic – 9 times 50 Hz = 450 Hz
- etc.

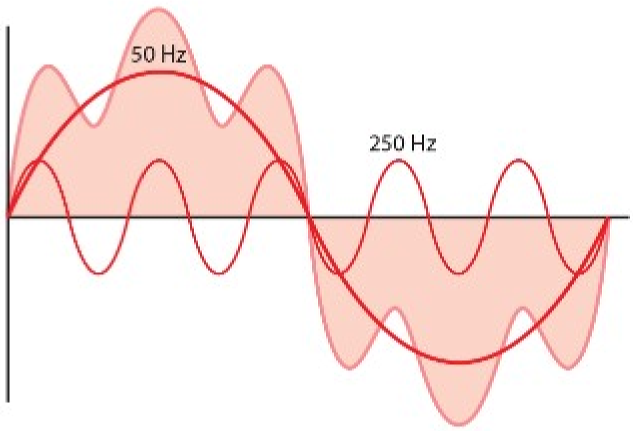
Topics

The resultant wave form produced by even harmonics are ‘asymmetrical’, and include:

- 2nd harmonic – 2 times 50 Hz = 100 Hz
- 4th harmonic – 4 times 50 Hz = 200 Hz
- 6th harmonic – 6 times 50 Hz = 300 Hz
- 8th harmonic – 8 times 50 Hz = 400 Hz
- etc.

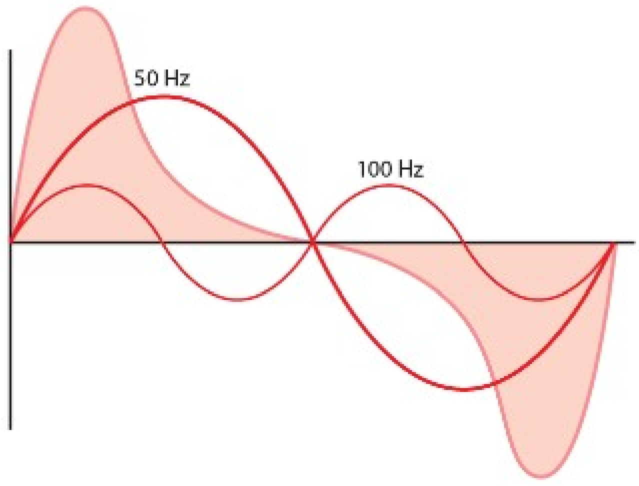
The following table provides some examples of odd and even harmonics and the resultant waveforms of each.

<table>
<tr><th colspan="2">Harmonic Multiples</th></tr>
<tr><th>Harmonic Multiple</th><th>Waveform</th></tr>
<tr><td rowspan="2">Odd harmonics
(symmetrical resultant)</td><td>

Third harmonic
3 times 50 Hz = 150 Hz</td></tr>
<tr><td>

Fifth harmonic
5 times 50 Hz = 250 Hz</td></tr>
</table>

Topics

Even harmonics (asymmetrical resultant)	 Second harmonic 2 times 50 Hz = 100 Hz

Sequence of Harmonics

The ‘sequence’ of a harmonic refers to the phase rotation of the harmonic frequencies in a three phase system, with respect to the phase rotation of the fundamental waveform.

Sequence of Harmonics		
Harmonic Direction of Rotation (relative to fundamental waveform direction of rotation)	**Type of Sequence**	**Example Harmonic**
Same	Positive	7^{th} harmonic
Opposite	Negative	5^{th} harmonic
No rotation	Zero	3^{th} harmonic

Sources of Harmonics

Harmonics in a.c. power systems are caused by ‘non-linear’ loads, which are a.c. loads that draw non-sinusoidal current from a sinusoidal voltage source.

The types of non-linear loads that can cause harmonics include:

- Electronic power supplies
- Variable speed drives
- Computers and printers
- Gas discharge lighting
- Arc furnaces
- Power factor correction (PFC) units

Topics

- In-line uninterruptible power supply (UPS) system

Negative Effects of Harmonics

Excessive harmonics in an a.c. system can have negative effects on the transmission and distribution system components and on consumers' equipment. The negative effects include:

- Overheating of conductors
- Excessive neutral currents
- Nuisance tripping of circuit protection
- Increased vibration in electrical machines
- Failure of a.c. and d.c. drives
- Flickering fluorescent lamps
- Reduced capacitor life
- Overheating of motors and transformers
- False meter readings
- Insulation breakdown

Reducing Harmonic Distortion

Harmonic distortion in a.c. power systems can be reduced by installing equipment designed to filter out the harmonic frequencies. This equipment includes:

- Passive filters
- Active filters
- Line reactors
- Isolation transformers
- Transformer tertiary windings

AS/NZS 3000 Requirements Relating to Harmonics

The AS/NZS 3000:2018 Wiring Rules requires that equipment and wiring be selected and installed that is suitable for any potential harmonic effects. AS/NZS 3000:2018 also provides guidance on the selection of neutral conductors for circuits supplying loads that may generate substantial harmonic currents.

