RTB | RWANDA TVET BOARD

RQF LEVEL 5

GENIE501

MANUFACURING TECHNOLOGY

Basic Industrial Electricity

TRAINEE'S MANUAL

October, 2024

BASICS OF INDUSTRIAL ELECTRICITY

2024

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TABLE OF CONTENT

ACRONYMS

AC: Alternative Current

ANSI: American National Standards Institute

CB: Circuit Breaker

CBT/A: Competency-Based Training and Assessment

DC: Direct Current

DOL: Direct Online (DOL) starter

FLC: Full Load Current

GND: Ground

IC: Indicative content

IEC: International Electrotechnical Commission

KOICA: Korea International Cooperation Agency.

MCB: Miniature Circuit Breaker

NC: Normally Closed

NO: Normally Open

PPE: Personal Protective Equipment

RCD: Residual Current Device

RMS: Root Mean Square

RPM: Revolution Per Minute

RQF: Rwanda Qualification Framework

RTB: Rwanda TVET Board

SPD: Surge Protective Device

TQUM Project: TVET Quality Management Project

TVET: Technical and vocational education and training

INTRODUCTION

This trainee's manual includes all the knowledge and skills required in Manufacturing Technology specifically for the module of **"Basics of Industrial Electricity".** Trainees enrolled in this module will engage in practical activities designed to develop and enhance their competencies. The development of this training manual followed the Competency-Based Training and Assessment (CBT/A) approach, offering ample practical opportunities that mirror real-life situations.

The trainee's manual is organized into Learning Outcomes, which is broken down into indicative content that includes both theoretical and practical activities. It provides detailed information on the key competencies required for each learning outcome, along with the objectives to be achieved.

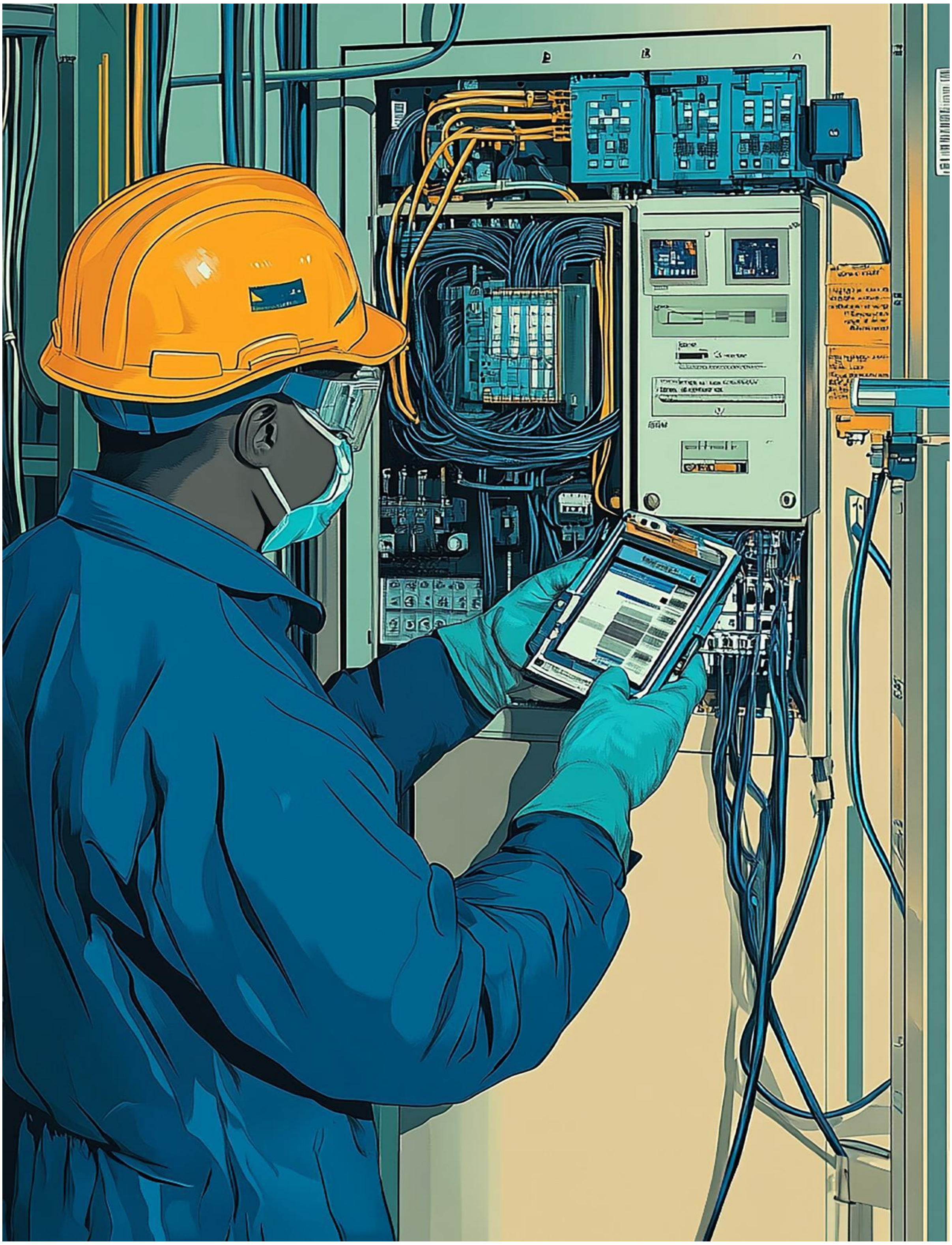
As a trainee, you will start by addressing questions related to the activities, which are designed to foster critical thinking and guide you towards practical applications in the labour market. The manual also provides essential information, including learning hours, required materials, and key tasks to complete throughout the learning process.

All activities included in this training manual are designed to facilitate both individual and group work. After completing the activities, you will conduct a formative assessment, referred to as the end learning outcome assessment. Ensure that you thoroughly review the key readings and the 'Points to Remember' section.

MODULE CODE AND TITLE: MATIE501 BASICS OF INDUSTRIAL ELECTRICITY

Learning Outcome 1: Apply power supply principles.
Learning Outcome 2: Apply 3-phases circuit working principles.
Learning Outcome 3: Apply winding principles.

Learning Outcome 1: Apply Power Supply Principles



Indicative contents
1.1 Introduction of electrical industrial power supply **1.2 Applying electrical safety at workplace** **1.3 Identifying power supply system** **1.4 Identifying electrical protection devices**

Key Competencies for Learning Outcome 1: Apply Power Supply Principles

Knowledge	Skills	Attitudes
• Description of power supply system • Identification of Electrical hazard at workplace • Explanation of faults in power system • Explanation of elements of electrical protection devices	• Applying electrical safety at workplace. • Ensuring that power supplies match the requirements of the devices they power • Designing power supply • Diagnosing and fixing issues in power supply system	• Having time management spirit while applying electrical safety at workplace • Being hard worker while designing power supply • Being accountable during controlling power supply working principles • Being critical thinker while diagnosing and fixing issues in power supply system • Being vigilant while applying electrical safety at workplace • Being respectful to the available rules and regulations.

Duration: 10 hrs

Learning outcome 1 objectives:

By the end of the learning outcome, the trainees will be able to:

1. Describe appropriately electrical industrial power supply system according to the electrical circuit.
2. Identify correctly electrical hazard at workplace.
3. Explain clearly the types of faults in power system.
4. Apply properly electrical safety at workplace according to the OSHE standards.
5. Identify correctly electrical protection devices used in industrial electricity.

Resources

Equipment	Tools	Materials
• PPEs (safety Gloves, safety shoes, overall, safety goggles) • Batteries • Generators • Fire extinguisher • Alarm • First aid kit	• Wire strippers, • Screwdrivers, • Insulated pliers, • Cable cutters, • Spanners • Voltage tester • Safety sign plate • Multimeters • Clamp meter	• Fuses • Wires • Timer relays • Lamps • Cable Tie • Lamp holders • Screws • Connectors • Cable clips • Cables • Insulators • Push button • Auxiliary contact • Switch box • Junction boxes • Circuit breaker • Transformer • Rectifier

Indicative content 1.1: Introduction of Electrical Industrial Power Supply

Duration: 2 hrs

Theoretical Activity 1.1.1: Description of electrical industrial power supply

Tasks:

1. Answer the following questions related to electrical industrial power supply:
   i. What do you understand about industrial electricity power supply?
   ii. According to your understanding, what is the function of the power supply?
   iii. What do you think are the components of power supply?
2. Write the answers on papers/flipcharts.
3. Present the answers to the whole class.
4. Ask clarifications where necessary.
5. Read the key readings 1.1.1

Key readings 1.1.1: Description of electrical industrial power supply

- **Definition of power supply**

✓ **A power supply** is a device or system that provides electrical energy to power electronic or electrical devices. It converts electrical energy from a source, such as an electrical outlet, battery, or generator, into a form suitable for use by the devices it powers.

✓ **Main power supply:** The main power supply is the primary source of electrical power for a system or device, typically connected to the utility grid and another primary source, providing essential power for normal operation.

✓ **Backup power supply:** A backup power supply is a secondary source used to provide electrical power when the main power supply fails or is interrupted, ensuring critical systems and equipment remain operational during power outages or disruptions. (Example: uninterruptible power supplies, generator set and battery backup systems).

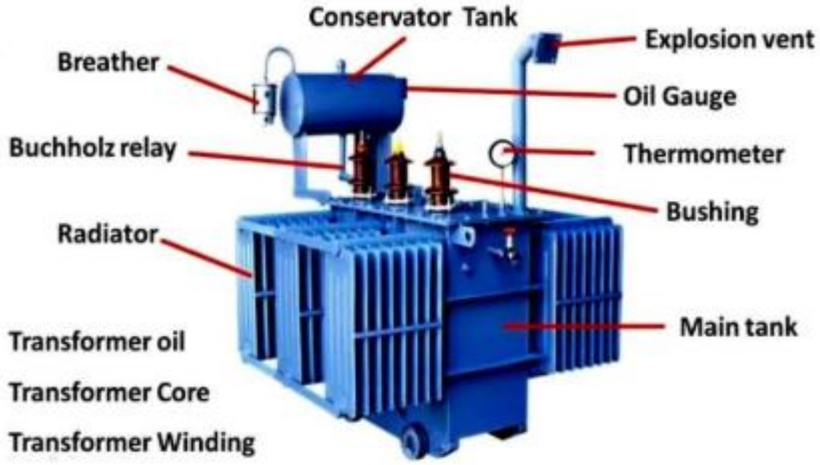
✓ **Regulated power supply:** A regulated power supply maintains a constant output voltage or current, ensuring stability for sensitive electronic devices. There are two main types: linear and switching. Linear supplies use linear regulators for low noise and simplicity, while switching supplies use high frequency switching and feedback mechanisms for efficiency and compactness, but may generate more electrical noise.

- **The function of power supply:**
  - ✓ The function of a power supply is to convert electrical energy from a source into the correct voltage, current, and frequency to power a device or system.
  - ✓ It provides the necessary power to operate electronic devices, ensuring they receive a stable and appropriate electrical input.
  - ✓ Power supplies can be AC (alternating current) or DC (direct current) and can regulate the output to protect devices from surges and spikes in the input power.

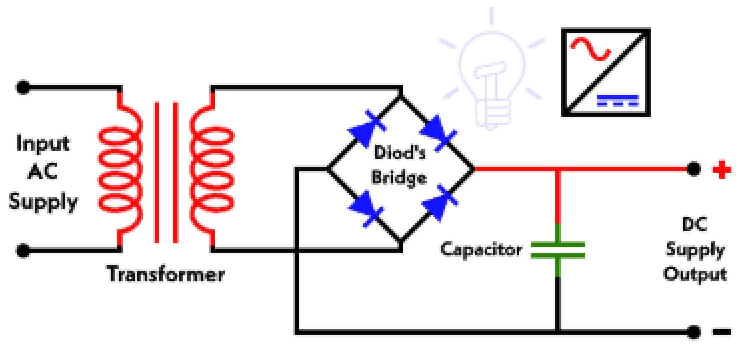
- **Identification of power supply components**

A power supply typically consists of the following components:

- ✓ **Transformer:** Steps up or steps down the voltage level from the input power source to the desired level.

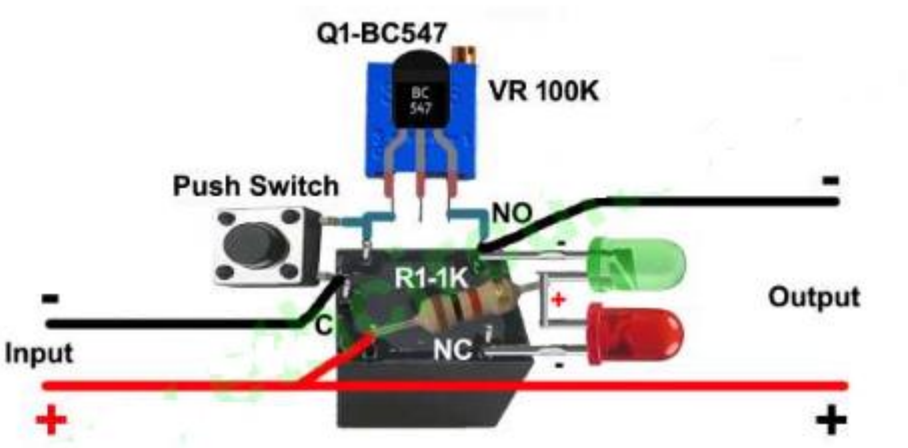


- ✓ **Rectifier**: Converts the AC (alternating current) input into DC (direct current) output. Common types include half-wave, full-wave, and bridge rectifiers.

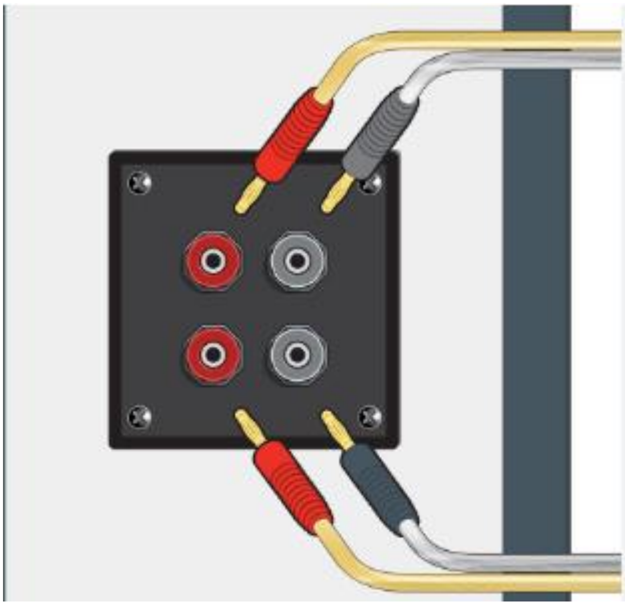


- ✓ **Voltage Regulator:** Maintains a constant output voltage despite variations in input voltage or load conditions. This component ensures the output remains stable.

- ✓ **Protection Circuit:** Protects the power supply and the connected device from over-voltage, over-current, overheating, or short circuits. Components like fuses, circuit breakers, and thermal shutdowns are commonly used.



- ✓ **Input and Output Terminals/Connectors:** Provide the points for connecting the input power source and delivering the output power to the connected device.



Points to Remember

- Remember that the voltage and current are the main and primary specifications to consider while selecting power supply.
- A power supply converts electrical energy into suitable form for devices it powers. It can be a main, backup and regulated power supply.
- A regulated supply maintains constant output voltage for sensitive electronic devices, using transformers, rectifiers, filters, regulators, and protection circuits.

Application of learning 1.1.

Go in manufacturing workshop, observe electrical installation of mechanical machines and identify the followings:

- The power supply used in manufacturing workshop.
- The functions of power supply used in manufacturing workshop.
- The components of power supply used in manufacturing workshop.
- Make a report detailing what acquired as new knowledge during the visit.

Indicative content 1.2: Applying Electrical Safety at Workplace

Duration: 2 hrs

Theoretical Activity 1.2.1: Description of electrical safety at workplace

Tasks:

1. Answer the following questions related to electrical industrial power supply:
   i. According to your understanding, what are the types of electrical hazards at the workplace?
   ii. What do you understand by the electrical hazard symbols? Moreover, give examples.
   iii. What do you think are the causes of electrical hazards?
   iv. According to your understanding, what are the Control measures for electrical hazards?
2. Write the answers on papers/flipcharts.
3. Present the answers to the whole class.
4. Ask clarifications where necessary.
5. Read the key readings **1.2.1**

Key readings 1.2.1: Identification of Electrical hazards at workplace

- **Definition of electrical hazards**

Electrical hazard refers to the electrical risks and potential dangers that are associated with electrical systems. These electrical hazards can cause danger like electric shock, electrocution, burns, arc flash and serious injuries. In severe cases, these hazards can even lead to explosions or fires, posing a risk to human life, assets and the overall protection of a place and its residents.

✓ **Electrical Hazards Examples**

The most common electrical hazards are; improper earthing, insufficient wiring., exposed electrical parts, overloaded circuits, wet conditions, damaged insulation, damaged tools, damaged equipment and overhead power lines.

- Faulty Wiring: Poorly installed and damaged wiring can lead to short circuits, electrical shock, and fires.

- Overloaded Circuits: Exceeding the safe capacity of an electrical circuit can cause overheating, leading to fires and damage to connected devices.
- Damaged Insulation: Damaged insulation on wires can expose live conductors, increasing the risk of shock or fire.
- Uninsulated tool/equipment: uninsulated too can lead to dangerous shock hazards.
- Improper Grounding: Failure to properly ground electrical systems and equipment can lead to dangerous shock hazards.
- Wet Conditions: Water is a good conductor of electricity, so working with electrical equipment in wet conditions increases the risk of shock.
- High Voltage area: high voltage could cause severe injury and death.

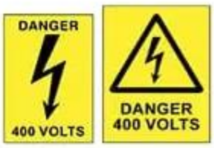
✓ **Types of electrical hazards**

- Electrical Shock: Occurs when a person encounters a live electrical conductor, causing current to pass through the body, potentially leading to serious injury and death.
- Electrical Burns: Result from the heat generated by the flow of electrical current through the point of contact with an energized source.
- Arc Flash: A sudden release of electrical energy through the air, caused by a fault and short circuit. It can result in intense heat, light, and pressure, leading to severe burns or death.
- Arc Blast: Accompanies an arc flash, creating an explosion that can cause shrapnel injuries and fatalities.
- Fire Hazards: Electrical faults, such as short circuits and overloaded circuits, can generate heat, leading to fires that may cause property damage or endanger lives.
- Explosions: Electrical equipment in hazardous environments (example: flammable gases and dust) can ignite these substances, causing explosions.

✓ **Electrical hazard symbols**

- High Voltage Symbol: Warns of the presence of high voltage that could cause severe injury and death.
- Electrical Shock Risk Symbol: Indicates areas where there is a risk of electrical shock.
- Static Electricity Hazard Symbol: Alerts to areas where static electricity might cause harm or damage sensitive electronic components.
- Electrical Equipment Symbol: Identifies locations and devices that are electrically powered and require caution.

- Earthing Symbol: Indicates grounding points where electrical equipment is connected to the earth to prevent shock.
- Isolation Symbol: Used to mark equipment that should be isolated before maintenance.



Voltage warning labels


Electrical voltage symbol

Danger of death from electricity warning

Switch off when not in use

Electric shock warning

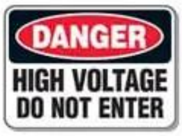
High voltage warning

Overhead cables warning

Live wires warning

Buried cables warning

Mains voltage warning



Danger do not enter sign

Warning to isolate before removing cover

✓ **Causes of electrical hazards**

The hazards in the following are the most common causes of electrical hazards, which are discussed below:

- Inadequate Insulation: Electrical insulation over time can go down because of rodents, exposure to moisture and corrosion. This degradation leads to exposed electrical wires and enhances the hazard of short circuits and electric shock.
- Failure of Circuit Breaker: If the CB fails to trip throughout an overload condition, then it loses its protecting function and increases the possibility of electrical hazards.
- Injured Electrical Appliances: Cracked insulation, loose wire connections and frayed wires result in electrical malfunctions.
- Poor Maintenance: Failing to frequently inspect electrical systems, and warning signs ignoring and bypassing security procedures can activate severe electrical hazards eventually.

- Improper Grounding: Failure to properly ground electrical systems and equipment can lead to dangerous shock hazards.
- Wet Conditions: Water is a good conductor of electricity, so working with electrical equipment in wet conditions increases the risk of shock.
- Lack of Maintenance: Neglecting regular maintenance of electrical systems and equipment can result in undetected faults and failures.
- Human Error: Accidental contact with live electrical parts and improper use of electrical equipment can cause injuries.

✓ **Control measures for electrical hazards**

- Proper Installation: Ensure qualified professionals according to relevant codes and standards install electrical systems.
- Regular Maintenance: Conduct routine inspections and maintenance of electrical systems to identify and rectify potential hazards.
- Use of PPE (Personal Protective Equipment): Workers should use appropriate PPE, such as insulated gloves and protective clothing, when working with electrical systems.
- Isolation Procedures: De-energize and isolate electrical equipment before performing maintenance.
- Grounding and Bonding: Properly ground electrical systems and ensure that bonding connections are intact to prevent shock hazards.
- Circuit Protection Devices: Use fuses, circuit breakers, and ground fault circuit interrupters (GFCIs) to protect against overcurrent, short circuits, and ground faults.
- Training and Awareness: Provide regular training for workers on electrical safety, including the identification of hazards and the correct procedures to follow.
- Safe Work Practices: Encourage adherence to safety protocols, such as lockout procedures, when working with electrical equipment.
- Signage and Labels: Clearly mark electrical hazards with appropriate warning signs and labels to alert personnel to potential dangers.

✓ **Personal Protective equipment (PPEs) used at workplace**

Personal Protective Equipment (PPE) is essential in workplaces to protect employees from various hazards. Common PPE includes head, eye, face, hearing, respiratory, hand, foot, body, fall, skin, and specialized PPE. PPE should be used in conjunction with other safety measures like engineering controls, administrative controls, and safe work practices to ensure a safe work environment.

Practical Activity 1.2.2: Applying electrical safety at the workplace

Task:

1: Request the trainees to wear PPEs and go in manufacturing workshop.

2: Respect workshop safety regulations.

3: Follow the instructions from your trainer.

4: Start to identify all electrical hazards in manufacturing workshop.

5. Present your findings to the trainer and whole class.

6: Read key reading 1.2.2 and ask clarification where necessary.

7: Perform the task provided in application of learning 1.2.

Key readings 1.2.2: Applying electrical safety at the workplace

- **Identification of electrical hazards methods and considerations**

  Electrical hazards pose serious risks to safety and operational efficiency, making their identification critical for preventing accidents and equipment damage. Various methods are employed to detect these hazards, each with its specific advantages depending on the context.

  ✓ **Visual Inspection**: A straightforward and effective method, visual inspection involves looking for obvious signs of damage, such as frayed wires, exposed conductors, loose connections, and corrosion. Inspectors also check for overloaded circuits and malfunctioning equipment. Regular visual checks can help detect hazards early, minimizing the risk of electrical failures.

  ✓ **Testing:** Electrical testing with specialized equipment, such as multimeters and insulation resistance testers, provides more in-depth hazard identification. Testing allows for measuring current, voltage, and resistance, ensuring that electrical systems are operating within safe limits. This method can detect issues like short circuits, faulty grounding, and insulation breakdown, which are not always visible.

  ✓ **Auditing:** An electrical safety audit involves a comprehensive review of electrical systems, procedures, and safety measures. It evaluates compliance with safety standards and identifies areas of potential improvement. Audits often involve both visual inspection and testing, providing a holistic approach to hazard identification.

  ✓ **Consulting Standards and Regulations:** Electrical hazards can be identified by ensuring compliance with local and international standards, such as the National Electrical Code (NEC) or the International Electrotechnical Commission (IEC) standards. These regulations offer clear guidelines for safe electrical installations, helping prevent hazards by ensuring systems are designed and maintained according to best practices.

  ✓ **Environmental Factors:** Environmental conditions can significantly affect electrical systems. Factors such as temperature, humidity, dust, and vibrations must be considered. Excessive heat can degrade insulation, while moisture may cause short circuits or corrosion. Dust can accumulate in electrical enclosures, increasing the risk of fire or equipment malfunction. Vibration from nearby machinery can loosen connections, creating potential hazards.

Points to Remember

- Electrical hazards in the workplace include shock, burns, arc flash, fire hazards, and explosions.
- The causes of electrical hazards include defective wiring, overloaded circuits, damaged insulation, improper grounding, and human error.
- Several types of electrical hazard warning signs and labels can be used, including danger signs, warning signs, caution signs, and labels. Signs and labels should be placed in areas where electrical hazards are present, such as on electrical panels, switch gear, and other equipment.
- The control measures of electrical hazards include proper installation, regular maintenance and use of Personal Protective Equipment (PPE).
- Personal Protective Equipment (PPE) is essential in workplaces to protect employees from various hazards.
- Detecting potential electrical hazards is crucial for minimizing risks

Application of learning 1.2.

Go in manufacturing workshop and identify the followings:

- The types of electrical hazard observed in that manufacturing workshop.
- The symbols of electrical hazard used in that manufacturing workshop.

Make a report detailing what acquired as new knowledge during the visit.

Indicative content 1.3: Identifying Power Supply System

Duration: 3 hrs

Theoretical Activity 1.3.1: Identifying power supply system

Tasks:

1. Answer the following questions:
   i. According to your understanding, what are the power supply system specifications?
   ii. What do you think are the types of the power supply system?
   iii. According to your understanding, identify the power supply control technic
2. Provide answers to asked questions on papers.
3. Present the findings/answers to the whole class.
4. Ask clarifications where necessary.
5. Read the key readings 1.3.1

Key readings 1.3.1: Identifying power supply system

- **Power supply system specifications**
  - ✓ Input Voltage: The range of voltage that the power supply system can accept from the input source. For example, a typical specification might be 100-240V AC for an AC power supply.
  - ✓ Input Frequency: The range of input frequency that the power supply can handle. Standard input frequencies are 50Hz or 60Hz, depending on the region.
  - ✓ Maximum Power Input: The highest amount of power the system can consume from the input source, typically measured in watts (W) or kilowatts (kW).
  - ✓ Input Current: The amount of current drawn from the input power source by the power supply system, usually measured in amperes (A).
  - ✓ Efficiency: The ratio of the output power to the input power, typically expressed as a percentage. Higher efficiency means less energy loss during the conversion process.
- **Types of power supply system**

✓ DC Power Supply: Converts AC input power to DC output. Used in electronics, communications, and computer systems. Types include linear regulators, switching regulators, and battery chargers.

