ASHRAE Hong Kong Chapter Technical Workshop

Fundamentals of HVAC Control Systems

18, 19, 25, 26 April 2007

About the Speakers

"The Black Hairs"

- **Dr. Sam C. M. Hui**
  - Dept. of Mechanical Engineering, HKU
  - Over 18 years of experience in teaching, research, consultancy & design

- **Mr. William Yick**
  - Business Development Director of Johnson Controls
  - Over 30 years of professional experience in the HVAC controls

"The White Hairs"

Know The Instructor

- **Dr. Sam C M Hui – Dept. of Mech. Engg., The University of Hong Kong**
  - PhD, BEng(Hons), CEng, CEM, MASHRAE, MCIBSE, MHKIE, MIESNA, LifeMAEE, AssocAIA
  - HKU Dept. of Mechanical Engineering (4.5 years)
  - HKU Dept. of Architecture (6 years)
  - Asia Pacific Energy Research Centre, Japan (~1 year)
  - PhD study (4 years)
  - Associated Consulting Engineers (2 years)
- **Current role in ASHRAE:**
  - President of ASHRAE Hong Kong Chapter

ASHRAE Study Guide

- **"Fundamentals of HVAC Control Systems"**
  - List price at US$150
  - Included for each participant of the workshop
  - Divided into 10 chapters
  - Typical structure of each chapter
    - Instructions
    - Study Objectives
    - Main Body
    - The Next Steps
    - Summary
    - Bibliography
    - Skill Development Exercises

Main Topics in Study Guide

- 1. Introduction to HVAC Control Systems
- 2. Basic of Electricity
- 3. Control Valves and Dampers
- 4. Sensors and Auxiliary Devices
- 5. Control Diagrams and Sequences
- 6. Self-Powered Controls
- 7. Electric Controls
- 8. Pneumatic Controls
- 9. Analog Electronic Controls
- 10. Digital Controls

(* Practical considerations and applications are added too.)

Assumptions & Focus

- **Assumptions**
  - Audience knows the basic HVAC equipment & terminology
  - Audience members have interest in HVAC control systems and may have some experience before or working on it now

- **Focus of this workshop**
  - Basic concepts of HVAC control systems
  - Practical considerations and applications
  - Updated with latest developments too, e.g. DDC system

Chapter 1
Introduction to HVAC Control Systems

Why We Need Controls?

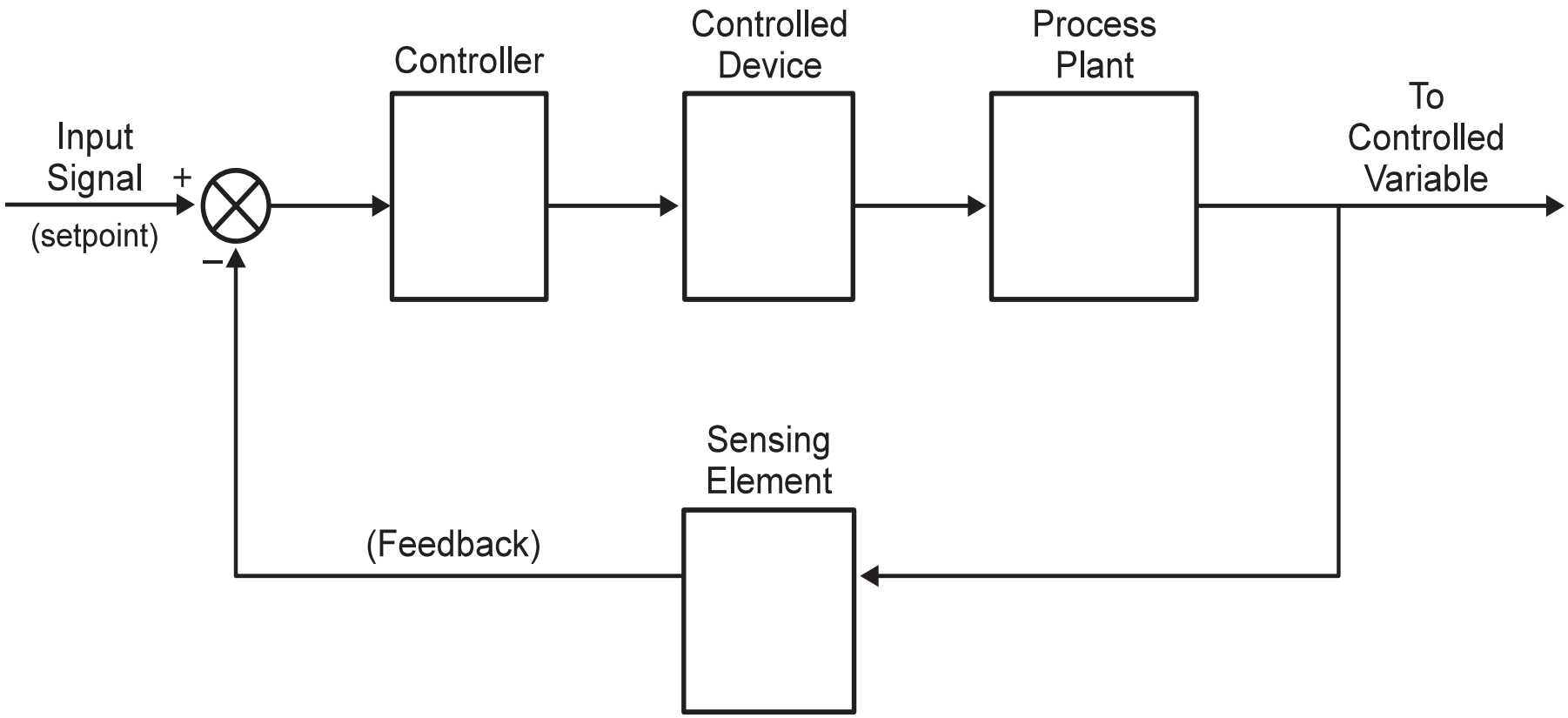
- **To regulate the output of systems and equipment**
  - **Such as your car**
- **For HVAC system, to regulate the movement of air, water, electricity to obtain desired indoor conditions**
  - **Also for energy management and safety**

Control System Types

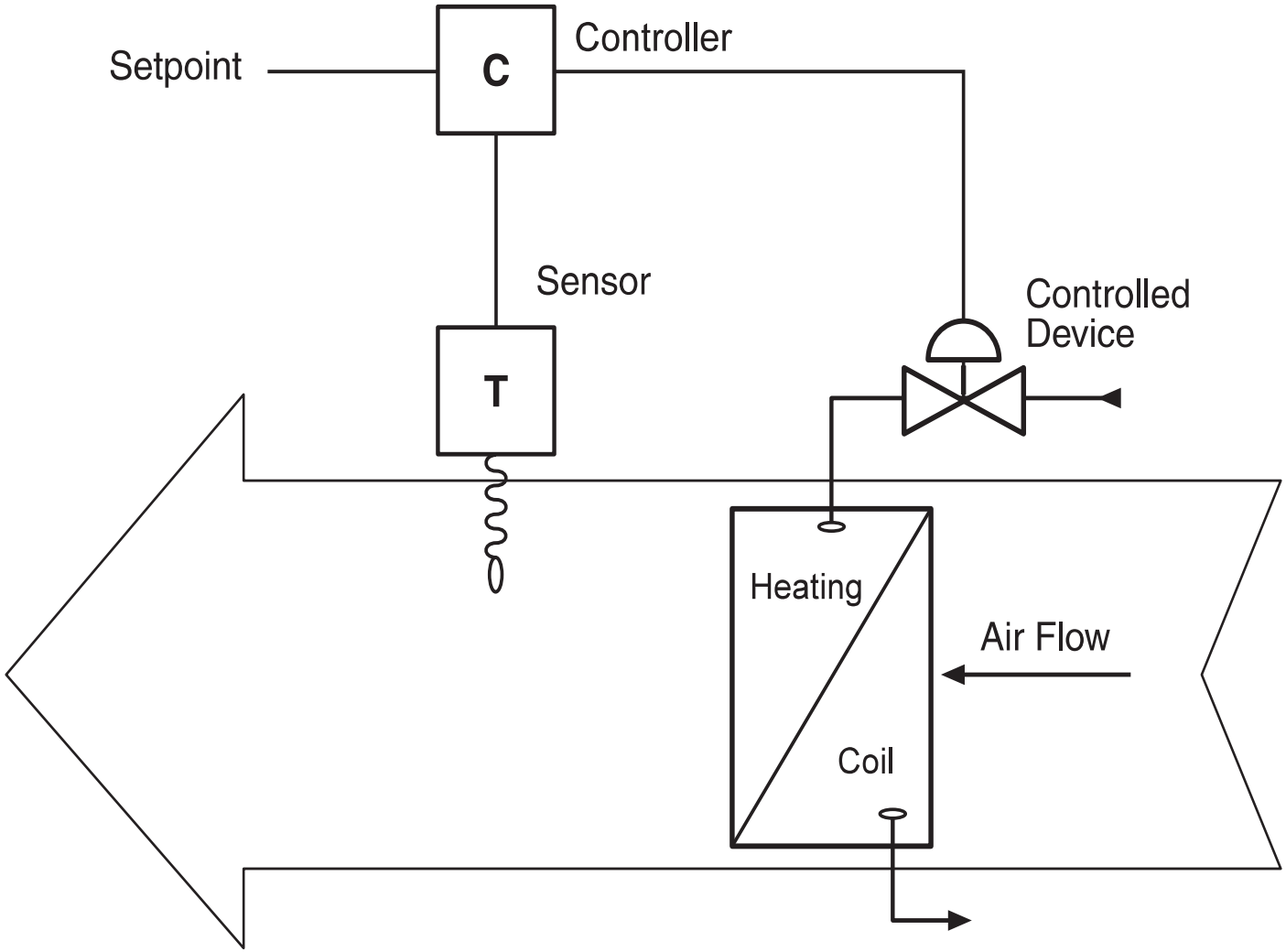
- Self-powered controls
- Electric controls
- Pneumatic controls
- Analog electronic controls
- Digital controls
  - Direct Digital Control (DDC)

- * Most control systems today use a combination of the 5 system types
  - Hybrid control system

Block Diagram of a Control Loop



Simple Heating System

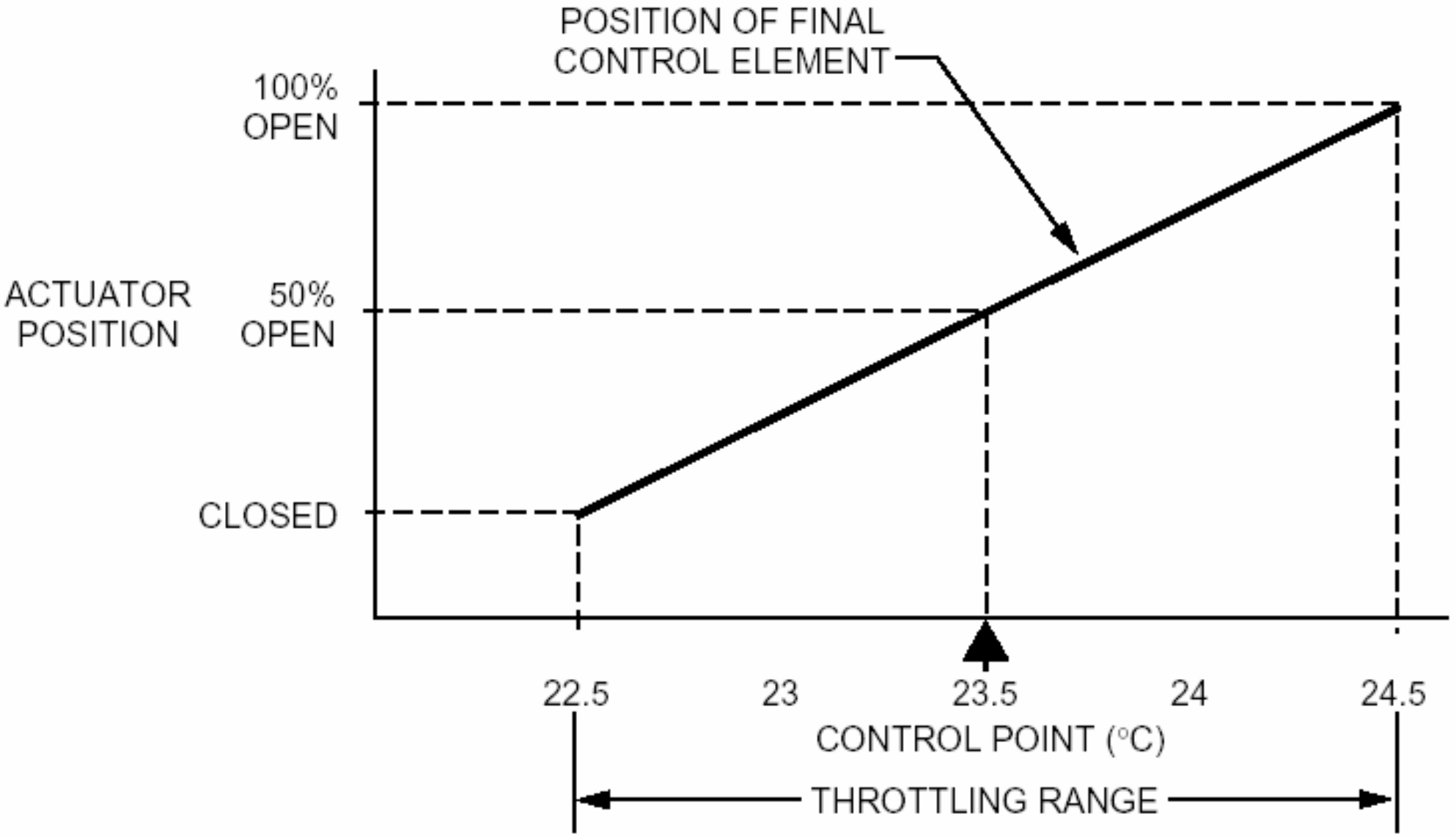


Key Terms

- Controlled variable
- Control point
- Setpoint
- Sensor
- Controlled device
- Process plant
- Controller
- Control loop
- Closed loop (i.e. w/ feedback)
- Open loop (i.e. w/o feedback)

Some Definitions

- Automatic control system: **A system that reacts to a change or imbalance in the variable it controls by adjusting other variables to restore the system to the desired balance.**
- Controlled Variable: **The quantity or condition that is measured and controlled.**
- Controller: **A device that senses changes in the controlled**

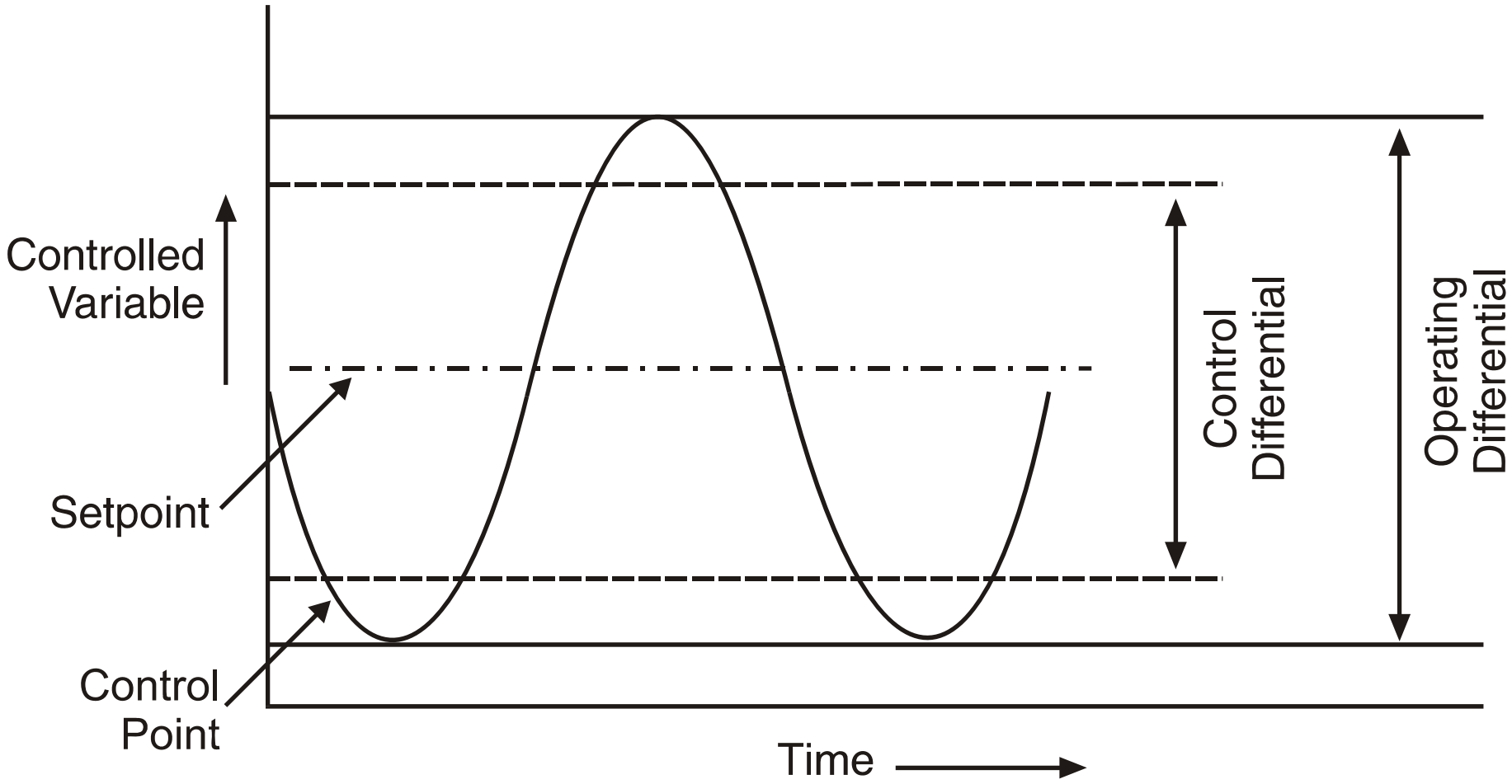


[Source: Honeywell, 1997. *Engineering Manual of Automatic Control: for Commercial Buildings*]

