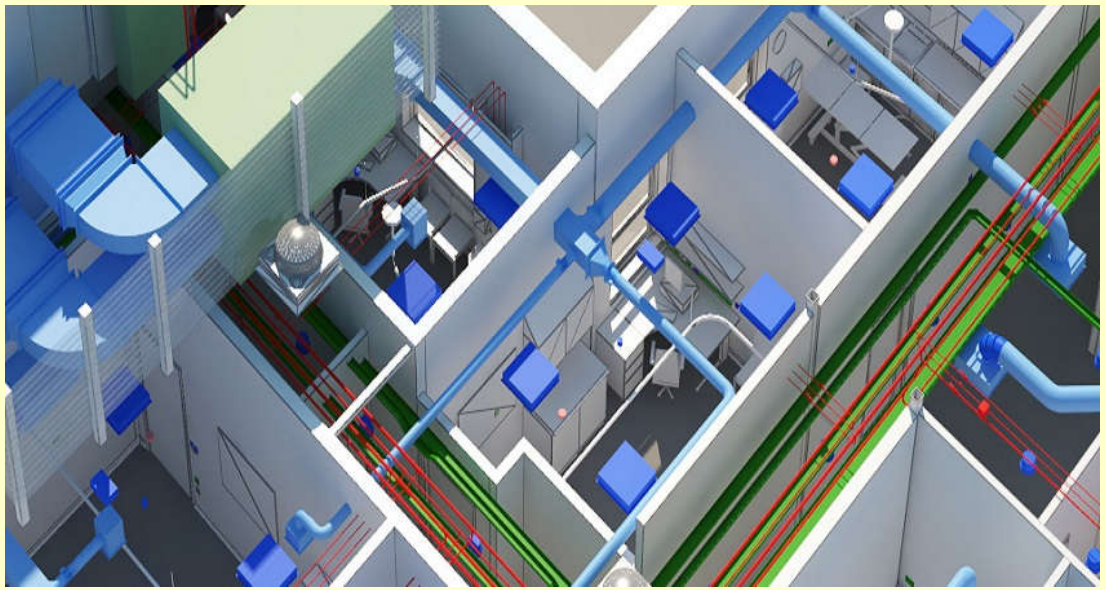

6. HVAC Part 2
6.2 Electrical system for HVAC

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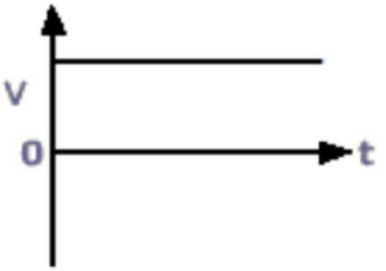
Nov 2020

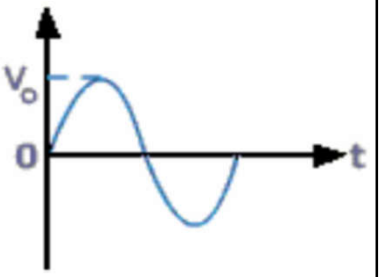
Contents 內容

- Basic electrical fundamentals 基本電氣原理
- Loads and controls 負載和控制
- Motors in HVAC systems 暖通空調系統中的電機
- Variable speed drives 變速驅動器

Basic electrical fundamentals

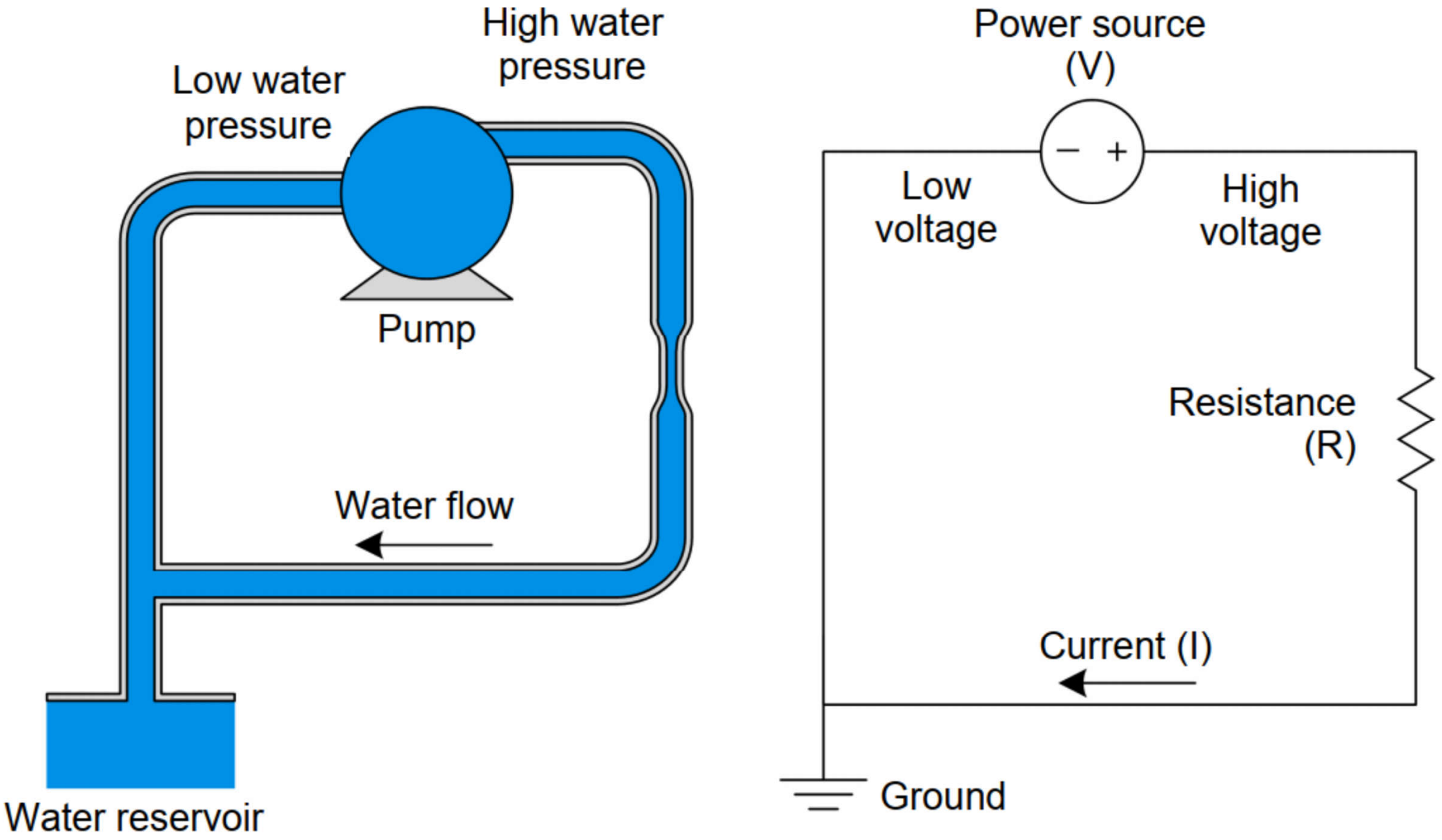
- Electricity in two common forms:
  - AC (alternating current)
  - DC (direct current)



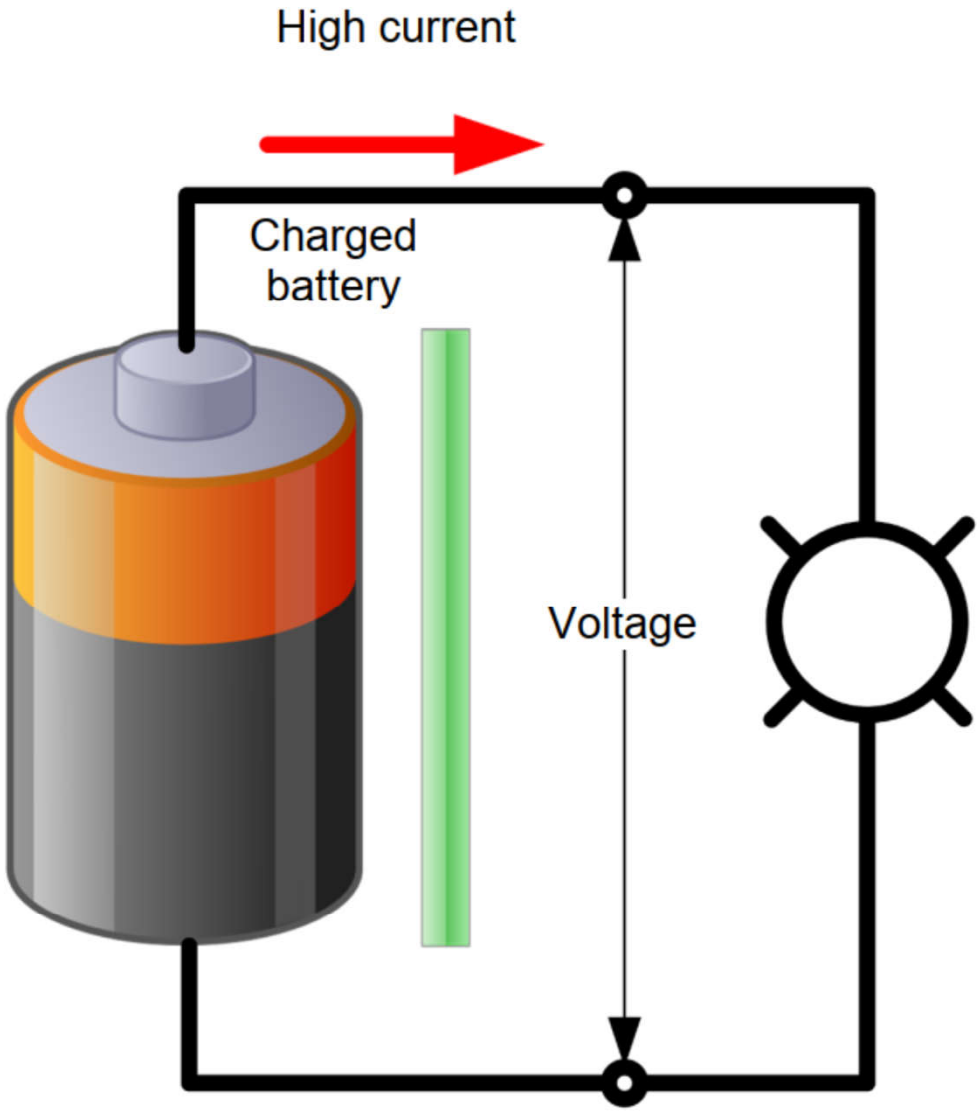


- Basic components of electrical energy:
  - Voltage (V): electrical potential difference
  - Current (I): flow of electrons (in amperes)
  - Resistance (R): opposition to electron flow (in ohms)
- Ohm's Law: $V = I \times R$

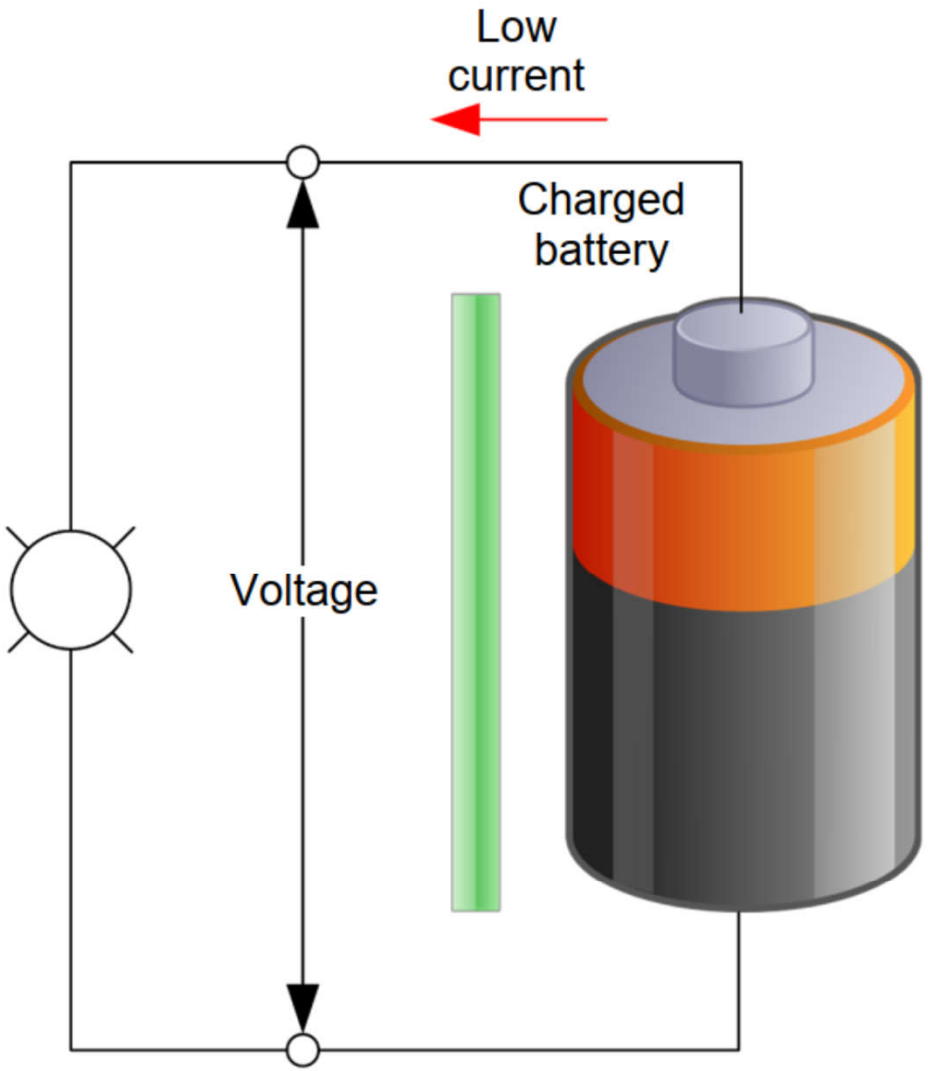
Water and electrical circuit analogy



Relationships between current and resistance in circuits connected using wires

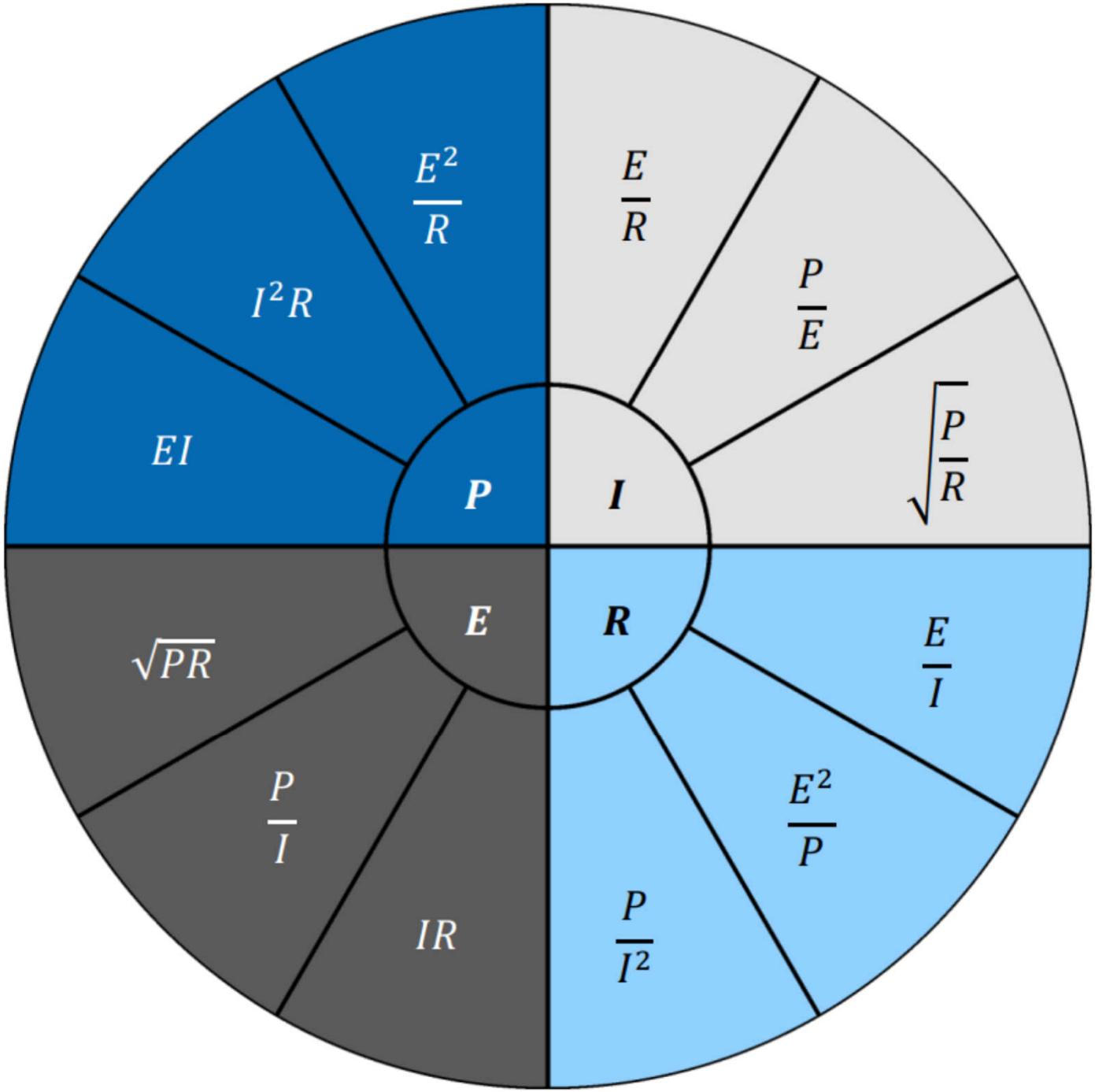


(a) Battery connected to a low-resistance circuit

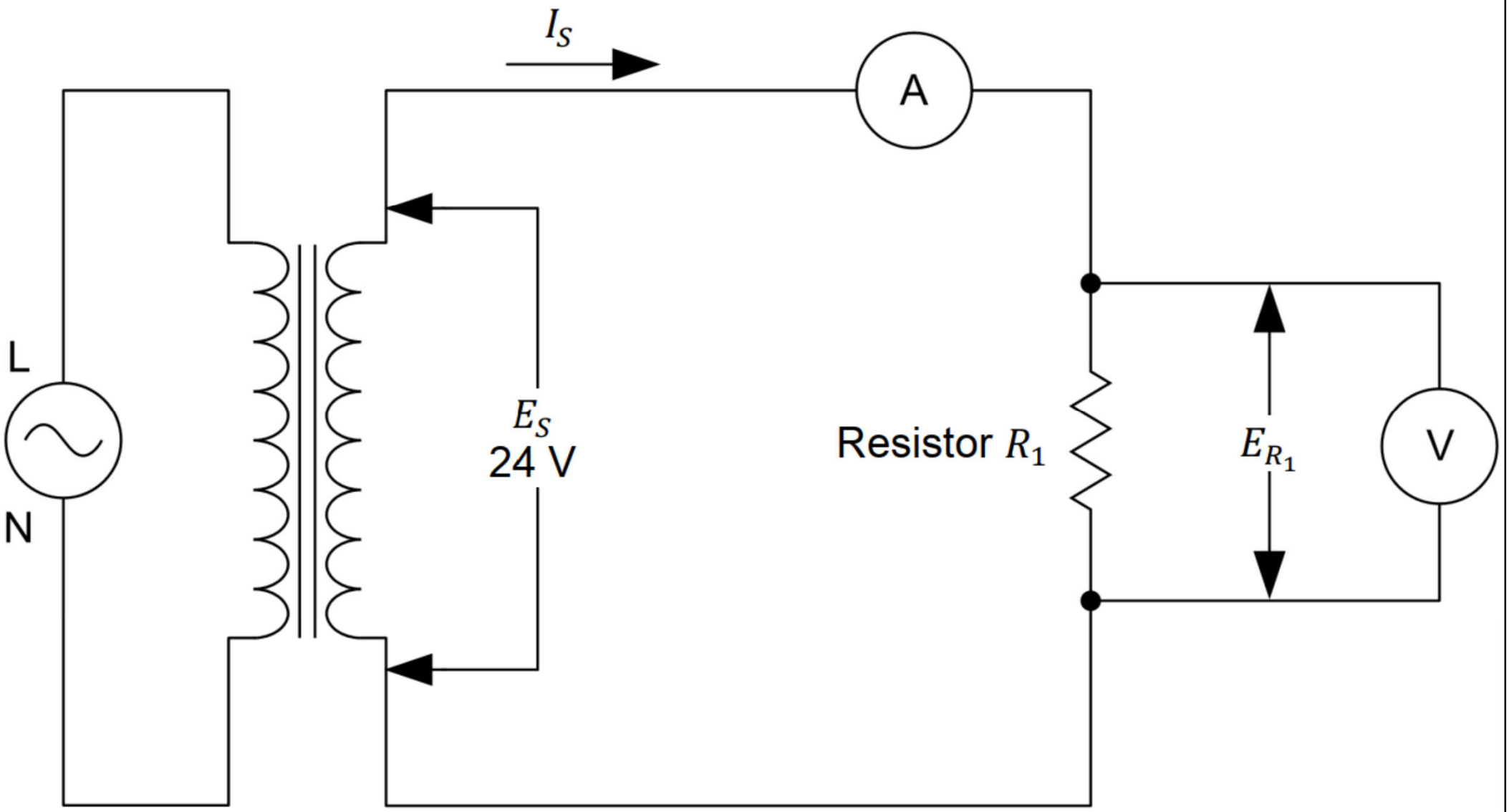


(b) Battery connected to a high-resistance circuit

Chart for calculating voltage, current, resistance, and power from any two other

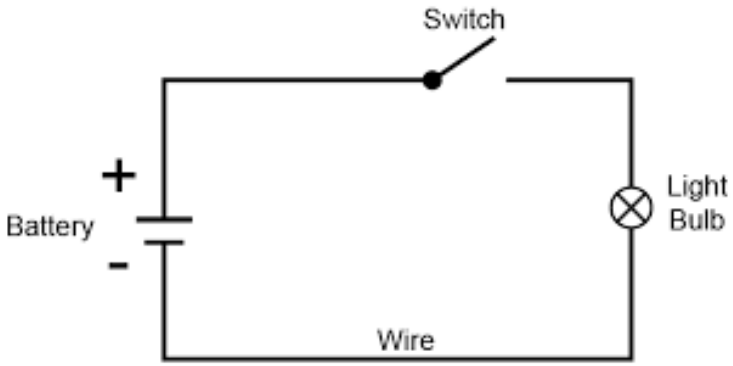


Example of an electrical circuit diagram



Basic electrical fundamentals

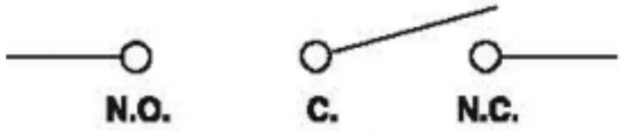
- Elementary types of circuits:
  - Series: carry the same current
  - Parallel: have the same voltage
  - Open: an incomplete circuit
  - Short: an alternative path to return
  - Power: carry power to electrical loads
  - Control: use control devices (usually lower voltage)
- Power consumption, power factor



