DEMec - Dep. of Mechanical Engineering
SAIC- Automation, Instrumentation and Control Section
Master in Mechanical Engineering

Electromechanical Systems

1st Year– 2nd Semester
2025-2026

Support documents to TP classes

Control circuits for electrical motors

Paulo Abreu

2026 Edition

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Electromechanical Systems

Control Circuits for Electrical Motors

Paulo Abreu
Dep. of Mechanical Engineering

pabreu@fe.up.pt
2026

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Electromechanical Components in Control Circuits

1. **Introduction**
    - Overview of Control Circuits: a brief introduction to control circuits for electrical motors, their importance, and applications
2. **Electromechanical Components in Control Circuits**
    - Key Components: contactors, relays, overload protection, motor starters, pushbuttons, rotary switches, and pilot lamps
    - Protective Devices: types of protective devices in electrical circuits
3. **Main Functions in Control Circuits**
    - Isolating (Disconnect)
    - Overload Thermal Protection
    - Short Circuit Protection
    - Switching
    - Emergency Stop
    - Implementation: how these functions are traditionally ensured by separate devices and integrated solutions

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Electromechanical Components in Control Circuits

4. **Causes and Protections for Overloads**
   - Normal Causes of Overloads
   - Abnormal Causes of Overloads
   - Purpose of Protection
5. **Causes and Protections for Short Circuits**
   - Causes of Short Circuits
   - Features and Purpose of Short Circuit Protection
6. **Protection of Electrical Machines**
   - Overload Thermal Protection: characteristics and importance of overload thermal protection
   - Short Circuit Current Protection: characteristics and importance of short circuit protection
7. **Reversing Motor Rotation Methods for Different Motors**
   - Asynchronous Three-Phase Induction Motors
   - Permanent Magnet DC Motors
   - DC Wound Motors
   - Stepper Motors

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Electromechanical Components in Control Circuits

8. Control Circuits for Various Motors: Examples and Diagrams

- Induction Motor Control Examples: Start/stop control, reverse control, star-delta starter
- Dahlander Motor Wiring: Low speed and high speed connections
- AC Single-Phase Motor Control: Reverse control setup
- Soft Starter Parametrization: Start time, stop time, initial start voltage, rated starting voltage
- VFD Control: Single-Phase and Three-Phase VFDs
- DC Motor Control: Reverse control and driver setups
- Stepper Motor Control: Bipolar and unipolar driver setups

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Introduction

Overview of Control Circuits for Electrical Motors

- Control circuits are essential for the safe and efficient operation of electrical motors. They are designed to manage the starting, stopping, speed, direction, and protection of motors. These circuits ensure that motors operate within their specified parameters, preventing damage and extending their lifespan.

Importance of Control Circuits

- **Safety**: Control circuits include protective devices that prevent accidents and equipment damage by detecting and responding to abnormal conditions such as overloads and short circuits.
- **Efficiency**: By optimizing motor performance, control circuits help reduce energy consumption and improve overall system efficiency.
- **Reliability**: Properly designed control circuits enhance the reliability of motor-driven systems, minimizing downtime and maintenance costs.

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Electromechanical Components in Control Circuits

Control circuits for electrical motors typically include a range of electromechanical components, each serving a specific function:

- **Contactors**: electromechanical switches used to control the power supply to the motor
- **Relays**: devices that open or close circuits electromechanically or electronically
- **Overload Protection**: devices that protect motors from excessive current, preventing overheating and damage
- **Motor Starters**: devices that safely start and stop motors, often incorporating overload protection
- **Pushbuttons and Switches**: manual controls for starting, stopping, and reversing motor operation
- **Pilot Lamps**: indicator lights that provide visual feedback on the status of the control circuit

Protective devices are critical components of control circuits, designed to prevent undesirable situations by:

- **Limiting Electrical Quantities**: ensuring that current, voltage, and other electrical parameters remain within safe limits
- **Detecting Leaks or Signal Loss**: identifying and responding to issues such as insulation failures or signal interruptions

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Main Functions in Control Circuits

Any circuit must implement 5 essential functions:

1. **Isolating** (disconnect)
   - **Purpose**: the isolating function is used to disconnect the power supply to the equipment for maintenance or repair. This ensures that the equipment is completely de-energized, preventing accidental startup and ensuring the safety of personnel
   - **Devices Used**: isolating switches or disconnect switches are typically used for this purpose. These switches are designed to handle high currents and provide a visible means of disconnection
2. **Overload thermal protection**:
   - **Purpose**: overload thermal protection protects electrical equipment from damage due to excessive current flow. This protection is crucial for preventing overheating and potential fire hazards.
   - **Devices Used**: thermal overload relays or devices that monitor the current flow are used to achieve this protection. These devices disconnect the equipment if the current exceeds a certain limit, either directly or indirectly
3. **Short circuit protection:**
   - **Purpose**: short circuit protection is used to protect electrical equipment from damage due to short circuits. Short circuits can cause extremely high currents that can damage equipment and pose safety risks.
   - **Devices Used**: circuit breakers or fuses are used to interrupt the current flow in the event of a short circuit. These devices are designed to react quickly to prevent damage

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Main Functions in Control Circuits

4. Switching

- **Purpose**: switching is the process of turning on or off electrical equipment. This function is essential for controlling the operation of motors and other devices
- **Devices Used**: switches, such as pushbuttons and rotary switches, are used to control the power supply to the equipment. These switches can be manual or automated

5. Emergency Stop

- **Purpose**: an emergency stop button is used to immediately stop the equipment in case of an emergency. This is an important safety feature that can prevent accidents and injuries
- **Devices Used**: emergency stop buttons are designed to be easily accessible and provide a quick means of stopping the equipment. They are often integrated into control panels

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Main Functions in Control Circuits Implementation

Implementation

- Separate devices traditionally ensure these functions, each designed to perform a specific role. However, integrated solutions are also available, combining multiple functions into a single device or system

- **Separate Devices**
  - **Fuses + Contactor + Thermal Overload Relay**: this combination provides short circuit protection (fuses), switching (contactor), and overload thermal protection (thermal overload relay)
  - **Circuit Breakers + Contactor + Thermal Overload Relay**: similar to the previous combination, but using circuit breakers for short circuit protection
  - **Pushbuttons and Switches**: used for manual control of switching and emergency stop functions

- **Integrated Solutions**
  - **Contactor-Circuit Breaker Units**: these integrated devices combine the functions of a contactor and a circuit breaker, providing both switching and short circuit protection in a single unit
  - **Motor Starters**: motor starters often incorporate overload protection, switching, and sometimes emergency stop functions, providing a comprehensive solution for motor control

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Causes and Protections for Overloads

- **Normal causes**
  - Starting a motor or an electronic device
  - Repetitive load points: in production cycles, certain points may require higher power, leading to repetitive overloads
- **Abnormal causes**
  - Excessive start/stop cycles
  - Too many consumers connected to a power supply
  - Overloading the motor
  - Voltage drop or phase failure (motors that draw more current and heat up)
- **Purpose of protection**
  - Differentiate between an allowable (normal) overload and an non-permissible (abnormal) overload taking into account thermal inertias
  - Cut the power circuit, but only when necessary, to prevent overheating and potential fire hazards

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Causes and Protections for Short Circuits

- **Causes for Short Circuits**
  - **Lack of insulation** in a cable or appliance: damaged or degraded insulation can cause conductors to touch, leading to a short circuit
  - **Foreign bodies:** objects such as metal filings or water can create unintended connections between conductors
  - **Wiring errors:** mistakes made during installation or maintenance can result in incorrect connections, causing short circuits
  - **Destruction inside an appliance:** internal failures within electrical devices can create short circuits

- **Features and Purpose of Short Circuit Protection**
  - The short circuit current is only limited by the upstream impedance
  - It then depends on the transformers and supply conductors
  - Can appear between two phases, phase and neutral, or phase and earth
  - **Limiting the short circuit current**
  - **Interrupt the circuit** as soon as possible

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Protection of Electrical Machines

- **Overload thermal protection**
  - **Characteristics of Overload Current**
    - **Magnitude**: overload current can range from 1 to 3 times the rated current
    - **Duration**: it is limited in time and may occur repetitively
    - **Normalcy**: such overloads can be a normal situation during certain operating conditions

- **Short Circuit Current Protection**
  - **Characteristics of Short Circuit Current**
    - **Magnitude**: short circuit current significantly exceeds the nominal current consumption of an appliance, often greater than 10 times the nominal consumption
    - **Cause**: it is typically a consequence of a defect in the installation or the material, and is considered irreversible.
    - **Action Required**: short circuits necessitate stopping the machine in question to prevent further damage and switching off the supply of electrical current

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Reversing Motor Rotation Methods

- **Asynchronous three-phase induction motors**
  - Use of contactors to exchange two power phases
  - Available as a function from a variable frequency drive (VFD)

- **Permanent magnet DC motors**
  - Changing polarity in the rotor power circuit

- **DC wounded motors**
  - Changing polarity in either the rotor supply circuit or the stator circuit (but only in one of the circuits !)