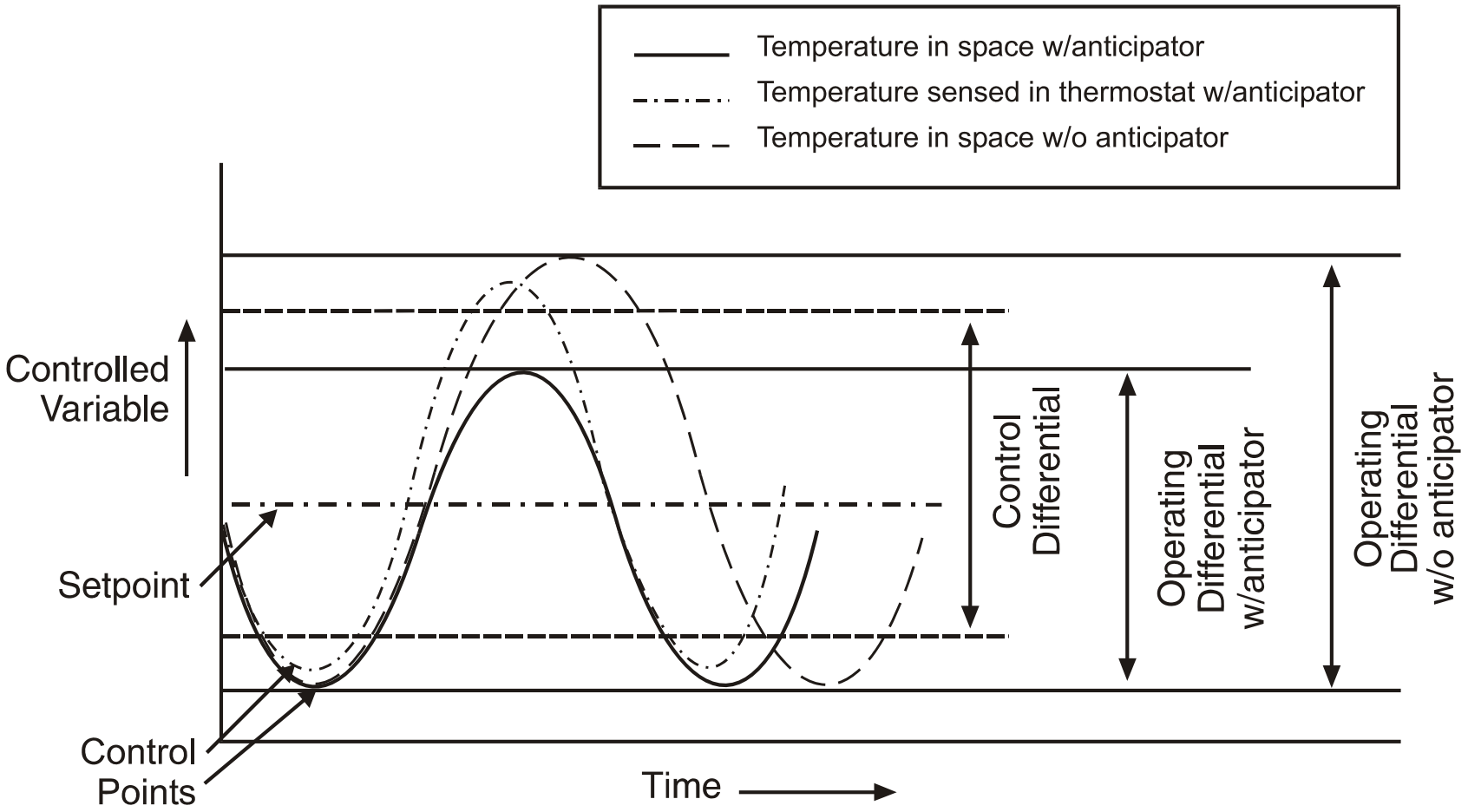
Basic Types of Control Modes

- **Two-position control**
- **Floating control**
- **Modulating control**

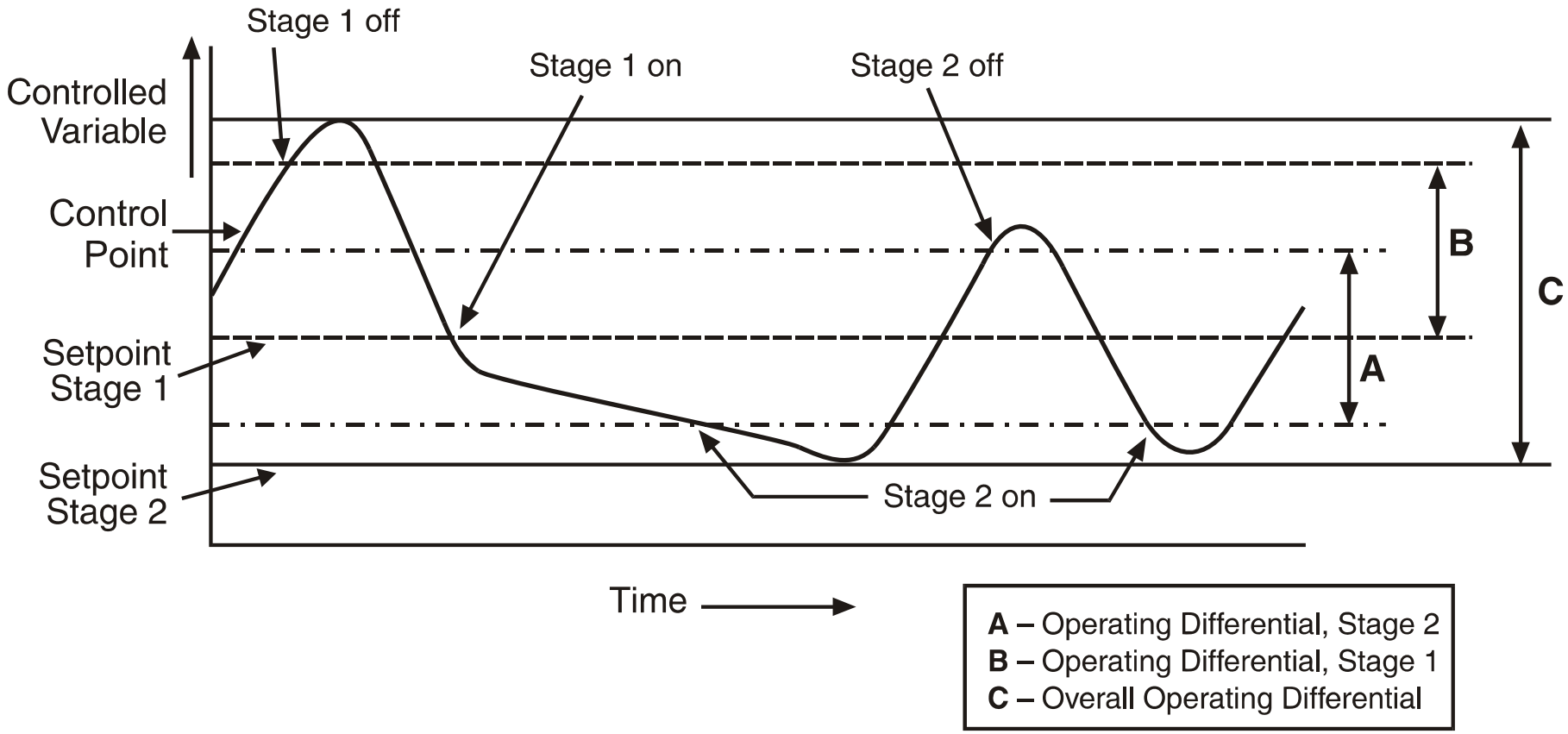
Two-Position Control



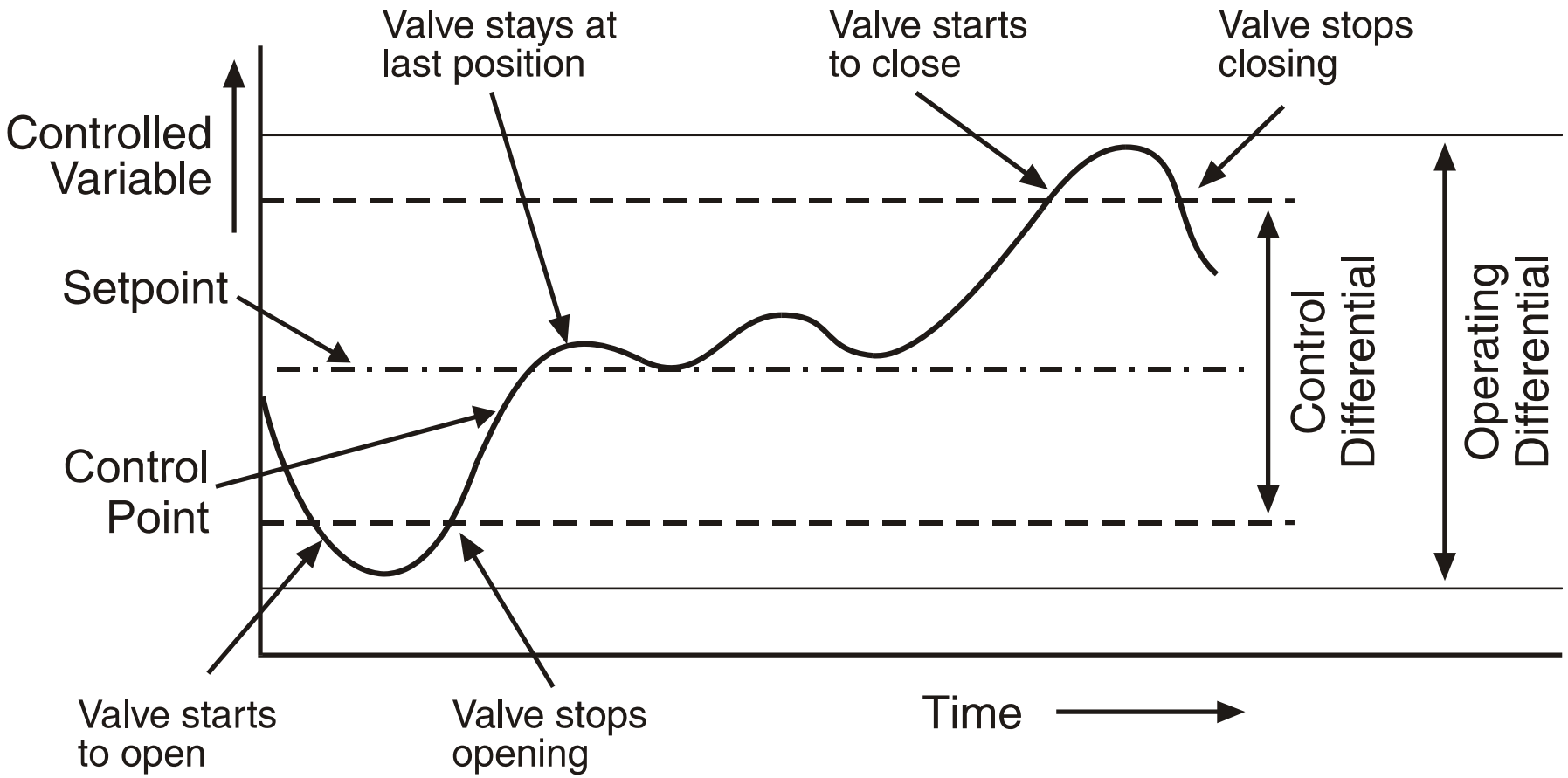
Two-Position Control With Anticipator



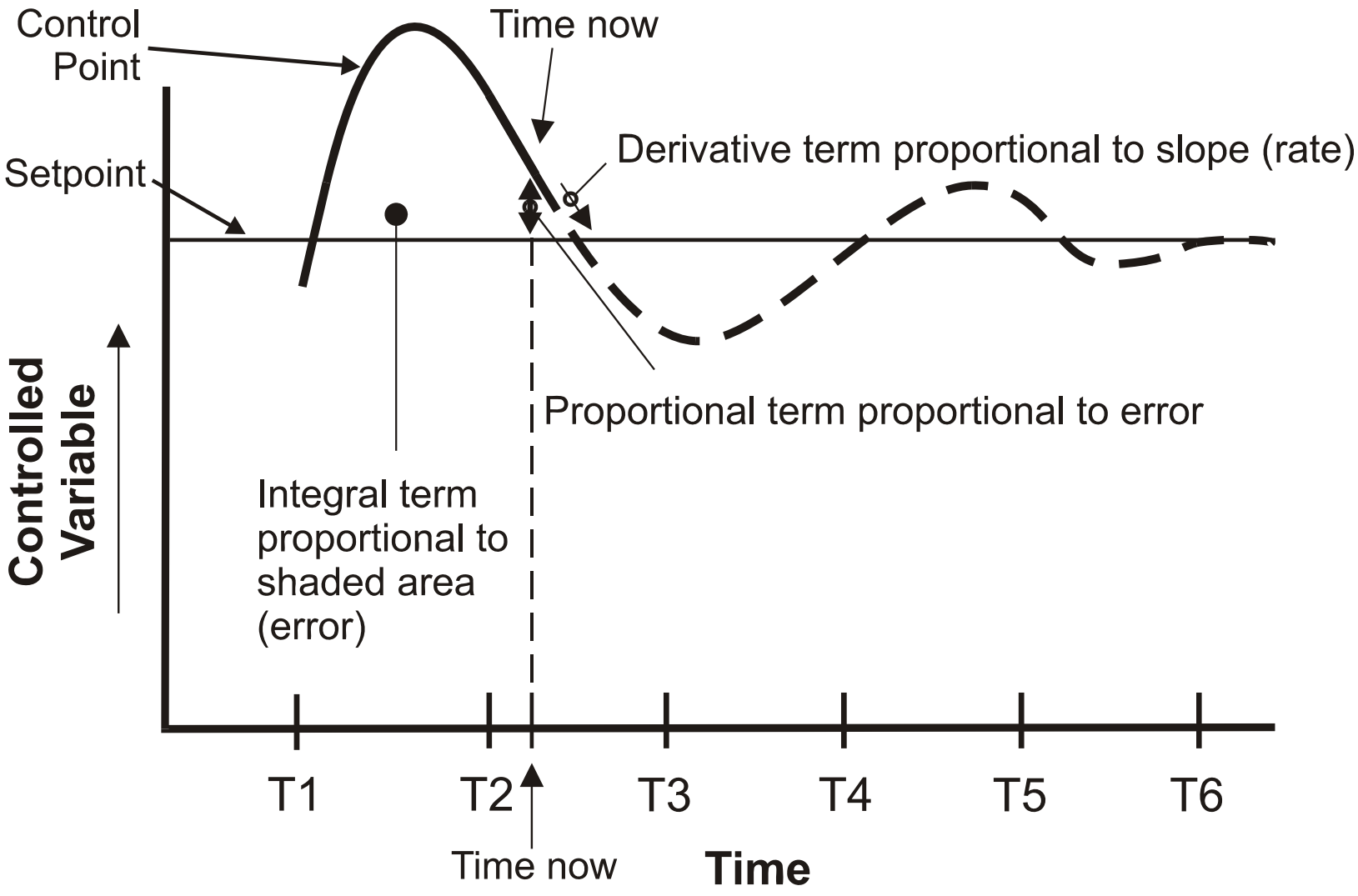
Step Control



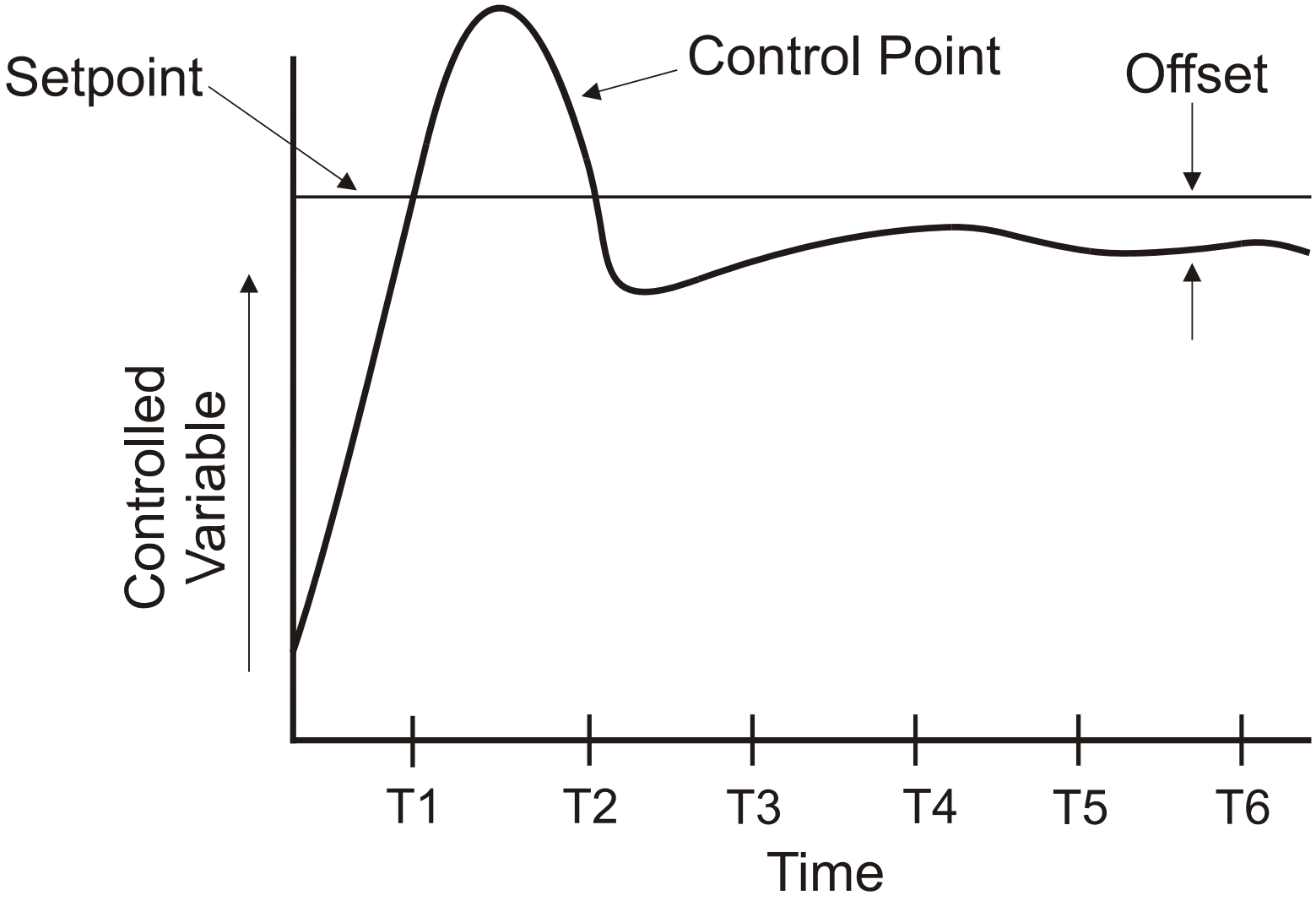
Floating Control



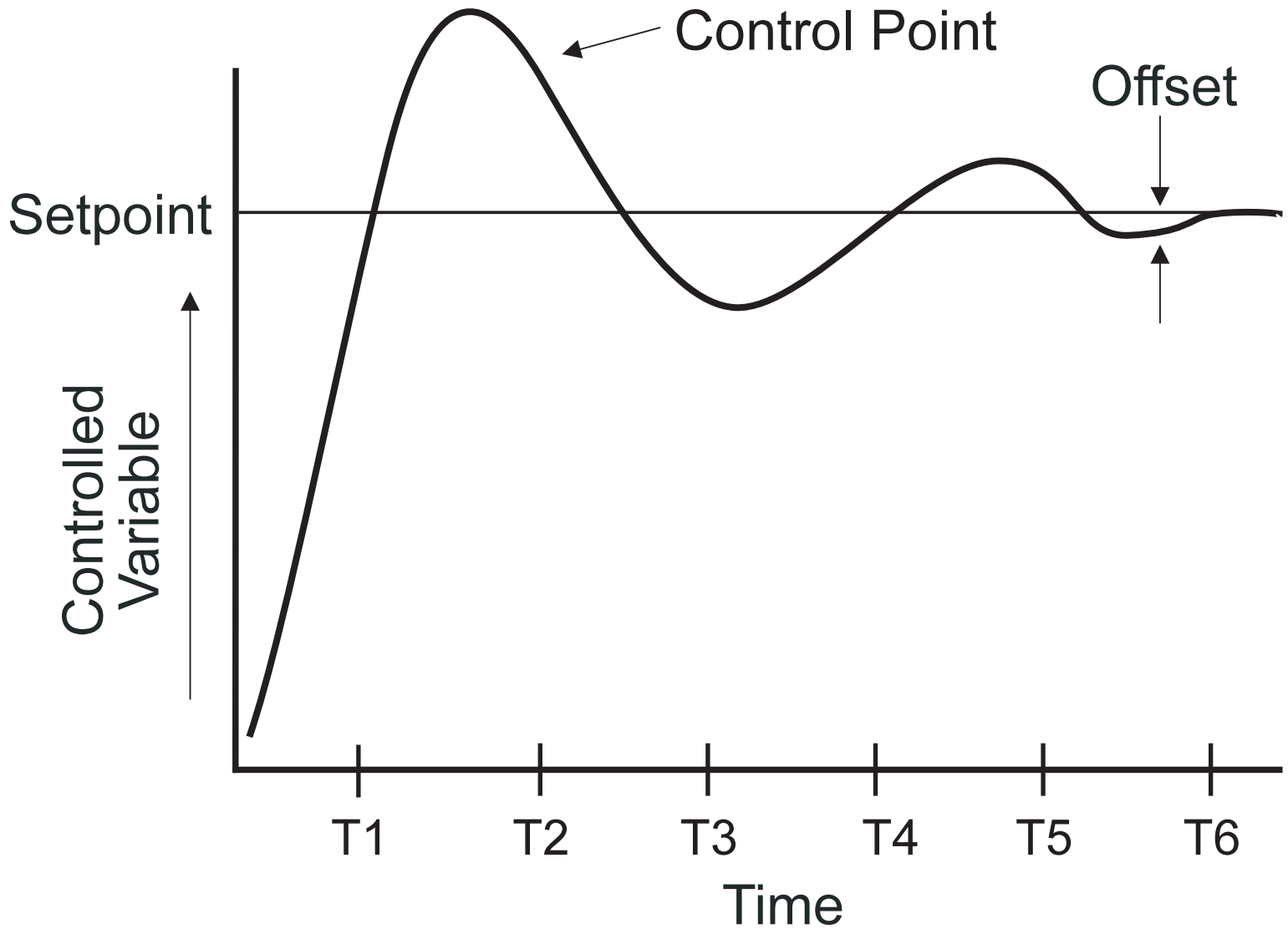
P-I-D Control

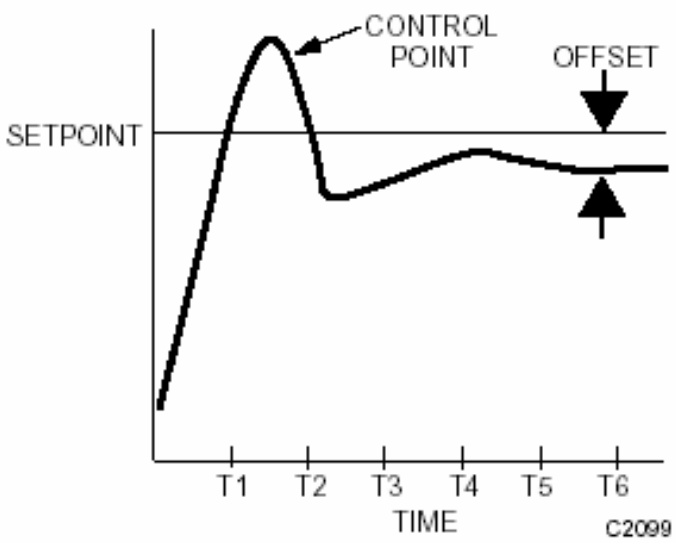


Proportional-Only Control

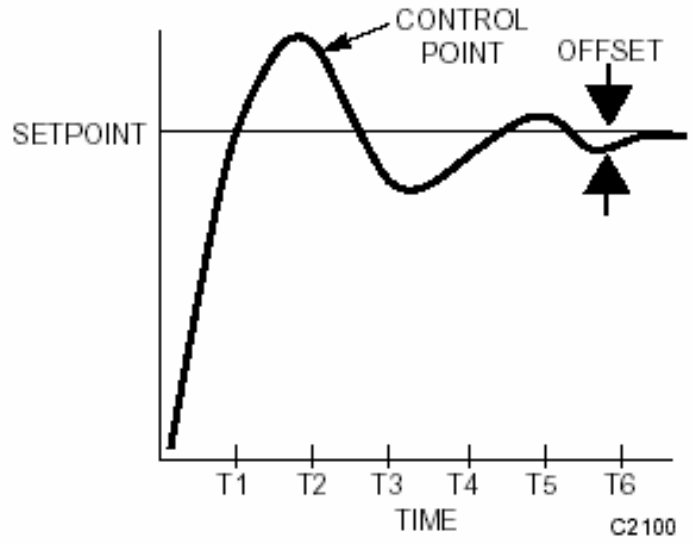


P-I Control

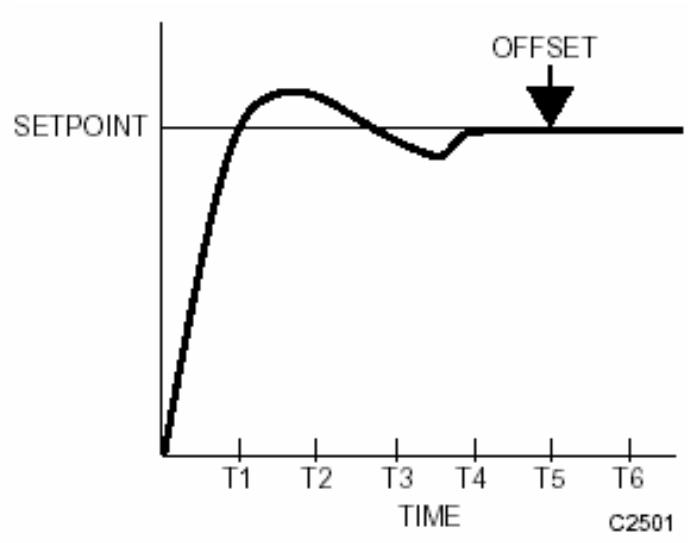




Proportional Control



Proportional-Integral (PI) Control



Proportional-Integral-Derivative (PID) Control

$$V = \underbrace{KE}_{\text{Proportional}} + \underbrace{\frac{K}{T_I}\int E\,dt}_{\text{Integral}} + \underbrace{KT_D\frac{dE}{dt}}_{\text{Derivative}} + M$$