The following table lists specific AS/NZS 3000:2018 clauses relating to harmonics in low voltage a.c. power systems

Topics

AS/NZS 3000:2018 Clauses Relating to Harmonics

Topics

Clause No.	Requirement
2.2.4.3 (Operating characteristics of equipment – current)	Requirement to ensure that electrical equipment is *selected and installed* to be suitable for any potential *harmonic* effects.
3.5.2 (Neutral conductor)	Requirements relating to the selection of *neutral conductors* for circuits supplying loads that generate substantial *harmonic* currents.
4.12.5.1 (Electricity converter protection)	Requirements relating to *circulating harmonic currents* where an *inverter system* is operating in parallel with the distribution network.
7.3.5 (Electricity generation system protection)	Requirements relating to *circulating harmonic currents* in a system consisting of two *parallel-connected standby generators.*

Effects on Conductor Current Carrying Capacity

The current carrying capacity of supply cables is affected by harmonics. Harmonic frequencies, most significantly the *third harmonic*, increase the current in the conductors which increases the heat dissipated by the cables. This can lead to deterioration of the cable insulation.

When conductors carry large harmonic currents, a reduction factor must be applied to the cables to ensure that the maximum insulation temperature is not exceeded.

AS/NZS 3008.1.1:2017 Clause 3.5.9, Table 2 and Appendix C provides guidance on the reduction factors which apply to cables carrying harmonic currents.

Worked Example – Effects on conductor Current Carrying Capacity

A four-core TPS cable is intended to supply a 400 V load with a load current of 65.3 A. Based on the harmonic reduction factors listed in AS/NZS 3008.1.1:2017 Table 2, determine the minimum current carrying capacity for the cable in the event that 25% third order harmonics are expected to be present.

From Table 2, if a 25% third harmonic is present then a reduction factor of 0.86 is applied, and the design load becomes:

$$\text{design load} = \frac{65.3}{0.86}$$

$$\underline{\textit{design load} = 75.93\ A}$$

* The cables supplying the load current (65.3 A) must have a current carrying capacity of at least *75.93 A* when a 25% third harmonic is present.

Summary

[Topics]

- Harmonic frequencies distort the fundamental sine waveform so that it is no longer sinusoidal.
- Harmonics exist as multiples of the fundamental frequency.
- Harmonics are classified as *odd* or *even* harmonics.
- Harmonics are created by non-linear loads.
- The effects of harmonics include:
    - Overheating of cables
    - Increased vibration in machines
    - Flickering fluorescent lamps
    - Excessive neutral currents, etc.
    - Harmonics can be reduced by installing filtering circuits.
- AS/NZS 3000:2018 and AS/NZS 3008.1.1:2017 both provide guidance for dealing with harmonics in a.c. power systems.
- A reduction factor must be applied to cables which carry harmonic currents.

4.2 Series Resonance

Series Resonance

In a RLC series circuit 'series resonance' occurs when the inductive reactance equals the capacitive reactance. When series resonance occurs:

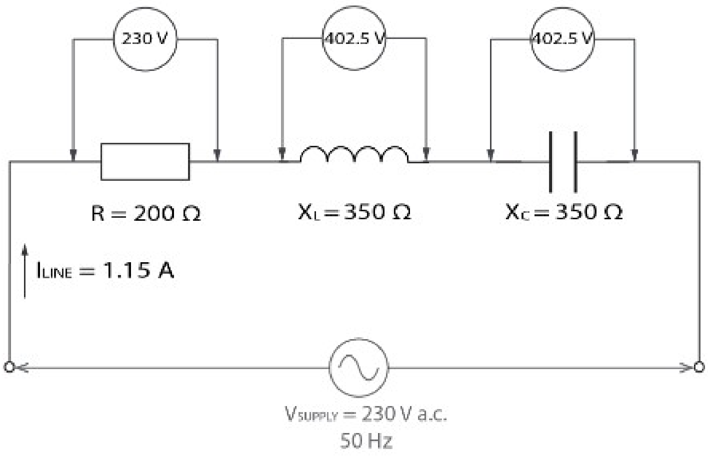
- Impedance is at a *minimum*.
- Line current is *maximum*.
- Phase angle is 0°
- The voltage across the inductor and capacitor can be much greater than the supply voltage.

This diagram shows a RLC series circuit where the inductive reactance equals the capacitive reactance.

Topics

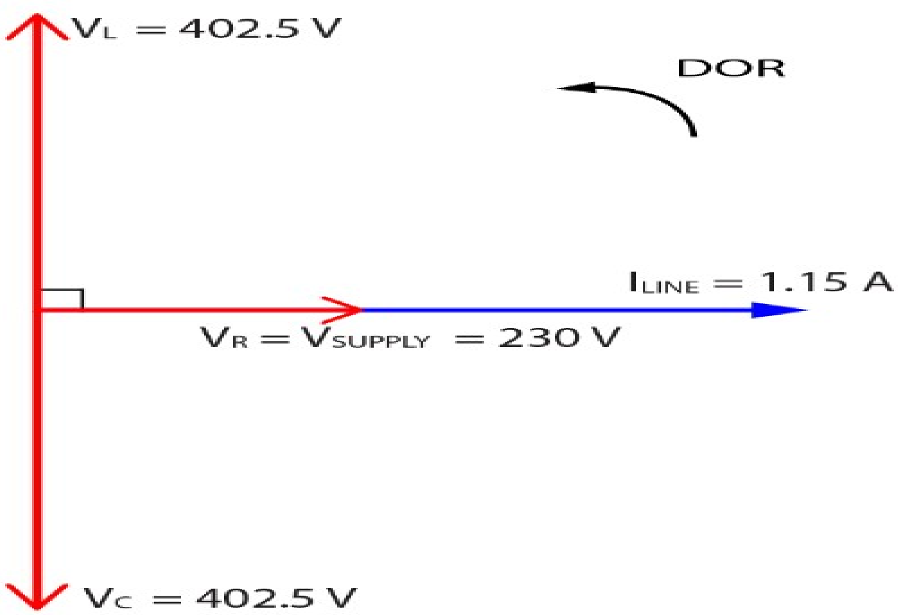
In this diagram:

- $X_L = X_C$ at 50 Hz
- $Z = R$
- $I_{LINE} = V_{SUPPLY}/Z$
- $V_L = V_C$



The phasor diagram for the RLC series circuit shows that:

- V_L and V_C are 180° out-of-phase.
- Voltage drops across V_L and V_C equal 402.5 V,
- The phasor sum of V_L and V_C is zero.
- Voltage drop V_R, equals the supply voltage V_{SUPPLY}, i.e. 230 V a.c.
- Line current I_{LINE}, is in phase with V_{SUPPLY}.