- ✓ AC Power Supply: Delivers AC power to devices, often without conversion. Commonly used in household appliances, industrial equipment, and large-scale power distribution.
- ✓ Hybrid Power Supply: Combines both AC and DC outputs, or integrates multiple power sources (example: solar, battery and grid). Used in renewable energy systems, backup power solutions, and complex industrial applications.
- **Power supply control technics**
- ✓ Monitoring System: it continuously tracks power supply parameters such as voltage, current, and temperature. It alerts users or automatically adjusts the system to maintain optimal performance and prevent faults.
- ✓ Relay Protection System: it uses relays to detect abnormal conditions (example: overcurrent, short circuit) and disconnect the power supply to prevent damage. It provides protection for electrical circuits and equipment, ensuring safe operation.
- ✓ DC Power Supply System: it involves regulating and distributing DC power, often used in telecommunications, IT, and electronics. Control techniques focus on voltage stabilization, current limiting, and thermal management.
- ✓ Frequency Control: it maintains the frequency of the power supply to match the requirements of the connected load. Essential for AC power systems where precise frequency is crucial for the operation of motors, clocks, and other sensitive equipment.

Points to Remember

- Power supply system specifications include input voltage, frequency, maximum power input, input current, and efficiency.
- Types of power supply system include DC, AC, and hybrid system.
- Power supply control technics include monitoring system, relay protection system, DC power supply system, and frequency control.

Application of learning 1.3.

Go in manufacturing workshop, observe power supply system and identify the followings:

- The specifications of power supply system used in manufacturing workshop.
- The types of power supply system used in manufacturing workshop.
- The power supply control technics used in manufacturing workshop.

Make a report detailing what acquired as new knowledge during the visit.

Indicative content 1.4: Identifying Electrical Protection Devices

Duration: 3 hrs

Theoretical Activity 1.4.1: Identifying electrical protection devices

Tasks:

1. Answers the following questions:
    i. According to your understanding, identify the purpose of protecting electrical system.
    ii. What do you think are the principle types of faults in the power system?
    iii. According to your understanding, identify the elements of electrical protection system.
    iv. According to your understanding, identify the types of electrical protection devices.
2. Provide answers to asked questions on papers.
3. Present the findings/answers to the whole class.
4. Ask clarifications where necessary.
5. Read the key readings 1.4.1

Key readings 1.4.1: Identifying electrical protection devices

- **Purpose of protecting electrical system**

Electrical system protection is crucial for personnel, equipment, reliability, regulatory compliance, economic considerations, environmental protection, and data protection. Protection mechanisms like insulation, grounding, and circuit breakers prevent electrical shock, fire, and equipment damage. They disconnect faulty parts, ensure power is generated, transmitted, and distributed with minimal interruptions and restoration time.

- **Principle types of faults in power system**

In power systems, faults are undesired conditions that occur due to various reasons such as equipment failure, insulation breakdown and environmental factors. The two principal types of faults in a power system are:

- ✓ **Open circuit fault:** It occurs when there is a break in the continuity of the circuit. A broken conductor, a loose connection and any situation can cause this fault where the current path is interrupted.
    - Causes of open circuit are broken wires, disconnected wires, fuse operation, and tripped circuit breakers.

- Effects of open circuit: It is typically result in no current flow in the affected part of the system, which can lead to loss of supply to the connected loads. The voltage across the open circuit will be at its maximum value.

- ✓ **Short circuit fault:** It occurs when there is a direct connection between two points in the circuit that should not be directly connected, resulting in a low-resistance path and excessive current flow.
    - Causes of short circuit are insulation failure, physical damage to cables, conductive objects meeting live parts.
    - Effects of short circuit are the extremely high currents, which can cause severe damage to equipment, overheating, fires, and power outages if not quickly isolated by protective devices.

- **Elements of electrical protection system**

A protection system consists of Current & Voltage Transformers, protective relays, circuit breakers, and batteries.

- ✓ Current transformers (CT's) & Potential Transformers (PT's): The purpose of these transformers is to reduce the current and voltage so that it could be used by relays for operation.
- ✓ Protective Relays: The purpose of relays is to detect the fault and initiate a trip sequence when an electrical quantity (example, voltage, current, frequency, phase-angle, etc.) goes beyond the normal range. Hence it will send a command to the circuit breaker to disconnect the faulty part.
- ✓ Circuit Breakers: The purpose of the circuit breakers is to operate on the trip sequence initiated by the relays in order to open the circuit.
- ✓ Batteries: The batteries are used as back up power supply in the event of mains supply failure.

- **Types of protection devices**

The circuit protection device is an electrical device used for preventing an unnecessary amount of current otherwise a short circuit. To ensure the highest security, there are many protection devices available in the market which offers you a total range of protection devices for circuits such as a fuse, circuit breakers, RCCB, SPD, and more.

- ✓ **Fuse:** In electrical circuits, a fuse is an electrical device used to protect the circuit from overcurrent. It consists of a metal strip that liquefies when the flow of current through it is high. Fuses are essential electrical devices, and there are different types of fuses available in the market today based on specific voltage and current ratings, application, response time, and breaking capacity.

- ✓ **A circuit breaker:** A circuit breaker is one kind of electrical switch used to guard an electrical circuit against short circuit otherwise an overload that will cause by excess current supply. The basic function of a circuit breaker is to stop the flow of current once a fault has occurred. Not like a fuse, a circuit breaker can be operated either automatically or manually to restart regular operation.

  - **MCB stands for Miniature Circuit Breakers.** The MCB is an electromechanical device that switches off the circuit automatically if an abnormality is detected. The MCB easily senses the overcurrent caused by the short circuit.

  - **MCCB is an abbreviation for Molded Case Circuit Breaker.** The MCCB is a protective device protecting the circuit from overloading. Additionally, it has a switch that is operated manually for tripping the circuit. The device features two arrangements, one for the overcurrent and one for the over-temperature. Moreover, the MCCB consists of bimetallic contact, which contracts and expands when the MCCB temperature changes.

- ✓ **RCD:** The RCD-residual current device (or) RCCB- residual current circuit breaker is a safety device that notices a problem in your home power supply then turns OFF in 10-15 milliseconds to stop electric shock. A residual current device does not give safety against short circuit or overload in the circuit, so we cannot change a fuse instead of RCD.

- ✓ **SPD:** The term SPD stands for Surge Protection Device is one type of component used in an electrical fitting security system. The SPD device is allied in parallel in the power supply circuit, which can be used on all stages of the power supply system. The surge protection device is the most frequently used and well-organized kind of over-voltage protective devices.

- ✓ **Over voltage protector:** is a piece of electrical equipment used to protect circuits and equipment from Over voltage.

- ✓ **Thermal relay:** A thermal relay, also known as a thermal overload relay, is an electromechanical device that senses abnormal temperature increases in electrical circuits.

Points to Remember

- Protection mechanisms like insulation, grounding, and circuit breakers prevent electrical shock, fire prevention, and equipment damage.
- To ensure the highest security, there are many protection devices available in the market that offers you a total range of protection devices for circuits such as a fuse, circuit breakers, RCCB, SPD, and more.

Application of learning 1.4.

Go in manufacturing workshop, observe electrical installation of mechanical machines and identify the followings:

- The types of circuit protection devices used in manufacturing workshop.
- The function of each protection device used in manufacturing workshop.

Make a report detailing what acquired as new knowledge during the visit.

Learning outcome 1 end assessment

Theoretical assessment

Question one: Read carefully the following questions industrial power supply and choose the letter corresponding to the right answer.

i. What is the primary function of an electrical industrial power supply?

a) To amplify electrical signals

b) To store electrical energy

c) To convert electrical energy from one form to another

d) To measure electrical resistance

ii. Which component of regulated power supply is responsible for converting AC to DC?

a) Transformer

b) Rectifier

c) Voltage regulator circuit

d) Protection circuit

iii. What is the main role of a voltage regulator circuit of a power supply?

a) To protect the circuit from overloads

b) To maintain a constant output voltage

c) To filter out noise from the electrical signal

d) To convert high voltage to low voltage

Question two: Complete the following sentences related to electrical safety at workplace using the following words (**types of electrical hazard, electrical hazard symbols, causes of electrical hazard, overall, safety boots and PPEs)**

i ………. are the visual indicators used to warn workers about the presence of electrical dangers.

ii. The various potential dangers associated with electricity that workers need to be aware of…………..

iii. ……. are the preventive measures and safety equipment used to protect workers from electrical hazards.

iv………. is the root factors that can lead to the occurrence of electrical hazards in the workplace?

Question three:

Carefully observe the following table and. Match the following correct definitions in column B with their terms in column C and provide answers in column A.

Column A: Answers	Column B: Definitions	Column C: Terms
1…….	1. It converts power suitable for electronics and automotive systems, and power supplies use standard mains electricity for household appliances and industrial equipment.	A. Input voltage and Input frequency
2…….	2. They measured in Hertz, are crucial for the functioning of AC-powered devices like motors, clocks, and timers.	B. DC power supply, AC power supply and hybrid power supply
3……	3. It is designed to provide a steady and consistent voltage or current for powering electronic devices and systems.	C. Monitoring system
4…….	4. It continuously collects and tracks data on various parameters such as voltage, current, frequency, power factor, and load conditions	D. Relay protection system
5…….	5. It is a critical component of electrical power systems, designed to safeguard electrical equipment and ensure system reliability.	E. DC power supply system
6…….	6. It is a critical aspect of managing electrical power systems, particularly in maintaining the balance between electricity supply and demand.	F. Frequency control G. Speed control H. Movement control

Question four: Read carefully the following statements about electrical protection devices and answer by **True** for the correct statement and **False** for the incorrect statement in provided space.

i. The purpose of protecting an electrical system is to prevent damage to equipment and ensure the safety of personnel. (…….)

ii. Open circuit faults and short circuit faults are the two principle types of faults in a power system. (…….)

ii. Protective relays, circuit breakers, and RCD’s (Residual Current Devices) are all elements of electrical protection devices. (…….)

iv. RCCB's (Residual Current Circuit Breakers) are designed to protect electrical systems from over-current situations. (…….)

Question five: Which type of PPE is essential for reducing exposure to excessive noise levels that can cause hearing damage?

a. Respiratory protection
b. Foot protection
c. hearing protection
d. skin protection

Question six: The following are the functions of a protective system except:

a. To maintain continuity of supply by safeguarding the entire system.
b. To generate electrical power
c. It minimizes damage and repair costs.
d. The safety of personnel must be ensured.

Practical assessment

You are requested to go in manufacturing workshop for your school and apply the safety and security measures required to control all electrical hazards in your workshop.

References

Bird, J. (2016). , Electrical and Electronic Principles and Technology (Fourth edition. ed.). Elsevier Ltd. Retrieved 2024

bsc, j. b. (2003).

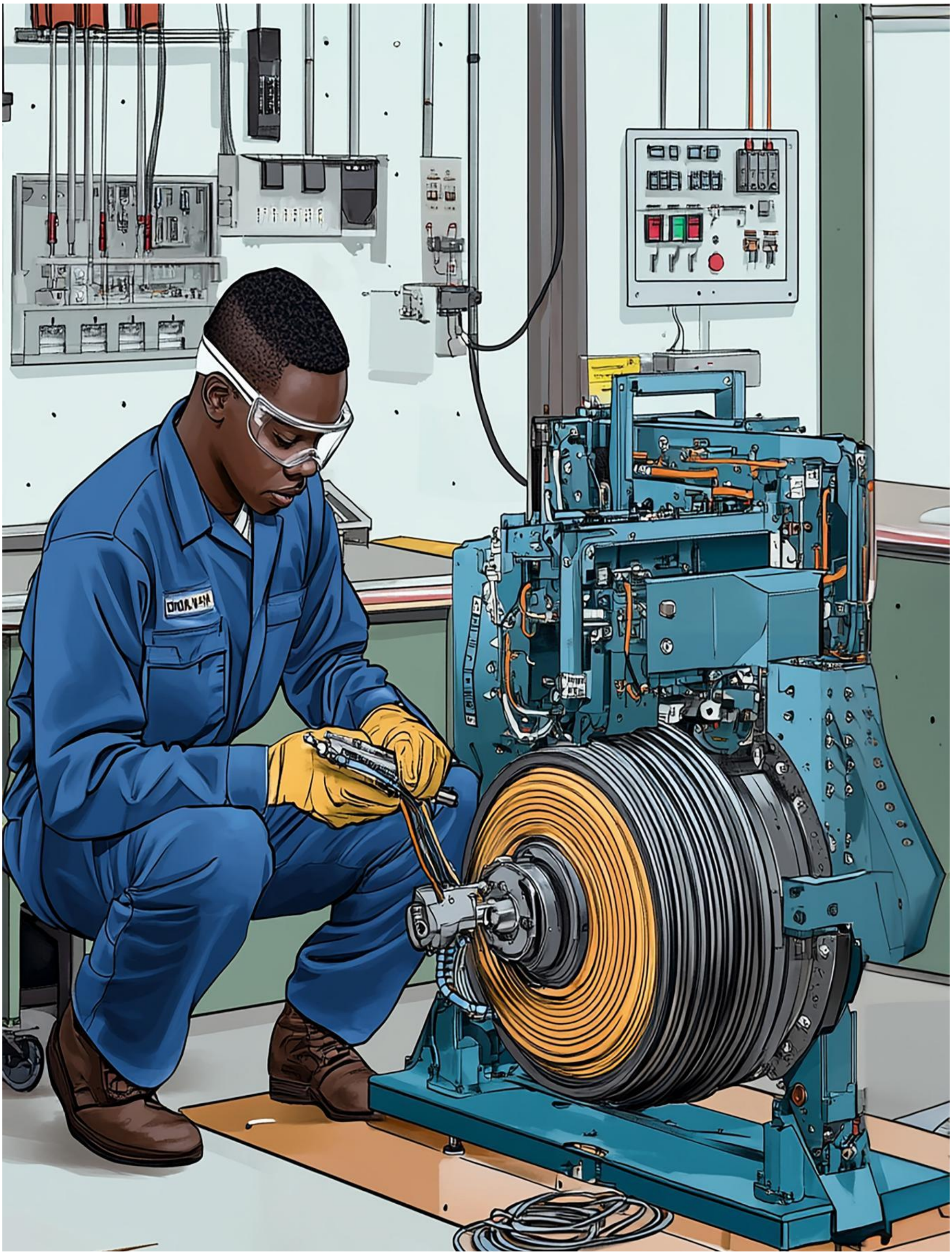
Electrical Principles and Technology for Engineering (Second edition ed.). previously published as Reprinted. Retrieved February 2024

Linsley. (2013).

Basic electrical installation work. Routledge.

Theraja, A. T. (n.d.). A textbook of electrical technology (2 ed.). (2, Ed.) Retrieved

Learning Outcome 2: Apply 3-Phase Circuit Working Principles



Indicative contents
2.1 Identifying three-phases AC circuit components
2.2 Interpretation of three-phases AC circuit drawings
2.3 Installation of three-phase AC circuit
2.4 Utilization of three-phases electrical measuring devices

Key Competencies for Learning Outcome 2: Apply 3-Phases Circuit Working Principles

Knowledge	Skills	Attitudes
• Identification of Three-phases AC circuit components • Identification of three phase circuit symbols • Description of three-phases AC circuit drawings • Description of common measurable parameters in electrical circuits	• Analysing single phase and three phase AC circuit diagrams • Interpreting of three-phases AC circuit drawings and symbols. • Installing three phase AC circuit • Using three-phases electrical measuring devices	• Being critical thinker while analysing single phase AC circuit diagram • Being cooperative while analysing single phase AC circuit diagram • Being vigilant while install three phase AC circuit • Being decisive while using three-phases electrical measuring devices • Being adaptive while using electrical measuring equipment

Duration: 20 hrs

Learning outcome 2 objectives:

By the end of the learning outcome, the trainees will be able to:

1. Identify properly three-phases AC circuit components used in electrical machine installation.
2. Identify properly three-phases AC circuit drawings and symbols used in AC circuit machine installation.
3. Analyse properly single phase and three phase AC circuit diagrams and symbols.
4. Install properly three phase AC circuit in mechanical machine installation according to installation requirements.
5. Utilize effectively three-phase electrical measuring devices while measuring electrical three phase parameters.

Resources

Equipment	Tools	Materials
• PPE (overall, head, eye and face, respiratory, hand and foot protection) • Wattmeter • Voltmeter • Ammeter • Multi-meter • Tachometer • Thermometer • Frequency meter • Clamp meter • Earth resistance meters • Insulation tester • Manometer • Portable drilling machine	• Combination plier • long nose plier • Electrician knife • Star screw driver • Flat screw driver • Hammer • Hack saw • Allen key	• Connectors • Scotches • Insulating tape • Screws • Switch box • Rails • Cable Tie • Female plugs and Male Plugs • Extension Cords • Drill bits • Soldering wires • Cable lugs • N/C push button • N/O push button • Circuit breakers • Fuses • SPD

• AC motors. • First aid kit.		• RCD • Disconnect switches • Contactors • Thermal relays • Delays • Auxiliary contacts • Indicating lamps • Wires/cable • Distribution board • Tables/panel

Indicative content 2.1: Identifying Three-Phases AC Circuit Components

Duration: 3 hrs

Theoretical Activity 2.1.1: Identifying Three-phases AC circuit components

Tasks:

1: Answer the following questions:

i. What do you understand by three-phase circuit?

ii. What do you think are the advantages of three-phase circuit?

iii. According to your understanding, differentiate between single phase and 3-phase configurations.

iv. From your point view, identify the types of three-phase circuit connection.

v. In your view, describe the three-phase AC (Alternating Current) components.

2: Provide answers to asked questions on papers.

3: Present the findings/answers to the whole class.

4: Ask clarifications where necessary.

5: Read the key readings **2.1.1**

Key readings 2.1.1.: Identifying Three-phases AC circuit components

- **Definition of three-phase circuit**

A three-phase circuit is an electrical circuit that utilizes three alternating currents (AC), each with the same frequency but offset by 120 degrees from each other in phase. These currents are typically supplied by three-phase generators and are distributed via three wires, with or without a neutral wire, depending on the system configuration. Three-phase circuits are commonly used in industrial settings due to their efficiency in delivering large amounts of power over long distances and to large loads.

- **Advantages of three-phase circuit**
  - ✓ **Higher efficiency:** Three-phase circuits can transmit more power than single-phase circuits while using less conductor material, making them more efficient in power transmission.
  - ✓ **Balanced power delivery:** The power delivered by a three-phase system is constant, unlike single-phase systems where the power varies. This

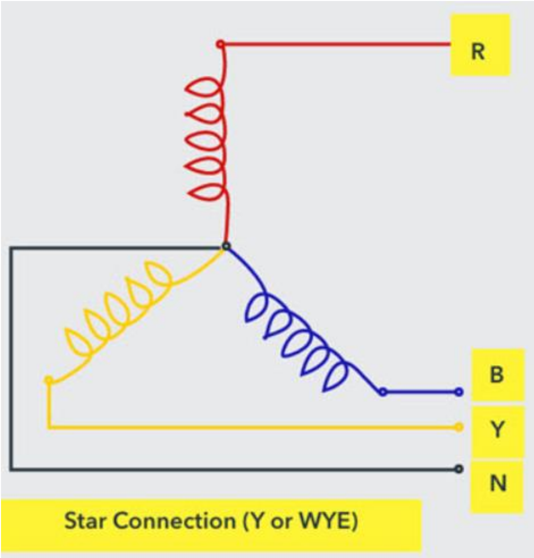
results in smoother and more reliable operation of motors and other equipment.

- ✓ **Smaller and cheaper equipment:** Three-phase motors and transformers are generally smaller, lighter, and less expensive than equivalent single-phase equipment.
- ✓ **More power for motors:** Three-phase motors are more powerful, have smoother torque, and can start more easily compared to single-phase motors.
- ✓ **Reduced losses:** Since the power is more evenly distributed in a three-phase system. Using three-phase power for loads allows for more efficient power distribution and equipment operation, reducing energy losses and improving overall performance.

- **Difference between single-phase and three-phase configurations**
  - ✓ **Power Delivery:** Single-phase systems deliver power through one alternating voltage, whereas three-phase systems use three alternating voltages that are out of phase by 120 degrees.
  - ✓ **Voltage Stability:** Single-phase systems experience power pulsations that can lead to unstable power delivery, while three-phase systems provide consistent power output, reducing voltage drops and improving system stability.
  - ✓ **Application:** Single-phase circuits are typically used for residential and small-scale applications, while three-phase circuits are used in industrial and large commercial settings due to their ability to handle high-power loads more effectively.
  - ✓ **Efficiency and Motor Performance:** Motors running on three-phase power are more efficient and experience less vibration and noise than motors on single-phase power.

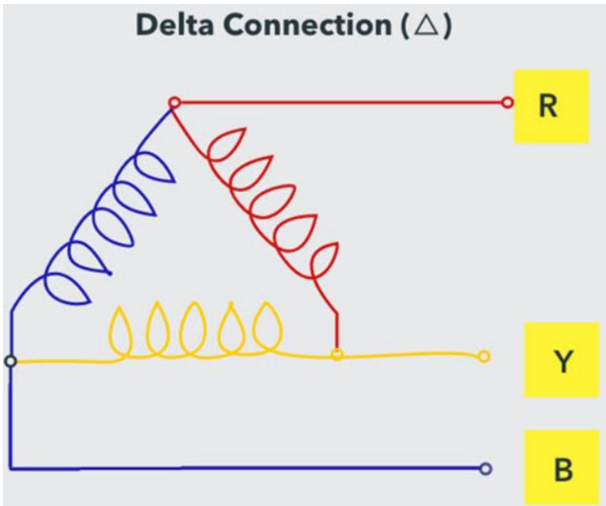
- **Types of three-phase circuit connections**
  - ✓ **Star (Wye) Connection**
    - **Configuration:** In a star (or wye) connection, one end of each of the three windings is connected to form a common point (neutral), while the other ends are connected to the three-phase power supply.
    - **Voltage Relationship:** The line voltage (voltage between any two-phase conductors) is √3 times the phase voltage (voltage between one conductor and the neutral point).
    - **Neutral Wire:** A neutral wire is typically available in this configuration, allowing both single-phase and three-phase loads to be connected.

- **Usage:** Star connection is used for long-distance transmission because it can transmit power at lower current levels and reducing losses.



✓ **Delta Connection**

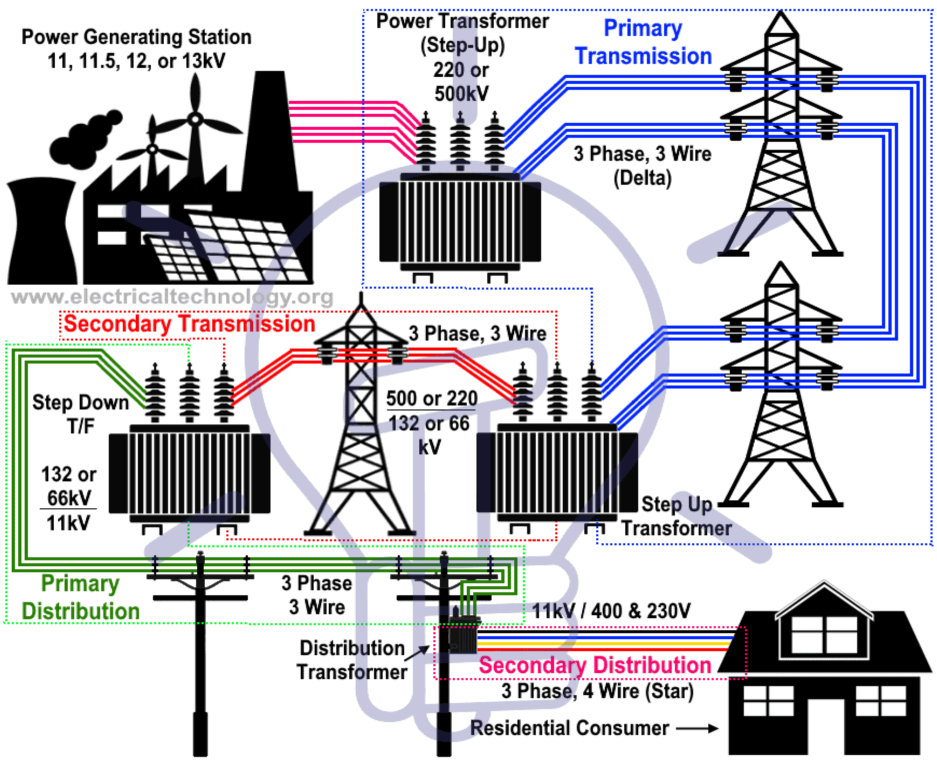
- **Configuration:** In a delta connection, the three windings are connected end-to-end to form a closed loop. The three-phase conductors are connected at the junction points of the windings.
- **Voltage Relationship:** In this configuration, the line voltage is equal to the phase voltage, and no neutral wire is required.
- **Higher Power Delivery:** Delta connections are often used in systems that require higher power delivery, such as heavy machinery and industrial motors.
- **Usage:** Delta connections are typically used for shorter distances and in settings where higher power and current are required.



- **Three-Phase AC Components**

- ✓ **Three-Phase Sources:** Three-phase power sources include generators or transformers that produce three alternating voltages offset by 120 degrees in phase. These sources are the backbone of industrial power systems, providing reliable and balanced power. The most common three-phase power sources are large-scale generators used in power plants, where mechanical energy is converted into electrical energy using electromagnetic induction.
- ✓ **Transmission/Distribution Line:** Transmission lines in a three-phase system are used to transport electricity from power plants to substations over long distances. Distribution lines carry this power from substations to industrial, commercial and residential areas.

  Three-phase transmission lines are more efficient than single-phase lines because they can carry more power with less loss over long distances.These systems typically consist of three conductors, and in some cases, a neutral wire may also be used, depending on whether a star and delta connection is implemented.



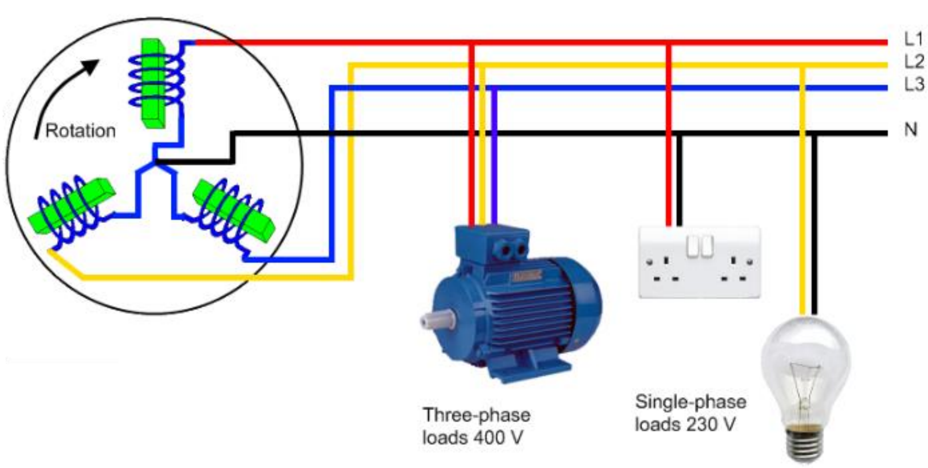
Typical AC Power Supply System (Generation, Transmission and Distribution)

- **Three-Phase Loads:** Three-phase loads refer to electrical devices or systems that require three-phase power for their operation. These are typically heavy-duty industrial equipment such as large motors, pumps, and HVAC systems.
  - ✓ **Balanced Load:** A balanced load is when all three phases of a three-phase system consume equal amounts of power, and the currents in each phase

are the same. This creates a situation where the system is operating at maximum efficiency, with no current flowing through the neutral conductor.