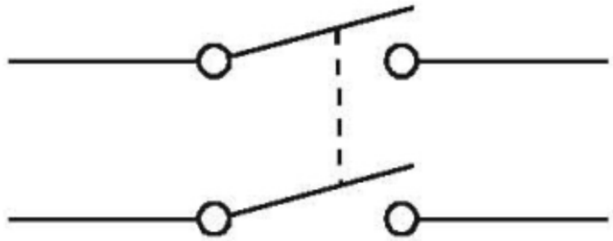
Basic electrical fundamentals

- Switches
  - Control devices connected with the loads
  - Normally open (N.O.) / normally closed (N.C.)
  - Poles: number of contacts
  - Throw: how many operating positions

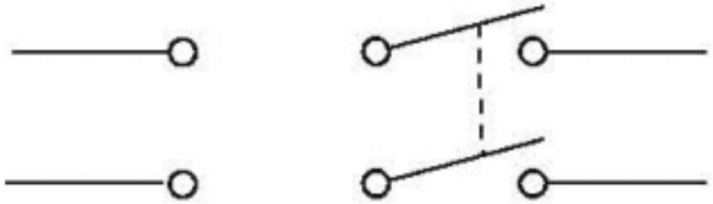
Single Pole, Single Throw (S.P.S.T.) Switch



Single Pole, Double Throw (S.P.D.T.) Switch



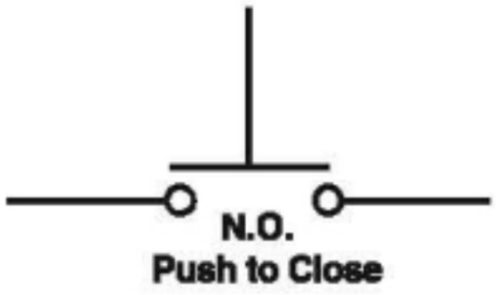
Double Pole, Single Throw (D.P.S.T.) Switch

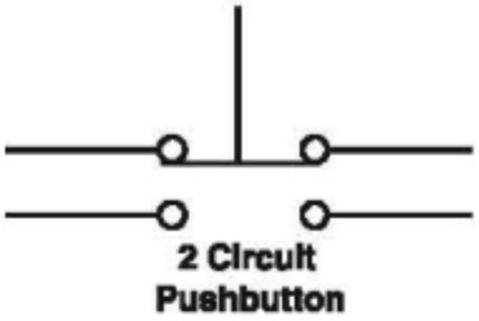


Double Pole, Double Throw (D.P.D.T.) Switch

Basic electrical fundamentals

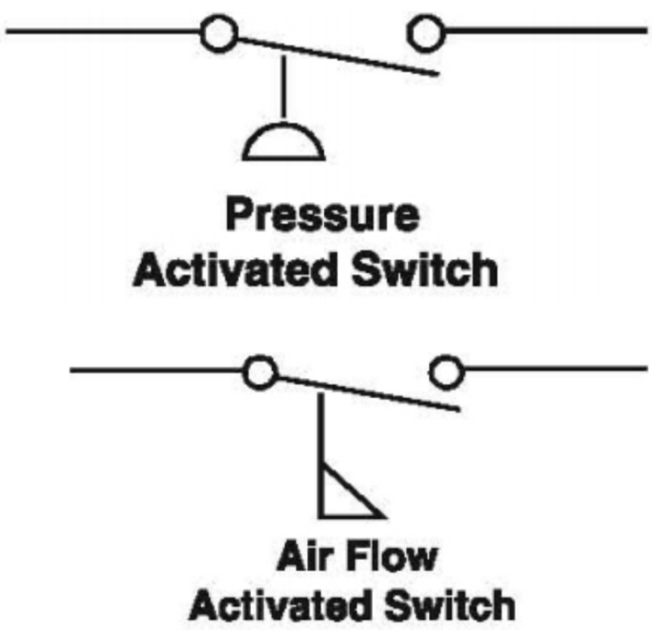
- Automatic switches & controls
  - Operating controls: used to activate a circuit
  - Safety controls: used to de-activate a circuit when something goes wrong (‘trip’)
- Push button





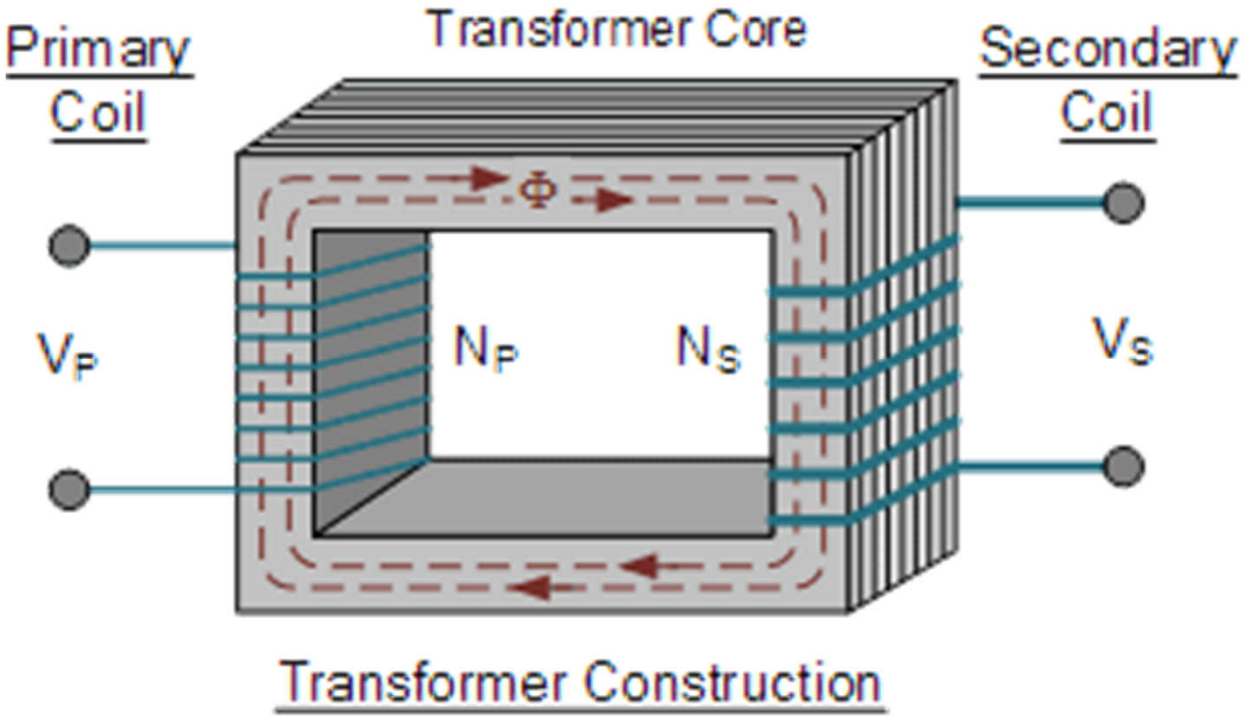
Basic electrical fundamentals

- Thermostats
  - Temperature-controlled switches
- Pressure switches
  - Air pressure switches
  - Refrigerant pressure switches
- Flow switches
  - Detect the flow of air & water
- Fuses and overloads: safety devices (e.g. for motors)

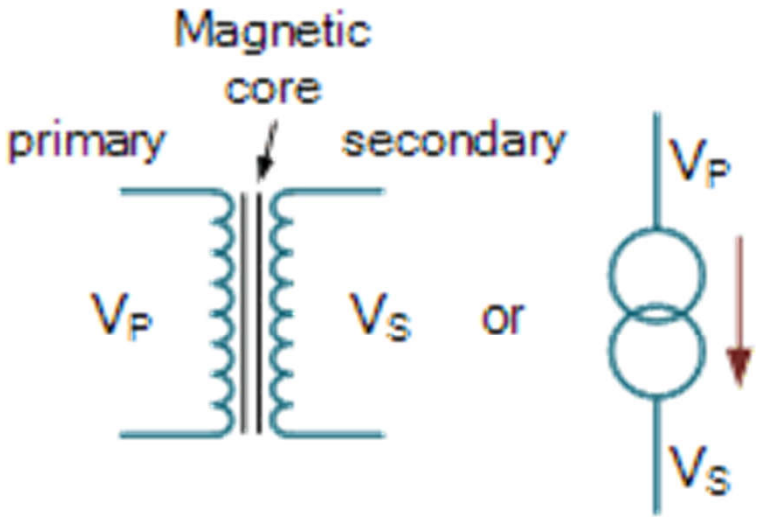


Basic electrical fundamentals

- Transformers
  - The source of control circuit voltage comes from the step-down transformer

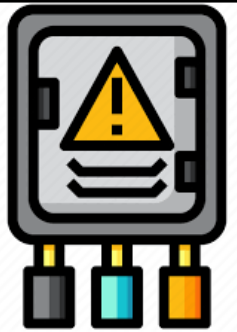


Transformer Construction

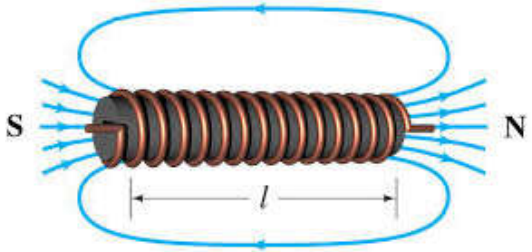


Transformer Symbols

Loads and controls

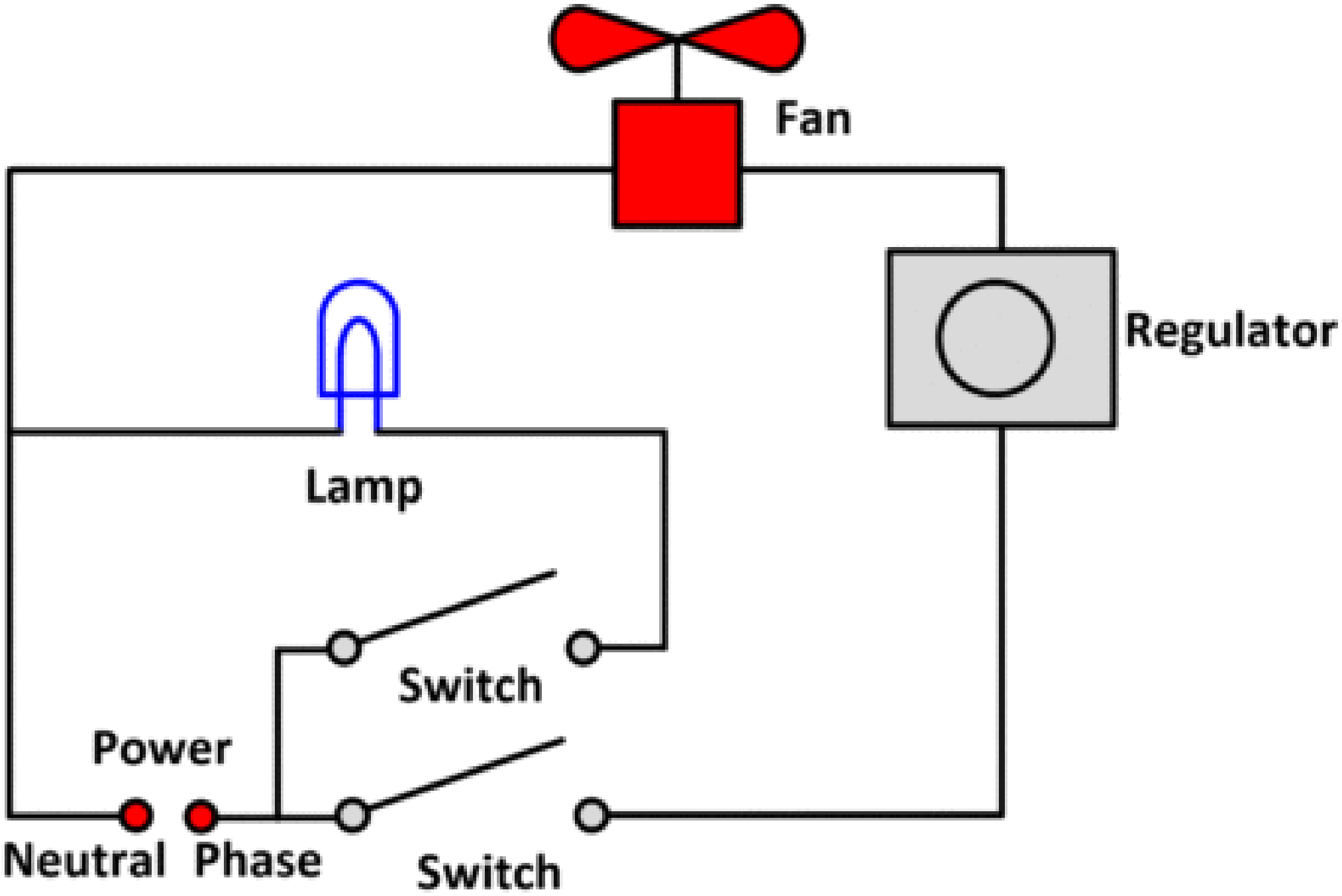


- Solenoids
  - A coil of wire that creates strong magnetic fields when voltage is applied



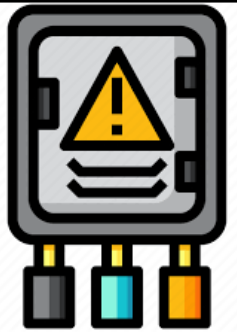
- Heaters
  - Such as resistive heaters in air handler, crankcase heaters for air conditioning compressors
- Signal lights (low voltage)
  - Neon bulbs with different colours
    - Green, blue, amber, red

Fan control wiring diagram



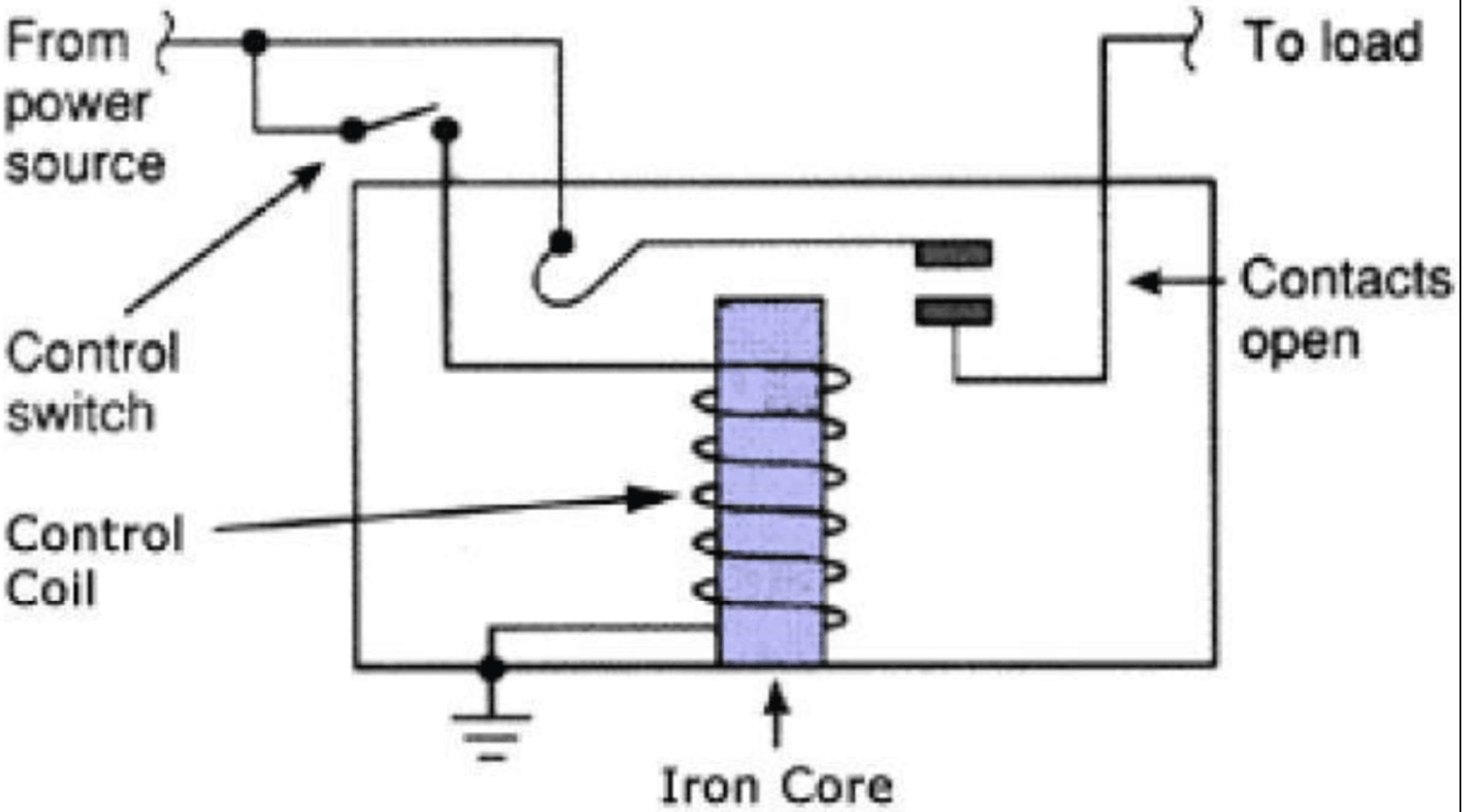
[Source: https://electricalacademia.com/control-systems/wiring-diagram-schematic-diagram-plc-ladder-diagram/]

Loads and controls



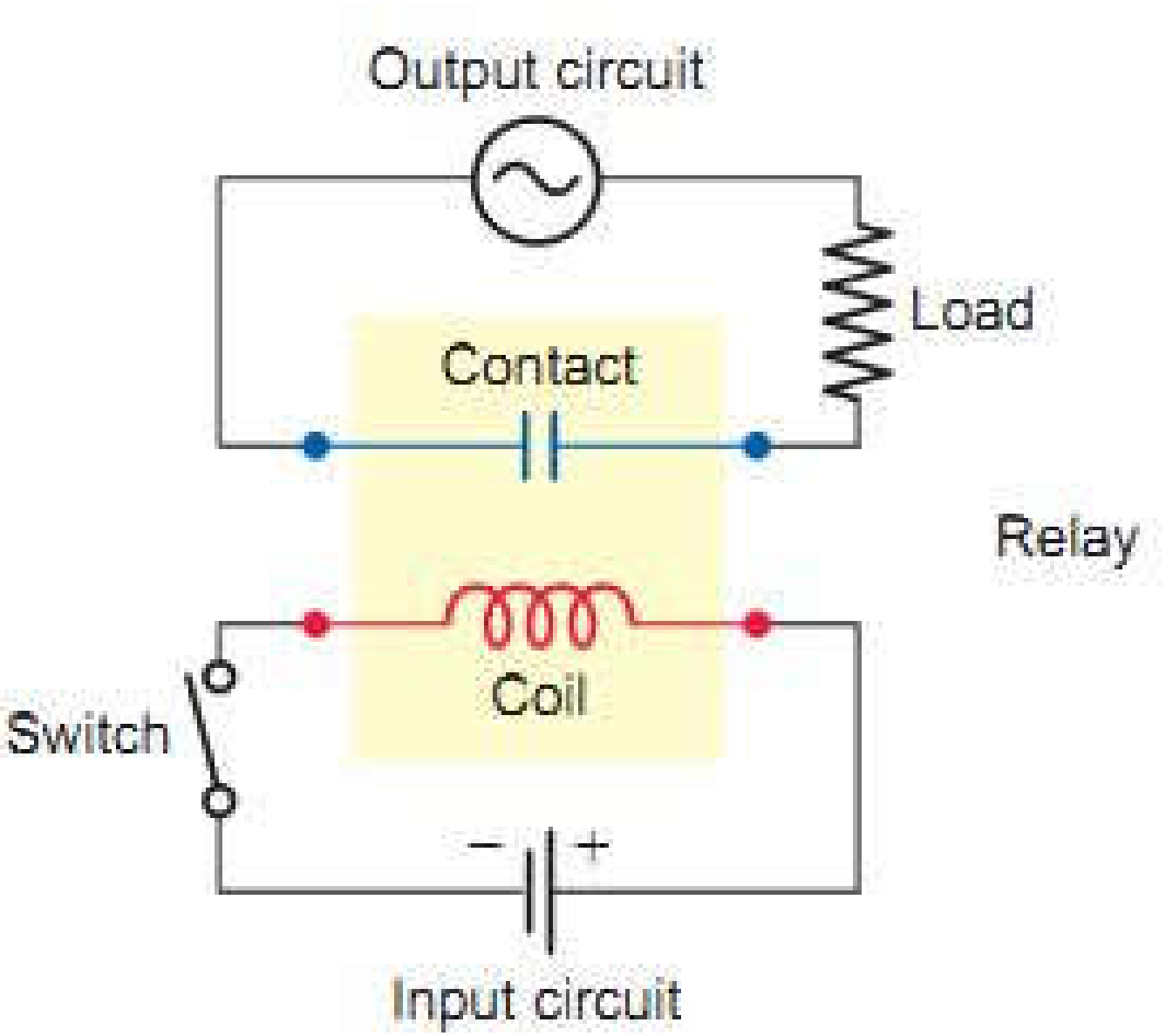
- Magnetic controllers (used to control the load)
  - Control relays
    - To operate control circuits & light duty loads
  - Fan duty relays
    - Service duty relays used to control fan motors
  - Contactors
    - Close heavy contacts to control high current in a compressor & condenser fan circuit

