People's Democratic Republic of Algeria

Ministry of Higher Education and Scientific Research

Echahid Cheikh Larbi Tebessi University - Tebessa

Faculty of Science and Technology

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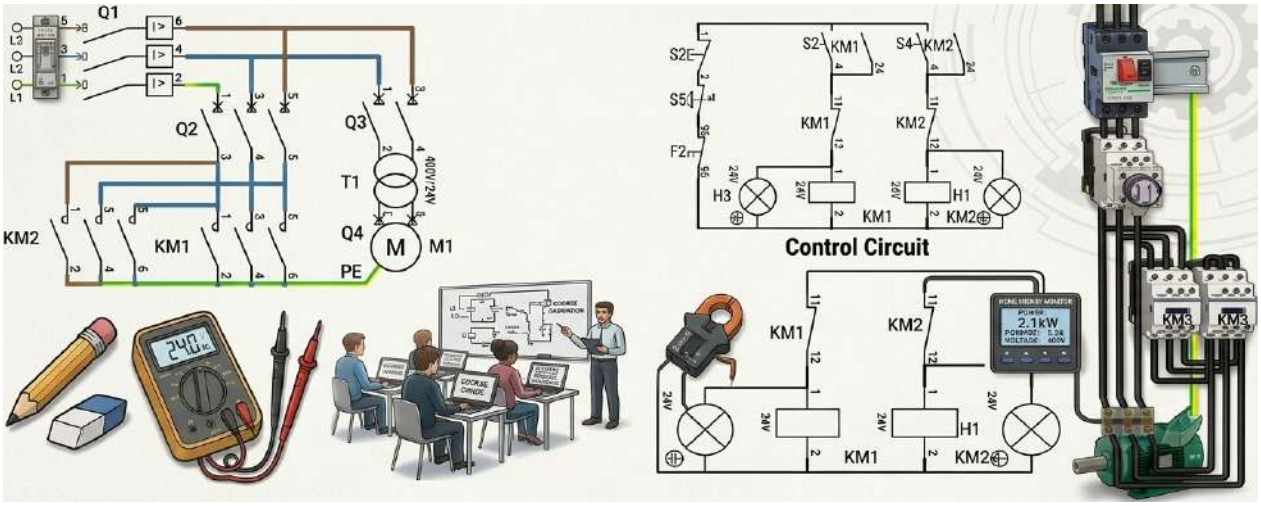
Course Materials and Practical Works:

Electrical Diagrams and Equipment

Third-year Bachelor's student in Electrical Engineering

Presented by:

Dr. AMIEUR Oualid



Academic year: 2025-2026

Preface

These **Course Materials and Practical Works** in **Electrical Diagrams and Equipment** are intended for **3rd year Bachelor's degree** students specializing in **Electrotechnics**. The technical project is carried out in the Electrotechnics workshop of **Echahid Cheikh Larbi Tebessi University, Tebessa**.

The works involve the implementation of electrical installations for both domestic and industrial settings. The wiring of the electrical circuits is completed by following diagrams based on established conventions. These diagrams represent the installations using standardized symbols, specify the sizing of the constituent elements of the electrical assemblies, and include the devices that help ensure proper operation while protecting both personnel and electrical installations.

Course Materials

The course materials are structured to provide a comprehensive understanding of electrical schematics and equipment. Students will have access to the following resources:

- **Lecture Notes**: Detailed theoretical coverage of electrical symbols, standards, protection devices, lighting circuits and motor control methods.
- **Practical Work Manual**: Step-by-step procedures for each lab session, including wiring diagrams and testing protocols.
- **Supplementary Readings**: Recommended textbooks and technical guides for deeper understanding.

Learning Outcomes

The course **Electrical Diagrams and Equipment** enables students to apply the knowledge they have acquired in this subject.

Prerequisites

To successfully complete these practical works, students must possess fundamental knowledge in the following areas: fundamental electricity, electrostatics and magnetostatics.

Students are expected to be up-to-date with the corresponding theoretical coursework.

Evaluation Criteria

Student performance is evaluated based on the Final Written Exam (**60% of Final Grade**)

Contact and Availability

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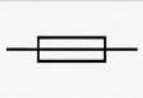
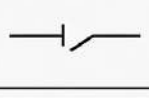
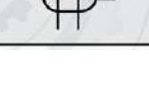
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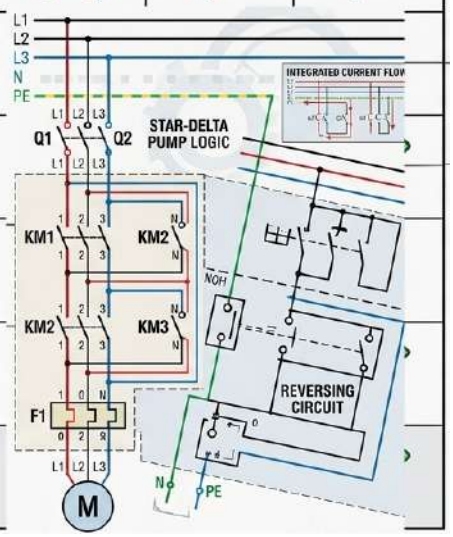
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Chapter 1
Electrical Equipment

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NAME	SCHEMATIC SYMBOL	PHYSICAL COMPONENT	FUNCTION: CONTROL	FUNCTION: ISOLATION	FUNCTION: PROTECTION
FUSE			✗	✓	✓
ISOLATOR					
CIRCUIT BREAKER					
SWITCH					
CONTACTOR					
ELCB/RCD					



Chapter 1

Electrical Equipment

1.1 Introduction

The regulations define three fundamental functions for electrical equipment and devices in the design of electrical installations [1, 2].

The three basic functions are:

1. **Protection**
2. **Control**
3. **Isolation**

These functions are crucial for ensuring the **safety, functionality, and maintainability** of any electrical system [3].

1.1.1 Protection

The primary goal of electrical protection is to ensure the safety of persons, livestock, and property against electrical hazards. This is achieved by limiting the destructive or hazardous consequences of over-currents or insulation faults through the automatic de-energization and isolation of the faulty section from the rest of the installation [4, 5]. Protective devices are designed to address several key hazards:

- **Protection Against Overcurrent (Overload & Short-Circuit):** Prevents damage from excessive current, which can cause overheating and fire.
- **Protection Against Electric Shock:** Mitigates the risk of current passing through the human body [4].
- **Protection Against Overvoltage:** Safeguards equipment from voltage spikes caused by lightning or switching surges.

A protective device must perform a dual function: it must continuously allow the nominal current (I_n) as well as normal over-currents to pass, while also performing safety shutdowns to protect against indirect contact [6].

Over-currents, defined as $I_S = \lambda \cdot I_n$, are categorized based on their magnitude, with each category typically handled by a specific protection method:

- **Low Overload** ($1 < \lambda < 2$): Protection is typically provided by thermal devices.
- **High Overload** ($2 < \lambda < 10$): Protection is typically provided by magnetic devices.
- **Short-Circuit** ($\lambda > 10$): Protection is provided by fuses and magnetic devices.

1.1.2 Control

Control functions are about the operational command of the electrical circuit. They allow a user (Manual Control) or an automated system (Automatic Control) to start, stop, or regulate the flow of electricity [3].

There are two types of control: Functional control and safety control.

- **Functional Control** (Normal Service): Manages the routine switching "ON" or "OFF" of an electrical system.
- **Safety Control** (Emergency Stop): Ensures the system is switched "OFF" in the event of a danger to personnel or equipment [7].

1.1.3 Isolation

Isolation (Switching or Disconnection) is the function of physically separating a part of the electrical installation from the live supply for the purpose of **safety during maintenance, repair, or inspection**, but only under no-load conditions [8].

Key Requirements for Isolation:

- **Visible Break:** Clear, visible confirmation of contact separation.
- **Adequate Dielectric Strength:** Must withstand system voltage when open.
- **Prevent Accidental Re-energization:** Must have lockout/tagout (LOTO) provisions [7].

In a well-designed installation, a single device can perform more than one function. For example, a **Circuit Breaker** often provides all three: **Protection** (overcurrent), **Control** (manual switching), and **Isolation** (visible disconnection) [9].

1.2 Electrical Switches



(a) (b) (c) (d)

Figure 1.1: Electrical Switches

Definition

A switch is a mechanical device designed to reliably make or break the conductive path in an electrical circuit, thereby establishing or interrupting the flow of electric current under a specified normal load [10].

Role

Part 1 of IEC 61058, which applies to appliance switches, defines their purpose. These switches are designed to control electrical appliances and other equipment for household or similar purposes. They are rated for a maximum voltage of 480 V and a maximum current of 63 A [10].

Appliance switches can be operated in the following ways:

1. **Direct:** By a person via an actuating member (e.g., button, lever, knob).
2. **Indirect:** Through an intermediary mechanism (e.g., pull-cord, remote linkage).
3. **Sensing Unit:** Automatically by a sensor (e.g., motion, temperature, light).

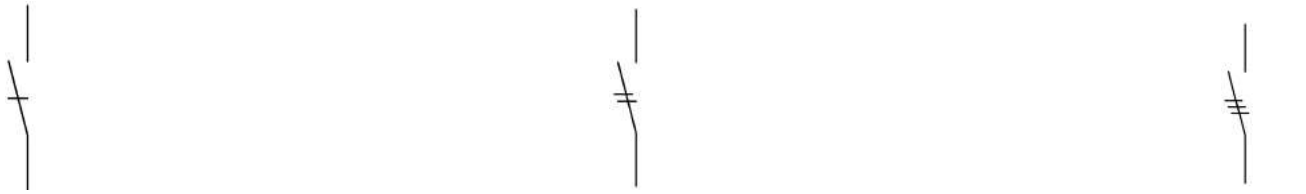
Symbol



Figure 1.2: Switch Symbol

Types of electrical switches

Switches are classified by their number of poles, which indicates how many independent electrical circuits they can control [11].



(a) Switch 1P

(b) Switch 2P

(c) Switch 3P

Figure 1.3: Types of electrical switches

Operating Principle

Manual force or an actuator mechanism physically moves conductive contacts together (to close the circuit) or apart (to open the circuit). The separation creates an air gap that extinguishes the electrical arc (for AC) or stops current flow (for DC) [2].

There are two operation patterns for Manual Switches:

1. **Momentary Operation:** The switch is ON only while it is pressed. The switch turns OFF when it is released.

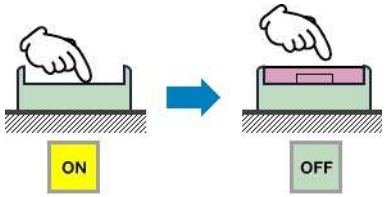


Figure 1.4: Momentary Electrical Switch

2. **Alternate Operation:** After you press the switch, the ON state is held even when the switch is released. To turn OFF the switch, you must press it again.

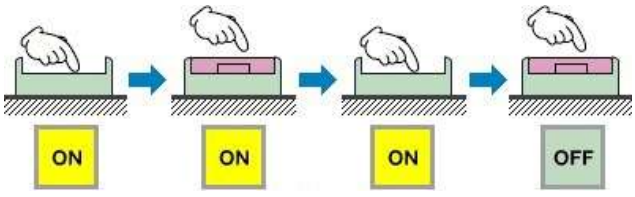


Figure 1.5: Alternate Electrical Switch

Categories of Electric Switches

- **By Operation:** Toggle switch, push-button, rocker switch, rotary switch, slide switch...

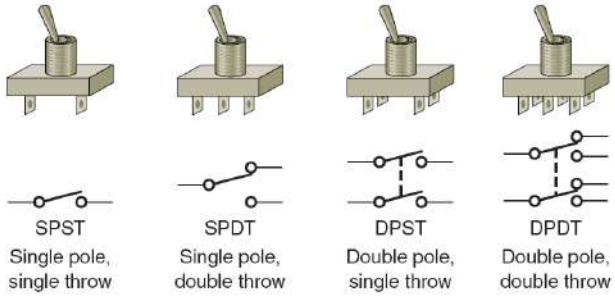


Figure 1.6: Common toggle switch types with their symbols and names



(a) Normally Open (NO)



(b) Push Button



(c) Normally Closed (NC)

Figure 1.7: Push Button Switches

- **By Configuration:** SPST (Single-Pole Single-Throw), SPDT (Single-Pole Double-Throw), DPST (Double-Pole Single-Throw), DPDT (Double-Pole Double-Throw).



(a) SPDT Slide Switch



(b) SPST Slide Switch



(c) DPST Slide Switch



(d) DPDT Slide Switch

Figure 1.8: Types of Slide Switches

- **By Application:** Appliance switch (IEC 61058-1) [10], limit switch, pressure switch, temperature switch.

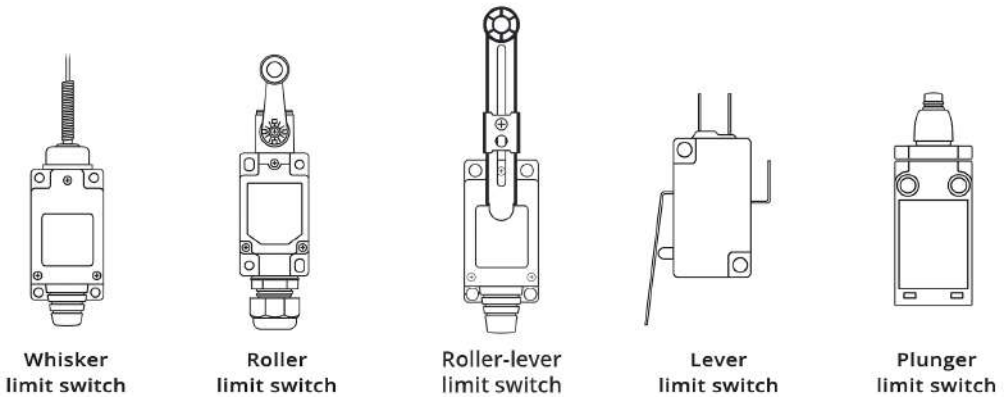


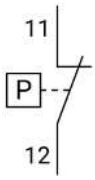
Figure 1.9: Styles of limit switches



(a) Normally Open (NO)



(b) Pressure Switch



(c) Normally Closed (NC)

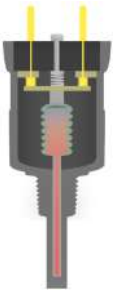
Figure 1.10: Pressure Switches



(a) NO: Resting temperature

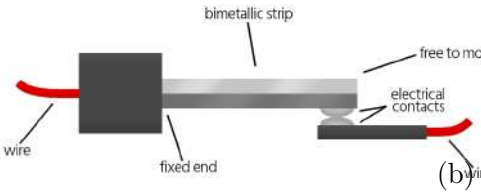


(b) Temperature Switch



(c) NC: Temperature increases

Figure 1.11: Temperature Switches



(a) NC: Resting temperature



(b) Bimetallic strip temperature switch



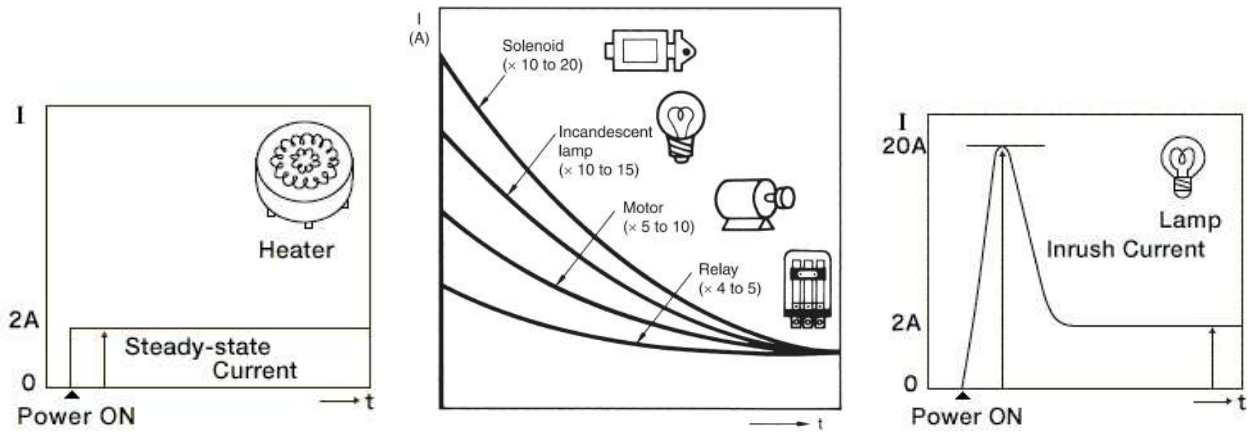
(c) NO: Temperature increases

Figure 1.12: Thermostat Switches

Switch Detailed Characteristics

- **Voltage Rating (U_e):** Up to 480 V – maximum voltage without arcing or insulation breakdown [10].
- **Current Rating (I_e):** Up to 63 A – maximum current without overheating or contact damage [10].
- **Power Rating:** Combined limit (e.g., 2 A at 250 V).
- **Breaking Capacity:** Ability to safely interrupt normal load current [8].
- **Load Type (Most Critical):** Resistive (simple), Inductive (arcing), Tungsten/Lamp (high inrush current).

A switch's load type is its most critical rating. Resistive loads are simple, but motors cause damaging arcs when turned off, and lamps create a massive inrush current that can weld contacts shut. Always select a switch specifically rated for your load—inductive, tungsten, or resistive—to ensure safety and prevent failure [9, 12].



(a) Heater: A resistive load (b) Load Types and Inrush Current (c) A lamp load

Figure 1.13: Inrush Current and Rating

1.3 Changeover Switches



(a) Changeover 1P

(b) Changeover 2P

(c) Changeover 3P

(d) Changeover 3P+N

Figure 1.14: Changeover Switches

Definition

A changeover switch, also known as a transfer switch, is a device that modifies connection configurations in an electrical circuit, typically to alternately power a load from different sources or to redirect power to different circuits from a single source [13].

Role

- **Circuit switching**: Enables switching between different sources or loads
- **Multiple control**: Lighting control from multiple points [11]
- **Automatic transfer**: In backup power supply systems
- **Direction reversal**: For electric motors [14]

Symbol

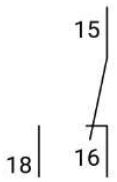


Figure 1.15: Changeover switch symbol

Types of Changeover Switches

- **BBM:** Break then make – prevents short-circuit (generators, UPS).

- **MBB:** Make then break – no power interruption (telecom, medical, data centers).
- **Center-Off:** Central OFF position – safe maintenance isolation (LOTO) [7].
- **ATS:** Automatic transfer – voltage monitoring, delays, remote monitoring [9].
- **Contactor-Based:** High current, remote operation, interlocks [15].
- **SSTS:** Ultra-fast (<4ms), semiconductors (SCR/TRIAC), silent, reliable.
- **Multi-Position Rotary:** Complex switching between multiple sources/loads.



(a) BBM Changeover switch



(b) MBB Changeover switch

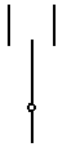

(c) Center-Off Changeover switch

Figure 1.16: Example of Changeover switch symbols

Characteristics & Specifications

- **Number of Poles:** 1P, 2P, 3P, or 4P, depending on the phase system (single-phase or three-phase) and whether the neutral needs to be switched.
- **Rated Operational Current (I_e):** The maximum current the switch can carry continuously (e.g., 25 A, 63 A, 125 A) [13].
- **Rated Insulation Voltage (U_i):** The maximum voltage it can safely withstand (e.g., 500 V, 690 V) [13].
- **Number of Positions:**
  - **Two-Position:** ON-OFF-ON (e.g., Source 1 - OFF - Source 2)
  - **Three-Position:** ON-OFF-ON with a central "OFF" position for complete isolation.
- **Mechanical & Electrical Durability:** The number of operating cycles (often 10,000+ mechanically, fewer at full electrical load).

1.4 Disconnectors (Isolators)



(a) Disconnector 1P



(b) Disconnector 2P



(c) Disconnector 3P



(d) High voltage disconnector 3P

Figure 1.17: Switch Disconnector

Definition

A disconnector is a mechanical switching device that makes, carries, or breaks currents under rated voltage, creating visible isolation. It operates by physically separating contacts to form an air gap, with slow deliberate action and positive ON/OFF indication. **Important:** Must only be operated when de-energized, as it lacks arc-quenching capability [13].

Role

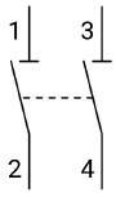
- **Visible isolation**: Creates visible physical separation of the circuit
- **Maintenance safety**: Enables safe work on installations [7]
- **Circuit sectioning**: Isolates part of the circuit for intervention
- **Voltage absence verification**: Allows insulation checking

Symbol

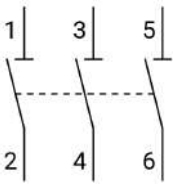
The (-) is the standard IEC symbol for the main contacts of a disconnector and isolator [16].



(a) Disconnector 1P



(b) Disconnector 2P



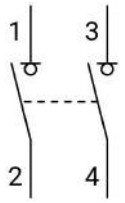
(c) Disconnector 3P

Figure 1.18: Disconnector Symbol [16]

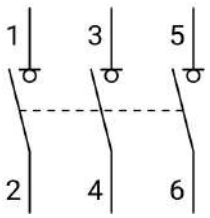
The (⍥) is the standard IEC symbol for the main contacts of a switch disconnector and isolator [16].



(a) Switch Disconnector 1P



(b) Switch Disconnector 2P



(c) Switch Disconnector 3P

Figure 1.19: Switch Disconnector/Isolator Symbol

Types

- **By Mounting:** Panel-mounted disconnectors, busbar-mounted disconnectors.
- **By Operation:** Rotary handle operated, lever operated, motor operated.
- **By Poles:** Single-pole, double-pole, triple-pole, 3-pole + neutral.
- **By Construction:** Knife-switch type, rotary cam type.
- **With Fuse:** Switch-disconnector-fuse combination [13].

Detailed Characteristics

- **Isolation Voltage:** Rated impulse withstand voltage (U_{imp}) specifies isolation capability [13].
- **Visible Contacts:** Provides a clear visible break for verification of isolation [7].
- **Padlocking Facility:** Allows locking in the "OFF" position for safety (Lockout/Tagout procedures) [7].
- **Short-Time Withstand Current (I_{cw}):** Ability to carry short-circuit current for a specified time (typically 1 second) [13].

Table 1.1: Example of technical characteristics of HV disconnectors

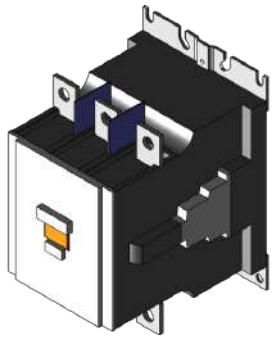
Parameter	**Typical Values**
Disconnection capacity	Load currents only
Locking system	Padlock system for safety
Visible position	Visible contacts or position indicator
Dynamic resistance	Withstands short-circuit currents
Rated voltage	Up to 36 kV
Rated current	125 A to 4000 A

1.5 Comparative Analysis

Table 1.2: Comparative table of electrical switchgear

Characteristic	**Switch**	**Changeover Switch**	**Disconnector**
Main function	Circuit opening/closing	Circuit changing	Visible isolation
Breaking capacity	High	Medium	None (under load)
Use under load	Yes	Yes	No
Maintenance safety	Limited	Limited	High
Locking capability	Rare	Occasional	Systematic
Typical application	Lighting	Multiple control	Main distribution board

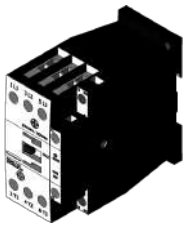
1.6 Contactors



(a) High power rating contactor



(b) Middle power rating contactor



(c) Low power rating contactor

Figure 1.20: Electrical Contactors

Definition

A contactor is an electrically controlled switch (electromechanical device) used for switching an electrical power circuit. It is characterized by a high-current capacity and is operated by an electromagnet [15].

Role

A contactor is an electrically controlled electromagnetic device with one rest position, capable of making, carrying, and breaking currents under normal conditions for many operations. It is widely used for motor control, power management of lighting and distribution panels, and automation of HVAC and production lines in PLC-controlled environments [15, 6].

Symbol

The (◧) is the standard IEC symbol for the main contacts of a contactor [16].

Contactors are available in various configurations: they can be single-pole, two-pole, three-pole, or even four-pole.

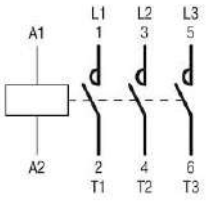
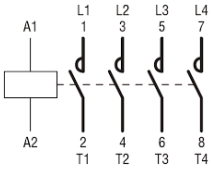


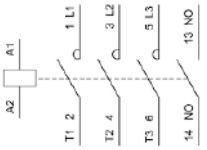
Figure 1.21: Contactor Symbol

Contactors Types

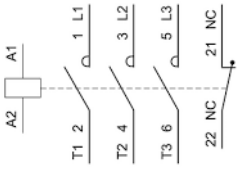
Contactors are available in various configurations: they can be single-pole, two-pole, three-pole, or even four-pole [15].



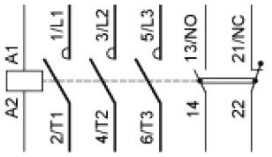
(a) 4P contactor



(b) 3P contactor + 1 NO



(c) 3P contactor + 1 NC

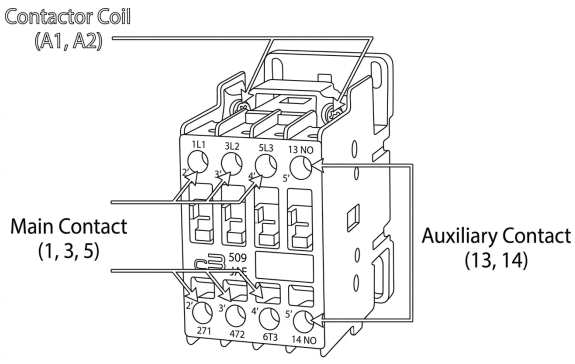


(d) 3P contactor + 1 NO+ 1NC

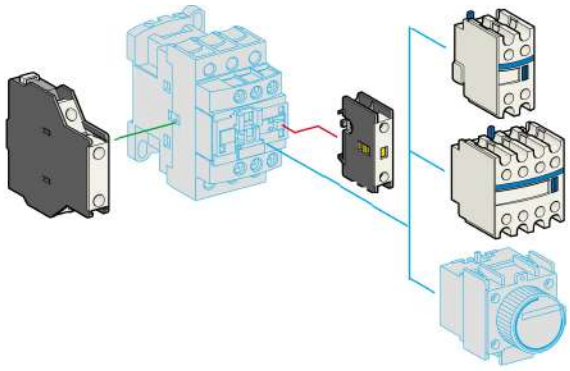
Figure 1.22: Contactor Symbol Variations

General Construction

Contactors are electromechanical devices comprising several key components designed for robust electrical switching [9].



(a) General structure of contactor



(b) Contact Accessories blocks

Figure 1.23: Contactor structure and accessories

A contactor consists of: (1) a **contact system** with main silver-alloy contacts for high current and auxiliary NO/NC contacts for control; (2) an **electromagnetic assembly** (coil and armature) that closes contacts when energized; (3) an **arc quenching system** (arc chutes for AC, magnetic blowouts for DC); and (4) an **insulated housing** for DIN rail mounting [15].