- ✓ **Unbalanced Load:** An unbalanced load occurs when the power consumption differs between the three phases, leading to unequal currents. This can cause problems like voltage imbalance, increased losses, and overheating in transformers or generators.

Figure below shows the Three-Phase AC Components**:**



Points to Remember

- A three-phase circuit is an electrical system that uses three alternating currents (AC) with a 120-degree offset, supplied by three-phase generators and distributed via three wires.
- Three-phase circuits offer higher efficiency, balanced power delivery, smaller and cheaper equipment, and improved motor performance.

Application of learning 2.1.

Go in manufacturing workshop, observe electrical installation of mechanical machines and identify the followings:

- The number of single-phase motors and the number of 3-phase motor used in manufacturing workshop.
- The types of connection for each three-phase motor used in manufacturing workshop.
- Make a report detailing what acquired as new knowledge during the visit.

Indicative content 2.2: Interpretation of Three-Phases AC Circuit Drawings

Duration: 5 hrs

Theoretical Activity 2.2.1: Description of three-phases AC circuit drawings

Tasks:

1: Answer the following questions:

i. What should be the three-phase circuit symbols?

ii. Draw a circuit diagram composed by a single-phase AC power supply, switch, wires and load.

iii. According to you, what are the difference between control circuit and power circuit?

2: Provide answers to asked questions on papers.

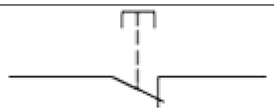
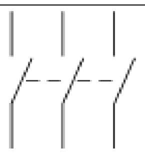
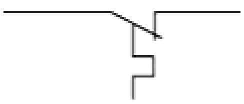
3: Present the findings/answers to the whole class.

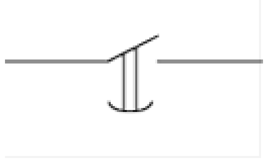
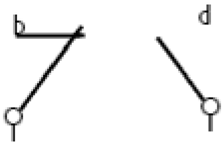
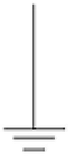
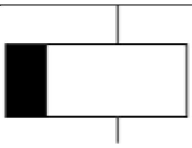
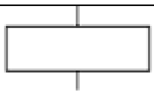
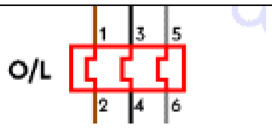
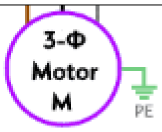
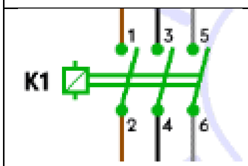
4: ask clarifications where necessary.

6. Read the key readings **2.2.1**

Key readings 2.2.1.: Description of three-phases AC circuit drawings

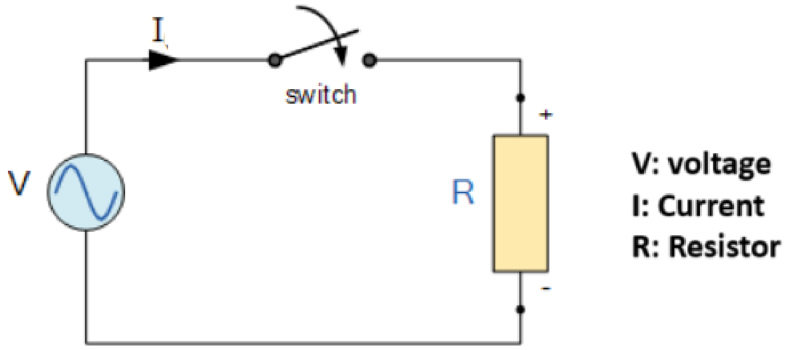
- **Interpret Three-Phase Circuit Symbols**

	Common schematic drawing symbols
Symbols	**Description**
	Normally open push button (N/O)
	Normal closed push button (N/C)
	Disconnect
	Thermal Switch

	Time delay(N/O)
	Circuit breaker
	Contacts of contactor
	Earth wire
	Delay off
	General Relay
	Overload Thermal Relay
	Three Phase AC Motor
	Contactor
	Three Phase AC Power Supply

- **Analyse Single-Phase AC Circuit Diagram**

A single-phase AC circuit consists of a Single Phase AC Power Supply connected to a load (resistor).



- **Analyse Three-Phase Circuit Diagrams**

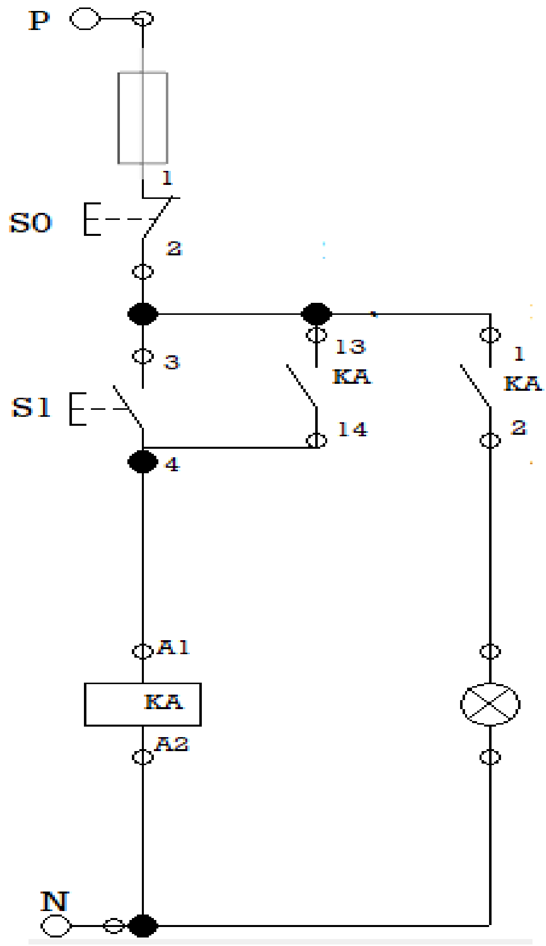
In a three-phase system, power is delivered through three alternating currents that are 120° out of phase with each other. The whole Three-Phase Circuit is divided into two parts: Control Circuit and power circuit.

- ✓ **Control circuits** are used to manage the operation of electrical systems. These circuits include relays, contactors, sensors, and switches.

Advantages of control circuit

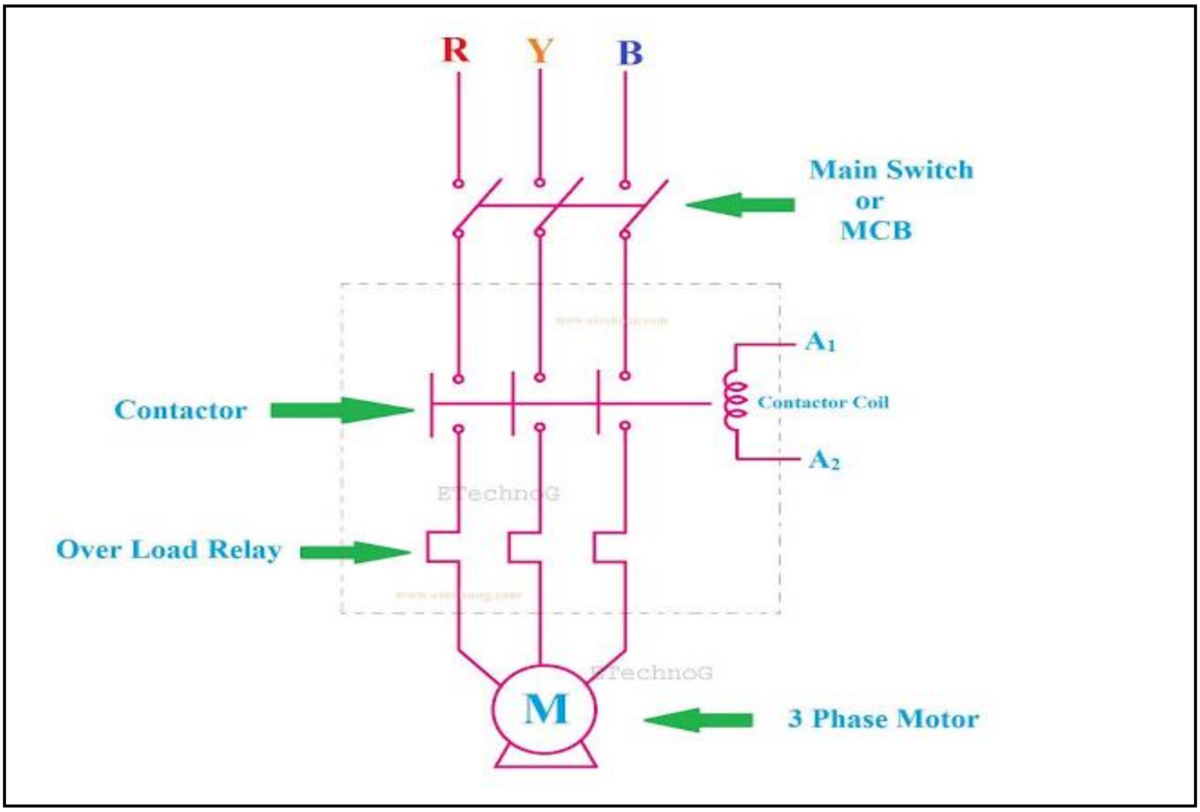
- Control the flow of electricity to actuate devices such as motors, lights, or solenoids based on user inputs or sensor feedback.
- Often show logic sequences using symbols for switches, relays, and push buttons.

EXAMPLE: Start/stop of contactor by the help of start /stop push button and self-holding contact of contactor.



- **Power circuits:** power circuits handle the transmission of electrical power to loads. Typically consist of power switches, transformers, fuses, and circuit breakers. Power circuits incorporate protective elements to prevent overloading or short circuits.

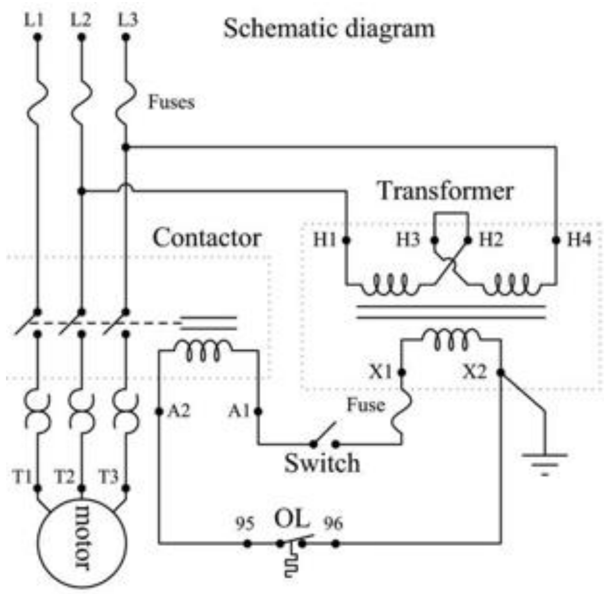
A motor power circuit includes a disconnect switch, a control transformer, protective devices (fuses or circuit breakers), a motor starter, and a motor as shown in figure below:



Practical Activity 2.2.2: Interpretation of three-phases AC circuit drawings

Task:

1: In Manufacturing workshop there is a three-phase motor to be installed as shown in diagram below. Before installing, you are requested to read and interpret the given schematic diagram.



2: Follow clear work instruction (Task, Time allocated) provided by your trainer.

3: Follow trainer's demonstration on how to perform the given task.

4: Present your work to the trainer and whole class.

5: Read key reading **2.2.2** and ask clarification where necessary.

6: Perform the task provided in application of learning **2.2**

Key readings 2.2.2 Interpretation of three-phases AC circuit drawings

- **The techniques used to interpret three-phases AC circuit drawings**

✓ **Familiarize with Symbols**

Standard symbols are used universally to represent components like protective devices, switches, loads, and power sources in electrical diagrams. Each component has a unique symbol to ensure consistency in design and interpretation. Additionally, most diagrams include a legend or key that explains the symbols, helping users easily understand and follow the diagram.

✓ **Understanding the Layout**

Schematic and wiring diagrams serve different purposes: schematics illustrate how a circuit functions, while wiring diagrams show the physical connections between components. Understanding the flow of current, which usually moves from positive to negative, is essential for grasping how different components interact within the circuit.

Schematic and wiring diagrams are both crucial tools in the design, analysis, and implementation of electrical circuits, but they serve distinctly different purposes. A schematic diagram is a symbolic representation of a circuit, designed to help engineers and technicians understand how the circuit works. It uses standardized symbols to represent various components, such as resistors, capacitors, diodes, and transistors, and it illustrates how these components are connected electrically. The primary goal of a schematic is to show the flow of current and the interaction between components within the circuit, without worrying about their physical placement or the specific routing of wires. For example, in a schematic of a power supply circuit, you would see symbols for the transformer, rectifier, and voltage regulator, along with lines representing electrical connections, giving insight into how each part contributes to converting AC to DC power.

- ✓ **Reading Connections**

Nodes and wires are crucial in circuit design, representing points of interconnection between components. Nodes are marked by dots or junctions, while straight lines represent wires. Continuous lines indicate conductors, while breaks indicate disconnections or interruptions. Understanding these elements is essential for accurate circuit functionality, assembly, and troubleshooting of electronic systems. Proper identification of nodes and wires is crucial for ensuring circuit functionality and preventing potential differences in current flow.

- ✓ **Analyzing Circuit Functionality**

Component relationships, specifically in series or parallel configurations, are crucial for predicting and analyzing circuit behavior. In series configurations, components are connected end-to-end, affecting the total resistance and voltage distribution. In parallel configurations, components share the same voltage but divide the total current among different paths. Analyzing these configurations helps engineers predict current flow, essential for power distribution systems. Applying Ohm's Law and Kirchhoff's laws helps calculate voltage drops and current flow within each part of the circuit, providing critical insight for effective circuit design and troubleshooting.

- ✓ **Using Labels and Numbers**

Component labels, such as R1, C1, and L1, are crucial for identifying specific components in a circuit diagram. They help differentiate between components of the same type and provide context for the circuit's design and functionality. Value indications, such as resistance in ohms, capacitance in farads, and inductance in henries, are essential for understanding the components' properties and their effect on circuit behavior. These labels help engineers predict component interactions, aiding in calculations related to current, voltage drops, and frequency response.

- ✓ **Referencing Standards**

ANSI/IEEE standards establish universally recognized conventions for electrical and electronic components, promoting consistency in design, interpretation, and communication across engineering disciplines. They include component symbols, labeling conventions, and electrical characteristics, ensuring clear diagrams and reducing misinterpretation. Familiarity with these standards enhances clarity and accuracy in diagram creation, communication, and design outcomes. By leveraging these standards, professionals foster collaboration and innovation in electrical and electronic engineering, promoting efficient workflows and better design outcomes.

✓ **Practice with Examples**

To improve your understanding of electrical circuits, start by working on sample diagrams, gradually progressing to more designs that are complex. This approach helps familiarize yourself with fundamental concepts and builds analytical skills. By constructing basic circuit diagrams, you can understand more configurations that are intricate. Incorporating circuit simulation software allows for real-time visualization and efficient troubleshooting. This hands-on approach reinforces theoretical knowledge and equips you with practical skills for real-world applications in electronics and engineering. Combining these methods will lead to a comprehensive understanding of circuit design and analysis.

✓ **Ask Questions**

If uncertain about a particular symbol or connection, research or consult resources to clarify. By combining these techniques, you will improve your ability to interpret electrical diagrams and enhance your understanding of circuit design and functionality.

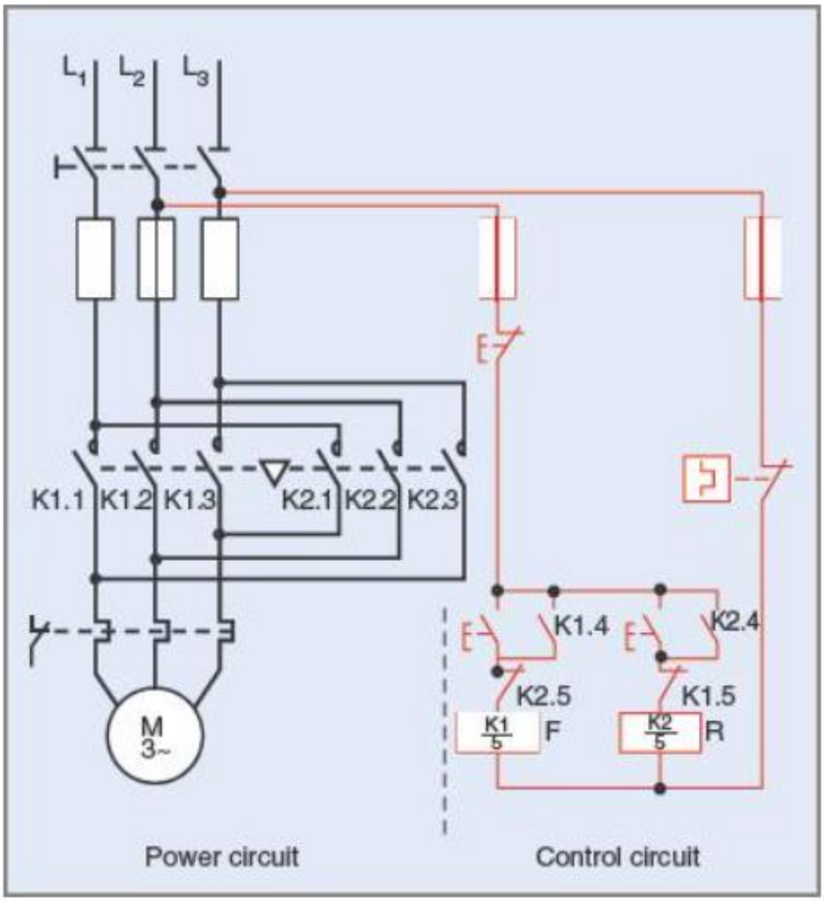
Points to Remember

- Understanding and interpreting three-phase circuit symbols is crucial for analysing electrical systems and their components.
- The whole Three-Phase Circuit is divided into two parts: Control Circuit and power circuit.
- Interpreting electrical diagrams requires an understanding of various symbols, conventions, and techniques.

Application of learning 2.2.

In manufacturing workshop, there is a new three phase motor need to be installed as shown in the following diagram, you are requested to:

- Analyse and interpret this drawing.



Indicative content 2.3: Installation of Three-Phase AC Circuit

Duration: 6 hrs

Theoretical Activity 2.3.1: Description of Three-Phase Induction Motor

Tasks:

1. Answer the following question:
   i. According to your understanding, what is a three-phase induction motor?
   ii. What do you understand by direct online starting of three-phase induction motor?
   iii. According to your understanding, what is the forward and reverse starting circuit of three-phase induction motor?
   iv. What do you think is the Star delta starting circuit of three-phase induction motor?
2. Provide answers to asked questions on papers.
3. Present the findings/answers to the whole class.
4. Ask clarifications where necessary.
5. Read the key readings 2.3.1

Key readings 2.3.1:

- **Description of three-phase induction motor**

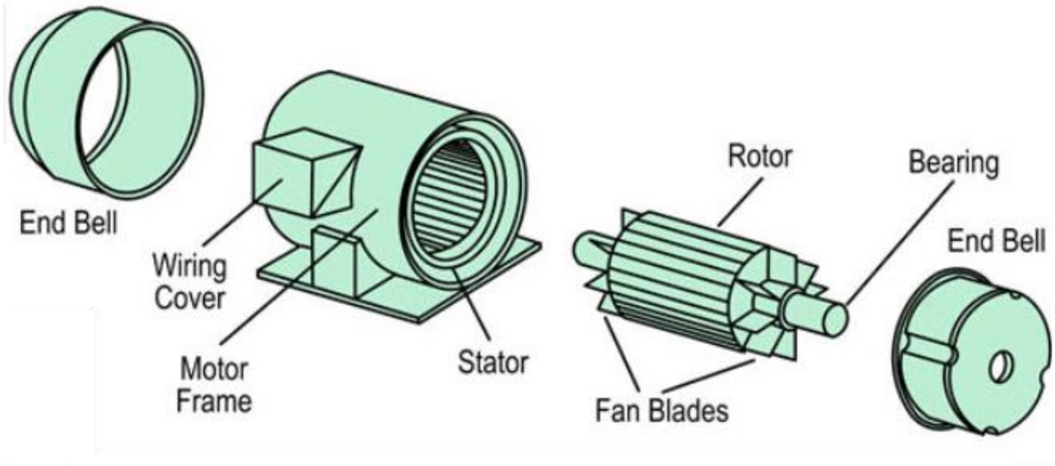
A three-phase induction motor is one of the most commonly used machines in manufacturing workshops due to its durability, efficiency, and ease of maintenance. It is widely applied to drive mechanical equipment such as pumps, conveyors, compressors, fans, and machine tools. Here's a breakdown of its key features and operation in a workshop setting:

✓ **Construction of three-phase induction motor**

The motor consists of two main parts:

- **Stator:** The stationary part that contains windings arranged in three phases (each phase displaced by 120 degrees electrically). These windings are powered by a three-phase AC supply, creating a rotating magnetic field.

- **Rotor:** The rotating part, usually a squirrel-cage design, consisting of conductive bars short-circuited by end rings. The magnetic field generated by the stator induces currents in the rotor, causing it to rotate.



✓ **Working principle of three-phase induction motor**

The three-phase induction motor operates by converting electrical energy into mechanical energy. When the three-phase AC supply is applied to the stator, the rotating magnetic field interacts with the rotor, inducing a current due to electromagnetic induction. This induced current generates its own magnetic field, which opposes the stator's field, creating a torque that causes the rotor to rotate. The rotor then drives the connected mechanical load, like a lathe and milling machine.

✓ **Advantages in workshop use**

- Efficiency: Three-phase induction motors are highly efficient, capable of running continuously under heavy loads for extended periods, which is ideal for workshop environments.
- Reliability and Durability: These motors have a simple construction with no brushes or commutators, leading to less wear and tear, reducing maintenance downtime.
- Cost-Effectiveness: Due to their simple design and widespread use, they are generally more affordable to operate and maintain.
- High Starting Torque: These motors can handle large initial loads, which is beneficial for starting heavy machinery.

✓ **Applications in manufacturing workshop**

The motor drives various types of machinery commonly found in manufacturing settings, such as:

- CNC machines: For precise cutting and shaping of materials.
- Conveyor systems: To move parts and products across production lines.

- Pumps and fans: For cooling systems or moving liquids in manufacturing processes.

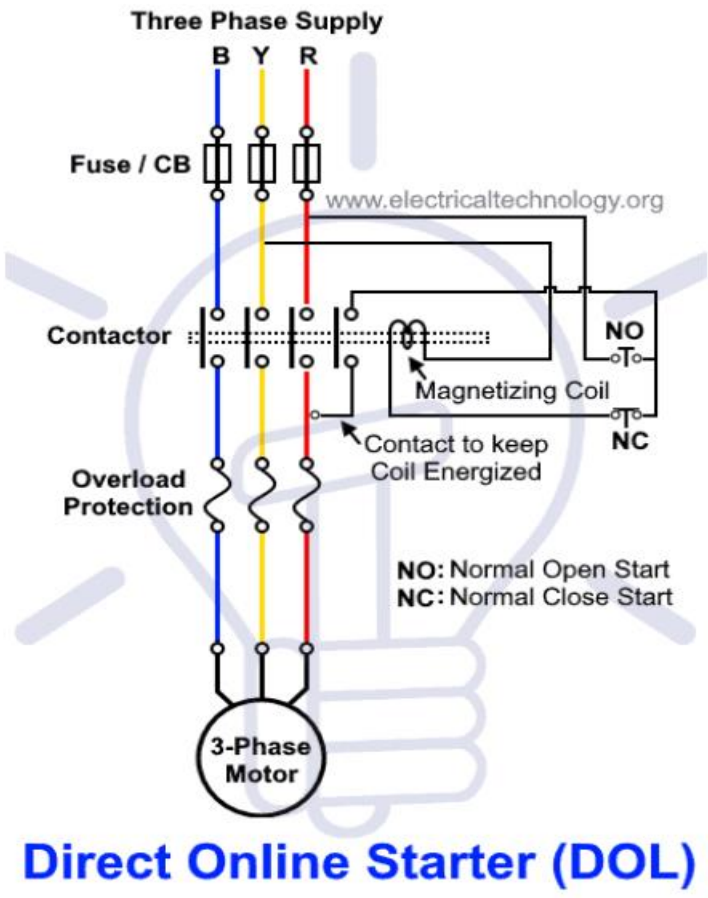
In summary, the three-phase induction motor is a workhorse in the manufacturing workshop, providing reliable and efficient mechanical power for a wide range of industrial applications. Its robustness and ability to handle demanding environments make it indispensable in production facilities.

- **Starting methods for three-phase induction motors**

Three-phase induction motors are essential for driving machinery in industrial applications, but starting these motors directly on full voltage can lead to high inrush currents, which may damage the motor and electrical systems. Various starting methods are employed to mitigate these effects and ensure smooth operation. Here are three common starting methods:

- ✓ **Direct Online (DOL) Starting of Three-Phase Induction Motor**

Direct Online (DOL) starting is the simplest and most straightforward method for starting a three-phase induction motor. In this method, the motor is connected directly to the full supply voltage, which results in the motor drawing a high starting current (typically 6-8 times the rated current) and producing a high starting torque.



- The components of a DOL Starter are:
  Contactor: Controls the connection of the motor to the power supply.
  Overload Relay: Protects the motor from overheating by disconnecting the power if the current exceeds a set limit.
  Start/Stop Buttons: Allow manual operation of the motor.

- **Operation of Direct Online (DOL) starter**

In Direct Online (DOL) starting, the motor is connected directly to the three-phase power supply via a contactor and overload protection relay. When powered, the rotor quickly accelerates to its rated speed, as the motor is supplied with full line voltage. This method is simple and effective, though it results in a high inrush current, which is generally tolerated in smaller motors (up to 5 kW). Since the high starting current does not typically cause significant disruptions to the electrical network, DOL starters are commonly used for applications where small motors are employed, providing full torque immediately.

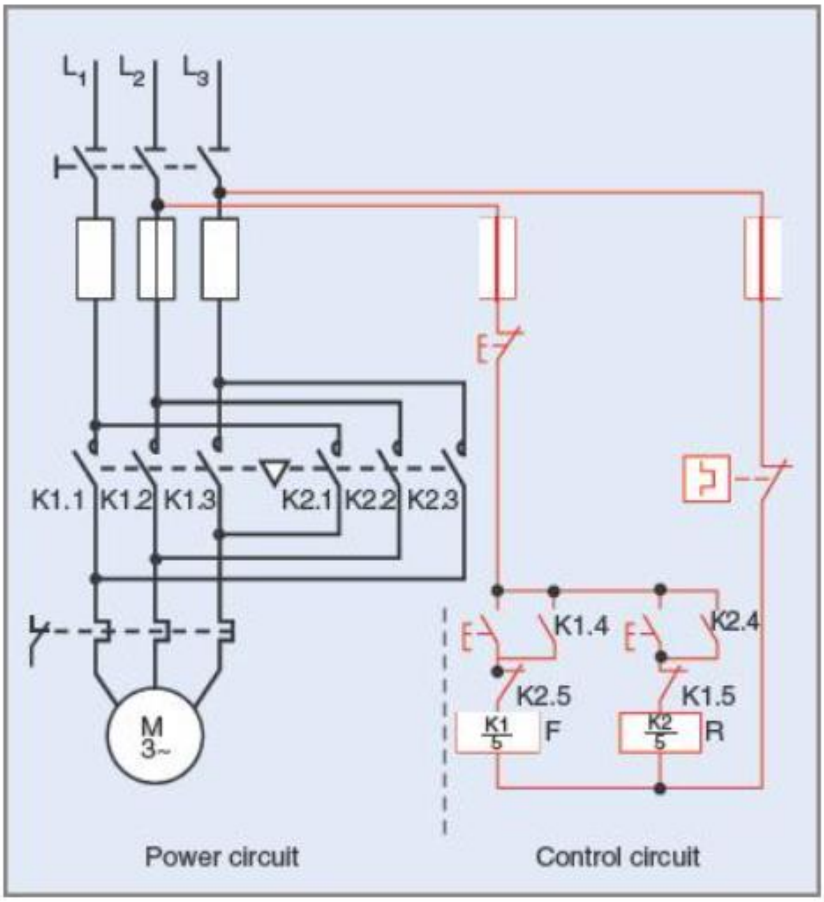
- Advantages of Direct Online (DOL) starter:
  1. Simple and cost-effective.
  2. Provides full torque during start-up.