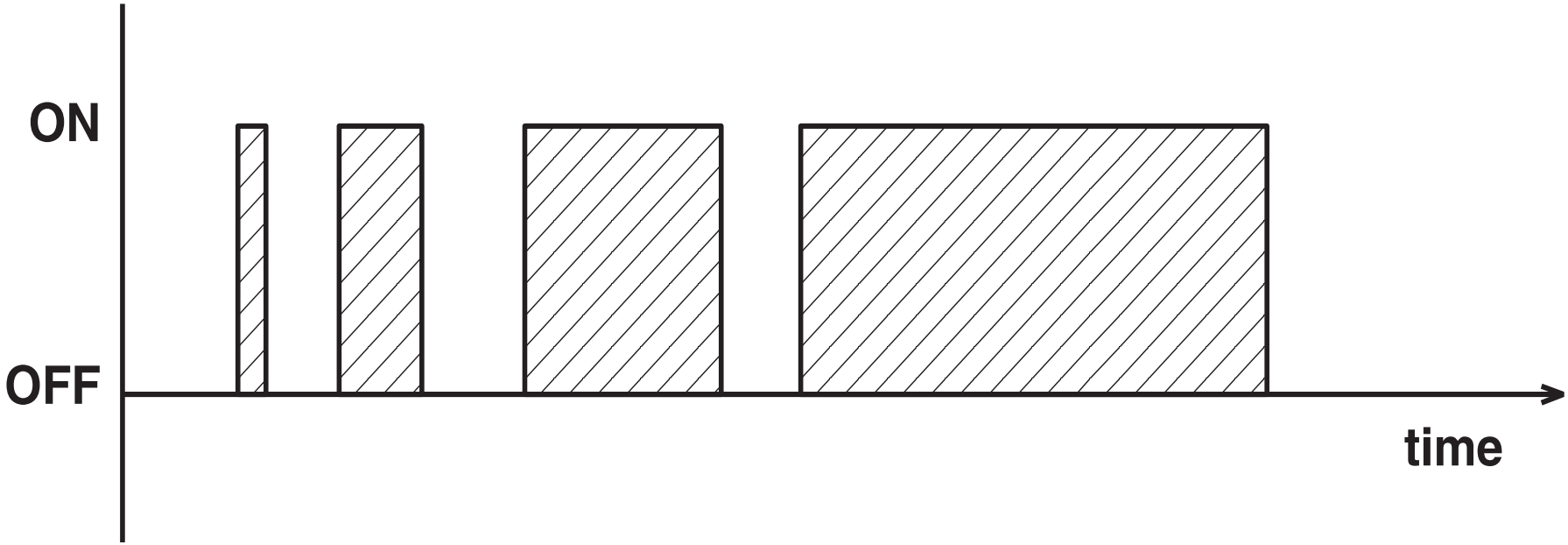
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control: for Commercial Buildings*]

Recommended control modes for HVAC system

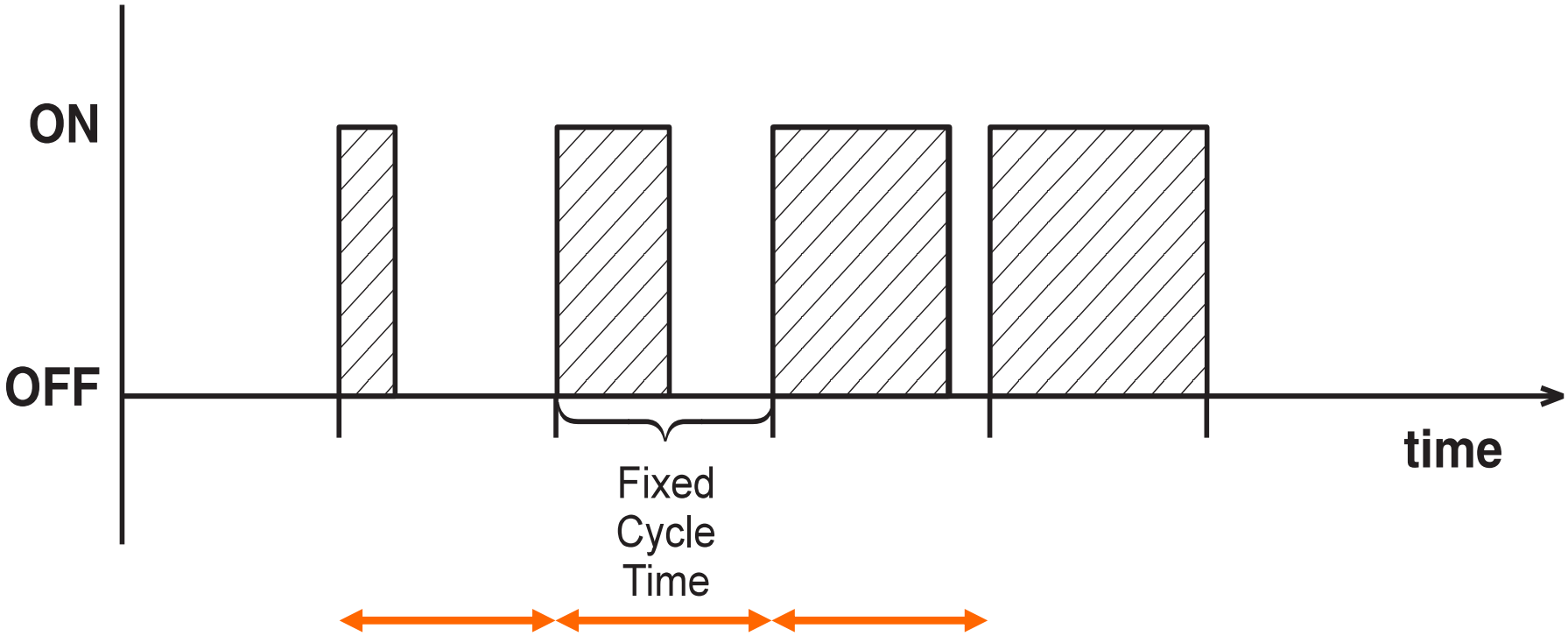
Application	Control mode
Space temperature	**P, PID**
Mixed air temperature	**PI, Enhanced PID**
Coil discharge temperature	**PI, Enhanced PID**
Chiller discharge temperature	**PI, Enhanced PID**
Air flow	**PI (use wide proportional band & a fast reset rate), PID**
Fan static pressure	**PI, Enhanced PID**
Humidity	**P, possibly PI for tight control**
Dewpoint temperature	**P, possibly PI for tight control**

[Source: Honeywell, 1997. *Engineering Manual of Automatic Control: for Commercial Buildings*]

Pulse Width Modulation

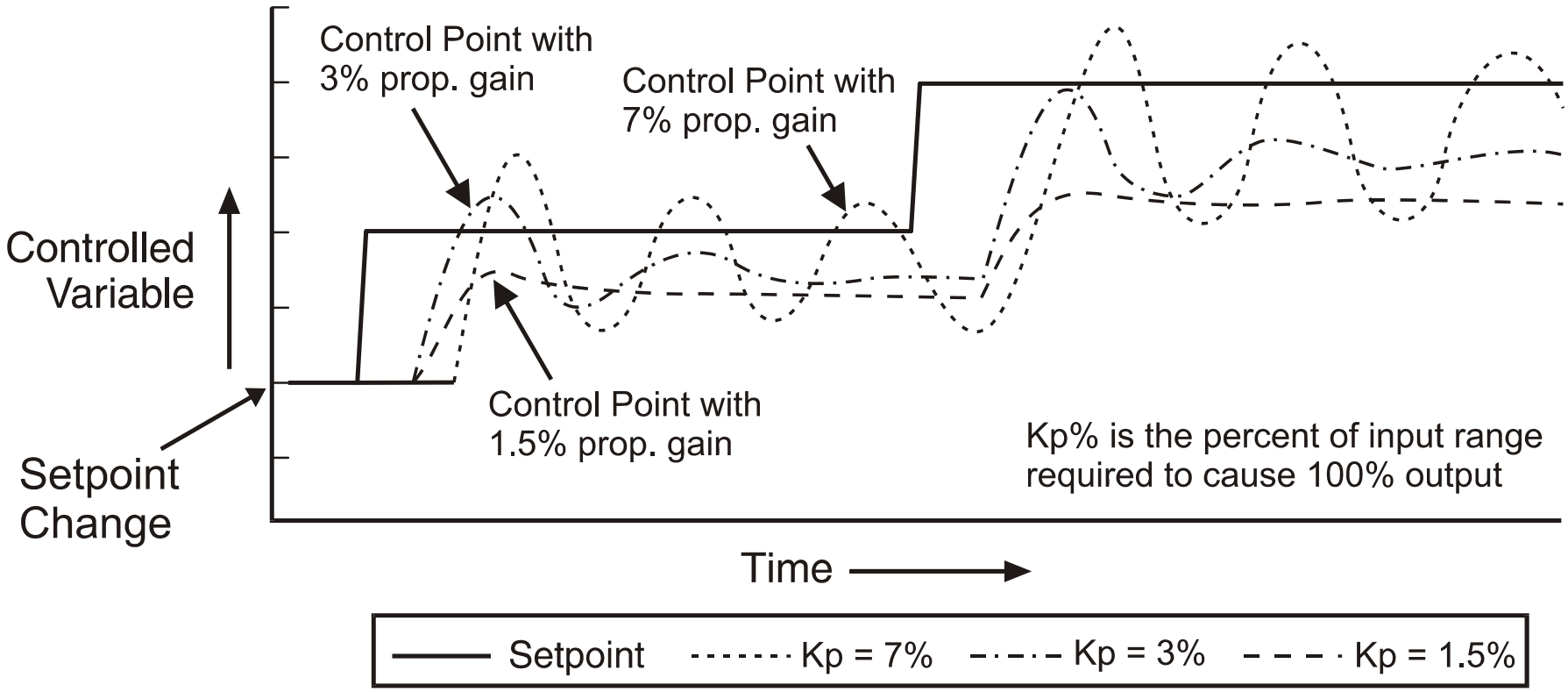


Time-Proportioning Control



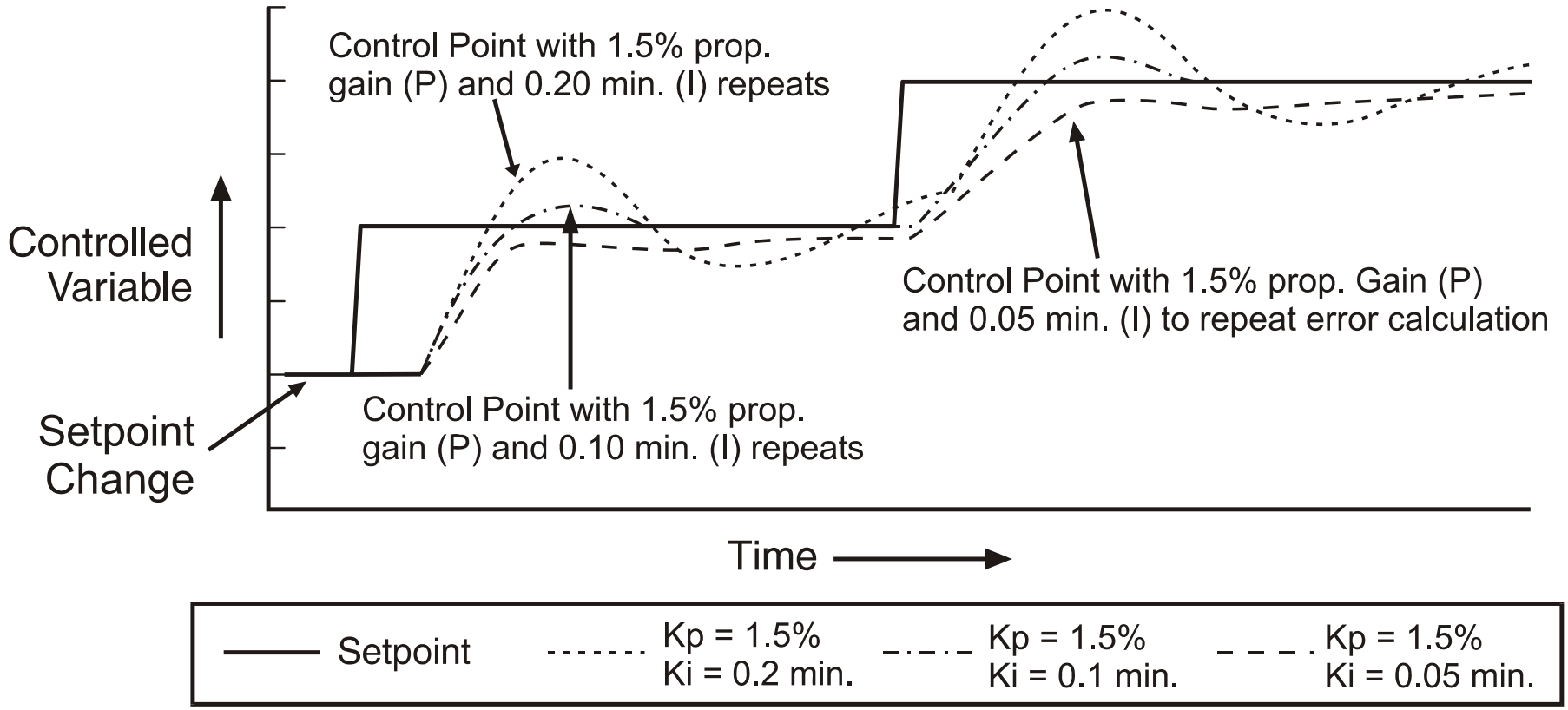
Proportional Control

(Gain and Loop Tuning – adjust the %gain to meet the specific application)



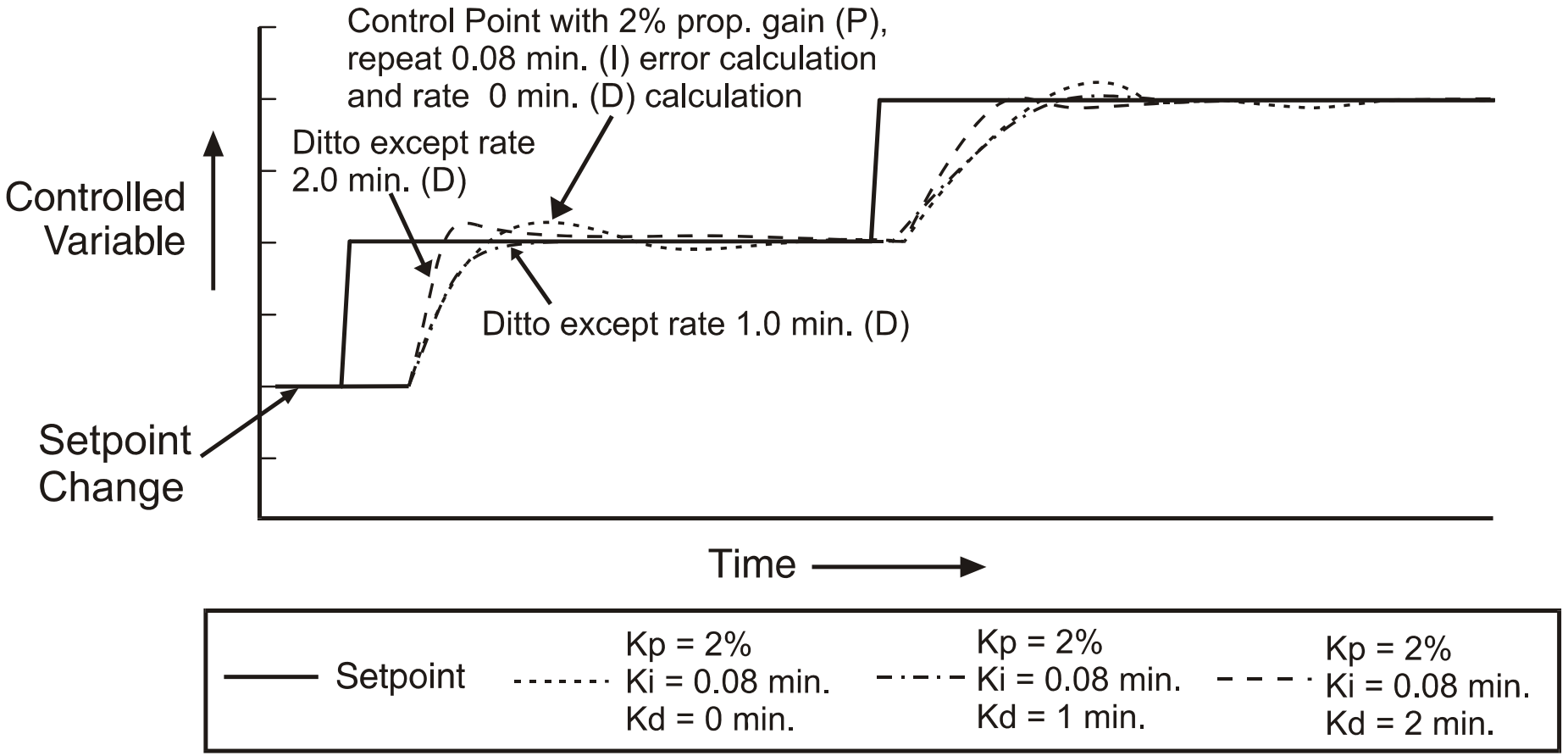
P-I Control

(Loop Tuning is an "art". Usually tune the P gain first, then adjust I gain to eliminate offset)

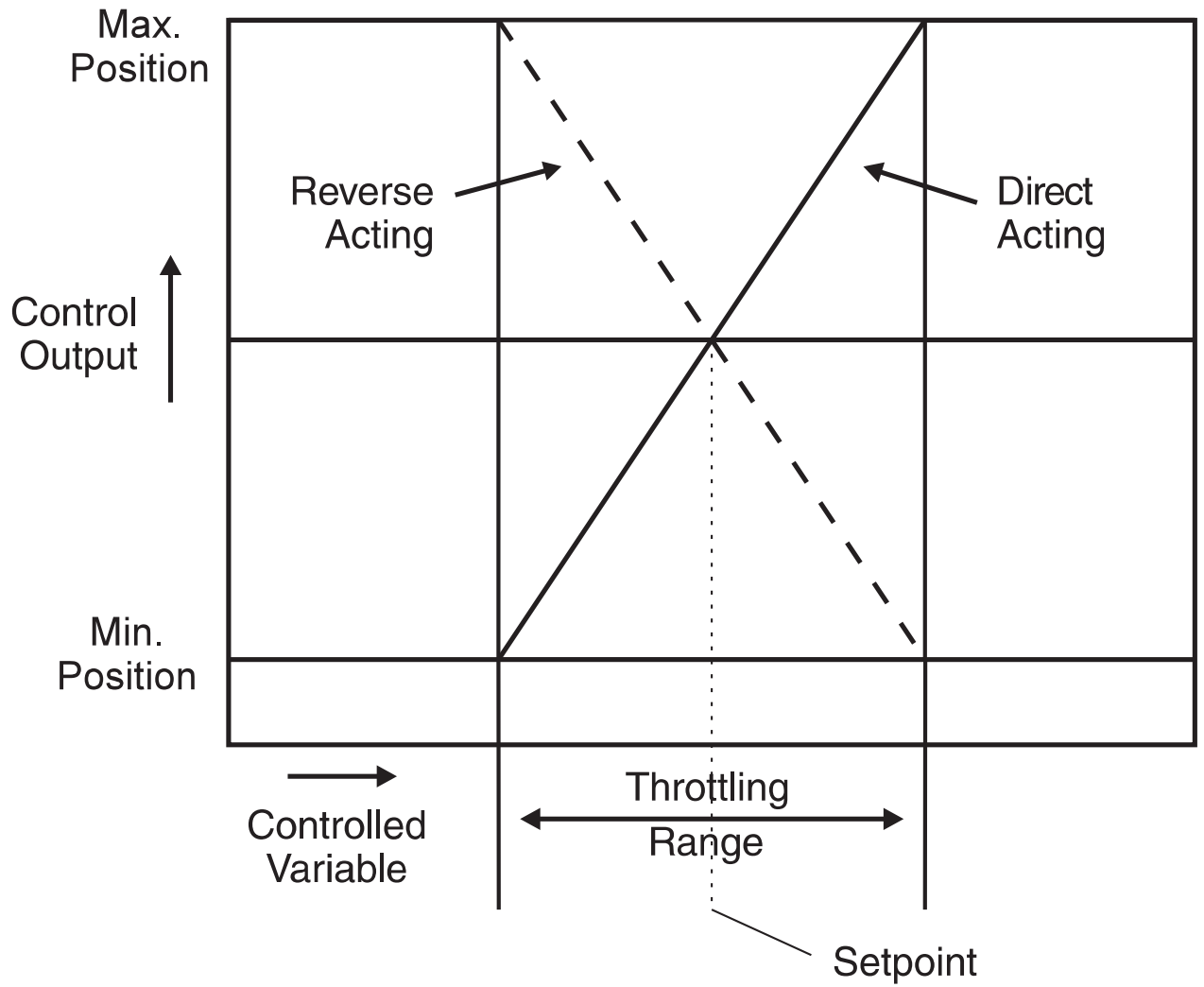


P-I-D Control

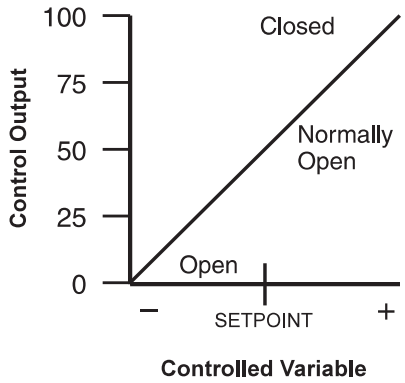
(Derivative is seldom used because HVAC system response is rather slow.)