Accessories are specialized components used in control circuits, rated for currents of 5 to 10 A. They offer flexible mounting (Front and side) options and can be installed in varying quantities on contactors to enhance their functionality [9].

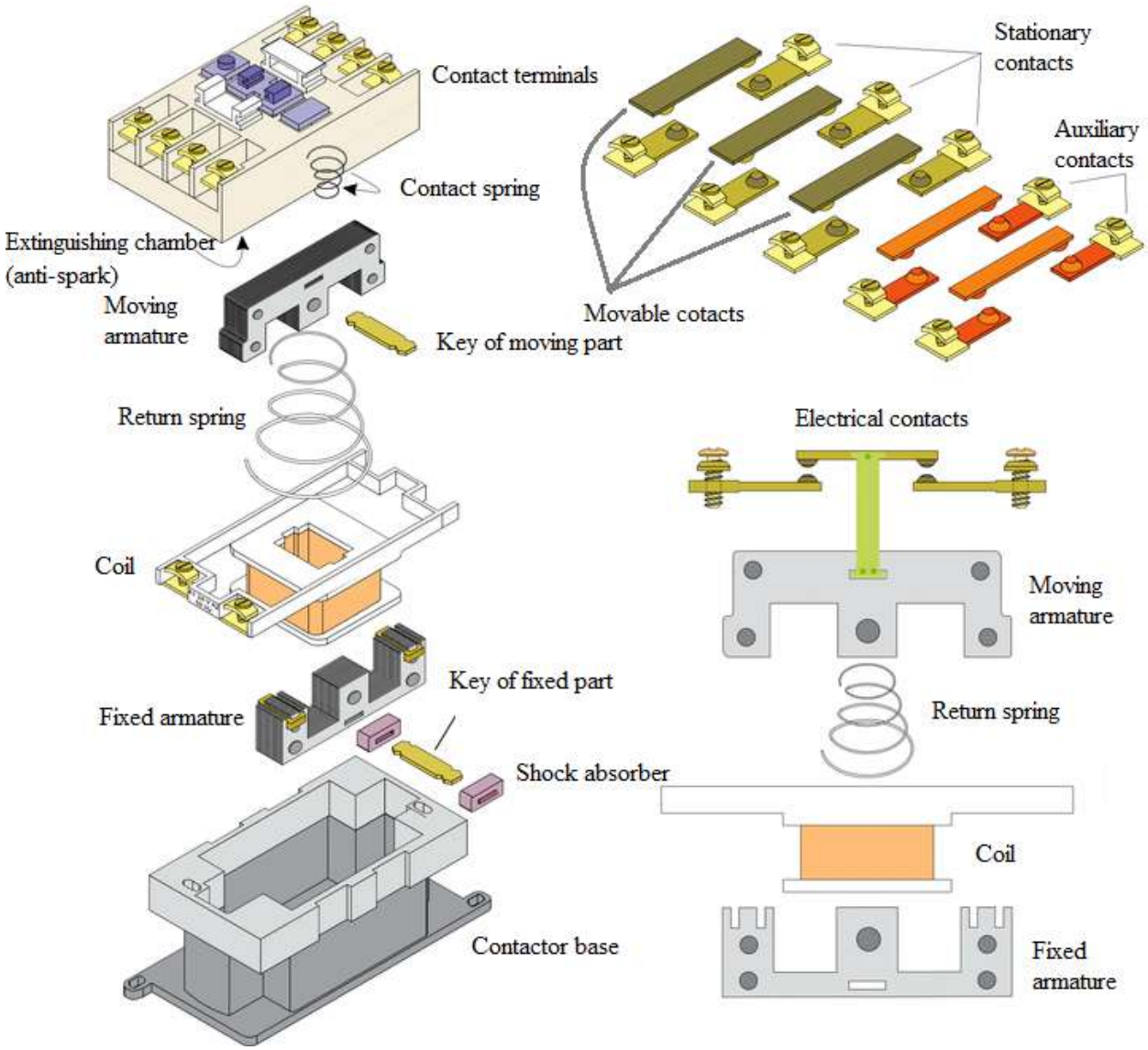


Figure 1.24: Detailed structure of a contactor

When a control voltage is applied to the electromagnet (coil), it generates a magnetic field that pulls in a movable armature. This armature is mechanically linked to the main power contacts, forcing them to close. When the coil is de-energized, a spring returns the armature and opens the contacts [2].

Characteristics

Their main characteristics include [15, 6]:

- **High Current Capacity:** >5000 A, >100 kW – superior to standard relays.
- **Arc Suppression:** Arc chutes extinguish arcs for safety and longevity.
- **Indirect Control:** Low-voltage coil isolates control circuitry (PLC, push buttons) from high-power load.
- **Durability:** High cycle rating for continuous industrial automation.
- **Safety Features:** Auxiliary modules for overload, short-circuit, under-voltage protection.

1.7 Fuses



(a) Fuse



(b) Fuse Holder



(c) Fuse Switch



(d) Fuse Disconnector 1P



(e) Fuse Disconnector 2P



(f) Fuse Disconnector 3P



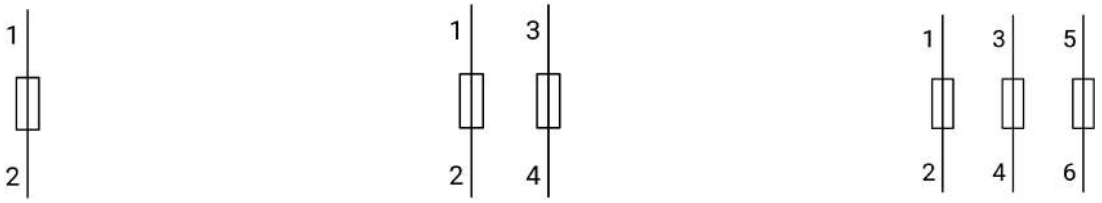
(g) Fuse Switch Disconnector 3P+N

Figure 1.25: Electrical Fuses

Role

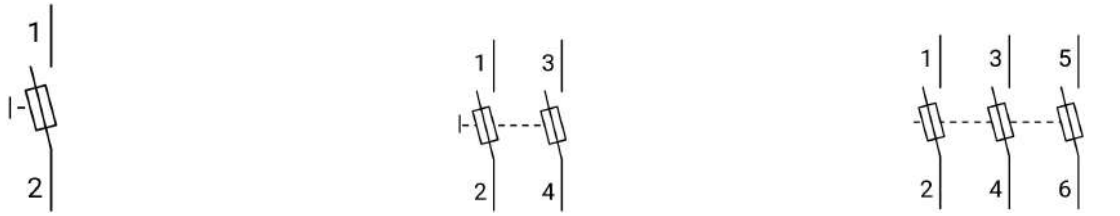
A fuse is a protective device that opens a circuit by melting a calibrated fusible element when the current exceeds a specific value for a sufficient time [17].

Symbol



(a) Fuse 1P (b) Fuse 2P (c) Fuse 3P

Figure 1.26: Fuse Symbol



(a) Fuse Switch 1P (b) Fuse Switch 2P (c) Fuse Switch 3P

Figure 1.27: Fuse Switch Symbol

General Construction

The fundamental components of a fuse structure are as follows [17]:

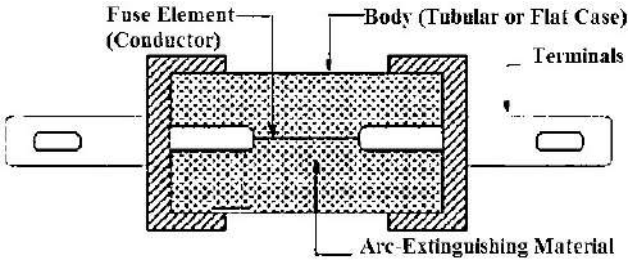


Figure 1.28: Detailed structure of a fuse

1. **Fuse Element (Conductor Section)**: Typically fabricated from metals such as lead or copper.
2. **Body (Tubular or Flat Case)**: Constructed from heat-resistant materials like hardened glass, ceramic, or plastic.

3. **Terminals**: Connection points that integrate the fuse securely into an electrical circuit.
4. **Arc-Extinguishing Material**: Filler material, such as quartz sand, which quenches the arc discharge upon melting.

Types

- **General Application (gG/gL):** For protection against overloads and short-circuits.



(a) gG Fuse (b) gL Fuse (c) gG/gL Fuse

Figure 1.29: gG/gL Fuses

- **Fast-Acting (aR/gR):** For protecting semiconductors (very fast operation).



(a) aR Fuse (b) gR Fuse

Figure 1.30: aR/gR Fuses

- **Motor Protection (aM):** For short-circuit protection of motor circuits, tolerating the high inrush current.



Figure 1.31: aM Fuses

Operating Principle

The current flows through a fusible element with a specific resistance. Under normal conditions, the heat generated (I^2R) is dissipated. During an overcurrent, the heat generation exceeds dissipation, raising the element's temperature until it melts (fuses), thereby opening the circuit and clearing the fault [5].

A fuse protects a circuit by melting its internal element when excessive current flows. The process has two phases:

1. **Melting Phase:** The fault current heats the fuse element until it melts. The energy released during this phase is called the *melting* I^2t.

2. **Arcing Phase:** After melting, an electric arc appears across the gap. The fuse extinguishes this arc, producing *arcing* I^2t.

The **total clearing** I^2t is the sum:

$$\boxed{I^2t_{\text{total}} = I^2t_{\text{melting}} + I^2t_{\text{arcing}}}$$

A **current-limiting fuse** interrupts the fault within less than half an AC cycle, reducing the peak current from a possible $2.3 \times I_{\text{RMS}}$ (without fuse) to a much lower *peak let-through current* I_{peak} [17].

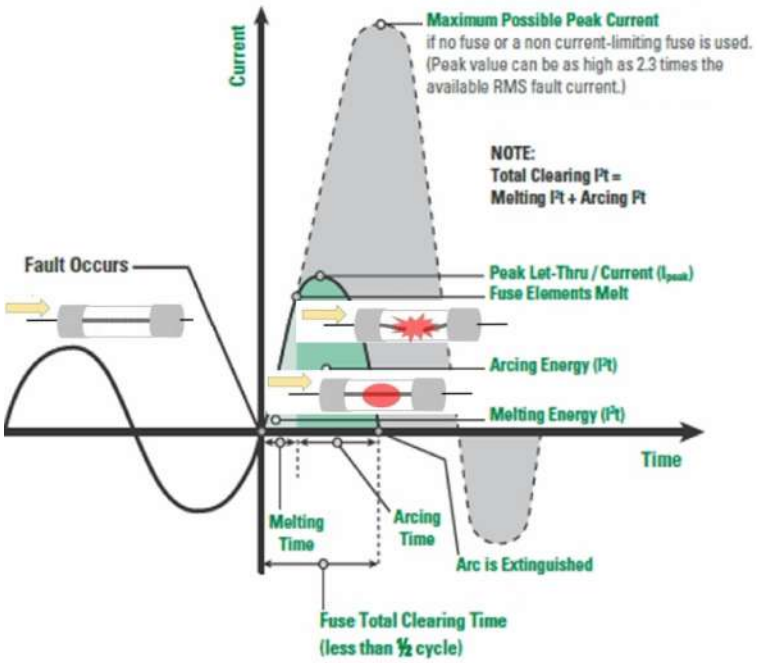


Figure 1.32: Fuse current-limiting operation

Detailed Characteristics

- **Rated Current** (I_n): Maximum current the fuse can carry continuously [17].
- **Rated Voltage** (U_n): Maximum system voltage for safe fuse operation.
- **Breaking Capacity (PdC)**: Maximum fault current (typically 80-170 kA) the fuse can safely interrupt.
- **Clearing Time**: Total time from overcurrent initiation to complete arc extinction.

1.8 Thermal Overload Relays



Figure 1.33: Thermal Overload Relay

Definition

A thermal overload relay is a protective device that uses the thermal effect of electric current to detect a prolonged overload in a circuit, typically for motor protection [15].

Role

To protect motors and cables against dangerous overheating caused by sustained overloads. It does not protect against short-circuits. (Standard: IEC 60947-4-1) [15].

Symbol

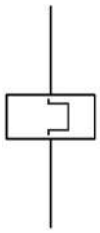
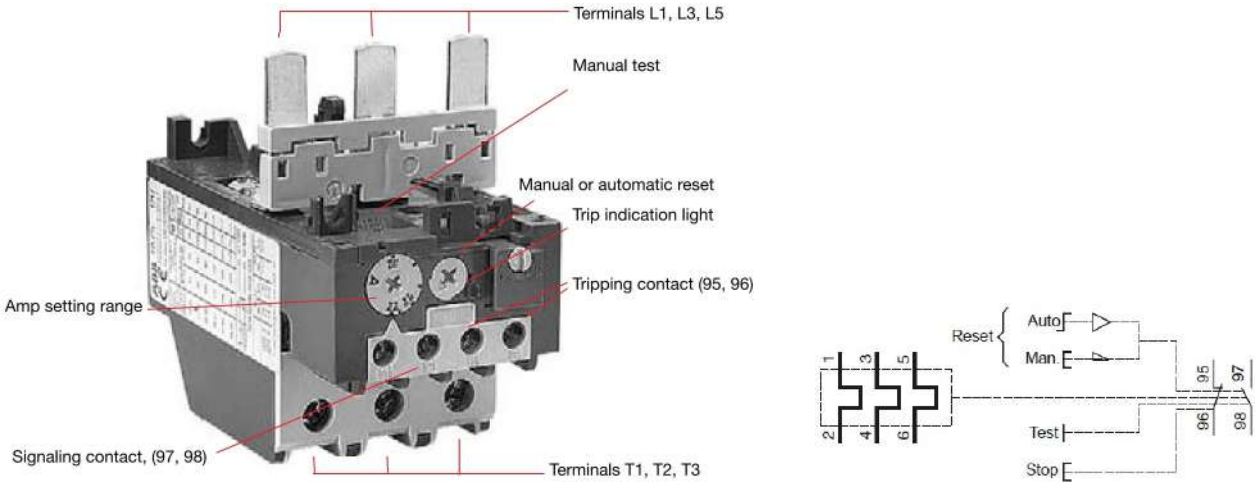


Figure 1.34: Thermal Overload Relay Symbol

General Construction



(a) Overload Relay Parts (b) Overload Relay Parts Symbol

Figure 1.35: Overload Relay Construction

Terminals: Terminals L1, L2, and L3 are input terminals. It can be directly mounted to the contactor. Supply to the motor can be connected to Terminals T1, T2, and T3.

Ampere Range Setting: A rotary knob allows setting the rated current of the motor within upper and lower limits.

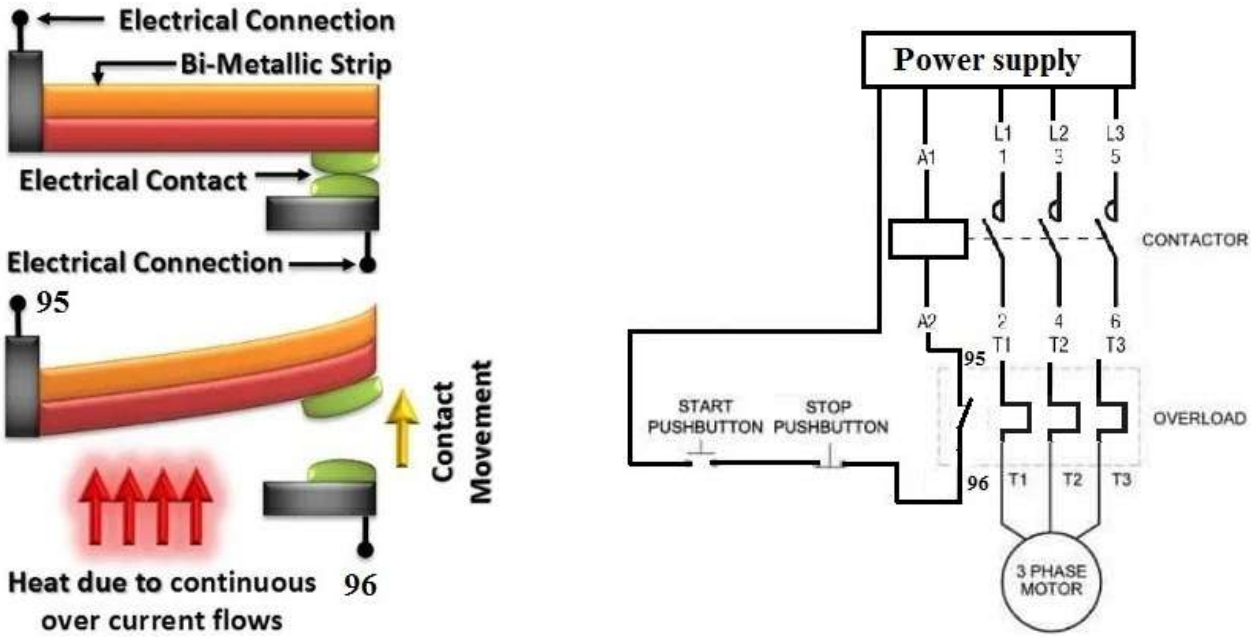
Reset Button: A reset button resets the overload relay after a trip and clearance of fault.

Manual/Auto Reset Selection: Allows choosing between manual and automatic reset after a trip.

Auxiliary Contact: Provided with two auxiliary contacts – one NO (97-98) for trip signaling and another NC (95-96) for disconnecting the contactor [15].

Operating Principle

The load current passes through a heater element. The heat generated warms a bimetal strip. Under overload conditions, excessive heat causes the bimetal to bend, actuating a trip mechanism that opens the associated NC (95-96) contact, stopping the motor [9].



(a) Thermal Overload

(b) Overload Relay with Contactor

Figure 1.36: Thermal Overload Relay Operating Principle

Types

- **By Compensation:** Ambient temperature compensated, uncompensated.
- **By Trip Class:** Class 10, Class 20, Class 30 (defining the trip time).
- **By Mounting:** Separate relay, block-mounted directly on a contactor.

Detailed Characteristics

- **Setting Current (I_r):** Adjustable current setting, usually $0.7 \times I_n$ to $1.05 \times I_n$ of the motor [15].

- **Trip Class:** Defines the maximum trip time at $7.2 \times I_r$ (e.g., Class 10 trips within 10 seconds) [15].

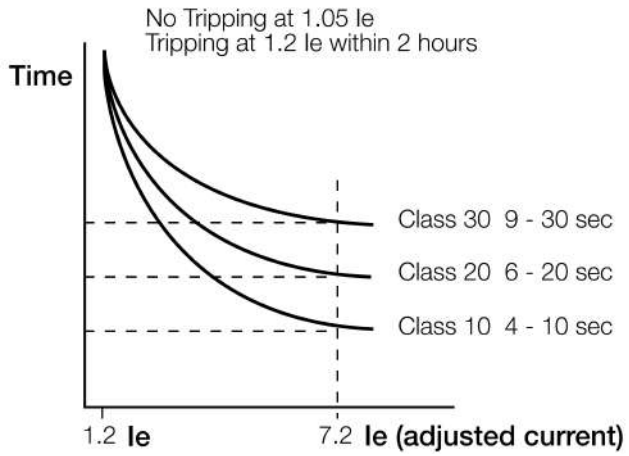


Figure 1.37: Thermal Overload Relay Trip Classes

The provided graph illustrates the tripping time versus adjusted current for Class 10, 20, and 30 relays. It demonstrates that increasing the current leads to a faster relay trip time. The relay is calibrated so that it will not activate at 1.05 times its set current (Ie), but is guaranteed to trip within two hours when the current reaches 1.2 times Ie. The class designation (10, 20, or 30) defines the time range in which the relay will operate at 7.2 times the set current: specifically, Class 10 relays trip in 4 to 10 seconds, Class 20 in 6 to 20 seconds, and Class 30 in 9 to 30 seconds.

1.9 Electromagnetic Relays

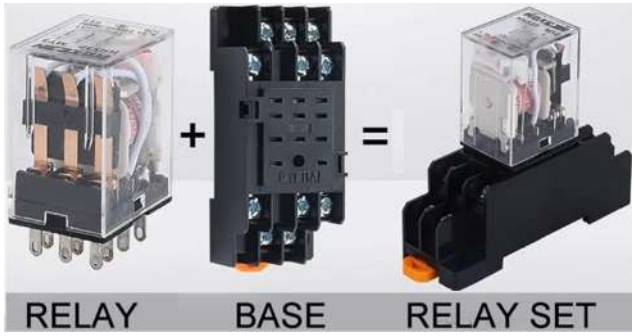


Figure 1.38: Electromagnetic Relay

Definition

An electromagnetic relay is a switch operated by an electromagnet. It uses a small electrical current in the coil to control a larger current in the switched contacts [18].

Role

To provide galvanic isolation between a low-power control circuit and a higher-power load circuit. Also used for logic functions and multiplying contacts [3].

Symbol

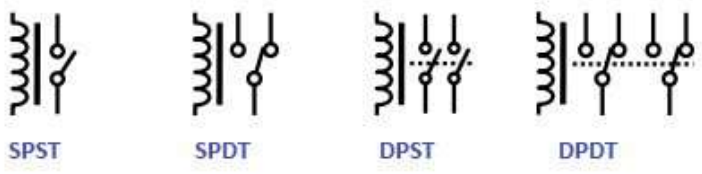
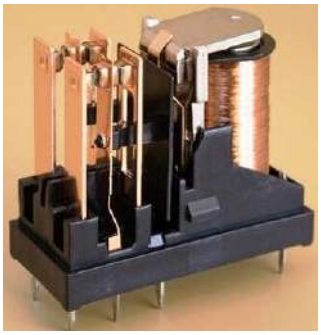


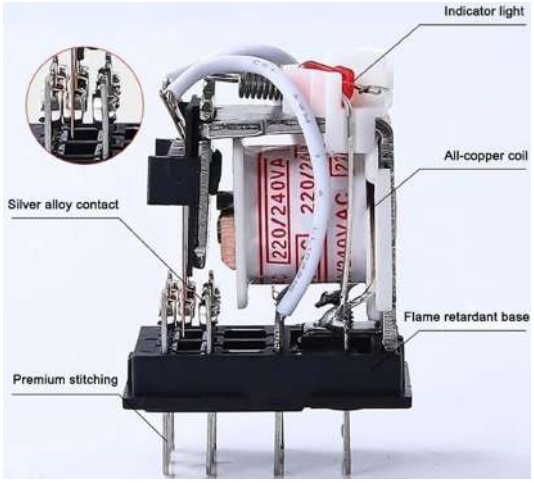
Figure 1.39: Electromagnetic Relay Symbol

General Construction

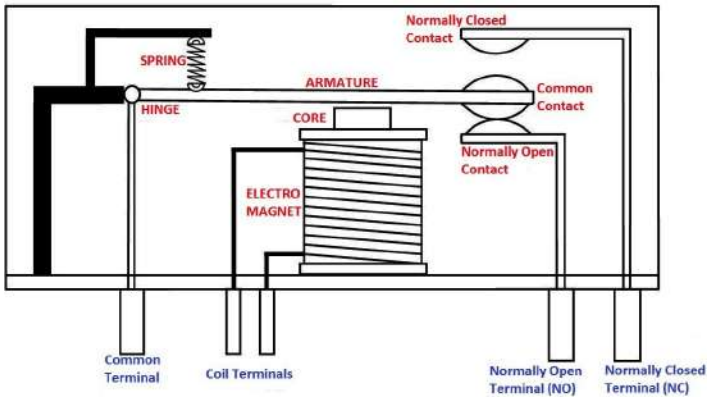
An electromagnetic relay is mainly made of three main components: Electromagnetic Coil, Movable Armature, and Contacts [2].



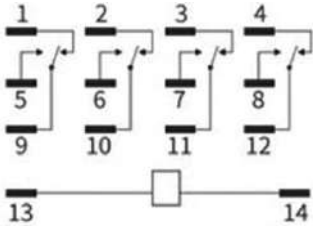
(a) Electromagnetic Relay Internal



(b) Electromagnetic Relay Parts



(c) Electromagnetic Relay Internal Diagram



(d) Electromagnetic Relay Schematic

Figure 1.40: Electromagnetic Relay Construction

Operating Principle

When a voltage is applied to the coil, it becomes an electromagnet. The generated magnetic field attracts a pivoting armature, which opens or closes the electrical contacts. When coil power is removed, a spring returns the armature to its rest position [2].

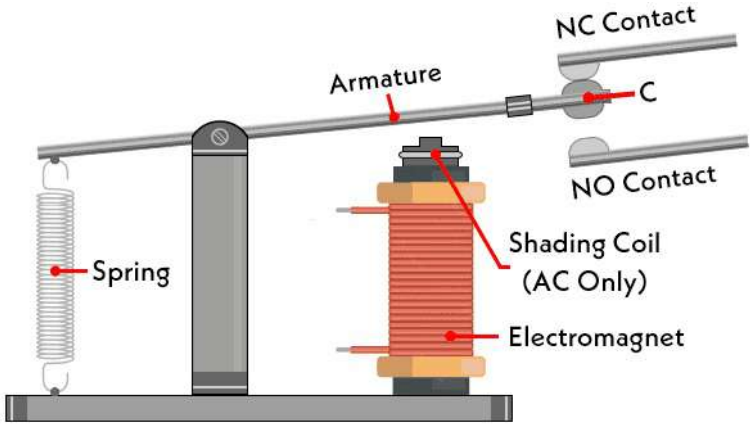


Figure 1.41: Electromagnetic Relay Operating Principle

Detailed Characteristics

- **Coil Voltage:** Rated control voltage (e.g., 12 V DC, 24 V DC, 230 V AC) [18].
- **Contact Rating:** The current and voltage the contacts can switch (e.g., 10 A at 250 V AC) [18].

Types

Electromagnetic Relays can be categorized by their operation mechanism, their function (latching behavior), their application, and their construction.

By Latching Behavior (Function):

- **Monostable Relay:** Returns to its de-energized state when the coil power is removed.
- **Bistable (Latching) Relay:** Remains in its last state after a coil pulse is removed.
- **General Purpose Relay:** Common industrial relay with multiple contact configurations.

By their working principle:

- Electromagnetic Attraction Relay
- Electromagnetic Induction Relay

1.10 Circuit Breakers



(a) MCB 1P (b) MCB 1P+N (c) MCB 2P (d) MCB 3P (e) MCB 4P

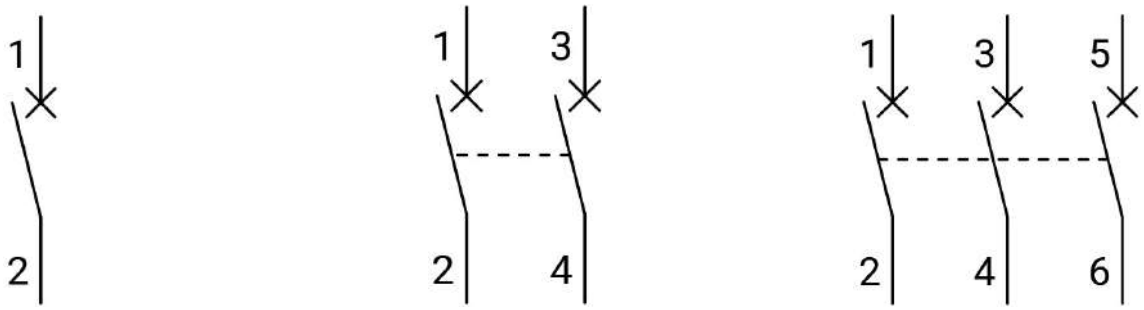
Figure 1.42: Circuit Breakers

Definition

A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage and fire caused by overcurrent (overload or short circuit) [19, 20].