Control relay circuit diagram



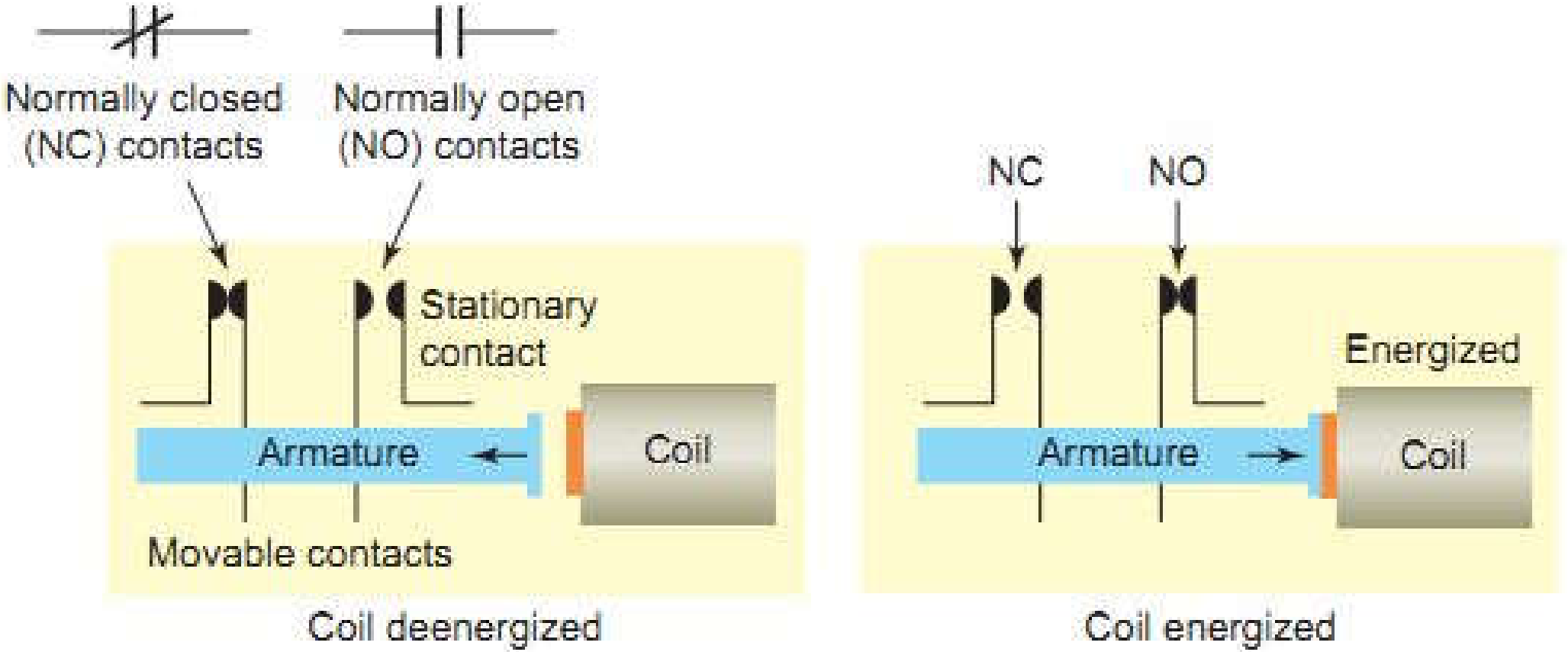
[Source: https://www.electgo.com/control-relay/]

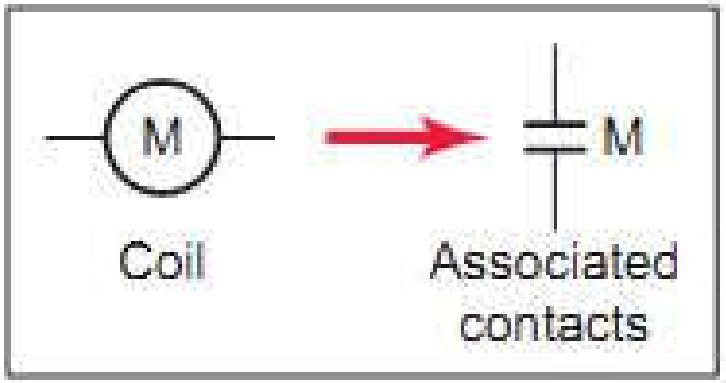
Electromechanical control relay: Input circuit; Output circuit; Contact

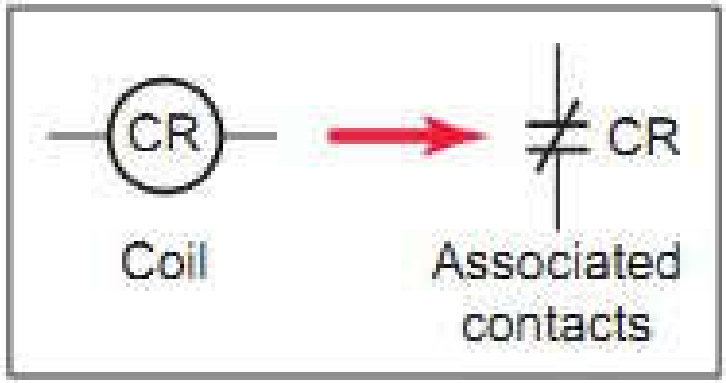


[Source: http://www.industrial-electronics.com/electric_mts--cntrl_syst--7.html]

Relay coil and contacts

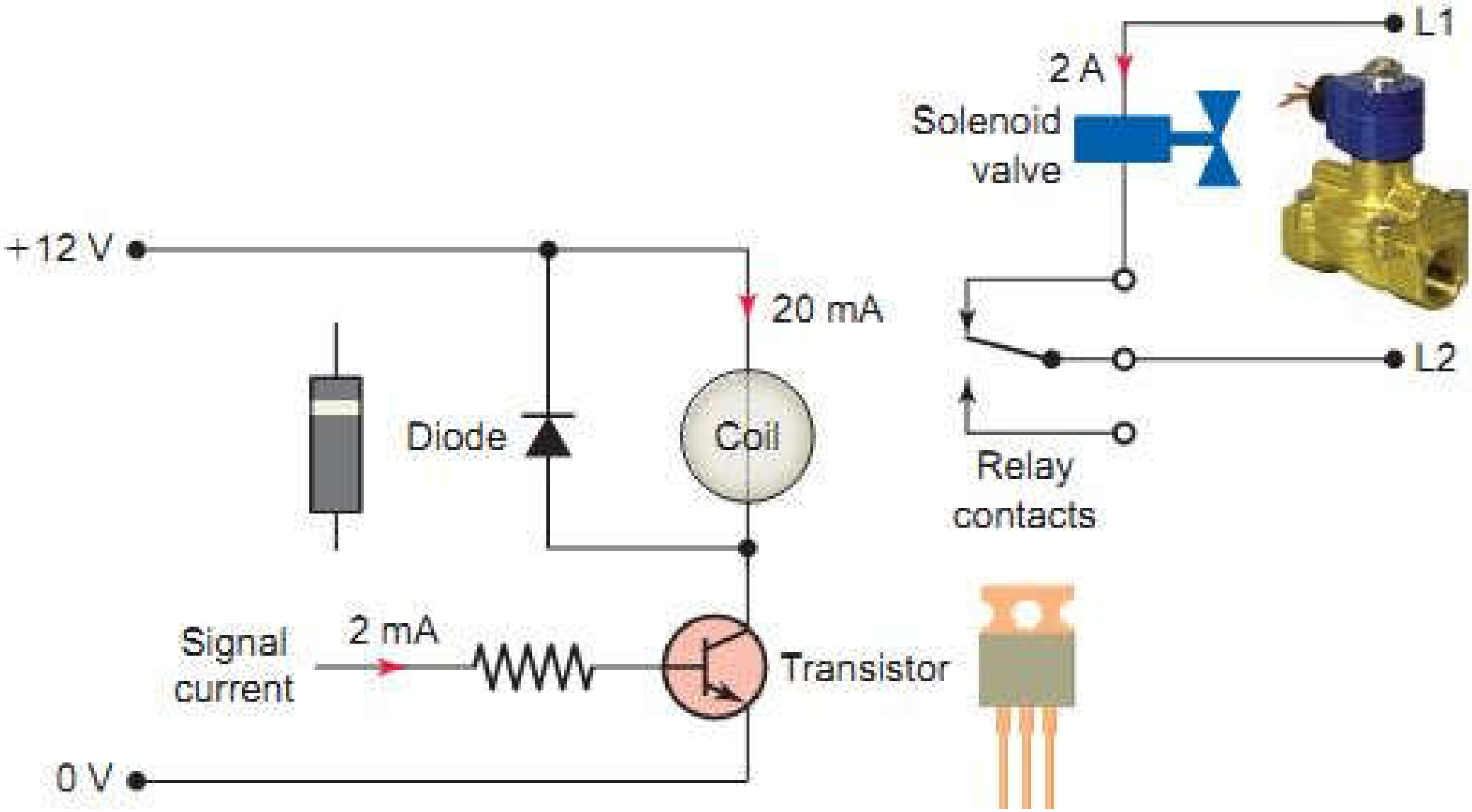






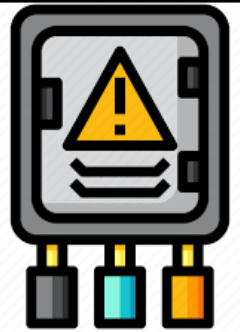
[Source: http://www.industrial-electronics.com/electric_mts--cntrl_syst--7.html]

Using a relay to control a high-current load circuit with a low-current control circuit



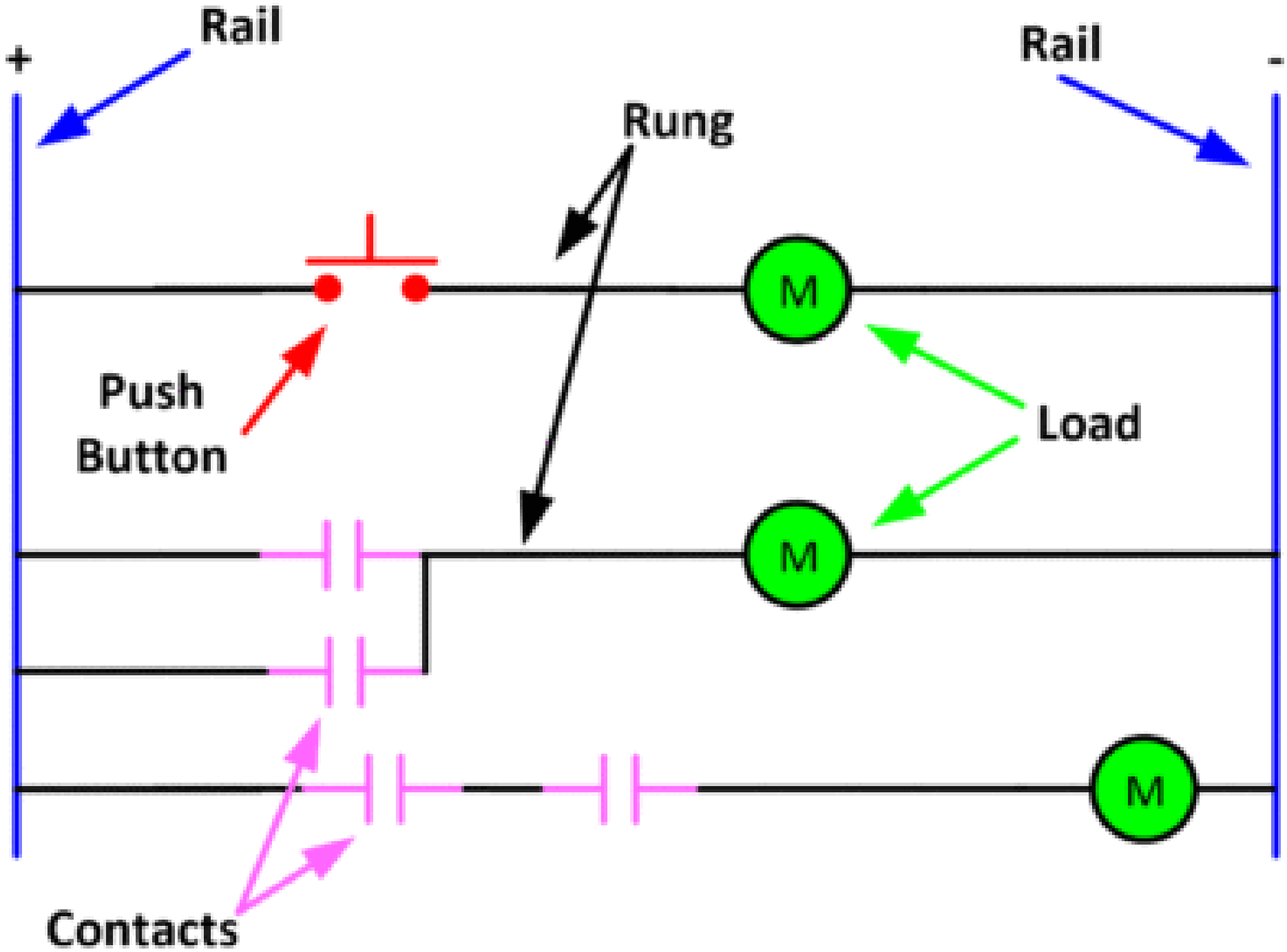
[Source: http://www.industrial-electronics.com/electric_mts--cntrl_syst--7.html]

Loads and controls



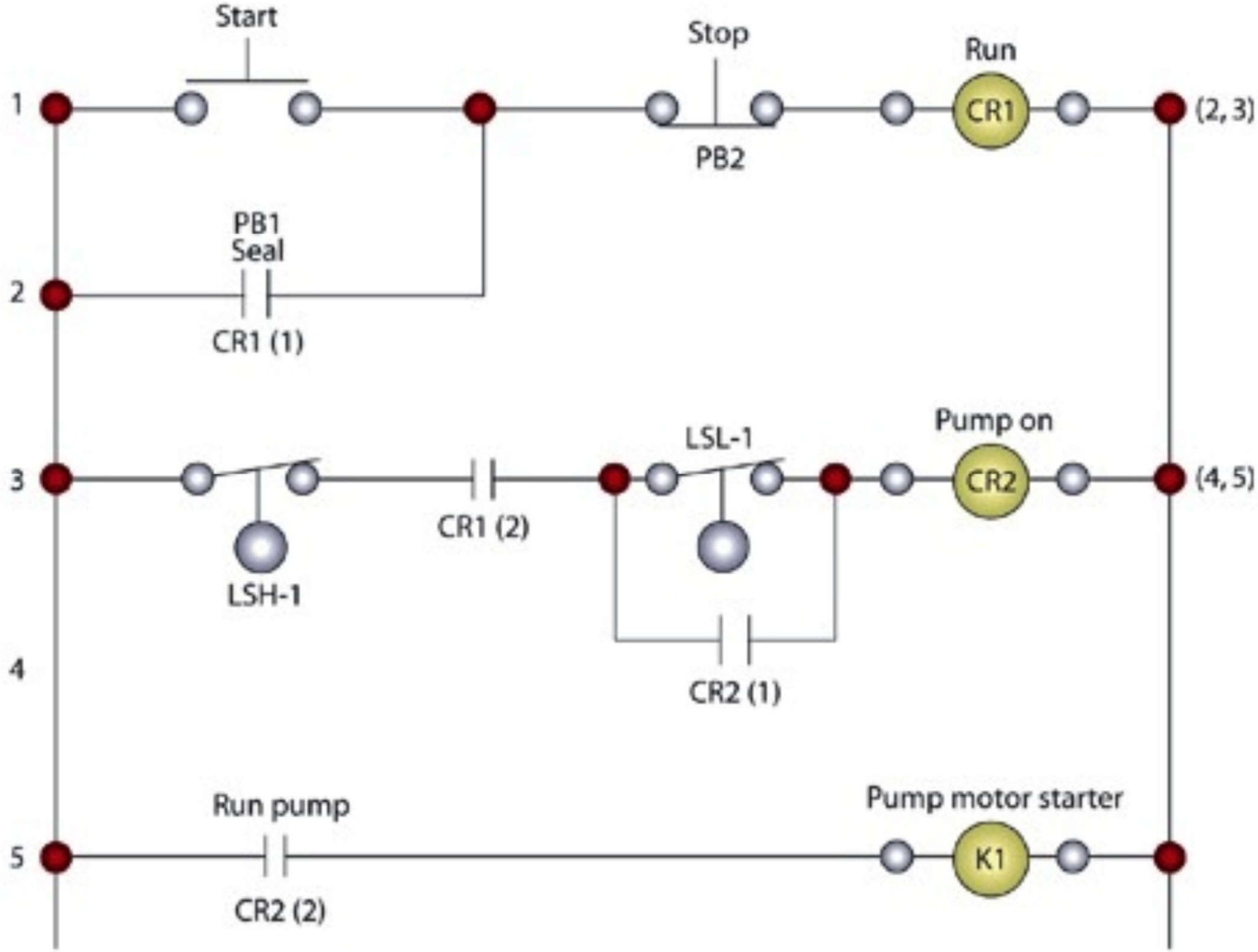
- Electrical wiring diagrams for HVAC systems
  - Ladder diagram
  - Line diagram
  - Installation diagram
  - Wiring diagram
- Two basic configurations in the schematic diagrams
  - Side-by-side arrangement
  - Up-and-down arrangement

Ladder diagram



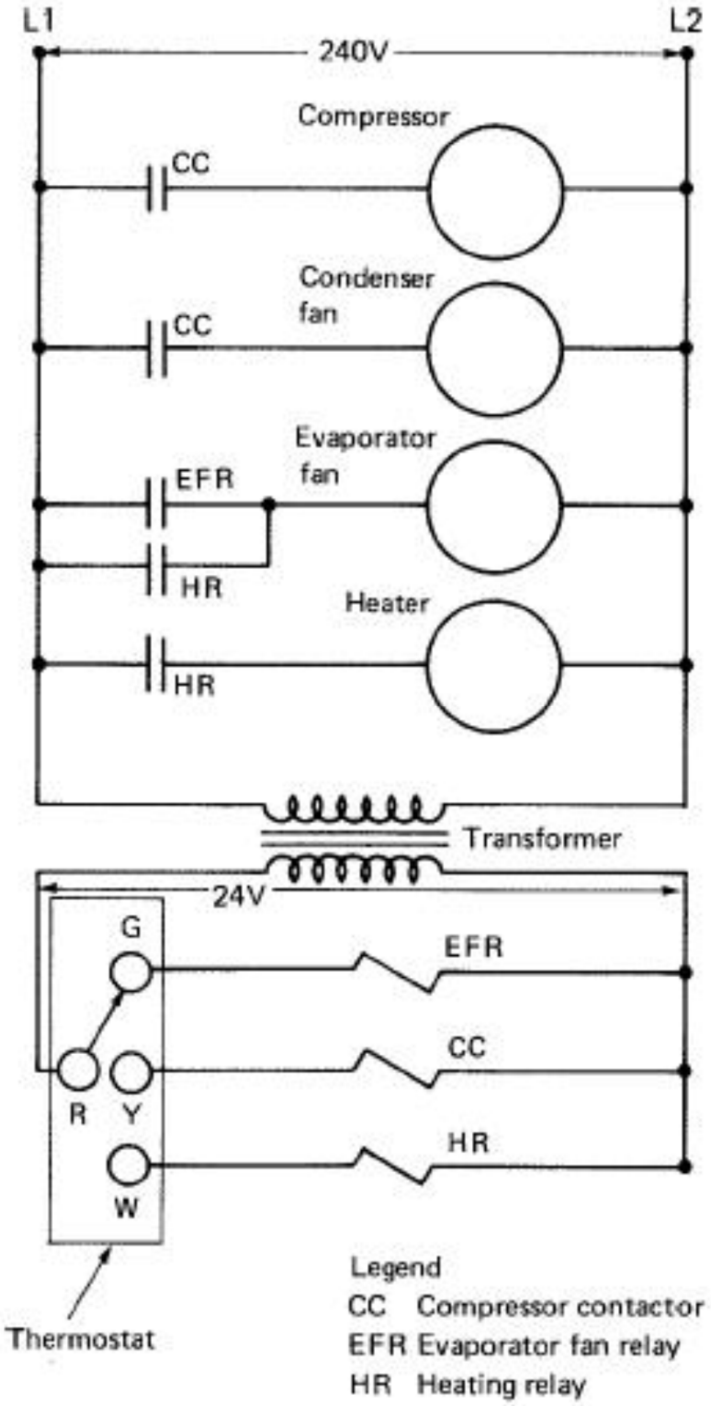
[Source: https://electricalacademia.com/control-systems/wiring-diagram-schematic-diagram-plc-ladder-diagram/]