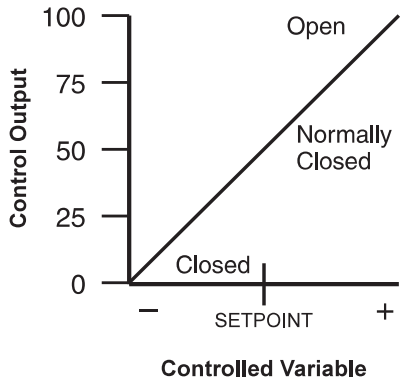


Proportional Control

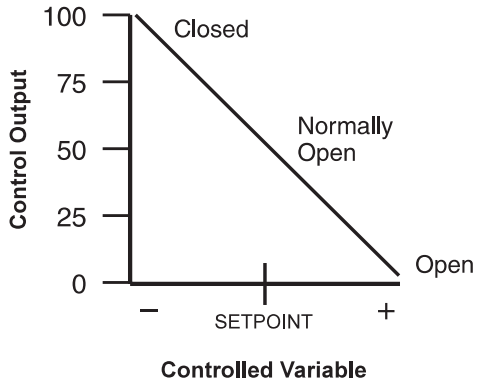


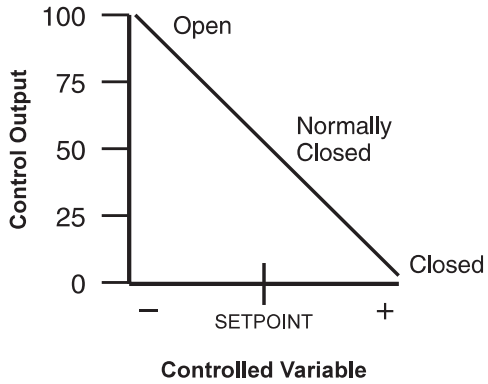
Control Action & Normal Position





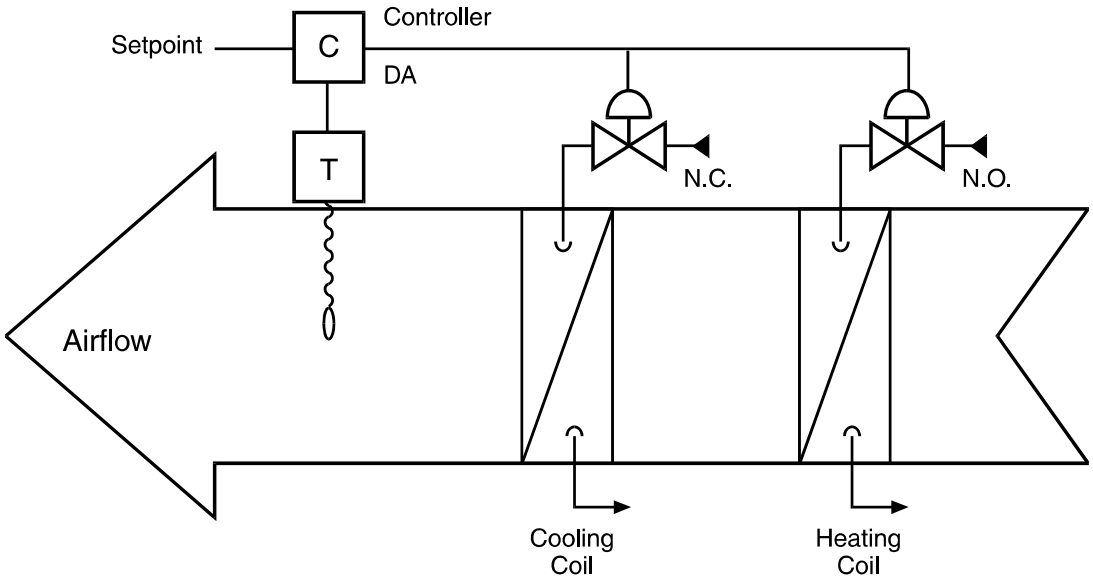
Direct Acting Controller

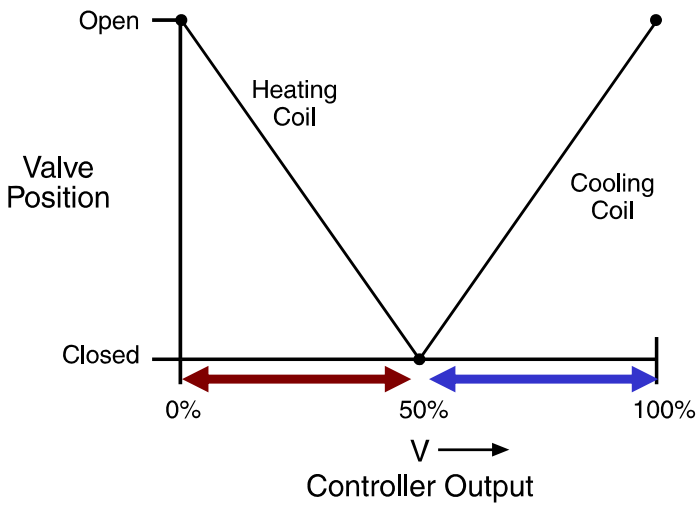




Reverse Acting Controller

Sequencing





Typical control ranges:
- Pneumatic = 3-13 psi
- Electronic = 2-12 Vdc

Control range (heating)

Control range (cooling)

Chapter 2
Basics of Electricity

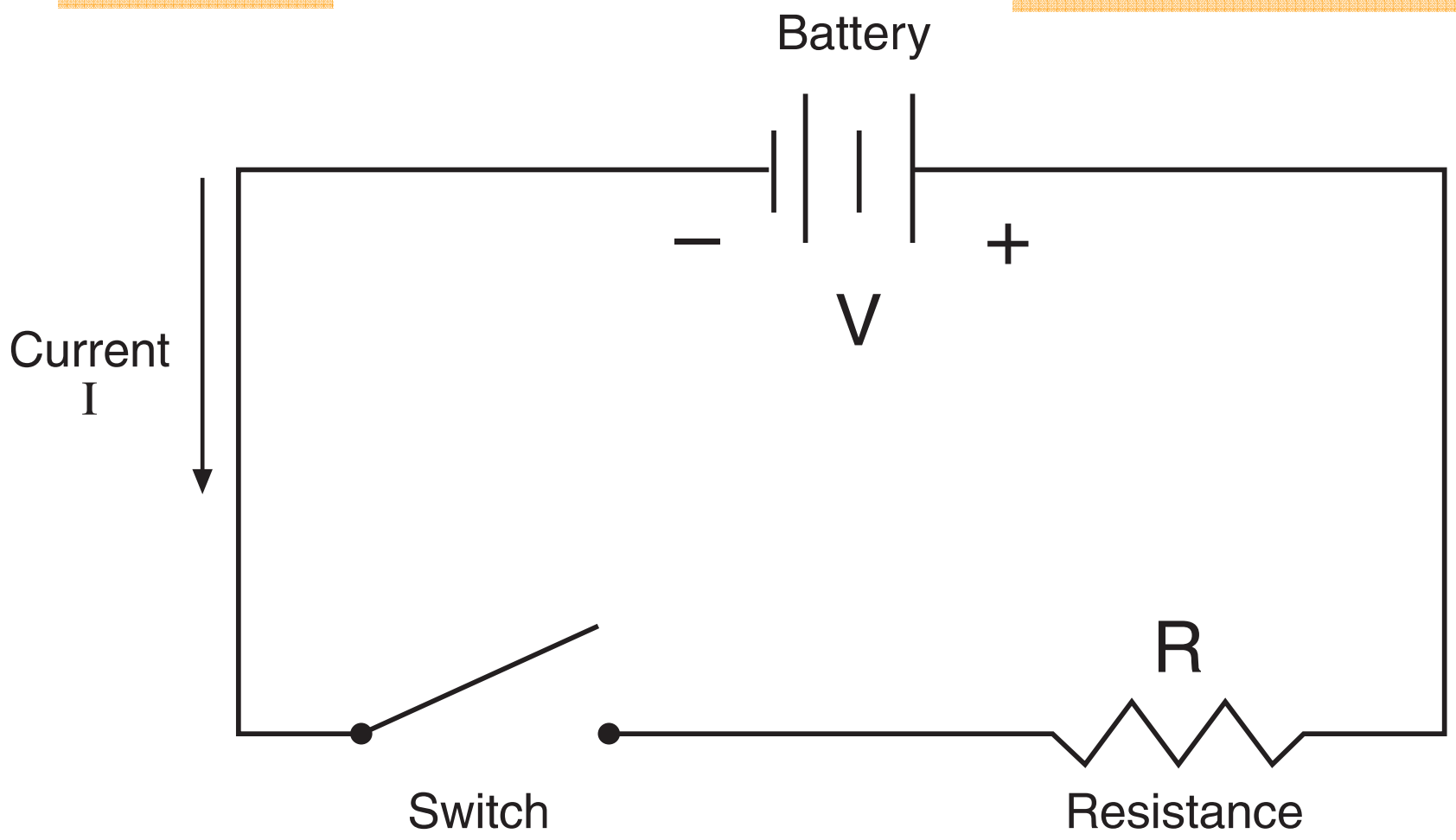
Introduce simple electrical circuits and common devices for controlling electrical power in HVAC systems. Some concepts of electronics are also helpful.