Symbol

The (**X**) is the standard IEC symbol for the main contacts of a circuit breaker:



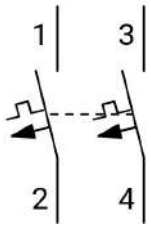
(a) Circuit Breaker 1P (b) Circuit Breaker 2P (c) Circuit Breaker 3P

Figure 1.43: Circuit Breaker Symbols

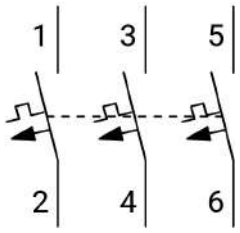
The symbol for a thermal-magnetic circuit breaker combines a standard circuit breaker symbol with additional elements for its two trip mechanisms: a serrated rectangle or a curved line for thermal protection (overloads) and a zigzag line or coil for magnetic protection (short circuits). This combination signifies the device's dual protection against both sustained overloads and sudden short circuits.



(a) Thermal Magnetic Circuit Breaker 1P

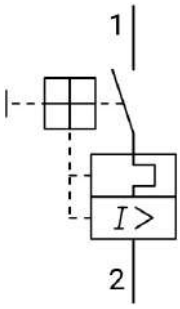


(b) Thermal Magnetic Circuit Breaker 2P

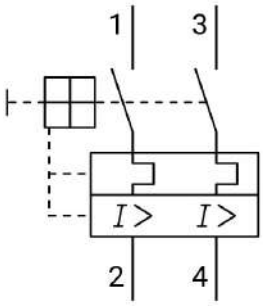


(c) Thermal Magnetic Circuit Breaker 3P

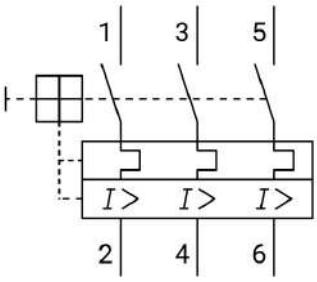
Figure 1.44: Thermal Magnetic Circuit Breaker



(a) Circuit Breaker 1P



(b) Circuit Breaker 2P



(c) Circuit Breaker 3P

Figure 1.45: Motor Circuit Breaker

Role

To automatically and safely interrupt current flow after a fault is detected. It is resettable after the fault is cleared. (Standards: IEC 60898-1 for residential, IEC 60947-2 for industrial) [19, 20].

General Construction

The DIN-rail-mounted thermal-magnetic miniature circuit breaker is the most common style in modern domestic consumer units and commercial electrical distribution boards throughout Europe.

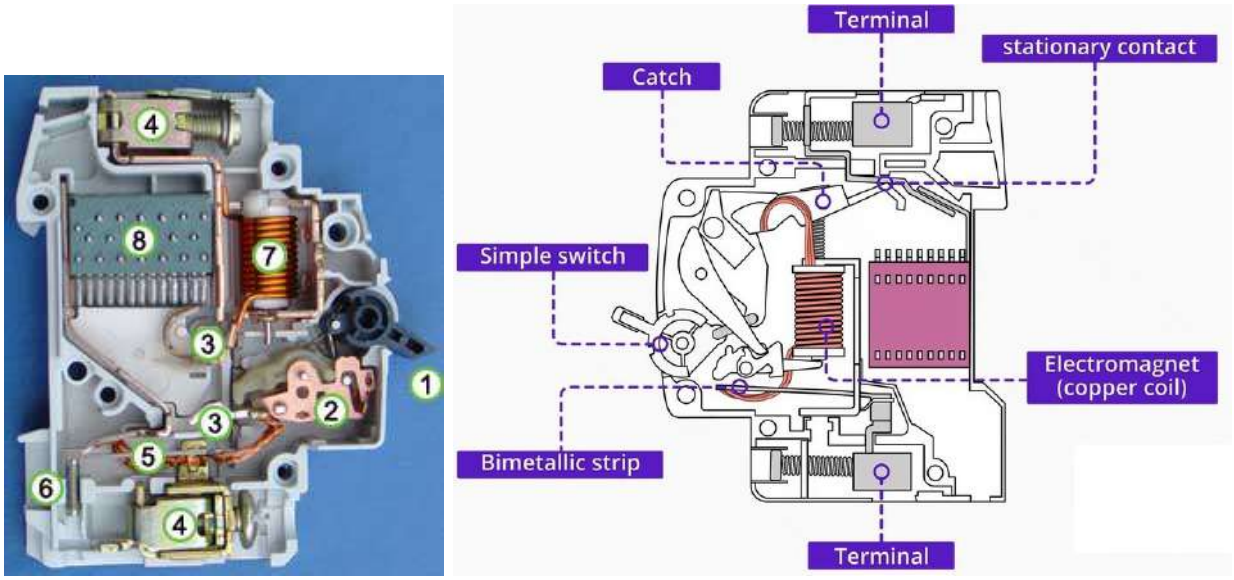


Figure 1.46: Structure of a miniature circuit breaker

The design includes the following components:

1. Actuator lever: used to manually trip and reset the circuit breaker. Also indicates the status of the circuit breaker (On or Off/tripped). Most breakers are designed so they can still trip even if the lever is held or locked in the "on" position. This is sometimes referred to as "free trip" or "positive trip" operation.
2. Actuator mechanism: forces the contacts together or apart.
3. Contacts: allow current when touching and break the current when moved apart.
4. Terminals
5. Bimetallic strip: separates contacts in response to smaller, longer-term overcurrents
6. Calibration screw: allows the manufacturer to precisely adjust the trip current of the device after assembly.
7. Solenoid: separates contacts rapidly in response to high overcurrents
8. Arc divider/extinguisher

Operating Principle

It combines two triggering mechanisms [5]:

- **Thermal Trip (Bimetal):** An overload current heats a bimetal strip, which bends slowly and trips the mechanism after a delay.
- **Magnetic Trip (Solenoid):** A large short-circuit current creates a strong magnetic field that instantly pulls a plunger, tripping the mechanism.

Detailed Characteristics

- **Rated Current (I_n):** The current it can carry continuously [19].
- **Breaking Capacity (I_{cu}):** The maximum short-circuit current it can safely interrupt [20].
- **Trip Curves (B, C, D):** Define the reaction time to overcurrents [19].

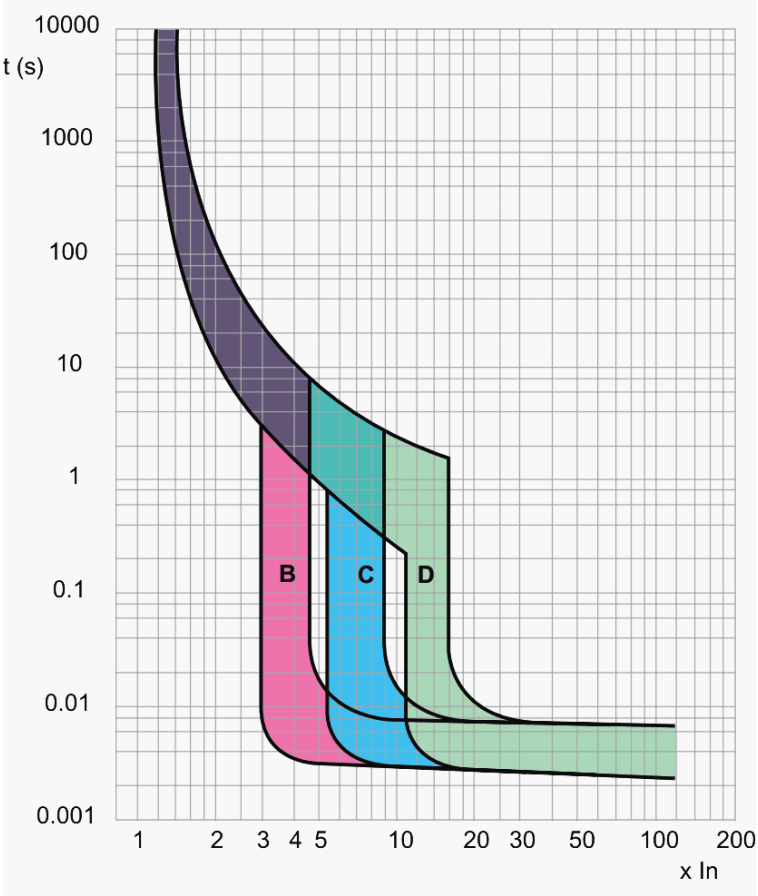


Figure 1.47: Tripping curves of MCBs (Types B, C, D)

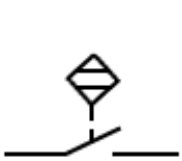
1.11 Sensors

Definition

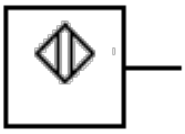
A sensor is a device that detects or measures a physical property (e.g., temperature, pressure, light, position) and converts it into a measurable electrical signal (e.g., voltage, current, resistance) [21].

Symbol

In electric schematic diagrams, specific symbols are used to represent the different physical quantities that a sensor is designed to measure [16].



(a) Proximity switch



(b) Sensitive sensor by proximity



(c) Switch by proximity to a magnet

Figure 1.48: Proximity Sensors Symbols

Role

To provide input data about physical conditions to measurement, control, or regulation systems. They form the essential interface between the physical world and electronic control systems [9].

Operating Principle

Sensors work by exploiting various physical effects where a change in the measured quantity causes a change in an electrical property [22].

Detailed Characteristics

- **Range:** The minimum and maximum values of the measured quantity.
- **Sensitivity:** The ratio of change in output to change in input.
- **Accuracy:** The closeness of the measurement to the true value.
- **Resolution:** The smallest detectable change.
- **Response Time:** Time required for output to reach a specified percentage of final value.

1.12 Conclusion

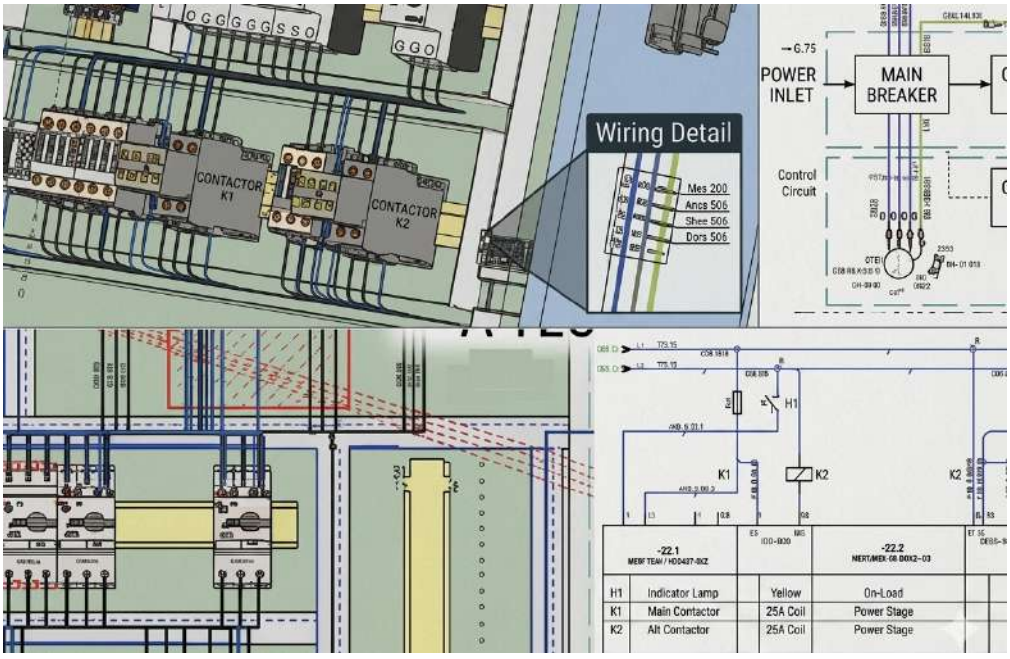
This chapter presented the essential electrical equipment used in modern installations. Each device has distinct characteristics, ratings, and applications. Proper selection requires understanding breaking capacity, trip curves, and load types. Together, these components form the foundation of safe, reliable, and functional electrical systems.

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Chapter 2

Development of Electrical Diagrams

◇ ◇ ◇



Chapter 2

Development of Electrical Diagrams

2.1 Introduction

2.2 Standardized Symbols for Electrical Equipment

2.2.1 Standardization and Standards Organizations

An electrical diagram is a method for representing electrical circuits and installations. It is a universal language that must be understood by every electrician, which is why the rules of representation must be respected and are therefore classified in international standards [23, 11, 2].

The goal of this standardization is to establish a common language among electricians, facilitating the writing, reading, and understanding of electrical diagrams [3].

The electrician, the electrical engineer, the automation specialist and the electronics engineer always work with standards for technical implementations and for the production of documents (manuals, diagrams, architectural plans, program listings). The names of the most commonly used reference organizations are as follows:

- **IEC**: International Electrotechnical Commission
- **CENELEC**: European Committee for Electrotechnical Standardization
- **UTE**, Union Technique de l'Electricité, is at the origin of the standard **NF C 15-100** [1]
- **ISO**: International Organization for Standardization
- **ANSI**: American National Standards Institute
- **IEEE**: Institute of Electrical and Electronics Engineers

2.2.2 Standardized Symbols

The foundational lexicon of any electrical diagram is its use of standardized graphical symbols. These symbols abstract the physical form of electrical components, representing their essential

function within the circuit [16, 24, 2]. This standardization allows an engineer in one country to accurately interpret a diagram created by a colleague anywhere else in the world.

The table presents the official standards that define standardized graphical symbols for electrical diagrams [25, 26].

UTE	**NF**	**Qualification**
NF EN 60617-1	NF C 03-201	General Information
NF EN 60617-2	NF C 03-202	Symbol Elements
NF EN 60617-3	NF C 03-203	Conductors and Connection Devices
NF EN 60617-4	NF C 03-204	Passive Components
NF EN 60617-5	NF C 03-205	Semiconductors and Electron Tubes
NF EN 60617-6	NF C 03-206	Production and Conversion of Electrical Energy
NF EN 60617-7	NF C 03-207	Contacts, Pushbuttons and Protection Devices
NF EN 60617-8	NF C 03-208	Measuring Instruments, Indicators and Signalling
NF EN 60617-11	NF C 03-211	Symbols for Installation Diagrams and Architectural Plans
NF EN 60617-12	NF C 03-212	Binary Logic Operators
NF EN 60617-13	NF C 03-213	Analogue Operators

As referenced in the standards table, electrical components can be fundamentally categorized by their function and application within a circuit [6, 27]. This systematic classification forms the basis for standardized representation in electrical diagrams.

(i) **Passive Components:** Passive components cannot amplify a signal or introduce energy into a circuit. They can only absorb, dissipate, or store energy and do not require an external power supply to function.

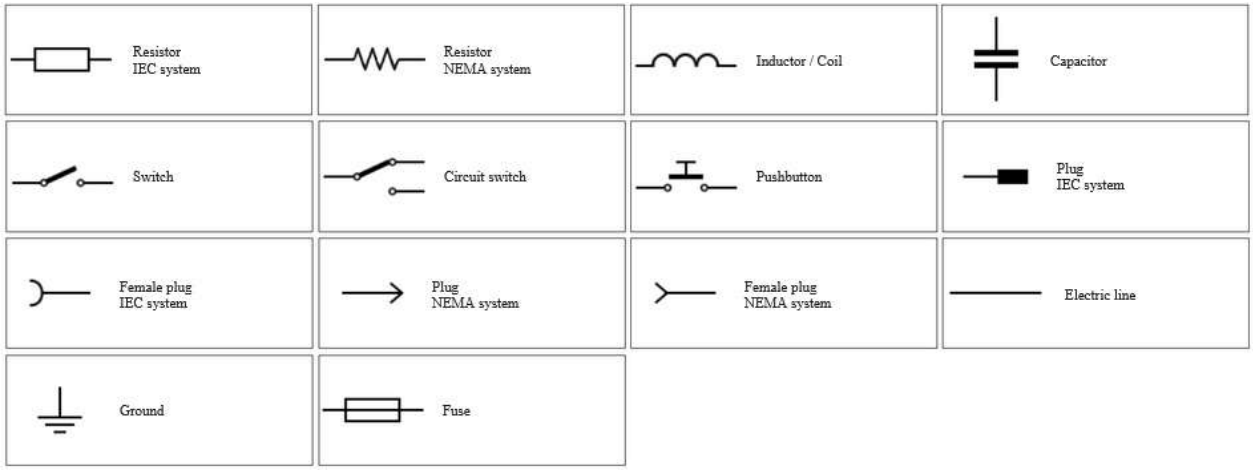


Figure 2.1: Passive components symbols

(ii) **Active Components:** Active components can control electron flow, amplify a signal (provide power gain), and typically require an external power supply to operate. They often use a small signal to control a much larger one.

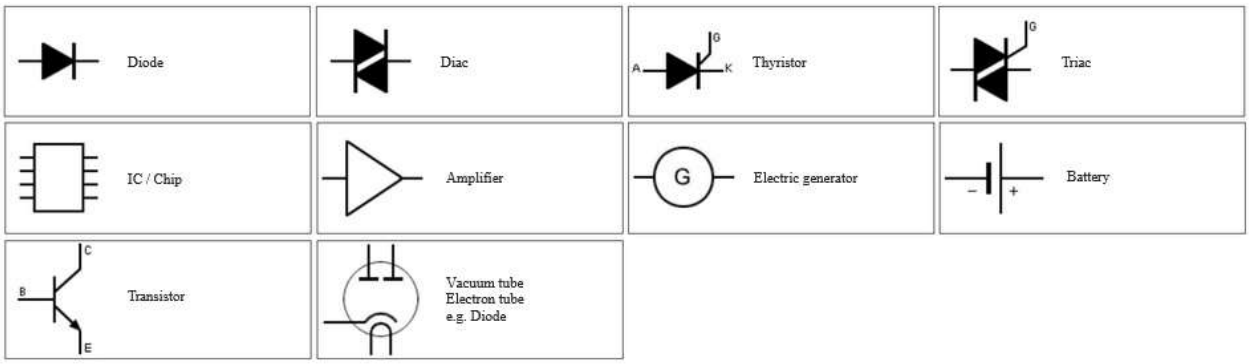
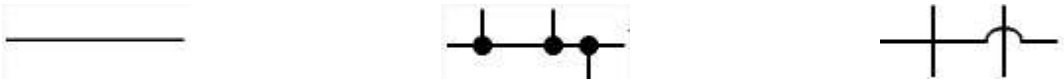


Figure 2.2: Active Components symbols

(iii) **Conductors and Connections (Neutral):** These elements are the pathways for energy and are neither passive nor active.



(a) Wire (b) Wires joined (c) Wires not joined

Figure 2.3: Wire and Connection Symbols

2.2.3 Identification of Elements

The standard separates the identification into two main aspects according to IEC 81346 [28]:

- **Function:** What the object does (e.g., `A` for Auxiliary, `K` for Control).
- **Product/Component:** What the object is (e.g., `-Q` for a power circuit breaker, `-F` for a fuse).
- **Numbers:** Instance identification (e.g., `(1, 2, 3...)`).

Table 2.1: Main Function Codes according to IEC 81346 Standard [28]

Code	Main Function	Typical Devices
A	Auxiliary	Auxiliary relays, auxiliary contacts
F	Protection	Circuit breakers, fuses
H	Signaling	Lamps, horns, pushbuttons
K	Control	Contactors, control relays, starters
M	Motor	Electric motors, solenoids
P	Measuring	Meters, sensors, transmitters
Q	Power Switching	Power circuit breakers, contactors
R	Resistor/Protection	Resistors, varistors, thermal overloads
S	Switching	Limit switches, selector switches
T	Transformer	Transformers, power supplies

Table 2.2: Functional Supplements according to IEC Standards

Supplement	**Meaning**	**Example**
AL	Alarm	HAL1
AV	Forward	KAV1
AR	Reverse	KAR1
ON	Closing/Turn On	QON1
OFF	Opening/Turn Off	QOFF1
ST	Start	KST1
STP	Stop	KSTP1

These tables provide a comprehensive reference for creating and interpreting electrical diagrams according to international IEC standards [14, 29].

Complete Identification Structure

Table 2.3: Element identification structure

A	B	C
Function of Element	Product/Component	Element Number

- **Identification of the Type of Element:** All elements are identified using a reference letter (Part A). Example: a contactor coil: **K**; a pushbutton: **S**.
- **Identification of the Element's Function:** A chosen reference must necessarily begin with a letter (Part B) which may be followed by necessary supplementary letters and/or digits (Part C).
- **Identification of Equipment Terminals:** This identification is based on an alphanumeric notation using uppercase letters and Arabic digits, where 'I' and 'O' should not be used.

Usage Examples

- `KM1`: First motor control contactor
- `Rth1`: First thermal protection relay
- `HAL2`: Second alarm signaling device
- `KAV1`: First forward control function

2.3 Classification of Diagrams by Representation Mode

2.3.1 Electrical Diagram Definition

It represents, using graphical symbols, the different parts of a network, an installation, or a piece of equipment that are functionally linked and connected [3]. An electrical diagram aims to:

- Explain the operation of the equipment
- Provide the basis for creating wiring and implementation diagrams
- Facilitate testing and maintenance

2.3.2 Classification According to Representation Mode

A complex electrical system cannot be fully or clearly represented in a single drawing [30, 11]. Therefore, a suite of diagram types is used, each serving a distinct purpose.

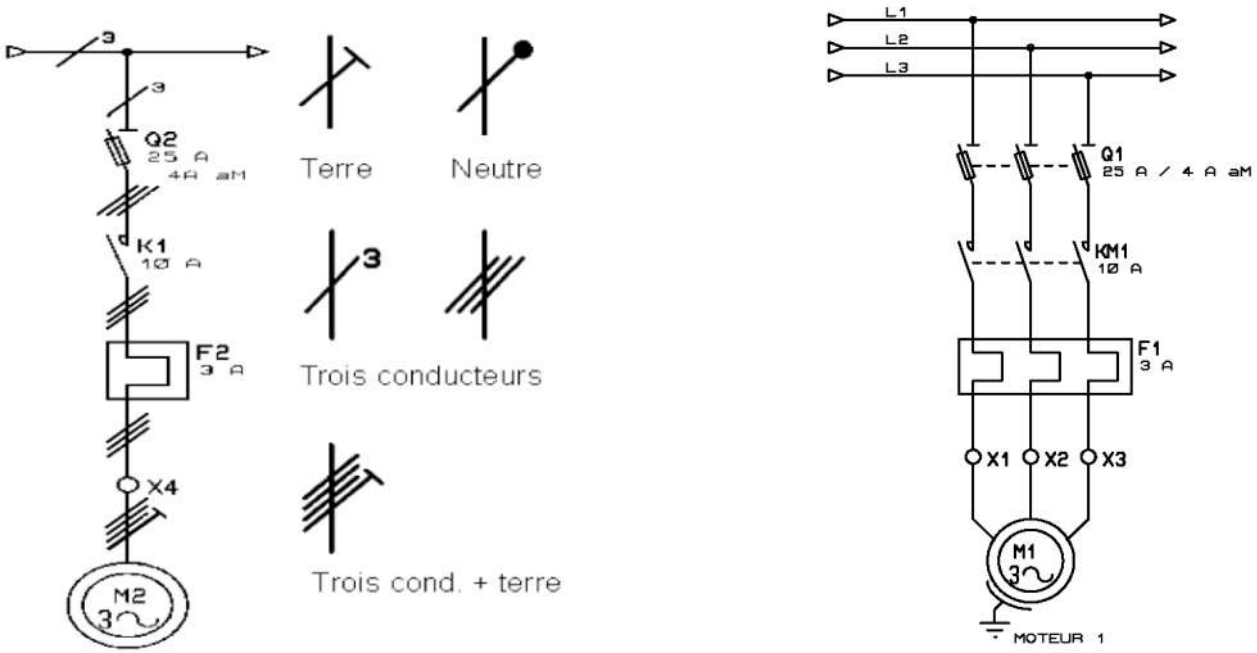
Three factors characterize the mode of representation:

- The number of conductors
- The topographical representation
- The location of symbols

I. **Schematic Diagrams**: Show electrical connections and functions without regard to physical layout [2].

   A. **Single-Line Diagrams (SLD):** Represents entire electrical system using a single line.

   B. **Multi-Line Diagrams:** Every conductor represented by separate line.



(a) Single-Line Diagram (b) Multi-Line Diagram

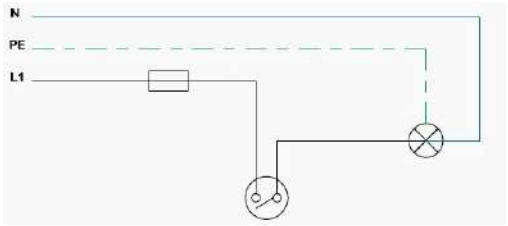
Figure 2.4: 3 Phase Induction Motor Direct On Line (DOL) Starter



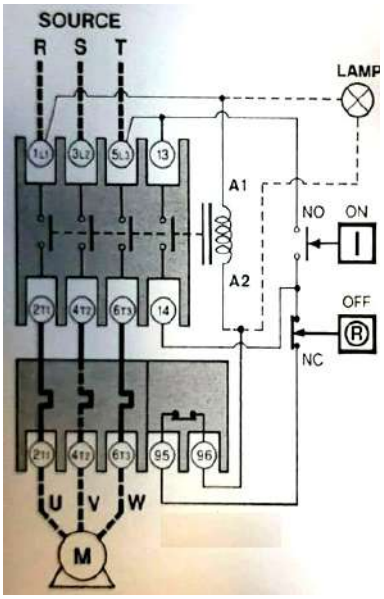
(a) Single-Line Diagram (b) Multi-Line Diagram

Figure 2.5: Simple light circuit

I. **Wiring Diagrams**: Illustrate physical connections and component locations [29].



(a) Simple light circuit



(b) 3 Phase Induction Motor DOL Starter

Figure 2.6: Wiring Diagram

I. **Architectural Plans**: Show electrical systems within building layouts [1].

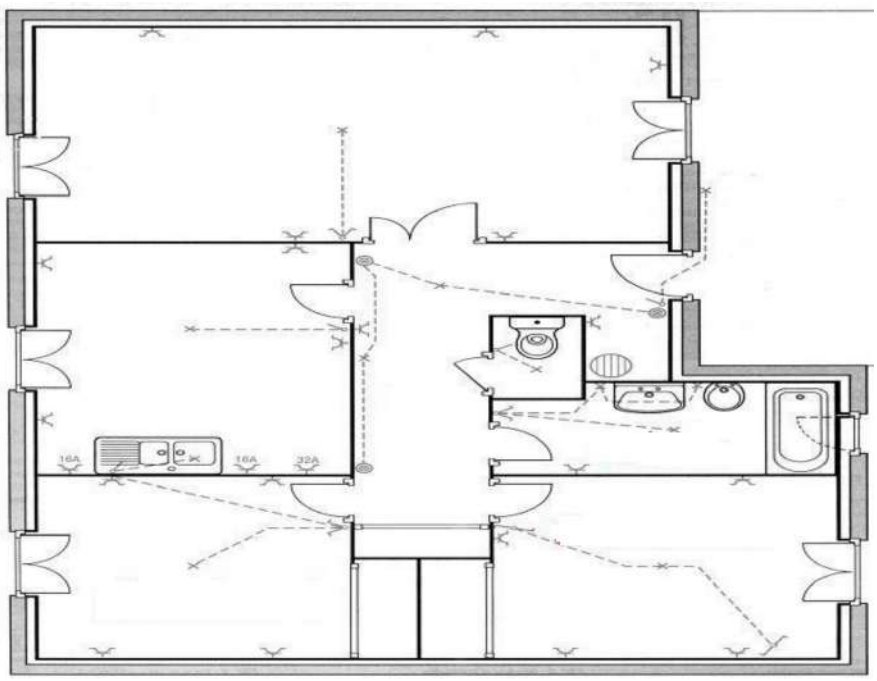


Figure 2.7: Architectural Plans

Here is the list of some symbols that you will position on the architectural plan:

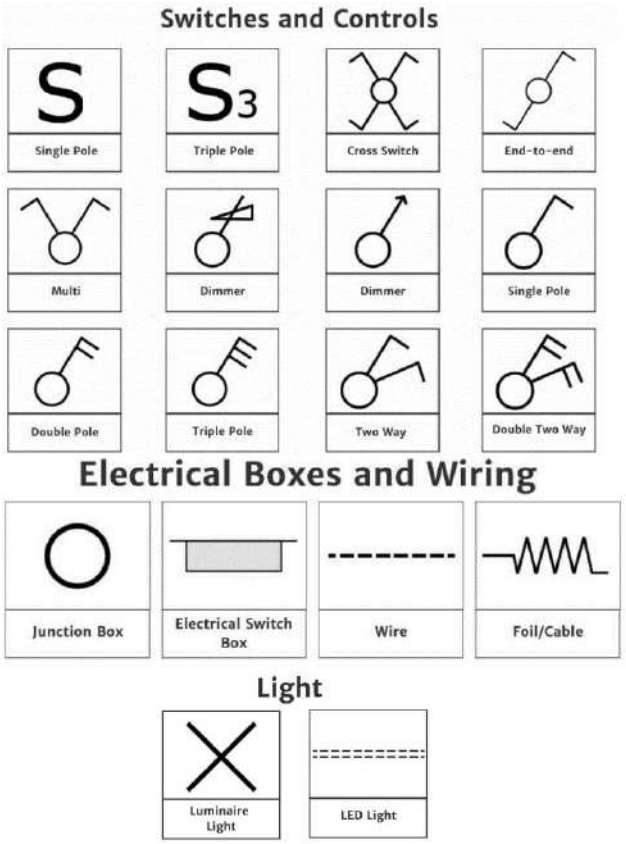


Figure 2.8: Architectural plan symbols

2.3.3 Diagram Selection by User Profile

In real-world projects, different diagram types are combined [9, 12]:

- **Project Manager:** Single-line, function-based, schematic
- **Panel Builder:** Multi-line, location-based, topographical
- **Troubleshooting Technician:** Multi-line, function-based, schematic
- **Installer:** Single-line, location-based, topographical

By choosing the correct combination of these three factors, designers create documentation that is both useful and usable for its intended audience.