- **Stepper motors**
  - Changing polarity
  - Available as a function from the driver

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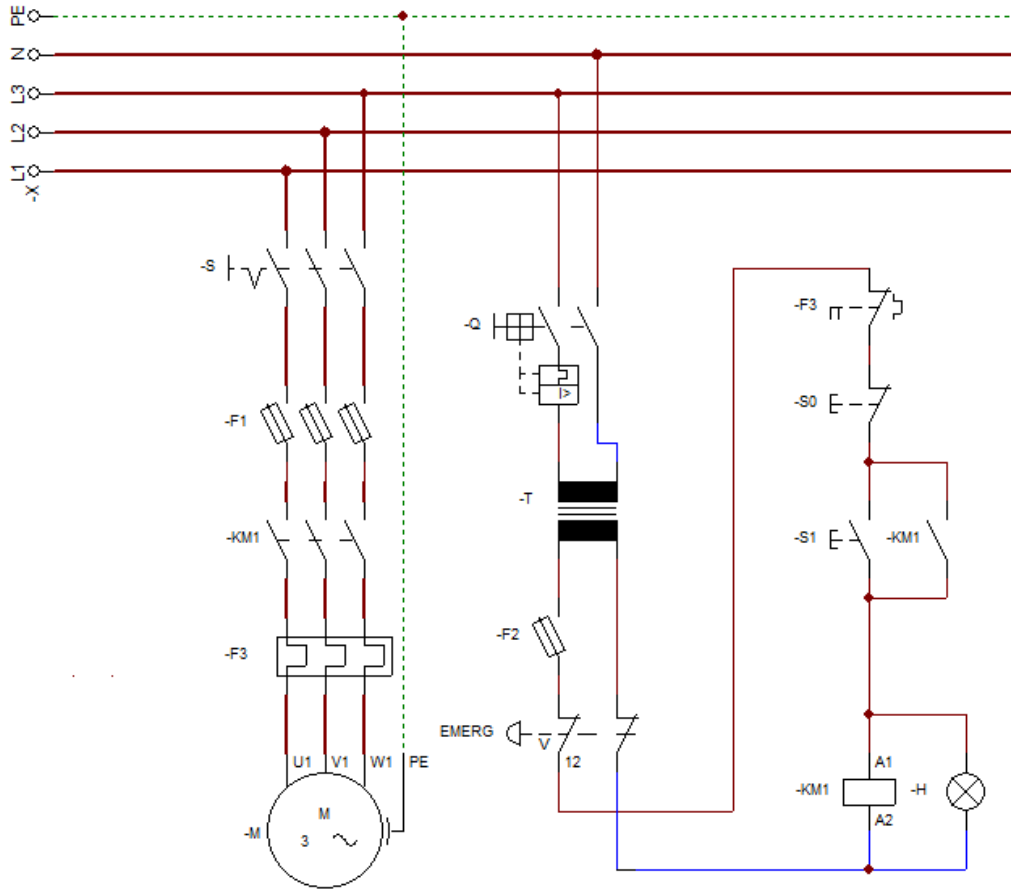
Induction Motor: start/stop control with two pushbuttons



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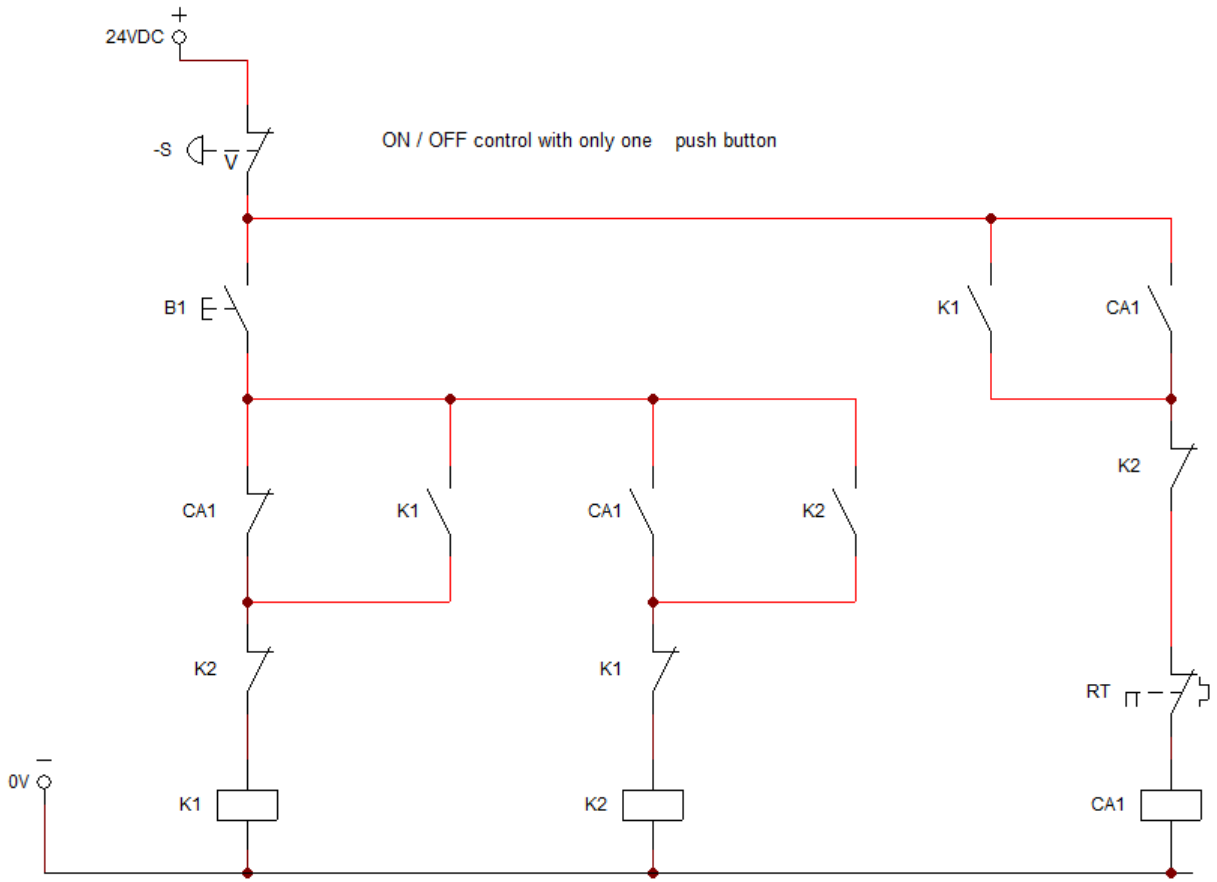
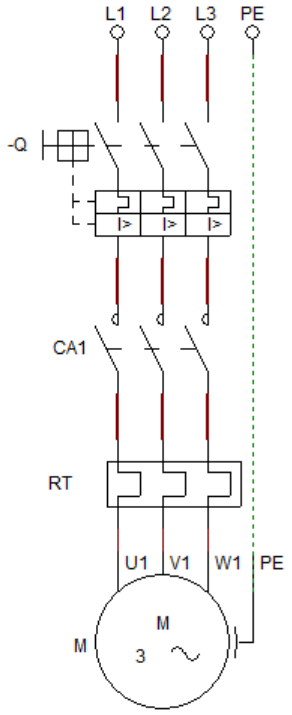
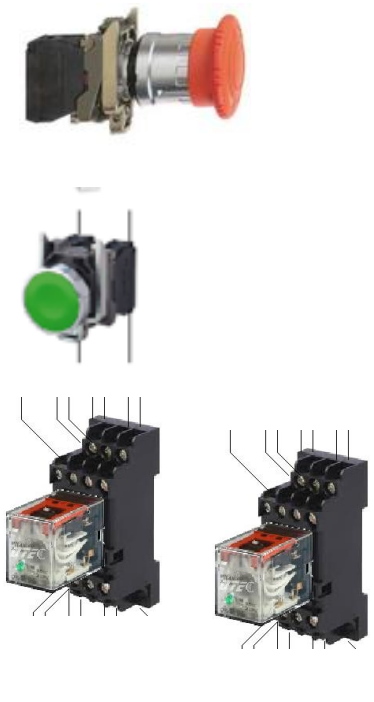
Induction Motor: start/stop control with only one pushbutton







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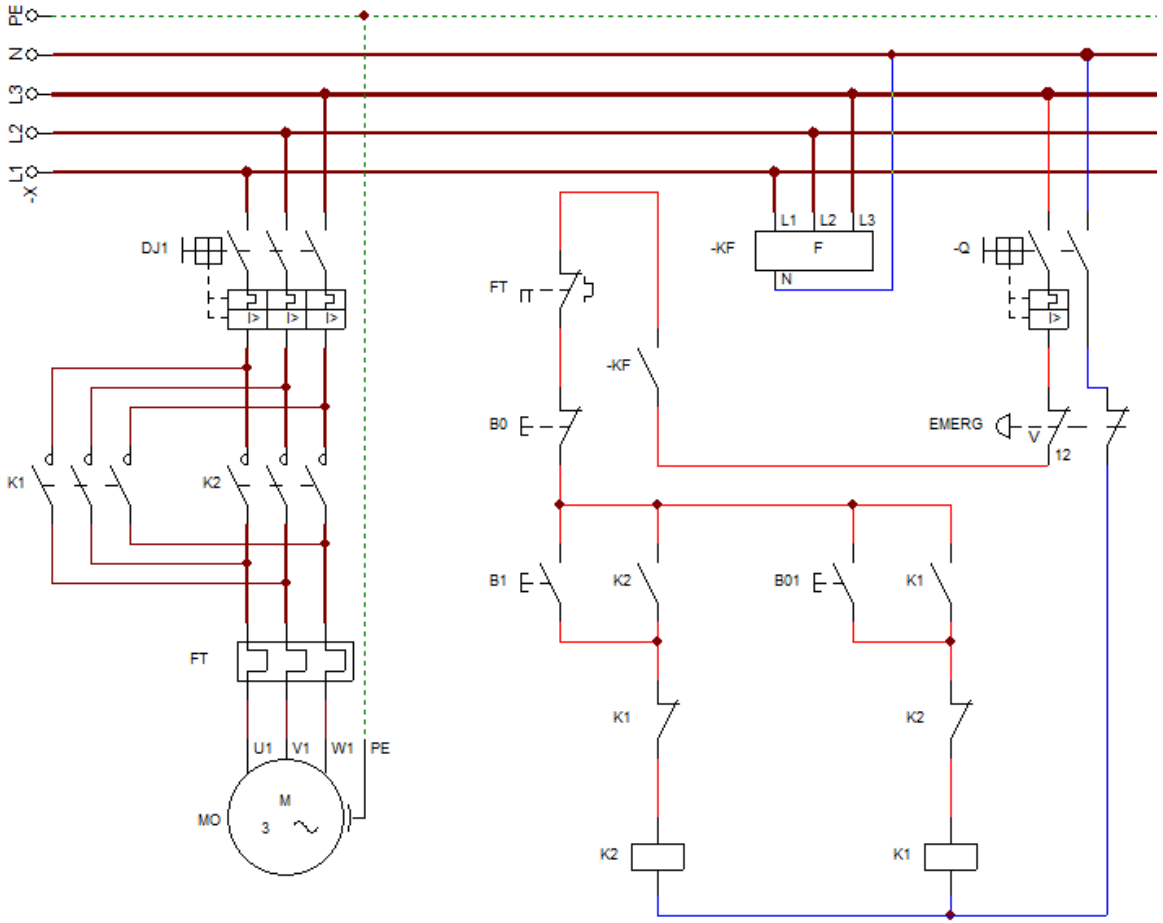
Induction Motor: Direction Reversal (I)