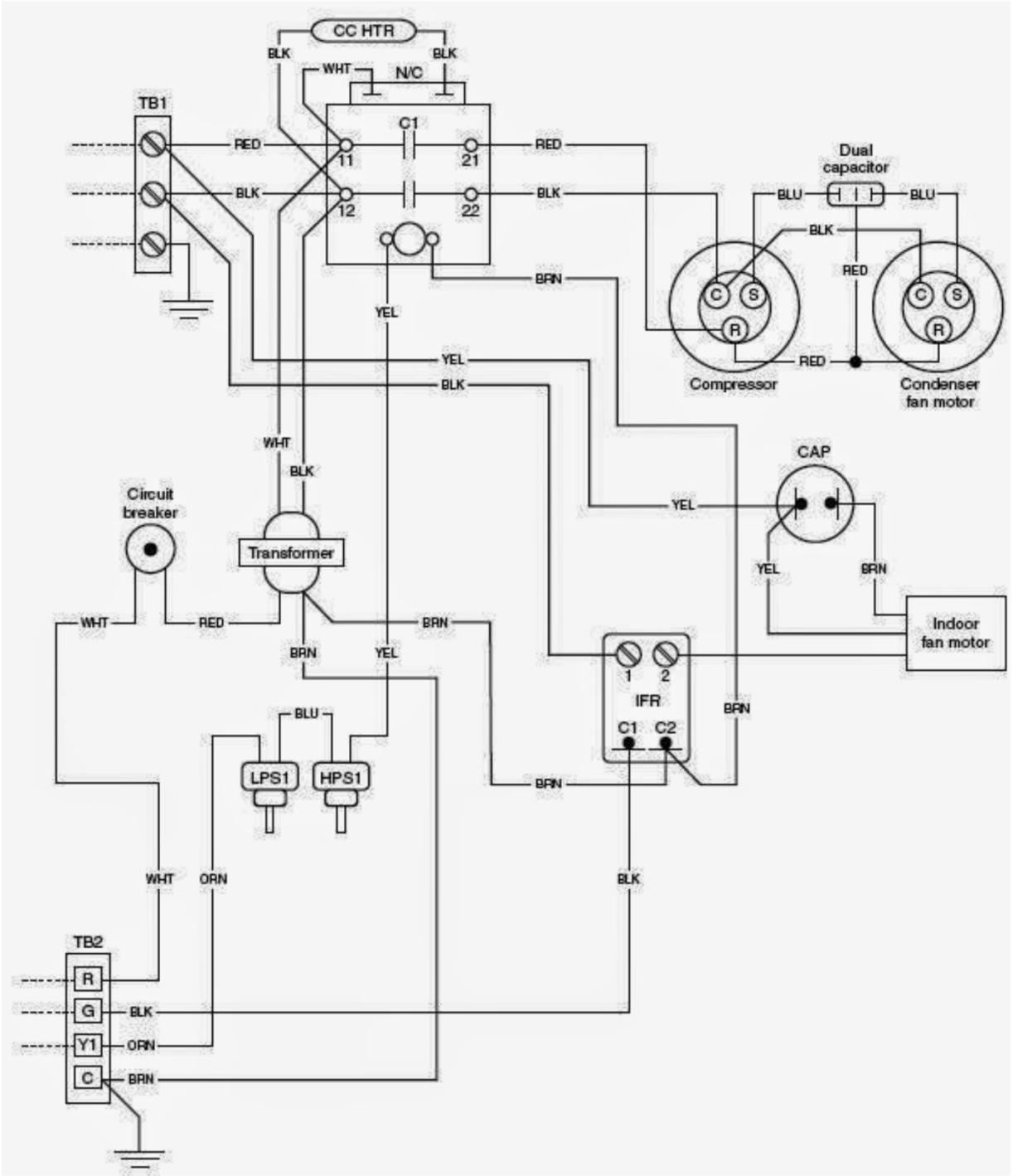
Ladder diagram for pump control



[Source: http://www.electrical-knowhow.com/2012/12/electrical-single-line-diagram-part.html]

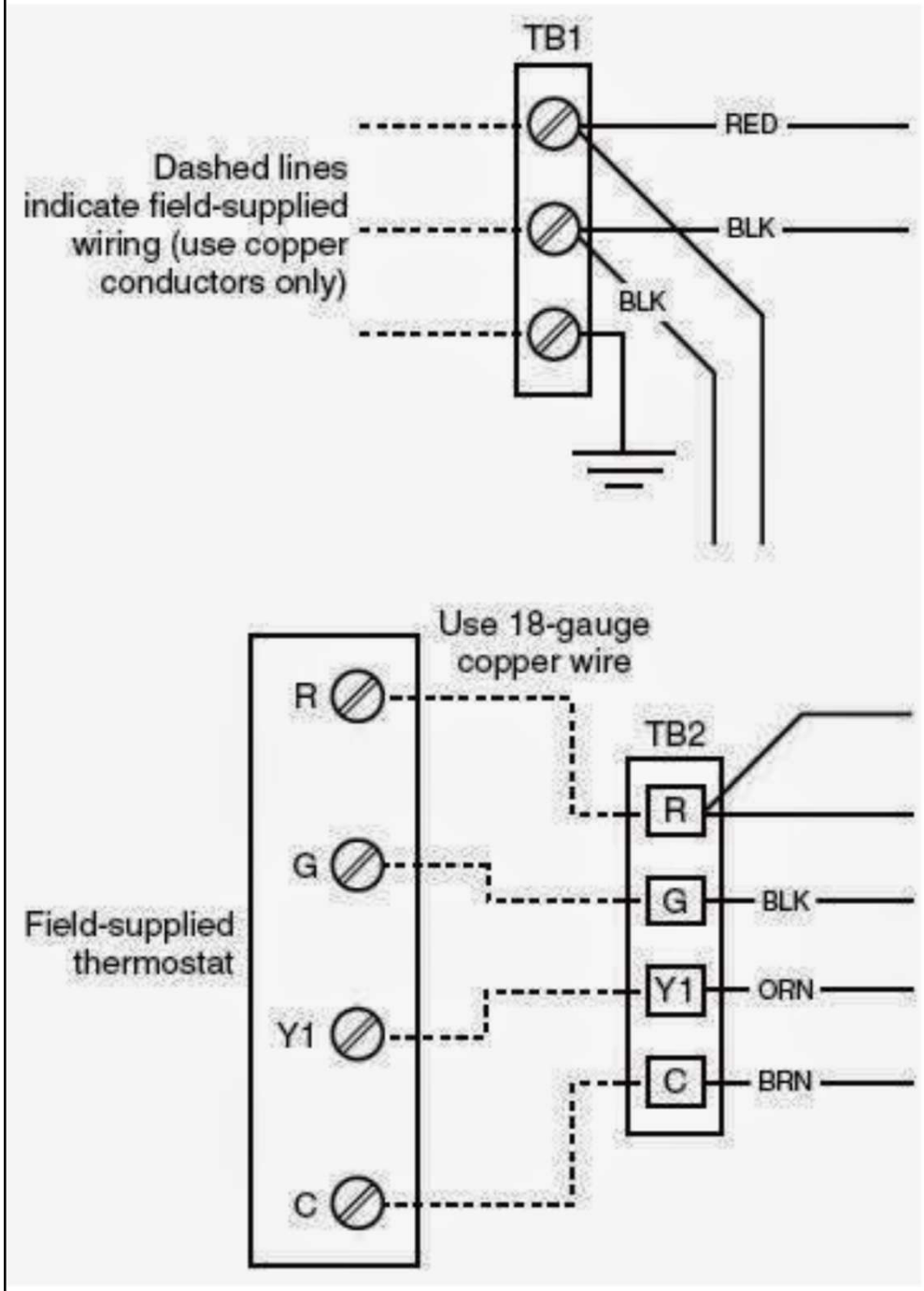
Ladder and line diagrams for HVAC systems

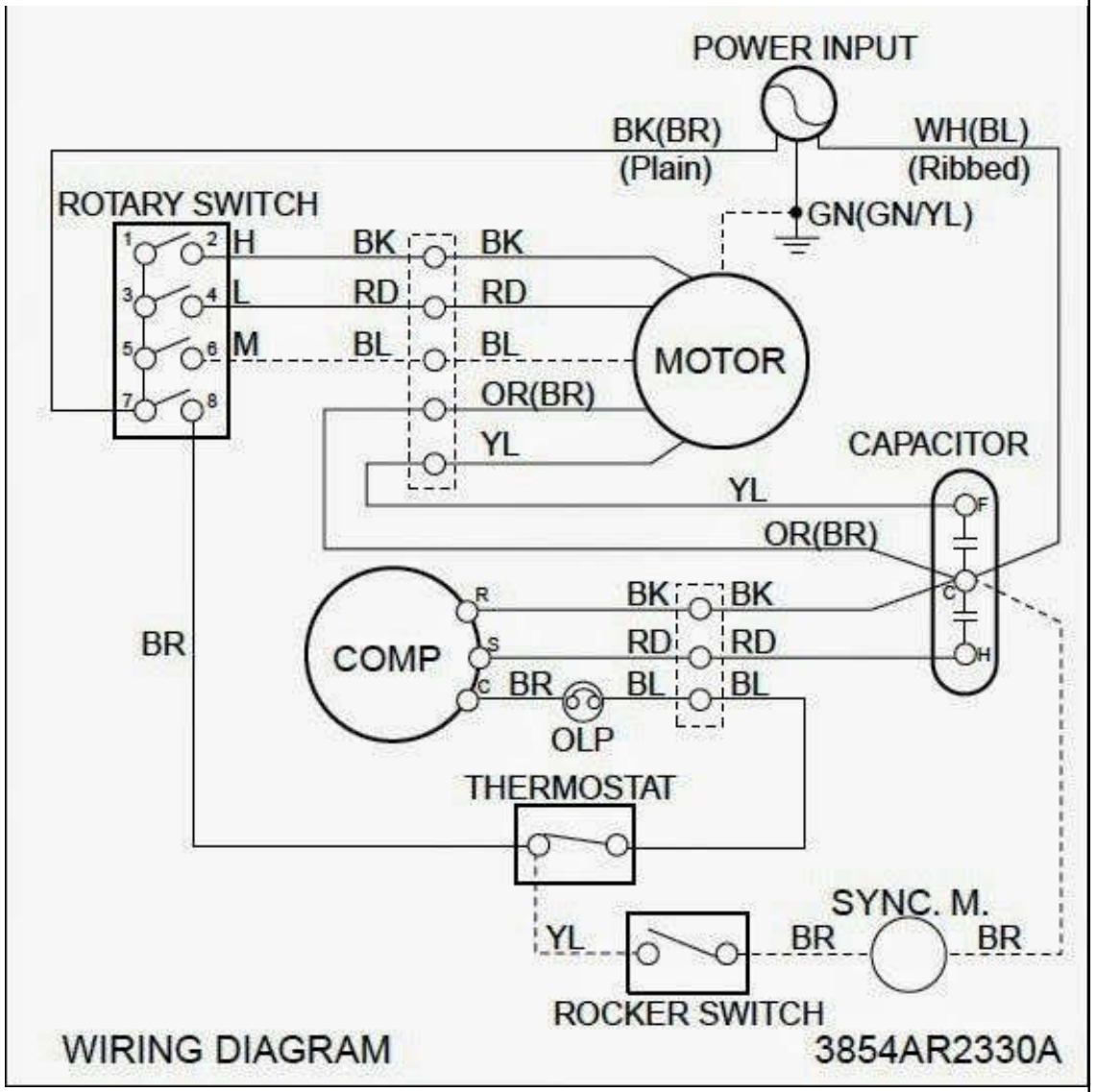




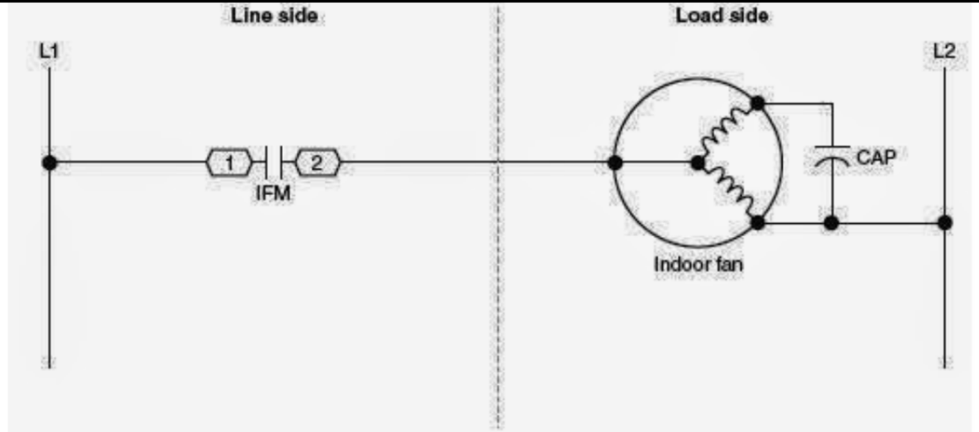
[Source: http://www.electrical-knowhow.com/2014/05/How-to-read-Electrical-Wiring-Diagrams.html]

Installation and wiring diagrams

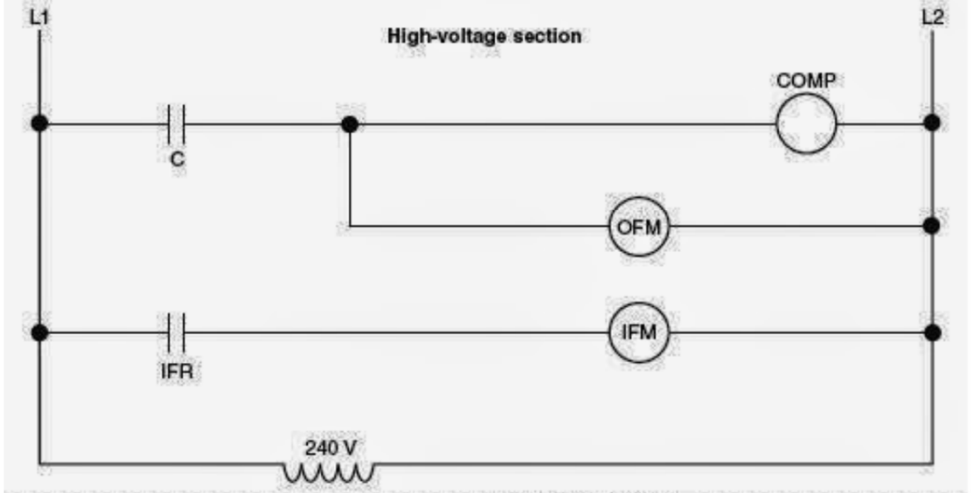




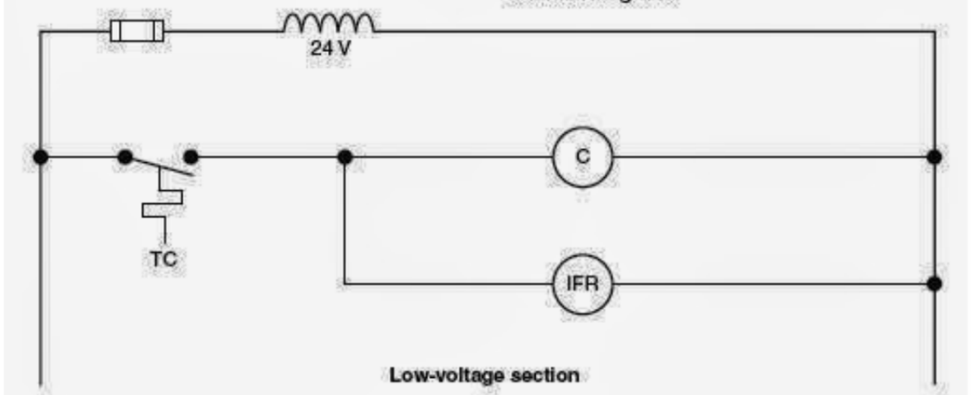
[Source: http://www.electrical-knowhow.com/2014/05/How-to-read-Electrical-Wiring-Diagrams.html]



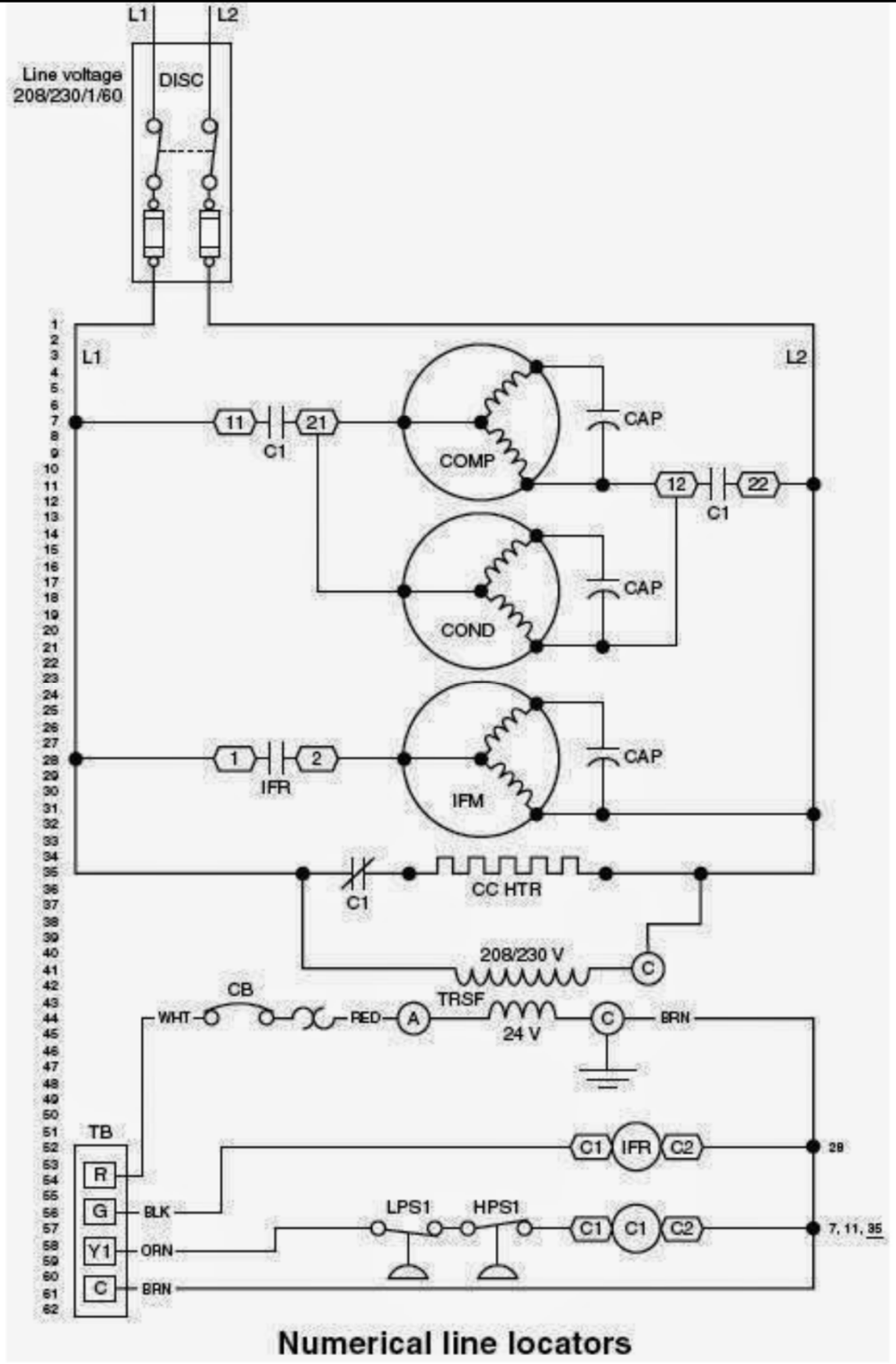
Side-by-side configuration



the dividing line



Up-and-down configuration



Numerical line locators

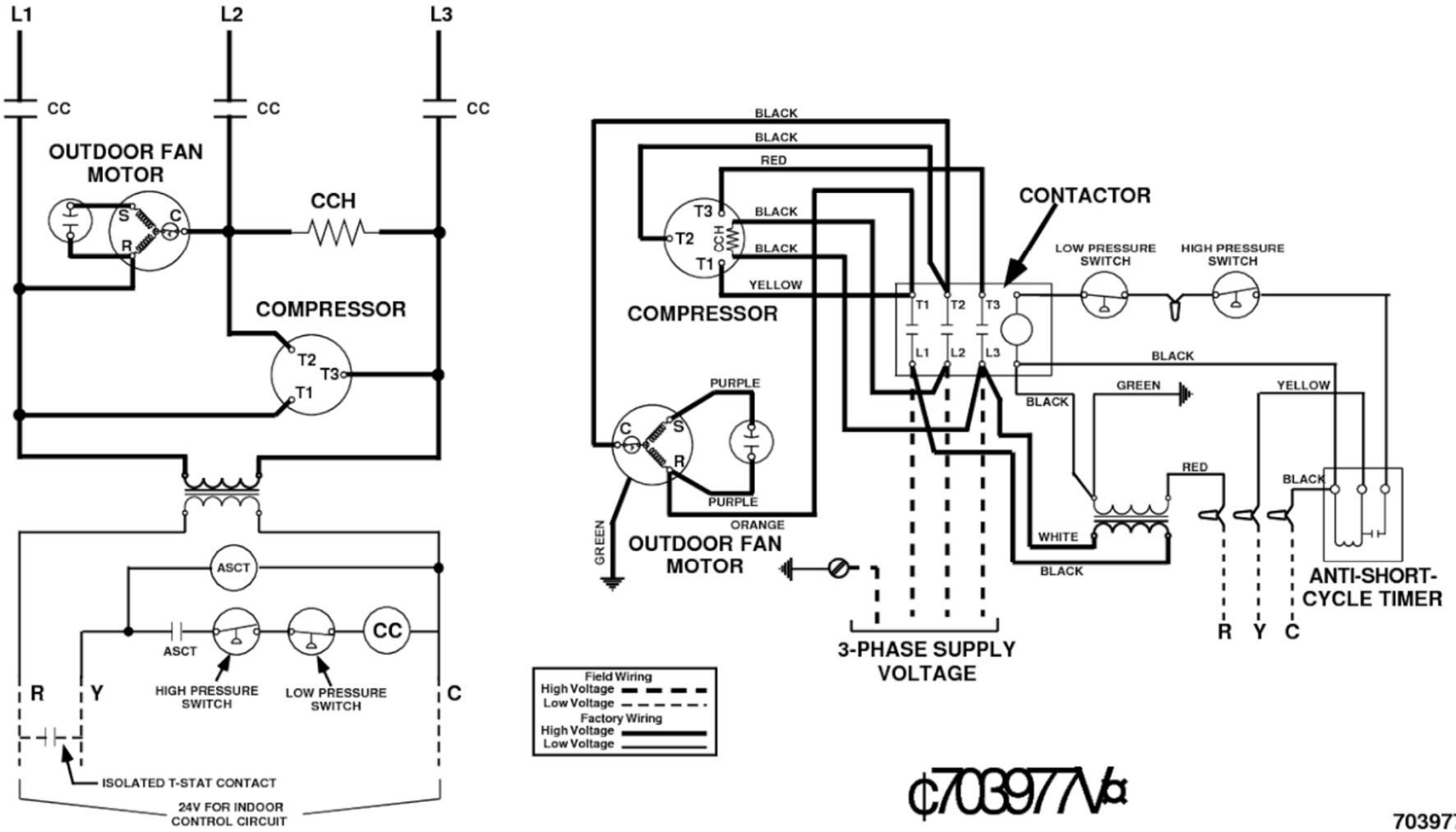
[Source: http://www.electrical-knowhow.com/2014/05/How-to-read-Electrical-Wiring-Diagrams.html]