2.4 Conventions and Standardization

Beyond the symbols themselves, a robust set of drafting and representation conventions ensures that diagrams are consistently structured and easily interpretable [23, 11].

2.4.1 Key Conventions in Practice

- **Signal and Power Flow:** The universal convention is for signal or logical power to flow from left to right and from top to bottom.
- **Component State:** Components are typically shown in their de-energized or normal state [24].
- **Reference Designations:** Each component is labeled with a unique alphanumeric code standardized in IEC 61346 [28] and ANSI/IEEE 200 [31].
- **Wire Numbering and Cross-Referencing:** Wires are numbered according to a specific scheme to aid in tracing circuits [29].

2.5 Rules and Standards for Establishing an Electrical Diagram

Creating a professional electrical diagram is a methodical engineering process governed by international and national standards [23, 1]. Adherence to these rules is critical for safety, functionality, and interoperability.

2.5.1 Standards for Electrical Installations

The **NF C 15-100 standard** [1] is a reference document that aims to establish implementation rules for electrical installations. Proper execution of these rules ensures:

- Safety of property, persons, and domestic animals
- Proper functioning of installations
- Normal electrical energy needs and user comfort

2.5.2 The Diagram Creation Process and Governing Standards

The development process can be broken down into the following key stages [23]:

1. **Define the Purpose and Scope:** Determine the type of diagram(s) needed (schematic, wiring, etc.) and the precise boundaries of the system to be documented.
2. **Information Gathering:** Collect all necessary data on components, including manufacturer datasheets with terminal identifications, voltage/current ratings, and coil specifications.
3. **Select and Apply the Correct Standards:** Adhere to the relevant standards for the project's location and industry. Key international standards include:
    - **IEC 61082:** Series of standards for the *preparation of documents* used in electrotechnology [23].

- **IEC 60617:** Defines the *graphical symbols* for diagrams [16].
- **IEC 61355:** Provides a system for the *classification and designation of documents* for plants, systems, and equipment [32].
- **NFPA 79:** The *Electrical Standard for Industrial Machinery* in the United States, which includes stringent requirements for documentation [7].
- **ISO/IEC 81714-1:** Guidelines for the *design of graphical symbols* [33].

4. **Drafting the Diagram (Best Practices):**
   - **Layout for Clarity:** Arrange symbols logically to minimize wire crossings. Group functionally related components together.
   - **Consistent Line Styles:** Use different line styles (solid for wires, dashed for mechanical linkages or auxiliary circuits) consistently throughout the document set.
   - **Text and Labeling:** Use a clear, sans-serif font. Ensure all components have reference designations, all wires are numbered, and all pages are clearly titled.
   - **Title Block:** Every sheet **must** include a standardized title block with the project name, diagram type, sheet number, revision level, date, and drafter's/engineer's name [34].
5. **Review and Revision Control:**
   - Diagrams must be subjected to a formal **checking and review** process by a second engineer to identify errors and ensure compliance with standards.
   - A formal **revision control** process is mandatory. All changes must be documented in a revision history table, ensuring that the latest version is always identifiable and available to all stakeholders.

2.6 Conclusion

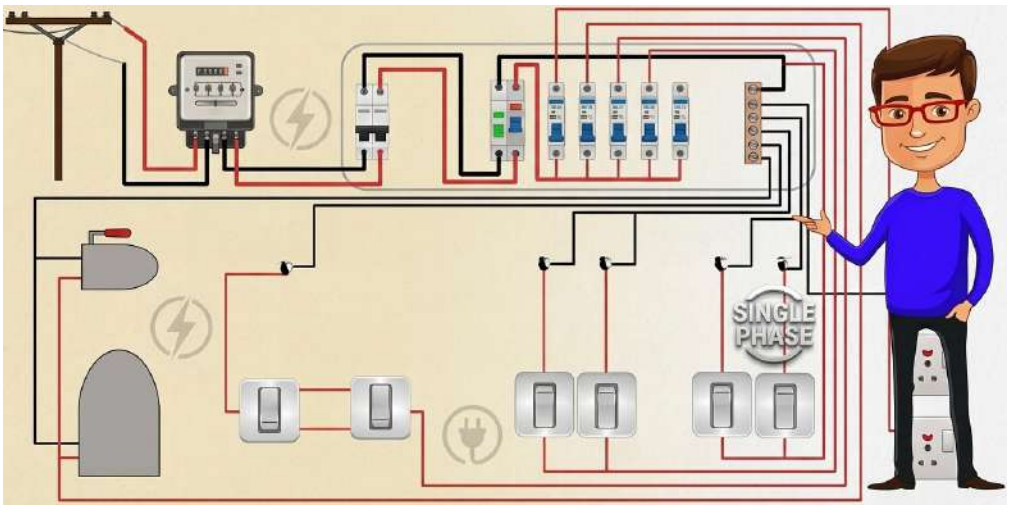
The development of an electrical diagram is a disciplined and precise engineering activity. By rigorously applying standardized symbols, selecting the appropriate type of diagram, following established conventions, and adhering to international rules and standards, engineers and technicians create a powerful, unambiguous, and legally defensible tool.

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Chapter 3

Lighting Circuits

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Chapter 3

Lighting Circuits

3.1 Introduction

This chapter details the standard wiring configurations for lighting installations as defined by norms such as NF C 15-100. Mastery of these fundamental circuits—simple switching, two-way switching, remote relay control, and timed control—is essential for the design, installation, verification, and maintenance of compliant and functional electrical systems in both domestic and industrial contexts.

3.2 Simple (One-Way) Lighting Circuit

This is the elementary circuit for controlling a luminaire from a single location using a single-pole switch, which interrupts the line conductor.

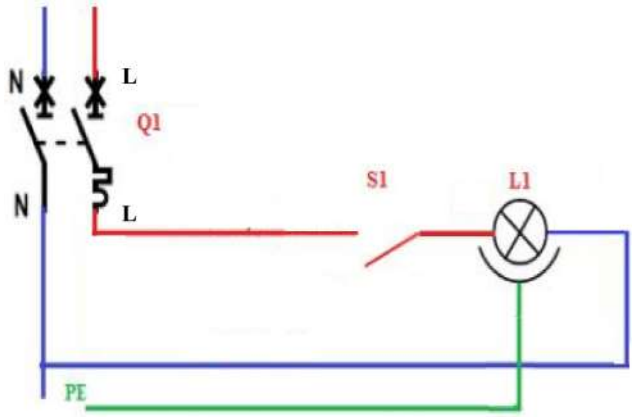


Figure 3.1: Schematic (Developed) Diagram - Simple Lighting

Technical Analysis:

- **Power Circuit:** The circuit is protected by an overcurrent device (F1, e.g., a fuse or circuit breaker). The line (L) passes through the single-pole switch (S1). The switched line then connects to one terminal of the lamp (H). The neutral (N) connects directly to

the lamp's other terminal. The Protective Earth (PE) is connected to the luminaire's exposed conductive parts.

- **Conductor Identification:** Standard color codes apply (e.g., Brown/Black/Grey for L, Blue for N, Green/Yellow for PE). The conductor between the switch and the lamp is the "switched line" or "return for lighting."
- **Operation:** Closing switch (S1) completes the circuit between L and N across the lamp (H), causing illumination. Opening the switch interrupts the circuit.

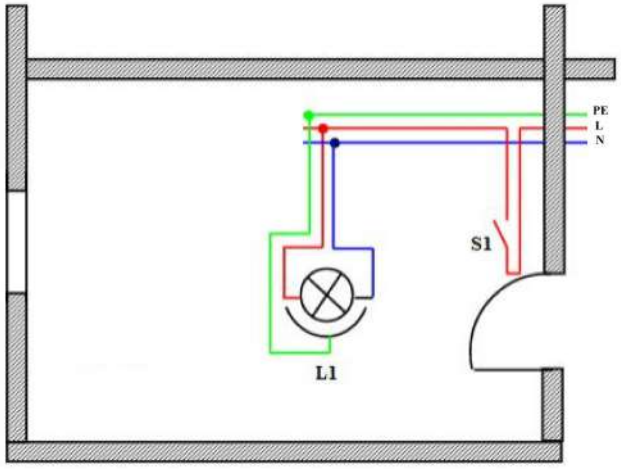


Figure 3.2: Multi-Line (Multifilar) Wiring Diagram

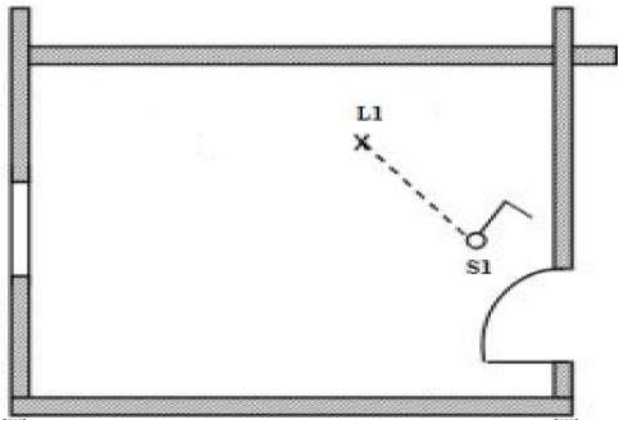


Figure 3.3: Architectural/Schematic Layout

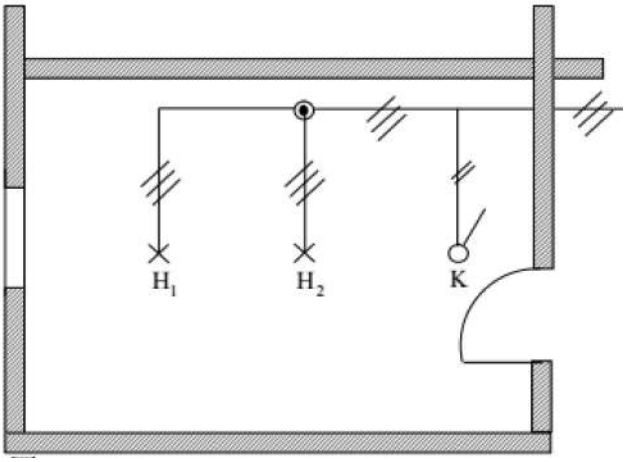


Figure 3.4: Single-Line (Unifilar) Diagram

3.3 Double-Switch Lighting Circuit

This configuration allows the independent control of two separate lighting loads (or groups of luminaires) from a single double-pole switch.

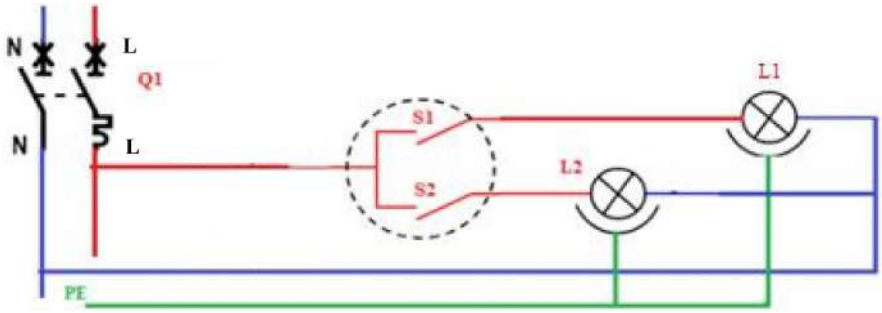


Figure 3.5: Schematic Diagram - Double-Switch Circuit

Technical Analysis:

- **Circuit Topology:** The circuit consists of two parallel sub-circuits originating from a common protection device (Q1). A double-pole switch (S) provides independent control for each pole.
- **Wiring:** The line (L) is connected to the common input of the switch. Each output pole (S1, S2) provides a switched line to its respective lamp (H1, H2). The neutral (N) and protective earth (PE) are common to all loads.
- **Application:** Commonly used to control two different lighting functions in a single room (e.g., main light and accent light) from one switch location.

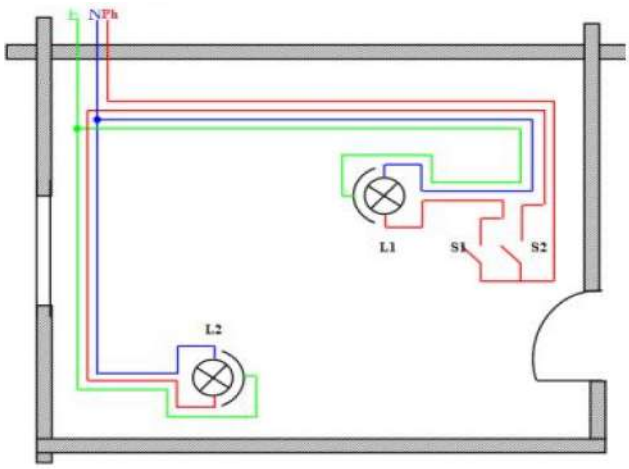


Figure 3.6: Multi-Line Wiring Diagram

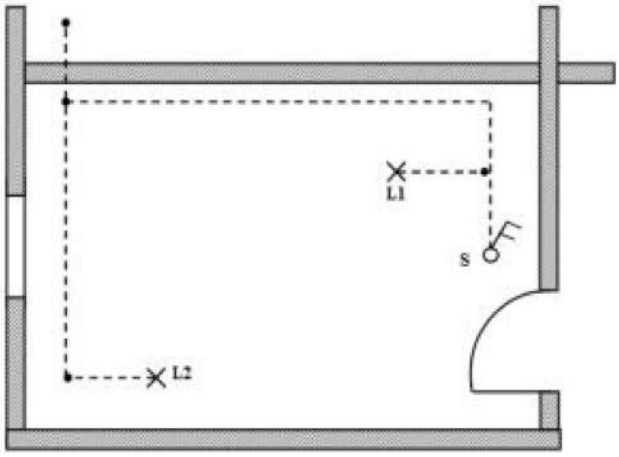


Figure 3.7: Architectural Layout

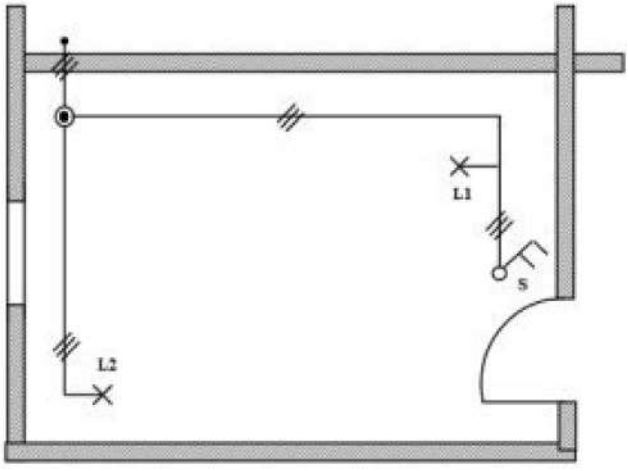


Figure 3.8: Single-Line Diagram

3.4 Two-Way (Staircase) Lighting Circuit

This circuit enables the control of one or more luminaires from two different locations using two specially designed "two-way" or "intermediate" switches (K1, K2).

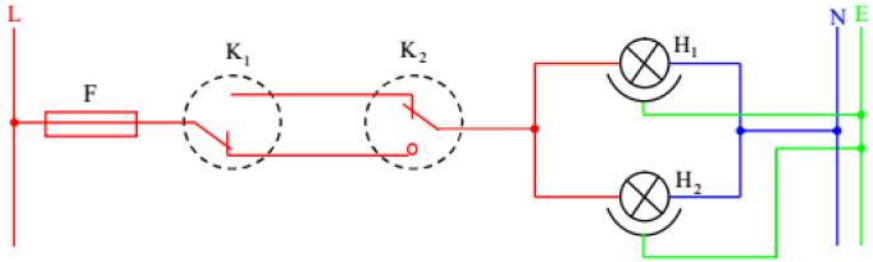


Figure 3.9: Schematic Diagram - Two-Way Switching

Technical Analysis:

- **Switch Mechanism:** Each two-way switch (K1, K2) has three terminals: a Common (C) and two Travelers (L1, L2). The internal contact connects the common terminal to one of the two travelers at any time.
- **Circuit Wiring:**
  1. The line (L) is connected to the Common (C) of the first switch (K1).
  2. The two Traveler terminals (L1, L2) of K1 are connected to the corresponding Traveler terminals of the second switch (K2) via "traveler wires."
  3. The Common (C) of the second switch (K2) is connected to the lamp (H).
  4. The lamp's other terminal is connected to Neutral (N).
- **Operation:** The state of the circuit (open/closed) depends on the relative positions of the two switches. If both commons are connected to the same traveler line (e.g., both to L1), the circuit is complete. If they are connected to opposite traveler lines (one to L1, the other to L2), the circuit is open. Toggling either switch changes the conduction path and thus the state of the light.

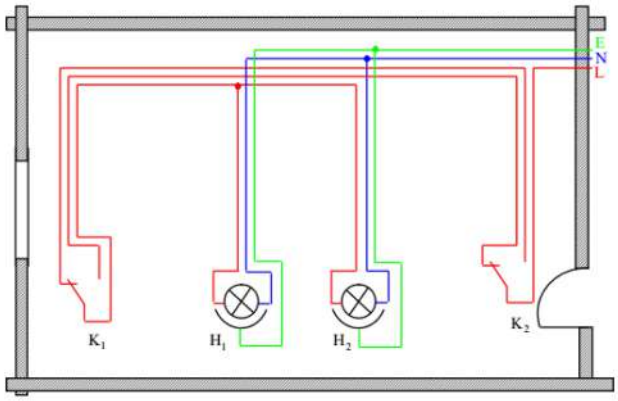


Figure 3.10: Multi-Line Wiring Diagram

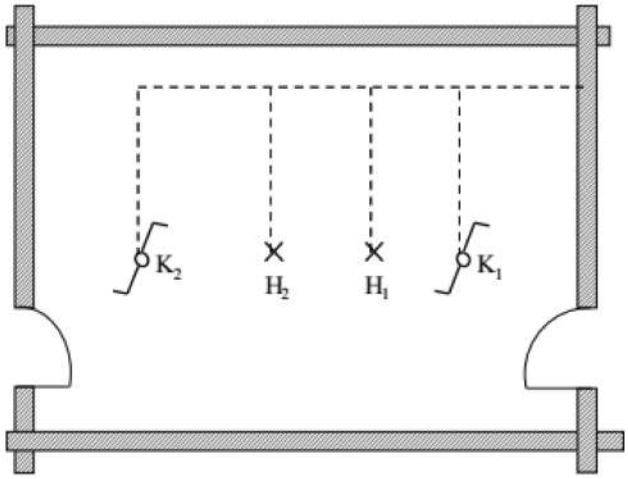


Figure 3.11: Architectural Layout

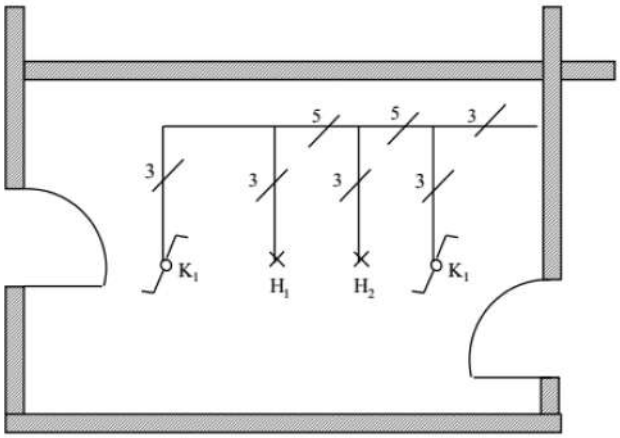


Figure 3.12: Single-Line Diagram

3.5 Impulse Relay Lighting Circuit

When control of a lighting circuit is required from more than two locations, traditional cabling using two-way (SPDT) and intermediate (DPDT crossover) switches becomes complex and costly due to the high number of conductors required. A more efficient and flexible solution for multi-point control is the use of an **impulse relay** (also known as a *bistable* or *latching relay*). This method separates the control circuit from the power circuit, enabling operation of multiple loads from multiple points.

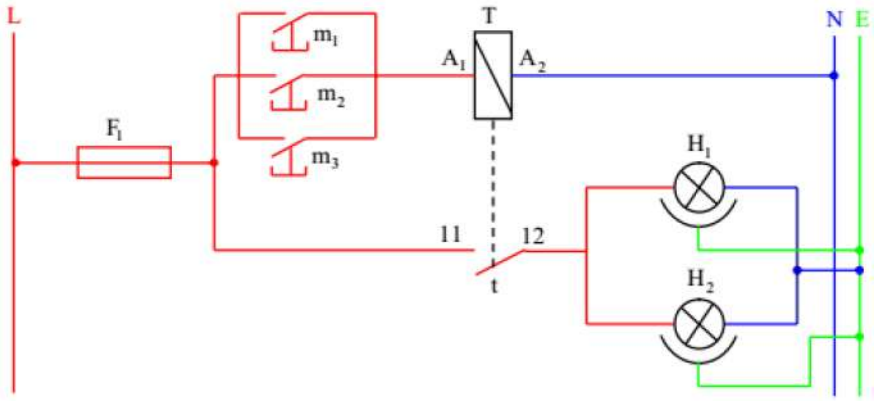


Figure 3.13: Schematic Diagram - Relay Control Circuit

Technical Analysis:

- **Components:** Power Supply, Stop/ Start Pushbuttons (m_1,m_2,m_3, NO), Relay Coil (T), Relay's Internal Contact (t, NO for latching).
- **Operation:**
  1. **Start:** Pressing pushbutton (m_1, m_2 or m_3) energizes coil T, its Internal contact t closes. This creates a parallel path around pushbutton, maintaining power to the coil after pushbutton is released. The main contact t acts as the switch in the line supplying the lamp. The state of the lamp mirrors the state of the relay coil.
  2. **Stop:** Pressing Pushbuttons (m_1, m_2, m_3, NO) again opens the circuit, de-energizing T. Contact t reopens, and the circuit resets.

3.6 Timer-Delay Relay Lighting Circuit

Timers are used to automatically de-energize a lighting circuit after a preset time delay, typically initiated by a momentary pushbutton.

When dealing with physical timer relays, we find 3-wire and 4-wire configurations for wiring and control logic. Here is a breakdown of the two types, often applied within timer-delay relay lighting circuits:

3.6.1 Principle of a 4-Wire Timer

A 4-Wire Timer has separate, dedicated terminals for its power supply and its trigger signal. This allows for independent operation.

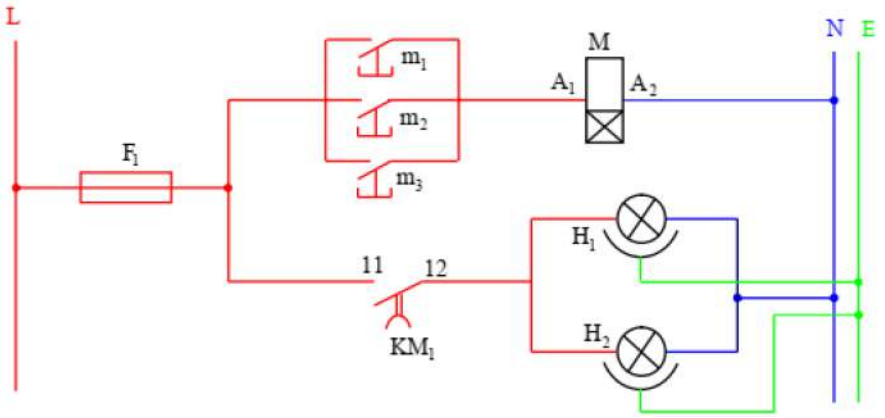


Figure 3.14: Schematic Diagram - 4-Wire Timer Circuit

Technical Analysis:

- **Components:** Power Supply (Line L, Neutral N, Earth E), Fuse (F_1), Momentary Start Pushbuttons (m_1,m_2,m_3, NO), Timer Relay Module (M) with its control coil terminals (A_1, A_2) and its load contact (KM_1) with terminals (11-12), Lamps (H_1, H_2).
- **Operation:**
  1. **Start:** Pressing pushbutton (m_1, m_2 or m_3) energizes coil M, its internal contact KM_1 closes. This creates a parallel path around pushbutton, maintaining power to the coil after pushbutton is released. The main contact KM_1 acts as the switch in the line supplying the lamp.
  2. **Stop:** The light switches on and remains on for a preset duration. At the end of the timing period, the internal relay opens, cutting power to the lamp. If a push button is reactivated before the end of the time delay, the timing cycle restarts from zero.