✓ **Forward and Reverse Starting Circuit of Three-Phase Induction Motor**

A forward and reverse starting circuit allows a three-phase induction motor to rotate in both directions. This is useful in applications where machinery needs to move forward and backward, such as conveyors or cranes.

- **Operation of Forward and Reverse Starting Circuit of Three-Phase Induction Motor**
  Reversing the direction of rotation of a three-phase induction motor is achieved by swapping two of the three supply phase connections to the motor. The motor's forward and reverse directions are controlled using two contactors: one for forward and the other for reverse rotation. Interlocking is required to ensure that both forward and reverse contactors cannot be engaged at the same time.

- **Circuit Components of Forward and Reverse Starting Circuit of Three-Phase Induction Motor:**



1. Forward Contactor (K1): Controls the motor in the forward direction.
2. Reverse Contactor (K2): Controls the motor in the reverse direction.
3. Interlock Circuit: Prevents both contactors from being energized simultaneously, which could lead to short circuits.
4. Overload Relay: Protects the motor from overcurrent conditions.

Working of Forward and Reverse Starting Circuit of Three-Phase Induction Motor:

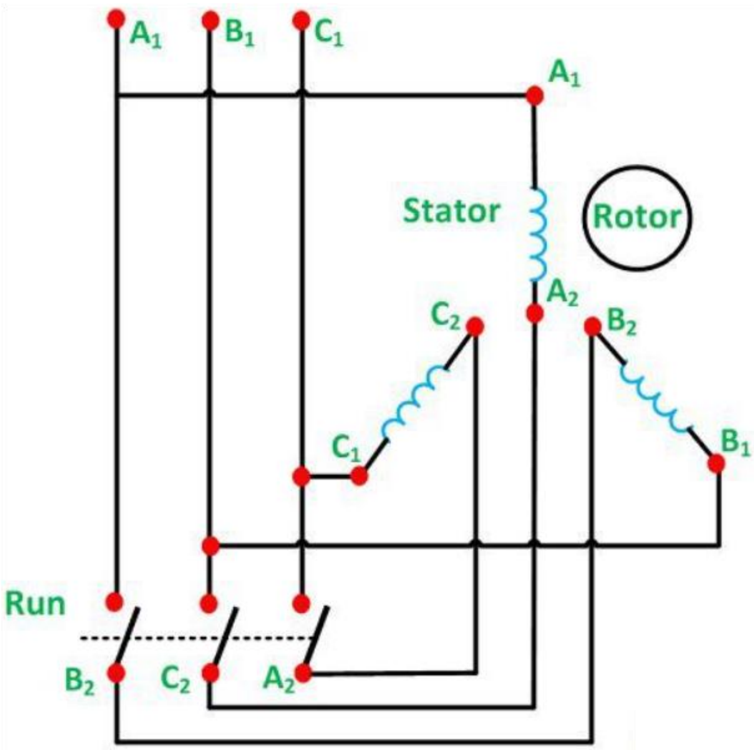
When the forward push-button is pressed, the forward contactor is energized, and the motor runs in the forward direction. When the reverse push-button is pressed, the reverse contactor is energized, and two of the phases are swapped, causing the motor to run in the opposite direction.

Advantages of Forward and Reverse Starting Circuit of Three-Phase Induction Motor:

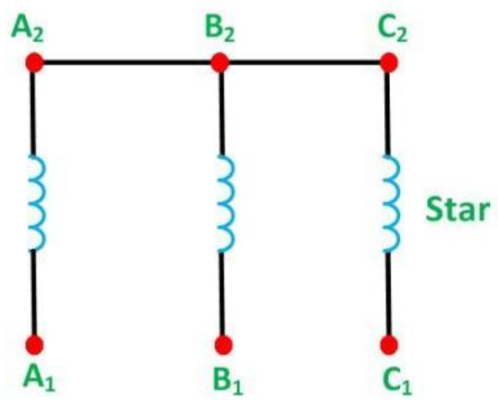
1. Allows for easy control of motor direction.
2. Provides flexibility in industrial operations requiring bidirectional movement.

✓ **Star-Delta Starting Circuit of Three-Phase Induction Motor**

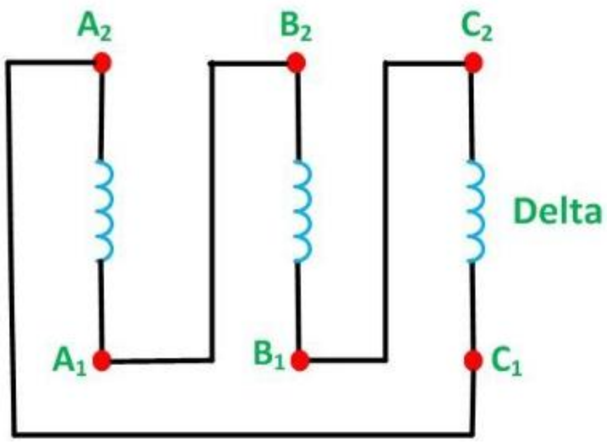
The star-delta starter is a reduced voltage starter used to minimize the high inrush current during the start-up of larger motors. In this method, the motor starts in the "star" configuration, which reduces the voltage applied to each phase by a factor of √3, and once the motor reaches a certain speed, it is switched to the "delta" configuration for normal running conditions.
The Star Delta Starter is a very common type of starter and is used extensively as compared to the other type of starting methods of the induction motor. A star delta is used for a cage motor designed to run normally on the delta-connected stator winding. The connection of a three-phase induction motor with a star-delta starter is shown in the figure below:



When switch S is in the START position, the stator windings are connected in the star as shown below:



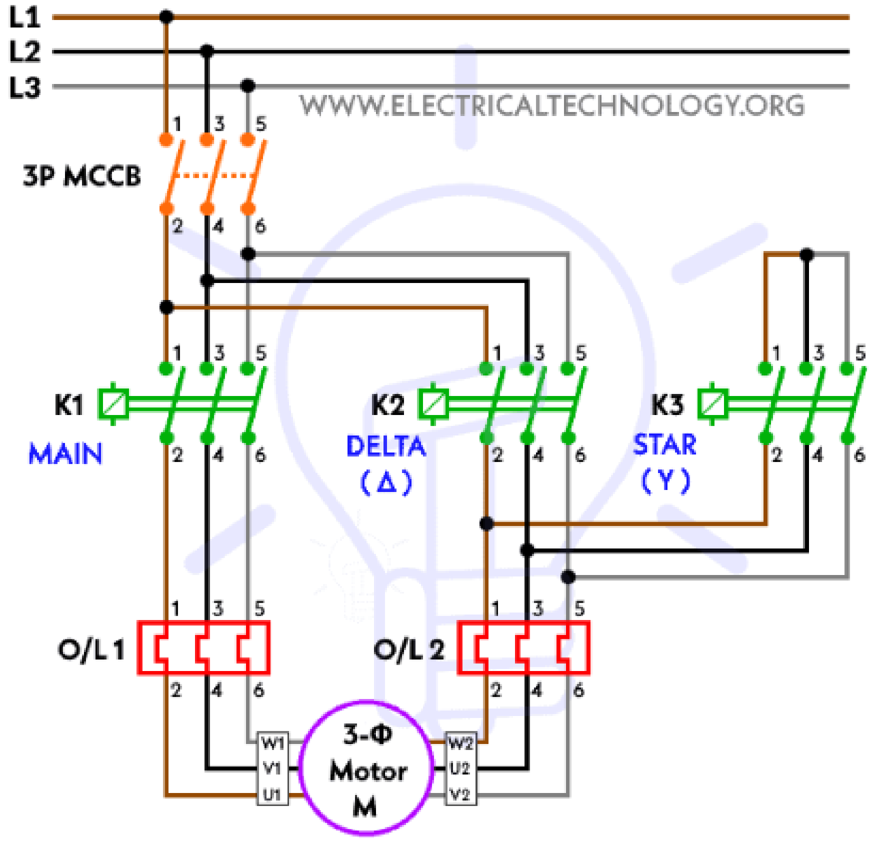
When the motor picks up the speed, about 80 percent of its rated speed, the switch S is immediately put into the **RUN** position. As a result, a stator winding which was in star connection is changed into **DELTA** connection now. The delta connection of the stator winding is shown in the figure below:



Firstly, the stator winding is connected in star and then in Delta so that the starting line current of the motor is reduced to one-third as compared to the starting current with the windings connected in delta.

- **Operation of Star-Delta Starting Circuit of Three-Phase Induction Motor:**
  During start-up, the motor windings are connected in a star (Y) configuration. This reduces the phase voltage to about 58% of the line voltage, which significantly reduces the starting current. After the motor reaches approximately 70-80% of its full speed, it is switched to the delta (Δ) configuration. This restores full line voltage to the motor windings for normal operation.

- **Components of a Star-Delta Starter:**
  1. **Three Contactors:** One for the main circuit, one for the star connection, and one for the delta connection.
  2. **Timer:** Automatically switches the motor from star to delta after a preset time.
  3. **Overload Relay:** Protects the motor from overcurrent conditions.



Power Circuit Diagram of Star Delta Starter

- **Working of Star-Delta Starting Circuit of Three-Phase Induction Motor :**
  Upon starting, the main and star contactors are energized, connecting the motor in the star configuration. After a preset time, the timer deactivates the star contactor and activates the delta contactor, switching the motor to delta mode.

- **Advantages of Star-Delta Starting Circuit of Three-Phase Induction Motor:**

1. Reduces starting current to approximately one-third of what it would be in a direct online start.
2. Suitable for large motors where high starting torque is not required.

Practical Activity 2.3.2: Installing three-phase AC circuit for induction motor by using direct online starting method.

Task:

You are requested to go to manufacturing workshop to install the new three-phase induction motor by using direct online starting method.

1: Install the following three-phase induction motor by using direct online starting method.

2: Follow clear work instruction (Task, Time allocated) provided by your trainer.

3: Follow trainer's demonstration on how to perform the given task.

4: Present your work to the trainer and whole class.

5: Ask clarification where necessary.

6: Read key reading **2.3.2**

7: Perform the task provided in application of learning **2.3.**

Key readings 2.3.2: Installing three-phase AC circuit for induction motor by using direct online starting method.

- **Procedure to install direct online starter**

To install a Direct Online (DOL) starter, the process involves two primary circuits: the **power circuit** and the **control circuit**. Here's the detailed step-by-step procedure:

- **Power Circuit Installation**

This circuit handles the direct power supply to the motor and consists of the main components such as circuit breakers, contactors, and overload relays.

Step 1: Ensure Power is Off: Turn off the main power supply to the panel or circuit where the DOL starter is being installed. Verify the voltage ratings of the motor, DOL starter, and supply are compatible.

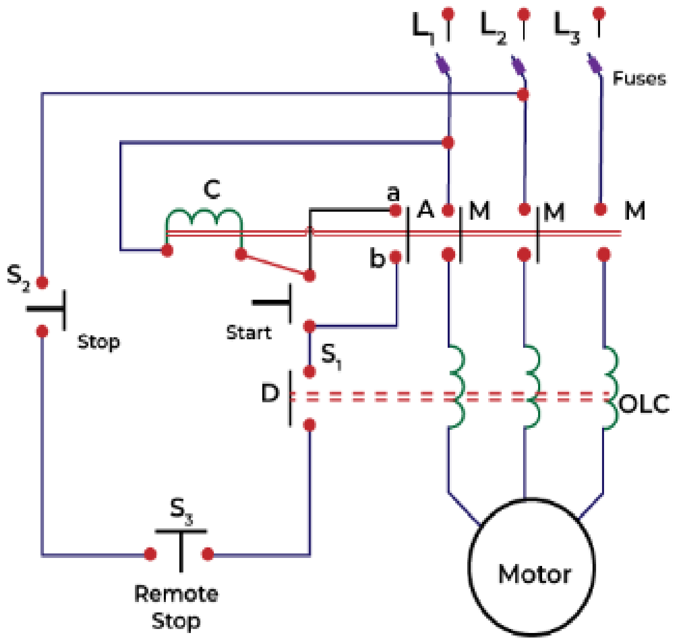
Step 2: Mount the DOL Starter: Securely mount the DOL starter to a suitable panel or wall. The starter will include the contactor, overload relay, and terminals for power input and output.

Step 3: Connect the Main Power Supply: Identify the three-phase supply lines (L1, L2, L3). Connect these three-phase lines to the incoming terminals of the DOL starter, usually labeled **L1, L2, L3** on the contactor.

Step 4: Connect the Motor: Connect the motor's three-phase wires to the outgoing terminals of the DOL starter, typically marked **T1, T2, T3**. Ensure the wire size is appropriate for the current rating of the motor.

Step 5: Install Circuit Protection: Install a circuit breaker or fuse at the input side of the DOL starter to protect the motor from short circuits or faults. Set the overload relay to match the full load current (FLC) of the motor. This ensures the motor is protected from overload conditions.

Step 6: Ground the Motor and Panel: Connect a grounding wire from the motor's ground terminal to the main ground bar of the panel for safety.



Control Circuit Installation

The control circuit handles the operation of the starter, allowing you to turn the motor on or off via push buttons and includes the connections to the contactor coil.

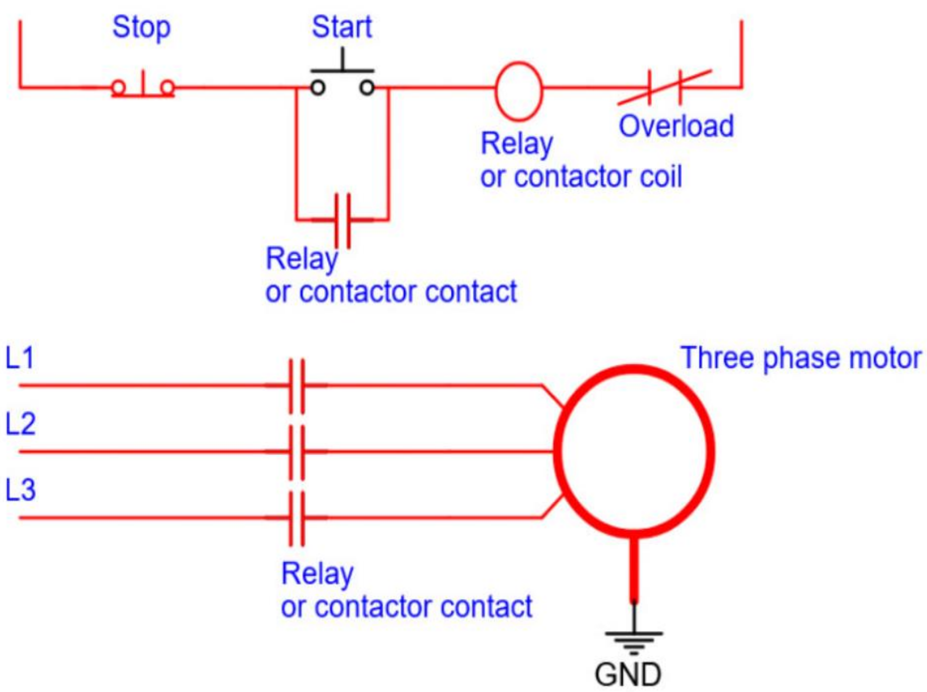
Step 1: Install Push Buttons: Install Start (NO – normally open) and Stop (NC – normally closed) push buttons on the control panel.

Step 2: Wire the Control Circuit: Connect one side of the Stop push button to the Line (L1) terminal in the control circuit. Connect the other side of the Stop button to one terminal of the Start push button. The output of the Start button is connected to one side of the contactor coil.

Step 3: Complete the Coil Circuit: Wire the other side of the contactor coil to the Neutral (N) terminal of the control circuit.

Step 4: Interlock the Control Circuit: Use an auxiliary contact (NO contact) on the contactor for holding the motor on after the Start button is pressed. Wire this auxiliary contact in parallel with the Start button to latch the circuit once the motor starts.

Step 5: Connect Overload Relay: Connect the overload relay's NC contact into the control circuit. This contact will open the control circuit if an overload occurs, stopping the motor.



- **Final Steps:**

Step 1: Check All Connections: Double-check all wiring connections, ensuring they are tight and in accordance with the wiring diagram of the DOL starter.

Step 2: Power Up and Test: Switch on the main power supply. Press the Start button to run the motor. The contactor should pull in, and the motor should start. Press the Stop button to halt the motor. The contactor should drop out, and the motor should stop.

Step 3: Adjust Overload Relay: Test the overload relay by manually setting it to a low value, then running the motor to see if it trips when overloaded. Reset the relay to the correct FLC setting for normal operation.

Practical Activity 2.3.3: Installation of three-phase induction motor by using forward and reverse starting method

Task:

You are requested to go to manufacturing workshop to install the new three-phase induction motor by using forward and reverse starting method:

1: Install the following motor in forward and reverse starting method.

2: Follow clear work instruction (Task, Time allocated) provided by your trainer.

3: Follow trainer's demonstration on how to perform the given task.

4: Present your work to the trainer and whole class.

5: Ask clarification where necessary.

6: Read key reading **2.3.3**

7: Perform the task provided in application of learning **2.3**

Key readings 2.3.3: Installation of three-phase induction motor by using forward and reverse starting method

- ✓ **Procedure to install forward and reverse starting circuit**

Here's a step-by-step guide to installing a Forward and Reverse Starting Circuit by detailing the Power Circuit and Control Circuit:

- **Power Circuit Installation**

The power circuit manages the direction of motor rotation by reversing the connections of two phases. This is achieved using two contactors: one for forward and one for reverse operation.

Step 1: Ensure Power is Off: Turn off the main power supply to prevent accidents during installation.

Step 2: Mount the Forward and Reverse Starter: Mount the starter unit on a suitable panel or enclosure. The starter will include the forward and reverse contactors, an overload relay, and terminals for power connections.

Step 3: Connect the Power Supply: Identify the three-phase power supply lines (L1, L2, L3). Connect the incoming power supply to both the Forward Contactor and Reverse Contactor on their input sides, typically labeled L1, L2, L3.

Step 4: Connect the Motor: For Forward Operation, connect the motor terminals U, V, W directly to the output of the Forward Contactor (T1, T2, T3).

For Reverse Operation, connect the motor terminals U, V, W to the Reverse Contactor, but swap two of the phases (e.g., connect L1 to T2, L2 to T1, and L3 to T3) to reverse the motor's rotation.

Step 5: Install Overload Relay: Wire the overload relay between the contactors and the motor to protect against overcurrent conditions. The overload relay will cut off power in case the motor exceeds its rated load.

Step 6: Ground the Motor and Panel: Connect the motor and the control panel to the grounding terminal for safety.

- **Control Circuit Installation**

The control circuit manages the start/stop operation of the motor and switches between the forward and reverse modes using push buttons.

Step 1: Install Forward and Reverse Push Buttons: Mount two push buttons: one for Forward (Normally Open – NO) and one for Reverse (Normally Open – NO), along with a Stop button (Normally Closed – NC).

Step 2: Wire the Stop Button (NC): Connect the Stop button in series with both Forward and Reverse push buttons. This will ensure that pressing Stop will deactivate either Forward or Reverse contactor.

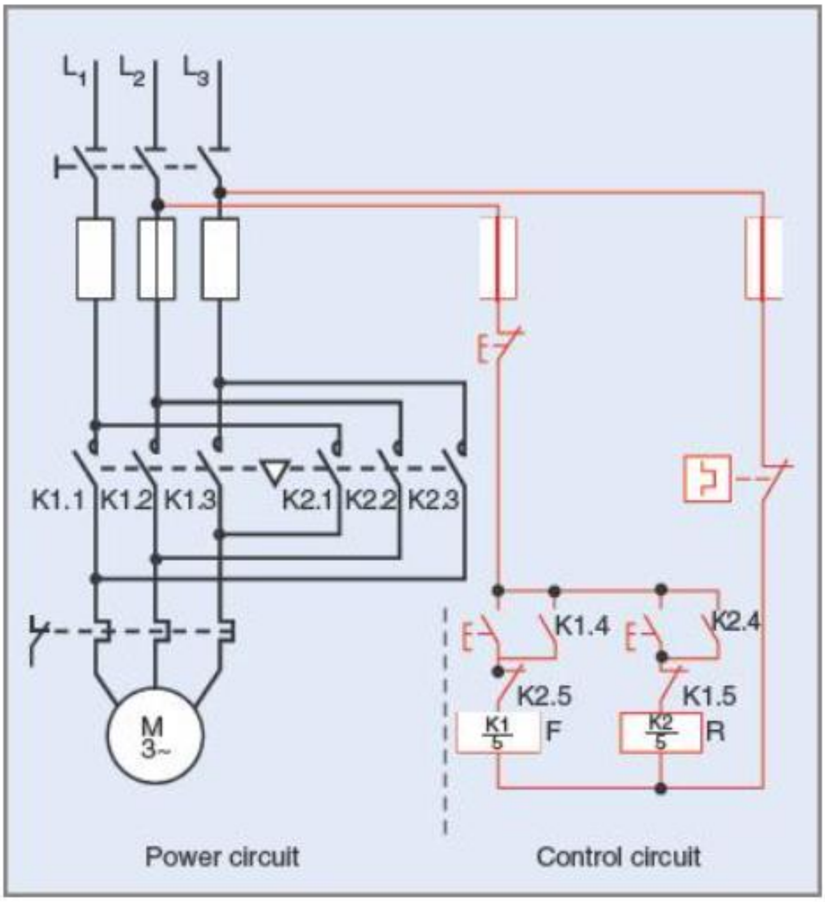
Step 3: Wire the Forward Push Button: Connect the Forward Push Button to the Forward Contactor coil. When pressed, it will energize the Forward Contactor to start the motor in the forward direction.

Step 4: Wire the Reverse Push Button: Connect the Reverse Push Button to the Reverse Contactor coil. When pressed, it will energize the Reverse Contactor, causing the motor to run in reverse by swapping two of the motor's phase connections.

Step 5: Add Electrical Interlocking: To prevent both Forward and Reverse contactors from being energized at the same time (which would cause a short circuit), install interlocks: Use the Normally Closed (NC) auxiliary contact of the Forward Contactor in series with the Reverse Contactor coil. This will prevent the Reverse Contactor from energizing while the Forward Contactor is active. Similarly, use the NC auxiliary contact of the Reverse Contactor in series with the Forward Contactor coil to prevent both from being engaged simultaneously.

Step 6: Add Mechanical Interlocking (Optional): If possible, install mechanical interlocking between the Forward and Reverse contactors. This physically prevents both contactors from being engaged at the same time.

Step 7: Connect Overload Relay to Control Circuit: Wire the NC contact of the overload relay into the control circuit to stop the motor in the event of an overload condition.



Final Steps

Step 1: Verify Wiring: Double-check all connections to ensure correctness and that they match the wiring diagram for the Forward/Reverse starter circuit.

Step 2: Power Up and Test: Turn on the main power supply. Press the Forward button to engage the Forward Contactor. The motor should start running in the forward direction. Press the Stop button to disengage the motor. Press the Reverse button to engage the Reverse Contactor. The motor should now run in the reverse direction.

Step 3: Test Interlocks: Ensure that pressing both Forward and Reverse buttons simultaneously will not energize both contactors at the same time (thanks to the electrical or mechanical interlocking).

Step 4: Adjust Overload Relay: Ensure that the overload relay is set correctly for the motor's full load current to protect the motor from overcurrent conditions.

By following these steps, you can successfully install a Forward and Reverse starting circuit, ensuring smooth and safe operation of the motor in both directions.

Practical Activity 2.3.4: Installation of three-phase induction motor using Star delta starting method

Task:

You are requested to go to manufacturing workshop to install the new three-phase induction motor by using Star delta starting method

1: Install the following three-phase induction motor by using Star delta starting method.

2: Follow clear work instruction (Task, Time allocated) provided by your trainer.

3: Follow trainer's demonstration on how to perform the given task.

4: Present your work to the trainer and whole class.

5: Read key reading **2.3.4** and ask clarification where necessary.

6: Perform the task provided in application of learning **2.3**

Key readings 2.3.4: Installation of three-phase induction motor using Star delta starting method

- **Procedure to install the Star delta starter circuit**

  Here's a step-by-step procedure for installing a Star-Delta starter circuit focusing on the Power Circuit and Control Circuit:

  - **Power Circuit Installation:**

  The power circuit controls the actual power supply to the motor. In the Star-Delta starter, the motor initially starts in star configuration to reduce the starting current, and then switches to delta configuration for normal operation.

Step 1: Ensure Power is Off: Turn off the main power supply before starting the installation to ensure safety.

Step 2: Mount the Star-Delta Starter: Mount the starter unit on the control panel. The starter contains three contactors (Main, Star, Delta), overload relay, and other protective devices.

Step 3: Connect the Power Supply: Identify the three-phase power supply lines (L1, L2, L3). Connect these power lines to the Main Contactor's input terminals, typically labeled as L1, L2, L3.