Common devices: relays, transformers, starters

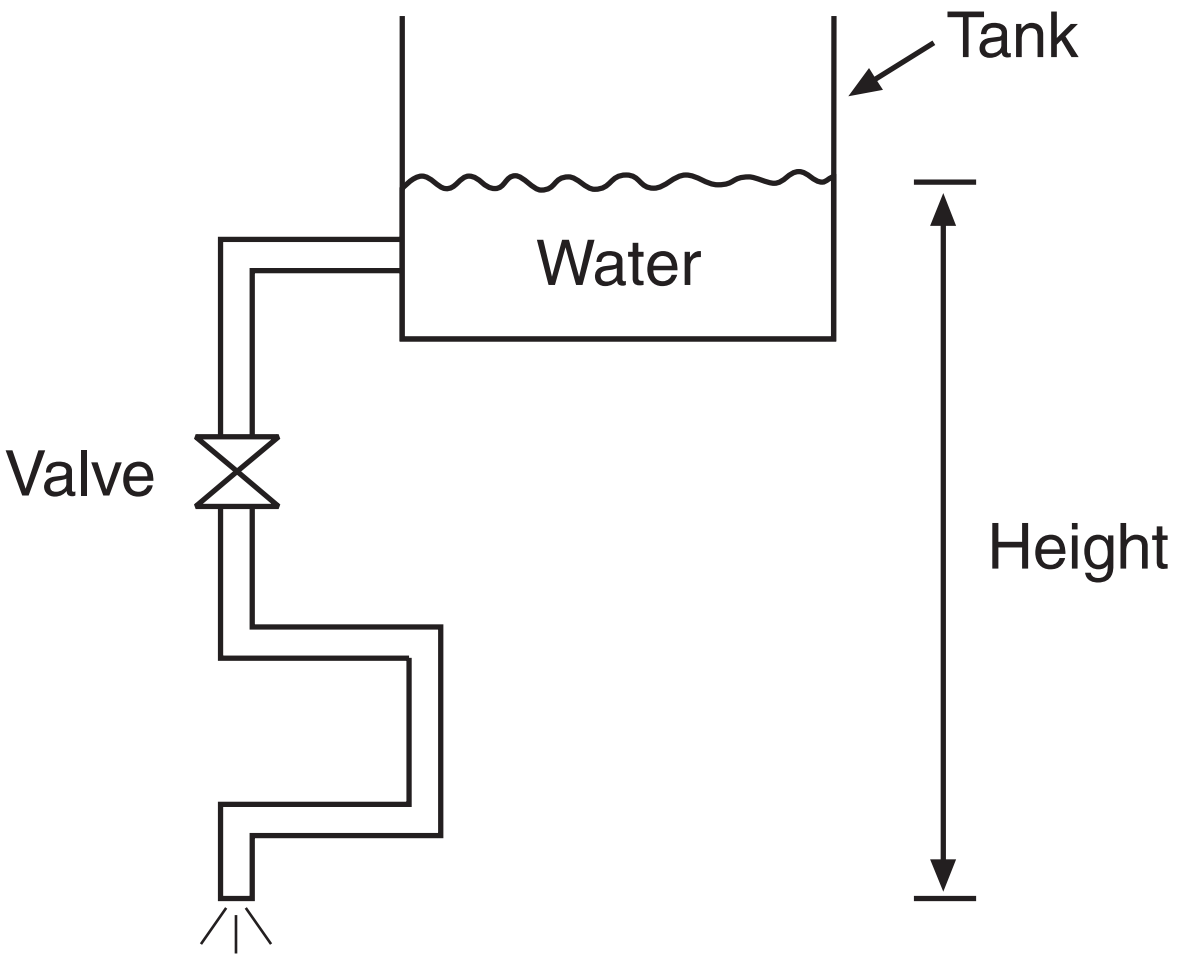
Simple Electrical Circuit

$V = I \times R$

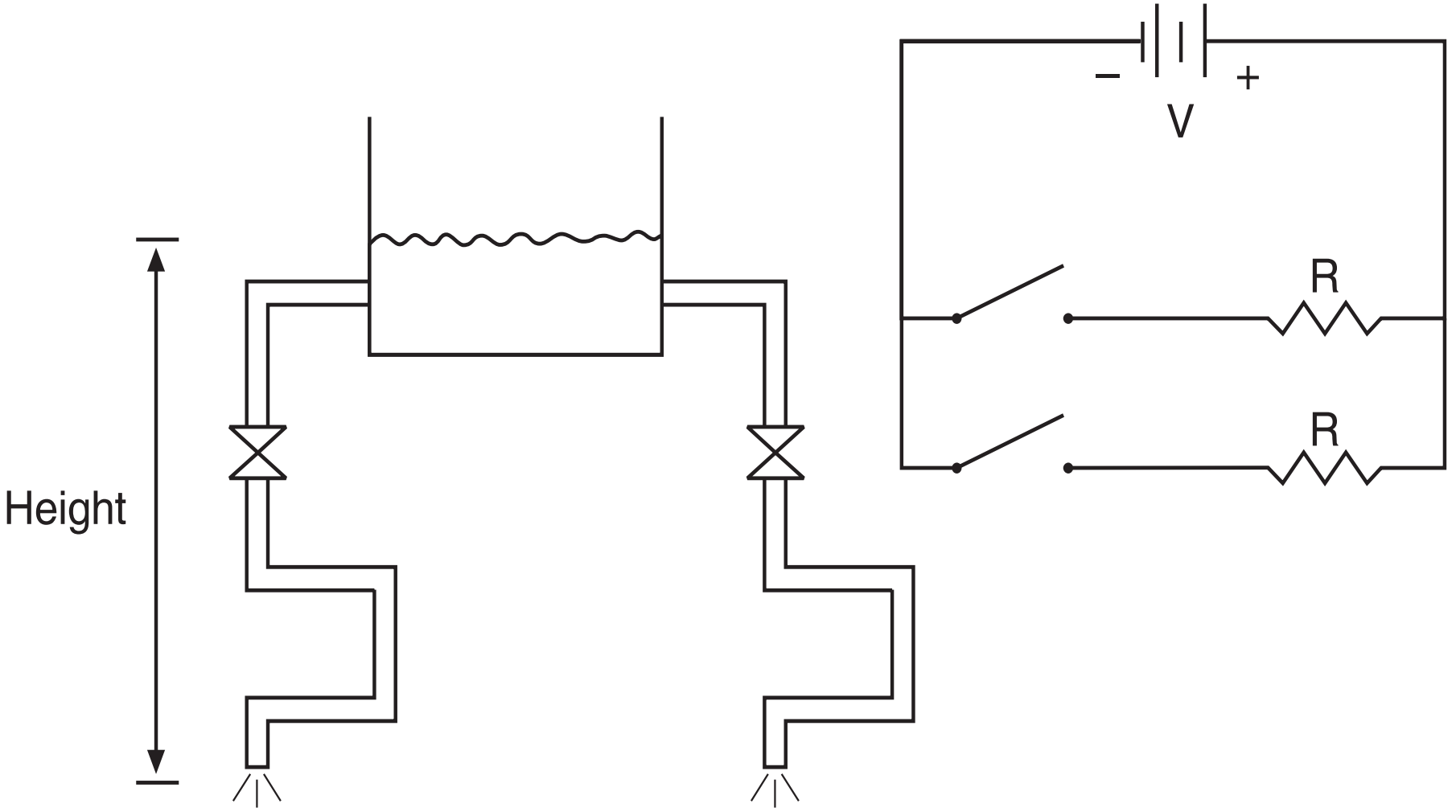
$P = V \times I = I^2 \times R$



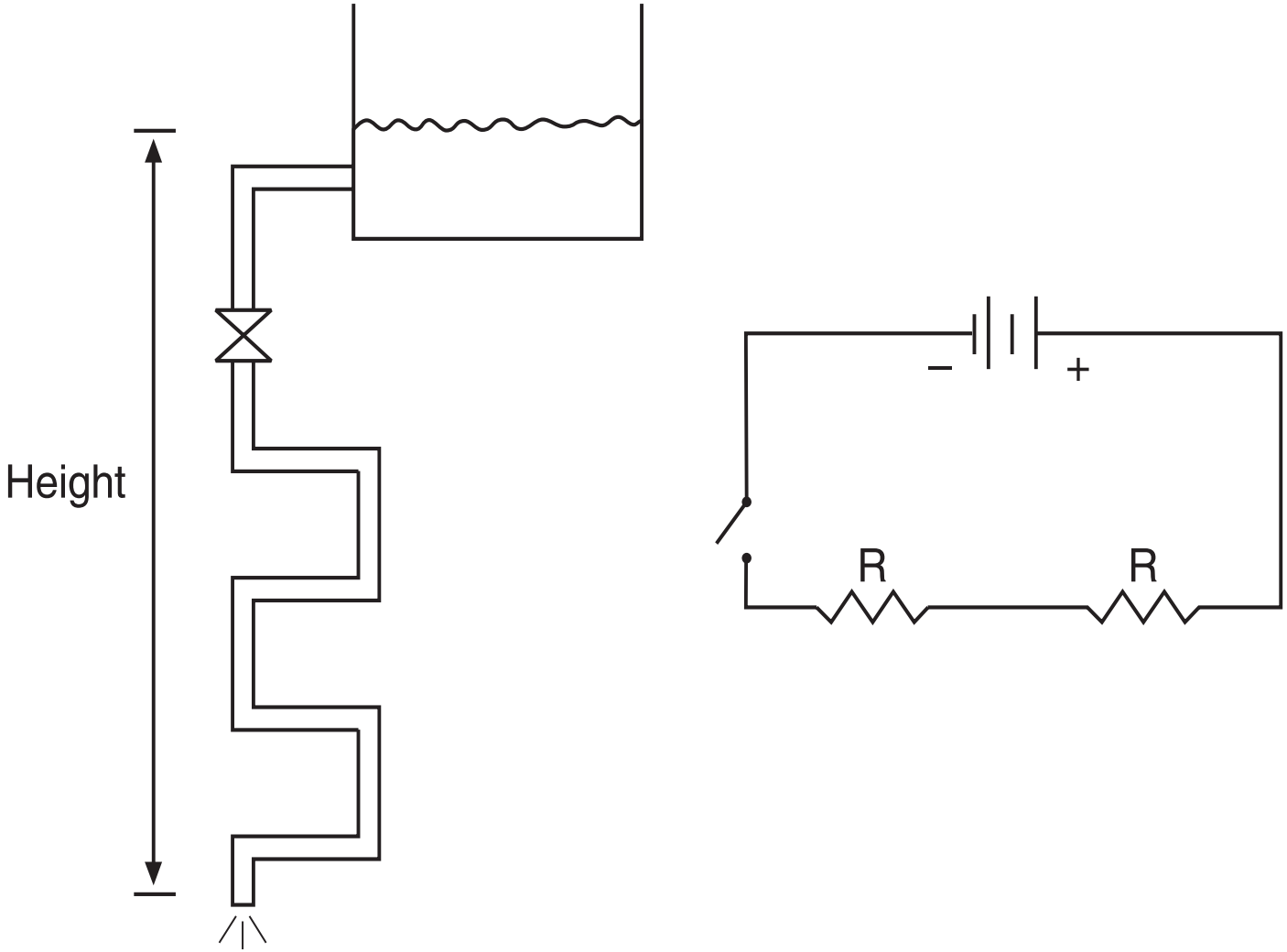
Water Tank Analogy



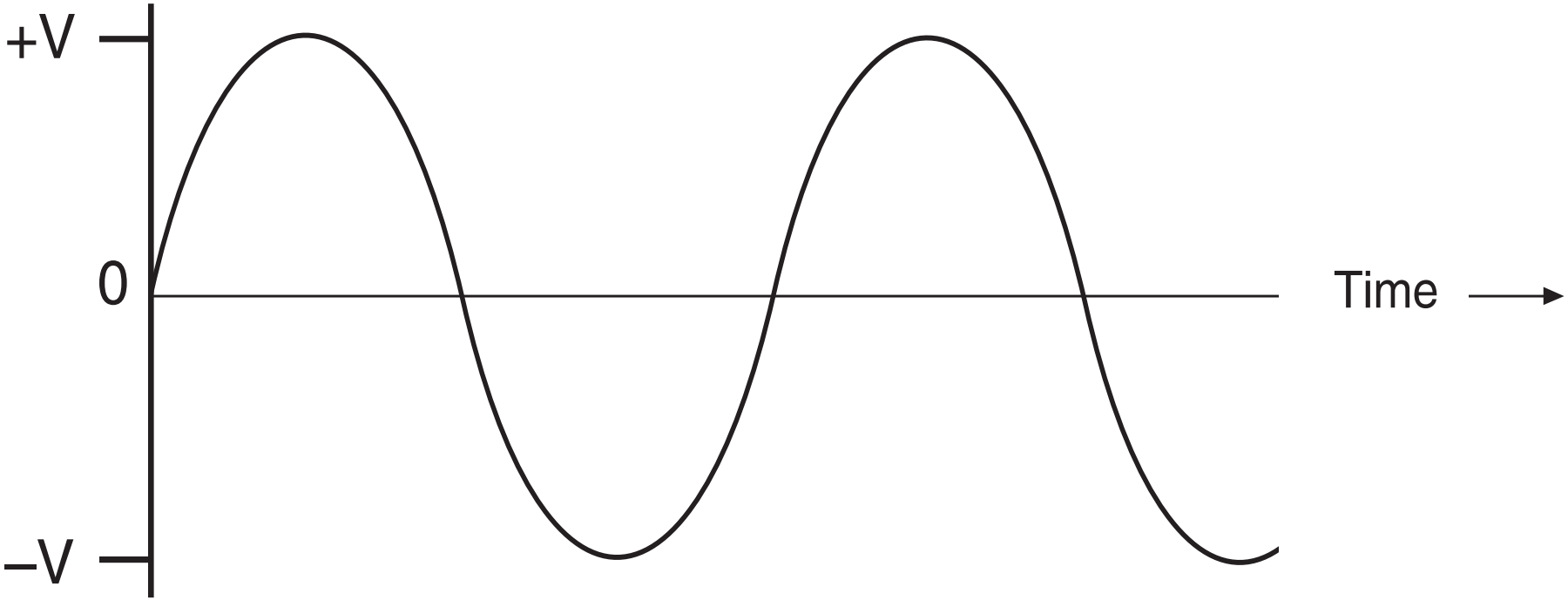
Parallel Circuits



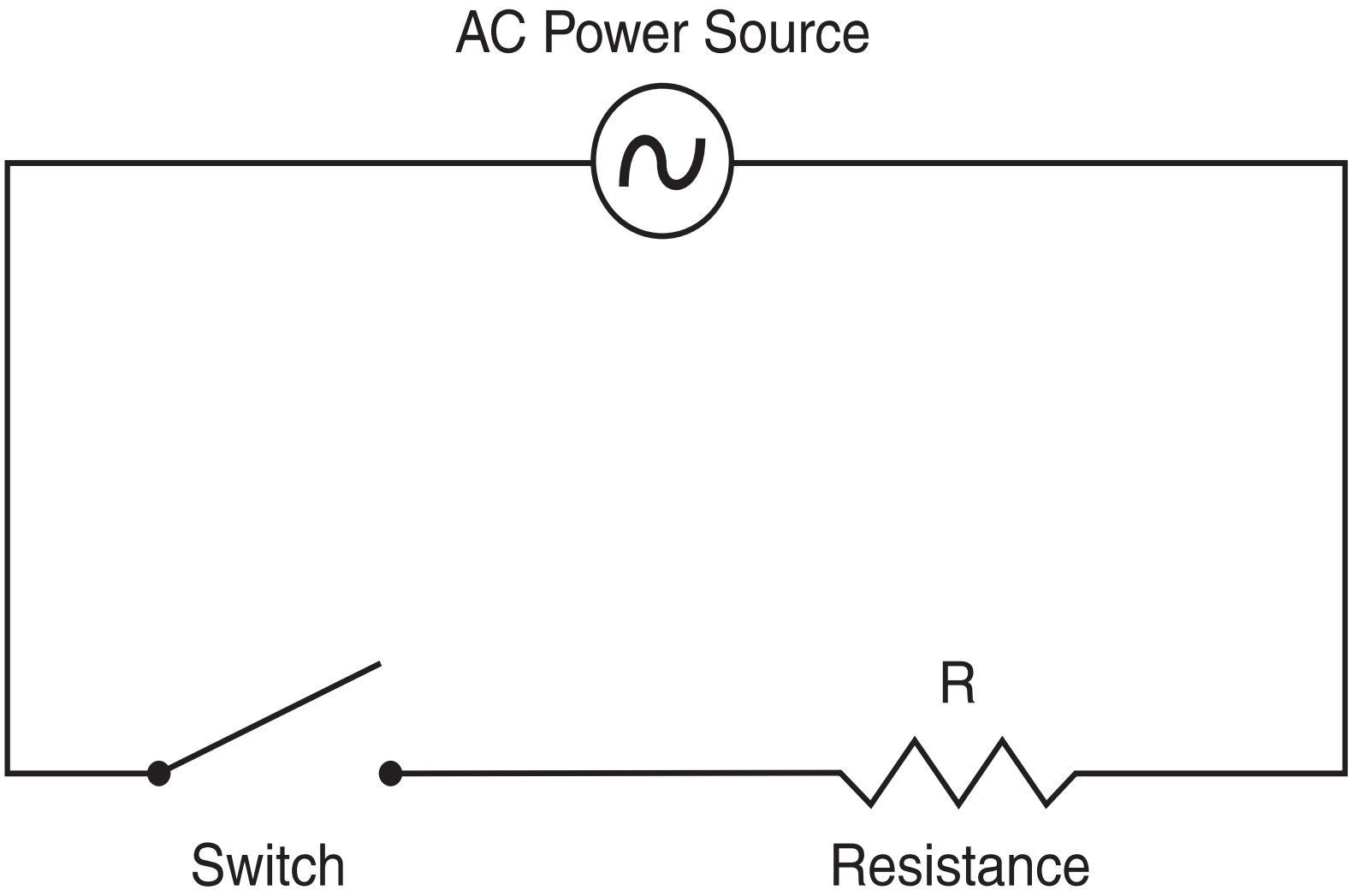
Series Circuits



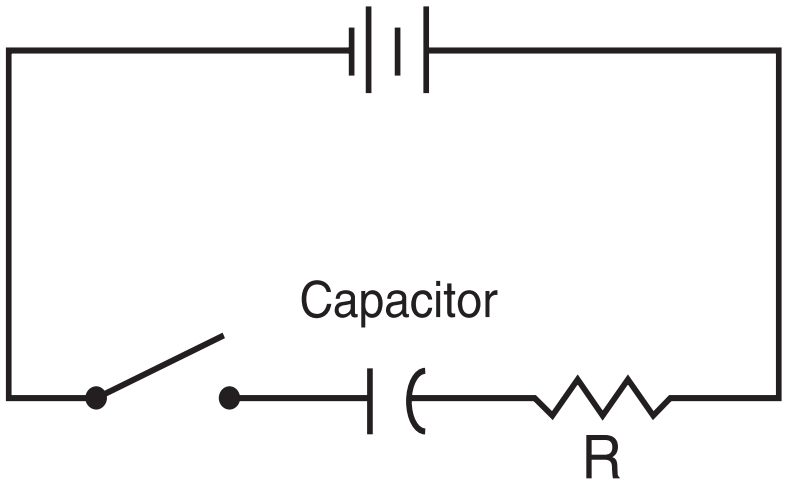
Alternating Voltage

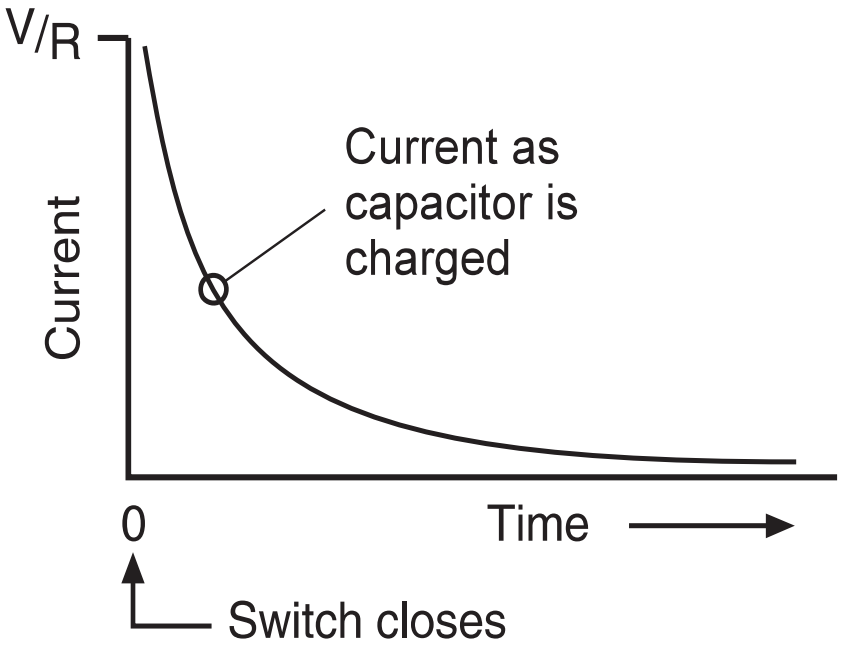


Simple AC Circuit

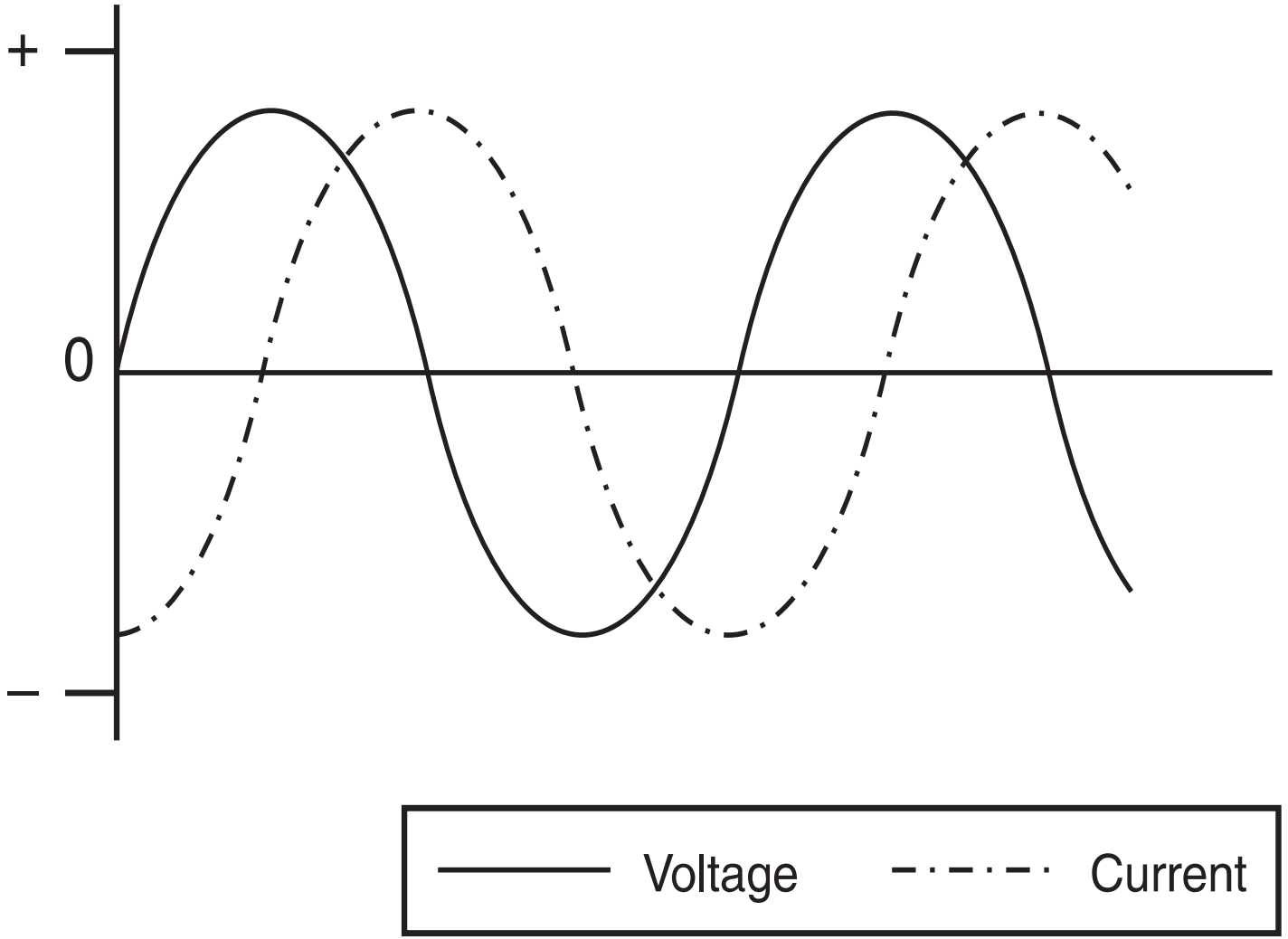


Capacitor in DC Circuit

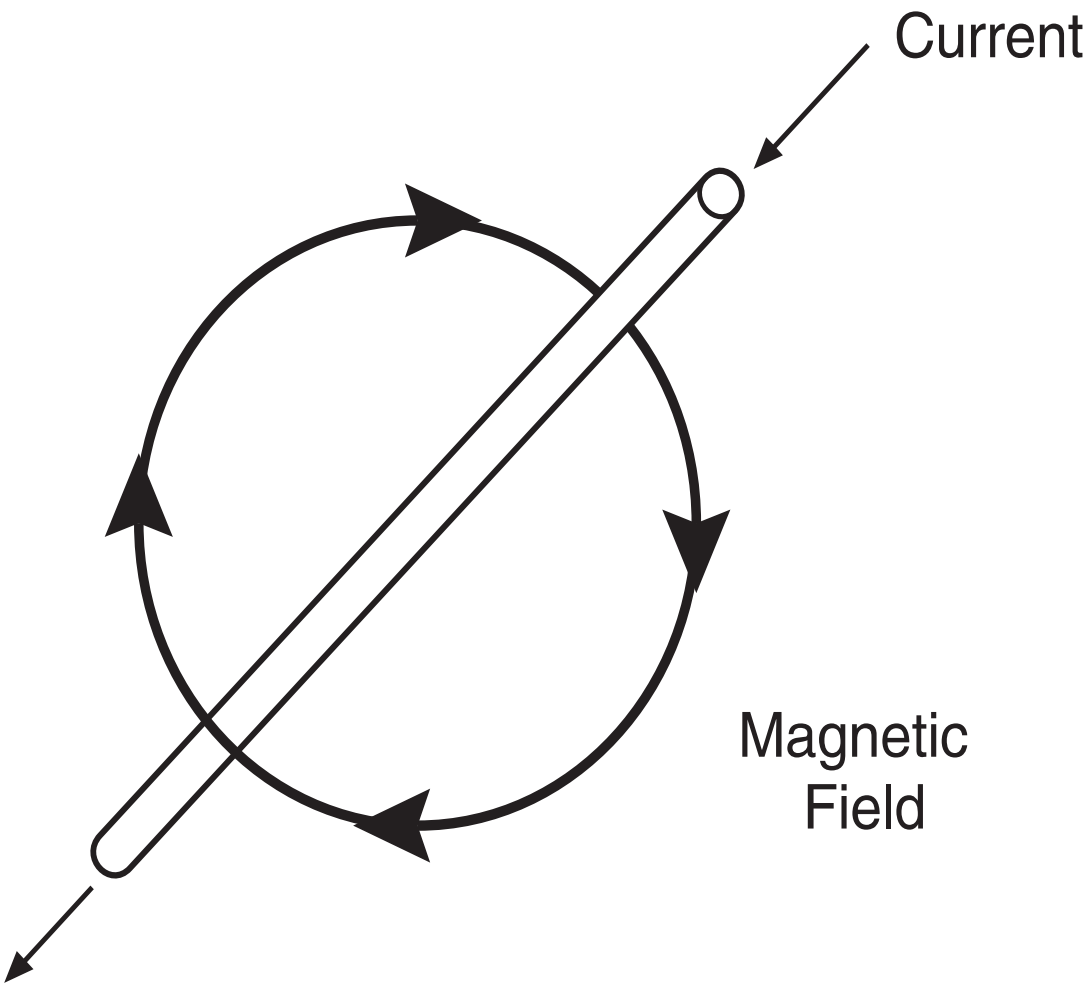


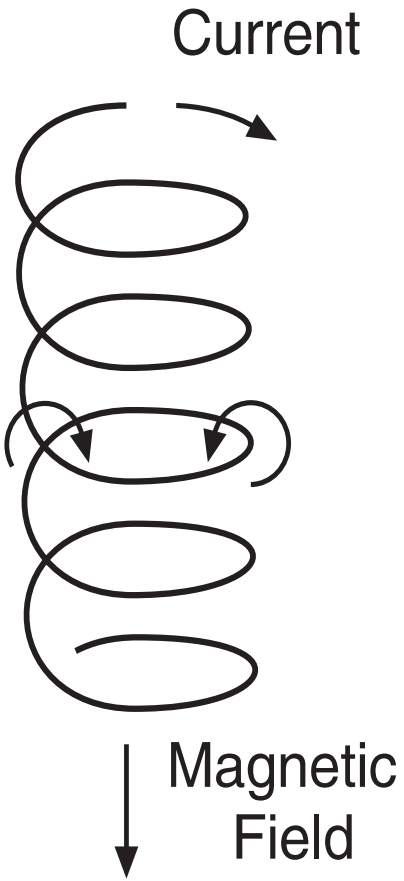


Voltage & Current Out of Phase

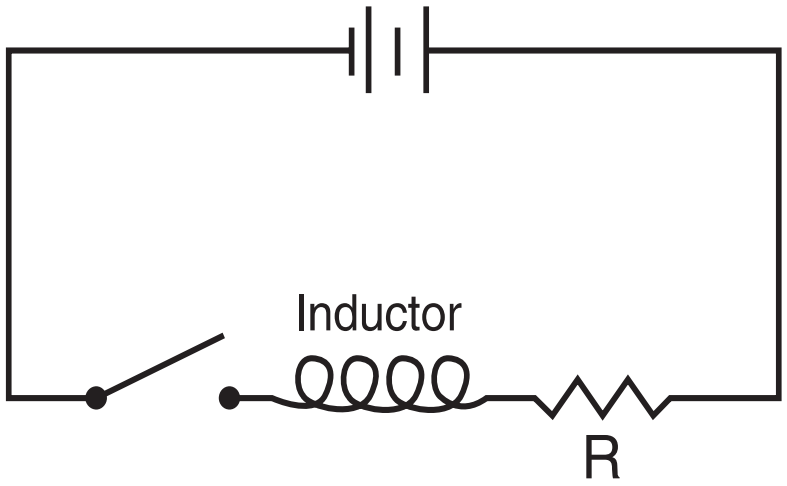


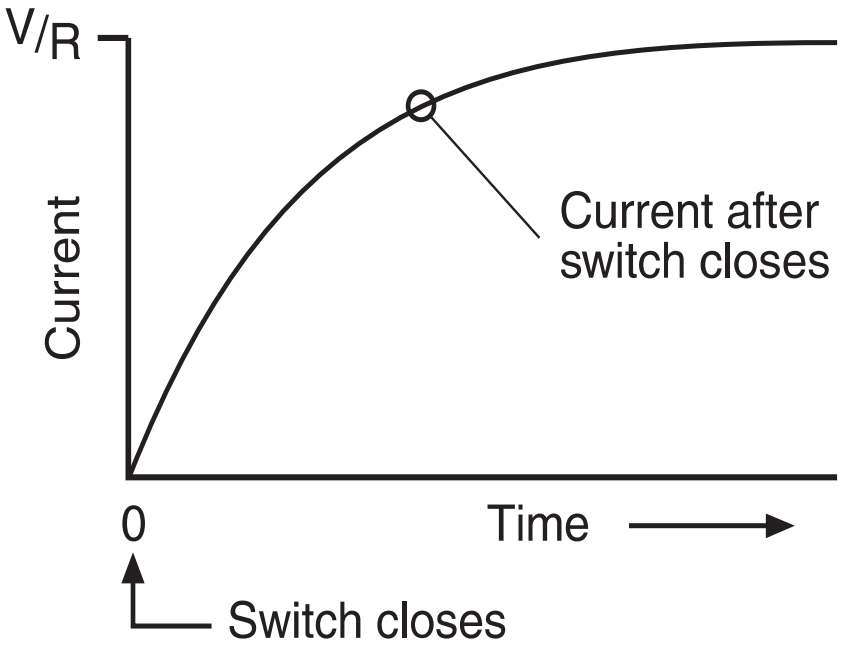
Magnetic Field





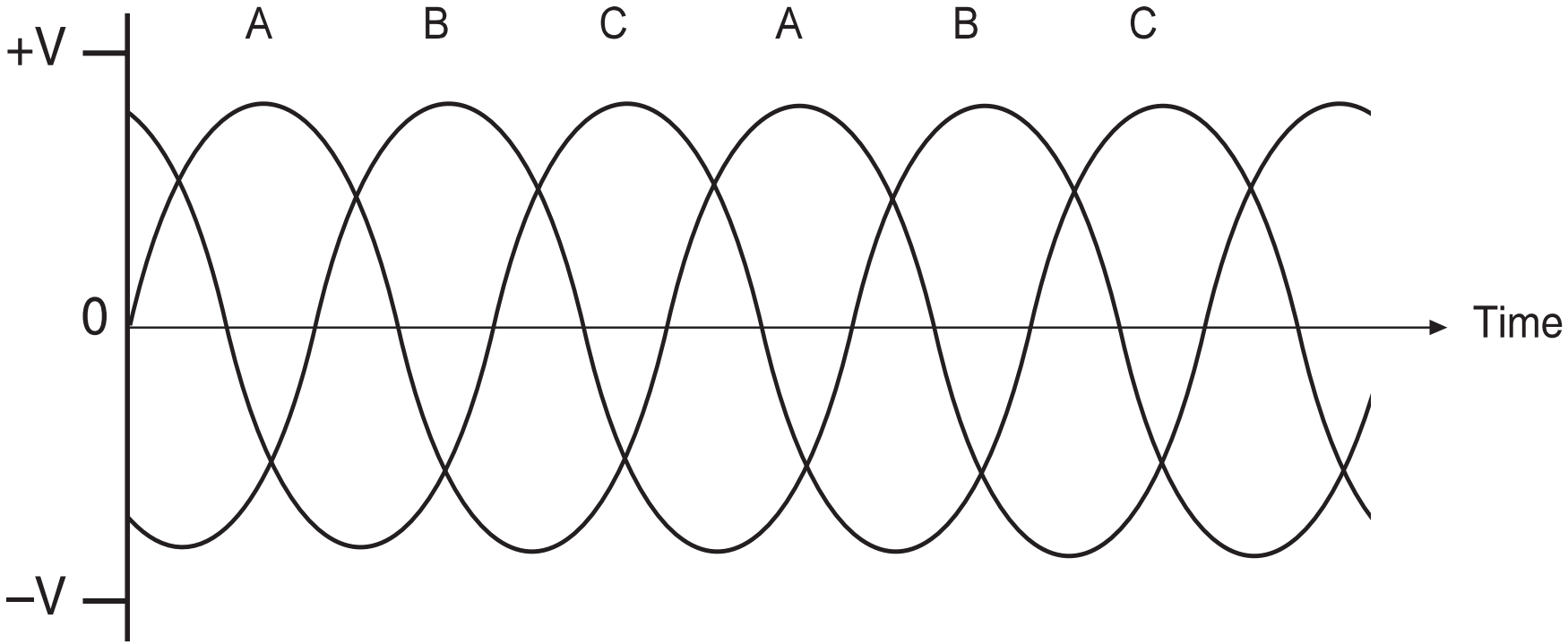
Inductor in DC Circuit