3.6.2 Principle of a 3-Wire Timer

A 3-Wire Timer uses a shared path for power and the trigger signal. Its operation is dependent on the state of the control switch KM_1.

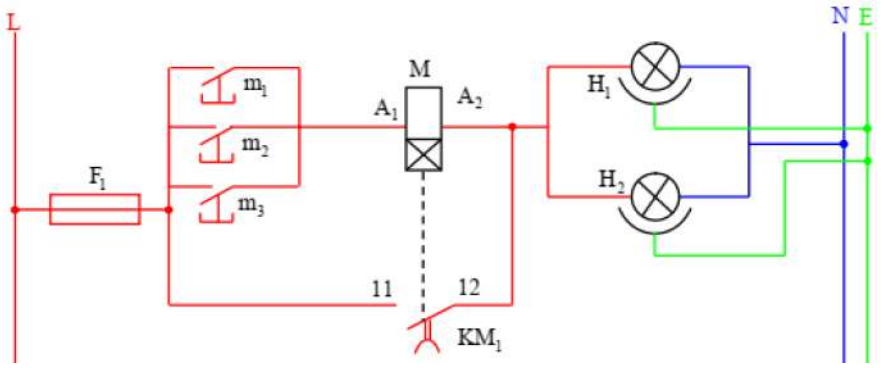


Figure 3.15: Schematic Diagram - 3-Wire Timer Circuit

The timer M is wired **in series with a normally open (NO) internal contact of the contactor** KM_1. This configures the timer to function only when KM_1 is already activated. This is characteristic of applications such as a **delay-after-energization** or a **delay-release** function, where the timing sequence is directly tied to the state of the main load.

Operation:

1. **Start:** Pressing the pushbutton applies the full line voltage (L) directly to the timer's command terminal. This voltage impulse triggers the timer's logic to start a cycle, closing its internal switch between the command terminal and the internal circuit. The lamp is now powered via the closed internal switch.

2. **Stop:** The timer's internal switch remains closed for the preset time before opening. Pressing a button during the timing cycle often has no effect (the cycle continues unchanged), unless specified as a "reset" type timer.

3.7 Normative Considerations (NF C 15-100)

- **Circuit Separation:** A dwelling with at least two main rooms must have a minimum of two separate lighting circuits.

- **Circuit Loading:** A single lighting circuit (protected by a 16A circuit breaker, with 1.5 mm^2 conductors) is limited to supplying a maximum of 8 lighting points or outlets.

- **Protection:** All final circuits, including lighting, must be protected by a 30mA Residual Current Device (RCD).

- **Switch Placement:** Manual control devices (switches) should be installed near room entrances, on the latch side of the door, at a height between 0.90m and 1.30m above finished floor level.

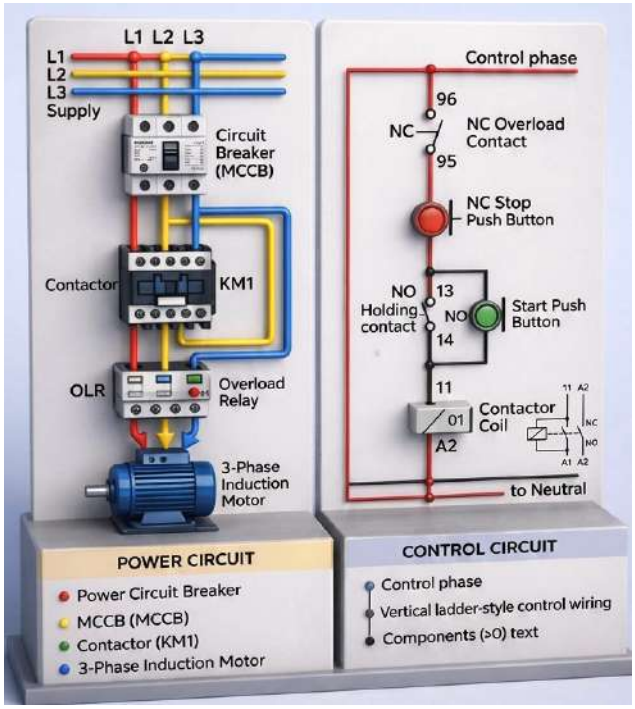
3.8 Conclusion

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Chapter IV

Three Control Modes of an Electric Motor

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Chapter 4

Three Control Modes of an Electric Motor

4.1 Introduction

The three-phase induction motor is the most widely employed prime mover in industrial applications. However, the induction motor draws a starting current typically 5 to 8 times its rated full-load current. The starting problem therefore requires a careful compromise between limiting electrical stress on the power system and providing sufficient mechanical torque for acceleration.

In general, regardless of the type of motor, the different starting procedures aim to **reduce the starting current intensity** [35]. This chapter examines three fundamental control modes for starting induction motors: direct-on-line starting with a single direction of rotation, direct-on-line starting with two directions of rotation, and star-delta starting.

4.2 Direct-On-Line Starting with a Single Direction of Rotation

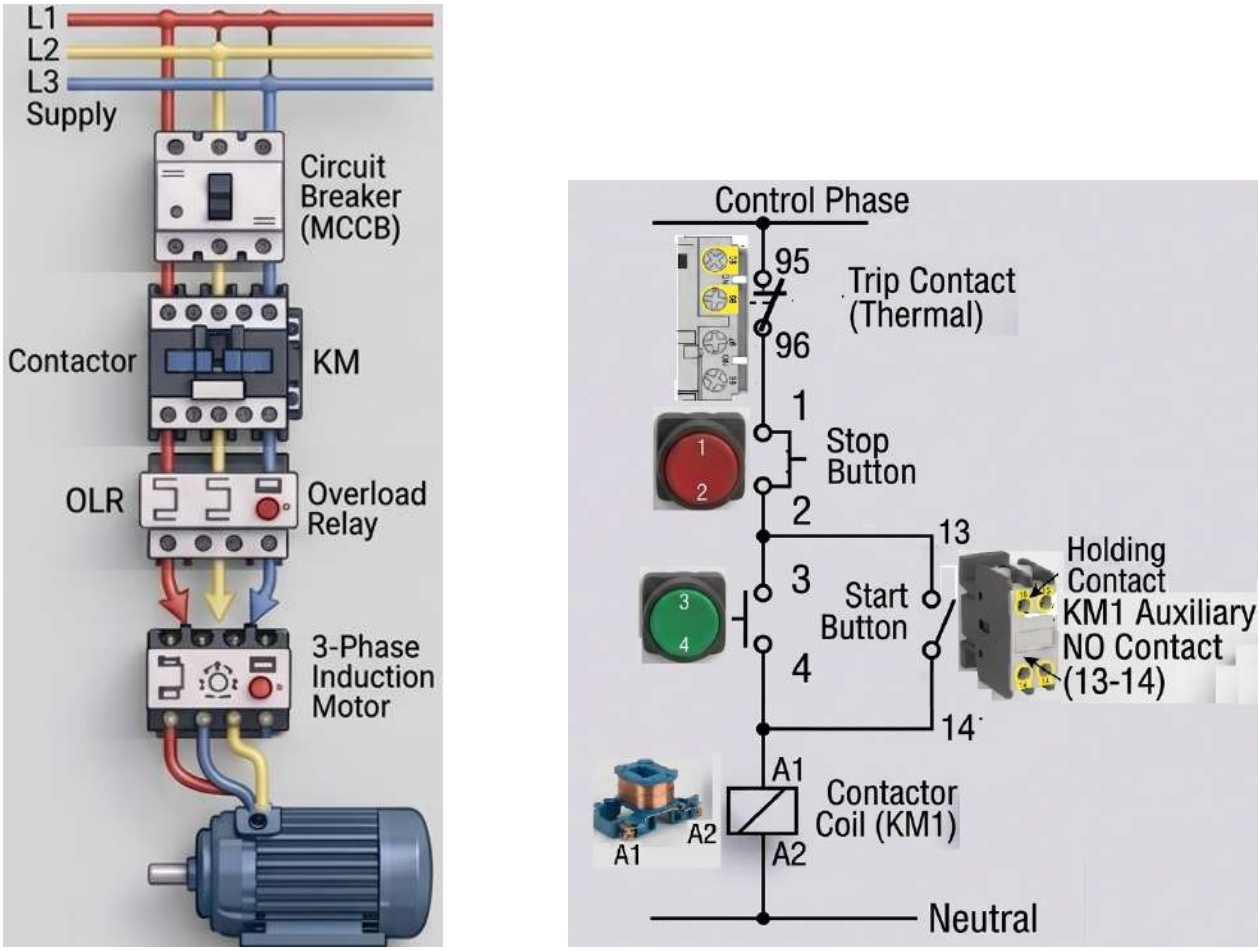
4.2.1 Principle

In this procedure, the stator of the motor is connected directly to the three-phase power supply network. The start is performed in a single step without any intermediate voltage reduction [36, 27].

4.2.2 Technical Characteristics

- Only three-phase induction motors with a squirrel-cage (short-circuited) rotor can be started directly [37].
- At motor start, the current peak is on the order of **4 to 8 times the rated current** [6, 14].
- The starting torque is high, approximately **1.5 times the rated torque** [27, 38].

4.2.3 Semi-Automatic Direct-On-Line Starting



(a) Power Circuit

(b) Control Circuit

Figure 4.1: Direct-On-Line (DOL) Starter Wiring Diagrams - Single Direction

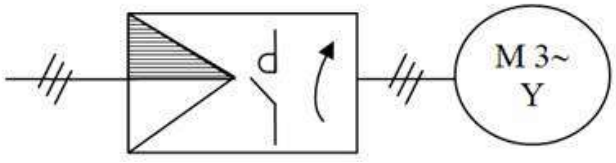


Figure 4.2: Functional Diagram for Semi-Automatic DOL Start, One Direction

4.2.4 Power and Control Circuits

We wish to start a three-phase induction motor in one direction of rotation via a push button **S2** and stop it by pressing a push button **S1** [3, 14].



(a) Power Circuit

(b) Control Circuit

Figure 4.3: Circuits for Semi-Automatic DOL Start - Single Direction

Power Circuit Components

- **L1, L2, L3:** Three-phase supply.
- **Q1:** Fuse-disconnector.
- **KM1:** Main contactor.
- **F1:** Thermal overload relay [15].
- **M:** Three-phase induction motor.

Control Circuit Components

- **F1:** Auxiliary contact of the thermal relay (NC, opens on overload).
- **S1:** Stop pushbutton (NC - Red).
- **S2:** Start pushbutton (NO - Green).
- **KM1:** Coil of the contactor.
- **$KM1_{13\text{-}14}$:** Auxiliary contact of the contactor (NO, for self-latching).

4.2.5 Operation

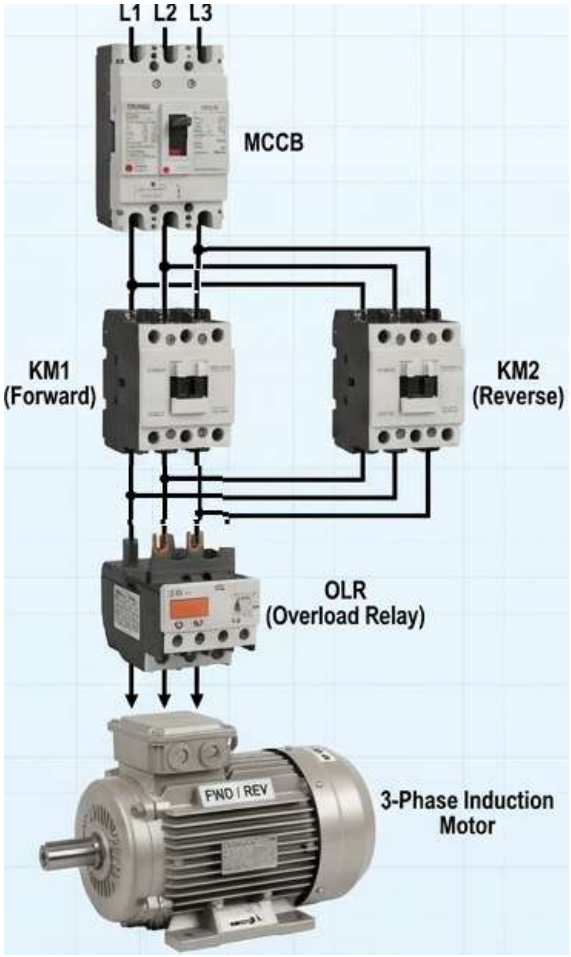
When the start pushbutton S2 is pressed, contactor coil KM1 is energized. The main power contacts of KM1 close, connecting the motor to the supply. Simultaneously, the auxiliary contact $KM1_{13\text{-}14}$ closes, providing a parallel path around S2. This **self-latching** or **sealing** function maintains the coil energized after S2 is released. Pressing the stop pushbutton S1 or the opening of the thermal overload contact F1 interrupts the control circuit, de-energizing KM1 and stopping the motor.

4.3 Direct-On-Line Starting with Two Directions of Rotation

4.3.1 Principle

The objective is to start a three-phase induction motor in two directions of rotation. Reversal of rotation is achieved by interchanging any two of the three supply phases to the motor stator.

4.3.2 Semi-Automatic Starting with Two Directions



(a) Power Circuit Layout

Figure 4.4: Direct-On-Line (DOL) Starter Wiring Diagrams - Two Directions of Rotation

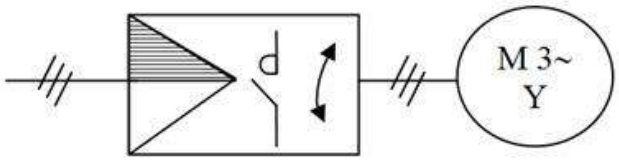
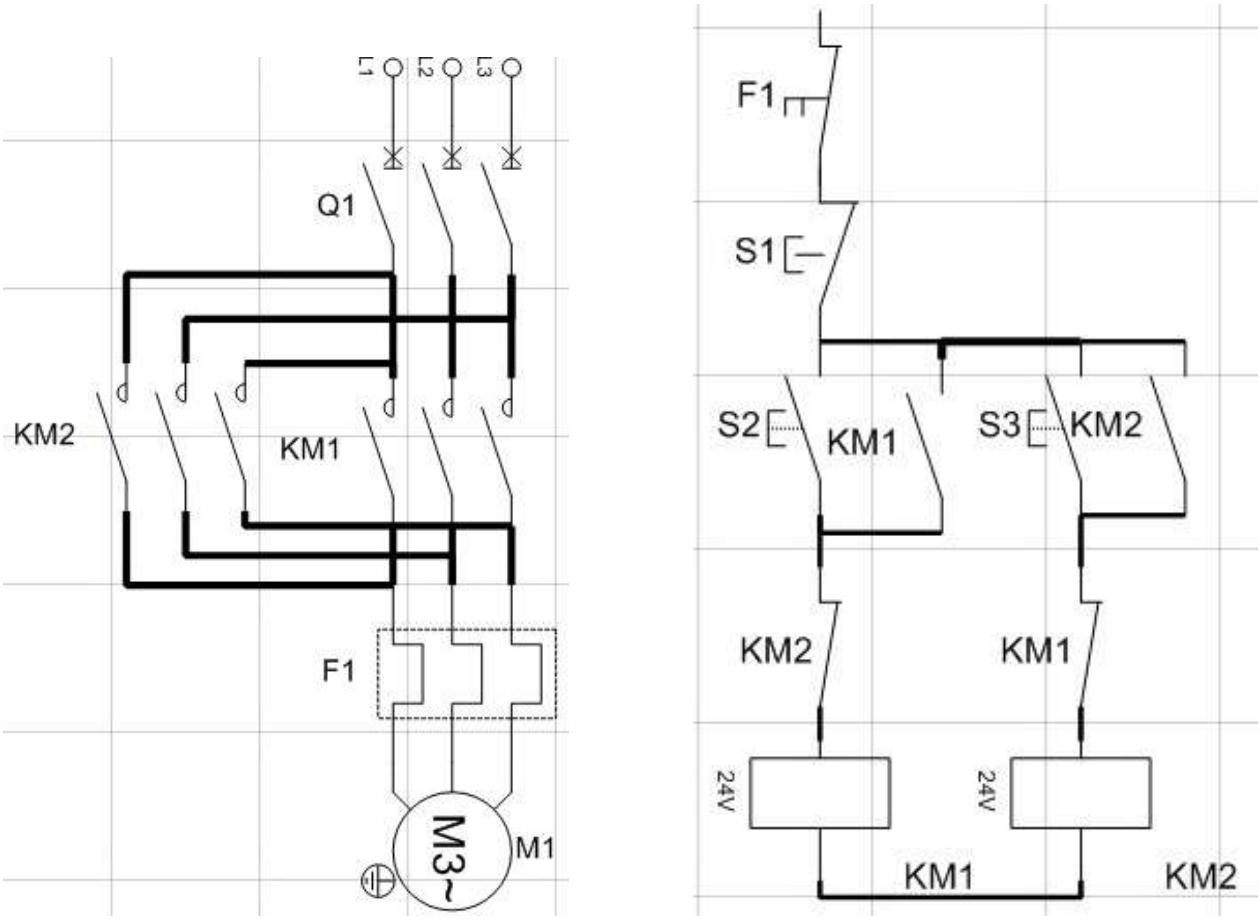


Figure 4.5: Functional Diagram - Two Directions of Rotation

4.3.3 Power and Control Circuits

Direction 1 is activated by pushbutton S2, and direction 2 is activated by pushbutton S3. The motor is stopped by pressing pushbutton S1 [14, 35].



(a) Power Circuit (b) Control Circuit

Figure 4.6: Circuits for Semi-Automatic DOL Start, Two Directions of Rotation

Power Circuit Components

- **Q1:** Fuse-disconnector.
- **KM1:** Contactor for rotation direction 1.
- **KM2:** Contactor for rotation direction 2 (swaps phases L1 and L3).
- **F1:** Thermal overload relay [15].
- **M:** Three-phase induction motor.

Control Circuit Description

- **F1:** Auxiliary contact of thermal relay (NC).
- **S1:** Stop pushbutton (NC).
- **S2:** Start pushbutton for direction 1 (NO).
- **S3:** Start pushbutton for direction 2 (NO).

- **KM1, KM2:** Contactor coils.
- **$KM1_{13\text{-}14}$, $KM2_{13\text{-}14}$:** Self-latching auxiliary contacts (NO).
- **$KM1_{21\text{-}22}$, $KM2_{21\text{-}22}$:** Electrical interlock contacts (NC) to prevent simultaneous operation.

4.3.4 Operation

Pressing S2 energizes KM1, which closes its main contacts to provide phase sequence L1-L2-L3 to the motor. The auxiliary contact $KM1_{13\text{-}14}$ seals the circuit, while the NC contact $KM1_{21\text{-}22}$ opens to prevent KM2 from being energized. Pressing S3 energizes KM2, which swaps two phases (typically L1 and L3), reversing the phase sequence to L3-L2-L1 and thus reversing motor rotation. Electrical and mechanical interlocks are essential to prevent simultaneous closure of KM1 and KM2, which would cause a phase-to-phase short circuit.

4.3.5 Starting with Limit Switches

The objective is to start a three-phase induction motor in two directions of rotation, with each direction stopped automatically by a limit switch: S3 for direction 1 and S4 for direction 2 [3].

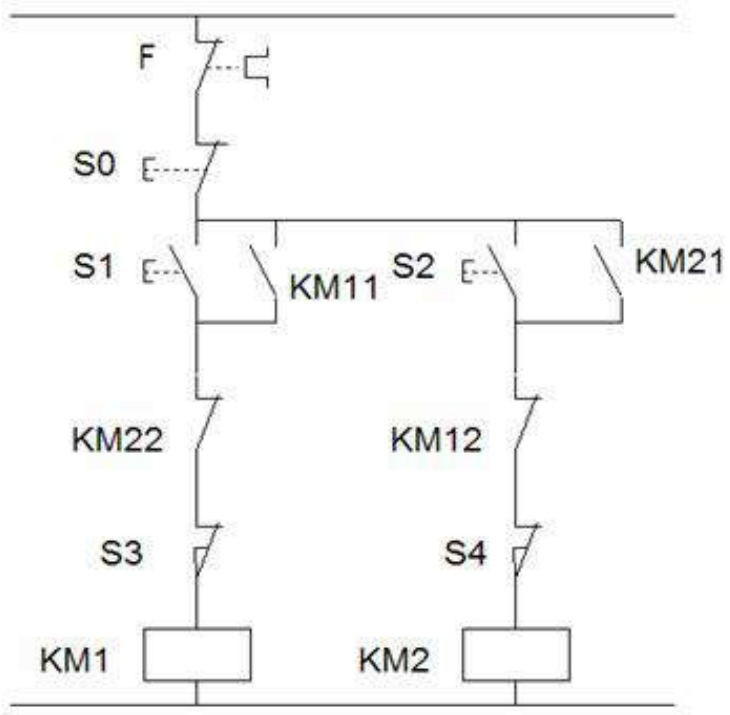


Figure 4.7: Control Circuit - Two Directions with Limit Switches

Operation:

- **S3 (limit switch for direction 1)**: NC contact opens to stop KM1 when the end position is reached.

- **S4 (limit switch for direction 2)**: NC contact opens to stop KM2 when the end position is reached.

4.3.6 Starting with Limit Switches and Automatic Reversal

When one of the two limit switches is activated, the direction of rotation is automatically reversed. The limit switches have two contacts: one Normally Open (NO) at rest and one Normally Closed (NC) at rest [14].

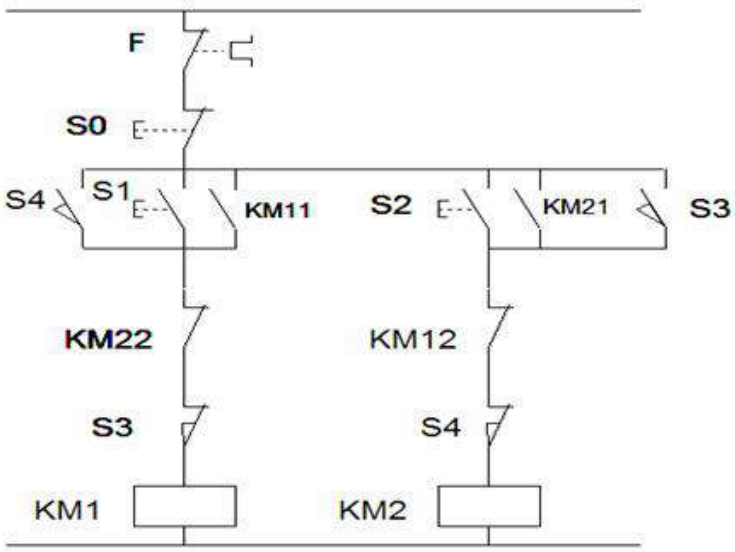


Figure 4.8: Control Circuit with Automatic Reversal

Operation:

- **S3 (limit switch for direction 1)**: NC contact stops KM1, NO contact starts KM2.
- **S4 (limit switch for direction 2)**: NC contact stops KM2, NO contact starts KM1.
- When S3 is activated: KM1 de-energizes (via NC) and KM2 energizes (via NO) after a brief dead time.
- When S4 is activated: KM2 de-energizes (via NC) and KM1 energizes (via NO).

4.4 Star-Delta Starting

4.4.1 Principle

Star-Delta (Y-Δ) starting is an electromechanical method used to reduce the starting current of three-phase induction motors. It is particularly useful for motors that are designed to run in delta connection but require reduced current during start-up [15, 14].

This starting method involves changing the stator winding connections to limit inrush current. Starting occurs in two steps:

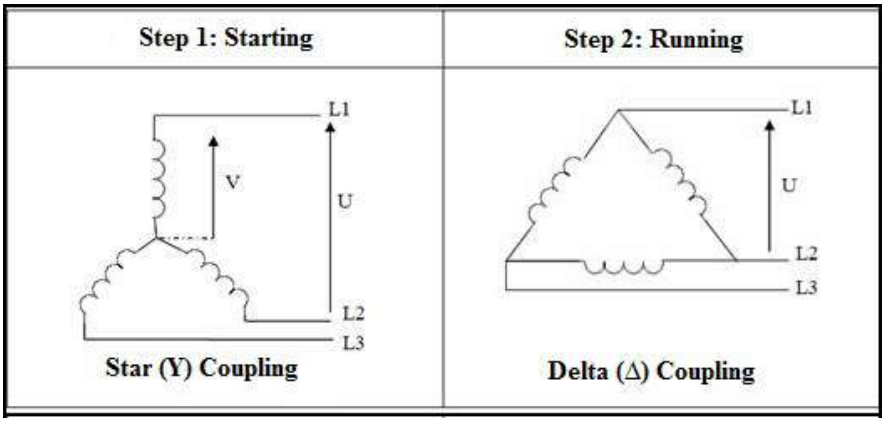


Figure 4.9: Star-Delta Starting Principle [14]

4.4.2 Step 1: Star (Y) Connection - Starting

During the starting period, the motor windings are connected in **star (Y) configuration**. Each winding receives the **phase voltage** $V = \frac{U}{\sqrt{3}}$, where U is the line-to-line voltage of the supply. This reduces the voltage across each winding to approximately **58%** of the line voltage.

Consequently, the **starting current** is reduced to about **one-third** of the direct-on-line starting current [6]:

$$I_{Y(\text{start})} \approx \frac{1}{3} I_{\Delta(\text{start})}$$

The **starting torque** is also reduced to about **one-third** of the full voltage torque [27]:

$$T_{Y(\text{start})} \approx \frac{1}{3} T_{\Delta(\text{start})}$$

This step typically lasts 5-30 seconds until the motor reaches approximately 75-85% of its rated speed [14].

4.4.3 Step 2: Delta (Δ) Connection - Running

Once the motor has accelerated to near its rated speed, it is switched to **delta (Δ) connection**. Now each winding receives the full **line voltage** U. The motor operates at its rated voltage and can deliver its full torque capability:

$$P_{\text{rated}} = \sqrt{3} \cdot U \cdot I \cdot \cos\phi$$

The transition must be quick (typically less than 100 ms) to prevent current surges and ensure continuous operation.

4.4.4 Mathematical Relationships

$$\begin{aligned} \text{Star connection:} \quad & V_{\text{phase}} = \frac{U_{\text{line}}}{\sqrt{3}}, \quad I_{\text{line}} = I_{\text{phase}} \\ \text{Delta connection:} \quad & V_{\text{phase}} = U_{\text{line}}, \quad I_{\text{line}} = \sqrt{3} \cdot I_{\text{phase}} \end{aligned}$$

4.4.5 Important Technical Considerations

1. The motor must be designed for **delta connection at the supply voltage**. For example, a 400V motor for delta connection would have windings rated for 400V. In star connection, these same windings receive only 230V [37].