Effects of

Topics

Resonance in a RLC series a.c. circuit can lead to dangerous circuit conditions due to the circuit being at minimum impedance. These conditions include:

- Higher line currents.
- Higher voltages across reactive components resulting in:
    - Insulation failure
    - Component failure

Parallel Resonance

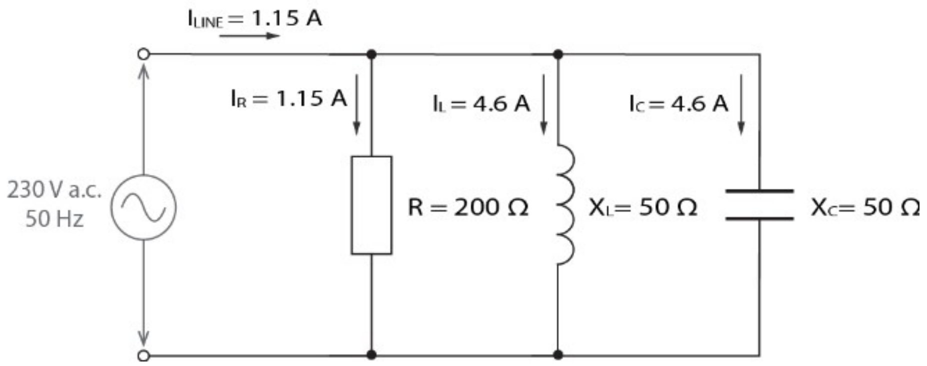
In a RLC parallel a.c. circuit 'parallel resonance' occurs when the inductive reactance equals the capacitive reactance. When parallel resonance occurs:

- Impedance is at a maximum.
- Line current is minimum.
- Phase angle is 0°.
- It is possible for high circulating currents between the inductive and capacitive components.

This diagram shows a RLC parallel a.c. circuit where the inductive reactance equals the capacitive reactance.

In this diagram:

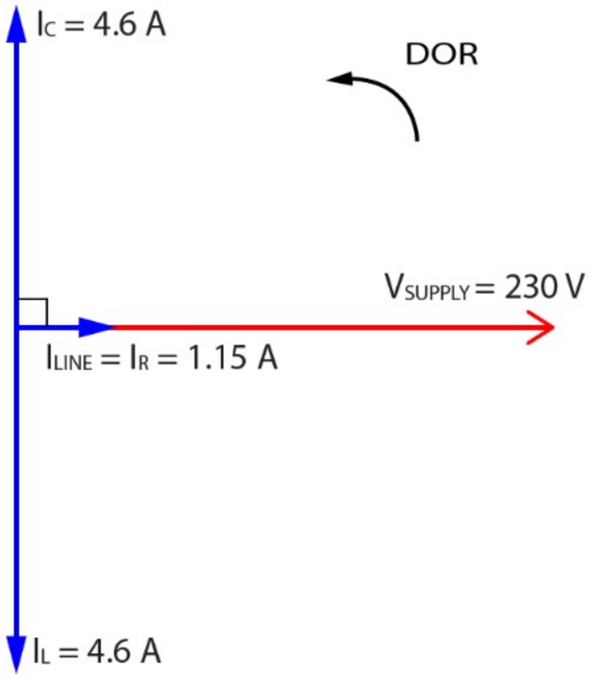
- $X_L = X_C$ at 50 Hz
- Z = R
- $I_{LINE} = V_{SUPPLY}/Z$
- $I_L = V_{SUPPLY}/XL$
- $I_C = V_{SUPPL}Y/X^C$



Topics

The phasor diagram for the RLC parallel circuit shows that:

- I_L and I_C are 180° out-of-phase.
- I_L and I_C equals 4.6 A
- The phasor sum of I_L and I_C is zero.
- Line current I_{LINE}, is in phase with the supply voltage V_{SUPPLY}.



Effects of Parallel Resonance

Resonance in a RLC parallel a.c. circuit can lead to some dangerous circuit conditions due to the possibility of large circulating currents in the inductive and capacitive branches of the circuit. When resonance occurs, energy from the inductor magnetic field is transferred to the capacitor electrostatic field, and back again. This continues as long as the circuit is in resonance.

These large circulating currents can lead to:

- Excessive conductor temperatures.
- Insulation failure.

Generally, parallel resonance is not as likely as series resonance to cause dangerous circuit conditions.

Summary

- Series resonance occurs when the inductive reactance equals the capacitive reactance.
- When series resonance occurs, the impedance is minimum, line current is maximum and the phase angle is 0°.

Topics

- Series resonance can lead to:
    - Higher line current
    - Higher voltages across reactive components
    - Insulation failure
    - Component failure
- Parallel resonance occurs when the inductive reactance equals the capacitive reactance.
- When parallel resonance occurs, the impedance is maximum, line current is minimum and the phase angle is 0°.
- Parallel resonance can lead high circulating currents in the inductive and capacitive branches of the parallel circuit.
- The resonant frequency depends on the relative values of inductance and capacitance in the circuit.