K8AK-PM 3-phase Voltage and Phase-sequence Phase-loss Relay

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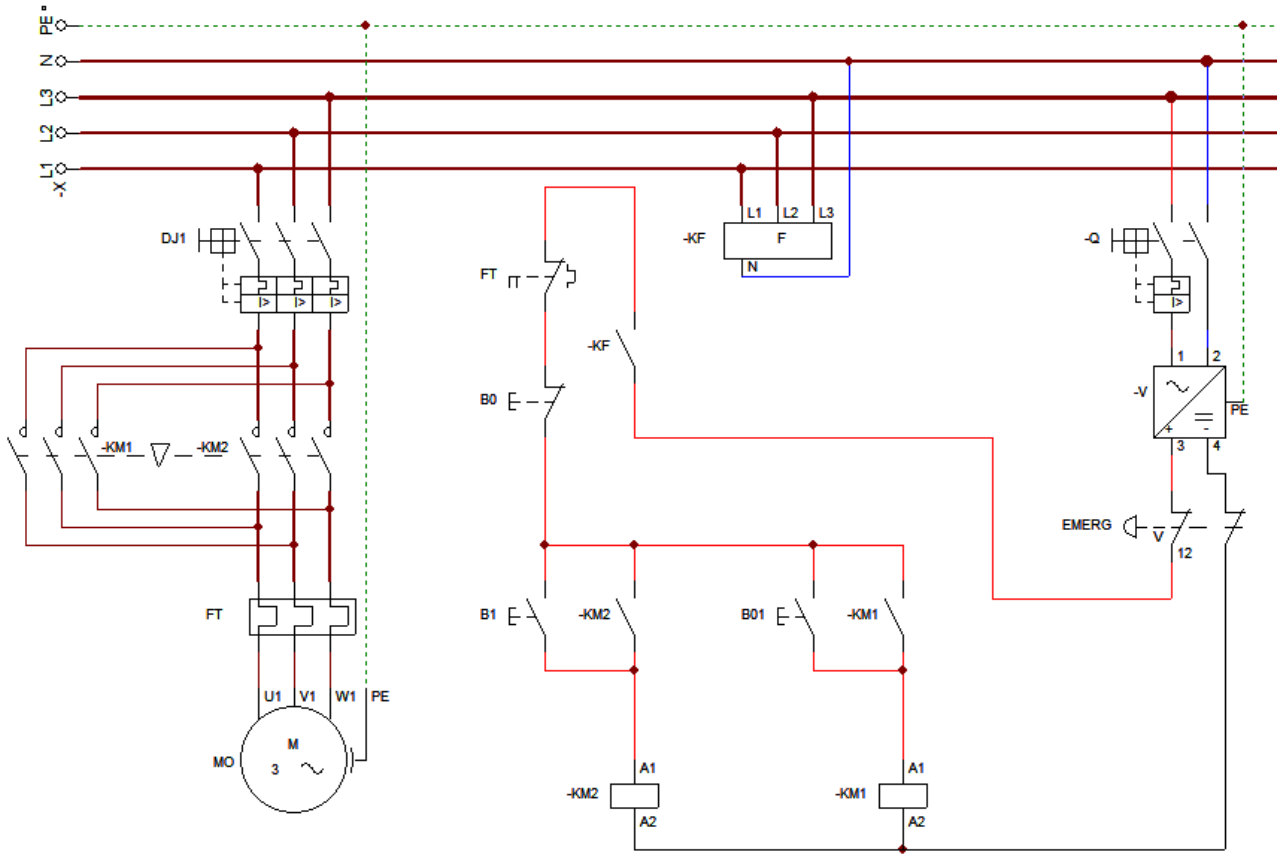
Induction Motor: Direction Reversal (II)



Power supply 230V AC-24V DC, 30 W

Contactor with interlock ABB AF26-30-00

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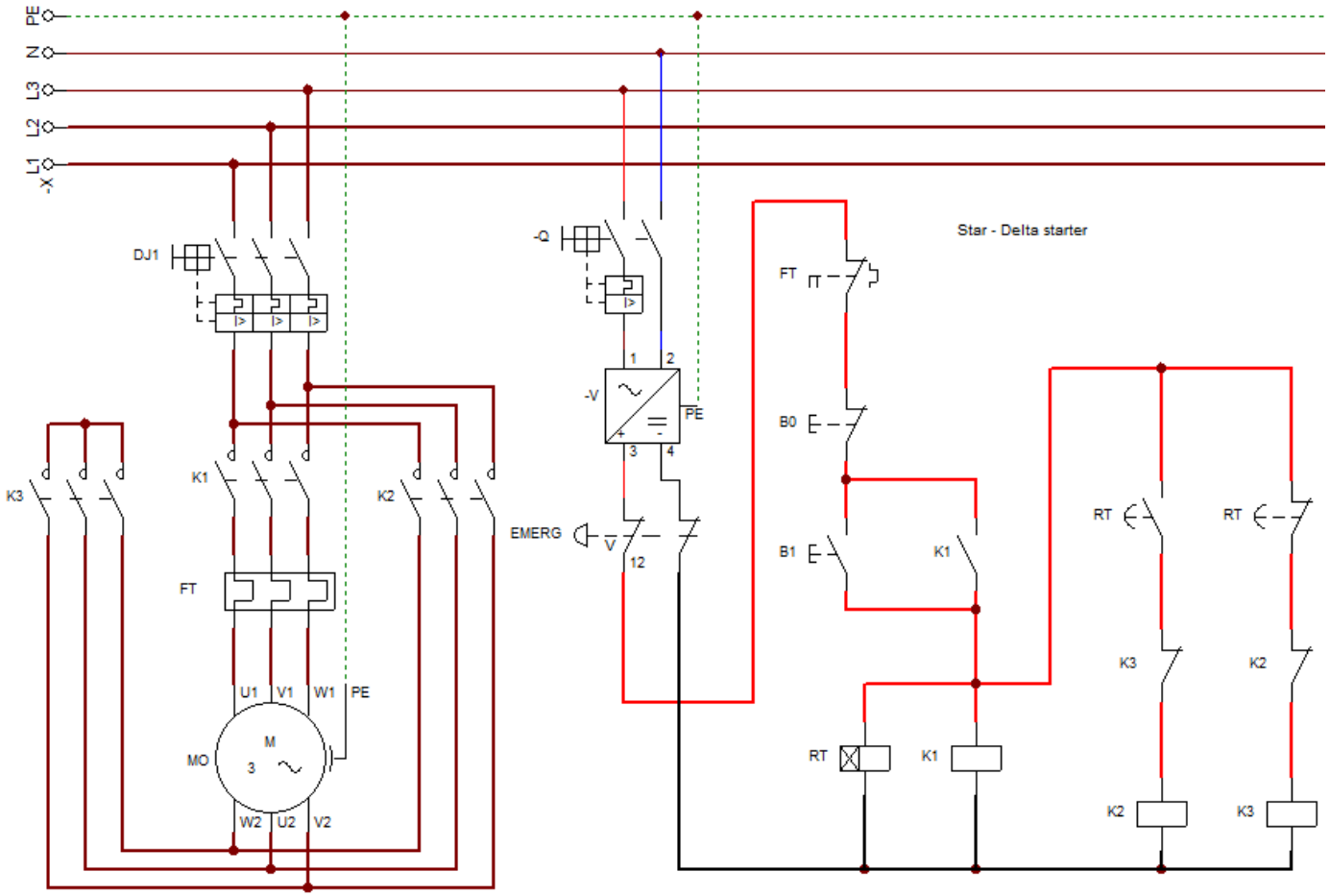
Induction Motor: Star-Delta Starter (I)



On-delay
ABB CT-ERS.12

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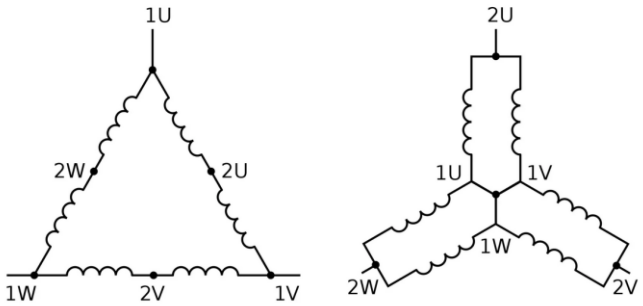
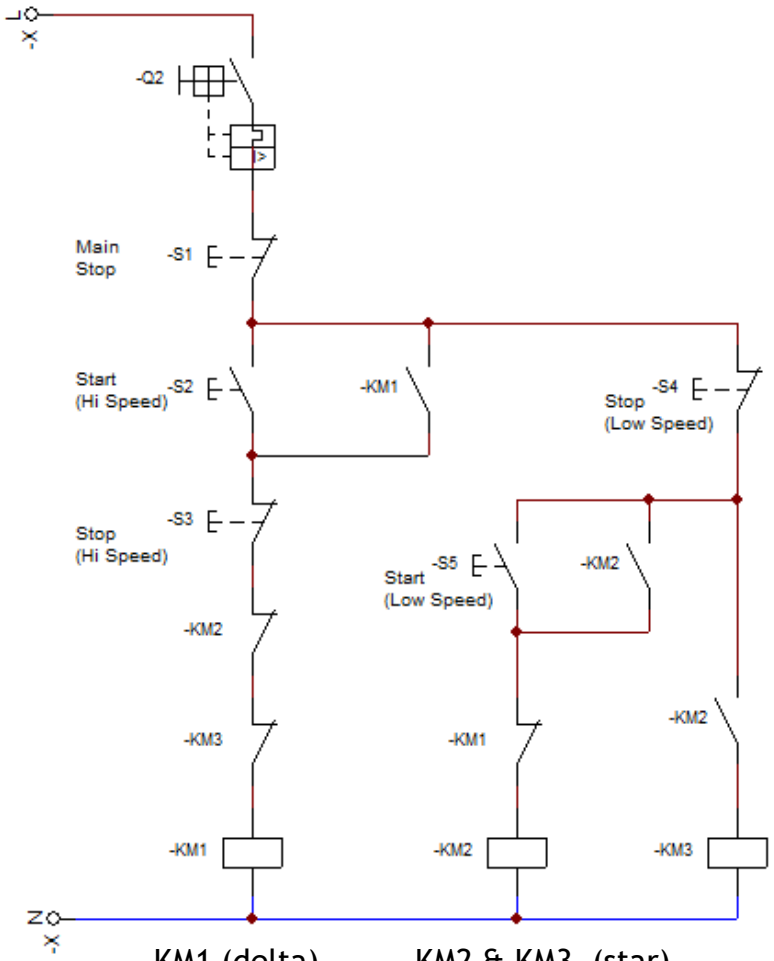
Dahlander Motor: Two Speed Motor