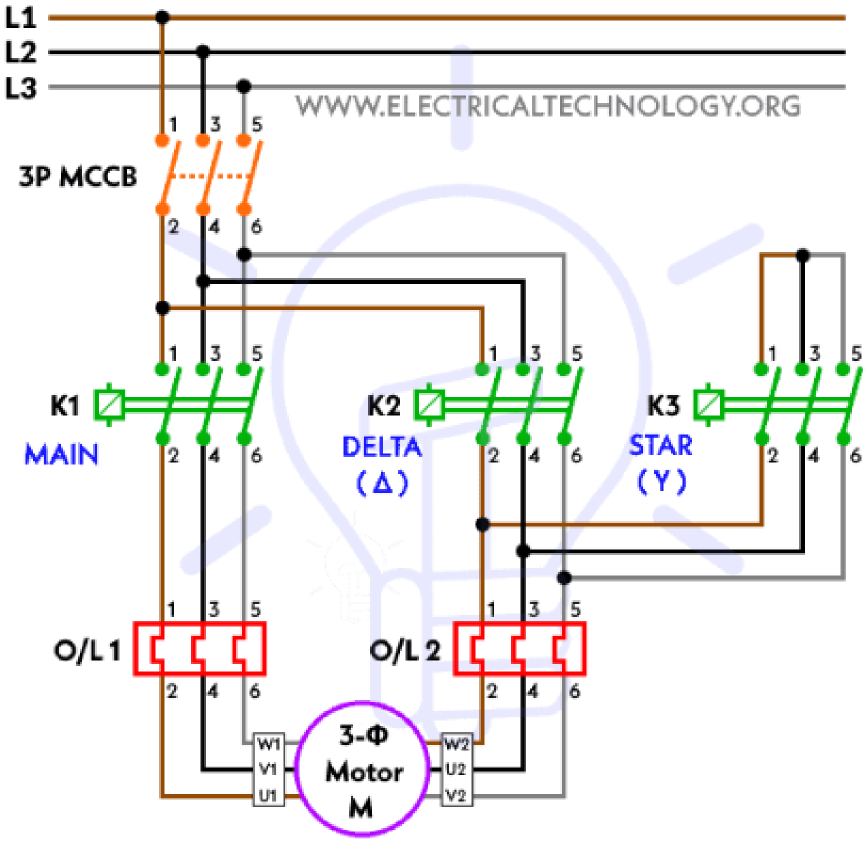
Step 4: Connect the Motor to the Starter: Motor Terminals: Connect the motor's three terminals (U, V, W) to the output terminals of the Main Contactor.

Step 5: Wiring the Star and Delta Contactors: Connect the output terminals of the Star Contactor to the motor terminals in a Star (Y) configuration (short-circuiting the windings).

Example: Connect the U2, V2, W2 ends of the motor to the Star Contactor.

Connect the output terminals of the Delta Contactor to the motor terminals in Delta (Δ) configuration. Example: U1 to W2, V1 to U2, W1 to V2 to form a Delta connection.

Step 6: Install the Overload Relay: Wire the overload relay between the Main Contactor and the motor to protect the motor from overcurrent situations.



Power Circuit Diagram of Star Delta Starter

Control Circuit Installation:

The control circuit handles switching between the Star and Delta configurations, along with start and stop functionality.

Step 1: Install the Start/Stop Push Buttons: Install Start and Stop push buttons on the control panel.

Step 2: Wire the Stop Button (NC): Connect the Stop button (normally closed contact) in series with the control circuit, between the control power source and the Start button (normally open).

Step 3: Wire the Start Button (NO): Connect one side of the Start button to the power line.

Wire the other side of the Start button to the Main Contactor coil.

Step 4: Control of Star Contactor: Wire a timer relay in series with the Star Contactor.

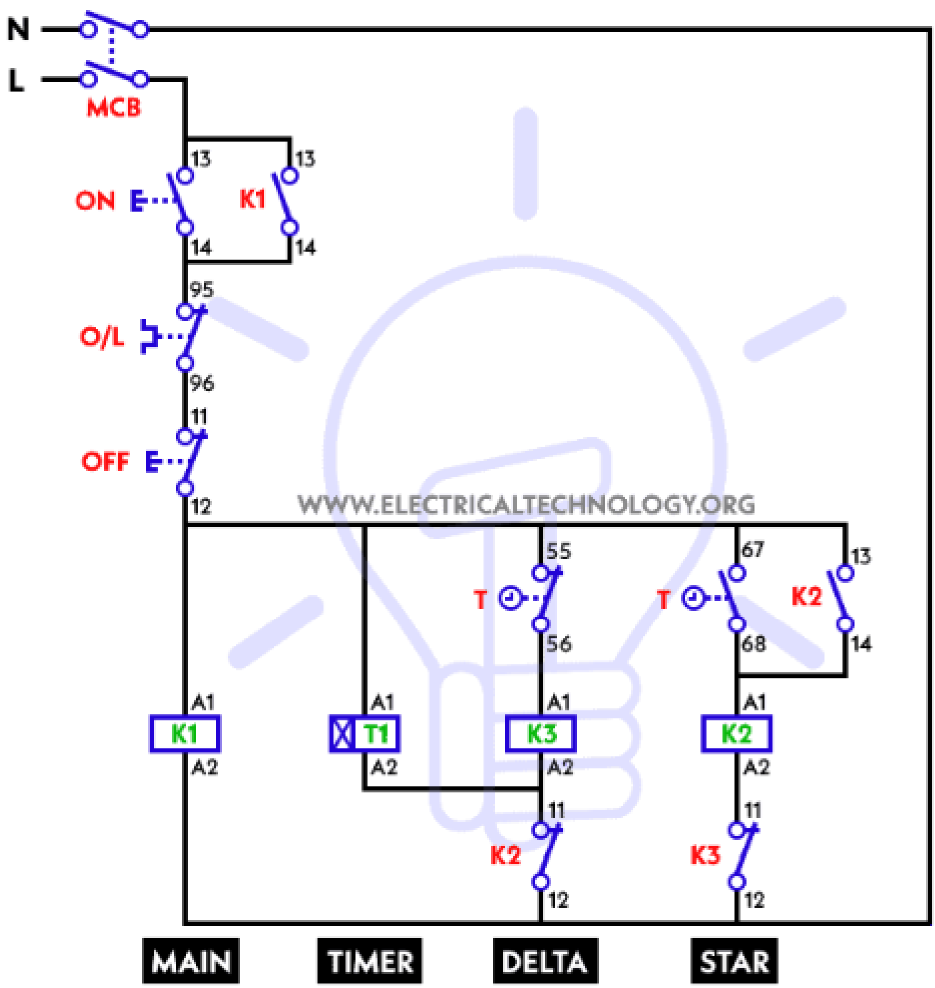
The timer relay will control the duration for which the motor operates in Star configuration.

Connect the output of the timer relay to the Star Contactor coil. When the Start button is pressed, both the Main and Star Contactors will engage, starting the motor in Star mode.

Step 5: Control of Delta Contactor: After the preset time on the timer relay, it will de-energize the Star Contactor and engage the Delta Contactor. Wire the Delta Contactor coil through the normally closed contact of the Star Contactor, ensuring that both contactors are not engaged at the same time.

Step 6: Interlocking of Contactors: To avoid both Star and Delta contactors closing simultaneously, wire interlocking contacts. Use the NC auxiliary contact of the Star Contactor to prevent the Delta Contactor from energizing while the Star Contactor is closed. Similarly, use the NC auxiliary contact of the Delta Contactor to prevent the Star Contactor from energizing when the Delta Contactor is closed.

Step 7: Overload Protection in Control Circuit: Wire the overload relay NC contact into the control circuit. If an overload occurs, this will de-energize the control circuit and stop the motor.



Control Diagram of Star Delta Starter using Timer

Final Steps:

Step 1: Verify Connections: Double-check all connections to ensure they match the wiring diagram.
Step 2: Power Up and Test: Turn on the main power supply. Press the Start button. The motor should start in Star configuration (low voltage/current) and, after the timer delay, automatically switch to Delta configuration (full voltage/current). Press the Stop button to halt the motor.
Step 3: Adjust the Timer: If needed, adjust the timer relay's delay to ensure the motor switches from Star to Delta at the right time, typically based on the load and size of the motor.
By following these steps, you can successfully install a Star-Delta starter, ensuring reduced starting current and proper motor control for both starting and running operations.

Points to Remember

- Three-phase induction motors are highly efficient, capable of running continuously under heavy loads for extended periods, which is ideal for workshop environments.
- Star-Delta Starting Circuit of Three-Phase Induction Motor reduces starting current to approximately one-third of what it would be in a direct online start.
- Forward and reverse starting circuit provides flexibility in industrial operations requiring bidirectional movement.
- The described method is a safety measure to prevent both forward and reverse contactors from being energized at the same time, which could create a short circuit or damage the equipment.
- The installation of a Direct Online starter involves two primary circuits: power and control.
- Forward and Reverse starting circuit, ensuring smooth and safe operation of the motor in both directions.
- The timer relay will control the duration for which the motor operates in Star configuration. After the preset time on the timer relay, it will de-energize the Star Contactor and engage the Delta Contactor.

Application of learning 2.3.

You have been tasked to install three (3) -phase motors in a new manufacturing workshop. The installation will involve using three distinct starting methods, one method for each motor depending on the machinery they will drive.

Task 1: Installing the First Motor with Direct Online (DOL) Starter

Install a 5-kW motor to drive a conveyor belt system using a Direct Online starter. Mount the motor, connect it to the power supply, and ensure all wiring is double-checked. Test the motor under load, and it performs efficiently without any noticeable issues.

Task 2: Installing the Second Motor with Star-Delta Starter

The task involves installing a 15 kW motor to power a hydraulic press, using a Star-Delta starter to reduce inrush current. The motor is wired, and connected to the power supply. It starts in star mode, then switches to delta mode, ensuring smooth transition without power drops or torque issues.

Task 3: Installing the Third Motor with Forward and Reverse Starter

The task involves installing a 7.5 kW motor to control a material hoist system, using a Forward and Reverse starter. Wiring the motor to two contactors ensures proper interlocking. Testing the system involves running the hoist upward, engaging the reverse starter, and verifying safety interlocks to prevent short circuits or system damage.

Task 4: Make a report detailing what acquired as new skills during the activities.

Indicative content 2.4: Utilization of Three-Phases Electrical Measuring Devices.

Duration: 6 hrs

Theoretical Activity 2.4.1: Description of common measurable parameters in three-phase circuits .

Tasks:

1: Answer the following questions:

i. According to your understanding, identify safety tips for operating electrical measuring equipment.

ii. What do you think are the common measurable parameters in electrical circuits?

iii. According to your understanding, what are electrical measuring devices used in three-phase electrical circuits measuring?

2: Provide answers to asked questions on papers.

3: Present the findings/answers to the whole class.

4: Ask clarifications where necessary.

5: Read the key readings **2.4.1**

Key readings 2.4.1: Description of common measurable parameters in three-phase circuits .

- **Common measurable parameters in electrical circuits for three-phases electrical measuring.**

For three-phase electrical circuits, the common measurable parameters are crucial for evaluating the performance and safety of the system. Here’s a brief overview of each parameter:

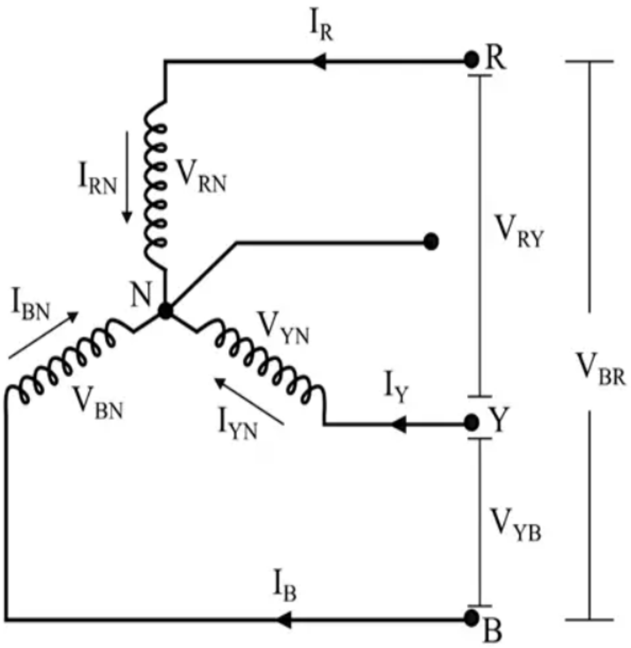
- ✓ **Voltage**
- **Definition:** The electrical potential difference between two points.
- **Types:**

Line-to-Line Voltage (V_L-L): The voltage between any two of the three phase conductors.

Line-to-Neutral Voltage (V_L-N): The voltage between a phase conductor and the neutral point.

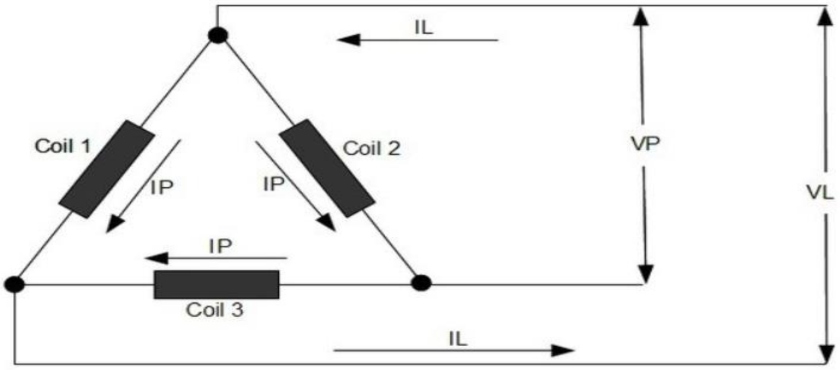
In a three-phase system, there are three conductors that form a three-phase system. If the voltage of phases is R, Y, and B,(Red, Yellow, and Blue), then the line voltage VRY is equal to the potential difference between the R and Y phases. Similarly, the line voltage VYB is equal to the potential difference between the Y and B phases.

The star connection is used where we need to implement a 3-phase 4-wire system to get neutral for single-phase loads, and the delta connection is used where we need to design a 3-phase 3-wire system. Both systems have different current and voltage relationships between their phases and lines. It has three phase windings namely R, Y, and B respectively. The common point of the three windings is termed neutral (N).



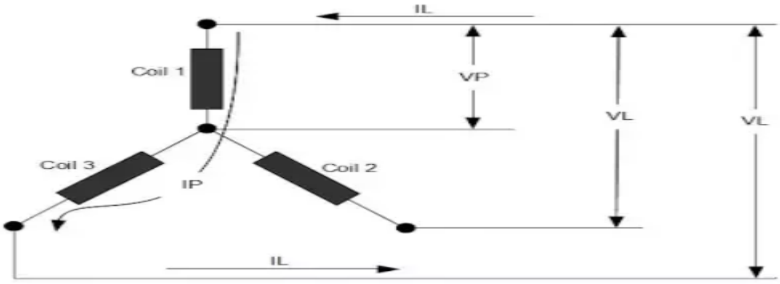
- **Measurement:** Use a three-phase voltmeter or a digital multimeter with three-phase capability.
- ✓ **Current**
- **Definition:** The flow of electrical charge through a conductor.
- **Types:**

Line Current (I_L): The current flowing through each phase conductor.
Phase Current (I_P): The current flowing through each phase winding in a star connection.



VP = VL
IP = IL / √3
IL = IP*√3

This is a delta configuration. The phase current is current which flow in phase winding which is represented as IP here in above figure. Line current in current flowing in line which is represented as IL in the figure . Here each line current is the vector sum of corresponding two-phase current (use KCL). Hence line current will be root three times of phase current in delta. But voltages between line and phase will be same
But the story will be different in star connection.



VP = VL / √3
VL = VP*√3
IP = IL

The above image is of star connection. Here as you can see current flowing in phase winding and line are same. Hence in star connection IP=IL.

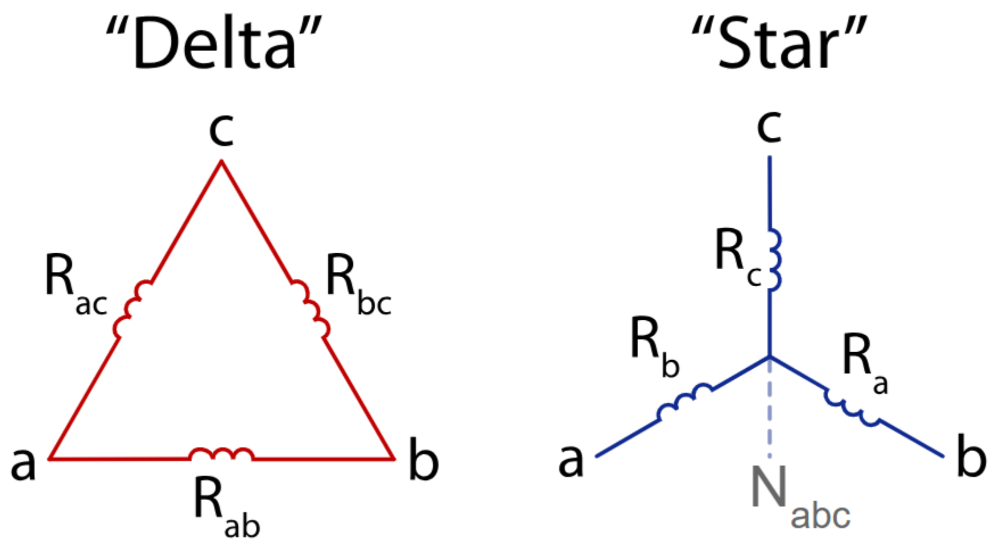
- **Measurement:** Use a clamp meter or ammeter with three-phase capability.

✓ **Resistance**

- **Definition:** The opposition to the flow of current within a conductor.
- **Types:**

  Phase Resistance: The resistance of each phase winding in a motor or transformer.

  Line Resistance: The resistance of the conductors in the system.



- **Measurement:** Use an ohmmeter or a resistance tester.

✓ **Power**

- **Definition:** The rate at which electrical energy is converted into another form of energy.
- **Types:**

  Active Power (P): The real power consumed by the load, measured in watts (W).

  Reactive Power (Q): The power that oscillates between the source and reactive components (example: inductors, capacitors), measured in volt-amperes reactive (VAR).

  - **Apparent Power (S):** The total power in the circuit, a combination of active and reactive power, measured in volt-amperes (VA).

- **Measurement:** Use a three-phase power meter or wattmeter. For active power, consider both power factor and phase voltages/currents.

✓ **Energy**

- **Definition:** The total work done or energy consumed over a period.
- **Energy Consumption:** Measured in kilowatt-hours (kWh) for electrical energy usage over time.
- **Measurement:** Use an energy meter to measure the total energy consumed by the circuit or system over a specified period.

- **Additional Parameters (for completeness):**

- ✓ **Power Factor (PF):** The ratio of active power to apparent power, indicating how effectively electrical power is being used. It ranges from 0 to 1. Use a power factor meter or calculate it using power measurements.
- ✓ **Frequency (f):** The rate at which the AC voltage cycles, measured in hertz (Hz). Use a frequency meter or multimeter with frequency measurement capability.
- ✓ **Phase Sequence:** The order of the phases in a three-phase system, which affects the direction of motor rotation. Use a phase sequence meter.

These parameters are essential for ensuring the efficient operation and safety of three-phase electrical systems. Accurate measurement and monitoring help in diagnosing problems, optimizing performance, and ensuring compliance with electrical standards.

Practical Activity 2.4.2: Perform three phase electrical circuit measurement

Task:

1: You are requested to go in manufacturing workshop and measure electrical three-phase measurement parameters using electrical measuring devices.

2: Apply safety precautions.

3: Identify electrical three phase measurement parameters to be measured.

4: Measure three-phase measurement parameters

5: Present your work to the trainer and whole class.

6: Read key reading **2.4.2** and ask clarification where necessary.

7: Perform the task provided in application of learning **2.4.**

Key readings 2.4.2: Perform three phase electrical circuit measurement

- **Safety tips for operating electrical measuring equipment for three-phases electrical measuring. In practical activities**

When dealing with three-phase electrical systems, safety is paramount to prevent accidents, injuries, and equipment damage. Here are some critical safety tips for operating electrical measuring equipment in these environments:

- ✓ **Understand the Electrical System:** Familiarize yourself with the three-phase system layout, voltage levels, power ratings, and wiring configurations before operating measuring equipment, reviewing the manual for functionality and safety precautions.
- ✓ **Personal Protective Equipment (PPE):** Prioritize safety when working with electrical systems by wearing insulated gloves, safety glasses, and flame-resistant clothing to protect against electric shock, sparks, and arc flashes.
- ✓ **Use Properly Rated Equipment:** Ensure measuring equipment is rated for three-phase system voltage and current levels, has appropriate CAT (Category) rating, and inspects for visible damage to prevent electric shock and ensure accurate measurements.
- ✓ **Ensure Proper Grounding:** Proper grounding of equipment and electrical systems is crucial for safety and accuracy, with Ground Fault Circuit Interrupters (GFCIs) providing additional protection against electrical hazards.
- ✓ **De-Energize the Circuit When Possible:** Turn off power before connecting or disconnecting measuring instruments, and use lockout/tagout procedures to secure equipment and minimize electrical hazards, ensuring a safer working environment.
- ✓ **Test the Environment Beforehand:** To ensure safety, use a non-contact voltage tester to check circuit voltage, identify high-risk areas, and avoid damp or wet environments, as these precautions prevent accidental electric shocks.
- ✓ **Safe Connection of Measuring Equipment:** Ensure test leads are in good condition and properly rated for the voltage and current levels. When working with three-phase systems, always connect the ground or neutral lead first and disconnect it last. Secure all connections tightly to prevent arcing and ensure accurate readings
- ✓ **Maintain Safe Distance and Clear Workspace:** Avoid contact with live circuits by keeping hands and body clear of live wires during measurements. Maintain a tidy work area, free of clutter, and use-insulated tools when needed to prevent accidental contact with live components.
- ✓ **Beware of Arc Flash Hazards:** Be aware of the risk of arc flashes when working

with high-voltage three-phase systems, as they can cause serious injuries or damage. In environments with potential arc-flash hazards, wear an arc-flash suit to ensure personal safety, especially in industrial settings.

- ✓ **Monitor for Overheating:** Regularly check electrical measuring equipment for overheating during extended use, as this can lead to malfunctions or safety hazards. Allow the equipment to cool down if it becomes too hot to prevent damage and ensure safe operation.

By following these safety tips, you can mitigate the risks associated with operating electrical measuring equipment in three-phase systems and ensure a safe working environment.

- **Perform three phase electrical circuit measurement**

Here are the steps for using various electrical measuring devices for three-phase electrical systems:

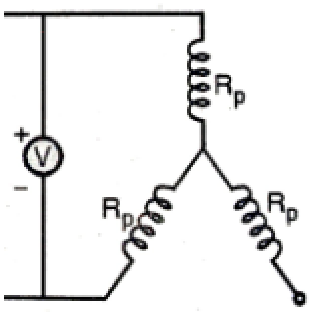
- ✓ **Voltmeters:** Measure the voltage in a three-phase system.

Steps:

1. **Safety First:** Ensure the system is de-energized if possible. Use personal protective equipment (PPE) as necessary.
2. **Select the Voltmeter:** Choose a three-phase voltmeter or a digital voltmeter capable of measuring three-phase voltages.
3. **Connect the Voltmeters:**

Line-to-Line Voltage: Connect the voltmeter probes to any two of the three-phase conductors. Record the voltage reading.

Line-to-Neutral Voltage: Connect the voltmeter probes to a phase conductor and the neutral point. Record the voltage reading.



4. **Read and Record Values:** Note the voltage values displayed. For three-phase systems, measure and record all relevant voltages.

5. **Disconnect:** Remove the probes carefully, ensuring no contact with live parts.

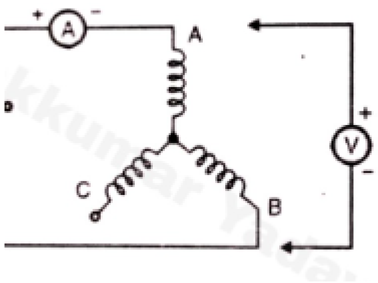
- ✓ **Ammeters:** Measure the current flowing through a conductor in a three-phase system.

Steps:

1. **Safety First:** Ensure the system is de-energized if possible. Use PPE as necessary.
2. **Select the Ammeter:** Use a clamp meter or a digital ammeter capable of measuring three-phase currents.
3. **Connect the Ammeter:**

   Clamp Meter: Open the clamp and position it around one of the phase conductors. Close the clamp and read the current value.

   Direct Measurement (for digital ammeters): If using a direct ammeter, disconnect the circuit and connect the ammeter in series with the load.



4. **Read and Record Values:** Note the current reading from the ammeter. Measure each phase current separately.
5. **Disconnect:** If using a direct ammeter, remove it from the circuit. For clamp meters, open the clamp and remove it from the conductor.

- ✓ **Ohmmeters:** Measure the resistance of components or windings in a three-phase system.

Steps:

1. **Safety First:** Ensure the system is de-energized. Disconnect the component or winding to be tested.
2. **Select the Ohmmeter:** Choose an ohmmeter appropriate for the expected resistance range.
3. **Connect the Ohmmeter:**

   For Components: Connect the leads of the ohmmeter to the terminals of the component or winding.

   For Windings: Measure the resistance between the phase windings.

4. **Read and Record Values:** Note the resistance readings displayed on the ohmmeter.
5. **Disconnect:** Remove the ohmmeter leads carefully.

- ✓ **Multimeters:** Measure voltage, current, and resistance in a three-phase system.

Steps:

1. **Safety First:** Ensure the system is de-energized if possible. Use PPE as necessary.
2. **Select the Multimeter:** Choose a digital multimeter (DMM) capable of three-phase measurements.
3. **Set the Multimeter:**

   For Voltage: Set the multimeter to the appropriate AC voltage range.

   For Current: Set the multimeter to the appropriate AC current range.

   For Resistance: Set the multimeter to the resistance measurement mode.

- ✓ **Connect the Multimeter:**

   Voltage Measurement: Connect the probes to the points where voltage measurement is needed.

   Current Measurement: For current measurement, break the circuit and connect the multimeter in series with the load.

   Resistance Measurement: Connect the probes to the component or winding to measure resistance.

4. **Read and Record Values:** Note the readings displayed on the multimeter.
5. **Disconnect:** Remove the multimeter leads carefully.

- ✓ **Wattmeters:** Measure the real power consumed by the electrical circuit.

Steps:

1. **Safety First:** Ensure the system is de-energized if possible. Use PPE as necessary.
2. **Select the Wattmeter:** Choose a three-phase wattmeter appropriate for the power range.
3. **Connect the Wattmeter:**

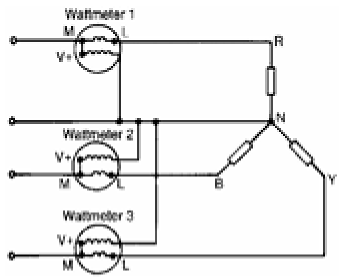
   For Three-Phase Loads: Connect the wattmeter to the appropriate phase and neutral or line-to-line terminals based on the wattmeter type (e.g., single-element or double-element).

4. **Read and Record Values:** Note the power readings displayed on the wattmeter.
5. **Disconnect:** Remove the wattmeter connections carefully.

Wattmeter Connection in Three Phase System:

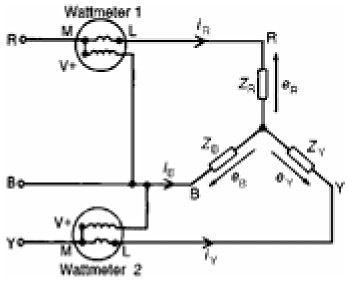
- **Three-wattmeter method for three phase 4wire system for balanced and unbalanced loads:**

Total power = P1 + P2 + P3



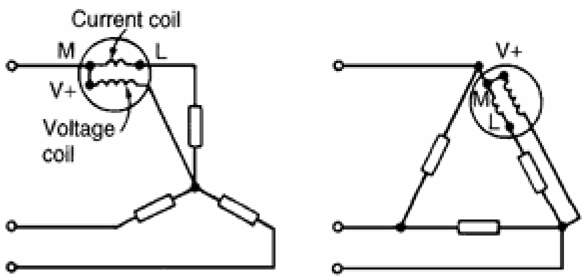
- **Two -wattmeter method for balanced loads:**

Total power = P1 + P2



- **One-wattmeter method for balanced load:**

Total power = 3 X wattmeter reading



- ✓ **Clamp Meters :** Measure the current flowing through a conductor without disconnecting it.