WIRING DIAGRAM

Split System Air Conditioner (Outdoor Section) — Three Phase

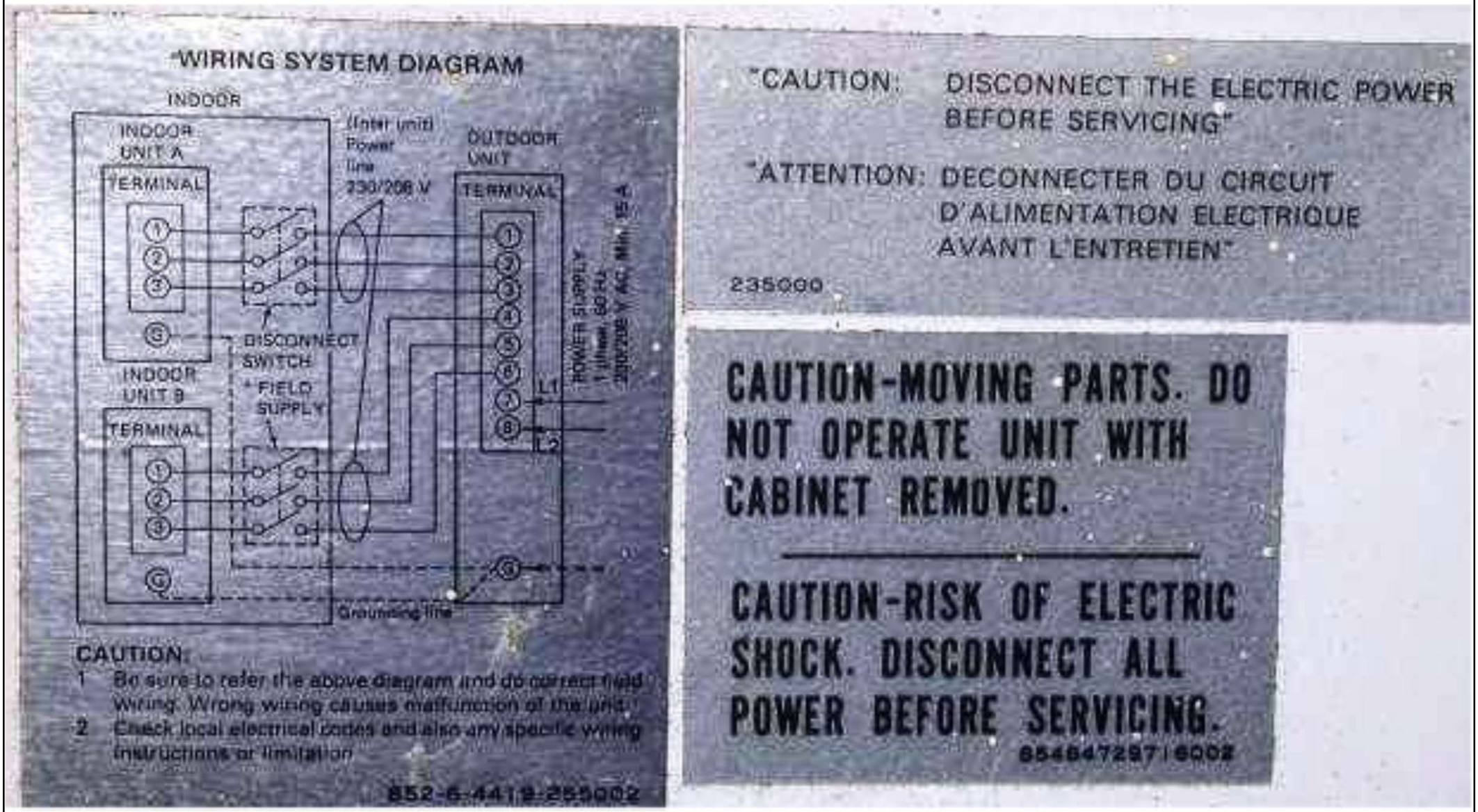
Notes:
1) Disconnect all power before servicing.
2) For supply connections use copper conductors only.
3) Furnace/Air Handler w/factory equipped 24 V control circuit transformers, should be modified/rewired to ONLY use 24V transformer from outdoor section. See installation instructions for typical modifications.
4) For replacement wires use conductors suitable for 105°C.
5) For ampacities and overcurrent protection, see unit rating plate.

1) Couper le courant avant de faire letretien.
2) Employez uniquement des conducteurs en cuivre.



[Source: http://www.electrical-knowhow.com/2014/05/How-to-read-Electrical-Wiring-Diagrams.html]

Wiring system diagram of split system air conditioner

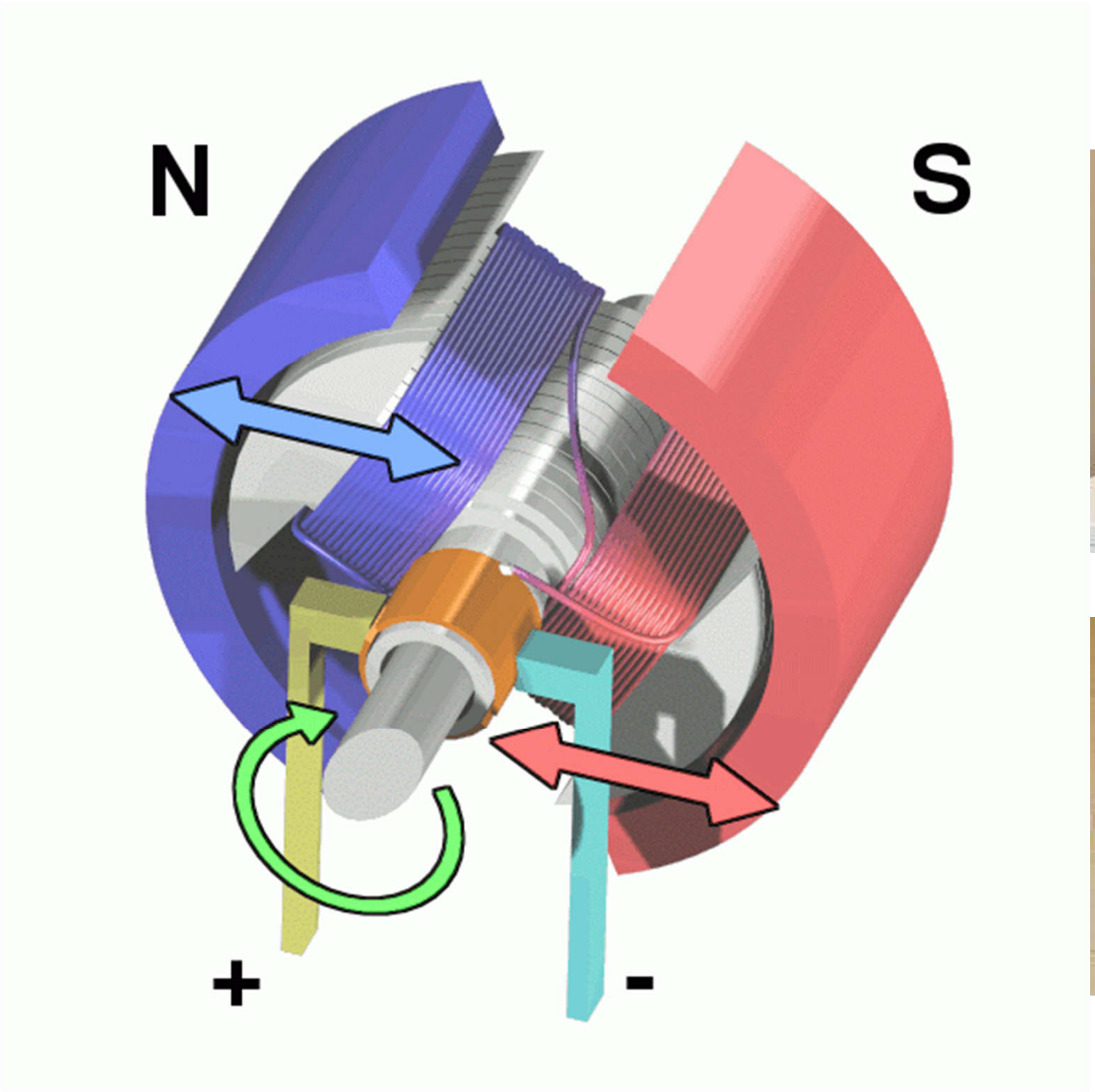


[Source: http://www.electrical-knowhow.com/2014/05/How-to-read-Electrical-Wiring-Diagrams.html]

Motors in HVAC systems

- Electric motors are used in HVAC systems to drive fans, pumps, refrigeration equipment and other processes that require motive force
  - Main types: AC motors and DC motors
- Type of motor commutation: 電機換向
  - Self-commutated
    - Mechanical-commutator motors
    - Electronic-commutator (EC) motors
  - Externally commutated (asynchronous, synchronous machines)

Operation of a brushed DC electric motor



[Source: https://en.wikipedia.org/wiki/Electric_motor]

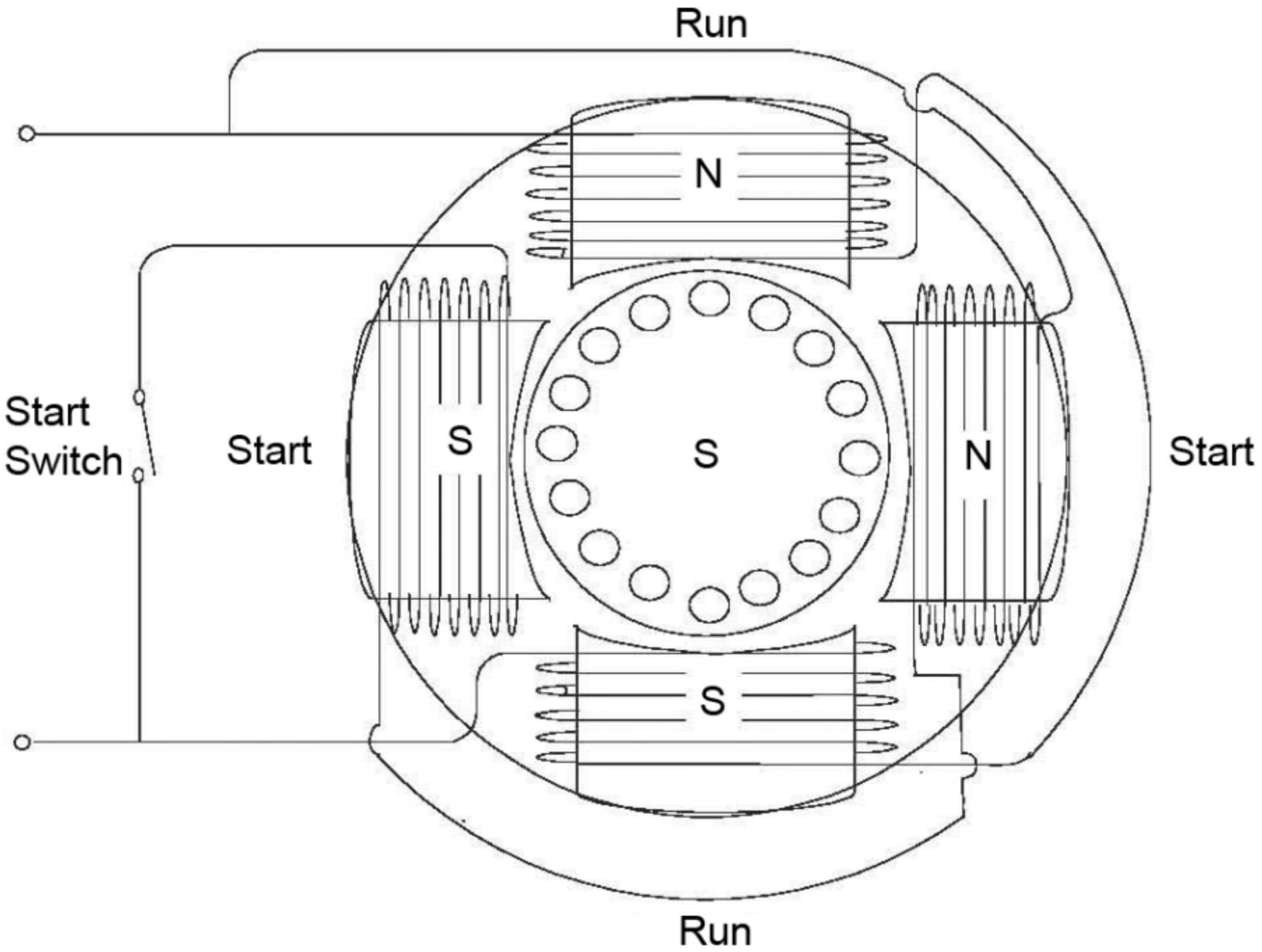
Repair fan motor in HVAC systems

[Source: https://www.thetrainingcenterofairconditioningandheating.com/hvac-repairs/5-different-types-of-air-conditioning-motors-how-to-replace-them/]

Motors in HVAC systems

- Single phase induction motors 單相感應電機
  - Split phase (two windings: a start & run winding)
  - Permanent split capacitor (PSC)
  - Capacitor start, capacitor run (CSCR)
  - Capacitor start, induction run (CSIR)
- Three phase induction motors 三相感應電機
- Electronically commutated motor (ECM)
  - Brushless DC motors
- Constant torque motor (CTM)

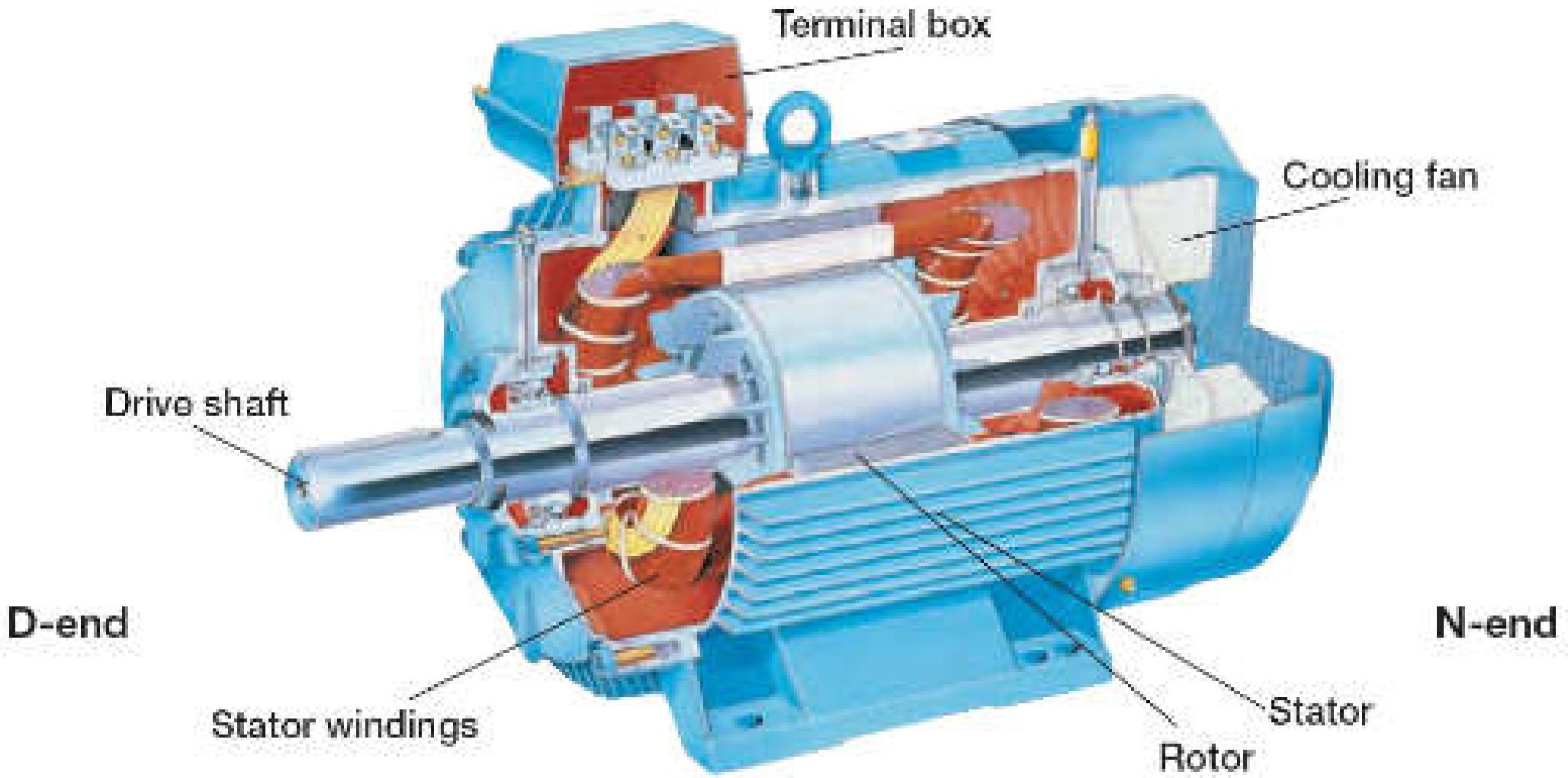
Design of a split phase motor



Motors in HVAC systems

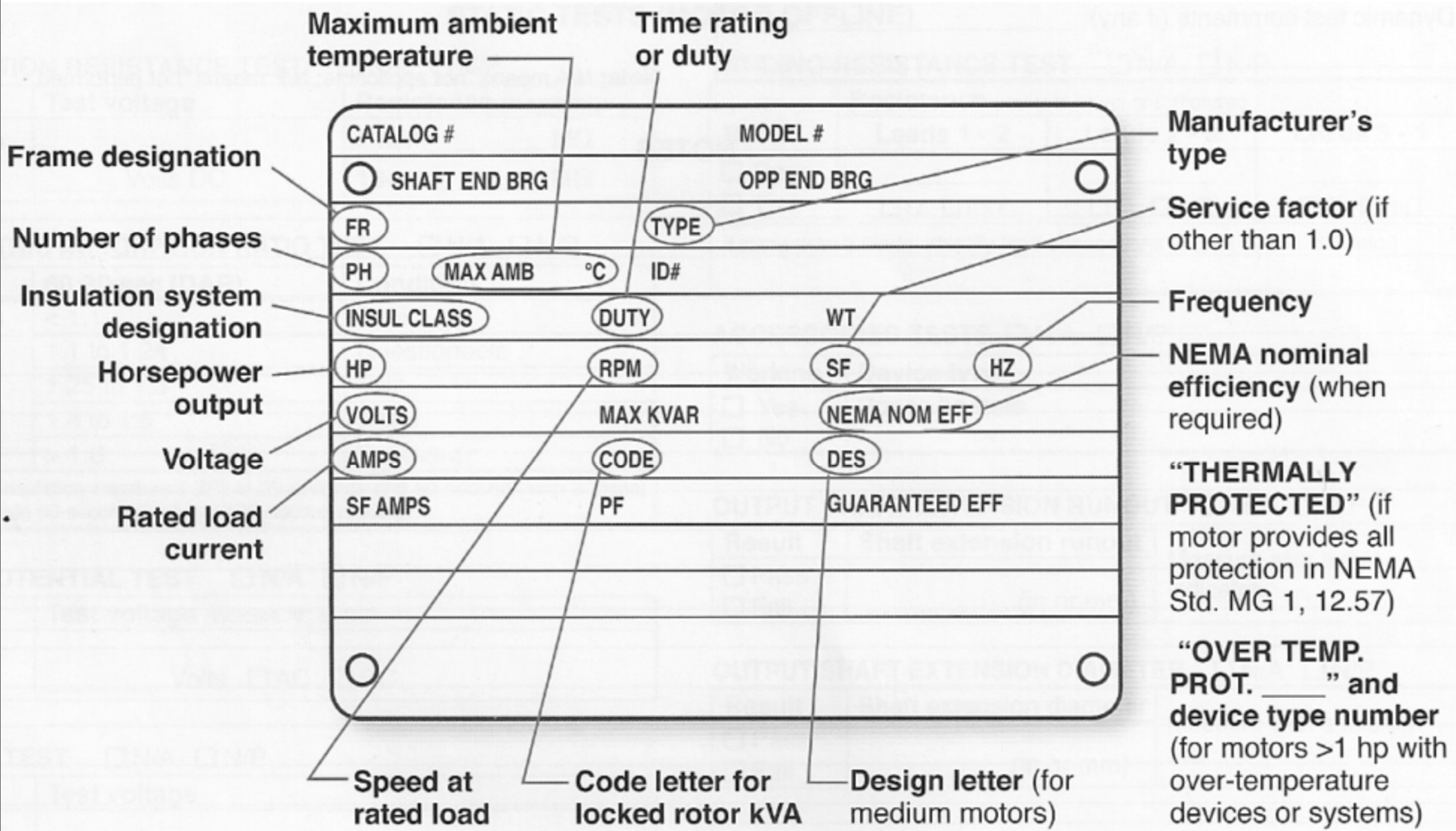
- Main parts of squirrel cage induction motor:
  - 1. Stator: a stationary component made of copper windings that carry current; surrounds the rotor
  - 2. Rotor: rotate under the influence of magnetic field of the stator
  - 3. Fan: it is used to cool the motor
  - 4. Bearings and seals: allow a motor shaft to move smoothly and reduce friction energy losses
    - The seals keep dust from entering the motor

Main parts of squirrel cage induction motor



[Source: https://www.enggcyclopedia.com/2012/09/squirrel-cage-induction-motors/]

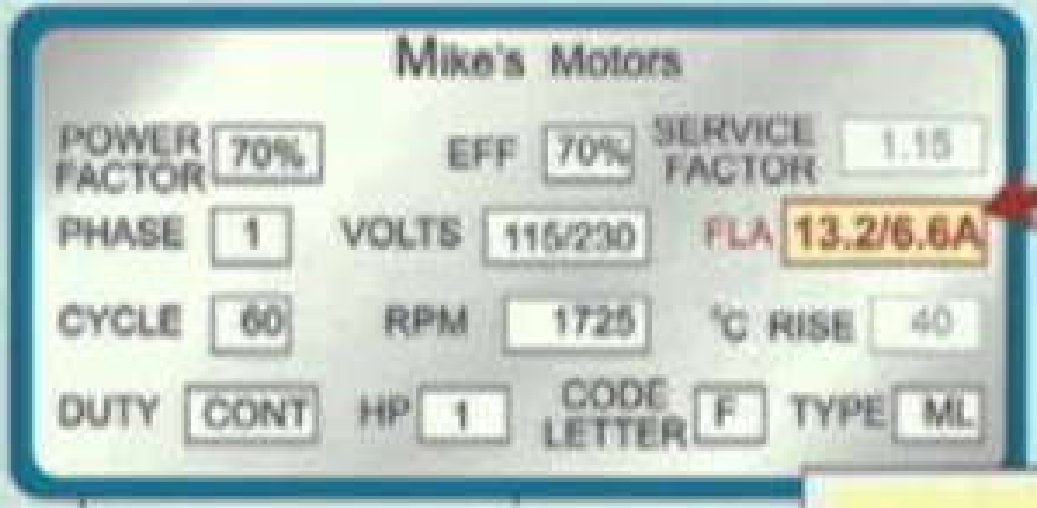
How to read an electric motor nameplate



Note: Nameplates may also include the manufacturer's name and usually its principal location.