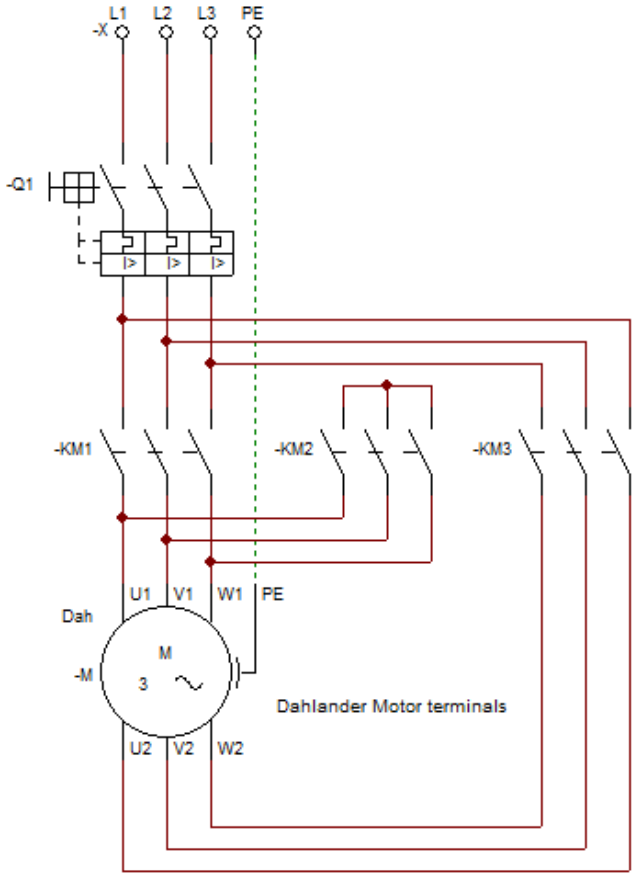
Dahlander motor wiring:

- for low speed, delta connection, (p = 2) and
- for high speed, double star connection, (p =1)





KM1 (delta) KM2 & KM3 (star)



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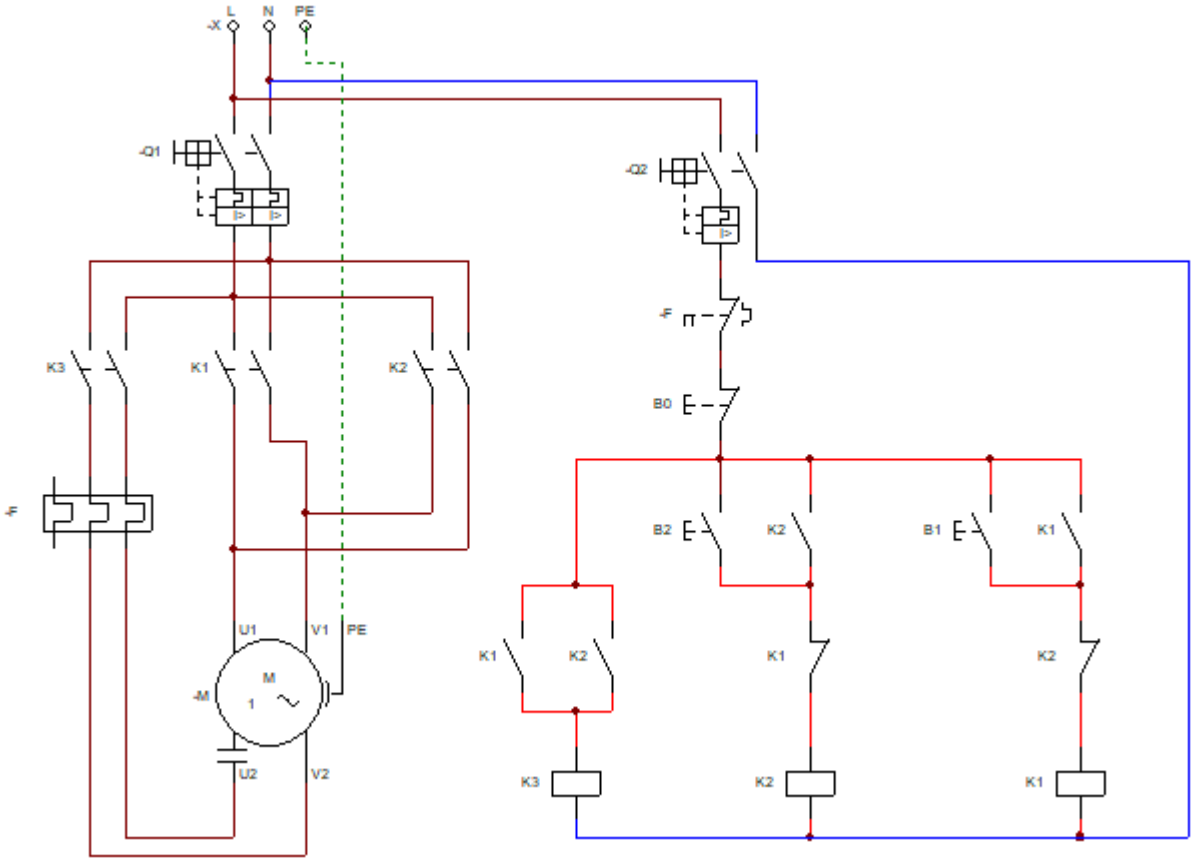
AC Single-Phase Motor: Direction Reversal



Note

- The use of a three pole overload thermal relay, but a one pole would be sufficient
- The use of two poles contactors

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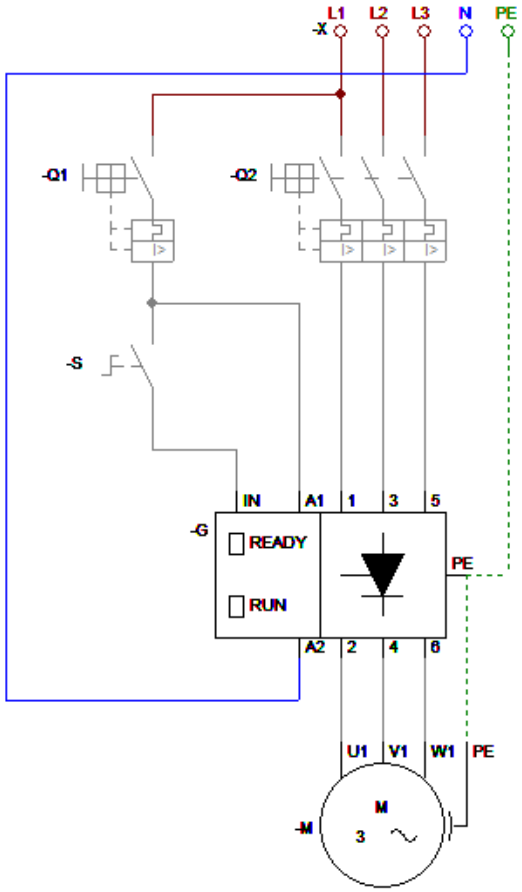
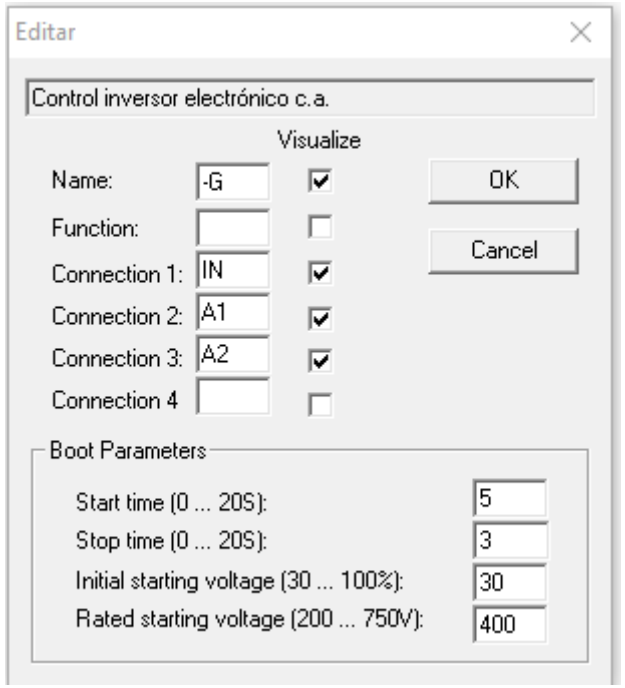
Induction Motor: Soft Start Control





Note

- The soft start parametrization:
  - Start time
  - Stop time
  - Initial start voltage
  - Rated starting voltage(full voltage)