5.1 Earth Fault Loop Impedance Page

Introduction

Low earth fault loop impedance is critical for the safe operation of an electrical installation. If it is too high and an active to earth fault occurs, the circuit protective device may not operate in the required time. This can result in a potentially fatal touch voltage appearing between exposed conductive parts and earth.

This topic will help you develop your understanding of earth fault loop impedance, factors to consider when calculating and measuring the earth fault loop impedance and AS/NZS 3000:2018 requirements.

In Topic 3.1, the critical functions of the neutral conductor in a 4-wire system were outlined.

Two of these functions included:

- To act as the combined protective earth neutral (PEN) conductor in the MEN (multiple earth neutral) system, i.e. to complete the earth fault loop.
- To ensure correct operation of circuit protective devices in the event of an earth fault in the MEN system.

The neutral conductor is an important part of the earth fault loop, which is made up of active, neutral and protective earthing conductors.

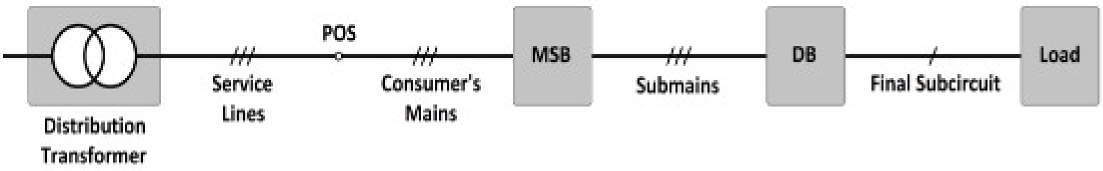
The term earth fault loop impedance refers to the total impedance (ZS) of the path through which a fault current will flow in the event of a short circuit between an active conductor and earth.

The impedance of each conductor in the earth fault loop, adds to the total earth fault loop impedance.

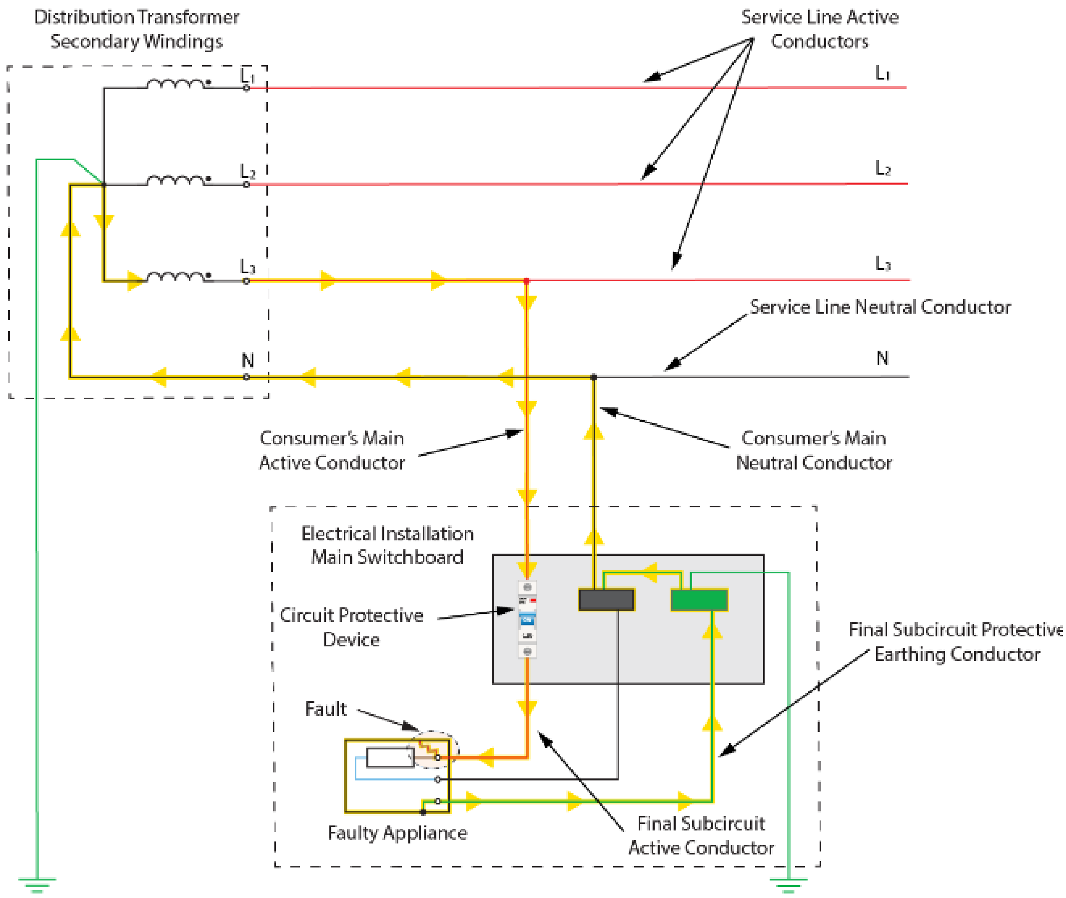
The earth fault loop conductors include:

- Service line active conductor.
- Service line neutral conductor.
- Consumer’s mains active conductor.
- Consumer’s mains neutral conductor.
- Submains active conductor.
- Submains protective earthing conductor.
- Final sub-circuit active conductor.
- Final sub-circuit protective earthing conductor.

Note: The neutral conductors of the submains and the final subcircuit are not part of the earth fault loop.