[Source: https://www.priestelectric.com/read-electric-motor-nameplate/]

Motor Nameplate - Full-Load Amperes (FLA)



FLA =
Full-Load Amps =
Nameplate Amps

$$\text{Nameplate (NP)} = \frac{746 \times \text{hp}}{E \times \text{Eff} \times \text{PF}}$$

746 = watts per hp
hp = 1 hp
E = 115V
Eff = 0.70 efficiency factor
PF = 0.70 power factor

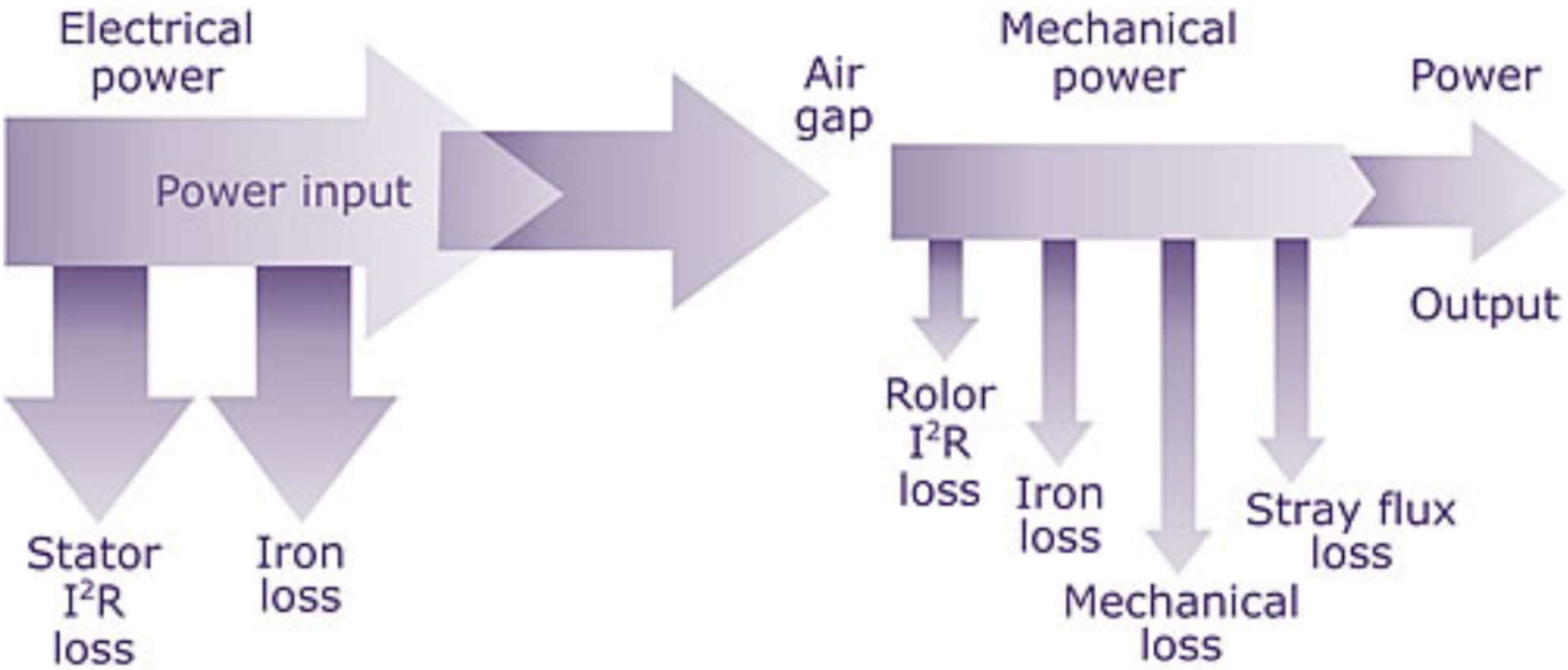
$$\text{NP} = \frac{746 \times 1 \text{ hp}}{115\text{V} \times 0.70 \text{ Eff} \times 0.70 \text{ PF}}$$

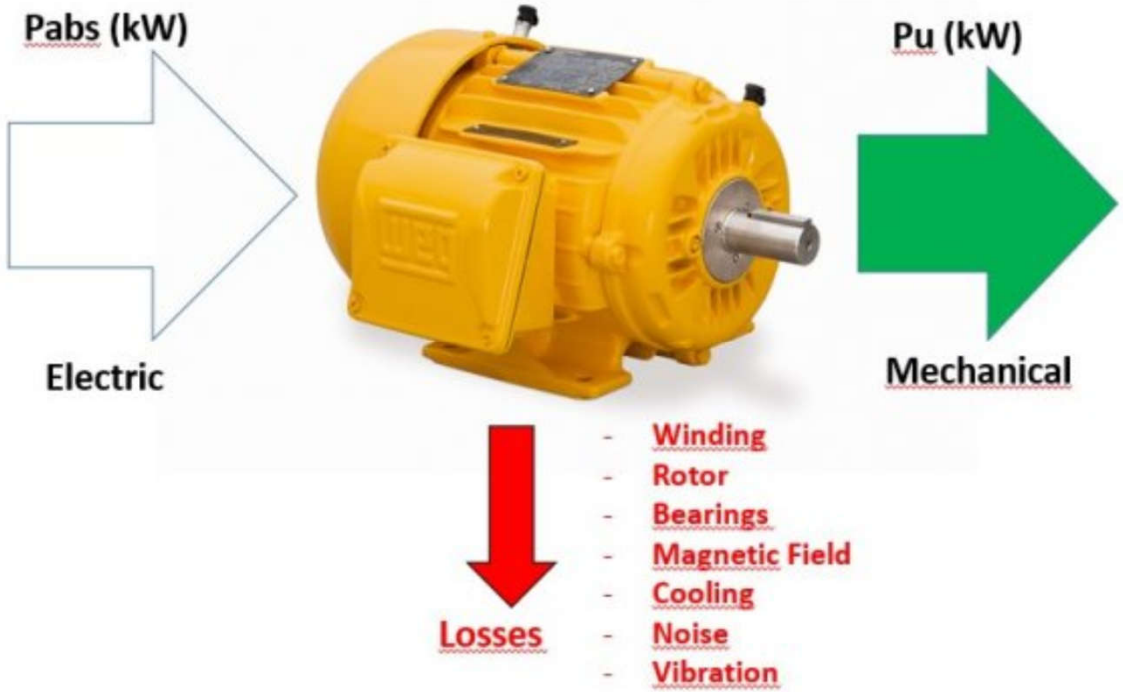
Nameplate = 13.20A

Motors in HVAC systems

- Motor efficiency
  - Power losses in induction motors
    - (a) Fixed losses, i.e. independent of motor load:
      - Iron or magnetic loss in the stator & rotor cores
      - Friction & windage loss
    - (b) Losses proportional to the motor load:
      - Resistive (I^2R) or copper loss in the stator & rotor conductors
      - Stray loss caused by components of stray flux
  - Define motor efficiency
    - Motor Efficiency (η) = Output Power / Input Power

Motor efficiency and major losses

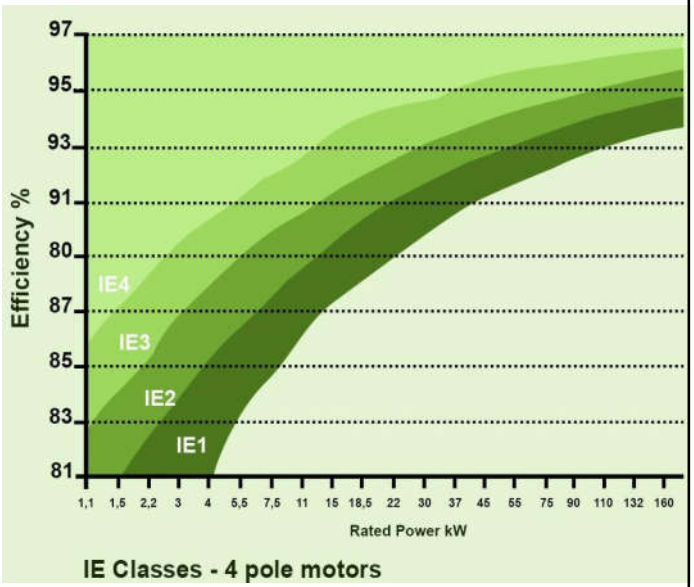


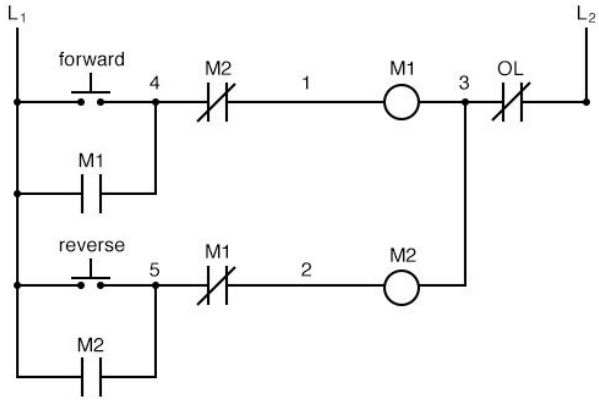


[Source: http://controlmakers.ir/en/what-is-motor-efficiency-how-to-improve-it/]

Motors in HVAC systems

- Efficiency classes of motors (IEC 60034-30)
  - IE1: Standard Efficiency Motors
  - IE2: High Efficiency
  - IE3: Premium Efficiency
  - IE4: Super Premium Efficiency
- Controlling motors
  - Turning the motor on and off
  - Overload relay protection
  - Control the speed and torque

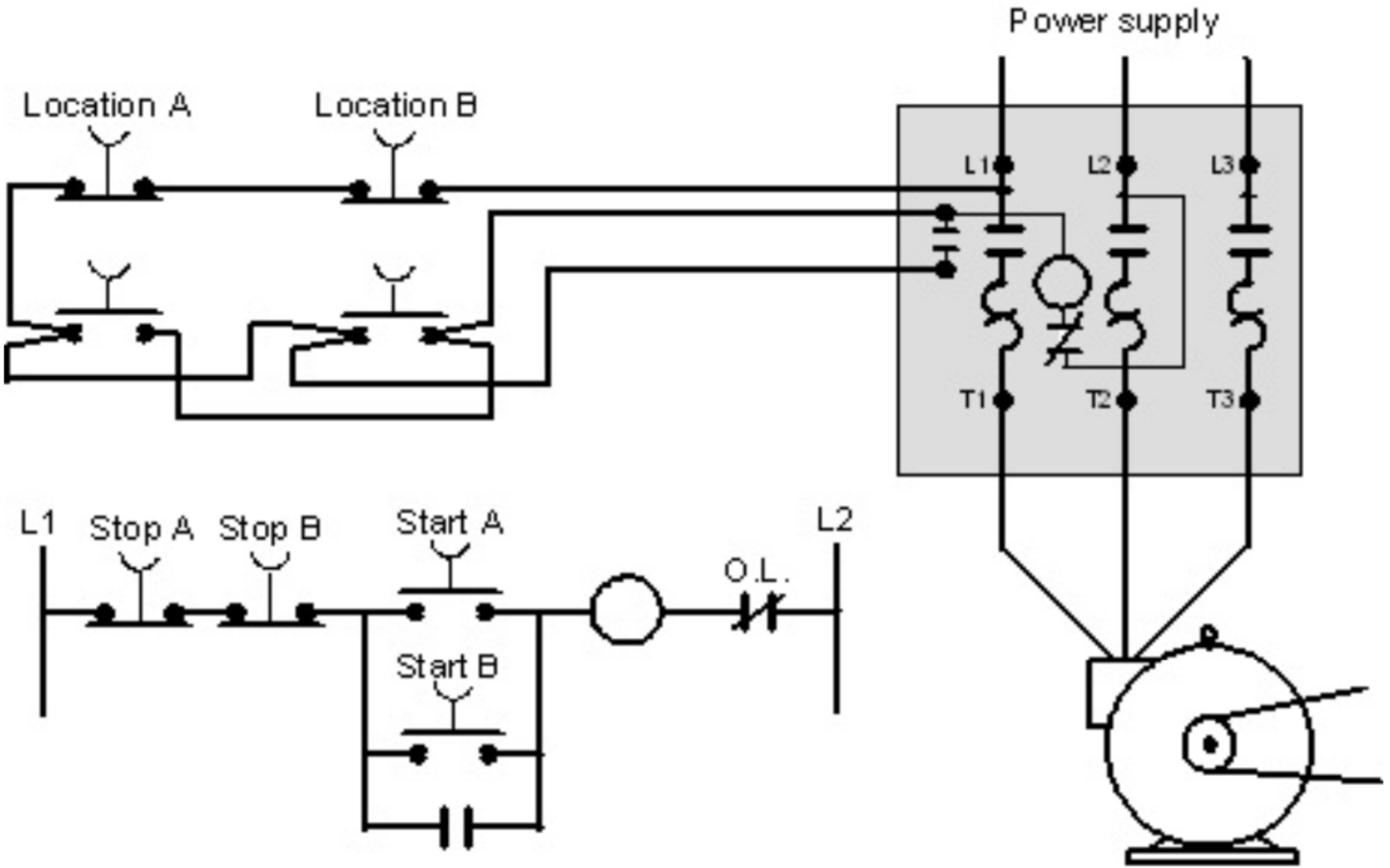




Motors in HVAC systems

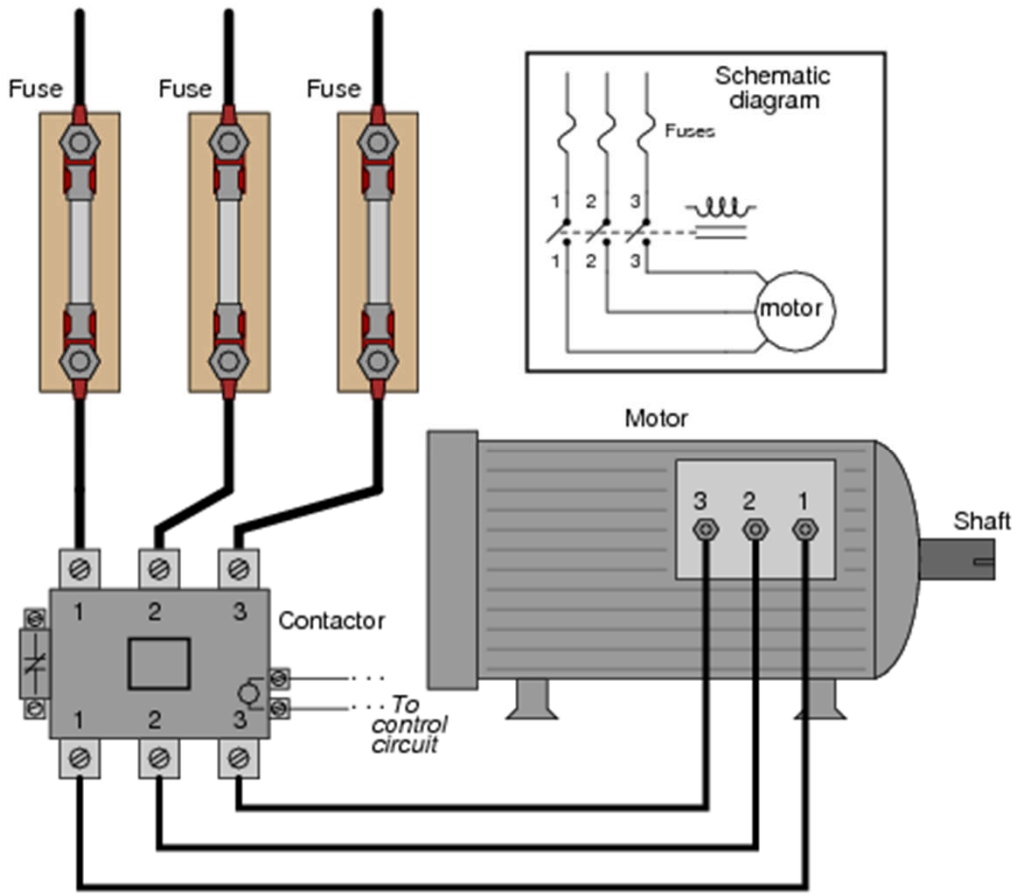
- Motor starting methods
  - 1. Direct-on-line (DOL) starting: stator windings directly connected to supply via contactors
  - 2. Star delta starting: star & delta connection of stator windings are used
  - 3. Autotransformer starting: stator windings connected to the supply through an auto transformer
  - 4. Soft starters: variable speed drive (VSD)

Motor start-stop from 2 different locations



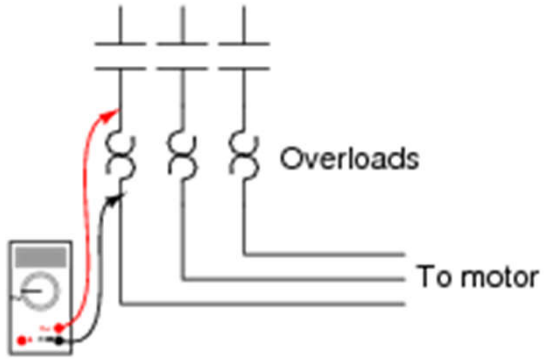
Motors in HVAC systems

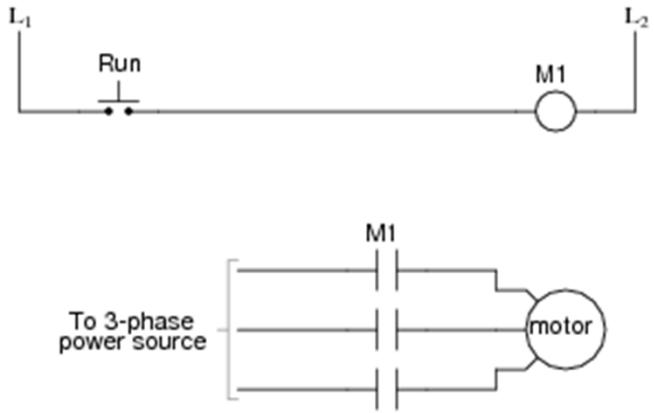
- Typical causes of motor faults
  - (a) External failures
    - Reverse phase sequence
    - Under-voltages
    - Single phasing
    - Unbalanced supplies
  - (b) Internal failures
    - Bearing faults
    - Winding failures
    - Overloads