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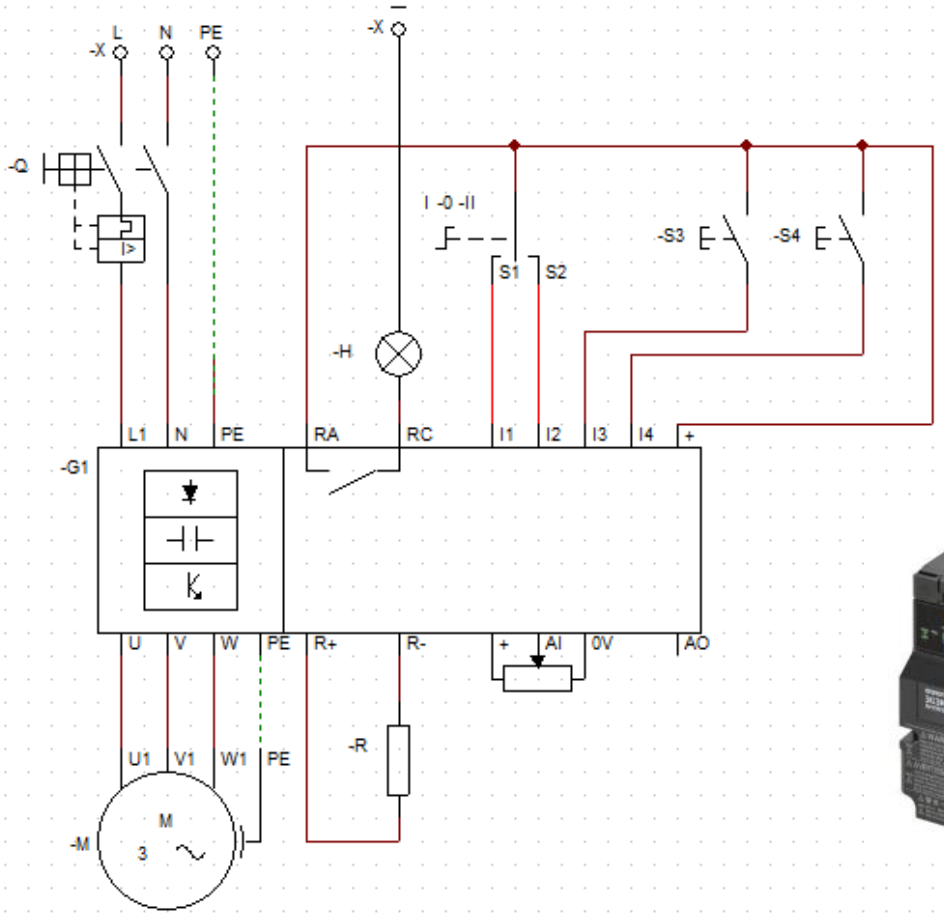
Induction Motor: VFD Control (Single-phase VFD)



S1 on, run cw at ref. speed

S2 on, run ccw at ref. speed

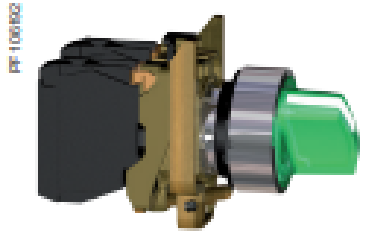
S3 on and S4 off, preset speed 2

S3 off and S4 on, preset speed 3

S3 on and S4 on, preset speed 4

R, braking resistor

Omron VFD model
M1



XB4BK123B5

Selector with 3 position, stay put
See Schneider catalogue

Potentiometer (22 mm, panel mounting, 10 k Ohm)

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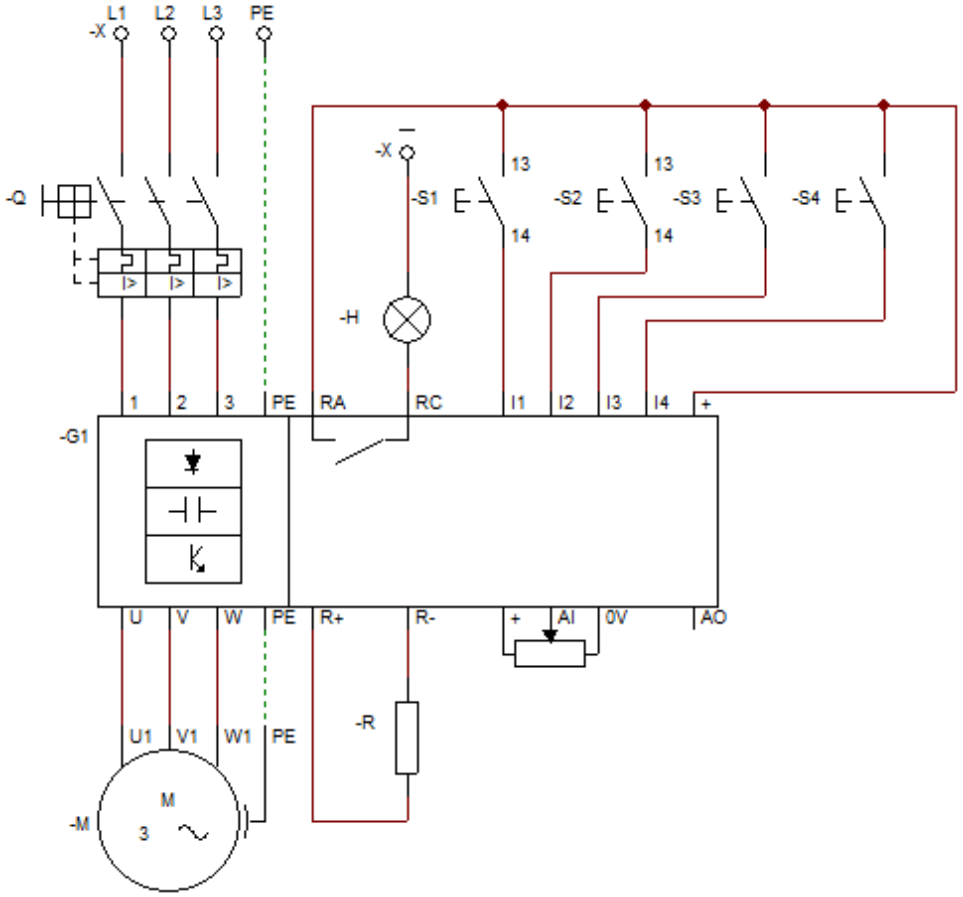
Induction Motor: VFD Control (Three-phase VFD)



S1 on, run cw at ref. speed

S2 on, run ccw at ref. speed

S3 on and S4 off, preset speed 2

S3 off and S4 on, preset speed 3

S3 on and S4 on, preset speed 4

R, braking resistor

Omron VFD model
MX2

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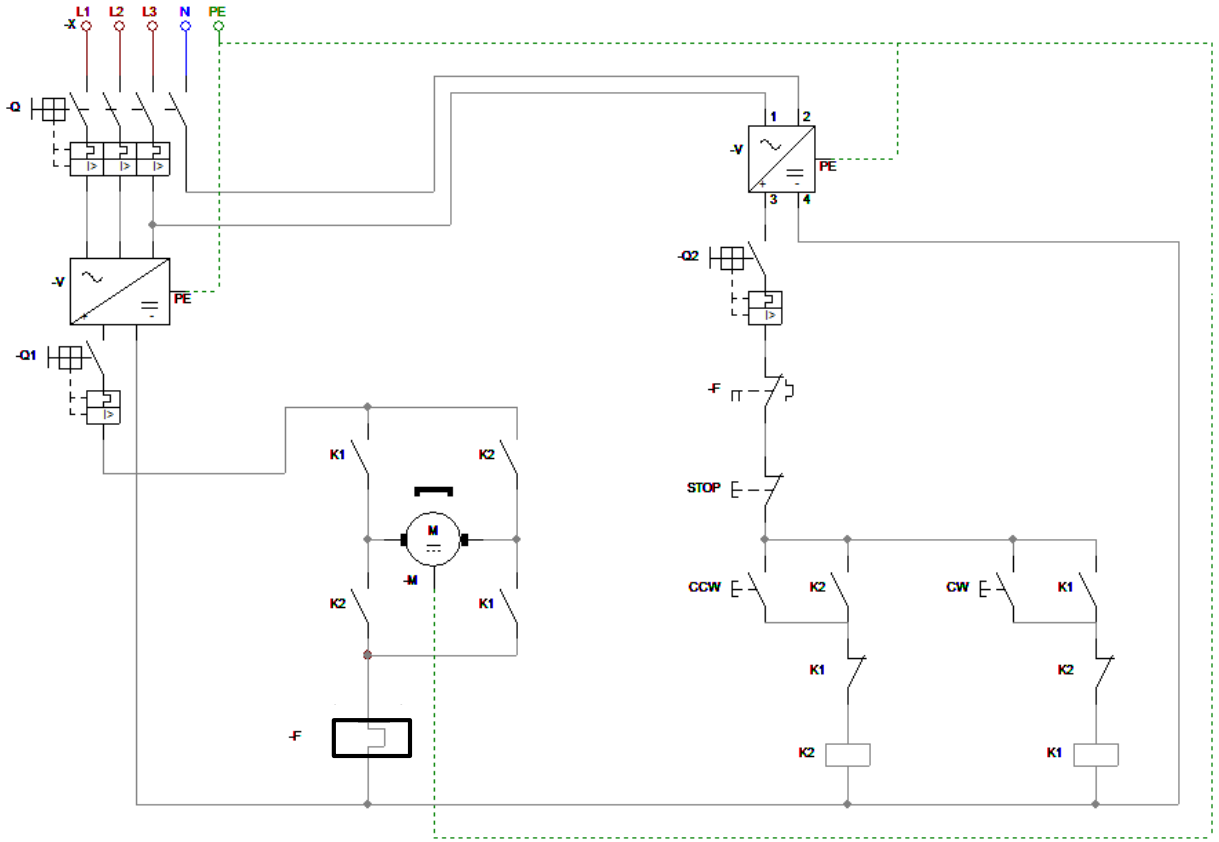
PM DC Motor: Reverse Control



Note

- One three-phase DC power supply
- One single-phase Dc power supply
- An overload thermal relay