This diagram shows the earth fault loop in a single phase installation. In the diagram an active to earth fault has occurred at the appliance. The yellow arrows represent the path of the fault current through the earth fault loop conductors, and ultimately back to the distribution transformer secondary winding.



The impedance of the earth fault loop must be very low. A low impedance ensures that a high enough fault current flows, in the event of an earth fault, to enable the protective device to operate to clear the fault in the specified time.

If the earth fault loop impedance is greater than the values specified in AS/NZS 3000:2018, the fault current may be too low to cause the automatic disconnection of the circuit in the required time. A potentially fatal touch voltage may appear between the exposed conductive parts of the appliance and earth.

AS/NZS 3000:2018 Clause 1.5.5.3 Protection by automatic disconnection, sets a limit on the value of Touch Voltage, and specifies the maximum disconnection times for equipment connected to 230/400 V supplies.

These limits are specified in the following table

Topics

Clause 1.5.3.3 Protection by Automatic Disconnection	
Touch Voltage Limits	• 50 V a.c. • 120 V ripple-free d.c.
Disconnection Times	• 0.4 s for final subcircuits supplying socket outlets, hand-held Class I equipment and portable equipment intended for manual movement. • 5 s for other circuits.

Summary

- The earth fault loop includes:
    - Service line active and neutral.
    - Consumer’s mains active and neutral.
    - Submains active and protective earthing conductors.
    - Final subcircuit active and protective earthing conductors.
    - The earth fault loop impedance includes the impedance of all the conductors in the earth fault loop.
- The earth fault loop impedance must be very low to allow high enough fault current to enable automatic disconnection of the supply in the specified time.
- AS/NZS 3000:2018 Clause 1.5.5.3 sets touch voltage limits and maximum disconnection times for automatic disconnection of the supply.

5.2 Australian Standards

Topics

AS/NZS 3000:2018 Requirements

The following table identifies the relevant AS/NZS 3000:2018 clauses relating to the earth fault loop impedance of an installation.

AS/NZS 3000:2007 Requirements for Earth Fault Loop Impedance	
Clause	**Requirement**
1.4.49 (Definitions)	The definition of *earth fault loop impedance.*
1.5.5.3 (Protection by automatic disconnection of supply)	Requirements for providing *protection by automatic disconnection* of the supply.
5.7.2 (Disconnection times)	*Maximum disconnection times* for 230 V circuits.
5.7.4 (Impedance)	Requirements for the *impedance* of the *earthing system*.
8.3.9 (Verification of impedance)	Requirements for *verification* of the installations earth fault loop impedance.

Maximum Values of Earth Fault Loop Impedance

AS/NZS 3000:2018 Table 8.1 specifies the maximum values of earth fault loop impedance for circuits operating at 230 V a.c.

From Table 8.1, the value of earth fault loop impedance (ZS at 230 V) depends on:

- The protective device rating in amperes (A).
- Disconnection times in seconds (s).
- The type of protective device installed:
  - Circuit breaker—Type B, Type C or Type D.
  - HRC fuse.

Worked Example – Maximum Values of Earth Fault Loop Impedance

Topics

Use AS/NZS 3000:2018 Table 8.1 to identify the maximum values of earth fault loop impedance permitted for circuits protected by the following protective devices, to ensure the protective device operates within 0.4 seconds.

a) 6 A Type C circuit breaker

b) 10 A Type B circuit breaker

c) 16 A HRC fuse

d) 20 A Type C circuit breaker

e) A Type D circuit breaker

f) 20 A Type B circuit breaker

g) 63 A HRC fuse

Protective device rating Amps	MCBs on the final subcircuit			Fuses on the final subcircuit	
	Type B	Type C	Type D		
	Disconnection times				
	0.4 s			0.4 s	5 s
	Maximum earth fault-loop impedance Z_s Ω				
6	9.6	5.1	3.1	11.5	15.3
10	5.8	3.1	1.8	6.4	9.2
16	3.6	1.9	1.2	3.1	5.0
20	2.9	1.5	0.9	2.1	3.6
25	2.3	1.2	0.7	1.6	2.7
32	1.8	1.0	0.6	1.3	2.2
40	1.4	0.8	0.5	1.0	1.6
50	1.2	0.6	0.4	0.7	1.3
63	0.9	0.5	0.3	0.6	0.9
80	0.7	0.4	0.2	0.4	0.7
100	0.6	0.3	0.2	0.3	0.5
125	0.5	0.2	0.1	0.2	0.4
160	0.4	0.2	0.1	0.2	0.3
200	0.3	0.2	0.1	0.1	0.2

a) 6 A Type C circuit breaker
$Z_s = 5.1\ \Omega$

b) 10 A Type B circuit breaker
$Z_s = 5.8\ \Omega$

c) 16 A HRC fuse
$Z_s = 3.1\ \Omega$

d) 20 A Type C circuit breaker
$Z_s = 1.5\ \Omega$

e) 40 A Type D circuit breaker
$Z_s = 0.5\ \Omega$

f) 20 A Type B circuit breaker
$Z_s = 2.9\ \Omega$

g) 63 A HRC fuse
$Z_s = 0.6\ \Omega$

Circuit Breaker – Mean Tripping Current

The circuit breaker type designation indicates the mean tripping current, Ia, causing automatic disconnection of the protective device. Ia is a multiple of the nominal rated current of the circuit breaker, as listed in AS/NZS 3000:2018 Appendix B4.5.