Steps:

1. **Safety First:** Ensure the system is de-energized if possible. Use PPE as necessary.
2. **Select the Clamp Meter:** Choose a clamp meter appropriate for the expected current range.
3. **Use the Clamp Meter:**

   Clamp Measurement: Open the clamp and position it around one of the phase conductors. Close the clamp and read the current value.

4. **Read and Record Values:** Note the current reading from the clamp meter.
5. **Disconnect:** Open the clamp and remove it from the conductor.

Each of these devices is used to measure specific parameters in three-phase systems, and proper handling and safety precautions are essential to ensure accurate measurements and safe operation.

Points to Remember

- Electrical measuring devices plays a crucial role in the accurate measurement and monitoring of electrical parameters in three phase systems,helping ensure reliable and safe operation of electrical equipment
- Proper handling and safety precautions are essential for accurate measurements and safe operation in these systems.
- Disconnect leads carefully and use appropriate multimeters and wattmeters for accurate results.

Application of learning 2.4.

Go in manufacturing workshop and perform measuring of parameters such as voltage, current, resistance and power on three-phase motors installed in manufacturing workshop by using the approprieted Electrical Measuring Devices.
Make a report detailing what acquired as new skills during the activities.

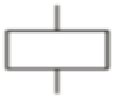
Learning outcome 2 end assessment

Theoretical assessment

Question 1: Observe the following symbols and name them by using the names given in bracket (normally closed contact, coil, start push button, stop push button, relay and fuse).

a)  (………)

b)  (………)

c)  (………)

d)  (………)

Question 2: Read the Read carefully the following questions related to star/delta starting and select the letter corresponding to the right answer.

i. Disadvantages of star/delta starting are:

a. The motor runs at a low speed at starting.
b. There is a cut off of power when changing star to delta connection
c. At starting the power of motor is reduced to one third (1/3)
d. Star/delta starting method can only be applied to the motors where the six leads or terminals can be accessed.
e. The supply voltage must be the same as the rated motor voltage for delta connection
f. All are correct

ii. Advantages of contactor are:

a. Set up and disconnect (switch off) the important current using auxiliary contacts controlling the control circuit having a low current.
b. Carry out (to execute) the manual command or automatic command (remote control)
c. To increase the number of operating stations

d. To place the number of the operating stations in low voltage (Safety voltage)
e. All are correct

iii. Protective's device can be used for protecting electrical motor against overheat is:

a. Fuses
b. Surge protection device
c. Thermal overload relay
d. All are correct

Question 3: Observe carefully the following table and Match the following role of electrical measuring devices in column B with their electrical measuring devices terms in column C and provide answers in column A.

Column A: Answers	**Column B: Role**	**Column C: electrical measuring devices**
1……….	1. It is used to measure power of the motor	A. Insulation Tester
2……..	2. It is used to measure earth resistance of the earthing system connected with the motor	B. Earth Resistance Tester
3……..	3. It is used to measure power factor of the motor	C. Voltmeter
4……..	4. It is used to measure the insulation resistance of a motor (between two windings or windings and cover)	D. Watt Meter
5……..	5. It is used to measure the voltage supplied to the motor	E. Power Factor Meter
6……….	6. It is used to measure the current following in the motor windings	F. Ammeter G. Ohm Meter

Question 4: Read carefully the following statements and answer by **True** for the correct statement or **False** for the incorrect statement in provided space.

a. In star delta starting, the starting current is reduced to approximately one-third of the rated current, the starting torque is also reduced to one-third. (…..)
b. DOL Starter causes a significant dip in voltage, hence suitable only for small motors. (…..)
c. Single-phase motors are more powerful, have smoother torque, and can start more easily compared to three-phase motors. (…..)

Practical assessment

ESCOP Ltd. is a manufacturing enterprise that fabricates various machinery. In order to install its three-phase induction motor in its manufacturing workplace, it is seeking a technician. You are request to install that motor in forward-reverse starting and measuring electrical parameters such line voltage, phase voltage, line current, and total power consumption of that motor.

Note: The three-phase motor has the following specification:

- The rated output of the motor is 15KW and its rated speed of 2800RPM.
- The stator windings can be connected in a **star** or **delta** formation.
- The power supply is **230/400V, 50Hz**.
- Those activities should be done within 6 hours.

References

Bird, J. (2016), Electrical and Electronic Principles and Technology (Fourth edition. ed.). Elsevier Ltd. Retrieved 2024 bsc, j. b. (2003).

Electrical Principles and Technology for Engineering (Second edition ed.). previously published as Reprinted. Retrieved February 2024

Linsley. (2013).

Basic electrical installation work. Routledge.

Theraja, A. T. (n.d.). A textbook of electrical technology (2 ed.). (2, Ed.) Retrieved 2024

Learning Outcome 3: Apply Winding Principles

Indicative contents
3.1. Introduction of electrical winding **3.2. Identifying Winding materials and machines**. **3.3. Identifying Winding principles** **3.4. Inspection of Winding/rewinding for electrical machines**

Key Competencies for Learning Outcome 3: Apply Winding Principles

Knowledge	Skills	Attitudes
• Identification of Winding materials and machines. • Identification of common sizes of wires used in winding/rewinding • Identification of motor and transformer winding/rewinding • Identification of the applications of motor and transformer winding/rewinding • Identification of Winding/rewinding insulation methods • Description of Transformer and motor nameplate elements • Explanation of Working principles of transformer and motor • Description of transformer and motor parts • Description of winding/rewinding techniques	• Applying motor and transformer winding /rewinding techniques • Winding/rewinding electrical machine • Inspecting wound/rewound of electrical machine • Diagnosis of induction motor failure • Verifying induction motor failure • Testing transformer phase	• Having time management spirit while applying motor and transformer winding/rewinding. • Being critical thinker while Interpreting rewinding motor/transformer steps • Being vigilant while Verifying/Diagnosis of induction motor failure • Being hard worker while applying motor and transformer winding/rewinding.

Duration: 20 hrs

Learning outcome 3 objectives:

By the end of the learning outcome, the trainees will be able to:

1. Identify properly the winding materials and machines used in winding/rewinding machine.
2. Identify properly the common sizes of wires used in winding/rewinding.
3. Identify properly the motor and transformer winding/rewinding according to their construction, the specific types of winding used, and the techniques employed during winding and rewinding.
4. Identify properly the applications of motor and transformer winding/rewinding
5. Describe properly electrical machines according to their types, principles of operation, components, and applications.
6. Describe properly motor and transformer winding /rewinding techniques as used in manufacturing machine.
7. Apply properly motor and transformer winding /rewinding techniques as used in manufacturing technology.
8. Wind/rewind correctly electrical machines as used in manufacturing technology.
9. Inspect properly wound/rewound of electrical machine as used in manufacturing technology.
10. Diagnosis properly induction motor failure as used in manufacturing technology.
11. Verify properly induction motor failure as used in manufacturing technology.
12. Test properly transformer phase as used in manufacturing technology.

Resources

Equipment	**Tools**	**Materials**
• PPEs • Multi-meter • Phase tester • Wattmeter • First aid kit • Winding machine • Generators • AC motors	• Screw Driver kit • Pliers Kit • wire stripper • coil tamping tools • taper measure • steel ruler • Vernier caliper • Micrometer	• Wires coils • Cores • Cables • Contactors • Timer relays • Pushbutton • Switch box • Junction boxes

• Transformer.	• Hack saw • Electric knife • Spanner Kit • Plumb wire • Wire drawer • Flashlight	• Insulators • Nails • Vanishing • Bake Insulation paper • Fuses • Female plugs • Male Plugs • Extension Cords • Soldering wires • Winding cord • Cable lugs

Indicative content 3.1: Introduction of Electrical Winding

Duration: 2 hrs

Theoretical Activity 3.1.1: Introduction of Electrical Windings

Tasks:

1. Answer the following questions:

   i. What do you understand by the terms: Winding/rewinding, coil, core, magnetic field and varnishing?

   ii. What do you think are the Common sizes of wires used in winding/rewinding?

   iii. What do you think are the types and the applications motor and transformer winding/rewinding?

2. Provide answers to asked questions on papers.
3. Present the findings/answers to the whole class.
4. Ask clarifications where necessary.

5.Read the key readings **3.1.1**

Key readings 3.1.1:

- **Definition of key terms:**
  - ✓ **Winding/Rewinding**: This refers to the process of winding wire around a core to create coils in devices like transformers or electric motors. Rewinding may involve replacing old or damaged wire to restore functionality.
  - ✓ **Coil**: A coil is a series of loops or turns of wire, often used to create a magnetic field when electric current passes through it. Coils are fundamental components in inductors, transformers, and electromagnets.
  - ✓ **Core**: The core is the central part of a magnetic device, often made from ferromagnetic material. It enhances the magnetic field generated by the coils, increasing efficiency and performance in transformers and motors.
  - ✓ **Magnetic Field**: This is the region around a magnetic material or current-carrying wire where magnetic forces can be detected. It's represented by magnetic field lines, indicating the direction and strength of the field.

- ✓ **Varnishing**: This process involves applying a protective coating (varnish) to coils and windings to insulate them and prevent short circuits. Varnishing also helps to protect against environmental factors like moisture and dust.

- **Common sizes of wires used in winding/rewinding**

When it comes to winding and rewinding applications, especially in motors, transformers, and other electromagnetic devices, common wire sizes are measured in AWG (American Wire Gauge). Here are some typical sizes used:

22 AWG: Often used for small coils and low-current applications.
20 AWG: Common for winding smaller transformers and inductors.
18 AWG: Used for medium power applications and larger coils.
16 AWG: Suitable for larger motors and higher current applications.
14 AWG: Used in heavy-duty applications where significant current is present.
12 AWG: Common in high-power applications, like larger motors.

- **Types of motor and transformer winding/rewinding**

  - ✓ **Types of Rotor Winding**
    - **Squirrel Cage Windings**:
      1. Common in induction motors.
      2. Consists of conductive bars shorted at both ends.

    - **Wound Rotor Windings**:
      1. Used in some induction motors.
      2. Windings are connected to external resistors for control.

  - ✓ **Stator Windings**:
    - Usually comprised of three-phase windings for three-phase motors.
    - Can be connected in star (Y) or delta (Δ) configurations.

  - ✓ **Permanent Magnet Windings**:
    - Utilized in brushless DC motors.
    - Involves magnets attached to the rotor.
  - ✓ **Single-Phase Windings**:
    - Used in smaller motors like those in household appliances.
    - May include capacitor start or split-phase designs.

  - ✓ **Types of Transformer Windings**

- **Primary Winding**:
  1. Receives input voltage.
  2. Can be wound in various configurations (e.g., delta, star).

- **Secondary Winding**:
  1. Delivers output voltage.
  2. May also have delta or star configurations.

- **Autotransformer Windings**:
  1. Shares a portion of winding for both primary and secondary.
  2. Generally, more compact and efficient.

- **Two-Winding Transformers**: Separate primary and secondary windings.
- **Multi-Winding Transformers**: Can have several secondary windings for different voltages.

- **Application of motor and transformer winding/rewinding**

  ✓ **Applications of Motor Winding/Rewinding:**

- **Electric Motors**: Winding is essential for creating the magnetic field necessary for motor operation. Rewinding can restore performance in damaged or worn-out motors.
- **Industrial Machinery**: Motors used in manufacturing equipment often require periodic rewinding due to wear and tear from continuous operation.
- **HVAC Systems**: Electric motors in heating, ventilation, and air conditioning systems benefit from winding for efficiency and reliability.
- **Automotive Applications**: Electric motors in vehicles (e.g., power windows, seats) may require rewinding to maintain functionality.
- **Home Appliances**: Motors in appliances like refrigerators, washing machines, and fans may need rewinding to extend their lifespan.

  ✓ **Applications of Transformer Winding/Rewinding:**

- **Power Distribution**: Transformers are essential in power systems for voltage transformation. Winding ensures they operate efficiently at various voltage levels.
- **Renewable Energy**: In wind and solar energy systems, transformers are used to convert generated power to suitable voltage levels for the grid.

- **Industrial Transformers**: Heavy-duty transformers used in factories may require rewinding to restore efficiency after years of operation.
- **Testing and Calibration**: Transformers may be wound to specific standards for use in testing equipment, ensuring accurate voltage and current measurements.
- **Audio and Signal Processing**: Special transformers (like isolation transformers) are used in audio systems, requiring precise winding for optimal performance.

Points to Remember

- Sizes of wires used in winding/rewinding can vary based on the specific requirements of the application, such as current capacity, resistance, and space considerations. Additionally, other factors like insulation type and thermal properties might influence the choice of wire.

Application of learning 3.1.

Go in manufacturing workshop to observe the electrical motor and transformer winding/rewinding and identify the followings:

- The Common sizes of wires used in winding/rewinding.
- The types of motor and transformer winding/rewinding.

Make a report detailing what acquired as new knowledge during the activity.

Indicative content 3.2: Identifying Winding Materials And Machines.

Duration: 3 hrs

Theoretical Activity 3.2.1: Identifying Winding materials and machines.

Tasks:

1. Answer the following questions:
   i. What are the types of materials used for motor and transformer winding/rewinding?
   ii. What do you think are the Winding/rewinding insulation methods?
   iii. What are the elements of Transformer and motor nameplate?

2. Provide answers to asked questions on papers.

3. Present the findings/answers to the whole class.

4. ask clarifications where necessary.

5.Read the key readings **3.2.1**

Key readings 3.2.1:

- **Types materials for motor and transformer winding/rewinding**
  - ✓ **Wires**
    - **Copper Wire**: The most common choice due to its excellent electrical conductivity, thermal conductivity, and malleability. Usually available in different gauges, it can be enamel-coated (magnet wire) for insulation.
    - **Aluminum Wire**: A lighter and cheaper alternative to copper, but with lower conductivity. Often used in larger transformers and motors.
  - ✓ **Coils/Solenoid Coils**: Made from copper or aluminum wire, these coils are designed to create a magnetic field when current flows through them.
  - ✓ **Insulating Materials**
    - **Enamel Coating**: A common insulation for copper wire, providing a thin, durable coating that allows for close winding.
    - **Paper Insulation**: Often used in larger transformers, this is typically impregnated with oil for better dielectric properties.
    - **Mylar and Polyester Films**: These are used as insulation between windings or layers, offering good thermal and electrical properties.

- **Fiberglass**: Sometimes used in high-temperature applications, fiberglass can provide additional mechanical strength.
- **Resin or Epoxy**: Used to encapsulate and insulate windings, providing excellent protection against moisture and environmental factors.
- **Varnish**: Often applied to finished windings to provide additional insulation and mechanical stability.

- **Winding/rewinding Insulation Methods**
  - ✓ **Winding Insulation Methods:**
    - **Layer Insulation**: Insulation is applied between layers of windings. Common materials include paper, film, or synthetic materials that can withstand high temperatures.
    - **Coated Wire**: Enamel-coated wire is often used, where the insulation is baked onto the wire, providing a robust barrier against electrical shorts.
    - **Pre-impregnated Materials**: These involve using pre-impregnated insulating materials (like epoxy) that cure when heat is applied, providing a solid, uniform insulation.
    - **Wraps and Tapes**: Insulation tapes or wraps can be used around the windings, typically made from polyester, Mylar, or other high-temperature materials.
  - ✓ **Rewinding Insulation Methods:**
    - **Stripping and Re-insulating**: When rewinding, old insulation is stripped away, and new insulation is applied to ensure integrity and performance.
    - **Vacuum Pressure Impregnation (VPI)**: This method involves placing the rewound coil in a vacuum chamber, applying resin, and then pressure to fully saturate the insulation, ensuring comprehensive coverage.
    - **Heat Shrink Tubing**: For some applications, heat shrinkable tubing is used to cover connections and exposed areas after rewinding to enhance insulation.
    - **Layered Insulation Reapplication**: Similar to the winding process, insulation is reapplied layer by layer during rewinding to maintain performance standards.

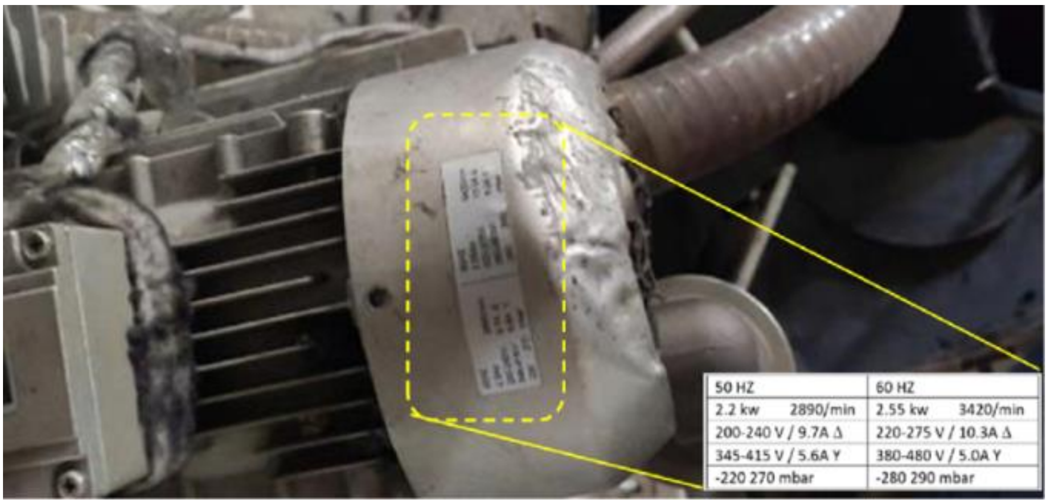
- **Transformer and motor nameplate elements**
  - ✓ **Transformer Nameplate Elements:**
    - **Manufacturer**: Name of the company that produced the transformer.
    - **Model Number**: Specific model identifier.
    - **Serial Number**: Unique identification number for tracking and warranty purposes.
    - **Voltage Ratings**: Primary and secondary voltage levels (e.g., 480V/240V).
    - **Power Rating**: KVA or MVA rating indicating the transformer's capacity.

- **Frequency**: Operating frequency, typically 50Hz or 60Hz.
- **Phase**: Number of phases (single-phase or three-phase).
- **Winding Type**: Configuration (delta or wye).
- **Insulation Class**: Type of insulation used, indicating thermal limits.
- **Cooling Type**: Cooling method (e.g., oil-immersed, dry-type).
- **Connections**: Description of terminal connections.
- **Weight**: Total weight of the transformer.
- **Standards Compliance**: Relevant industry standards (e.g., IEEE, ANSI).

✓ **Motor Nameplate Elements:**

- **Manufacturer**: Name of the company that produced the motor.
- **Model Number**: Specific model identifier.
- **Serial Number**: Unique identification number for tracking.
- **Horsepower (HP)**: Power rating of the motor.
- **Voltage**: Operating voltage rating (e.g., 230V/460V).
- **Current**: Full load current (Amperes).
- **Frequency**: Operating frequency (e.g., 50Hz or 60Hz).
- **Phase**: Number of phases (single-phase or three-phase).
- **Efficiency Rating**: Efficiency percentage, indicating performance.
- **Service Factor**: Ability to operate above its rated load for short periods.
- **Temperature Rise**: Maximum allowable temperature rise during operation.
- **Frame Size**: Physical dimensions of the motor frame.
- **Speed**: Rated speed (RPM) under full load.
- **Insulation Class**: Type of insulation used.
- **Rotation Direction**: Direction of rotation (clockwise or counterclockwise).
- **Standards Compliance**: Relevant industry standards (e.g., NEMA, IEC).

Example of motor name plate



Practical Activity 3.2.2: Interpret the motor/transformer nameplate

Task:

1: You are requested to read and interpret the following nameplate:

2: Follow clear work instruction (Task, Time allocated) provided by your trainer.

3: Follow trainer's demonstration on how to perform the given task.

4: Present your work to the trainer and whole class.

5: Read key reading **3.2.2** and ask clarification where necessary.

6: Perform the task provided in application of learning **3.2**

Key readings 3.2.2

- **The key techniques and components of transformer nameplate**

Reading a transformer nameplate is essential for understanding its specifications and safe operation. The key techniques and components to look for:

- **Manufacturer Information**

Name and Logo: Identifies the maker of the transformer.

- **Model Number**

This helps in referencing the specific design and features.

- **Power Rating (kVA or MVA)**

Indicates the maximum load the transformer can handle. Look for "kVA" (kilovolt-amperes) or "MVA" (megavolt-amperes).

- **Voltage Ratings**

Primary Voltage: Input voltage, usually higher.
Secondary Voltage: Output voltage, usually lower.
Ensure to check if these are line-to-line or line-to-neutral voltages.

- **Frequency**

Commonly 50 Hz or 60 Hz. This indicates the frequency of the AC supply.

- **Phase**

Indicates whether the transformer is single-phase or three-phase.

- **Winding Connection**

Describes how the windings are connected (e.g., Delta or Wye). This affects voltage transformation and phase shifts.

- **Impedance (%Z)**

Indicates the voltage drop when full load current flows through the transformer, important for short-circuit calculations.

- **Cooling Method**

Types include Oil-immersed (ONAN, ONAF, etc.) or Air-cooled. This affects maintenance and operational conditions.

- **Insulation Class**

Indicates the temperature rating of the insulation materials, affecting longevity and thermal limits.

- **Weight and Dimensions**

Helpful for installation considerations and logistics.

- **Standards Compliance**

Look for compliance with local or international standards (e.g., ANSI, IEC).

- **Serial Number and Manufacturing Date**

Useful for tracking and warranty information.

- **Additional Features**

This may include surge protection, taps, and other specifics like audible alarm features or environmental ratings.

- **Reading Tips:**
  - ✓ **Take Your Time:** Ensure you understand each component before proceeding.
  - ✓ **Cross-Reference:** If possible, use the manufacturer's documentation for clarity.
  - ✓ **Seek Help:** If unsure, consult with an electrical engineer or technician for complex transformers.

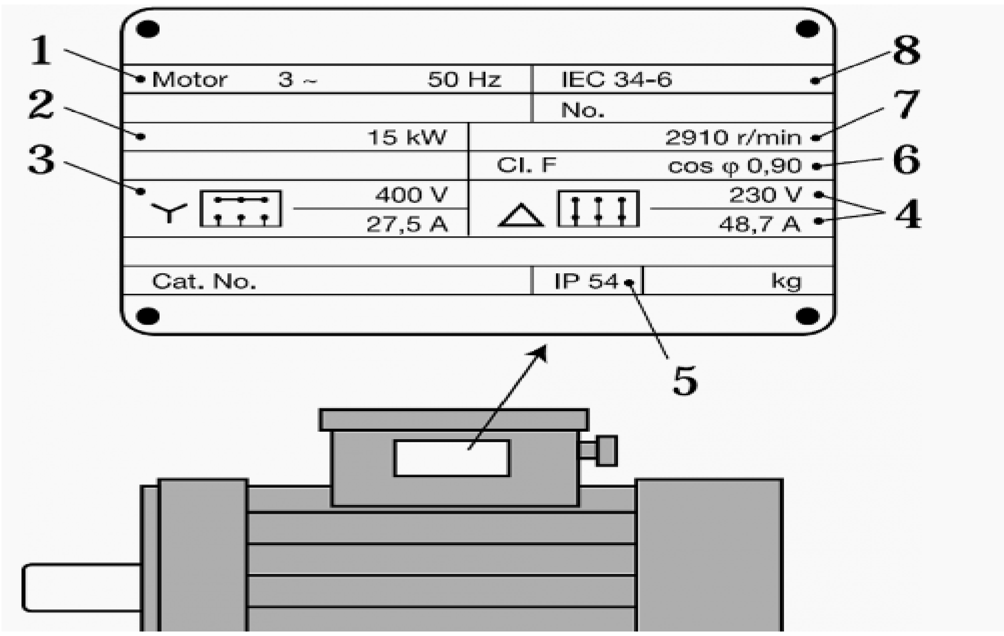
Points to Remember

- Reading a transformer nameplate is essential for understanding its specifications and safe operation.
- Choosing the right materials depends on the specific application, desired performance, and environmental conditions. Each material has its advantages and is selected based on factors like conductivity, insulation requirements, and temperature ratings
- Winding/rewinding methods ensure that electrical components operate safely and efficiently while prolonging their lifespan. Each method is selected based on the specific requirements of the application, such as voltage, temperature, and environmental conditions.
- Transformer and motor nameplate elements help ensure proper installation, operation, and troubleshooting for transformers and motors.

Application of learning 3.2.

Go in manufacturing workshop to observe the electrical motor name plate and identify the followings:

- The key details typically found on the following motor nameplate and explain how to use them.



Indicative content 3.3: Identifying Winding Principles

Duration: 10 hrs

Theoretical Activity 3.3.1: Description of transformer and electrical motor

Tasks:

1. Answer the following questions:

    i. What do you think are the Parts of transformer and electrical motor?

    ii. Can you explain the working principle of transformer?

    iii. Can you explain the working principle of induction motor?

2. Provide answers to asked questions on papers.
3. Present the findings/answers to the whole class.
4. Ask clarifications where necessary
5. Read the key readings **3.3.1**.

Key readings 3.3.1:

- **Description of rotating machines (motors and generators)**
    - ✓ **Parts of rotating machine**

The electrical parts of a rotating machine, such as an electric motor or generator, include components that are crucial for the generation, conversion, and control of electrical energy. Here are the main electrical parts of a rotating machine:

- **Stator** is the stationary part of the rotating machine. It typically consists of a laminated iron core with slots for winding. The stator winding is connected to the power supply and produces a rotating magnetic field when energized.
- **Rotor** is the rotating part of the machine. It can have different configurations, such as a squirrel-cage rotor in induction motors or a wound rotor in some types of motors and generators. The rotor interacts with the stator's magnetic field to produce mechanical rotation.
- **Brushes and Slip Rings (for Wound Rotors):** In machines with wound rotors, brushes and slip rings are used to connect the rotor winding to external circuits. Brushes maintain electrical contact with the rotating rotor through slip rings.

- **Terminal Box or Connection Box** houses the points where external electrical connections are made. It provides access to the stator and rotor windings for connecting power and control circuits.
- **Insulation:** Insulation materials are used to electrically isolate different parts of the machine to prevent short circuits. Common insulation materials include varnish, insulation tapes, and insulating coatings.
- **Thermal Protection Devices** such as temperature sensors or thermal switches, are employed to monitor the temperature of the machine. They help prevent overheating and damage by triggering protective measures.
- **Cooling Systems** such as fans or liquid cooling, are used to dissipate heat generated during operation and maintain the machine's temperature within acceptable limits.
- **Voltage Regulators and Control Devices:** In generators, voltage regulators and control devices are utilized to regulate and control the generated voltage to meet specific requirements.