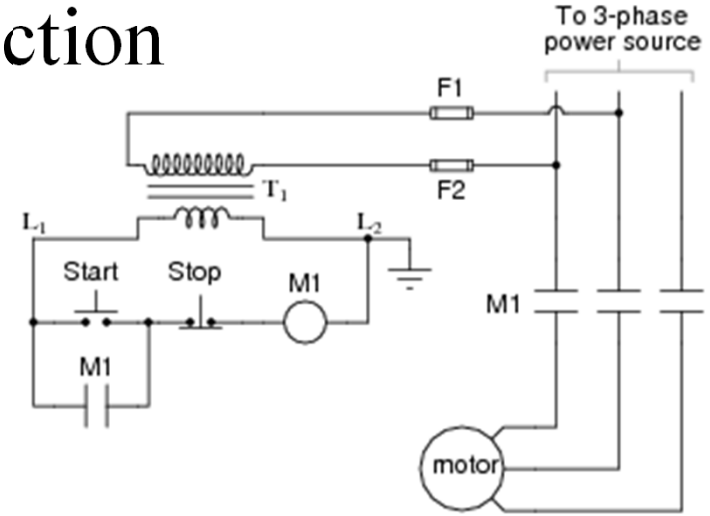


Motors in HVAC systems

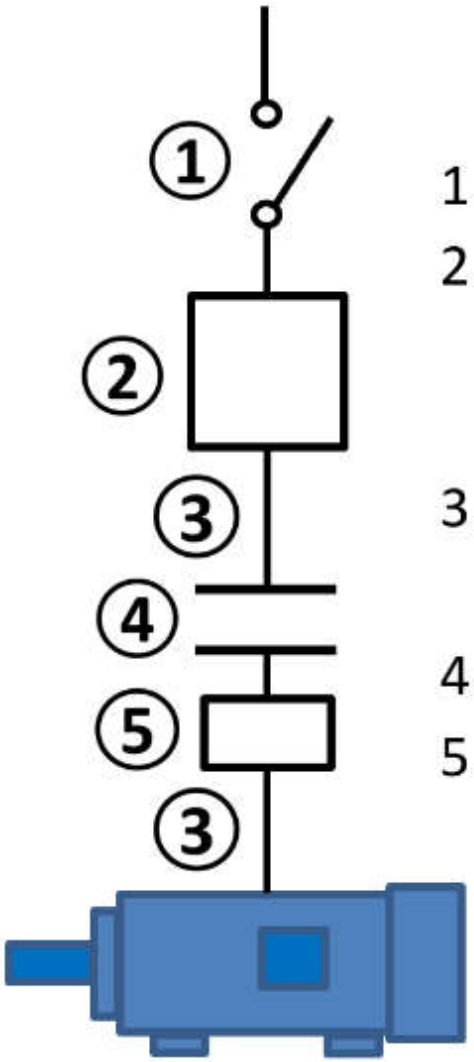
- Types of motor protection device:
  - 1. Overload protection
  - 2. Short circuit protection
  - 3. Over temperature protection
  - 4. Under voltage protection
  - 5. Phase failure & reversal protection



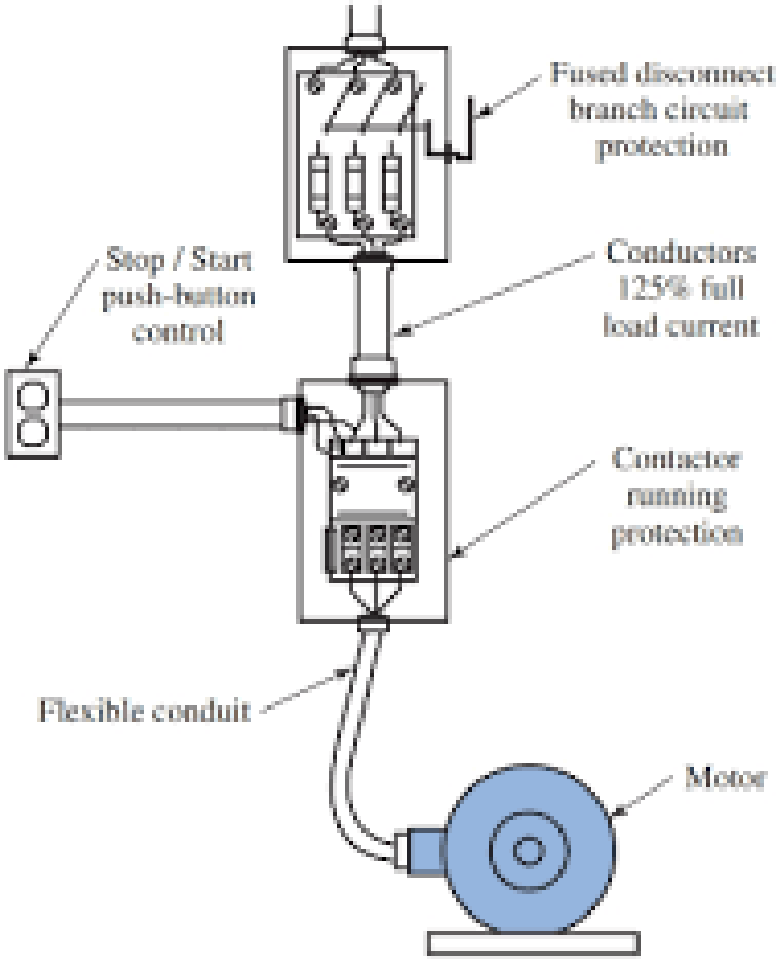




Motor branch-circuit overcurrent protection devices

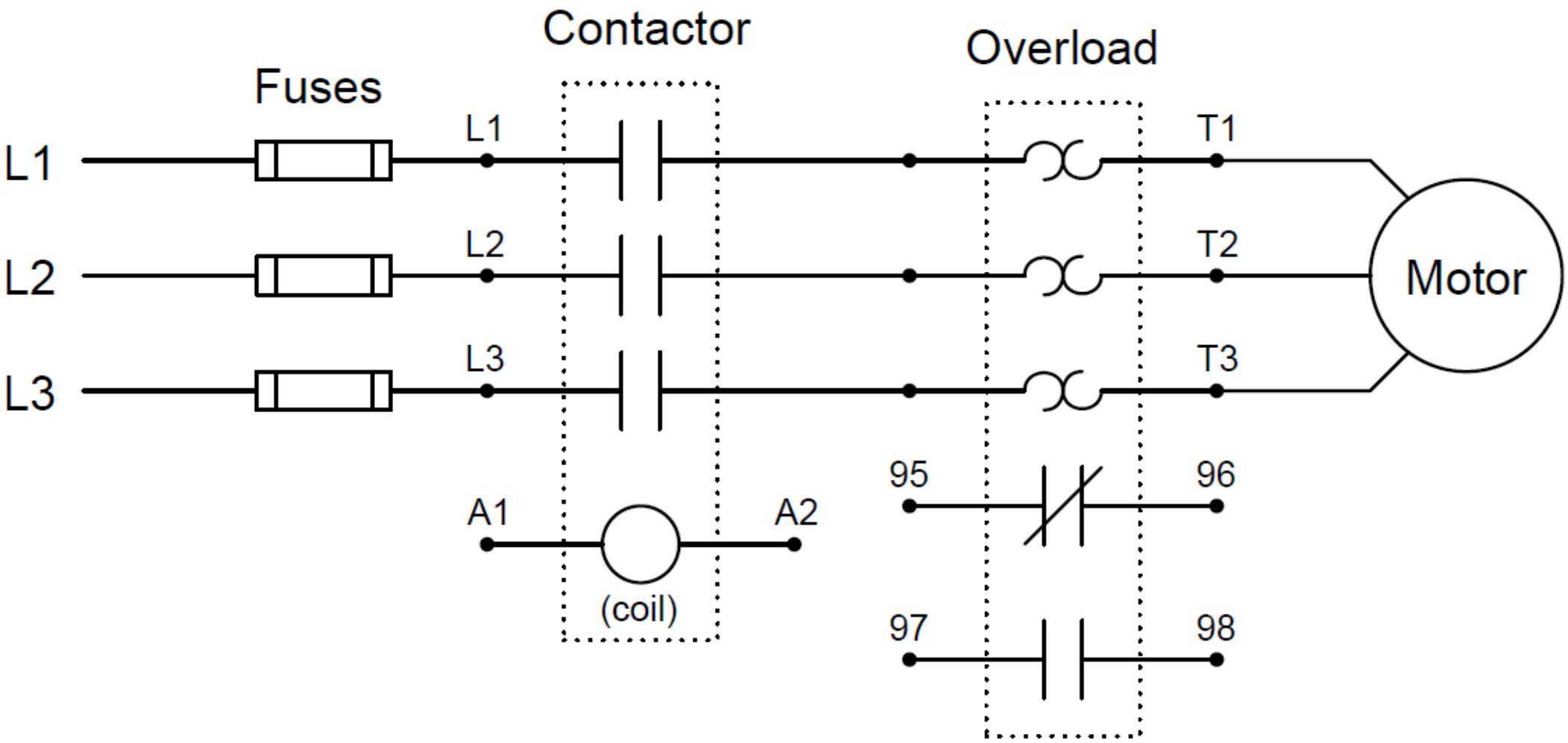


1. Motor Disconnecting Means
2. Motor Branch-Circuit Short-Circuit and Ground-Fault Protection
3. Motor Branch-Circuit Conductors
4. Motor Controller
5. Motor Overload Protection



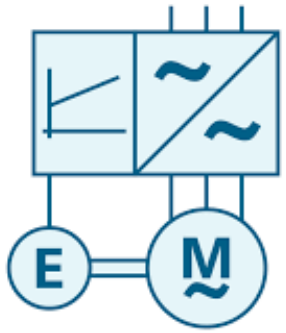
[Source: https://www.jadelearning.com/blog/understanding-motor-branch-circuit-overcurrent-protection-devices/]

Schematic diagram of a three-phase overload connected to a three-phase contactor and three phase motor



[Source: https://instrumentationtools.com/motor-protection-circuits/]

Variable speed drives



- Variable speed drive (VSD) / adjustable speed drives (ASD) / variable frequency drive (VFD)

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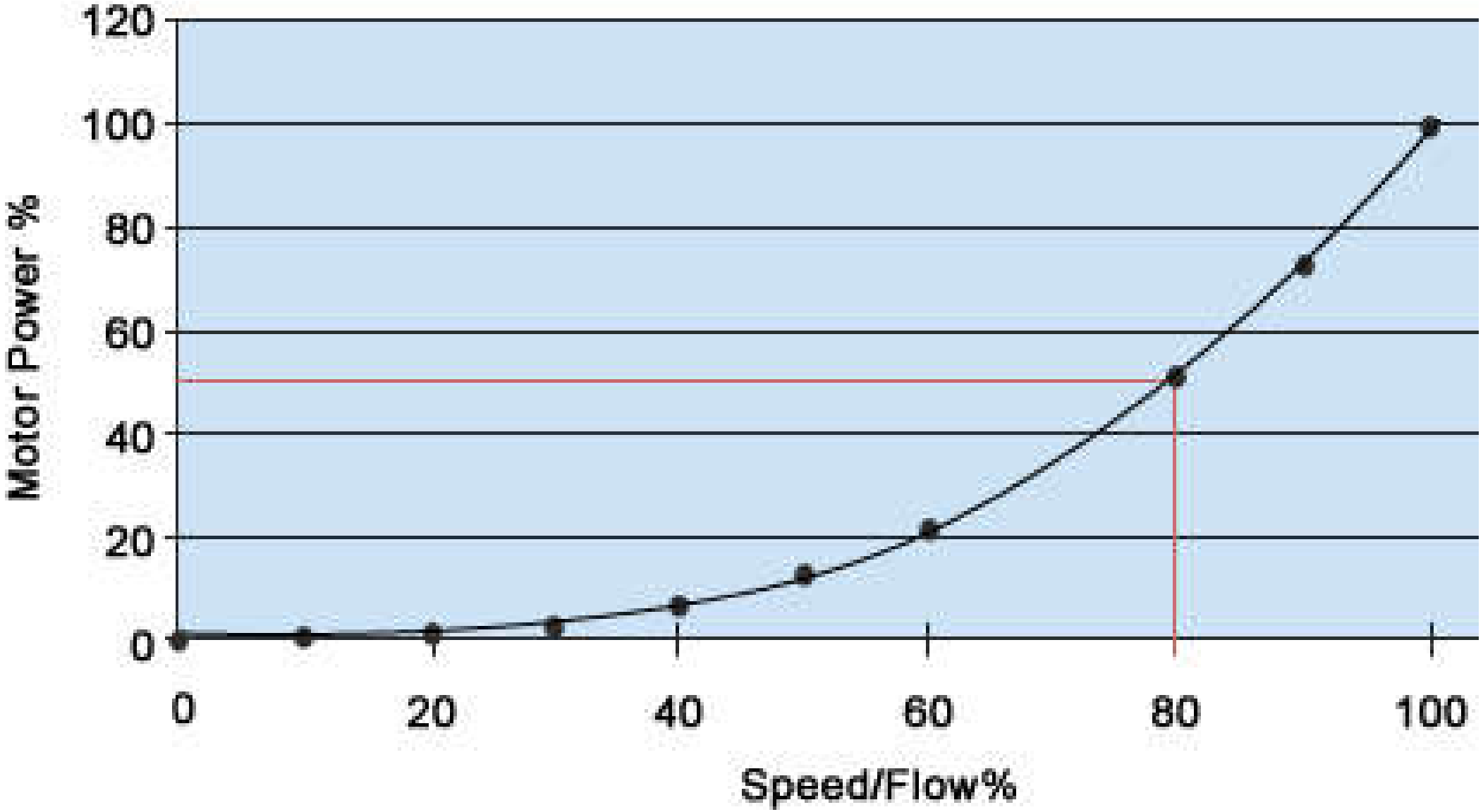
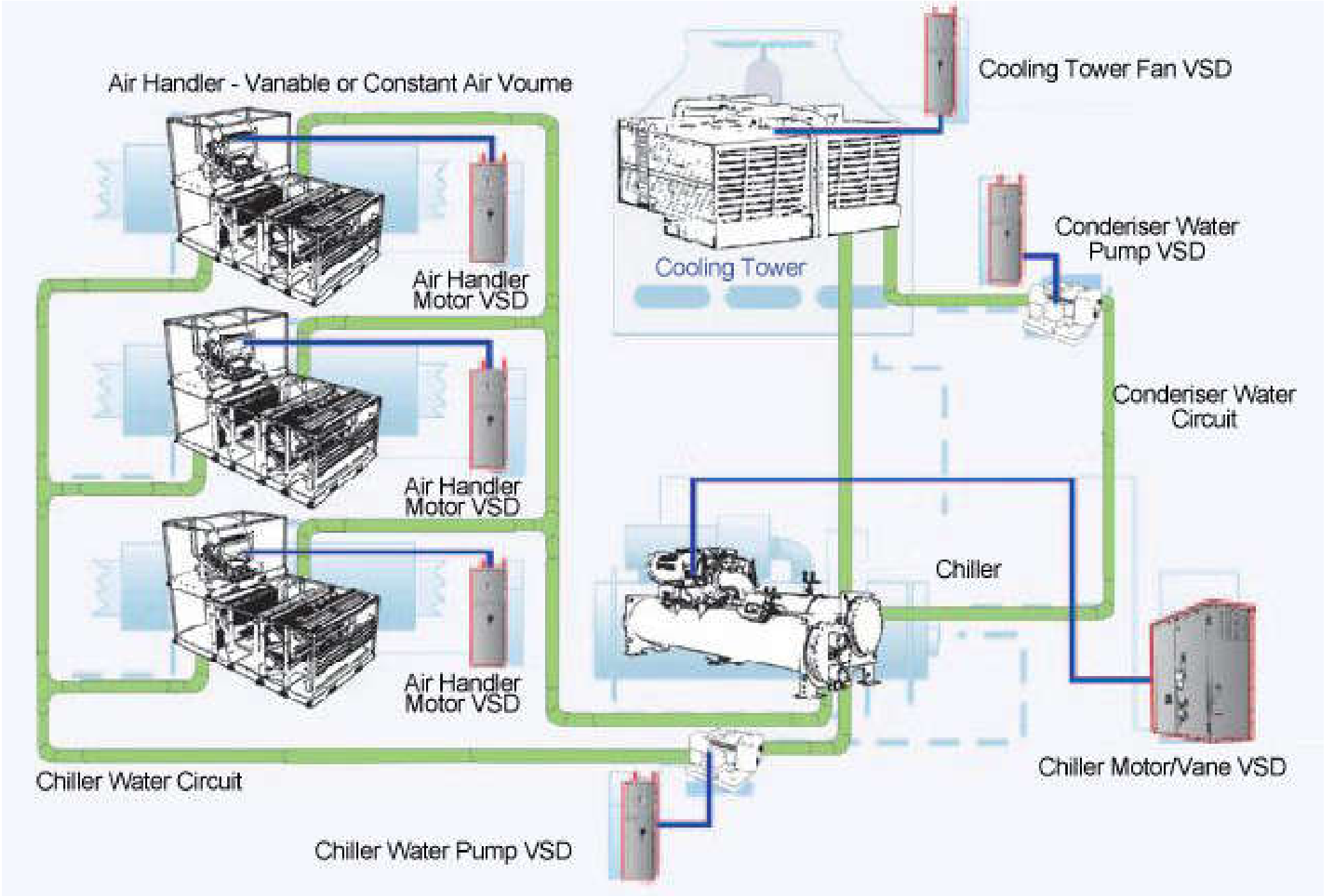
  - Control the speed of the motor to match the load requirements (e.g. fans & pumps)
  - Advantages:
    - Improve energy efficiency
    - Improve power factor & process precision
    - Provide other performance benefits e.g. soft starting
    - Less mechanical stress on the system

Motor energy saving with variable speed drive (VSD)



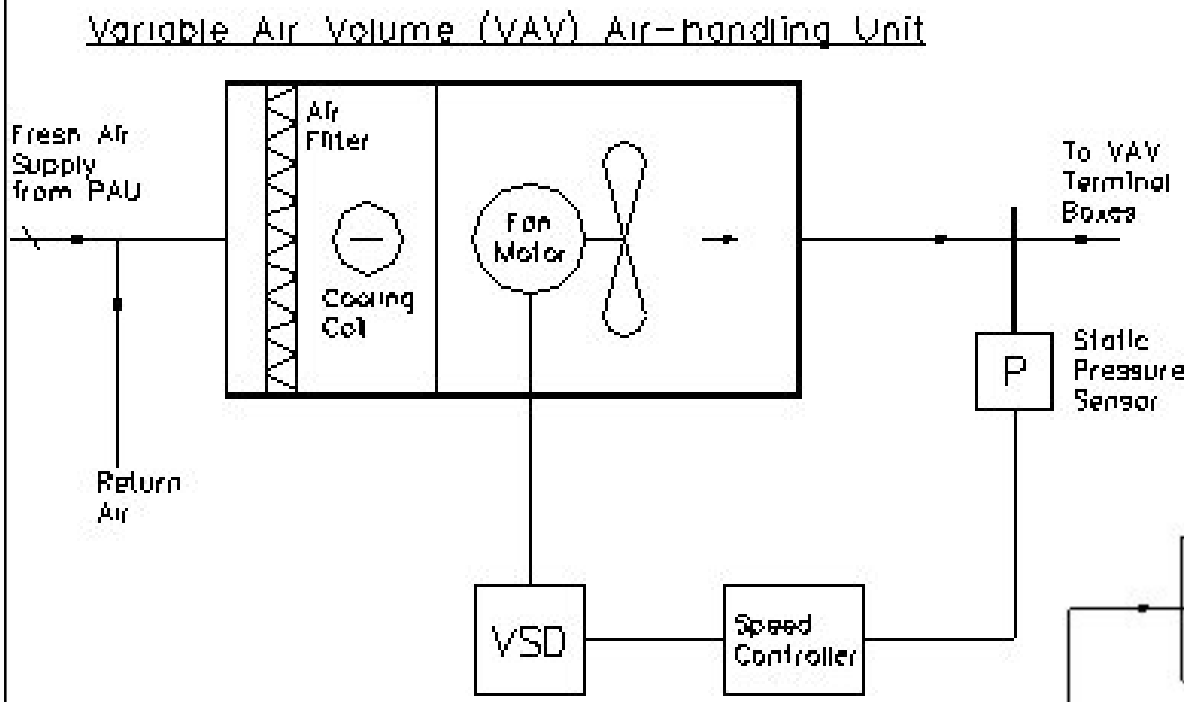
[Source: https://www.emsd.gov.hk/energyland/en/appAndEquip/equipment/air_conditioning/vsd.html]

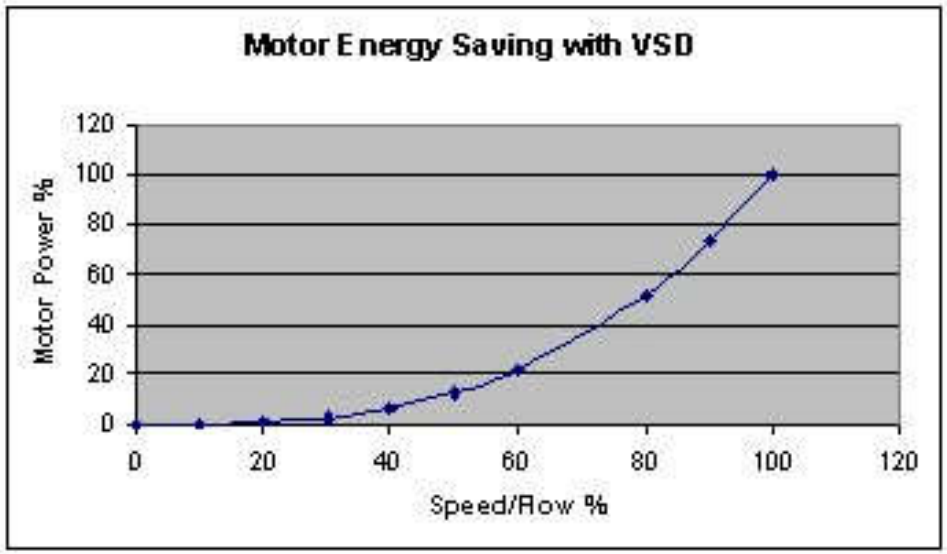
Variable speed drives (VSDs) in air-conditioning systems