2. The switching time must be properly adjusted based on motor inertia and load characteristics.

3. If the motor doesn't accelerate sufficiently in star mode before switching to delta, excessive current may flow.

4. This method cannot be used for speed control—it is strictly a starting method [36].

4.4.6 Advantages and Disadvantages

Advantages:

- **Reduced starting current** (approximately 1/3 of DOL starting)
- Simple and economical compared to electronic soft starters
- No voltage drops in the supply network during start-up
- Reduced mechanical stress on driven equipment

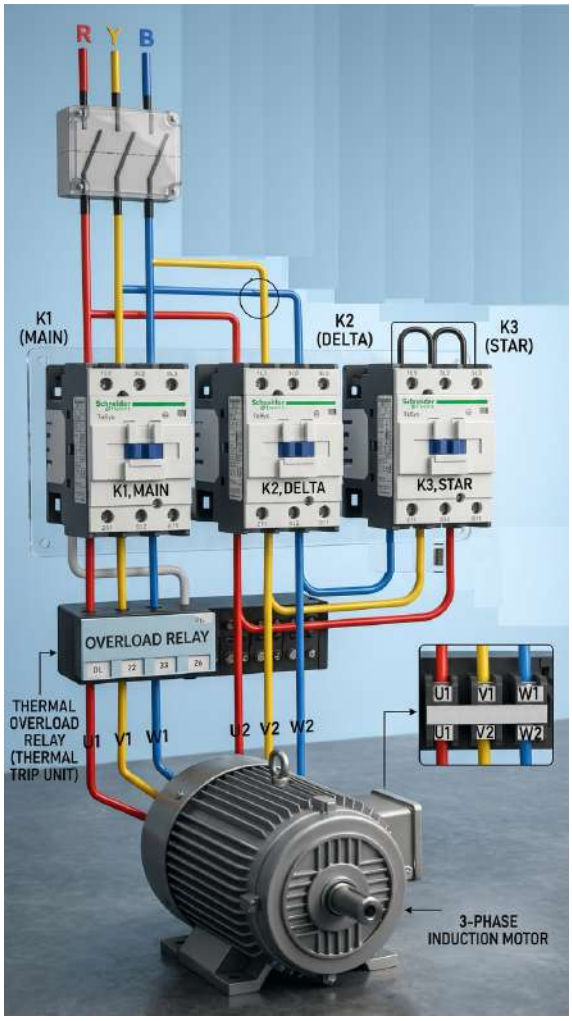
Disadvantages:

- **Reduced starting torque** (only 1/3 of full voltage torque)
- Not suitable for applications requiring high starting torque
- Current surge during switching from star to delta
- Requires six motor terminals (dual voltage motors)

4.4.7 Typical Applications

- Centrifugal pumps and fans
- Compressors with low starting torque requirements
- Conveyor systems (light load start)
- Machine tools
- Motors rated from 4 kW to 25 kW (though can be used up to several hundred kW)

4.4.8 Semi-Automatic Star-Delta Starting



(a) Power Circuit Layout

Figure 4.10: Star-Delta Starter Wiring Diagrams

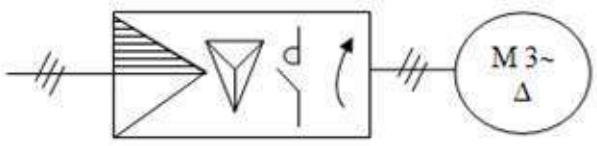
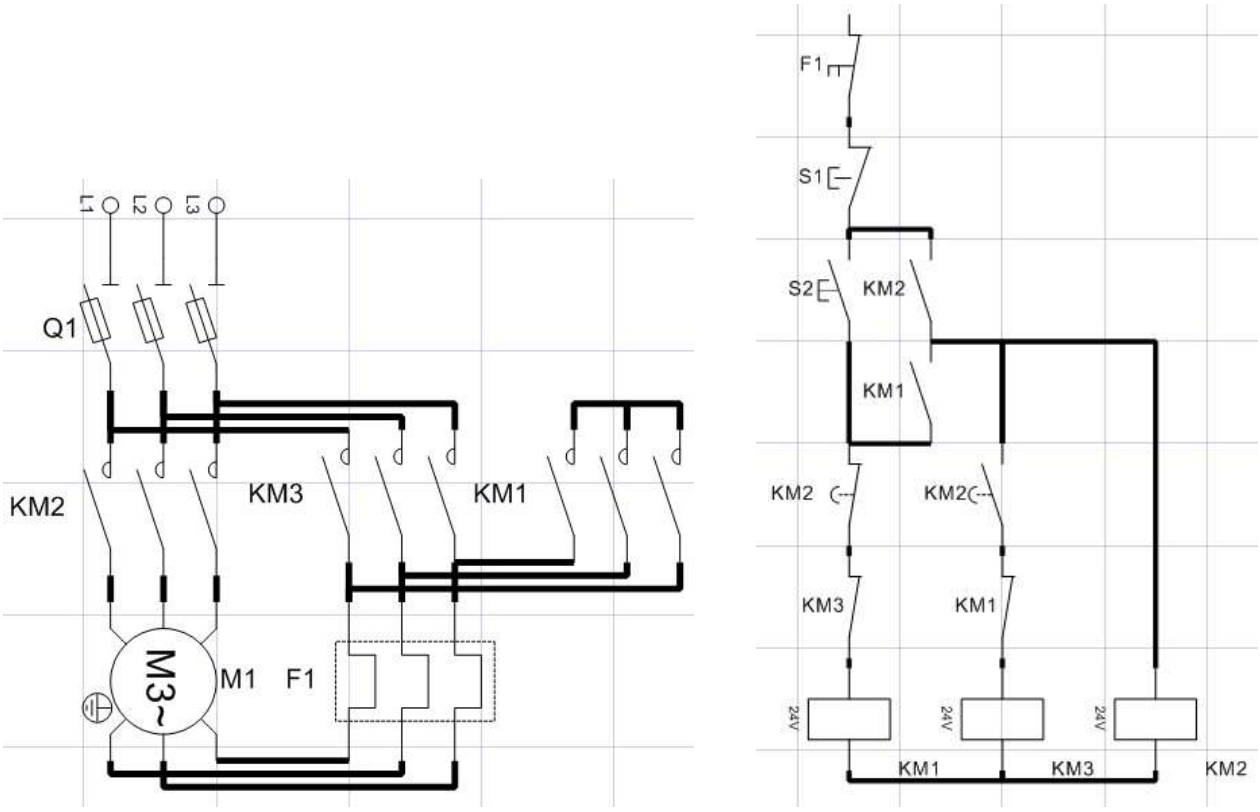


Figure 4.11: Functional Diagram - Semi-Automatic Star-Delta Starting

4.4.9 Power and Control Circuits

Start a three-phase induction motor in star-delta configuration in one direction using push-button **S2** and stop it using pushbutton **S1** [14, 35].



(a) Power Circuit (b) Control Circuit

Figure 4.12: Circuits for Semi-Automatic Star-Delta Start, Single Direction

Components of Power Circuit:

- **L1, L2, L3:** Three-phase supply
- **Q1, Q2, Q3, Q4:** Fuse-disconnectors / Circuit breakers
- **KM1:** Star-connection contactor
- **KM2:** Line contactor (main)
- **KM3:** Delta-connection contactor
- **F1:** Thermal overload relay [15]
- **M3:** Three-phase induction motor

Components of Control Circuit:

- **F1:** Auxiliary contact of thermal relay (NC - 95-96)
- **S1:** Stop pushbutton (NC - Red)
- **S2:** Start pushbutton (NO - Green)
- **KM1:** Coil of star-connection contactor

- **KM2:** Coil of line contactor
- **KM3:** Coil of delta-connection contactor
- **KM2C:** Time-delayed contact of KM2 (or auxiliary contact)
- **24V:** Control circuit voltage supply

Logical Equations

Based on the control circuit shown in the figure, the logical equations are:

$$KM2 = S2 \cdot \overline{S1} \cdot \overline{F1} + KM2 \cdot \overline{S1} \cdot \overline{F1}$$
$$KM1 = KM2 \cdot \overline{KM3}$$
$$KM3 = KM2_C \cdot \overline{KM1}$$

Where:

- $KM2_C$ is the time-delayed contact of line contactor KM2
- $\overline{X}$ represents the normally closed (NC) contact of component X
- The interlock contacts $\overline{KM1}$ and $\overline{KM3}$ prevent simultaneous energization

Contact Designations Reference

Table 4.1: Contactor Designations in Star-Delta Circuit

Contactor	**Function**	**Connects**
KM2	Line Contactor (Main)	Supply to motor terminals U1, V1, W1
KM1	Star Contactor	Motor terminals U2, V2, W2 together (Star point)
KM3	Delta Contactor	Supply to motor terminals W2, U2, V2 (Phase shift)

Timing Diagram

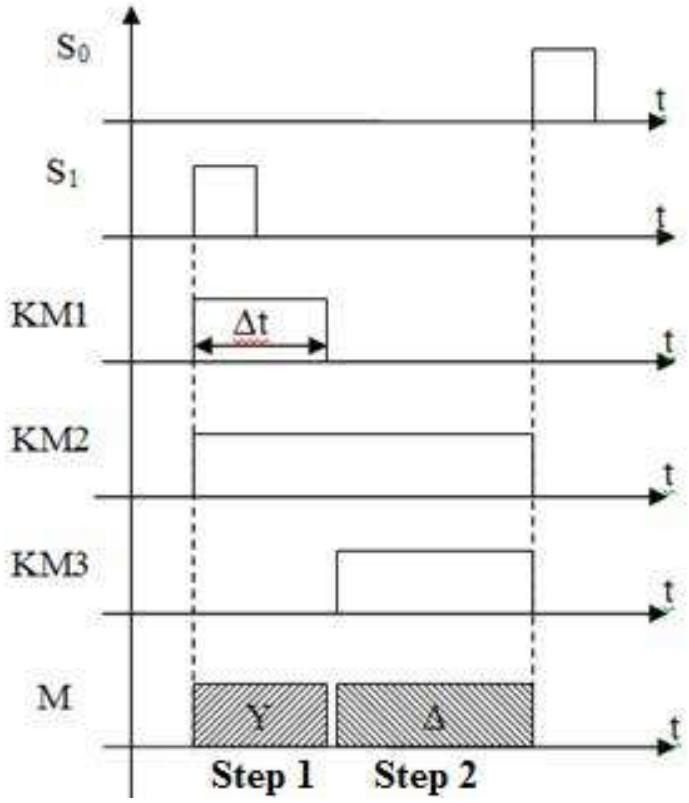


Figure 4.13: Timing Diagram of Star-Delta Starting [14]

Sequence of Operations:

1. **Initial State:** Start button S2 is open, stop button S1 is closed. All contactors KM1, KM2, KM3 are de-energized. Motor is stopped.

2. **Start Command:** S2 is pressed. Line contactor KM2 and star contactor KM1 energize simultaneously. Motor starts in **star (Y) configuration** with reduced voltage. Phase voltage: $V = U/\sqrt{3}$.

3. **Star Running Phase:** Motor accelerates in star configuration. Timer (KM2C) begins counting the preset delay Δt (typically 5–30 seconds depending on motor size and load).

4. **Transition Period:** Timer delay Δt expires. The KM2C contact changes state. Star contactor KM1 de-energizes. A brief dead time (typically 50–100 ms) ensures KM1 is fully open. Delta contactor KM3 energizes. Motor reconnects in **delta (Δ) configuration**.

5. **Delta Running Phase:** Motor runs at full voltage in delta connection. Full torque is available for normal operation.

6. **Stop Command:** Stop button S1 is pressed. All contactors KM1, KM2, KM3 de-energize. Motor coasts to stop.

Important Timing Considerations

- **Dead Time:** The brief interval between KM1 de-energizing and KM3 energizing is critical to prevent short circuits. This is typically implemented with electrical or mechanical interlocks [15].
- **Timer Setting (Δt):** Must be adjusted so the motor reaches 75–85% of rated speed before switching [6].
- **Safety Interlocks:** KM1 and KM3 must never be closed simultaneously (would cause a phase-to-phase short circuit). Mechanical interlocks are often used between KM1 and KM3 contactors, along with electrical interlocks using auxiliary contacts.
- **Control Voltage:** The circuit operates on 24V control voltage for safety.

Typical Timer Settings [14]

Motor Power	Typical Δt	Remarks
4–7.5 kW	5–10 seconds	Light loads
7.5–15 kW	10–15 seconds	Medium inertia
15–30 kW	15–25 seconds	High inertia loads
>30 kW	20–40 seconds	Heavy starting loads

Note: Timer setting should be verified by measuring motor current during start-up. The switch to delta should occur when current drops to near rated current.

Typical Timer Settings [14]

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Note: Timer setting should be verified by measuring motor current during start-up. The switch to delta should occur when current drops to near rated current.

4.4.10 Star-Delta Starting with Two Directions of Rotation

The objective is to start a three-phase induction motor in star-delta configuration with the ability to select either direction of rotation.

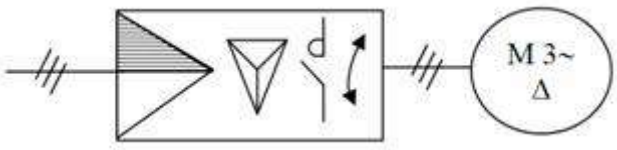
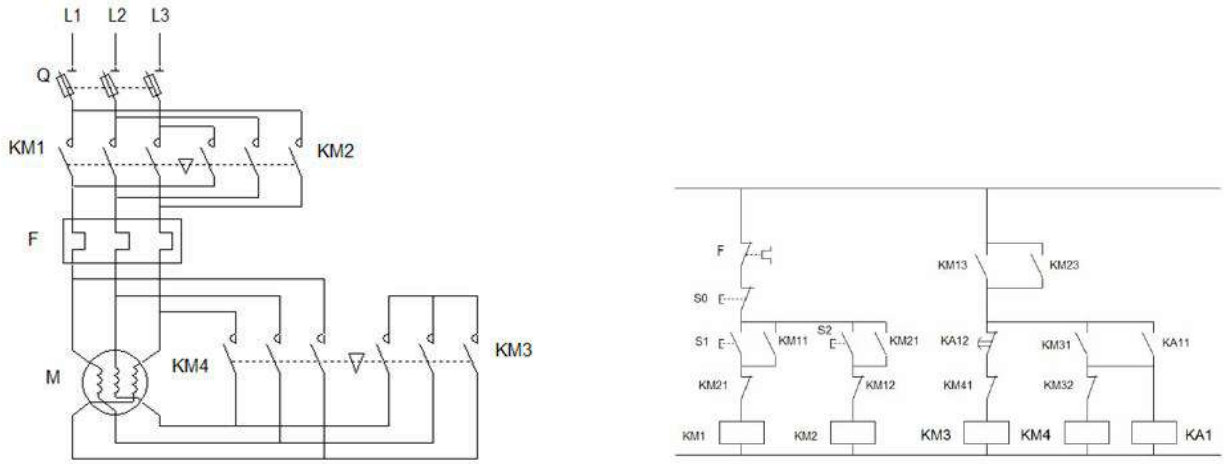


Figure 4.14: Functional Diagram - Star-Delta Two Directions [14]

4.4.11 Power and Control Circuits

Direction 1 (Forward) is activated by pushbutton **S1**, and Direction 2 (Reverse) is activated by pushbutton **S2**. The motor is stopped by pressing pushbutton **S0**. Phase reversal is achieved by interchanging two supply phases (typically L1 and L3) using dedicated direction contactors [14].



(a) Power Circuit

(b) Control Circuit

Figure 4.15: Circuits for Star-Delta Start, Two Directions of Rotation

Components of Power Circuit:

- **Q:** Fuse-disconnector
- **KM1:** Contactor for direction 1
- **KM2:** Contactor for direction 2
- **KM3:** Star-connection contactor
- **KM4:** Delta-connection contactor
- **F:** Thermal overload relay
- **M:** Three-phase induction motor

Logical Equations

$$
\begin{aligned}
KM1 &= S1 \cdot \overline{S0} \cdot \overline{F} \cdot \overline{KM2} + KM1 \cdot \overline{S0} \cdot \overline{F} \cdot \overline{KM2} \\
KM2 &= S2 \cdot \overline{S0} \cdot \overline{F} \cdot \overline{KM1} + KM2 \cdot \overline{S0} \cdot \overline{F} \cdot \overline{KM1} \\
KM3 &= (KM1 + KM2) \cdot \overline{KM4} \\
KM4 &= T \cdot (KM1 + KM2) \cdot \overline{KM3}
\end{aligned}
$$

Where:

- T represents the time delay function
- $\overline{KM1}$ and $\overline{KM2}$ are electrical interlocks preventing simultaneous operation of direction contactors

4.5 Conclusion

This chapter has examined three fundamental control modes for starting three-phase induction motors. Direct-on-line starting with a single direction of rotation is the simplest method but imposes high inrush currents, limiting its use to small motors on robust networks. Direct-on-line starting with two directions of rotation extends this principle with phase reversal contactors and essential electrical/mechanical interlocks to prevent short circuits. Star-delta starting reduces both starting current and torque to approximately one-third of full-voltage values by initially connecting windings in star before switching to delta. Proper timing, dead-time control, and interlocks are essential for safe transition.

The selection of the appropriate starting method depends on motor power rating, supply network capacity, and load torque requirements. Understanding these three control modes provides the foundation for more advanced motor control techniques such as soft starters and variable-frequency drives.

◇ ◇ ◇

Practical Works

Electrical Diagrams and Equipment

◇ ◇ ◇

Echahid Cheikh Larbi Tebessi University — Tebessa

Faculty of Science and Technology

Department of Electrical Engineering

3rd Year Bachelor's Degree — Electrical Engineering

4.6 Introduction

These practical works in **Electrical Schematics and Equipment** are specifically designed for students in the **3rd year of the Bachelor's Degree in Electrical Engineering**. The technical project is carried out in the **Electrotechnical Workshop** of Echahid Cheikh Larbi Tebessi University — Tebessa.

The practical sessions focus on the construction of electrical assemblies for:

- **Domestic installations**: lighting circuits, electrical outlets, control circuits
- **Industrial installations**: motor control, automation systems, equipment protection

4.7 Objectives

The practical works in electrical schematics and equipment enable students to apply the theoretical knowledge acquired during lectures. The targeted competencies are structured around three domains:

4.7.1 Knowledge

In terms of **knowledge**, students will be able to:

- Identify the various symbols of electrical equipment and their functions on an electrical schematic
- Recognize the physical phenomena associated with the operation of electrical components
- Understand the operating principles of protection and control devices
- Interpret standardized electrical diagrams according to IEC standards
- Distinguish between power circuits and control circuits
- Explain the function of each component in an electrical installation

4.7.2 Know-How

In terms of **know-how**, students will understand and implement the following electrical installations: domestic and industrial installations.

4.7.3 Soft Skills

In terms of **soft skills** and professional behavior, students will be capable of:

- Applying acquired theoretical knowledge in practical situations
- Understanding and implementing electrical connections and wiring
- Applying knowledge to develop and manipulate electrical schematics

- Analyzing and testing the proper functionality of an electrical circuit
- Synthesizing knowledge to answer evaluation questions
- Working safely in an electrical workshop environment
- Troubleshooting and diagnosing faults in electrical circuits
- Collaborating effectively within a team during practical sessions
- Documenting experimental work in a clear and organized manner

4.8 Prerequisites

To successfully complete these practical works, students must possess fundamental knowledge in the following areas: Fundamental Electricity, Electrostatics and Magnetostatics.

Students are expected to be up-to-date with the corresponding theoretical coursework.

4.9 Safety Instructions

Working in an electrical workshop requires strict adherence to safety protocols.

4.10 Evaluation Criteria

Student performance is evaluated based on the following criteria:

Criterion	**Weight**
Attendance and Punctuality	10%
Preparation (Pre-lab questions)	10%
Practical Work Execution (Wiring and Testing)	40%
Lab Report	20%
Final Practical Exam	20%
Total Continuous Assessment	**40% of Final Grade**
Final Written Exam	**60% of Final Grade**

Table 4.2: Evaluation Breakdown for Practical Works

PW1: Main Lighting Circuits

Last Name and First Name: .....

Submission Date: .....

4.11 Introduction

This section is dedicated to the study and implementation of various domestic electrical installation setups. This manual presents several practical works structured in the same way.

4.12 Required Work

- Complete the required work clearly and in colored lines, marking all the connections shown in the pictures for each type of lighting.
- Using electrical tools and equipment, complete the electrical circuit appropriate for each type of lighting separately.
- When the electrical circuit is complete, explain the working principle and test it in the presence of the teacher.

4.13 Outlet Circuit

An electrical outlet circuit is a wall-mounted installation capable of supplying power to a variety of electrical devices from a power source. The standard configuration involves:

- **Phase (L)**: Live conductor (typically brown or red)
- **Neutral (N)**: Return conductor (typically blue)
- **Protective Earth (PE)**: Ground conductor (yellow/green)

Outlets are typically connected in **parallel** to ensure that each outlet receives the full supply voltage independently of the others.

4.13.1 Circuit Description

This practical exercise aims to create and implement an electrical schematic for an installation consisting of **four electrical outlets from a single supply source**. A simplified schematic for implementing the outlet wiring is presented in Figure 4.16.

4.13.2 Wiring Layout

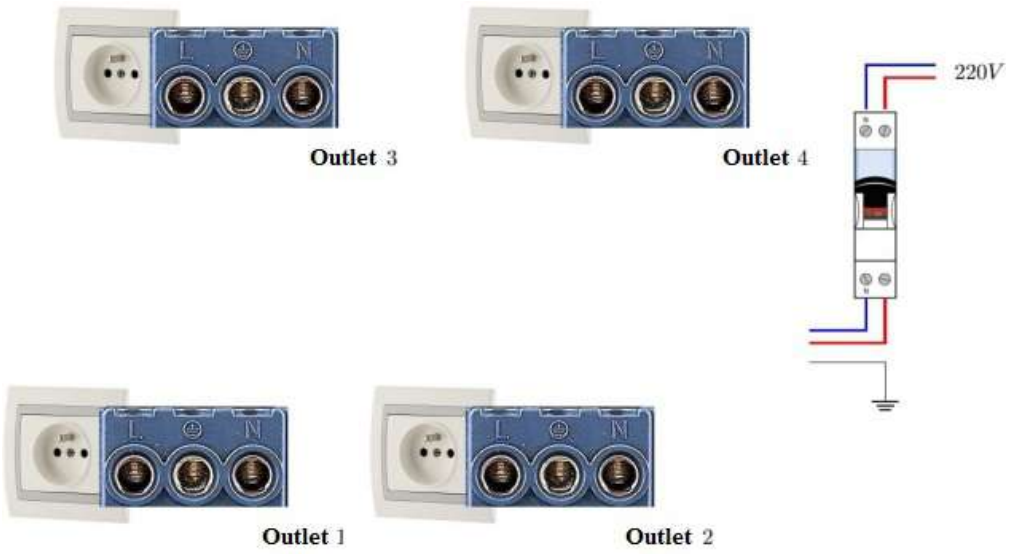


Figure 4.16: Four Outlets from Single Supply

4.13.3 Developed Schematic

Complete the developed schematic of the single-switch lighting circuit.

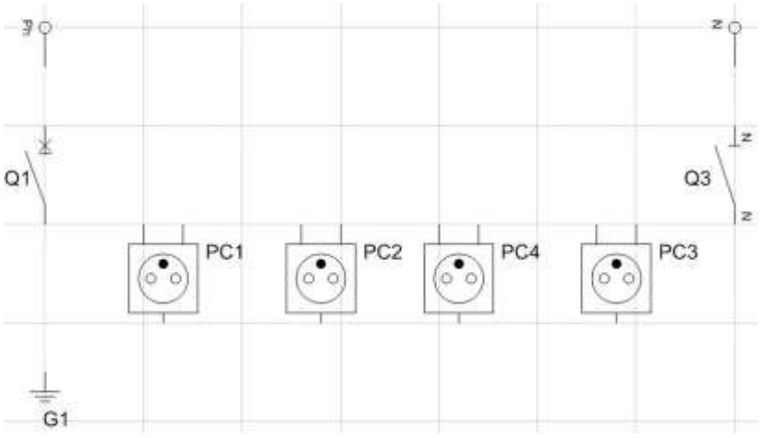


Figure 4.17: Developed Schematic — Four Outlet Circuit

4.14 Single-Switch Lighting Circuit

A single-switch lighting circuit, also known as a one-way or single-pole switch, controls a single light or a group of lights from one location.

4.14.1 Wiring Layout

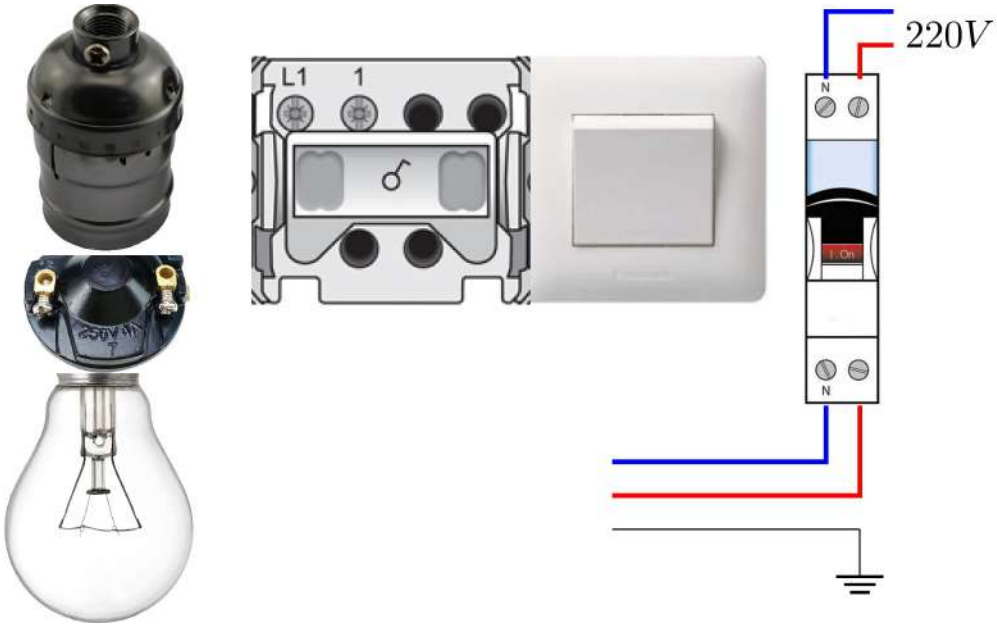


Figure 4.18: Single-Switch Lighting Circuit

4.14.2 Developed Schematic

Complete the developed schematic of the single-switch lighting circuit.

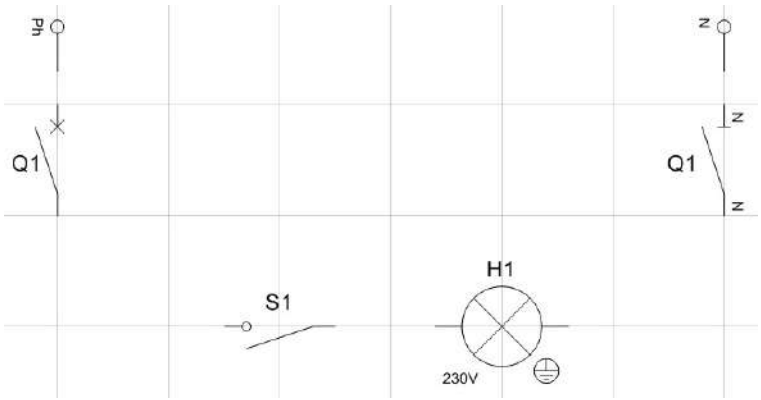


Figure 4.19: Developed schematic of a single-switch lighting circuit

4.14.3 Architectural Schematic

Complete schematic for two lamps controlled from S1.