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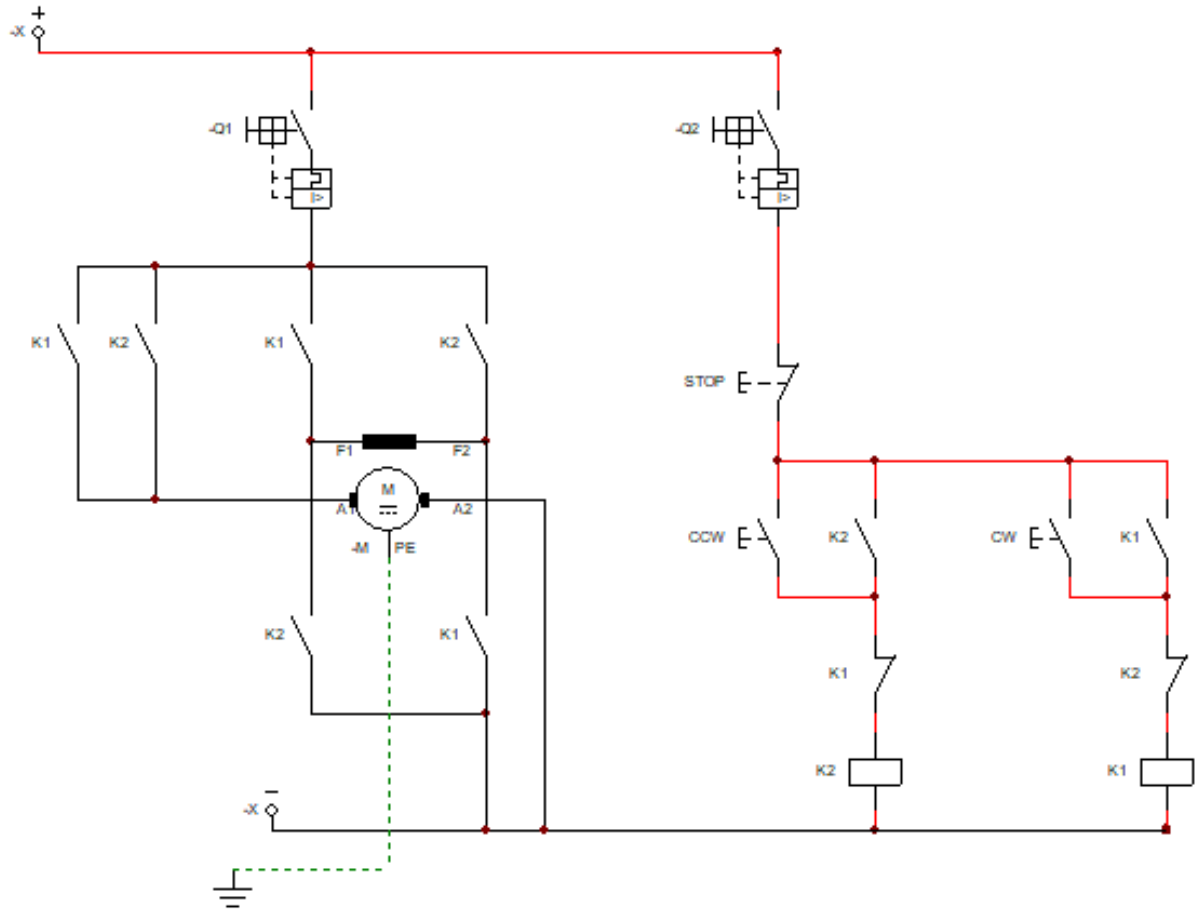
Shunt Wound DC Motor: Reverse Control



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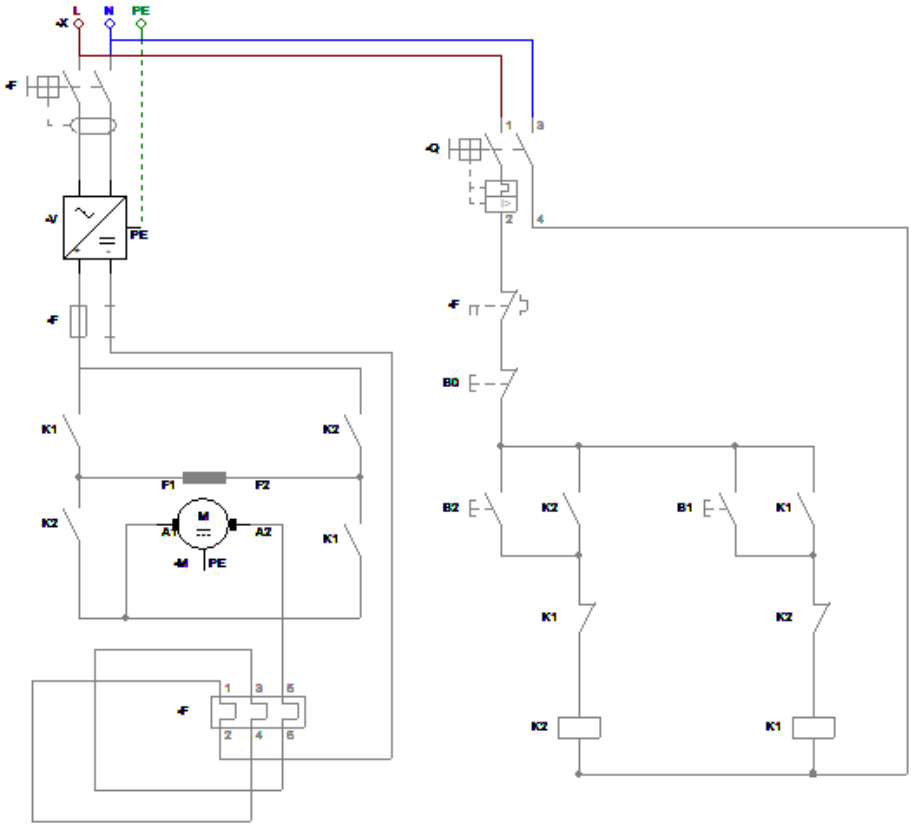
Series Wound DC Motor: Reverse Control



Note

- One single-phase DC power supply for the motor
- Control circuit AC powered
- The use of a three pole overload thermal relay

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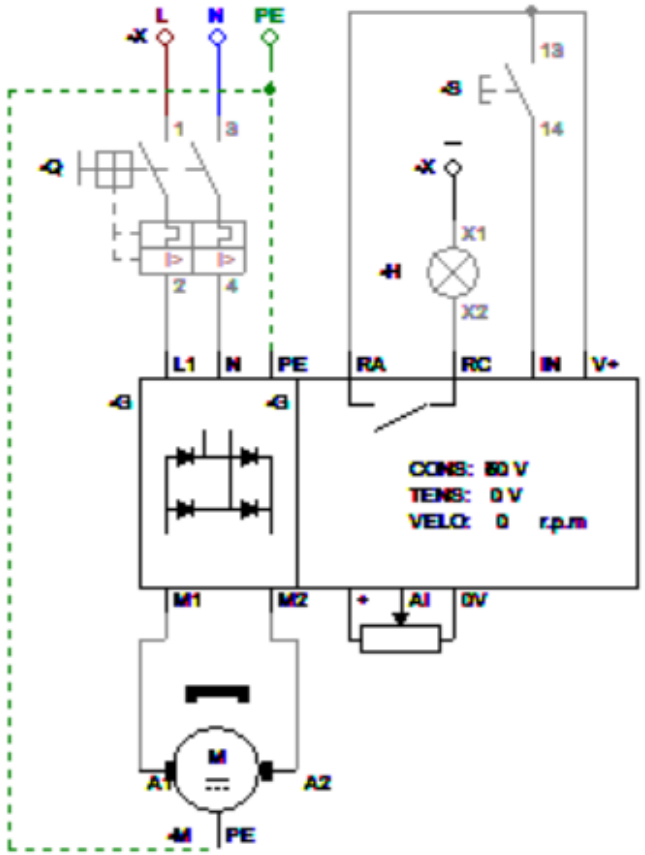
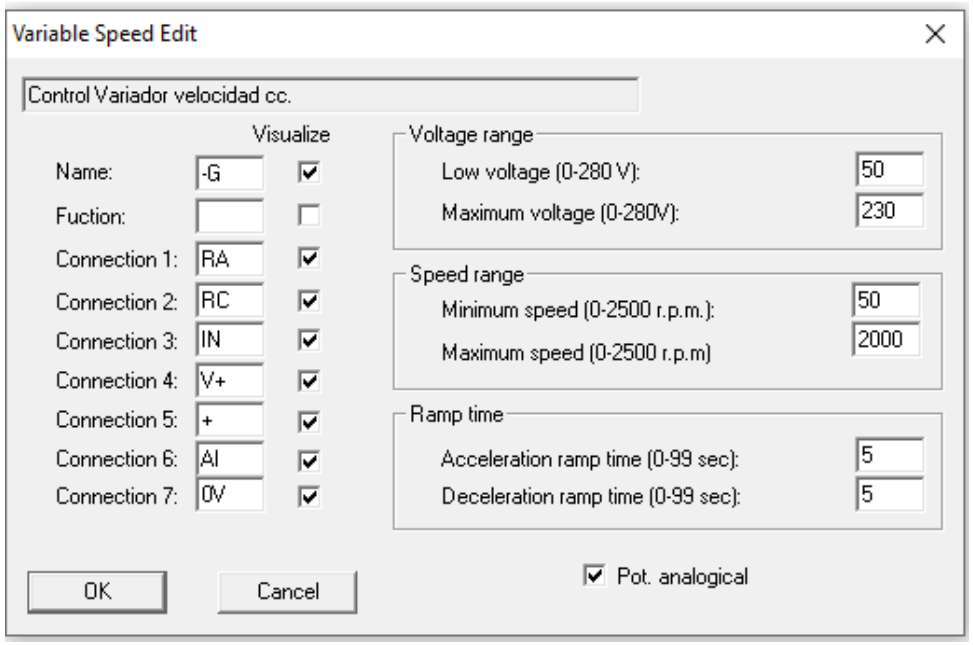
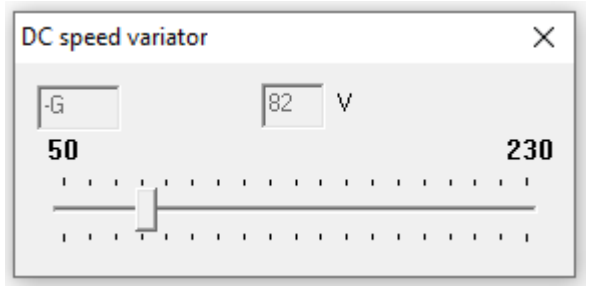
PM DC Motor: Control with Driver