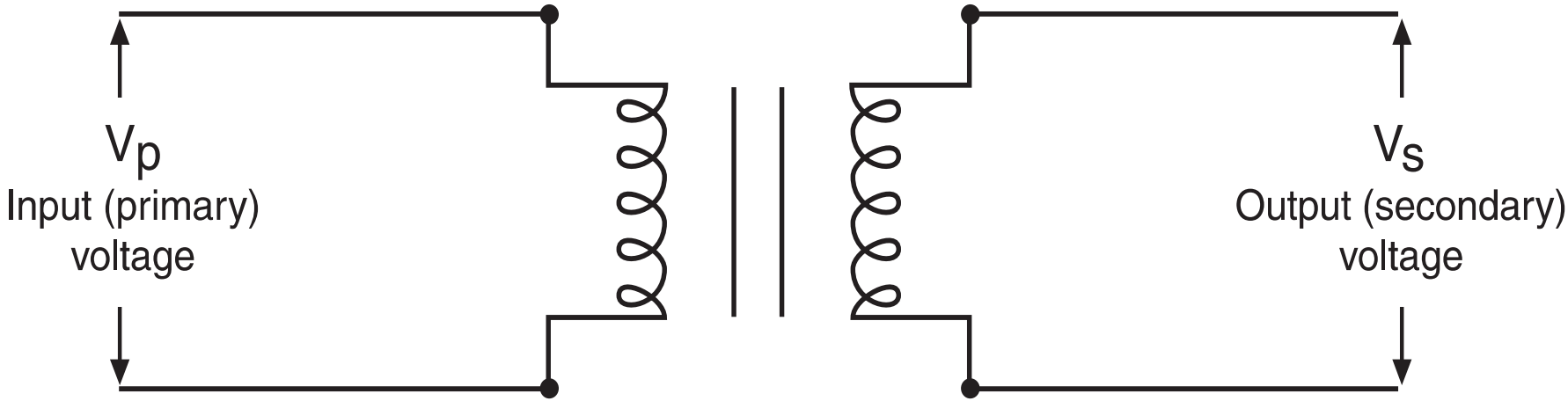


3-Phase Voltage

$$P = V \times I \times PF \times \sqrt{3}$$

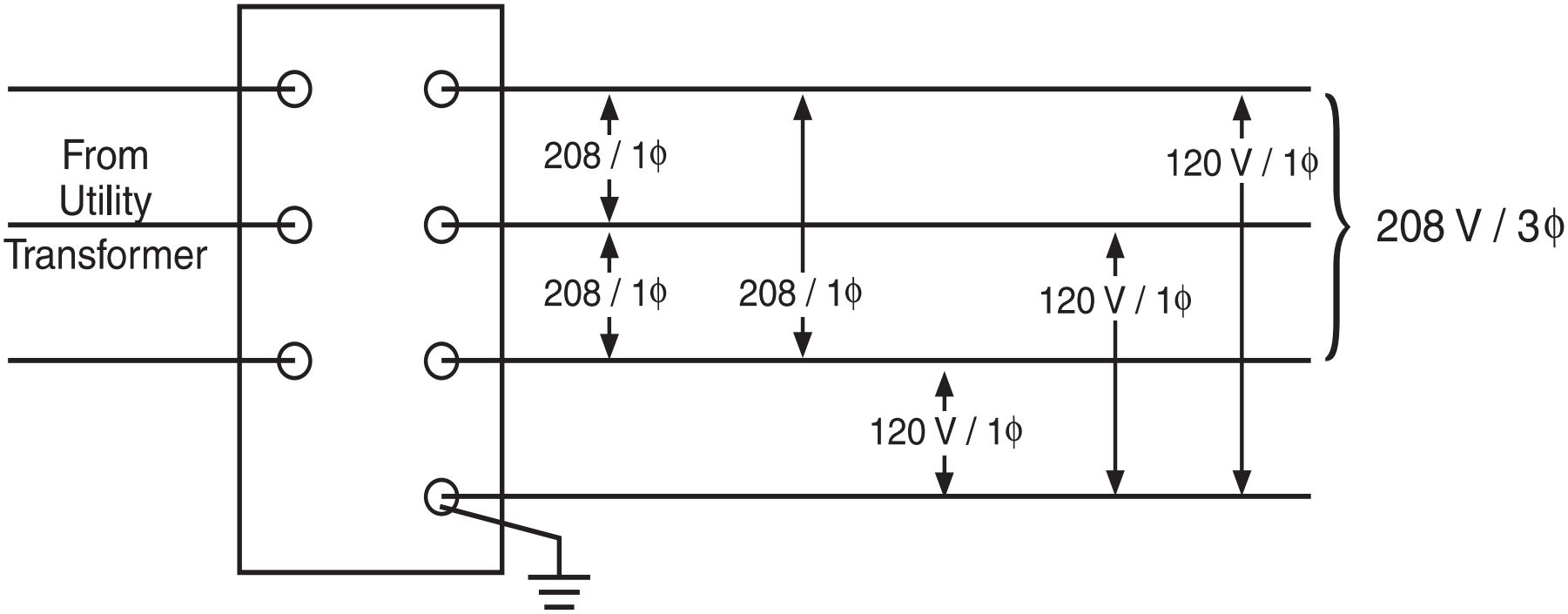


Transformer



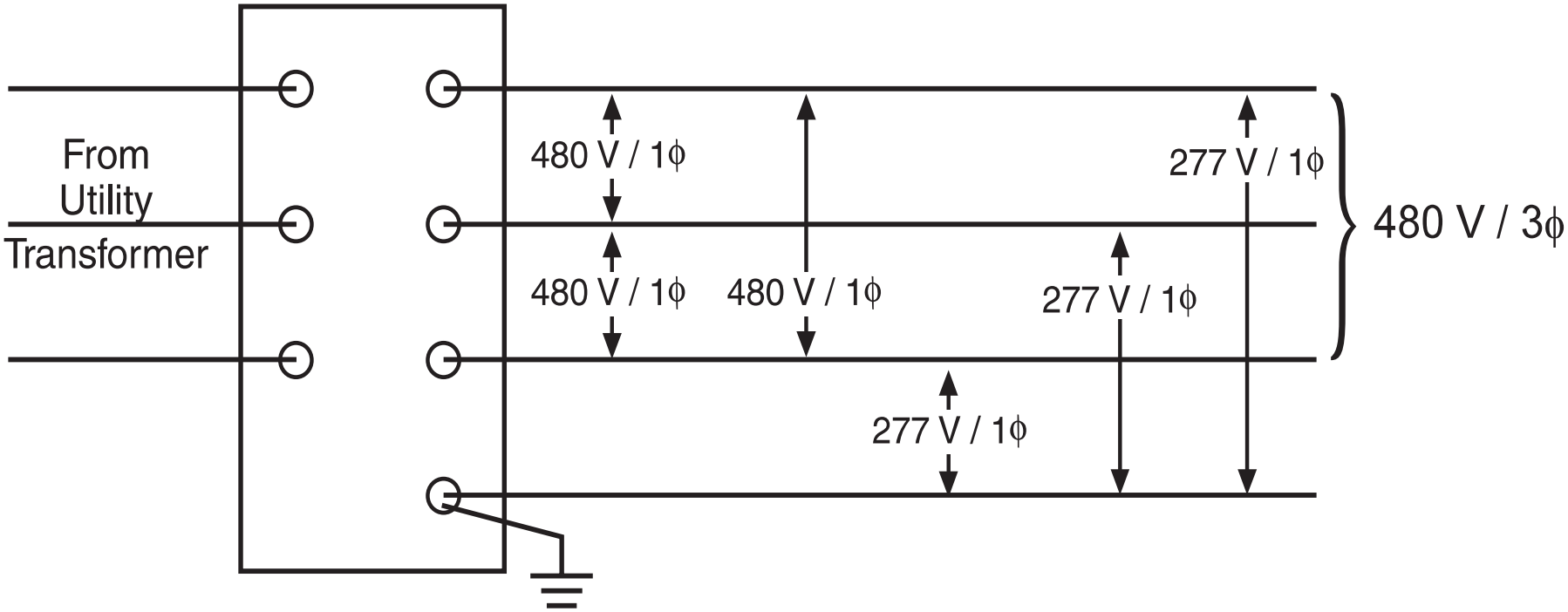
120/208V Service

(4-wire Wye Connected)



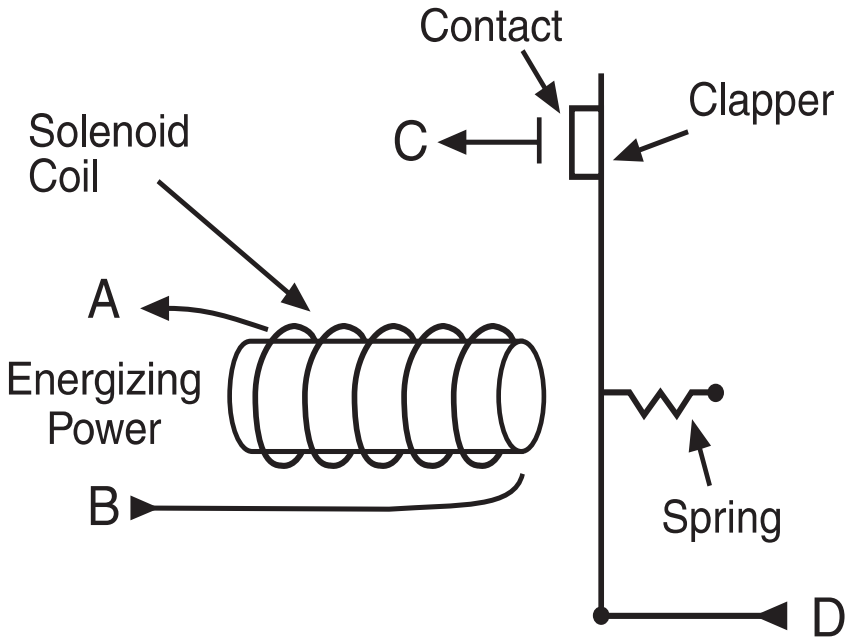
480/277V Service

(4-wire Wye Connected)

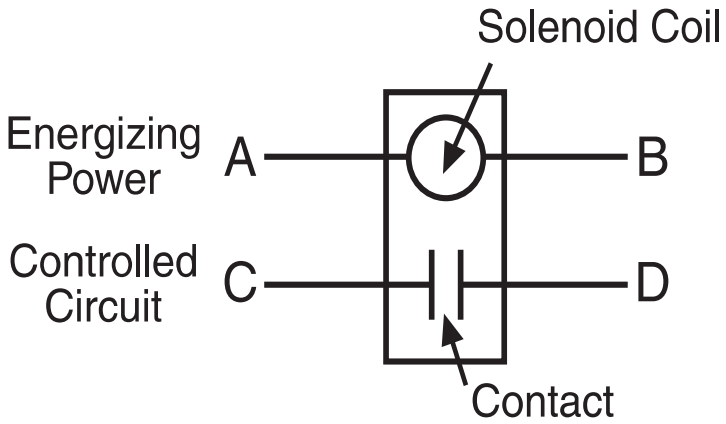


Electromagnetic Relay

(On/Off signal; a type of remote-controlled switch)

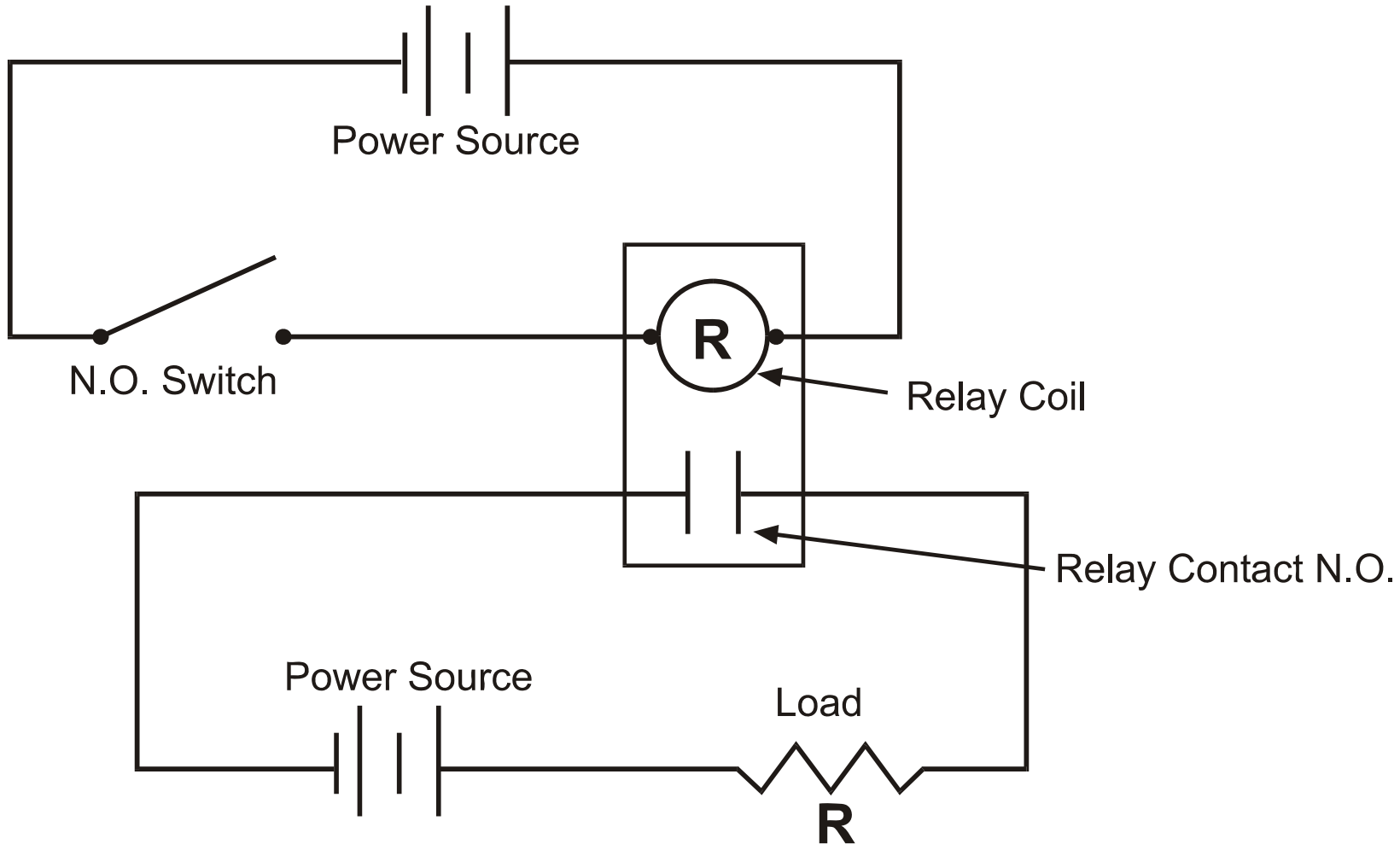


PHYSICAL SCHEMATIC

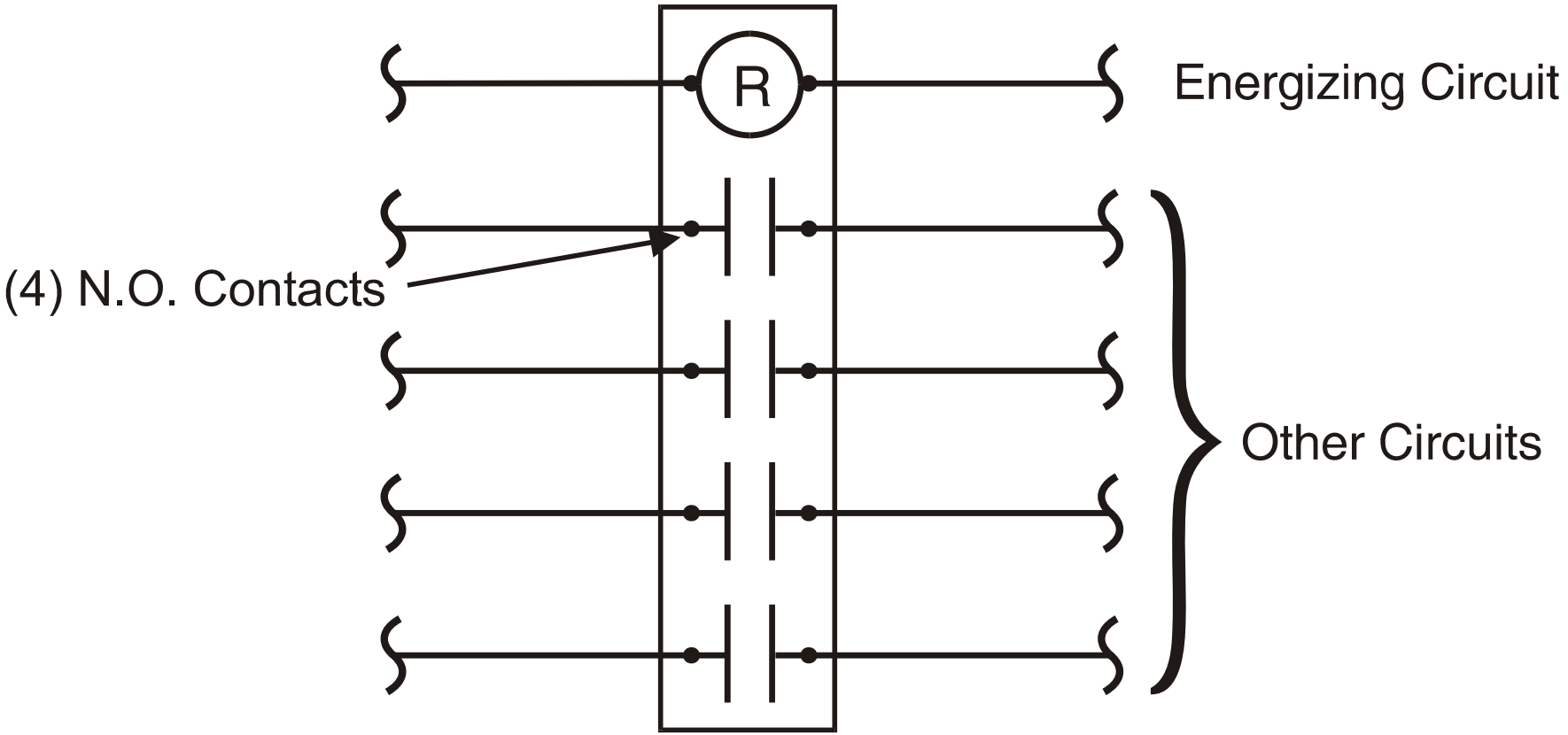


DIAGRAM

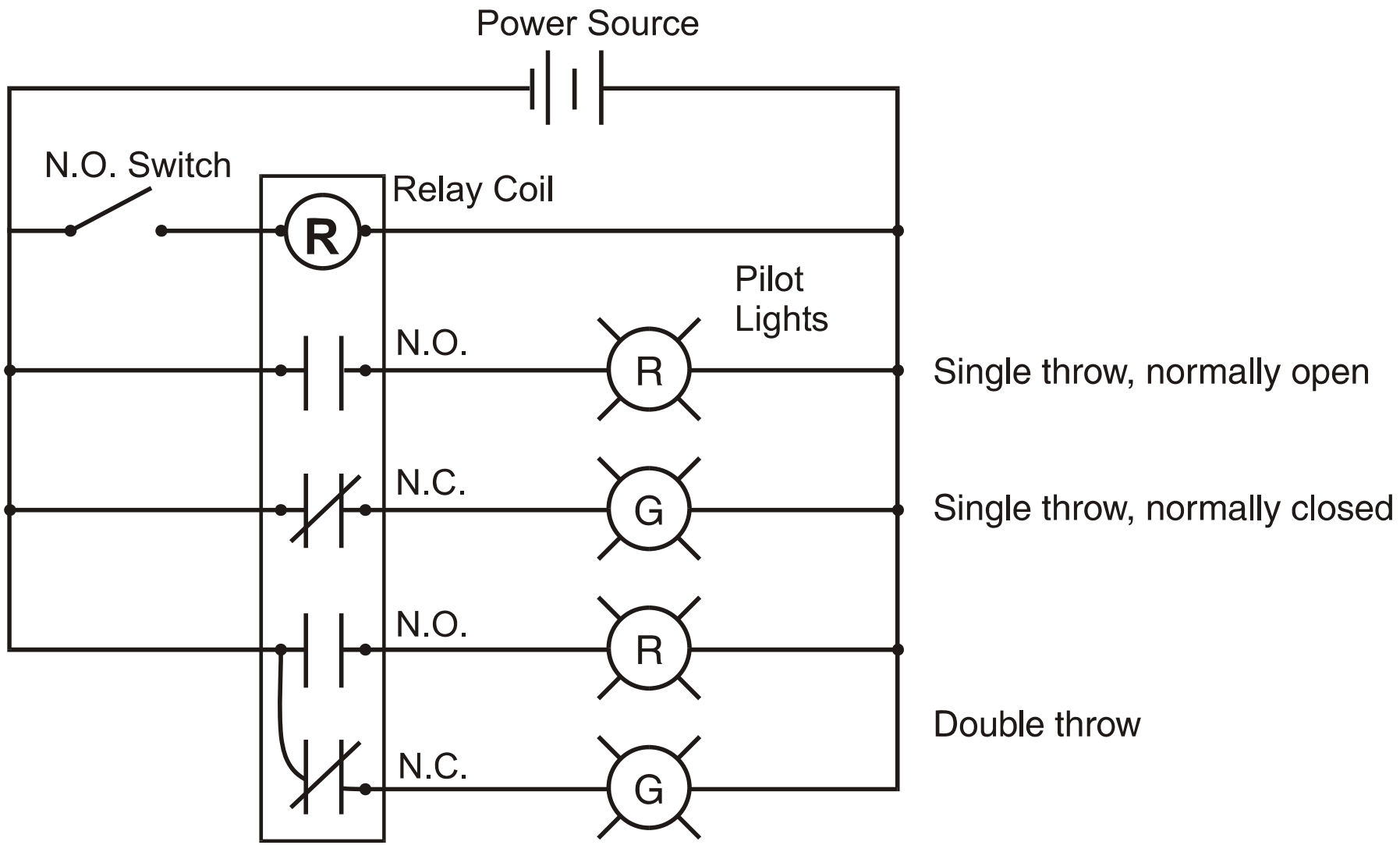
Simple DC Circuit With Relay



Multipole Relay

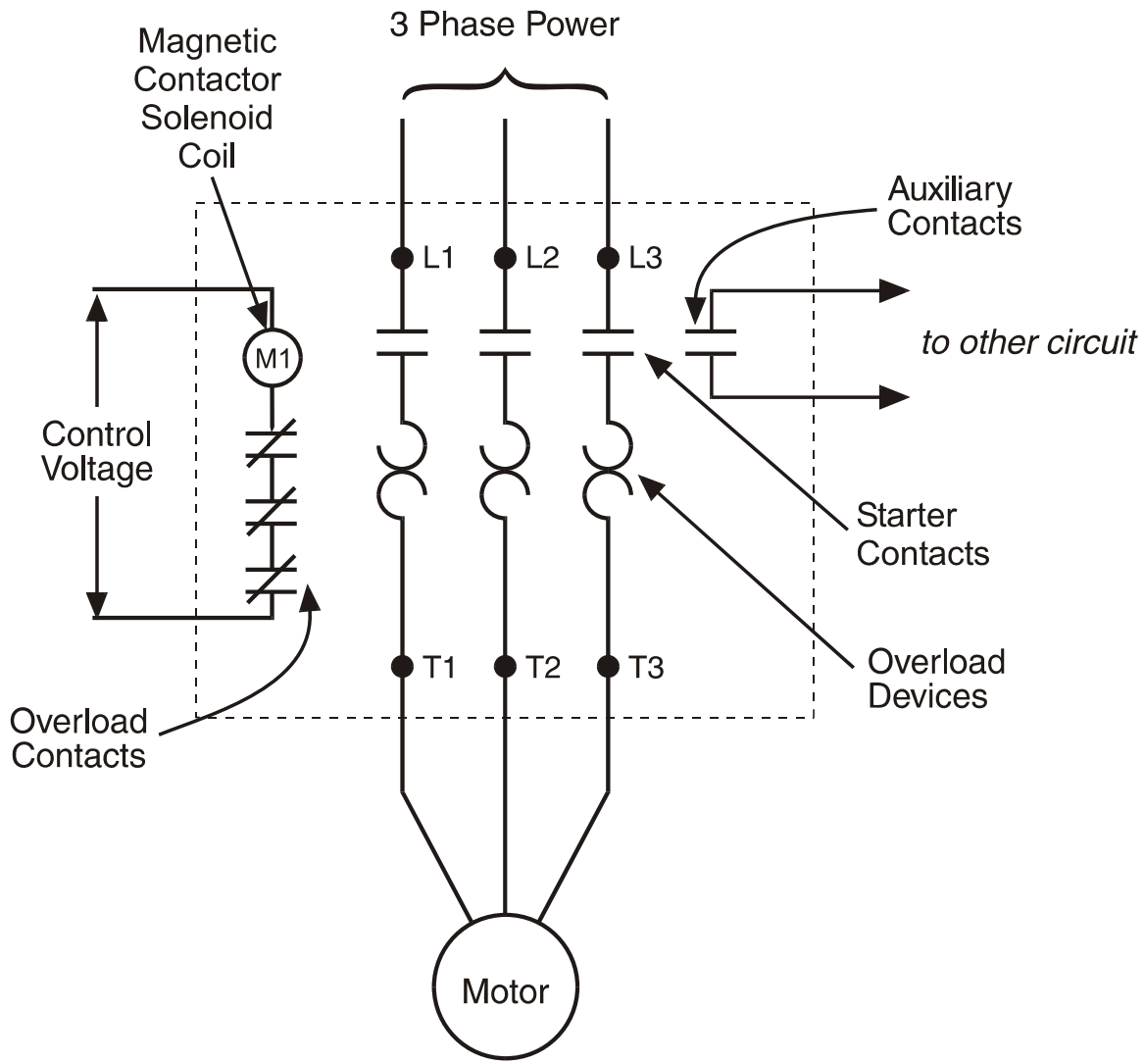


Single- & Double-Throw Contacts



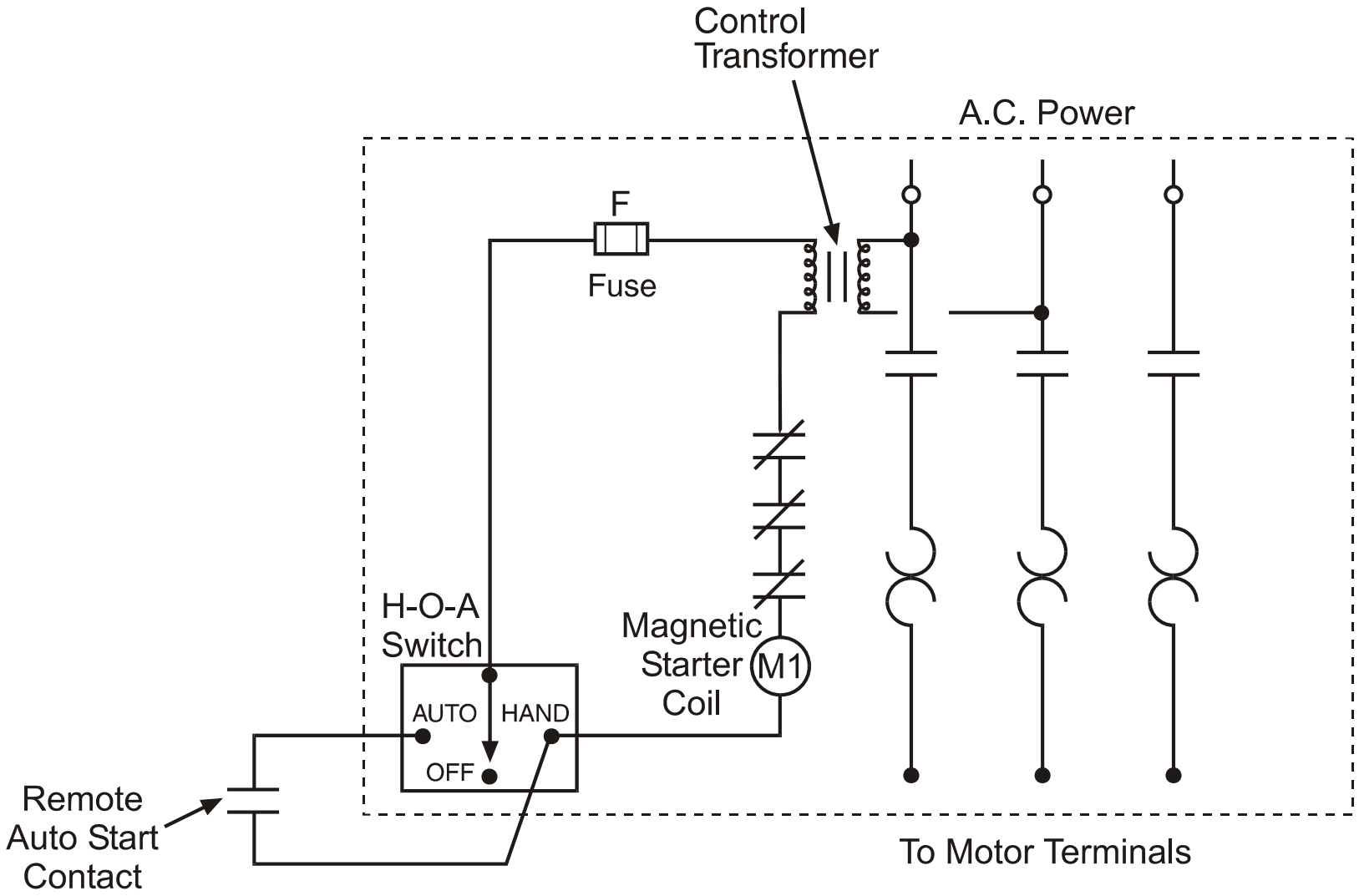
Across-the-Line Motor Starter

(Start/stop control and overload protection)