- Type B = 4 x rated current.
- Type C = 7.5 x rated current.
- Type D = 12.5 x rated current

Worked Example – Circuit Breaker Mean Tripping Current

Topics

Determine the mean tripping current for the following types of circuit breakers.

a) 32A Type C
b) 16A Type B
c) 20 A Type C
d) 63 A Type D
e) 25 A Type B
f) 10 A Type D

a) 32A Type C

$I_a = 32 * 7.5 = 240A$

b) 16A Type B

$I_a = 16 * 4 = 64A$

c) 20 A Type C

$I_a = 20 * 7.5 = 150A$

d) 63 A Type D

$I_a = 63 * 12.5 = 787.5A$

e) 25 A Type B

$I_a = 25 * 4 = 100A$

f) 10 A Type D

$I_a = 10 * 12.5 = 125A$

AS/NZS 3008.1.1:2017 Reactance and a.c. Resistance Tables

AS/NZS 3008.1.1:2017 provides a.c. resistance and reactance values for various types of cables operating at 50 Hz. The values are given in ohms per kilometre (Ω/km). These values can be used to calculate the impedance of the earth fault loop conductors.

The following table lists the AS/NZS 3008.1.1:2017 table numbers to reference for various common cable types. Tables 30-33 provide Reactance, X_C, values. Tables 34-39 provide a.c. Resistance, $R_{C,}$ values.

AS/NZS 3008.1.1:2017 Resistance and Reactance Tables (at 50 Hz)	
Table Number	**Cable Types**
Table 30 *(Reactance X_C)*	All cables—excluding flexible cords, flexible cables, MIMS and aerial cables.
Table 31 *(Reactance $X_{C)}$*	Flexible cords and flexible cables.
Table 32 *(Reactance $X_{C)}$*	MIMS cables.
Table 33 *(Reactance $X_{C)}$*	Single core aerial cables with bare or insulated conductors.
Table 34 *(a.c. Resistance $R_{C)}$*	Single core cables.
Table 35 *(a.c. Resistance $R_{C)}$*	Multicore cables with circular conductors.
Table 36 *(a.c. Resistance $R_{C)}$*	Multicore cables with shaped conductors.
Table 37*(a.c. Resistance $R_{C)}$*	Flexible cords and flexible cables with copper conductors.
Table 38 *(a.c. Resistance $R_{C)}$*	MIMS cables.
Table 39 *(a.c. Resistance $R_{C)}$*	Single core aerial cables with bare or insulated conductors.

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Worked Example – Determine conductor a.c. resistance

Use AS/NZS 3008.1.1:2017 to determine the total combined a.c. resistance at 50 Hz, of the active and protective earthing conductors within a 25 metre length of 2.5 mm2 Cu twin and earth TPS cable, at a conductor temperature of 75°C.

Refer to AS/NZS 3008.1.1:2017 Table 35 Column 4.

a) R_C – active conductor = 9.01 Ω/km

$$R_{25} = (9.01 \div 1000) \times 25$$

$$R_{25} = 0.23\ \Omega$$

b) R_C – protective earthing conductor = 9.01 Ω/km

$$R_{25} = (9.01 \div 1000) \times 25$$

$$R_{25} = 0.23\ \Omega$$

c) Total resistance – active + protective earthing conductor

$$R_T = 0.23 + 0.23$$

$$\underline{R_T = 0.46\ \Omega}$$

[precise answer (no rounding at intermediate steps) R_T = 0.45 Ω]*

Worked Example – Determine conductor reactance

Use AS/NZS 3008.1.1:2017 to determine the total reactance at 50 Hz, of a single core 4.0 mm2 XLPE active conductor, laid flat touching. The circuit length is 64 metres.

Refer to AS/NZS 3008.1.1:2017 Table 30 Column 7.

a) X_C = 0.146 Ω/km

$$X_{C64} = (0.146 \div 1000) \times 64$$

$$\underline{X_{C64} = 9.34\ m\Omega}$$

Summary

- AS/NZS 3000:2018 specifies the requirements for earth fault loop impedance.

- AS/NZS 3000:2018 Table 8.1 specifies the values of earth fault loop impedance for circuits operating at 230 V.
- The circuit breaker type indicates the mean tripping current causing automatic disconnection of the protective device.
- AS/NZS 3008.1.1:2017 provides reactance and resistance values for different cable types operating at 50 Hz.

6.1 Earthing concepts

Introduction

The ‘multiple earthed neutral’ (MEN) earthing system is an essential and central part of an electrical installation and of the electricity supply network. This system of earthing ensures a stable supply voltage, and allows our protection systems to operate correctly.

Earthing arrangements and connections are a CRITICAL part of an electrical installation. It is very important for electrical workers to have a comprehensive understanding of earthing system components, characteristics and operation, as will be discussed in this topic.

Earthing Terms and Definitions

In order to understand the earthing concepts and principles specified in the Wiring Rules, it is important to first become familiar with several terms and definitions.