Note

- The use of a single phase powered drive

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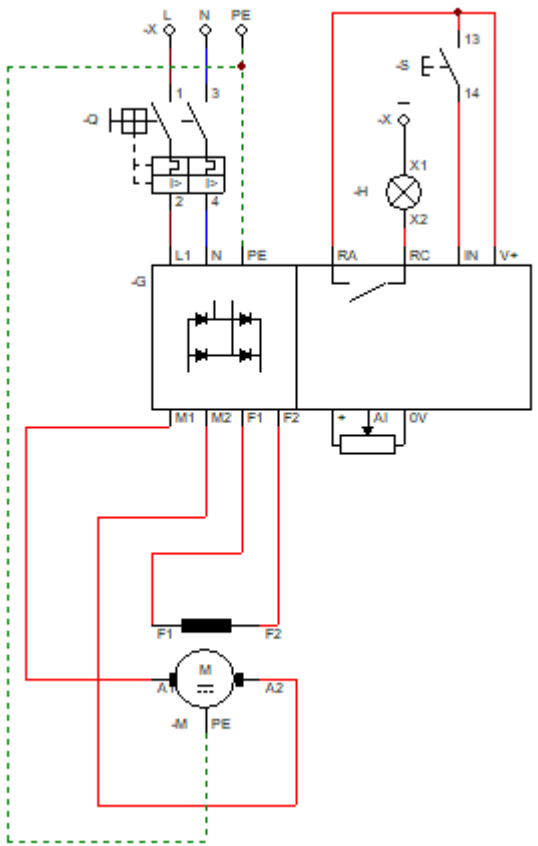
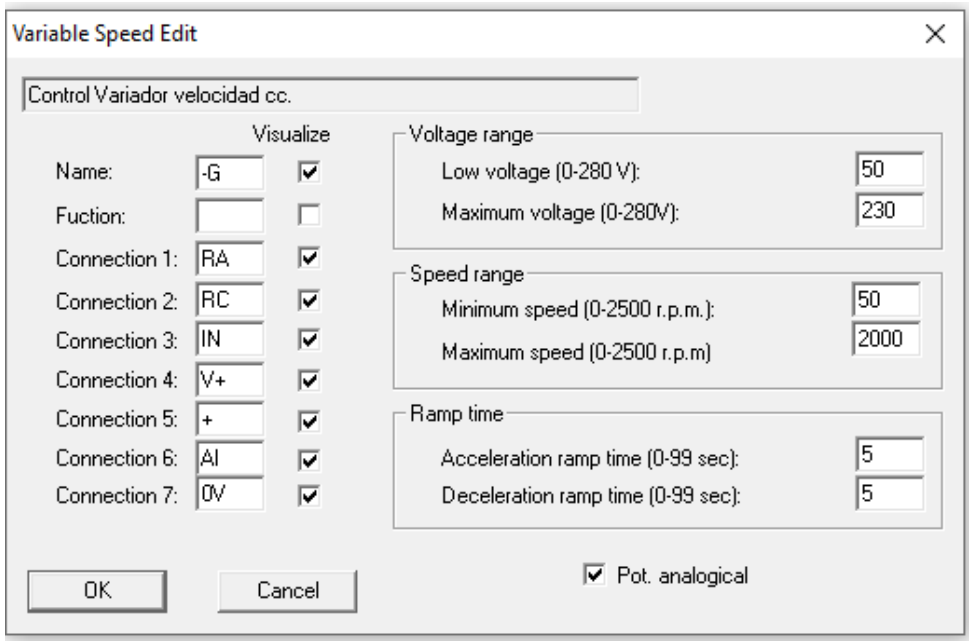
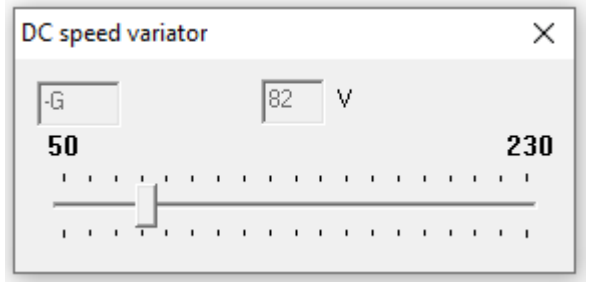
Wound DC Motor: Control with Driver (I)







Note

- The use of a single-phase powered drive

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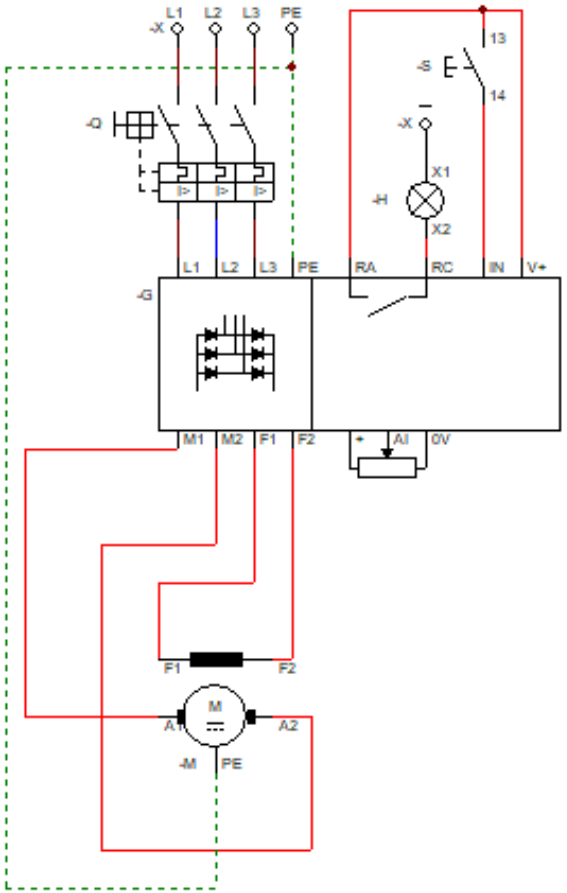
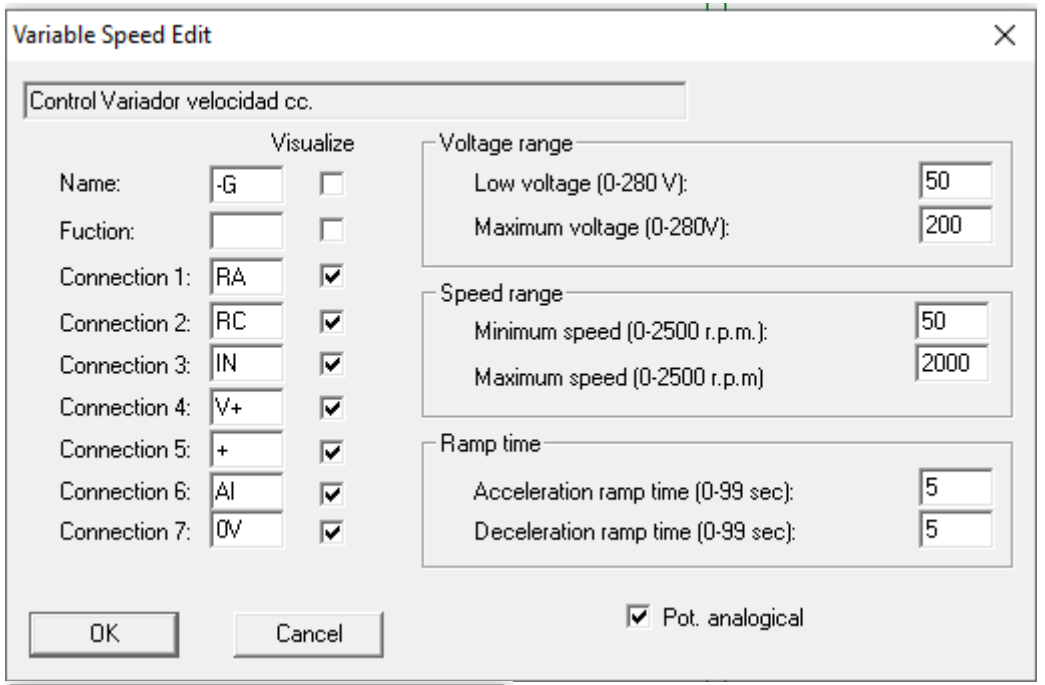
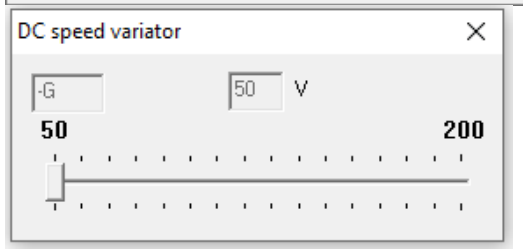
Wound DC Motor: Control with Driver (II)