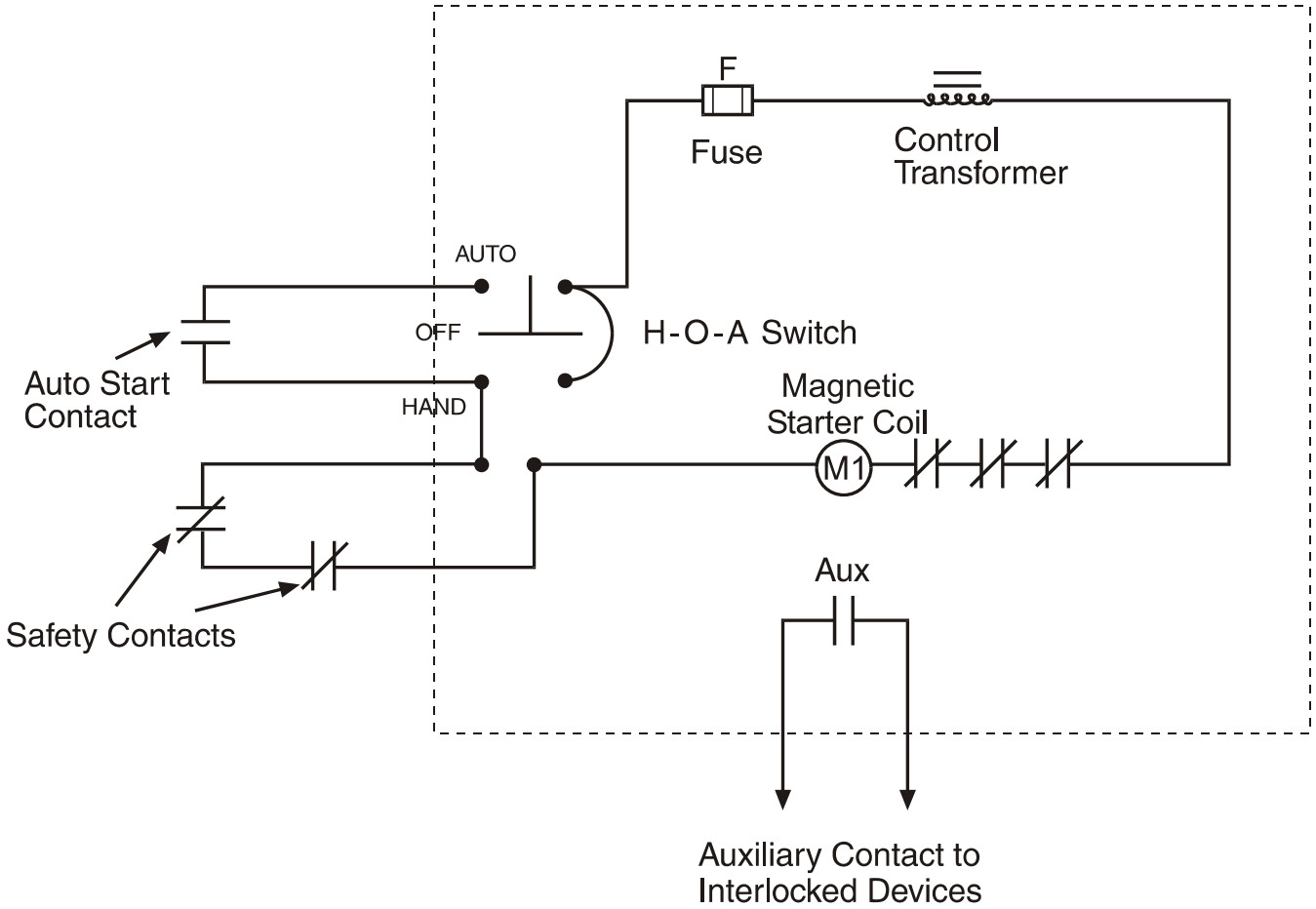


Starter With H-O-A Switch

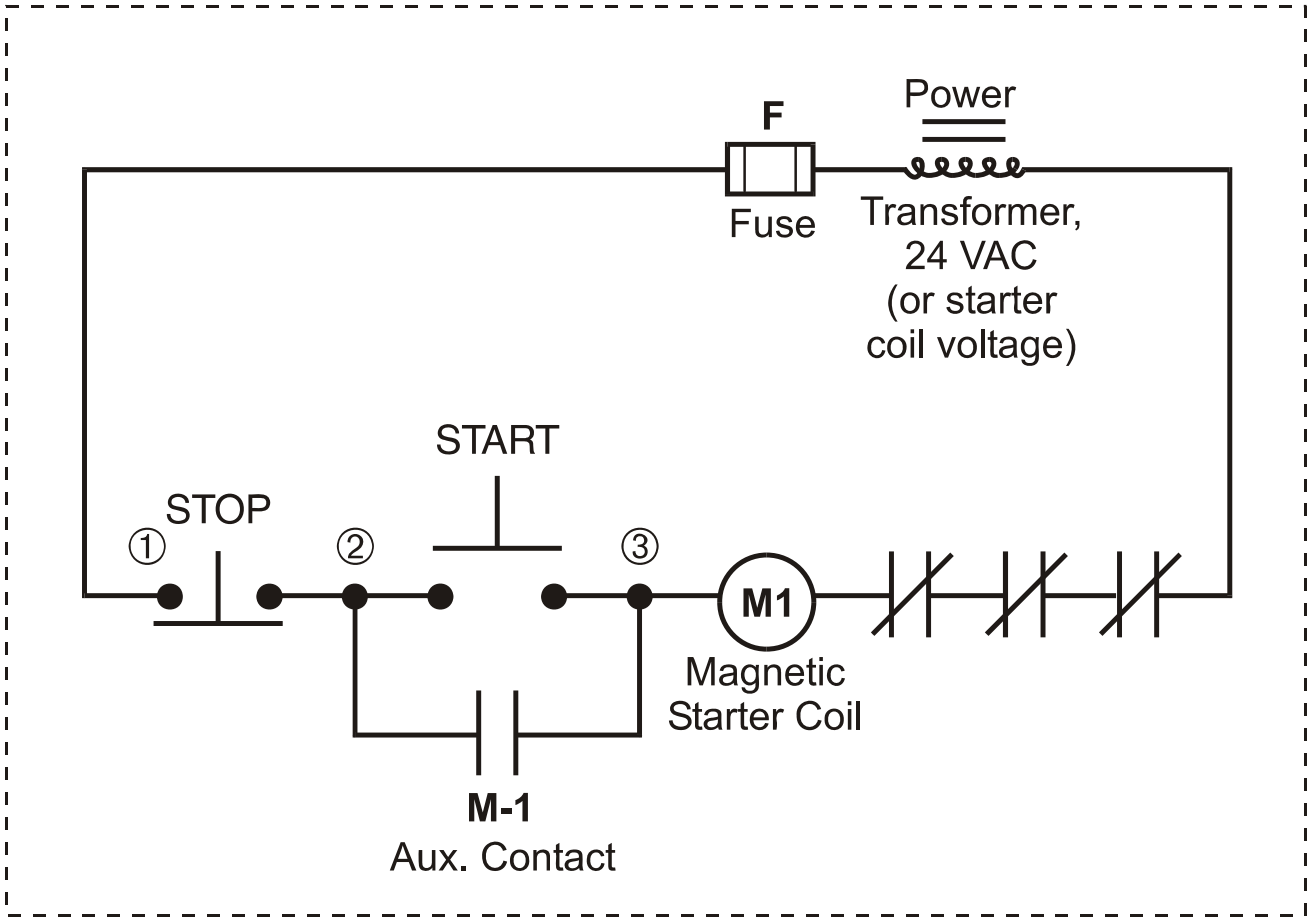
(H-O-A = hand-off-auto)



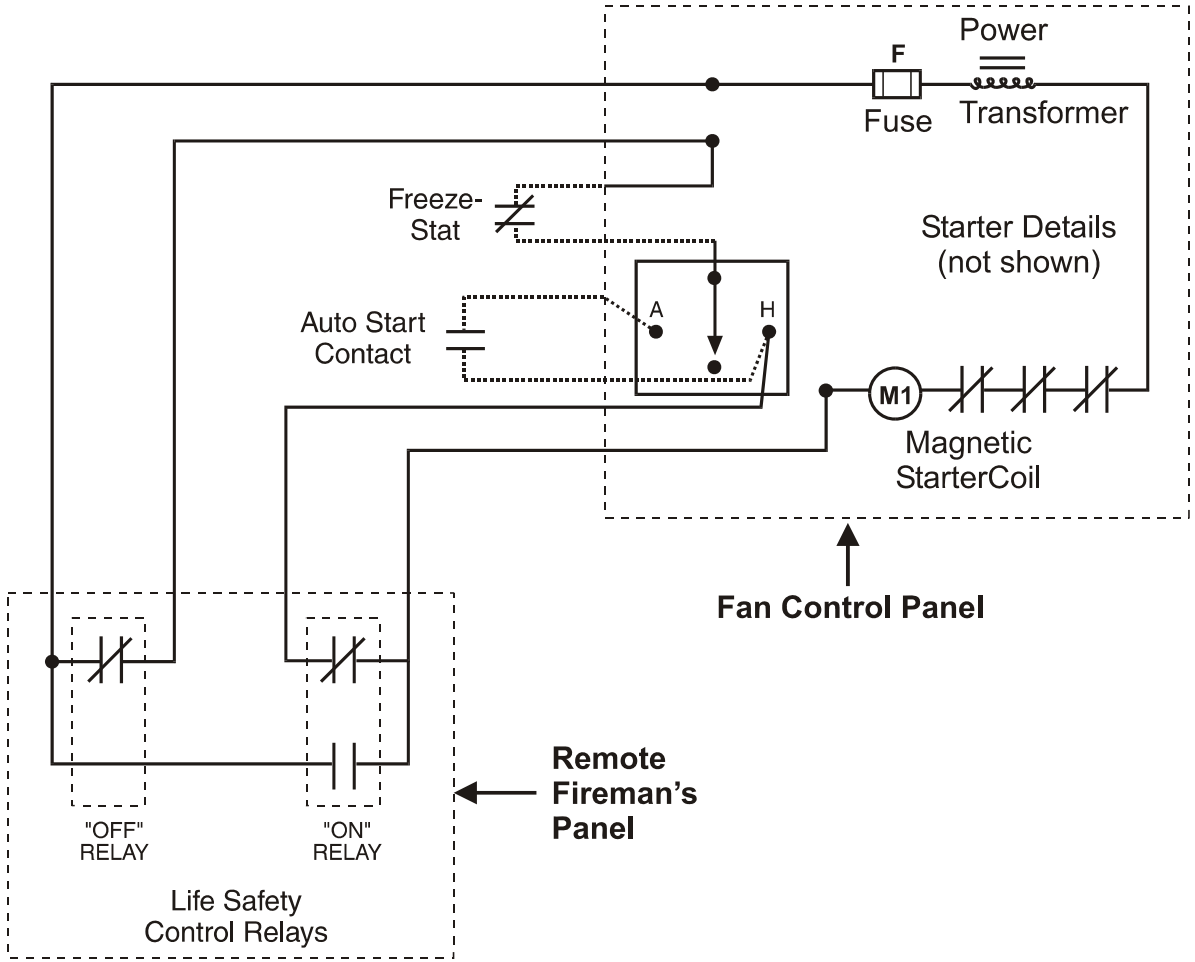
Starter With H-O-A Switch & Aux. Contact



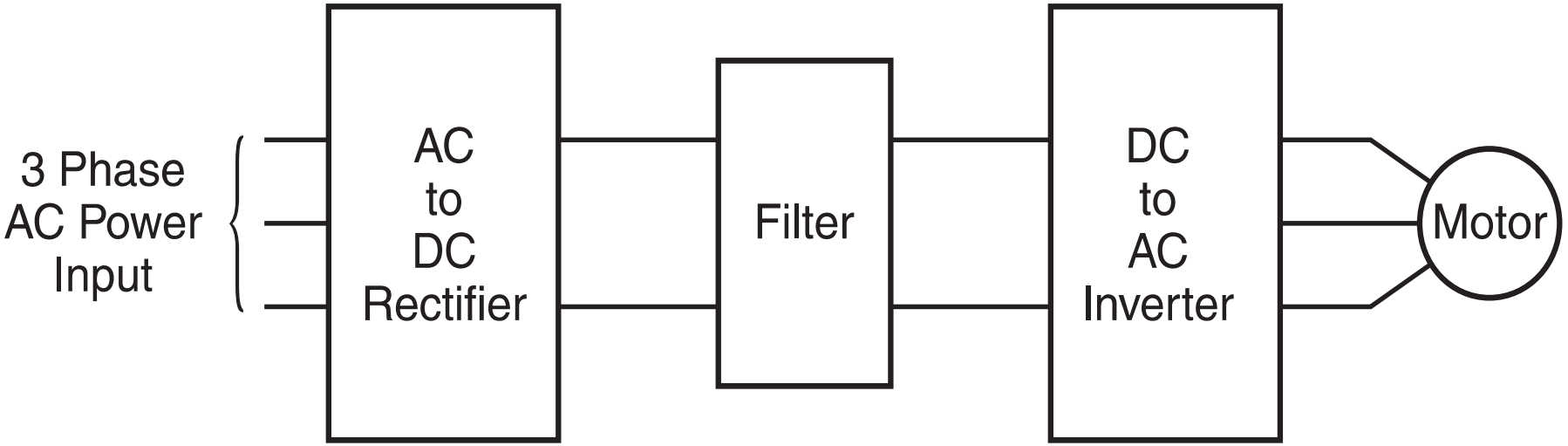
Starter With Manual Start/Stop Buttons



Magnetic Starter With Life Safety Fan Wiring



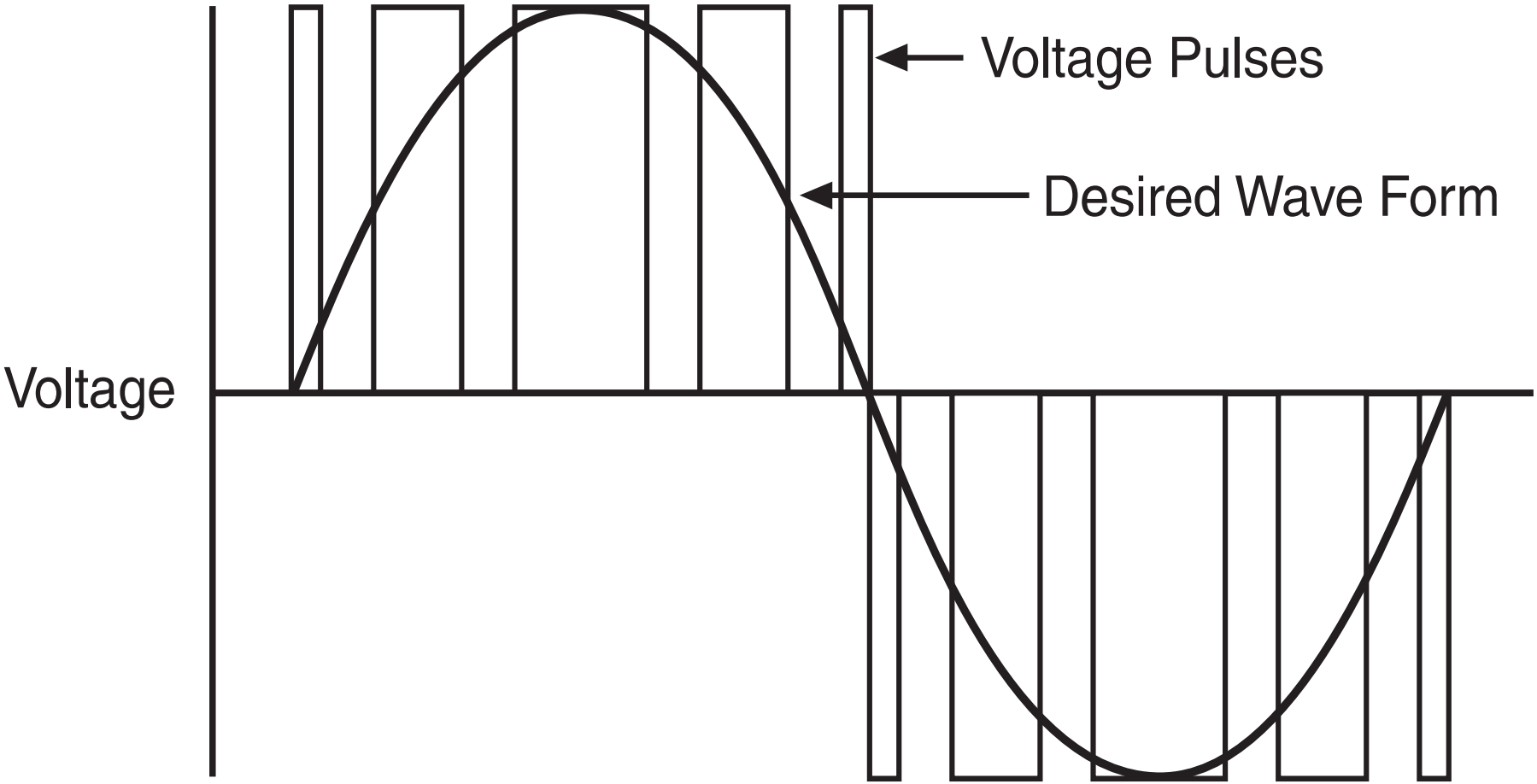
Variable Speed Drives - Inverter Variable Frequency Drive



VSD = variable speed drive
ASD = adjustable speed drive
VFD = variable frequency drive

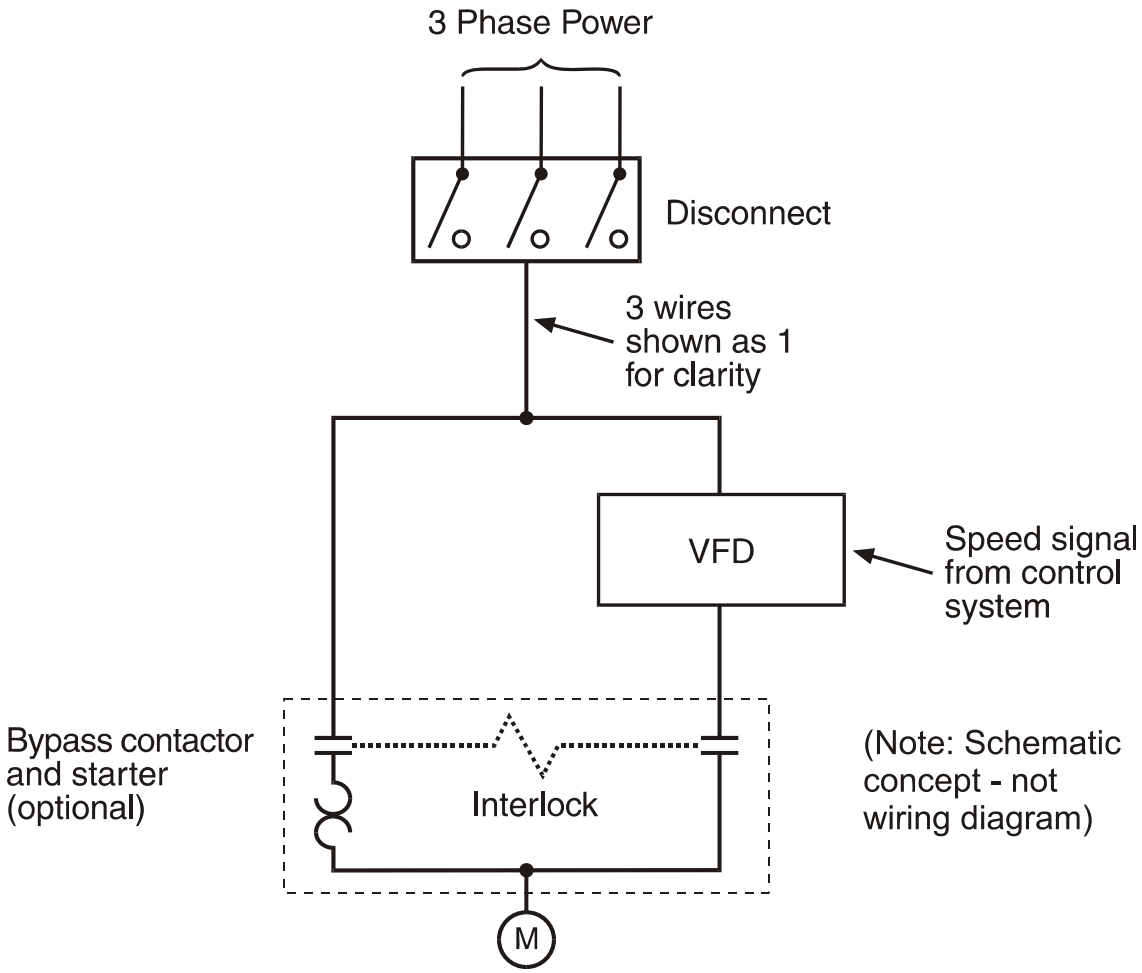
Sine-Coded PWM Waveform

(PWM = pulse-width modulation)