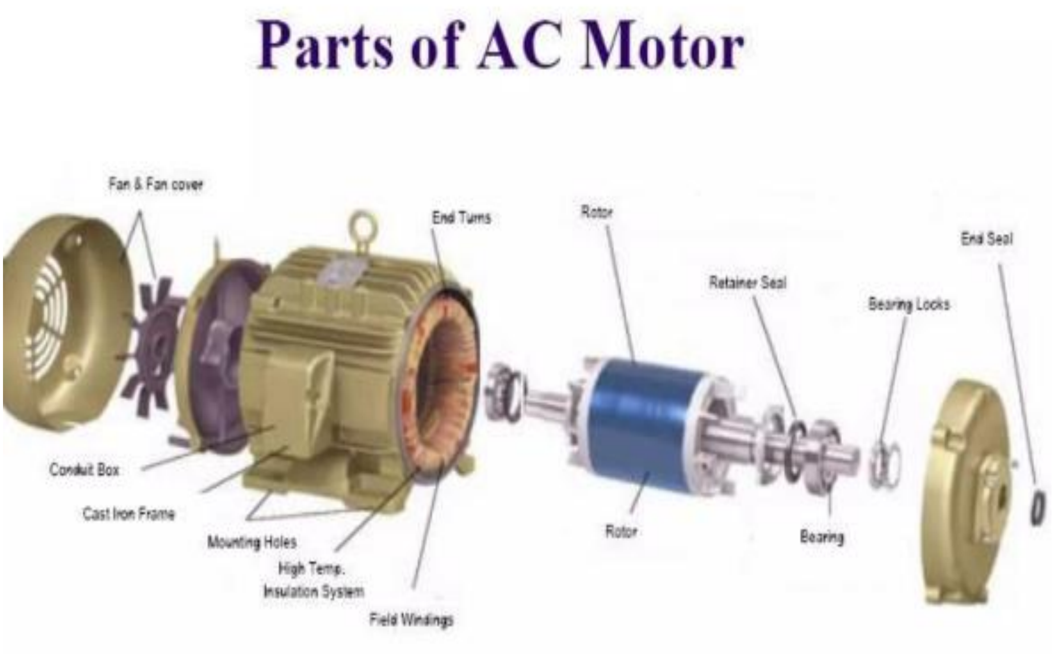
- **Mechanical parts of rotating machine**

The mechanical parts of a rotating machine, such as an electric motor or generator, contribute to its structural integrity, rotational movement, and overall mechanical performance. Here are the main mechanical parts of a rotating machine:

- **Frame** is the structural component that supports and encases the stator, rotor, and other internal components. It provides rigidity and support for the entire machine.
- **Shaft** is a rotating rod that connects the rotor to external devices or loads. It transmits mechanical power from the rotating machine to the driven equipment.
- **Bearings** support the rotor shaft, allowing it to rotate smoothly within the stator. They reduce friction and wear, ensuring proper alignment and stability.
- **Couplings** are used to connect the rotor shaft to external loads or devices, allowing the transfer of mechanical power. They provide flexibility and accommodate misalignments.
- **Fan or Cooling System** are used to dissipate heat and maintain the machine's temperature within acceptable limits.
- **Pulleys or Gears (if applicable):** In some applications, rotating machines may be connected to other machinery using pulleys, gears, or other mechanical transmission components.
- **Seals** are used to prevent the entry of contaminants, such as dust or moisture, into the machine. They help protect internal components from damage and ensure a clean operating environment.

- **Lubrication System:** Bearings and other moving parts require lubrication to reduce friction and wear. A lubrication system ensures that the rotating parts operate smoothly and efficiently.
- **Balancing Elements** such as counterweights or balancing rings, are used to minimize vibrations and ensure that the rotating machine operates smoothly.
- **Casing or Enclosure** surrounds the entire machine, providing protection against external elements and helping contain noise generated during operation

Figure below shows the parts of AC motor:



- ✓ **Working principle of induction motor**

An induction motor or asynchronous motor is an AC electric motor in which the electric current in the rotor that produces torque is obtained by electromagnetic induction from the magnetic field of the stator winding. An induction motor therefore needs no electrical connections to the rotor. An induction motor's rotor can be either wound type or squirrel-cage type.
Three-phase squirrel-cage induction motors are widely used as industrial drives because they are self-starting, reliable, and economical. Single-phase induction motors are used extensively for smaller loads, such as garbage disposals and stationary power tools.

The working principle of an induction motor is based on electromagnetic induction. Here’s a simplified explanation:

- **Stator and Rotor**: An induction motor consists of two main parts: the stator (stationary part) and the rotor (rotating part). The stator has coils that are supplied with alternating current (AC), creating a rotating magnetic field.
- **Rotating Magnetic Field**: When AC flows through the stator windings, it generates a rotating magnetic field that rotates at a synchronous speed determined by the supply frequency and the number of poles in the motor.
- **Induction of Current**: The rotating magnetic field passes through the rotor, which is usually made of conductive material (like aluminum or copper). According to Faraday's law of electromagnetic induction, this changing magnetic field induces an electric current in the rotor.
- **Rotor Movement**: The induced current in the rotor creates its own magnetic field. The interaction between the stator's rotating magnetic field and the rotor's magnetic field produces a torque, causing the rotor to turn.
- **Torque Generation**: The torque produced is proportional to the amount of slip and the strength of the magnetic field. As the load on the motor increases, the rotor slows down slightly, increasing the slip and thus the induced current and torque until equilibrium is reached.
- **Synchronous Speed**

  When Alternating current (AC) is applied to the stator of a three phase motor, a rotating magnetic field is setup. This rotating magnetic field moves with a speed called synchronous speed. The Synchronous speed can be calculated as follows: 120 times the frequency (F), divided by the number of poles (P):

$$N_s = \frac{120F}{P}$$

The synchronous speed decreases as the number of poles increases. The table below shows the synchronous speed associated with various numbers of poles at supply frequencies of 50Hz and 60Hz:

No. of Poles	Synchronous Speed @ 50Hz	Synchronous Speed @ 60Hz
2	3000	3600
4	1500	1800
6	1000	1200
8	750	900
12	500	600

- **Rated Speed:** The speed of operation of an AC motor when fully loaded at rated voltage is called the rated speed. It is usually given in RPM (Revolutions per minute) on an electric motor nameplate. The rated speed is the speed of the rotor.
- **Slip**: The speed of the rotor magnetic field in an induction motor lags slightly behind the synchronous speed of the changing stator magnetic field. This difference in speed between rotor and stator fields is called slip and is measured in %. The slip of an AC motor is a key factor and is necessary to produce torque. The greater the load (torque), the greater slip. The formula for calculating motor slip is given by:

$$Slip = \frac{N_S - N}{N_S}$$

$$Where:$$

$$N_s = Synchronous - speed$$

$$N = Rotor - speed$$

In summary, an induction motor operates by using electromagnetic induction to generate torque, enabling it to convert electrical energy into mechanical energy efficiently.

- **Description of static machines (transformers)**
  - ✓ **Construction parts and accessories**

Following are the various parts of transformer:

1. Laminated core
2. Windings
3. Insulating material
4. Tank
5. Terminals and bushings
6. Transformer oil
7. Tap changer
8. Buchholz relay
9. Oil conservator
10. Explosion vent
11. Breather
12. Radiator and fans

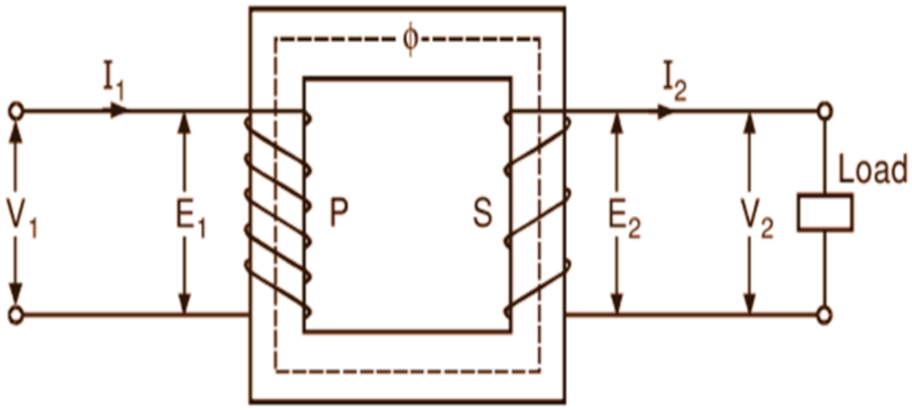
From all the above-listed parts of transformer, laminated soft iron core, windings, and insulating material are the basic parts of transformer. These three are available in all types of transformers.

Figure below shows the parts of transformer:

- ✓ **Working principle of transformer**

A transformer operates on the principle of electromagnetic induction to transfer electrical energy between two circuits. Here's how it works:

- **Basic Components**: A transformer consists of two coils of wire (the primary and secondary windings) wrapped around a magnetic core.
- **AC Input**: When alternating current (AC) flows through the primary winding, it creates a changing magnetic field around it.
- **Magnetic Induction**: This changing magnetic field induces a voltage in the secondary winding through electromagnetic induction. The core enhances this magnetic coupling between the two windings.
- **Voltage Transformation**: The induced voltage in the secondary winding depends on the turns ratio of the primary to secondary windings. If the secondary winding has more turns than the primary, the transformer steps up the voltage; if it has fewer turns, it steps down the voltage.



$$K = \frac{E_2}{E_1} = \frac{V_2}{V_1} = \frac{N_2}{N_1}$$

Step up transformer

If $K > 1$ i.e. $V_2 > V_1$, transformer is called a step up transformer. It is that transformer which receives electrical energy at one voltage and delivers it at a higher voltage.

Step down transformer

If $K < 1$ i.e. $V_2 < V_1$, transformer is called a step-down transformer. It is the transformer which receives electrical energy at one voltage and delivers it at a lower voltage.

One to one transformer

If $K = 1$ i.e. $V_2 = V_1$, transformer is called a one to one transformer. Obviously, such a transformer transfers electrical energy from one circuit to another circuit without any change in the voltage.

- **Power Conservation**: Ideally, the power input to the primary winding (voltage multiplied by current) equals the power output from the secondary winding (voltage multiplied by current), minus any losses (like heat).

Practical Activity 3.3.2: Winding/rewinding of static machines

Task:

1: You are requested to rewind a single-phase step-up transformer which increasing the output of the transformer to double the input.

2: Draw electrical diagram to be used to perform the given task.

3: Referring to the drawing provided from task above, Perform the given work.

4: Present your work to the trainer and whole class.

5: Read key reading **3.3.2** and ask clarification where necessary

6: Perform the task provided in application of learning **3.3.**

Key readings 3.3.2

- **Single phase Transformer Project Directions:**

✓ Start by calculating the turns ratio using the formula

✓ Winding a transformer a few hundred times will take a while, so make sure you have the time to do it in one sitting and are able to focus on the count at the same time. In this lesson, we will use the example of making a step-up transformer and increasing the output of the transformer to double the input.

✓ Take one end of the thinner wire (26 AWG) and solder it to a connector pin on the corner of the bobbin.

✓ Wind the secondary side with your calculated number of turns. In our example, we will wind 800 turns. Try to wind it relatively tight and evenly throughout that side of the core.

✓ Once the 800 turns have completed, solder the end to the other corner connector pin on the transformer bobbin. It is a good idea to use the pin next to the previous one so it is easier for you to track.

✓ Using the thicker wire (20 AWG), solder one end to the third corner of the bobbin.

✓ Wind the primary side with half the number of turns as the secondary side. In our example, this will be 400 turns. Again, try to wind it relatively tight and evenly throughout the side of the core.

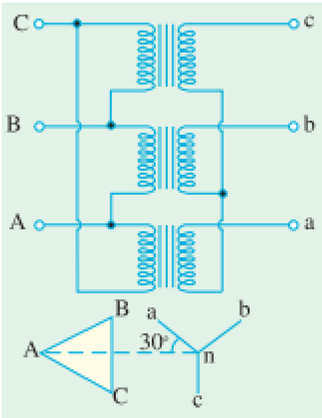
✓ After soldering the end of the wire to the last corner of the bobbin, wrap everything in electrical tape to protect it from the environment and ensure there are no opportunities for accidental short circuits.

- ✓ Snap each E-core piece onto the bobbin with the center of the "E" going through the core of the bobbin.
- ✓ You will notice that only four pins have been used. This is mainly for safety and simplicity. Following our example, you can add an AC voltage to the primary side to double its voltage across the secondary side. Remember to measure it with a multimeter before using it in any applications.

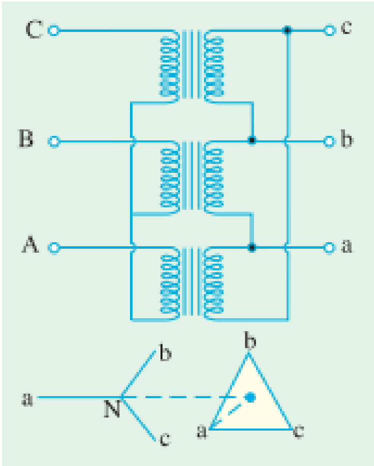
- **Prepare winding diagram**

Transformer windings connection diagrams:

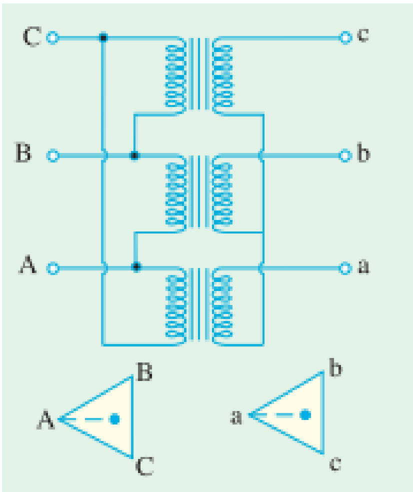
- ✓ **Delta-Wye (Δ-Wye) Connection:** In this configuration, one winding (usually the primary) is connected in a delta (Δ) or triangular arrangement, and the other winding (usually the secondary) is connected in a wye (Y) or star configuration. This connection is often used for transformers with a high-voltage primary and a lower-voltage secondary.



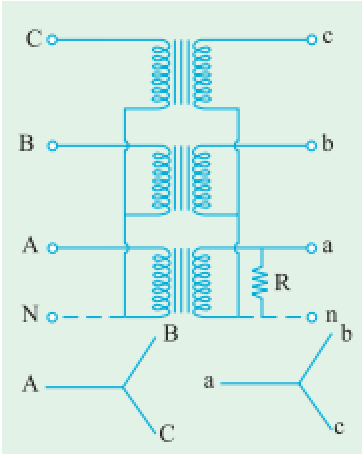
- ✓ **Wye-Delta (Wye-Δ) Connection:** This is the reverse of the delta-wye connection. The primary winding is in a wye configuration, and the secondary winding is in a delta configuration. This connection is commonly used for transformers with a high-voltage secondary and a lower-voltage primary.



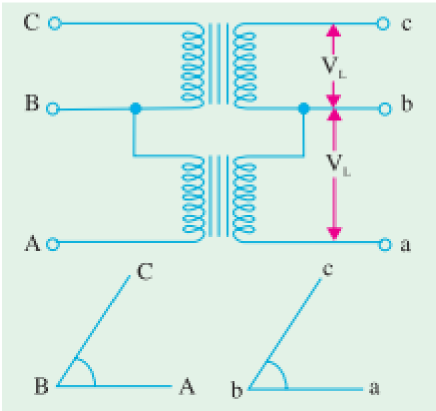
- **Delta-Delta (Δ-Δ) Connection:** In a delta-delta connection, both the primary and secondary windings are connected in a delta configuration. This connection is often used in applications where a transformer's primary and secondary voltages are approximately equal.



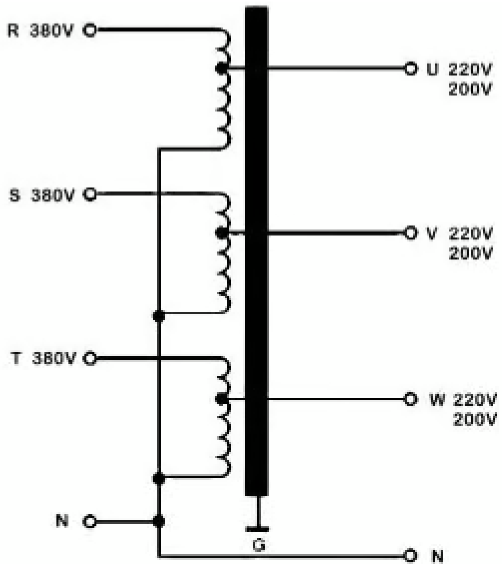
- **Wye-Wye (Y-Y) Connection:** In a wye-wye connection, both the primary and secondary windings are connected in a wye configuration. This connection is suitable for applications where the primary and secondary voltages are approximately equal.



i. **Open-Delta (V-V) Connection:** In an open-delta connection, three single-phase transformers are used to create a three-phase system. One of the transformers is omitted, making it more cost-effective than a full three-phase transformer. This connection is used when a three-phase load is not constant.

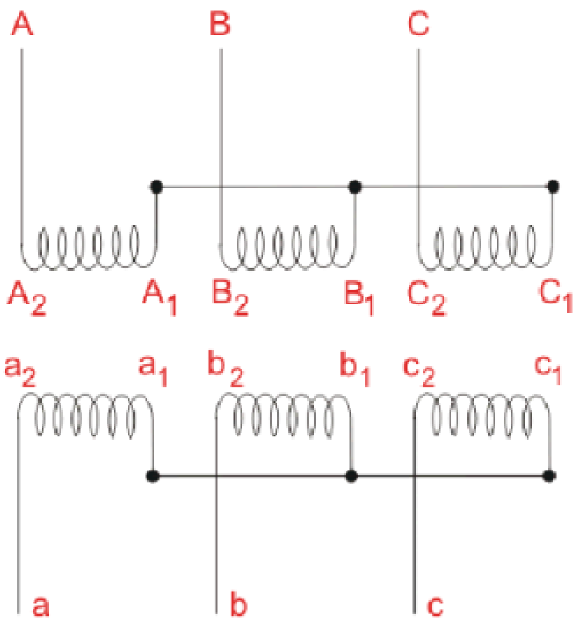


- ✓ **Auto-transformer Connection:** An auto-transformer has a single winding with a portion of it shared between the primary and secondary. This connection allows for voltage transformation and is more compact than traditional transformers.



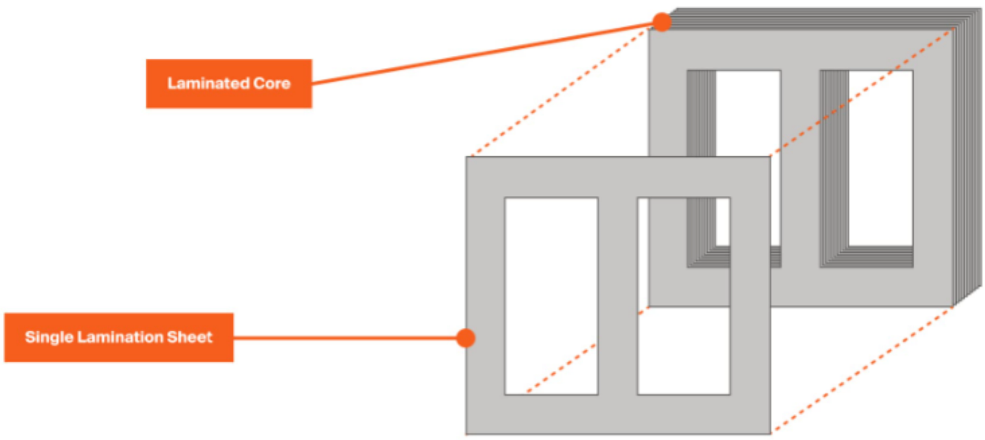
- **Transformer winding termination/labelling**

Transformer winding termination or labeling refers to the identification and marking of the terminals on the windings of a transformer. Proper termination and labeling are essential for ensuring correct connections during installation, maintenance, and troubleshooting. The labeling typically includes designations for the high-voltage (primary) and low-voltage (secondary) terminals, as well as other relevant information.



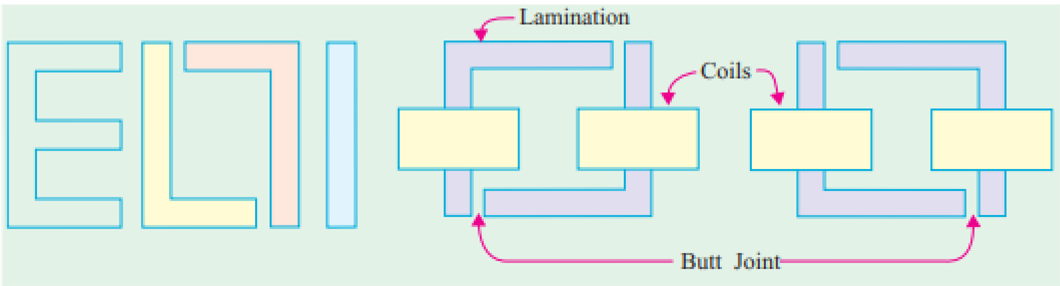
- **Construction materials of transformer laminated sheets**

A transformer core is a structure of thin laminated sheets of ferrous metal (most commonly silicon steel) stacked together, that the primary and secondary windings of the transformer are wrapped around.



- **Types of transformers laminated sheets**

In both the shell and core type transformer constructions, in order to mount the coil windings, the individual laminations are stamped or punched out from larger steel sheets and formed into strips of thin steel resembling the letters "E's", "L's", "U's" and "I's" as shown below.



- **Steps of coils winding:**

  - ✓ Begin by preparing the coil form, which is a cylindrical or rectangular structure around which the wire will be wound.
  - ✓ Choose the appropriate wire for winding based on the transformer's design specifications.
  - ✓ Connect the starting end of the wire to the designated terminal on the coil form.
  - ✓ Start winding the wire around the coil form in a specific direction. The winding direction (clockwise or counterclockwise) depends on the transformer design and winding configuration.
  - ✓ Ensure consistent tension on the wire as you wind it to maintain uniformity. Keep the wire aligned and evenly spaced to prevent overlaps or gaps.

- ✓ Wind multiple layers of wire, creating turns or windings. The number of turns and layers depends on the transformer's design and required voltage ratios.
- ✓ Introduce insulation material between layers to prevent short circuits between adjacent turns. Insulation can be in the form of paper, Mylar, or other suitable materials.
- ✓ Continue winding until the desired number of turns or layers is achieved. For multi-turn windings, the direction of winding may change from layer to layer.
- ✓ Once the required turns are wound, connect the finishing end of the wire to the designated terminal on the coil form. Ensure a secure and reliable connection.
- ✓ Use tape, adhesive, or other securing methods to hold the windings in place and maintain the coil's shape.
- ✓ Apply a final layer of insulation over the entire winding to protect it from external influences and enhance electrical insulation.
- ✓ If the transformer has multiple windings (e.g., primary and secondary), repeat the winding process for each coil, ensuring proper insulation and connection between windings.
- ✓ Perform tests and quality checks on the completed coil, including insulation resistance tests, continuity checks, and other relevant electrical tests.
- ✓ Incorporate the completed coils into the overall transformer assembly, including placing them in the core and connecting them to other components.

- **Insulate winding**

Basic Insulation Techniques:

- ✓ **Turn-to-Turn Insulation:** Each turn of the coil is insulated from adjacent turns to prevent short circuits. Insulation can be in the form of paper, Mylar, or other insulating materials.
- ✓ **Layer Insulation:** Insulating material is applied between layers of windings to prevent electrical contact and ensure proper electrical insulation.

Practical Activity 3.3.3: Winding/rewinding of rotating machine

Task:

1: You are requested to go in manufacturing workshop and rewind a three phase induction motor of the lifting machine.

2: Use the information's on motor nameplate to draw a wiring diagram to be used while perform the work.

3: Referring to the drawing above, Perform the given task.

4: Present your work to the trainer and whole class.

5: Read key reading **3.3.3** and ask clarification where necessary

6: Perform the task provided in application of learning **3.3.**

Key readings 3.3.3

- **Winding methods (Hand winding, Formed coil winding)**

Winding methods for rotating machines involve the process of placing conductive wire coils onto the stator or rotor core. Two common winding methods are hand winding and formed coil winding:

✓ **Hand Winding:** Hand winding is a traditional method where the conductor wire is manually wound around the stator or rotor core. This method is often used for small-scale production or custom designs where automation may not be practical.

Procedure: A technician manually guides the conductor wire around the core, creating individual coils. The winding process requires precision to ensure proper coil placement, tension, and insulation.

Advantages:

- **Flexibility:** Hand winding allows for flexibility in adapting to unique designs or small-scale production.
- **Customization:** It is suitable for prototypes or specialized winding configurations.

Challenges:

- Labor-Intensive: Hand winding can be labor-intensive and time-

consuming, making it less suitable for large-scale manufacturing.
- Consistency: Achieving consistent winding tension and spacing can be challenging.

- ✓ **Formed Coil Winding:** Formed coil winding, also known as machine winding or automated winding, involves the use of machinery to wind pre-formed coils onto the stator or rotor core. This method is commonly employed in mass production and industrial settings.

Procedure: Automated winding machines guide the conductor wire through pre-formed coil winding heads. These heads shape the wire into coils and place them precisely on the core. The process is highly automated for efficiency.

Advantages:

- Efficiency: Formed coil winding is faster and more efficient than hand winding, making it suitable for high-volume production.
- Consistency: Automated machines ensure uniform winding tension and spacing, resulting in consistent quality.
- High Precision: The use of machines allows for precise control over winding parameters.

Challenges:

- Limited Flexibility: Formed coil winding may have limitations in adapting to highly customized or non-standard designs.
- Initial Investment: The setup cost for automated winding machines can be relatively high.

- **The steps for motor rewinding**

The following are the steps for motor rewinding:

1. Checking all mechanical and electrical faults of motor
2. Dismantling the motor
3. Recording stator and name plate information
4. Pulling out the windings
5. Insertion on inners in slots
6. Insertion of windings (coils) in slots
7. Stripping and connecting the group
8. Assemblage and test

Step 1. Checking all mechanical and electrical faults of motor

Checking mechanical faults is done by using appropriate tools to see if: the rotor shaft is not bent, there is no Jam between stator and rotor (air gap), alignment is right, there is no loose of rotor bar and if the fan is not broken.

But electrical faults are checked by using either multimeter or other means to know if: the motor doesn't receive power, there is an open circuit in windings, there is no short circuit between windings, there is no earth leakage, and if single phasing is not applied in power supply and observes the correctness of the connections.

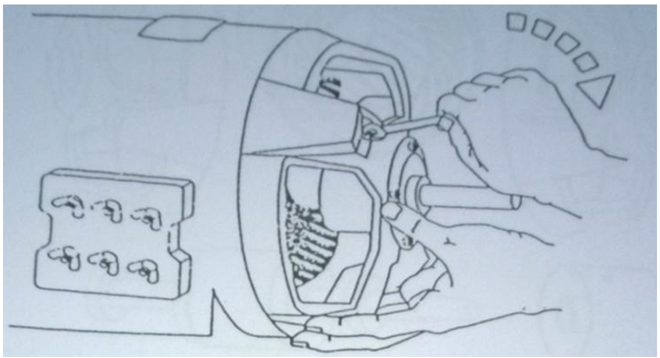
Step 2: Dismantling the motor

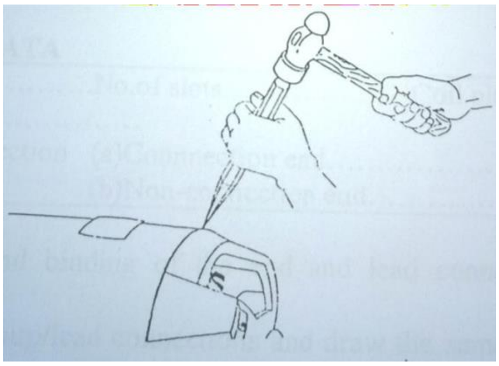
Motor dismantling is done by anyone if needed. It is just done by putting apart every part of the motor; it is done progressively by stating to make center punch for alignment the alignment then unscrew the screws.