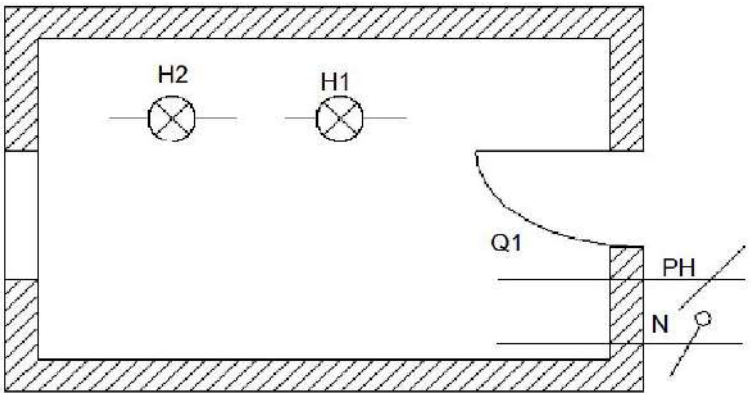


Figure 4.20: Schematic of a single-switch lighting circuit

4.15 Double-Switch Lighting Circuit

This lighting circuit is designed to control two different lights from a single double switch unit.

4.15.1 Wiring Layout



Figure 4.21: Double-Switch Lighting Circuit

4.15.2 Developed Schematic

Complete the developed schematic of the double-switch lighting circuit:

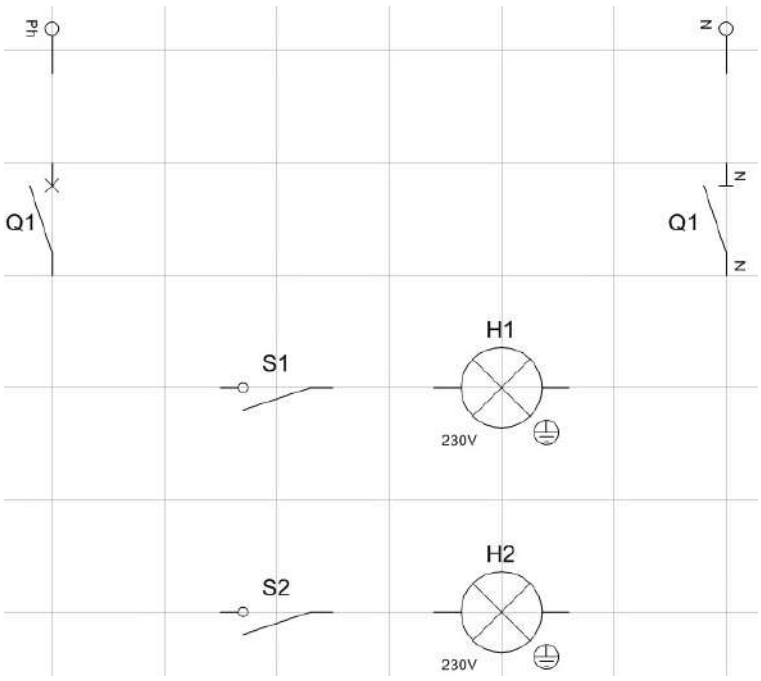


Figure 4.22: Developed schematic of a double-switch lighting circuit

4.15.3 Architectural Schematic

Complete the single-line diagram.

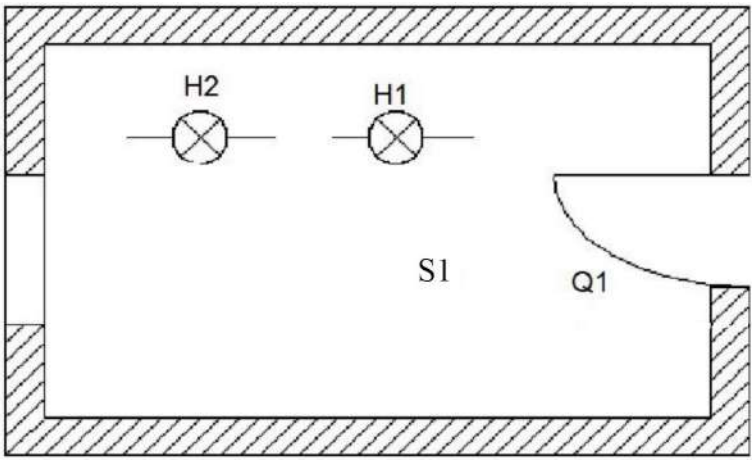


Figure 4.23: Single-line diagram of a double-switch lighting circuit

4.16 Two-Way Switch Lighting Circuit (Va-et-Vient)

A two-way switch lighting circuit allows you to control a single light or group of lights from two separate locations.

4.16.1 Wiring Layout

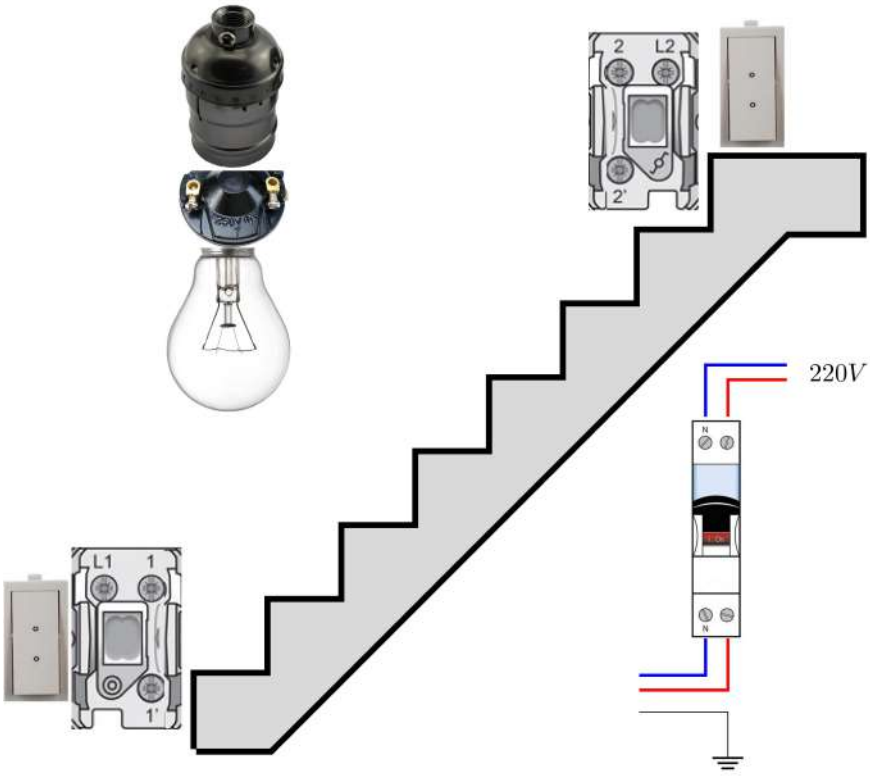


Figure 4.24: Two-way switch circuit

4.16.2 Developed Schematic

Complete the developed schematic in Figure.

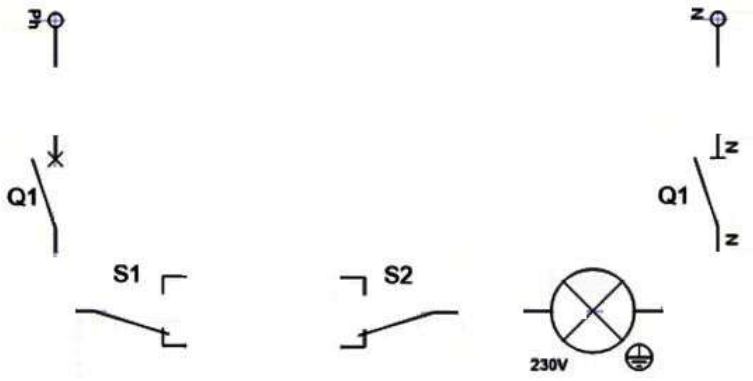


Figure 4.25: Developed schematic of a two-way switch circuit

4.16.3 Architectural Schematic

Deduce the single-line diagram of the two-way switch circuit.

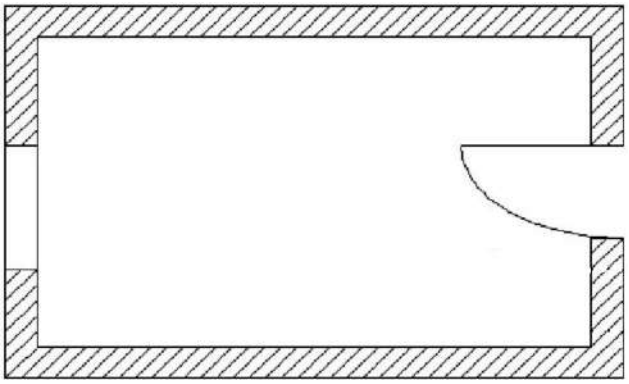


Figure 4.26: Single-line diagram of a two-way switch circuit

4.17 Circuit with an Impulse Relay

This circuit allows a lighting circuit to be controlled from several different locations. A circuit with an impulse relay consists of a contactor with mechanical latching. When a push button is pressed, the coil is energized, the contact closes, and the lamp turns on. When the push button is released, the coil de-energizes but the contact remains closed (lamp stays on). A second press energizes the coil and opens the contact (lamp turns off).

4.17.1 Wiring Layout

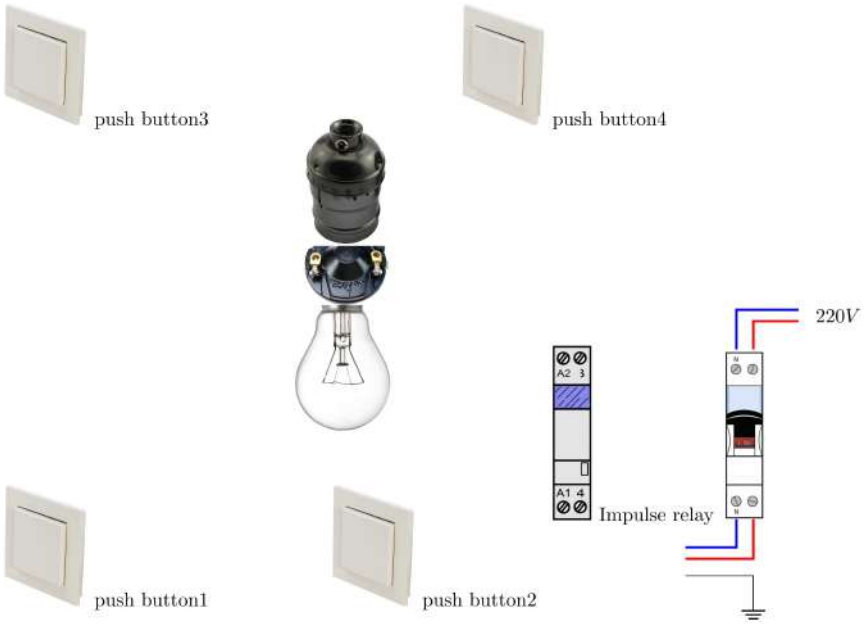


Figure 4.27: Lighting circuit with an impulse relay

4.17.2 Developed Schematic

Complete the developed schematic in Figure 4.27.

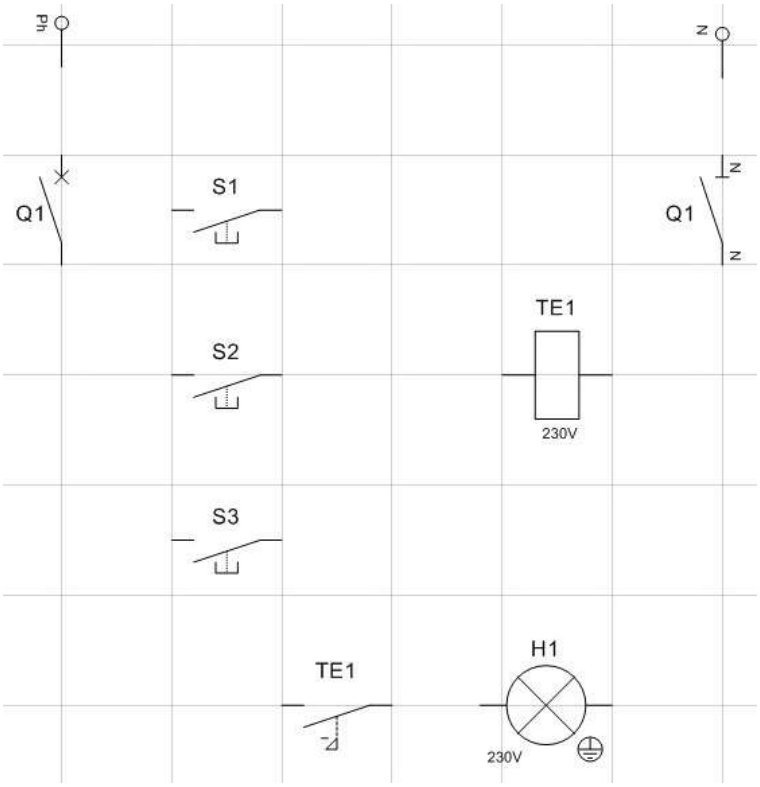


Figure 4.28: Developed schematic of a circuit with an impulse relay

4.18 Circuit with a Timer Relay

A timer switch setup allows the lamp to be switched on for a predetermined amount of time, after which it automatically turns off.

4.18.1 Wiring Layout

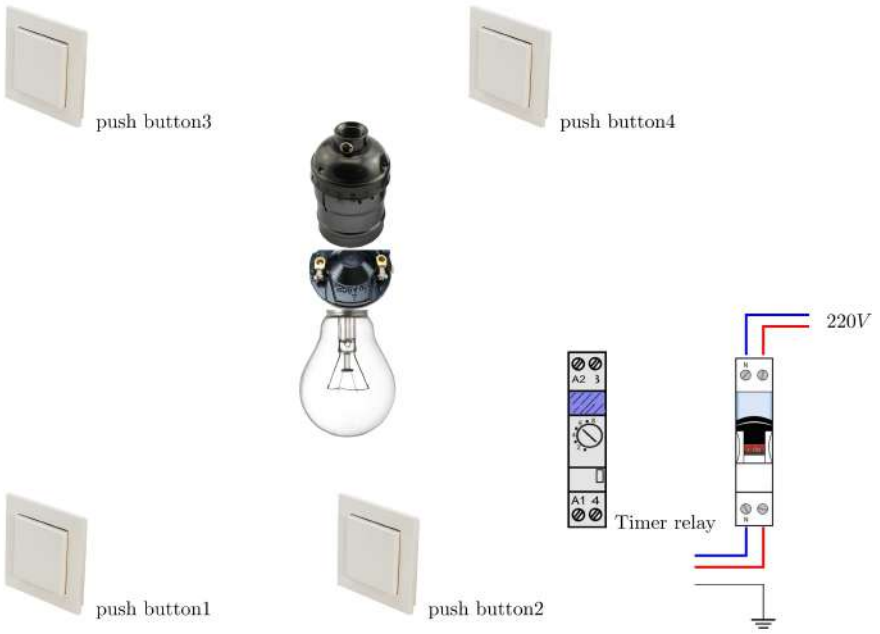


Figure 4.29: Lighting circuit with a timer relay

4.18.2 Developed Schematic

Complete the developed schematic in Figure 4.29.

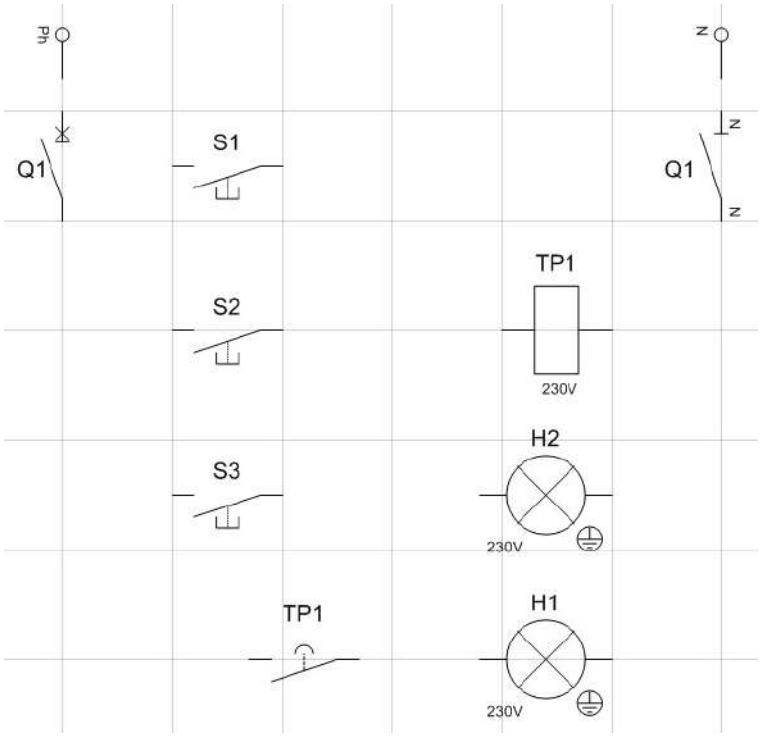


Figure 4.30: Developed schematic of a circuit with a timer relay

Based on the figure below, we want to control a bedroom light with four push buttons and a timer. Complete the wiring in Figure 4.31.

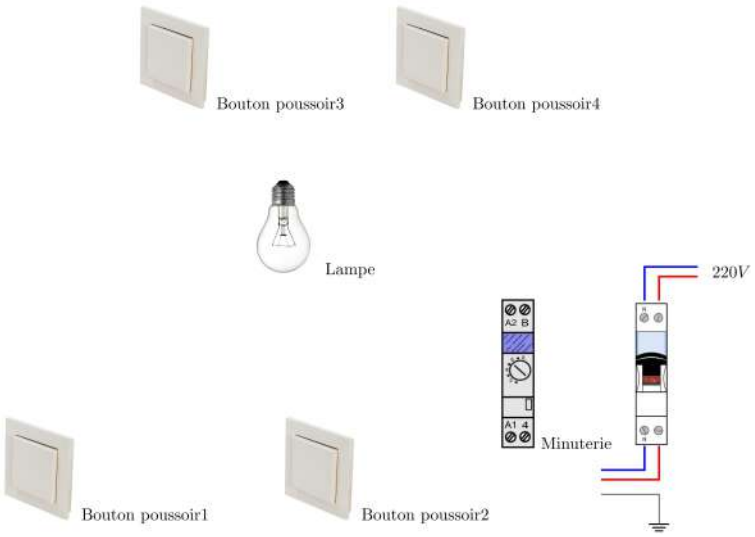


Figure 4.31: Implementation of a connection with a timer

4.18.3 Architectural Schematic

- Build the circuit with a timer (Figure 4.29) using the "Schémaplic" program.
- Verify the correct operation of the circuit.

PW2: Manual Control of One and Two Contactors

Last Name and First Name: .....

Submission Date: .....

4.19 Introduction

The contactor is an electromagnetic component designed to establish or interrupt the current flow, based on remote control from a switch, push button, etc. This part is dedicated to the study and implementation of manual control circuits for one contactor and for two contactors.

4.20 Control of a Contactor by Switch

The contactor with manual control is equipped with a two-position control switch:

- Permanent ON – 1
- Permanent OFF – 0

4.20.1 Wiring Layout

A simple design schematic for implementing the connection is presented in the figure below. Try to complete the schematic.

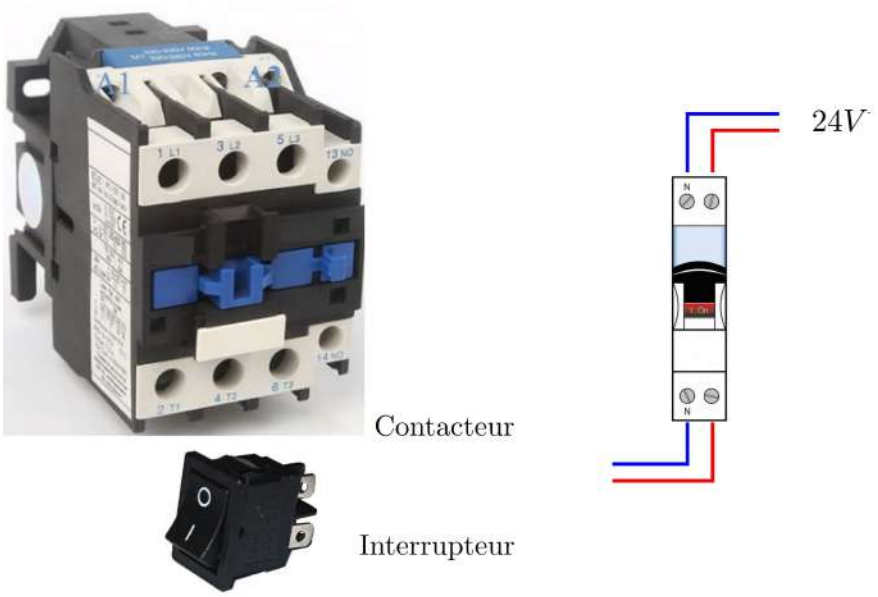


Figure 4.32: Implementation of control of a contactor by switch

4.20.2 Developed Schematic

Complete the schematic diagram.

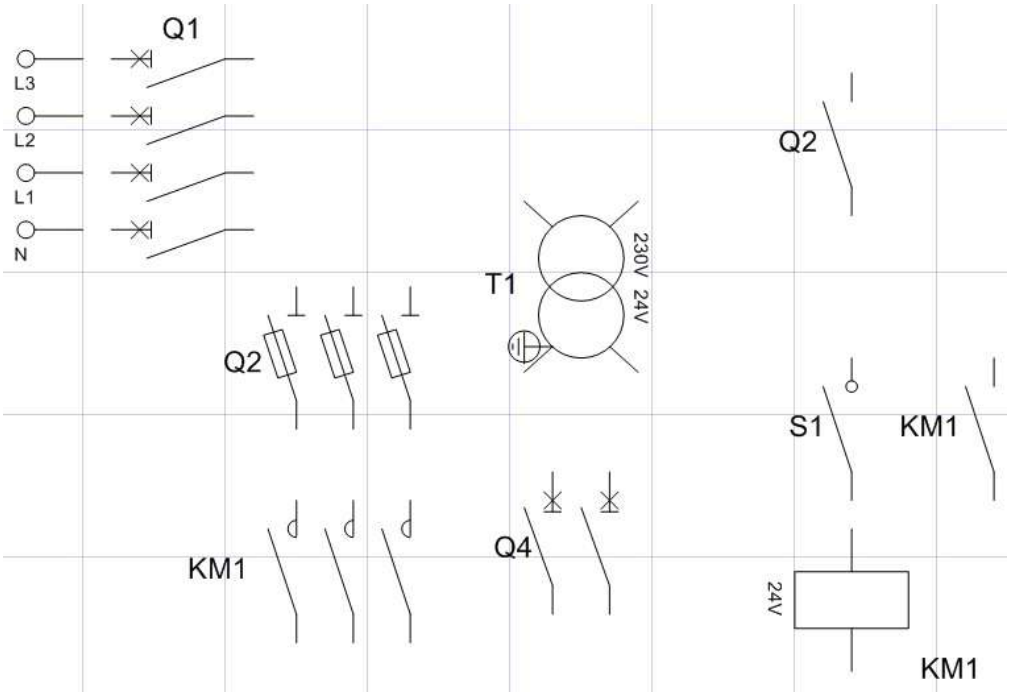


Figure 4.33: Schematic diagram of control of a contactor by switch

4.21 Control of a Contactor by Push Button

This part aims to create and implement an electrical schematic for the control of a contactor by a push button. The contactor with manual control is equipped with two push button actions:

- First action: Start
- Second action: Stop

4.21.1 Wiring Layout

A simple design schematic for implementing the connection is presented in the figure below. Try to complete the schematic.

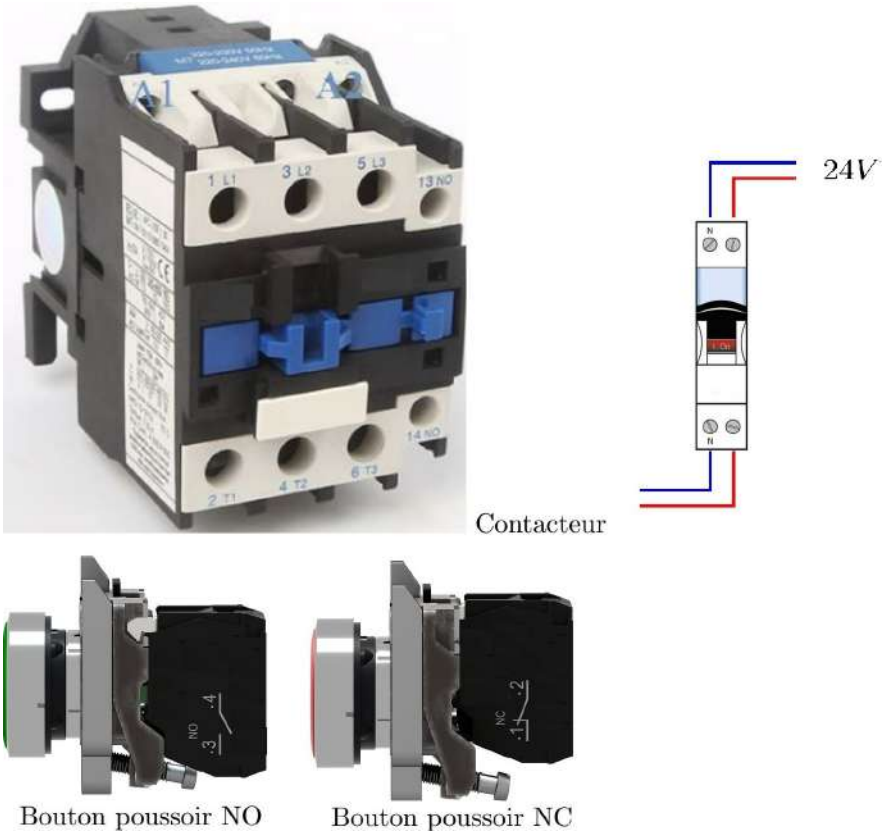


Figure 4.34: Implementation of control of a contactor by push button

4.21.2 Developed Schematic

Complete the schematic diagram.