Earthing – Terms and Definitions	
Term	**Definition**
Earthed	Connected to both the supply neutral and to the general mass of earth.
Earthed Situation	A situation where there is a reasonable chance of a person simultaneously touching exposed conductive parts of an electrical installation and earth.
Multiple Earthed Neutral (MEN) System	An earthing arrangement where the parts of an electrical installation required to be earthed are bonded together by a network of conductors, which is also connected to both the supply neutral and the general mass of earth.
Earth Electrode	A device, usually a conductive rod, used to connect the earthing system of an electrical installation to the general mass of earth.
Main Earthing Conductor	A conductor that connects the main earthing terminal to the earth electrode. Essentially it connects all installation earthing conductors to the general mass of earth.
Main Earthing Terminal	A point in the main switchboard where all earthing conductors of an installation are connected together.
MEN Link	A connection made between the earth and neutral in the main switchboard of an electrical installation.
Equipotential Bonding	Electrical connections between conductive parts that are not associated with the electrical installation, that are intended to ensure no voltage exists between them.
Protective Earthing (PE) Conductor	A conductor (other than the main earthing conductor) that connects those parts of an electrical installation required to be earthed, to the earthing system. The connection to the earthing system usually occurs at an earth terminal in a switchboard. Protective earths are NOT intended to carry current during normal operation.
Protective Earthing and Neutral (PEN) Conductor	A conductor used as both a protective earthing conductor and a neutral conductor. Unlike other protective earthing conductors, a PEN conductor carries current during normal operation.
Functional Earthing	An earthing arrangement provided to ensure correct operation of electrical equipment (e.g.

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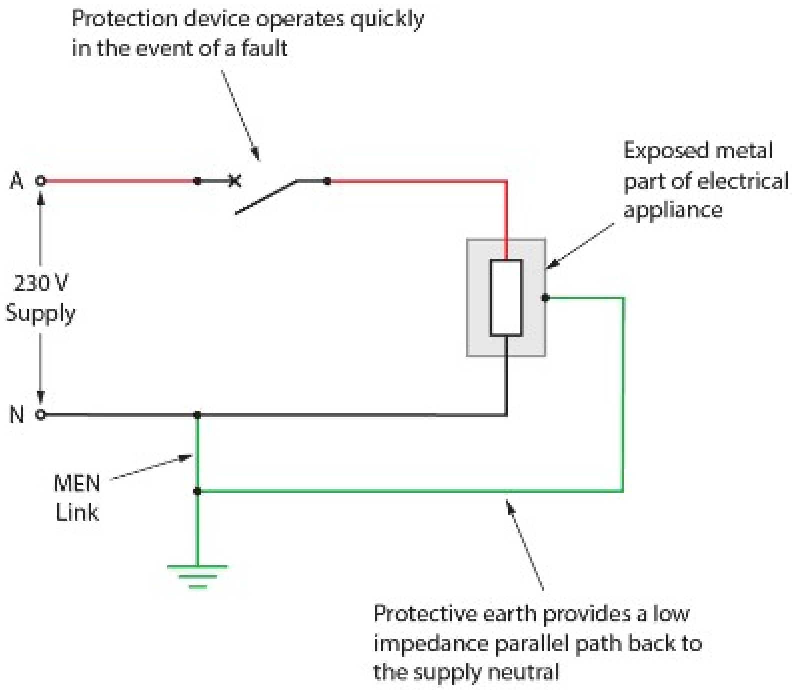
	certain RCDs) or to permit reliable and proper functioning of electrical installations. Functional earthing is not for protective purposes and functional earthing conductors are not intended to carry fault currents.

6.2 MEN earthing systems

The following diagram shows the basic arrangement and operation of protective earthing in a MEN system. In the event of a fault between a live conductor and the exposed metal parts of electrical equipment, the protective earthing conductor provides a low impedance parallel path back to the supply neutral via the MEN link. This low impedance path results in a high fault current, which is actually desirable – the high fault current causes the protection device to operate quickly to disconnect the fault.



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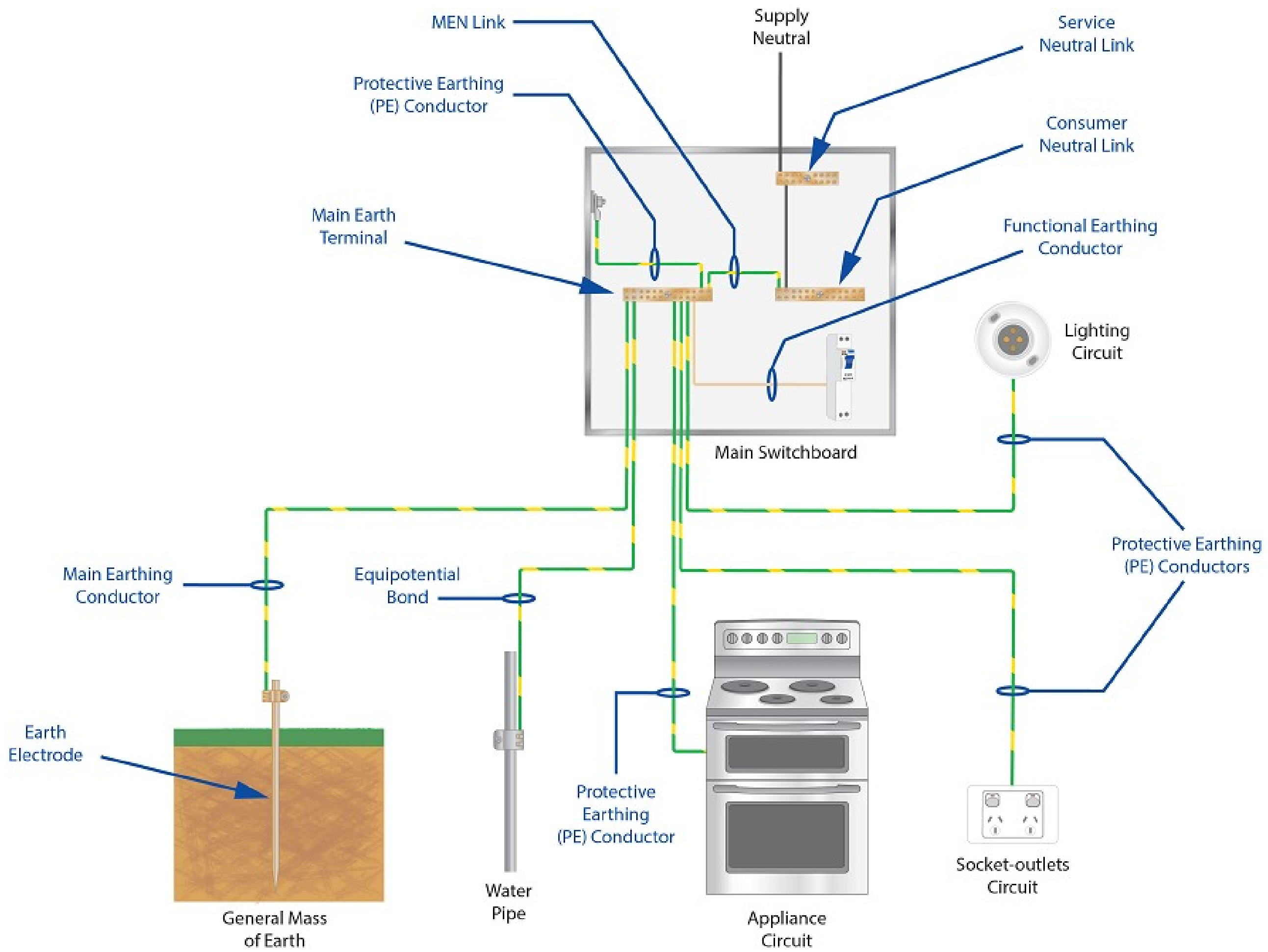
MEN Earthing Arrangements