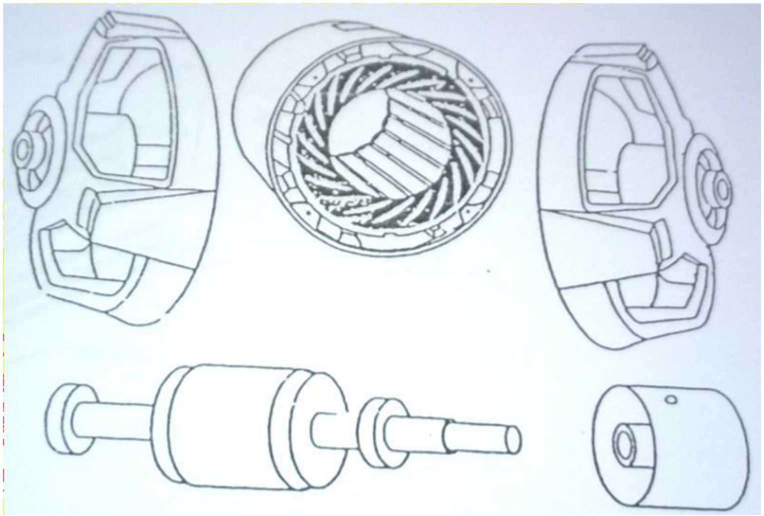
Procedures:

Prepare the motor and fix it on prepared appropriate table

- ✓ Set appropriate needed tools.
- ✓ Start dismantling the motor
- ✓ Make center punch for alignment
- ✓ Move the Allen screws
- ✓ Knock out the end cover
- ✓ Remove the rotor
- ✓ Move out the pulley using wheel pulley
- ✓ Make a certain report when difficulties met.







Step3. Recording stator and name plate information

Motor name plate recordings is often done before dismantling for guiding user during reconnecting and it helps to know the working conditions of the motor. It is done by noting down all the information on name plate consisting of Voltage, frequency, current.

Procedures:

- ✓ Prepare the motor and fix it on prepared appropriate table
- ✓ Set appropriate needed tools
- ✓ Start to record everything on name plate such as Frequency, current….
- ✓ Record the stator information as wire insulation, number of slots, number of coils, size of wire, coil connections.

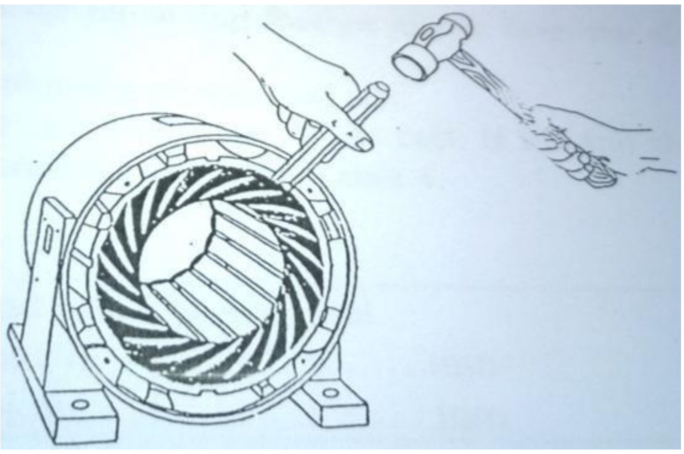
Make a certain report concerning the stator and name plate information.

Step 4. Pulling out the windings

The windings in the stator are tightened, in order to rewind a motor, it's required to remove the damaged ones before inserting the new ones, therefore the old or damaged windings are pulled out by using appropriate tools and hands.

Procedures:

- ✓ After preparation of a motor to rewind and tools, get started the process of pulling out the windings by cutting one side of windings foreign matters from the slots.
- ✓ Pull out the windings by using either hands, pliers or other related tools.
- ✓ Check and record coil information (width, length, weight and number of turns)



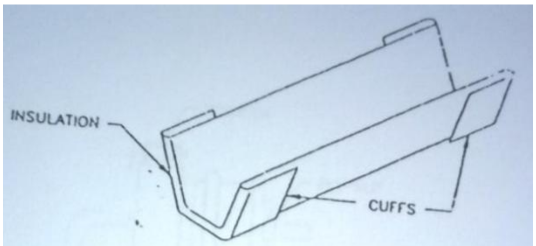
STEP 5. Insertion on inners in slots

The process of inserting inners in slots is made carefully by a trained or instructed person after cutting them on size using either side cutter or paper cutter considering

the dimensions of the slot. Inner insulations are mostly made in plastic or rubber for more resistivity against current flow.

Procedures:

- ✓ Remove the remaining foreigner matters from slots
- ✓ Check slot dimensions (lower width, upper width, length and depth).
- ✓ Cut insulation paper (inners).
- ✓ Start to insert the sized insulation in slot one by one until all slots are insulated.



STEP6: Insertion of windings (coils) in slots

The process of inserting windings in slots is done carefully by instructed person after insertion of inner insulation procedure. Windings are likely the connected coils, considering that the coil has to take two slots and the coils is made by any number of turns depending on size of winding wire and the size of slot. Now it is required to make a design in order to know how many coils to be formed, which type of rewinding to be used. The number of slots of motor helps preferring the kind of design.

Procedures:

- ✓ Get ready of the type of rewinding design (spread or group)
- ✓ Design a preferred type of winding.
- ✓ Select a suitable size of former
- ✓ Wind the designed number of turns
- ✓ Tie the coils width on other side of coil
- ✓ Remove coils from former and check it correctness be inserting in slot.
- ✓ Make the required number of coils
- ✓ Insert coils in slots

DESIGN: Design of a 3 phase motor having 18 slots , 2 poles, Group type

Calculations: 3 phase/pole: → 18 slots

1phase/2pole: → 6 slots

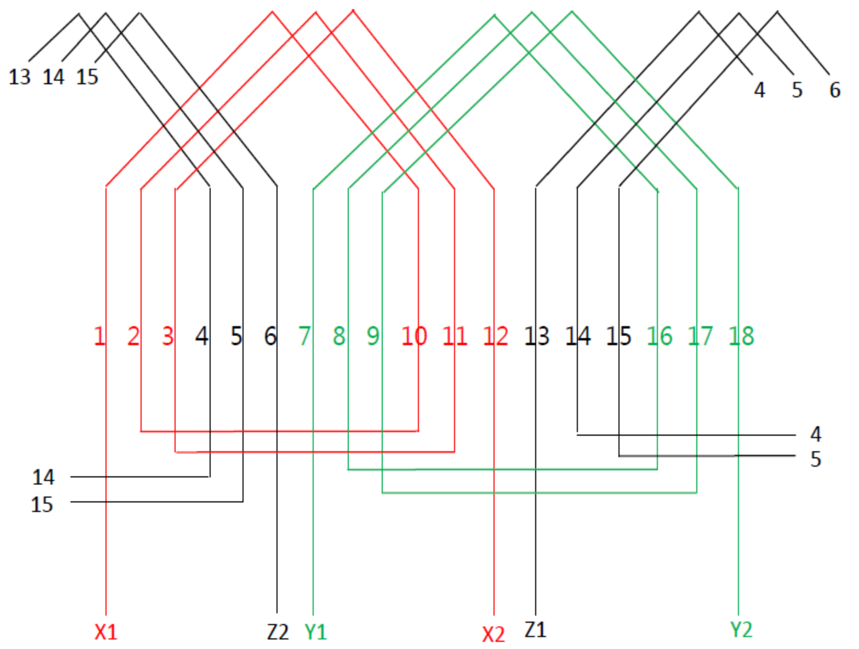
1phase/1pole: 3 slots

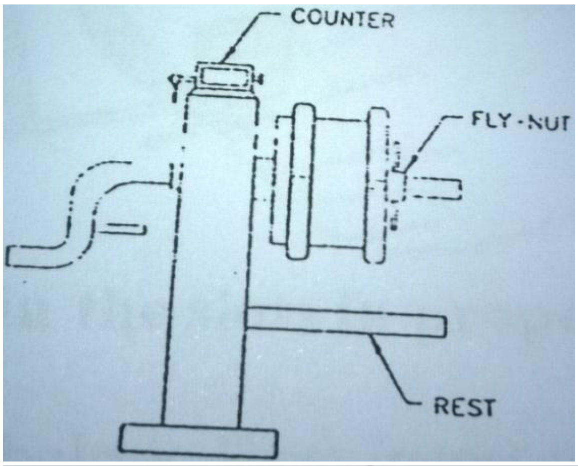
1 group: 3 slots

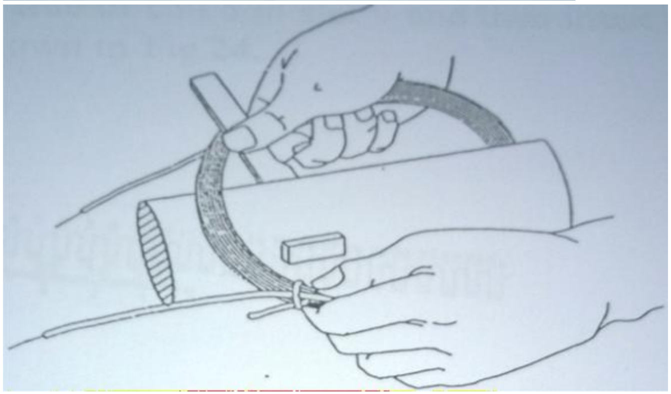
1 coil: 2 slots

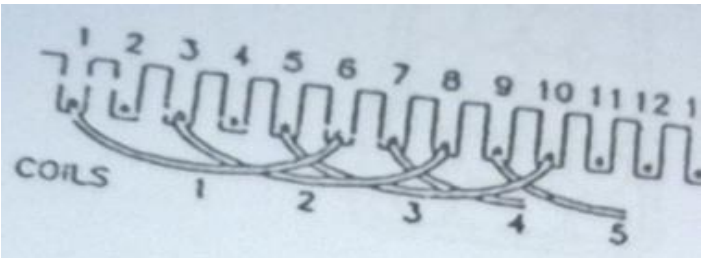
Phase sequence: 120*18/360*1= 6 slots

Draw the wiring Diagram









STEP7: Stripping and connecting the group

The action of stripping is done by using soldering Ion of a certain amount of heat to remove a very thick but strong insulator coating the winding wire; it is done on both end and start of every coil, after stripping, the ends and starts of every group be connected to the stranded wire of 2.5mm2 being set in connection box and the connection of coils forming groups are done inside the stator but after the joint must be insulated. The end and starts of every group must be identified by marking, using numbers or letters; XYZ, UVW OR 123, ABC or other symbols identifying groups.

Procedures:

- ✓ Connect the group connections of the same phase and solder them according to the end connection and developed diagram. Sleeve the joints.
- ✓ Connect the phase leads with the coil groups and insert the sleeve over the

joints.

- ✓ Use a nylon hammer and shape the overhang to the original size.
- ✓ Tie the hemp thread to bind the soldered joints along with the overhang.

STEP 8: Assemblage and test

Assemblage of motor is executed when it is disassembled; it is just to make a complete motor by joining its separate parts. Motor is disassembled before rewinding especially

rotor is removed from stator and both end cover and end shields are moved so. Therefore, assemblage is required when the action of rewinding is completed at all. By following the steps, assemblage is executed by a trained person.

Procedures:

- ✓ Check the continuity of winding with a test lamp.
- ✓ Measure the resistance between A1-A2, B1-B2, and C1-C2 and record the values.
- ✓ Measure the insulation resistance between the winding and the stator core with 500V volts Megger and record it.
- ✓ Test the winding for correct polarity following the instructions contained.
- ✓ Varnish the winding following the instruction contained in the related theory.
- ✓ Assemble the motor and test for its performance.

Points to Remember

- Electrical apparatus consisting of coils of insulated wire is usually finished off with an insulating varnish.
- The synchronous speed decreases as the number of poles increases.
- The induced voltage in the secondary winding depends on the turns ratio of the primary to secondary winding. If the secondary winding has more turns than the primary, the transformer steps up the voltage; if it has fewer turns, it steps down the voltage.
- Proper termination and labelling are essential for ensuring correct connections during installation, maintenance, and troubleshooting. The labelling typically includes designations for the high-voltage (primary) and low-voltage (secondary) terminals, as well as other relevant information.

Application of learning 3.3.

Go in manufacturing workshop and perform the following tasks:

1. Design of a 24 slots, 3phase, 4pole motor “group type”
2. Design of a 3 phase motor having 12 slots, 2pole, “group type”
3. Design of a 3 phase motor having 12 slots, 2pole, “spread type”
4. Design of a 3 phase motor having 12 slots, 4pole, “Group type”
5. Design of a 3 phase motor having 18 slots, 2pole, “Spread type”
6. Design of a 3 phase motor having 18 slots, 2pole, “Spread type”
7. Design of a 3 phase motor having 24 slots, 2pole, “Spread type”

Indicative content 3.4: Inspection of Winding/Rewinding for Electrical Machines

Duration: 5 hrs

Theoretical Activity 3.4.1: Description of induction motor/transformer faults

Tasks:

1. Answer the following questions:
   i. According to your understanding, what are the factors of failure on induction motor?
   ii. According to your understanding, what are the possible causes of transformer damage or failure within the windings?
2. Provide the answer for the asked questions and write them on papers.
3. Present the findings/answers to the whole class.
4. ask clarifications where necessary.
5. Read the key readings 3.4.1

Key readings 3.4.1

- **Factors of failure on induction motor**

Induction motors can fail for various reasons, each with distinct causes and consequences. Here's a breakdown of the factors you mentioned:

1. Stator Winding Failure

- ✓ **Causes:** Insulation breakdown, overheating, moisture ingress, or manufacturing defects.
- ✓ **Consequences:** Short circuits, increased losses, reduced efficiency, or complete motor failure.

2. Rotor Winding Bar Failure

- ✓ **Causes:** High current, mechanical stress, thermal overload, or poor manufacturing quality.
- ✓ **Consequences:** Imbalance in rotor performance, vibrations, loss of torque, or motor stalling.

3. Bearing Failure

- ✓ **Causes:** Poor lubrication, contamination, misalignment, or excessive loading.

- ✓ **Consequences:** Increased friction, overheating, noise, and potential motor seizure.

4. External Conditions

- ✓ **Causes:** Environmental factors such as humidity, temperature extremes, dust, or corrosive substances.
- ✓ **Consequences:** Reduced lifespan, increased wear and tear, and compromised motor operation.

5. Shaft Coupling Issues

- ✓ **Causes:** Misalignment, wear, improper installation, or incorrect sizing.
- ✓ **Consequences:** Vibration, increased loads on the motor and driven equipment, and potential damage to both components.

- **Fault of transformer**

1. Winding Fault

- ✓ **Definition**: Damage or failure within the windings, which can lead to short circuits.
- ✓ **Types**:
  - **Turn-to-turn Fault**: A short circuit between turns in the same winding, often caused by insulation breakdown.
  - **Phase-to-phase Fault**: A short circuit between different phases, usually resulting from severe insulation failure.

2. Connection Fault

- ✓ **Definition**: Issues related to the connections between transformer windings or external connections.
- ✓ **Causes**:
  - Poor connections or loose terminals.
  - Corrosion or damage to terminals, leading to increased resistance and overheating.

3. Fault in Auxiliary Equipment

- ✓ **Definition**: Failures in supporting components such as cooling systems, protection devices, or monitoring systems.
- ✓ **Impact**: Can lead to transformer overheating or failure if not addressed promptly. Common issues include:
  - Failed cooling fans or pumps.
  - Malfunctioning temperature sensors.

4. Overload

- ✓ **Definition**: Occurs when the transformer is subjected to loads beyond its rated capacity.
- ✓ **Consequences**: Overheating, reduced lifespan, and potential damage to windings or insulation.

5. External Short Circuit

- ✓ **Definition**: A fault occurring outside the transformer, often involving the connected load or distribution system.
- ✓ **Impact**: Can cause high fault currents, leading to mechanical stress and damage to the transformer, along with potential cascading failures in the system.

Practical Activity 3.4.2: Inspection and testing of Winding/rewinding for electrical machines

Task:

1: You are requested to go in manufacturing workshop and perform the task below:

- Inspect the windings of electrical machine for proper placement and secure connections.
- Verify that the transformer is rated for the intended voltage
- Use a megohmmeter or ohmmeter to check for continuity between turns in each winding.
- Perform insulation resistance tests at various intervals (e.g., 1 minute, 10 minutes) to assess insulation health over time.
- Look for any short circuits between adjacent turns, which could indicate insulation failure.

2: Perform the **open circuit test** and **short circuit test** for determining the core and copper losses, as well as the voltage regulation and efficiency of the transformer.

3: Present your work to the trainer and whole class.

4: Read key reading **3.4.2** and ask clarification where necessary

5: Perform the task provided in application of learning **3.4**

Key readings 3.4.2

- **Steps for inspecting rewound motor/transformer**

When inspecting a rewound motor or transformer, it's important to follow a systematic approach to ensure thorough evaluation. Here's a step-by-step guide based on the key areas:

1. Visual Inspection

- ✓ **Exterior Check**: Look for physical damage, signs of overheating (burn marks), or corrosion.
- ✓ **Windings**: Inspect the windings for proper placement and secure connections. Check for signs of wear or fraying.
- ✓ **Connections**: Ensure all terminals and connections are clean, tight, and free of oxidation.
- ✓ **Ventilation**: Confirm that cooling fins and ventilation openings are clear of debris.

2. Electrical Inspection

- ✓ **Voltage Ratings**: Verify that the motor/transformer is rated for the intended voltage.
- ✓ **Phase Connections**: Check that the phase connections are correctly wired.
- ✓ **Control Circuits**: Inspect control circuits for correct operation and integrity.

3. Continuity Between Turns

- ✓ **Turn-to-Turn Testing**: Use a megohmmeter or ohmmeter to check for continuity between turns in each winding.
- ✓ **Short Circuits**: Look for any short circuits between adjacent turns which could indicate insulation failure.

4. Electrical Insulation

- ✓ **Insulation Resistance Testing**: Use a megohmmeter to measure insulation resistance between windings and to ground.
- ✓ **Baseline Values**: Compare readings against manufacturer specifications; typically, a minimum of 1 MΩ is acceptable, but higher values are preferable.

5. Insulation Resistance

- ✓ **Time-Based Testing**: Perform insulation resistance tests at various intervals (e.g., 1 minute, 10 minutes) to assess insulation health over time.
- ✓ **Temperature Correction**: Adjust readings based on the temperature of the motor/transformer during testing to account for variations.

- **Induction motor test**

In testing induction motors, the open circuit test, short circuit test, and winding-to-winding test serve different purposes in assessing motor performance and characteristics. Here's a brief overview of each test:

1. Open Circuit Test (No-load Test)

- **Purpose**: To determine the no-load losses and the magnetizing inductance of the motor.
- **Procedure**: The motor is run at its rated voltage without any load connected. The input power, voltage, and current are measured.
- **Results**: This test helps calculate the core loss (hysteresis and eddy current losses) and provides insight into the magnetizing characteristics of the motor.

2. Short Circuit Test

- **Purpose**: To determine the full-load copper losses and impedance of the motor.
- **Procedure**: The motor is short-circuited at the terminals and connected to a reduced voltage supply, typically around 10-20% of its rated voltage. Current, voltage, and power are measured.
- **Results**: This test provides information about the copper losses (I^2R losses) in the stator windings and the equivalent circuit parameters.

3. Winding-to-Winding Test

- **Purpose**: To assess the insulation integrity and condition of the windings.
- **Procedure**: A high voltage is applied to one winding while the other winding is grounded or shorted. Insulation resistance is measured, often using a megohmmeter.
- **Results**: This test helps identify any faults or weaknesses in the winding insulation, ensuring reliability and safety.

- **Summary**
  - **Open Circuit Test**: Assesses core losses and magnetizing characteristics.
  - **Short Circuit Test**: Evaluates copper losses and impedance.
  - **Winding-to-Winding Test**: Checks insulation integrity of windings

- **Transformer test phase**

In transformer testing, the **open circuit test** and **short circuit test** are essential for determining the core and copper losses, as well as the voltage regulation and efficiency of the transformer.

- **Open Circuit Test**
  - ✓ **Purpose:** To measure the no-load losses (core losses) and to determine the no-load current and impedance of the transformer.
  - ✓ **Procedure:**
    - **Setup:** Connect the primary winding to the rated voltage supply while keeping the secondary winding open (no load).
    - **Measurements:** Measure the voltage, current, and power (using a

wattmeter) in the primary circuit.

- **Calculations:**
  1. Calculate the core losses (iron losses) using the power measured.
  2. Determine the no-load current and the equivalent no-load impedance.

- **Key Results:**
  - No-load losses (core losses)
  - No-load current
  - No-load impedance
- **Short Circuit Test**
  - ✓ **Purpose:** To measure the copper losses (load losses) and to determine the equivalent short-circuit impedance of the transformer.
  - ✓ **Procedure:**
    - **Setup:** Short the secondary winding of the transformer and apply a reduced voltage to the primary winding until the rated current flows in the primary.
    - **Measurements:** Measure the voltage, current, and power in the primary circuit.
    - **Calculations:**
      - Calculate the copper losses (I^2R losses) using the power measured.
      - Determine the equivalent impedance from the applied voltage and the short-circuit current.

Key Results:

- Copper losses (load losses)
- Short-circuit impedance

Points to Remember

- Inspecting a rewound motor or transformer is crucial to ensure safety, efficiency, and longevity.
- In testing induction motors, the open circuit test, short circuit test, and winding-to-winding test serve different purposes in assessing motor performance and characteristics.
- Short circuit and open circuit tests provide crucial parameters for transformer design and performance evaluation, including efficiency, voltage regulation, and loss characteristics. The open circuit test focuses on core losses under no-load conditions, while the short circuit test focuses on copper losses under load conditions.
- Some common causes of failure in induction motors are overheating, phase imbalance, short circuits, bearing failure, rotor damage, vibration, contamination, electrical supply issues, inadequate maintenance, improper installation, frequency variations, and insulation breakdown.

- Regular maintenance, monitoring, and protective measures can help prevent transformers faults and extend the life of transformers.

Application of learning 3.4.

Go in manufacturing workshop and perform preventive maintenance of the electrical machines included three-phase induction motor and transformers.

Make a report detailing what acquired as new knowledge during the activity.

Learning outcome 3 end assessment

Theoretical assessment

Question one: Read carefully the following statements sentences related to three-phase motor winding and fill in blanks space with the following words in brackets (**core, coil, and copper**)

a. A ……………………. is a length of wire wound in a spiral or loop?

b. The………………… refers to the central, innermost, or essential part of an inductor or transformer, typically made of magnetic material, which helps in the conduction of magnetic fields.

Question two: Read carefully the following statements about identifying Winding materials and machines and answer by **True** for the correct statement or **False** for the incorrect statement in provided space.

i. The smaller the AWG number, the thicker the wire. (…..)

ii. Auto transformer has a single winding that acts as both primary and secondary, providing variable output voltage. (…..)

iii. Aging transformers may need rewinding to extend their life and maintain performance standards. (…..)

iv. Continuity Faults involve an increase in the electrical continuity of a circuit**.** (…..)

v. A Loose Connection in a circuit can create high resistance or open circuits**.** (…..)

vi. Insulation breakdown between different phases can lead to a phase-to-phase short circuit**.** (…..)

vii. The No-Load Test measures the full-load current, full-load voltage, and core losses**.** (…..)

viii. A Vibration Analysis is conducted to assess the condition of insulation between windings and the transformer's core**.** (…..)

ix. Varnishing means Coating the windings with insulating varnish, either by dipping or spraying, to provide moisture resistance. (…..)

x. The synchronous speed determines the maximum speed at which an AC motor can operate. (…..)

Question three: Read carefully the following questions related to identifying Winding principles and **select** the letter corresponding to the right answer.

i. What is the purpose of the Insulation Test in transformer testing?

a. Measure winding resistance
b. Assess the insulation resistance
c. Determine core losses
d. Evaluate short-circuit impedance

ii. Which fault involves a short circuit between adjacent turns within the same winding?

a. Insulation Breakdown Between Different Phases
b. Inter-Turn Fault
c. Continuity Faults
d. Transformer Core Faults

iii. What is the main principle behind the operation of electric motors?

a. Electromagnetic induction
b. Electrical conduction
c. Thermal expansion
d. Mechanical rotation

iv. From the list below, select the motor nameplate elements:

a. Primary and secondary voltage
b. Voltage rating
c. Frequency
d. Power rating
e. Motor speed (RPM)

v. If you have a motor with a frequency of 60 Hz and 4 poles, the synchronous speed would be:

a. 1500RPM
b. 1800RPM
c. 3000RPM
d. 750RPM

vi. Phase Sequence of a 3-phase motor having 24 slots, 2pole, "Spread type**"** has**:**

a. 8 slots
b. 6 slots
c. 4 slots

Question four: Observe carefully the following table and match the following electrical motor fault in column B with their possible causes in column C and provide answers in column A.

Column A: Answers	Column B (electrical motor fault)	Column C (possible causes)
1……………………	1. Shaft Coupling Issues	A. Poor lubrication, contamination, misalignment, or excessive loading.
2…………………….	2. Rotor Winding Bar Failure	B. Misalignment, wear, improper installation, or incorrect sizing.
3……………………	3. Bearing Failure	C. High current, mechanical stress, thermal overload, or poor manufacturing quality.
		D. High voltage or high resistance.

Practical assessment

Amazon Company Ltd., a manufacturing company that fabricates various machinery, is situated in JABANA Sector, GASABO. In its manufacturing workshop, a three-phase induction motor needs to be rewound by a trained technician

To make sure the motor is safe, effective, and long-lasting, you are requested to rewind it and conduct visual inspection, insulation resistance testing, and short circuit and open circuit testing.

Note:

- The rated output of the motor is 15KW and its rated speed of 2800RPM.
- The stator windings can be connected in a **star** or **delta** formation. If the mains voltage is **400V**, the windings must be connected in star formation. The motor current is **then 27.5A per phase**. If the mains voltage is 230V, the windings must be connected in a delta formation. The motor current is then **48.7A per phase.**
- The power supply is **230/400V, 50Hz**.

Those activities should be done within 6 hours.

References

Karl Wilkinson October 22, 2013 4, Rewinding small motors

Mark Brown 2005, Practical Troubleshooting of Electrical Equipment and Control Circuit

MCLYMAN February 18,2009 5t, Transformer and inductor design handbook Third Edition, Revised and Expanded by COLONEL WM. T.

Muhammad Irfan. September, 2018 2, Najera University, Saudi Arabia, Advanced Condition Monitoring and Fault Diagnosis of Electric Machines.

Stephen L. Herman January 21,2009 3. third edition, Industrial Motor Control

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