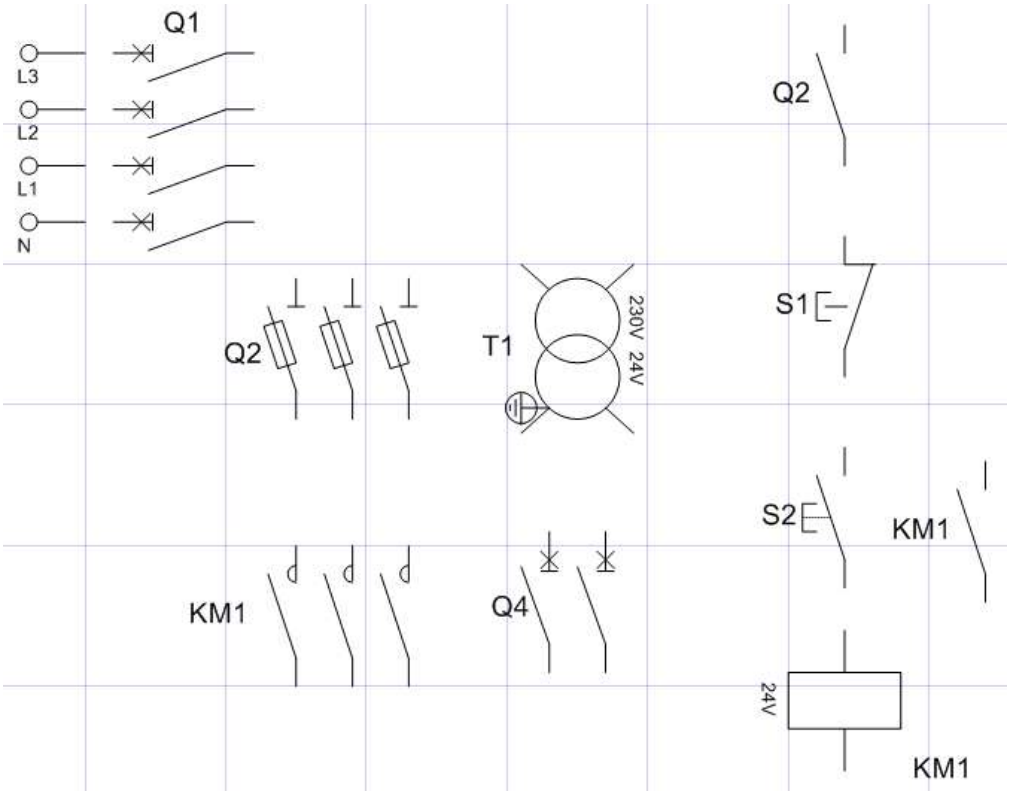


Figure 4.35: Schematic diagram of control of a contactor by push button

4.22 Control of Two Contactors by Push Buttons

This part aims to create and implement an electrical schematic for the control of two contactors by push buttons. In the control circuit, an electrical or mechanical interlock (or both) is used to prevent the simultaneous powering of the coils of the two contactors, which must not be engaged at the same time. Each contactor is controlled by two push buttons:

- 2 Push buttons: Start
- 2 Push buttons: Stop

4.22.1 Wiring Layout

A simple design schematic for implementing the connection is presented in the figure below. Try to complete the schematic.

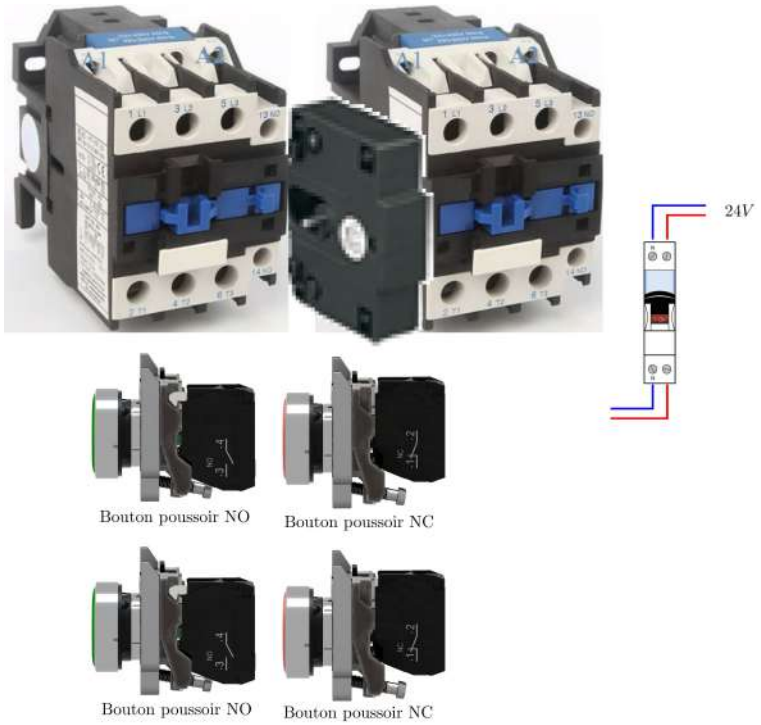


Figure 4.36: Implementation of control of two contactors by push buttons

4.22.2 Developed Schematic

Complete the schematic diagram.

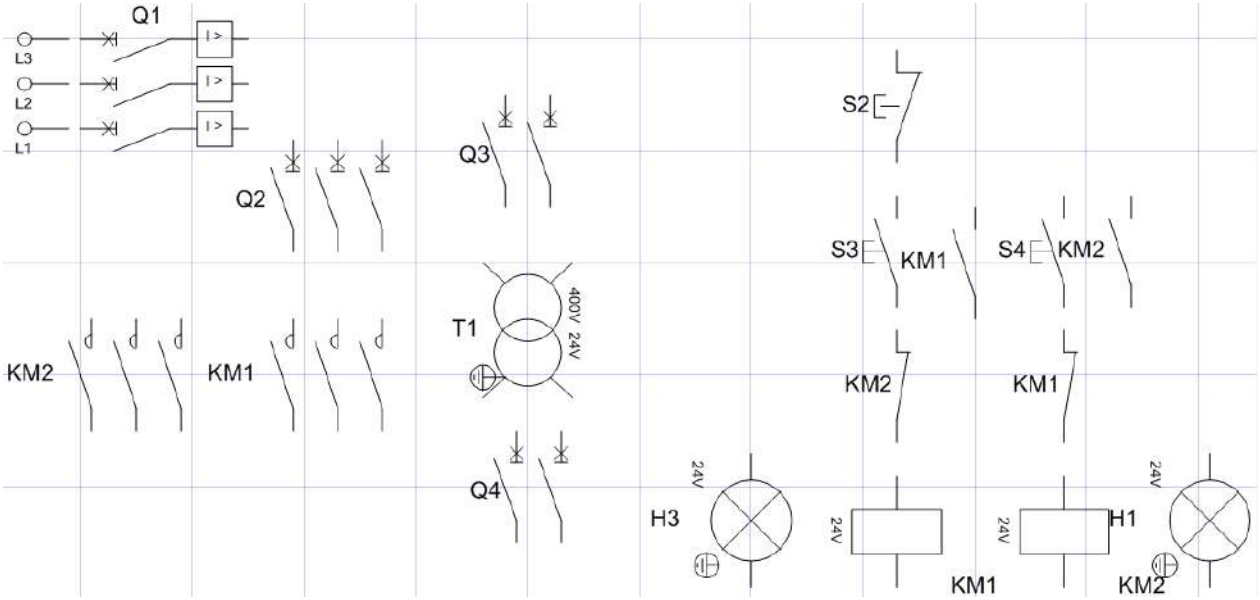


Figure 4.37: Schematic diagram of control of two contactors by push buttons

PW3: DOL Starting of a Three-Phase Squirrel-Cage Induction Motor – Single Direction of Rotation

Last Name and First Name: .....

Submission Date: .....

4.23 Learning Objectives

The student must be able to install a direct-on-line starter for a single direction of rotation of an electric motor.

4.24 Technical Characteristics

In this method, the motor stator is connected directly to the three-phase power supply. Starting is done in a single step. At motor start-up, the starting current is of the order of 4 to 8 times the rated current. The starting torque is very high, reaching about 1.5 times the rated torque.

4.25 Developed Schematic

The power and control circuits for the direct-on-line starting of a three-phase induction motor are illustrated in the figure below. Where:

Control Schematic Components

- Transformer 400/24 V
- Emergency stop (Q3)
- Normally Closed (NC) push button (S1 – Stop)
- Normally Open (NO) push button (S2 – Start)

- Contactor coil KM 24 V (KM1)
- NC contact of thermal overload relay (F1)
- 3 indicator lamps (24 V indicators: H2/H3/H4)
- NO contact of KM1 (for self-latching)
- NO contact of thermal overload relay (F1 – Fault indication)

Power Schematic Components

- 3-Phase lines
- Fuse-disconnector (Q1)
- Contactor (KM1)
- Thermal overload relay (F1)
- Three-phase induction motor (M3)

a) Identify the role of different components of the control circuit

S1: .....
S2: .....
Q2: .....
KM1(A1-A2): .....
KM1[1](13-14): .....
F1: .....
F1[1](97-98): .....
H1, H2, H3: .....

b) Identify the role of different components of the power circuit

L1, L2, L3: .....
Q1: .....
Q2: .....
KM1: .....
F1: .....

c) Complete the developed schematic in Figure 4.38

d) Carry out the installation and check the operation of the circuit

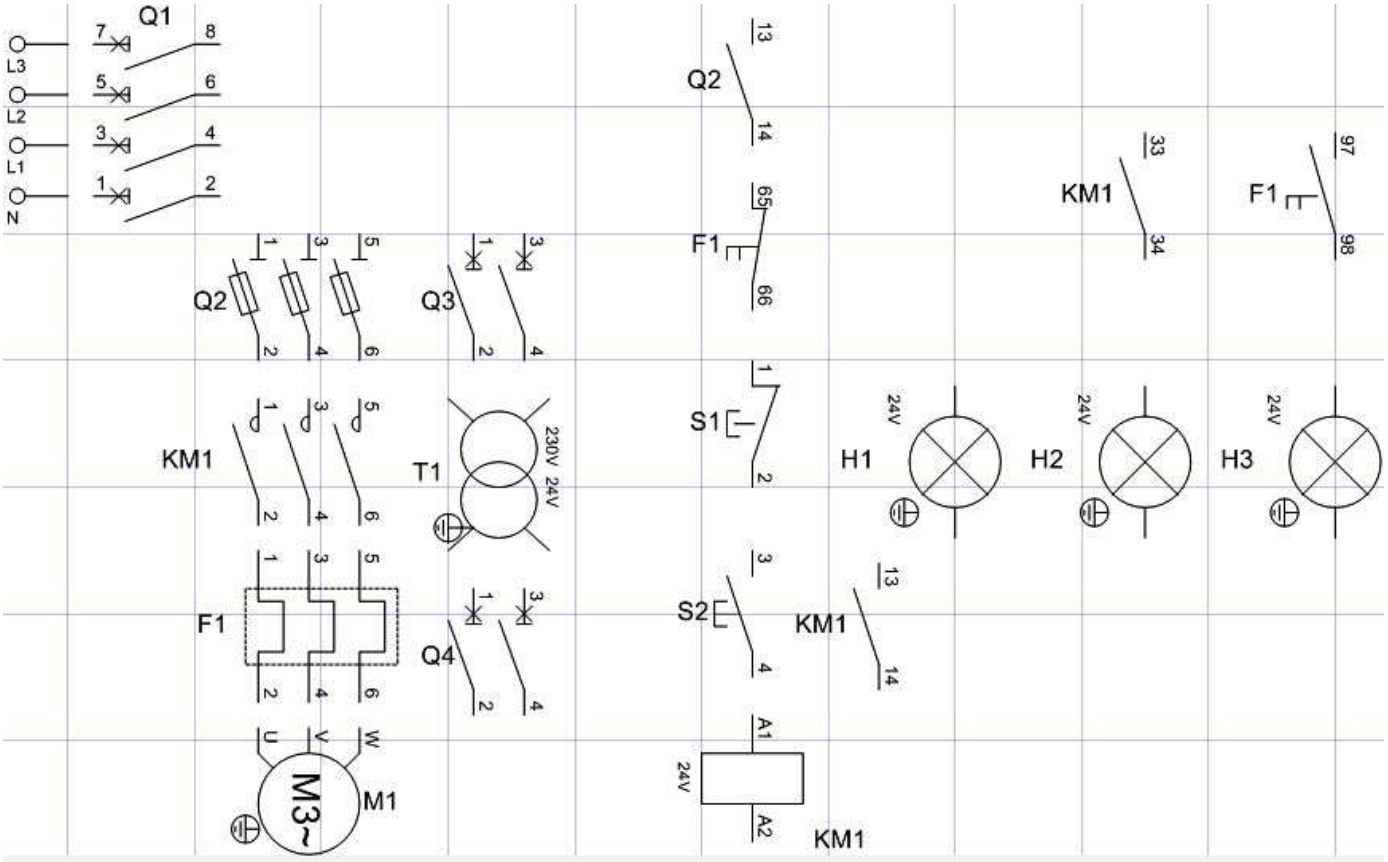


Figure 4.38: Developed schematic of a direct-on-line starter

PW4: DOL Starting of a Three-Phase Squirrel-Cage Induction Motor – Two Directions of Rotation

Last Name and First Name: .....

Submission Date: .....

4.26 Learning Objectives

The student must be able to install a direct-on-line starter for two directions of rotation of an electric motor with electrical and mechanical interlocks.

4.27 Technical Characteristics

Reversing the direction of rotation of a three-phase induction motor is achieved by swapping any two phases of the power supply. This requires two contactors:

- **KM1**: Contactor for forward rotation (direction 1)
- **KM2**: Contactor for reverse rotation (direction 2)

Critical Safety Requirement: KM1 and KM2 must **never** be energized simultaneously, as this would create a phase-to-phase short circuit. Both electrical interlocks (using auxiliary NC contacts) and mechanical interlocks must be implemented.

4.28 Developed Schematic

The power and control circuits for the direct-on-line starting of a three-phase induction motor with two directions of rotation are illustrated in the figure below.

Control Schematic Components

- Transformer 400/24 V

- Emergency stop (Q3)
- Normally Closed (NC) push button (S0 – Stop)
- Normally Open (NO) push button (S1 – Forward Start)
- Normally Open (NO) push button (S2 – Reverse Start)
- Contactor coil KM1 24 V (Forward)
- Contactor coil KM2 24 V (Reverse)
- NC contact of thermal overload relay (F1)
- 3 indicator lamps (24 V indicators: H1/H2/H3)
- NO contact of KM1 (for self-latching)
- NO contact of KM2 (for self-latching)
- NC contact of KM1 (electrical interlock for KM2)
- NC contact of KM2 (electrical interlock for KM1)
- NO contact of thermal overload relay (F1 – Fault indication)

Power Schematic Components

- 3-Phase lines (L1, L2, L3)
- Fuse-disconnector (Q1)
- Contactor KM1 (Forward – L1-L2-L3 to U-V-W)
- Contactor KM2 (Reverse – L1-L3-L2 to U-V-W, phases 2 and 3 swapped)
- Thermal overload relay (F1)
- Three-phase induction motor (M3)

a) Identify the role of different components of the control circuit

KM2 (A1-A2):
KM2 (13-14):
KM1 (21-22):
KM2 (21-22):
H1, H2, H3:

c) Complete the developed schematic in Figure 4.39

d) Explain why KM1 and KM2 must never be energized simultaneously

. . . . . .

e) Carry out the installation and check the operation of the circuit

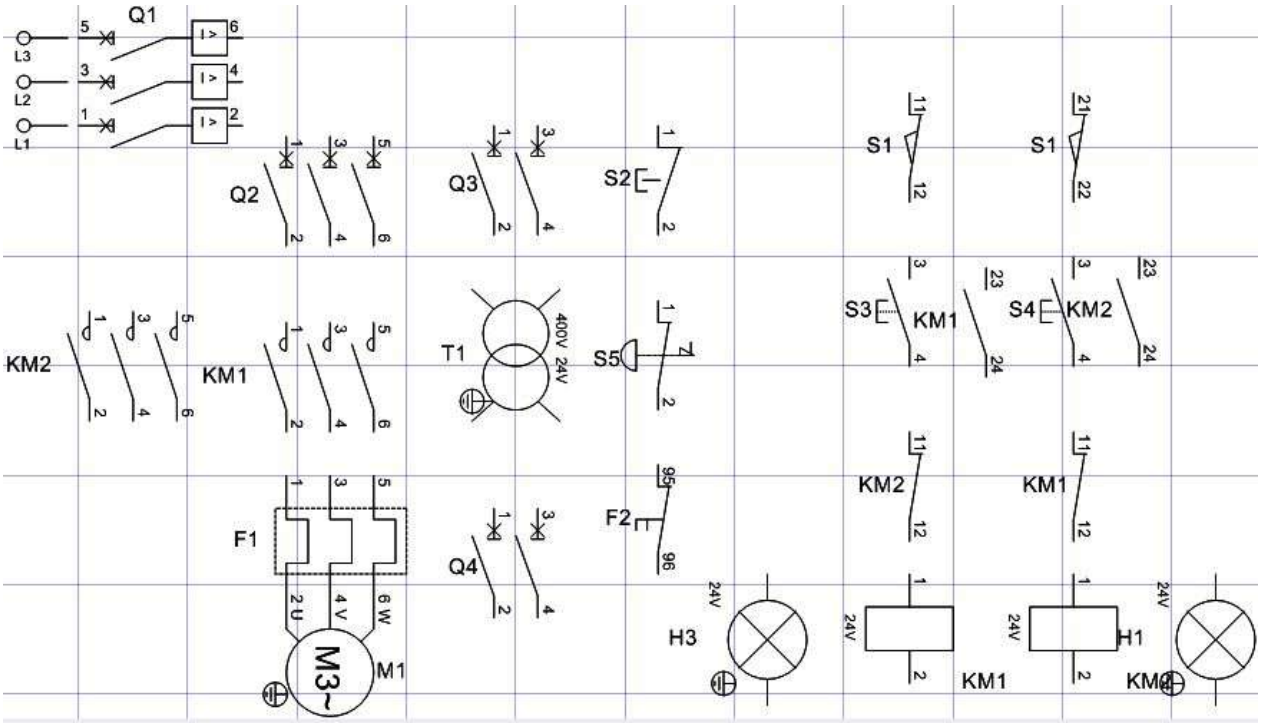
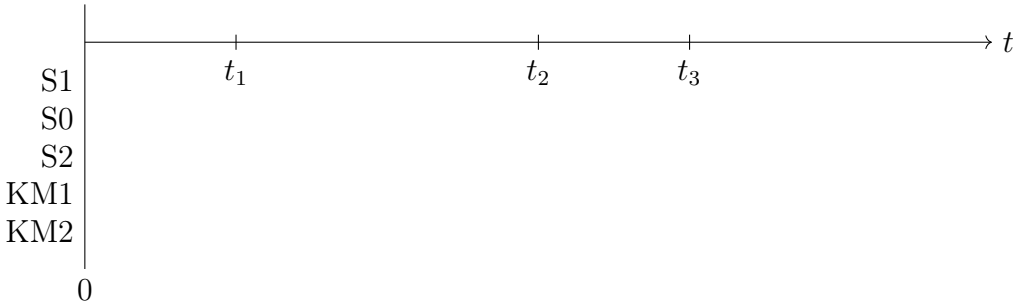


Figure 4.39: Developed schematic of a direct-on-line starter – Two directions of rotation

F) Write the logical equations for the control circuit:

$$KM1 = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$KM2 = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$H1 \text{ (Power ON)} = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$H2 \text{ (Forward RUN)} = \ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$H3 \text{ (Reverse RUN)} = \ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$H4 \text{ (Fault)} = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

J) Sketch the timing diagram showing the sequence when S1 is pressed, then S0 is pressed, then S2 is pressed:



PW5: Star-Delta Starting of a Three-Phase Squirrel-Cage Induction Motor – Single Direction of Rotation

Last Name and First Name: .....

Submission Date: .....

4.29 Learning Objectives

The student must be able to install and configure a star-delta (Y-Δ) starter for a three-phase induction motor, including proper timer adjustment and interlock verification.

4.30 Technical Characteristics

Star-Delta starting is used to reduce the starting current of three-phase induction motors. The motor starts in star (Y) configuration with reduced voltage, then switches to delta (Δ) configuration for normal operation.

Key Specifications:

- **Star connection:** Phase voltage $V = U/\sqrt{3}$ (58% of line voltage)
- **Starting current in star:** $\approx 1/3$ of DOL starting current
- **Starting torque in star:** $\approx 1/3$ of DOL starting torque
- **Transition time (Δt):** Typically 5–15 seconds (adjustable)
- **Motor requirement:** Must be rated for delta connection at line voltage

Critical Safety Requirements:

- KM1 (Star) and KM3 (Delta) must **never** be energized simultaneously
- A dead time (50–100 ms) must be ensured between star opening and delta closing
- Both electrical and mechanical interlocks are mandatory

4.31 Developed Schematic

The power and control circuits for star-delta starting are illustrated below.

Control Schematic Components

- Transformer 400/24 V
- Emergency stop (Q3)
- Normally Closed (NC) push button (S0 – Stop)
- Normally Open (NO) push button (S1 – Start)
- Contactor coil KM1 24 V (Star contactor)
- Contactor coil KM2 24 V (Line/Main contactor)
- Contactor coil KM3 24 V (Delta contactor)
- Timer relay (KT1) with delayed opening contact
- NC contact of thermal overload relay (F1)
- 4 indicator lamps (24 V: H1/H2/H3/H4)
- NO contact of KM2 (for self-latching)
- NC contact of KM1 (electrical interlock for KM3)
- NC contact of KM3 (electrical interlock for KM1)
- NO contact of thermal overload relay (F1 – Fault indication)

Power Schematic Components

- 3-Phase lines (L1, L2, L3)
- Fuse-disconnector (Q1)
- Contactor KM2 (Line/Main – connects supply to U, V, W)
- Contactor KM1 (Star – shorts U, V, W together)
- Contactor KM3 (Delta – connects U-Z, V-X, W-Y)
- Thermal overload relay (F1)
- Three-phase induction motor (6 terminals: U, V, W, Z, X, Y)

a) Identify the role of different components of the control circuit

KT1 (Timer):
KM2 (13-14):
KM1 (21-22):
KM3 (21-22):

b) Identify the role of different components of the power circuit

KM1 (power contacts):
KM3 (power contacts):

c) Complete the developed schematic in Figure 4.40

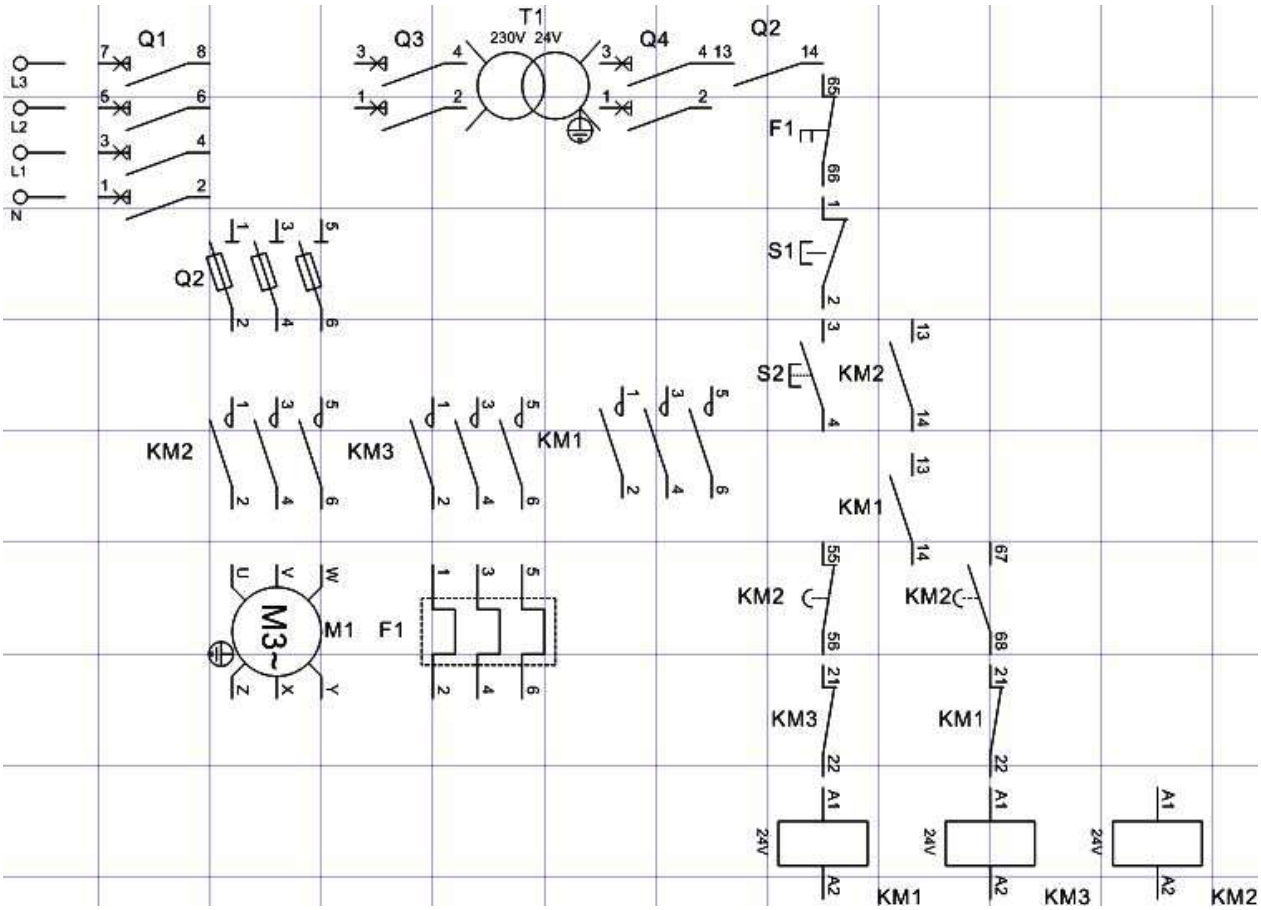


Figure 4.40: Developed schematic of a star-delta starter – Single direction

I)Write the logical equations for the control circuit:

d) Why is a timer necessary in the star-delta starting circuit?

. . . . . .

e) Explain why KM1 and KM3 must never be energized simultaneously

. . . . . .

f) What happens if the timer delay (Δt) is set too short?

. . . . . .

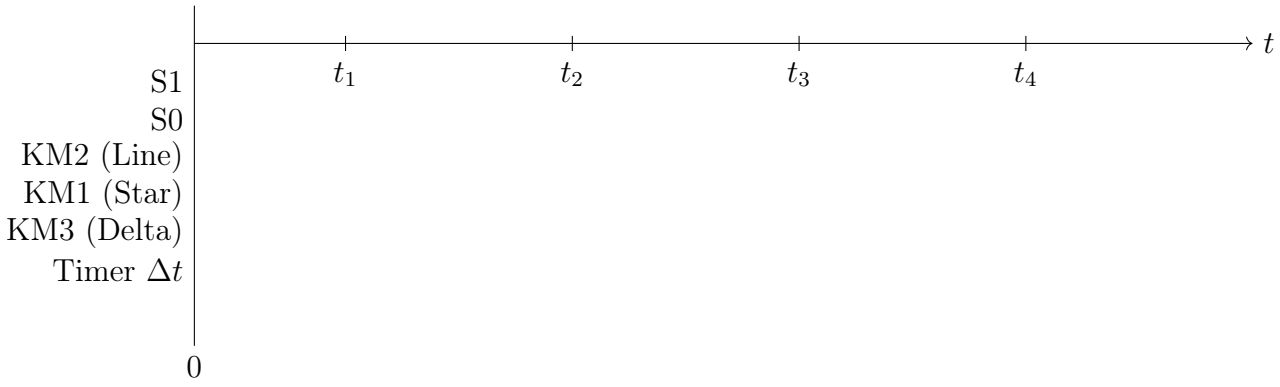
g) What happens if the timer delay (Δt) is set too long?

. . . . . .

h) Carry out the installation and check the operation of the circuit

$KM2 =$ . . . . . .
$KM1 =$ . . . . . .

J)Complete the timing diagram for a complete start-stop cycle:



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