Note

- The use of a three-phase powered drive

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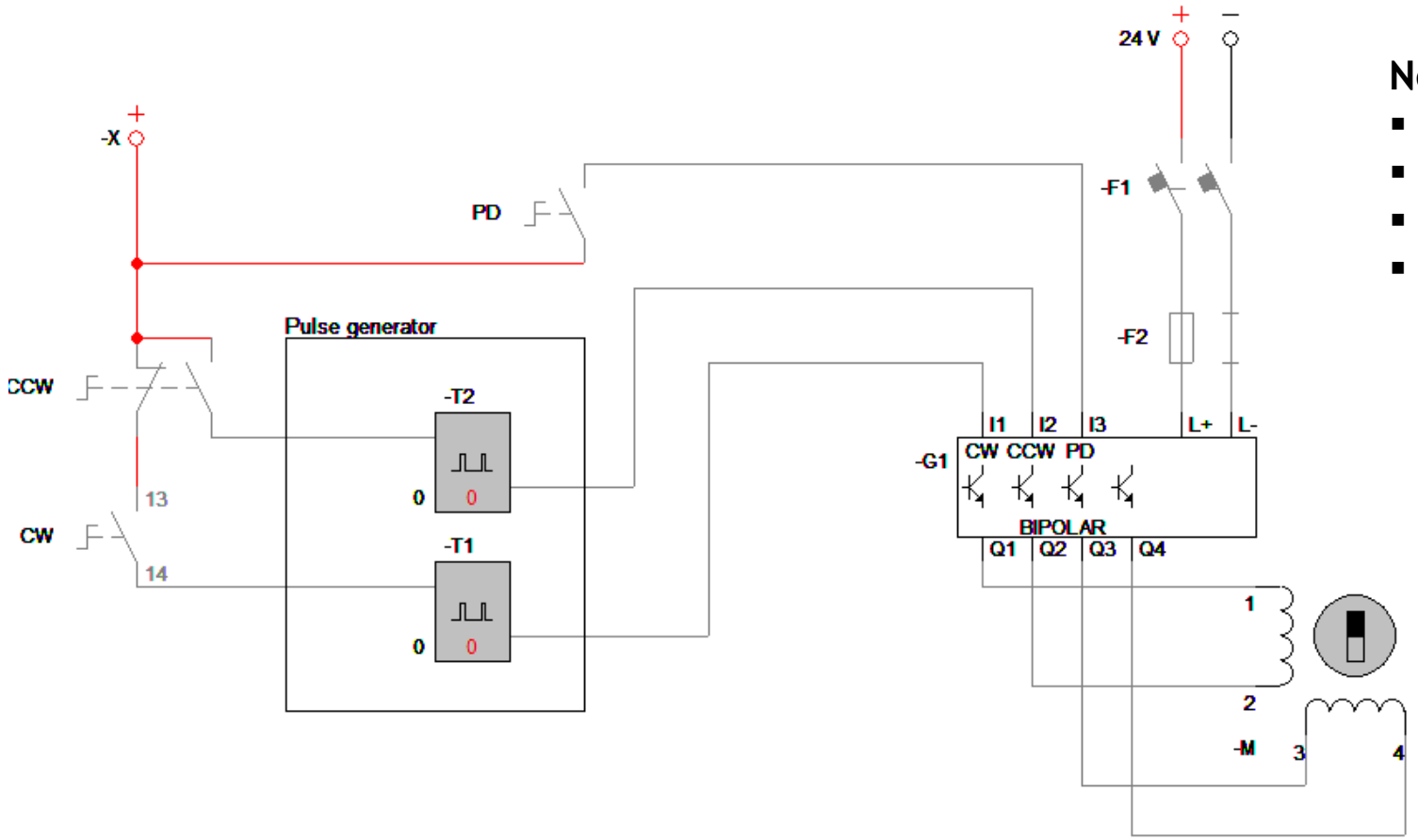
Stepper Motor: Control with Bipolar Driver



Note

- Two-phase, four wires, stepper motor
- Bipolar driver
- Pulse generator
- Motor command with three signals: CW, CCW, PD (enable/disable)

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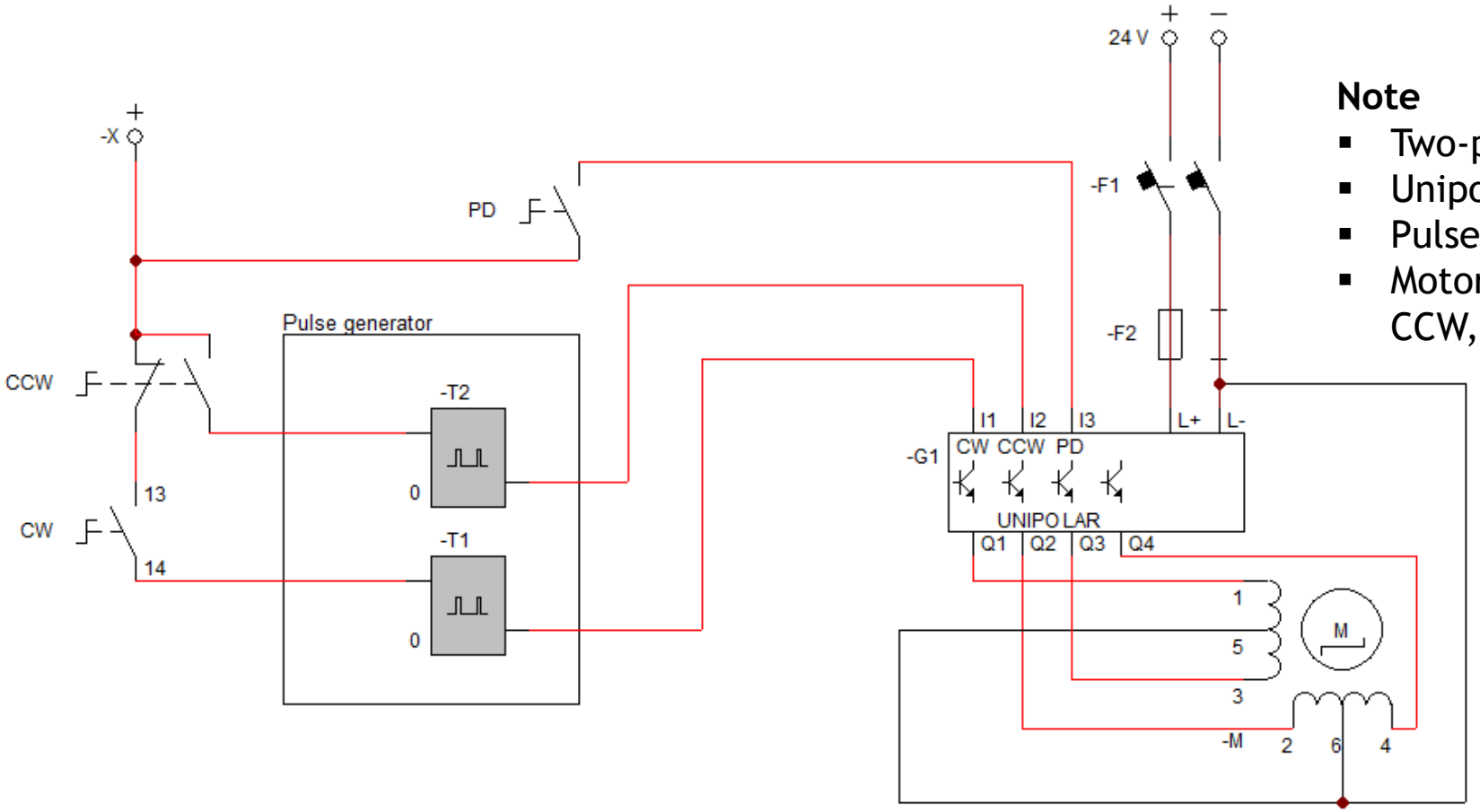
Stepper Motor: Control with Unipolar Driver (I)



Note

- Two-phase, six wires, stepper motor
- Unipolar driver
- Pulse generator
- Motor command with three signals: CW, CCW, PD (enable/disable)

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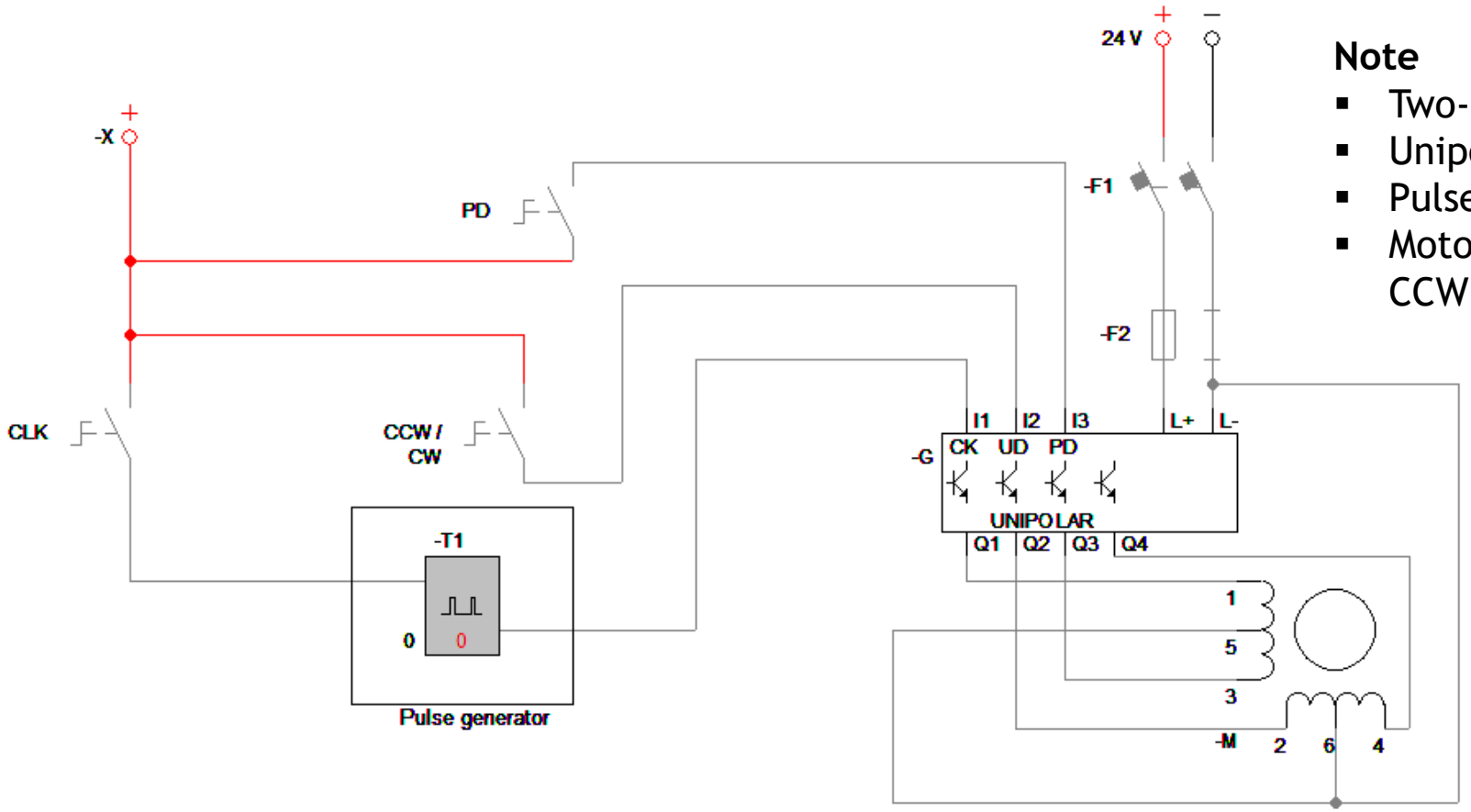
Stepper Motor: Control with Unipolar Driver (II)



Note

- Two-phase, six wires, stepper motor
- Unipolar driver
- Pulse generator
- Motor command with three signals: CLK, CCW/CW, PD (enable/disable)