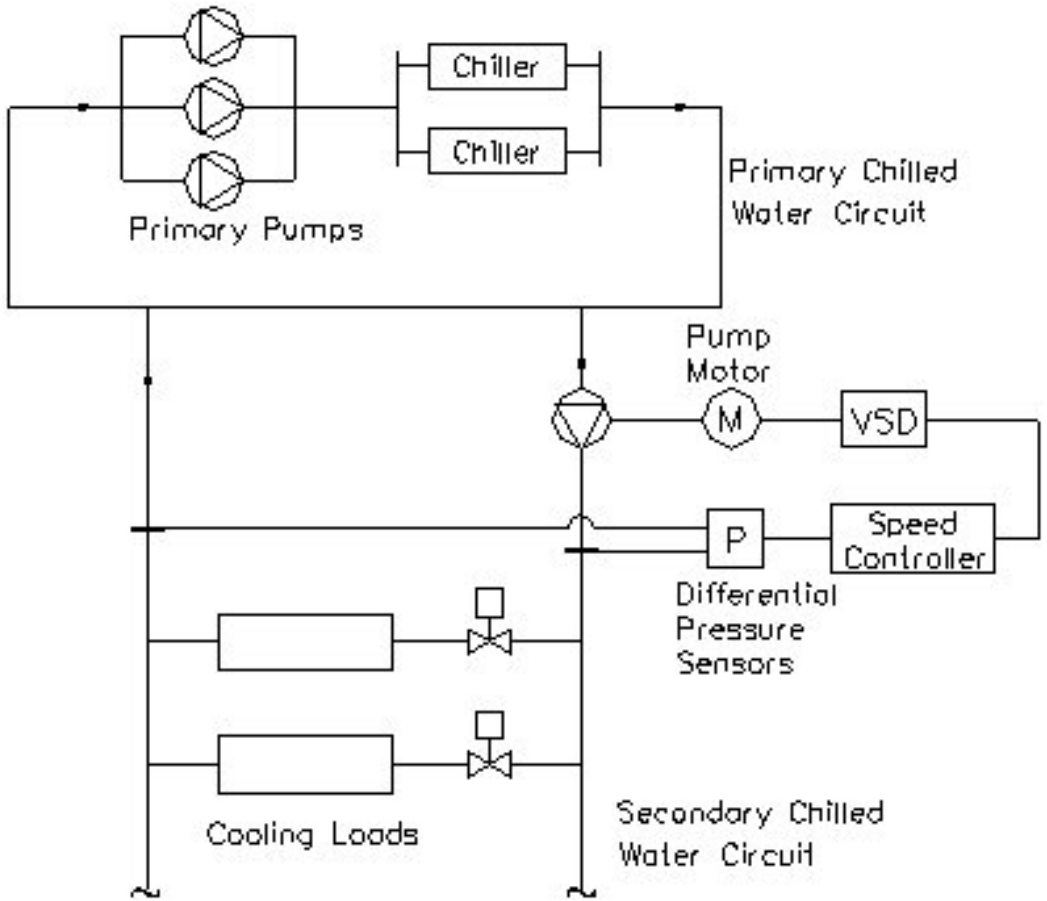


[Source: https://www.emsd.gov.hk/energyland/en/appAndEquip/equipment/air_conditioning/vsd.html]

Applications of variable speed drive (VSD) in HVAC systems

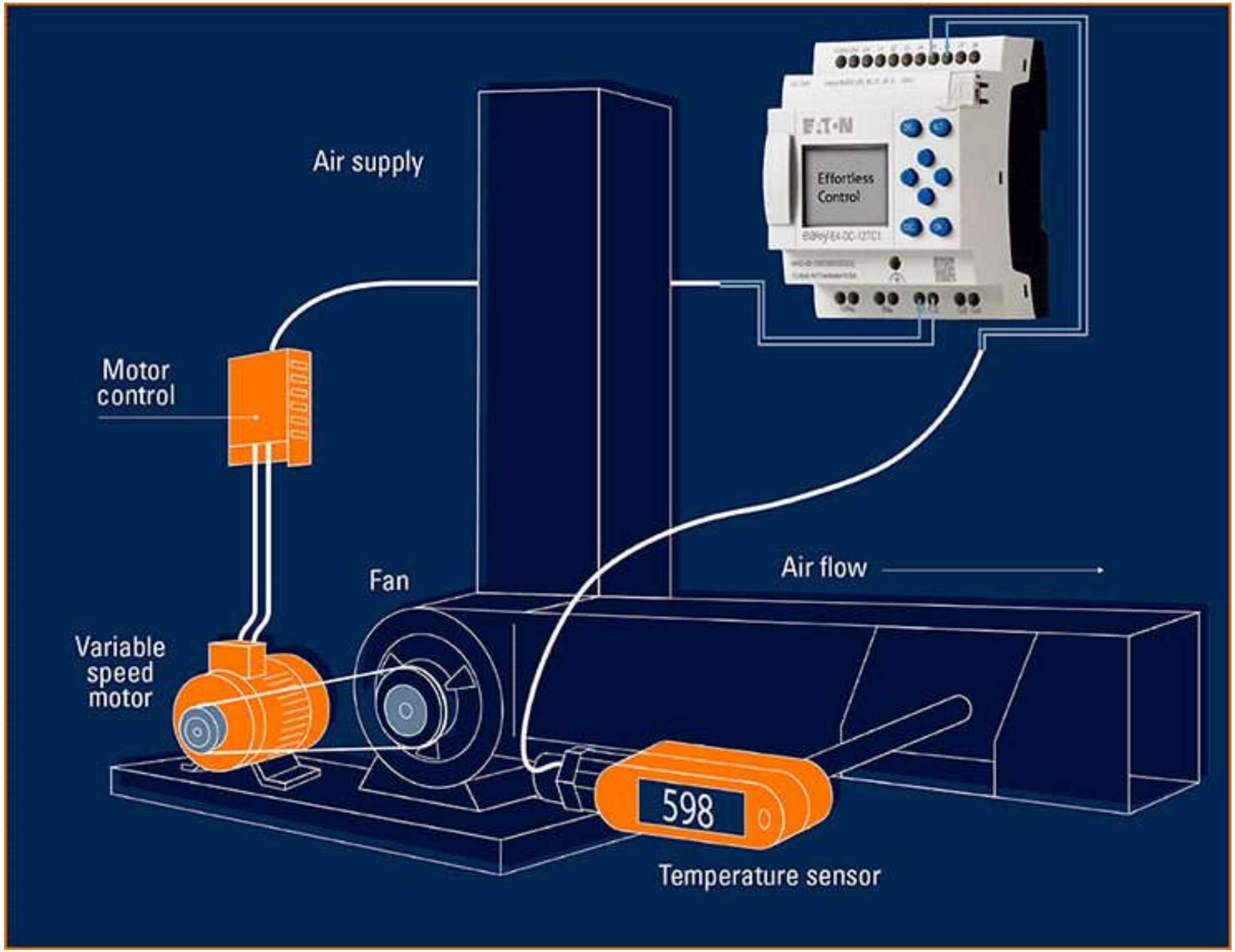






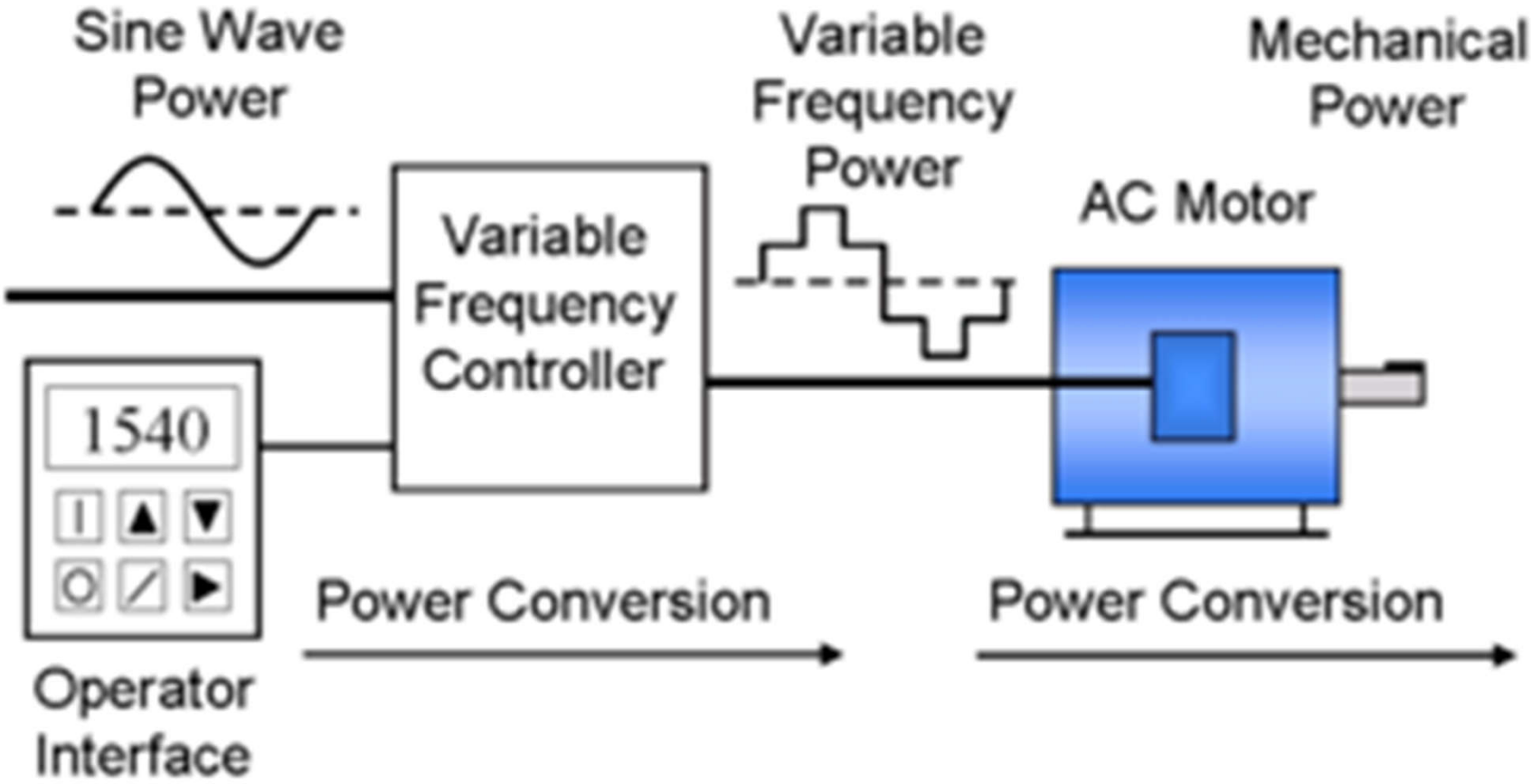
[Source: https://www.emsd.gov.hk/en/energy_efficiency/energy_management/publications/application_guide_to_variable_speed_drives_vsd/]

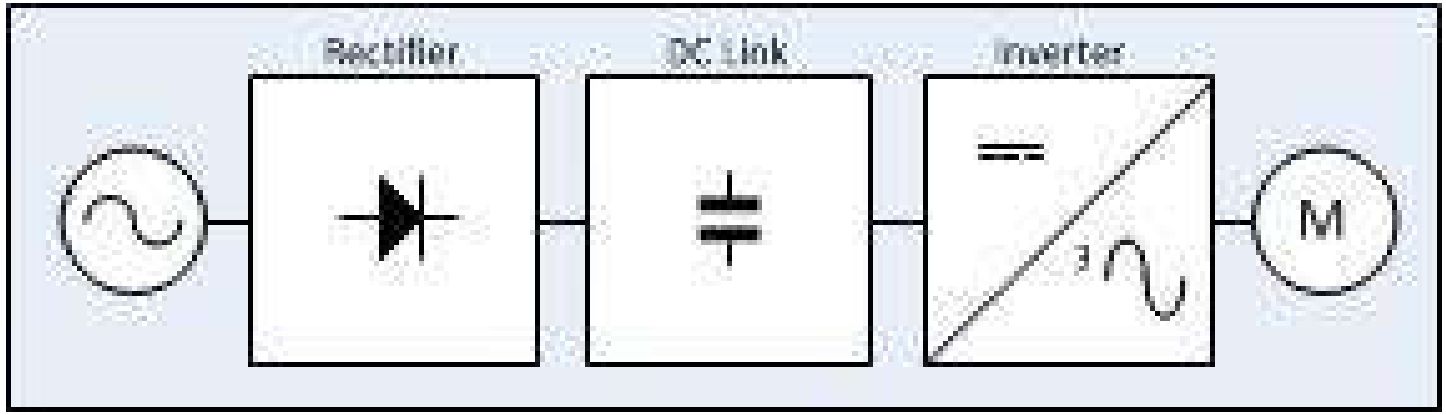
A practical example of variable speed drive (VSD) in HVAC systems



[Source: https://www.eaton.com/]

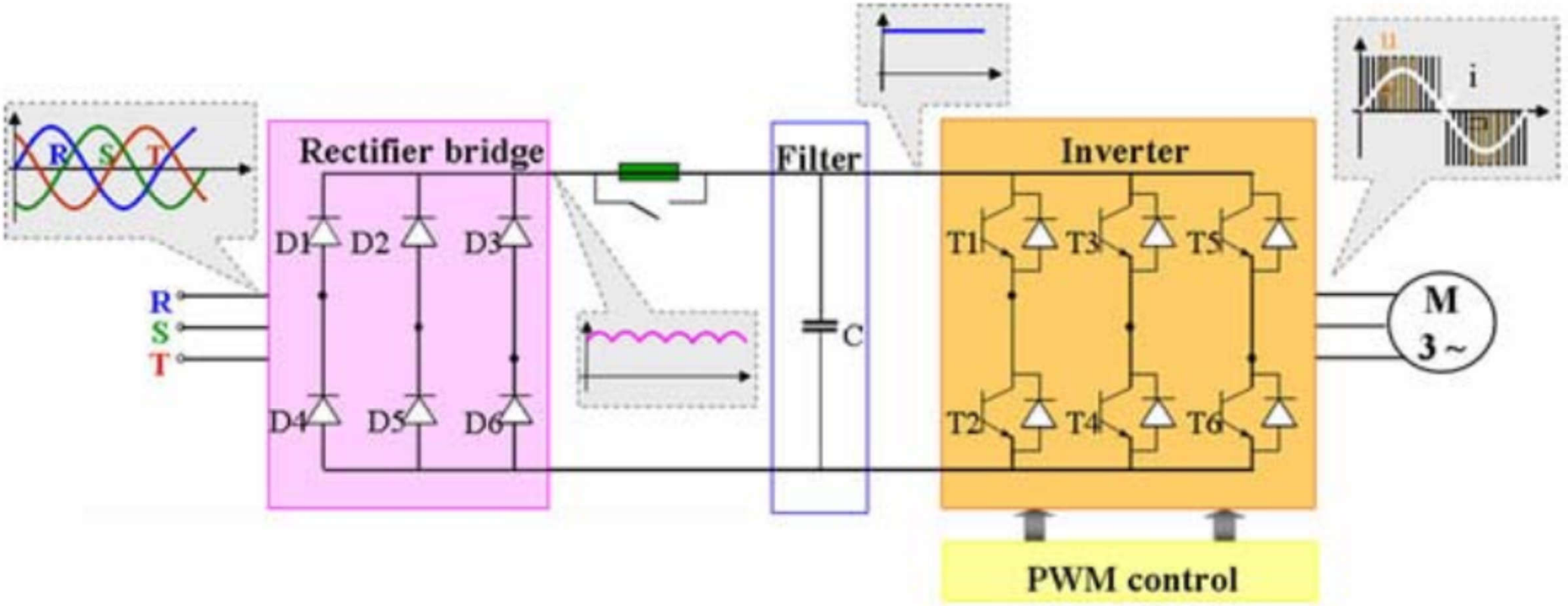
Principles of variable speed drive (VSD) or variable frequency drive (VFD)

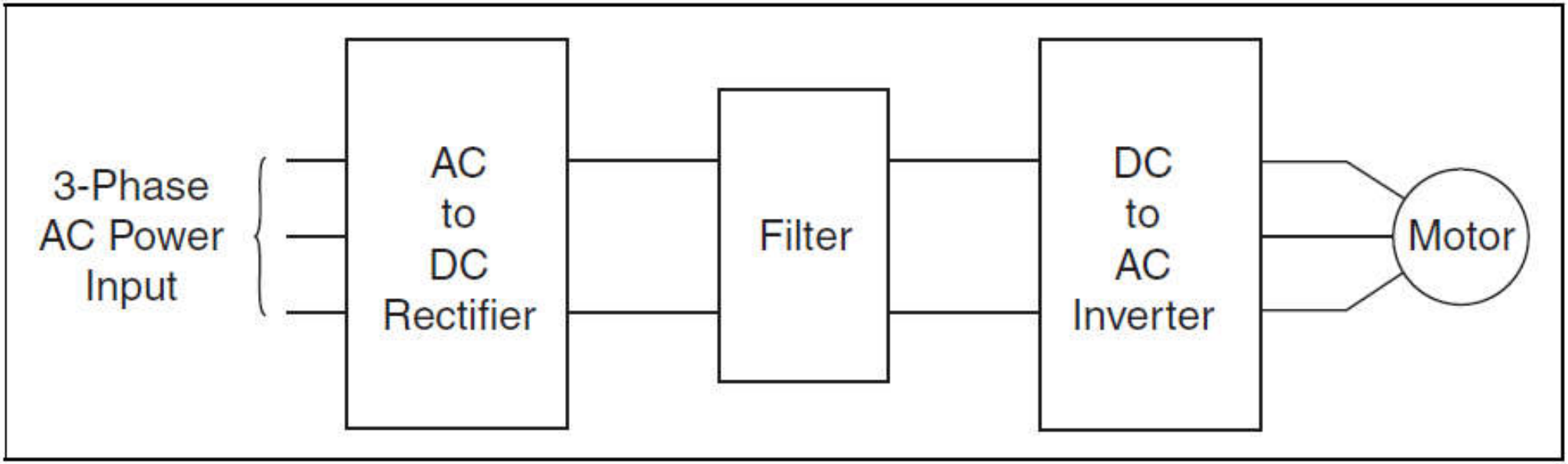




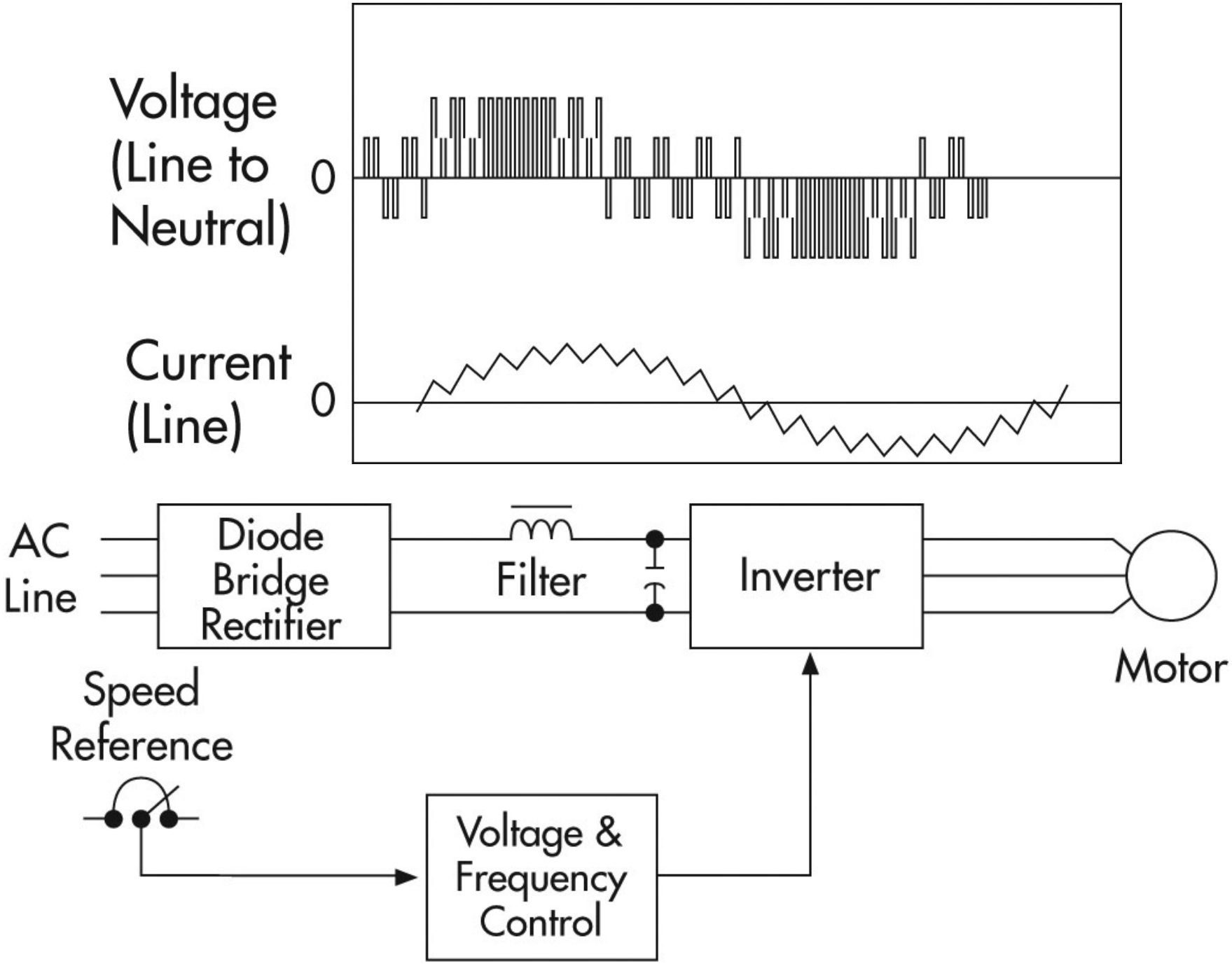
[Source: https://en.wikipedia.org/wiki/Variable-frequency_drive]

Pulse width modulation (PWM) voltage control



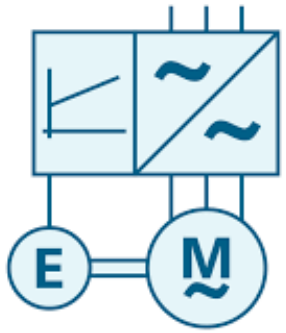


Pulse width dodulated (PWM) variable frequency drive



[Source: https://www.nrcan.gc.ca/energy-efficiency/energy-star-canada/about/energy-star-announcements/publications/variable-frequency-drives/principles-operation-ac-vfd-drives/15433]

Variable speed drives



- Application considerations
  - Minimum VSD/VFD speed
    - Such as to prevent motor overheating due to inadequate airflow
  - AC line harmonics
    - Causes voltage distortion to electrical systems
  - Electromagnetic interference (EMI)
    - Adverse effects on the operation of the control system and motor components