The following diagram shows the arrangement of MEN earthing system conductors.



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The following table explains the purpose of each MEN system component.

MEN System Components	
Component	**Purpose**
Earth Electrode	To connect the earthing system to the general mass of earth.
Main Earthing Conductor	To provide the connection between the main earth terminal and the earth electrode.
Main Earth Terminal	To provide a point at which all the installation earthing conductors can be connected together.
MEN link	To connect the earthing system to the main neutral conductor.
Equipotential Bonding Conductors	To connect any exposed or extraneous conductive parts together and to the earthing system.
Protective Earthing (PE) Conductors	To provide a low impedance path for earth fault currents.
Functional Earthing	To allow correct operation of certain electrical equipment.

Selecting Earthing Conductors

In the event of a fault, an earthing conductor must be capable of carrying the prospective earth fault current, until the circuit is disconnected by the protection device. Protection devices are intended to operate very quickly in the event of a fault, so the earthing conductor will not generally need to carry the fault current for a long duration.

Earthing conductor sizes are selected based on the size of the associated circuit active conductor, but this method cannot be solely relied upon. The impedance of the earth fault loop must be verified.

Section 5 of AS/NZS 3000:2018 provides guidance on the selection of minimum sizes for earthing conductors (see Table 5.1), Section 8 specifies minimum values of earth fault loop impedance (see Table 8.1) and final subcircuit active and earthing conductor resistance (see Table 8.2).

Maximum Circuit Length

The two main variables that will affect the impedance of the earth fault loop are the c.s.a (i.e. size) and length of the associated active and earthing conductors. Increasing the c.s.a. of the conductors reduces the impedance, whilst increasing the length of the conductors increases the impedance.

AS/NZS 3000:2018 Appendix B provides guidance on determining maximum permissible circuit lengths for different cable sizes and protection devices. The following equation can be used to determine the maximum lengths for circuit wiring:

$$L_{max} = \frac{0.8\, U_o\, S_{ph}\, S_{pe}}{I_a\, \rho\, (S_{ph} + S_{pe})}$$

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Where:

L_{max} = maximum route length in metres (m)

U_o = nominal phase voltage in volts (V)

S_{ph} = cross-sectional area of the active conductor in square millimetres (mm^2)

S_{pe} = cross-sectional area of the protective earthing conductor in square millimetres (mm^2)

I_a = instantaneous trip current for the protection device in amperes (A)

ρ = conductor resistivity:

- 22.5 x 10-3 for copper
- 36 x 10-3 for aluminium

Worked Example – Maximum Circuit Length

Determine the maximum permitted circuit length for a 230 V final subcircuit that is protected by a 32 A Type C circuit breaker, and is supplied by a 4 mm^2 two-core and earth TPS cable, with a 2.5 mm^2 protective earthing conductor.

The 32 A Type C circuit breaker has an instantaneous tripping current of 7.5 times the nominal current rating (see AS/NZS 3000:2018 Clause B4.5).

$$I_a = 32 \times 7.5$$

$$I_a = 240\,A$$

$$L_{max} = \frac{0.8 \times 230 \times 4 \times 2.5}{240 \times (22.5 \times 10^{-3}) \times (4 + 2.5)}$$

$$L_{max} = \frac{1840}{35.1}$$

$$L_{max} = 52.42\text{ m}$$

Note: Refer to AS/NZS 3000:2018 Table B1 for maximum cable lengths of common wiring and protection device arrangements.

Equipotential Bonding

Equipotential bonding is required for:

- Conductive piping that is accessible in the installation and in contact with the general mass of earth.
- Conductive sheaths, armour or wiring enclosures associated with circuits operating above ELV.
- Conductive reinforcement in the concrete walls or floors of a bathroom/shower.
- Exposed and extraneous conductive parts in any zone of a swimming pool or spa.

Generally, equipotential bonding conductors should not have a cross-sectional area of less than 4 mm^2. The requirements for equipotential bonding can be found in section 5 of AS/NZS 3000:2018.

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