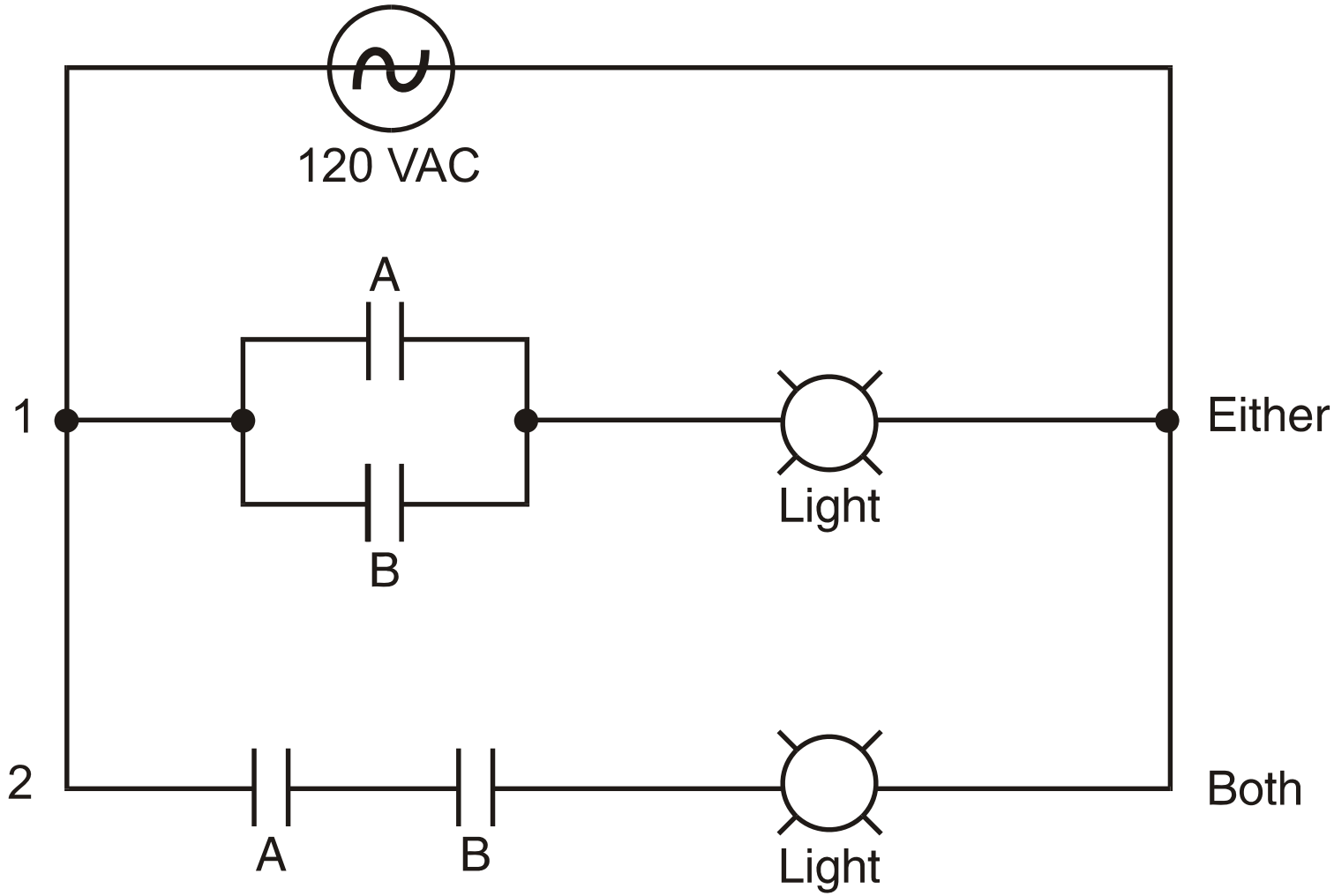
Variable Speed Drive With Optional Starter

(the starter is provided as a backup, in case the VSD fails)

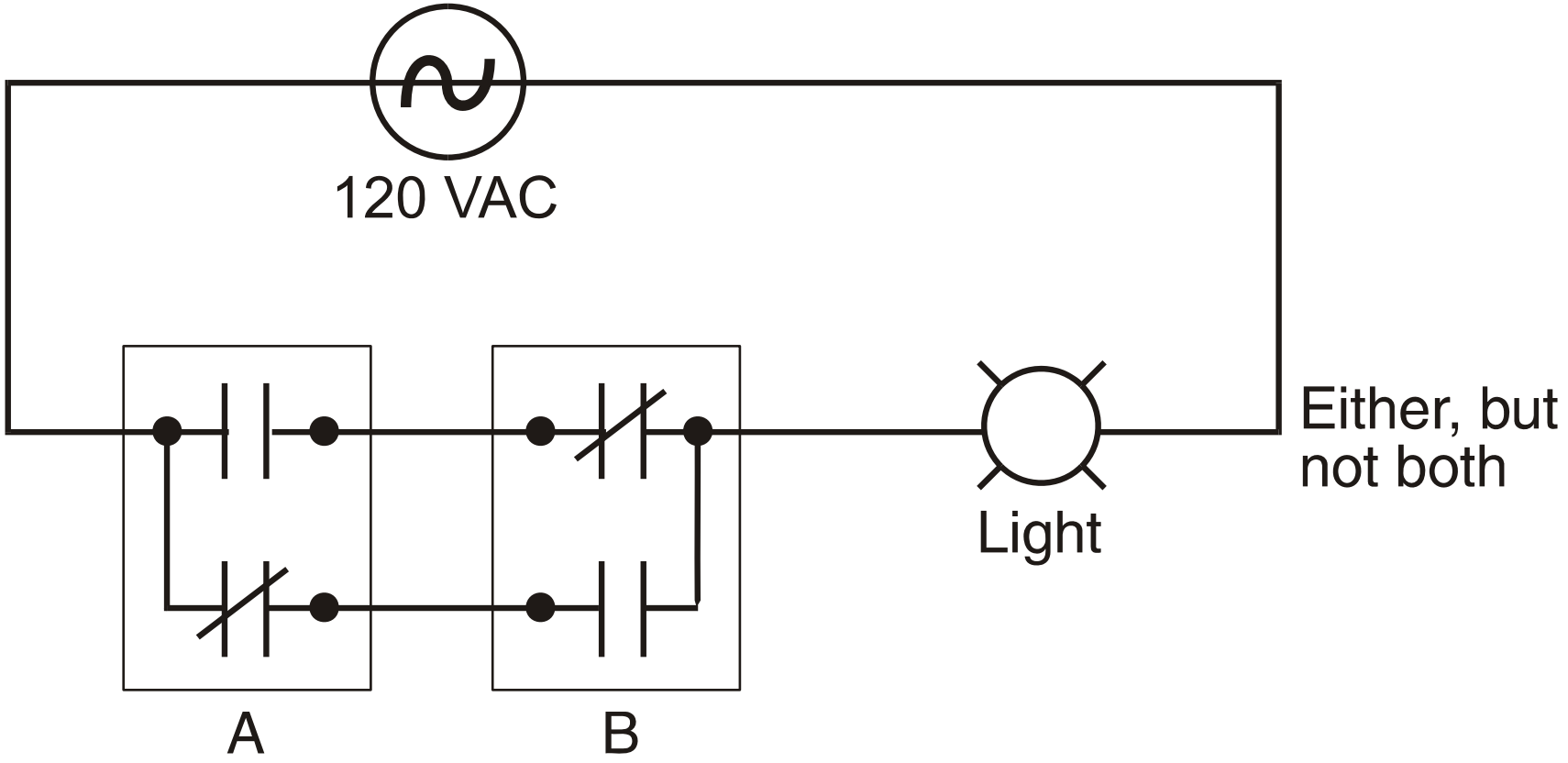


Simple Relay Logic

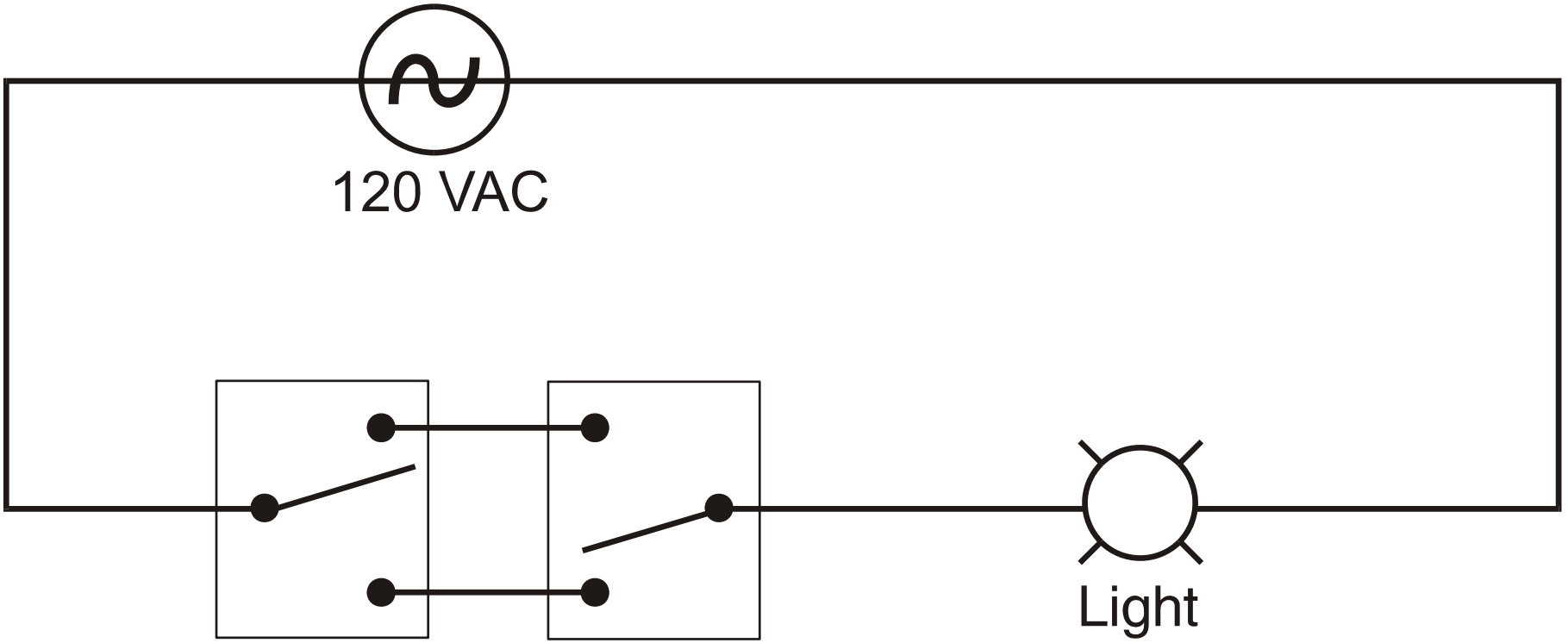
(Boolean logic notation, e.g. if (A or B) then C)



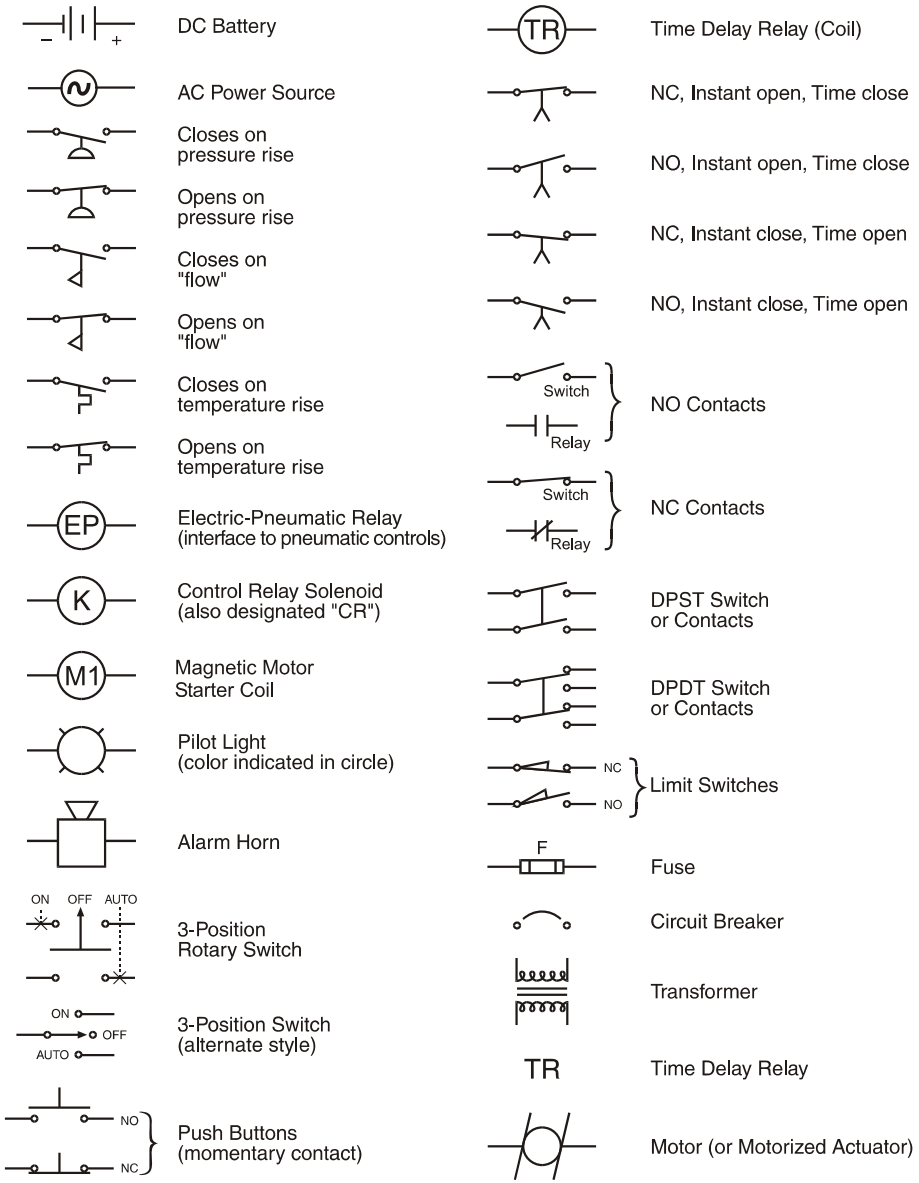
Relay Logic With Double-Throw Contact



Three-Way Light Switch

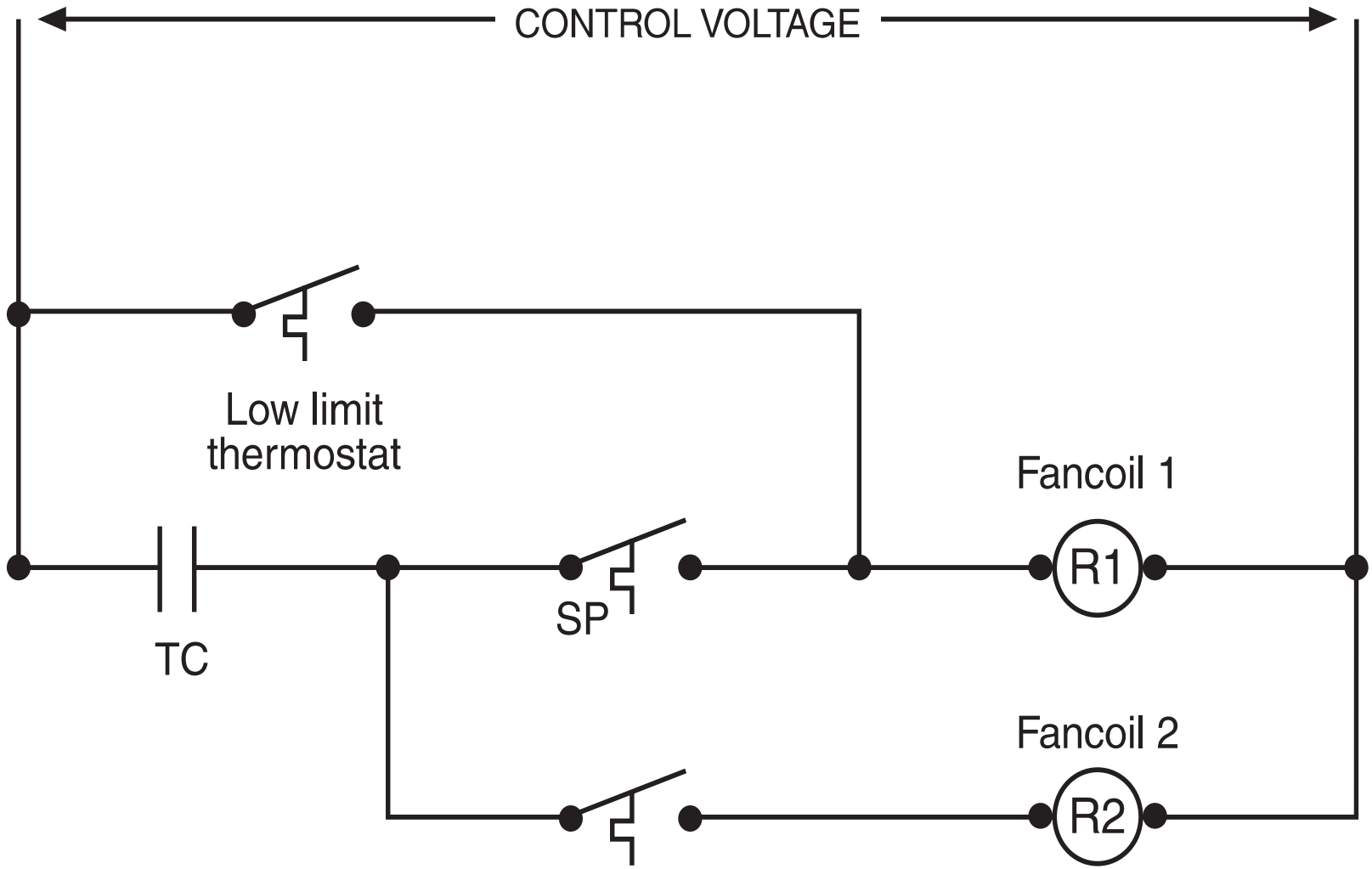


Symbols for Elec. Logic Devices

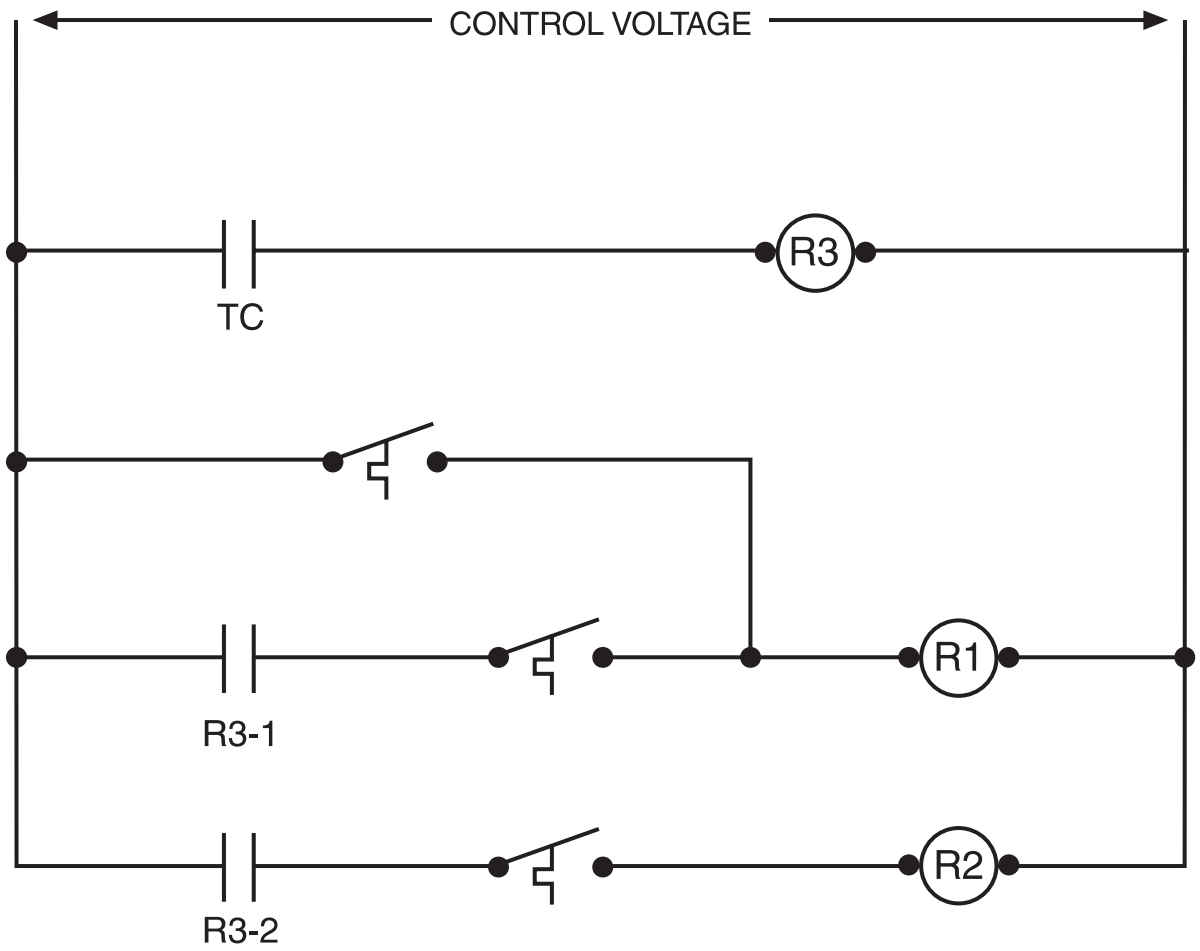


Voltage Feedback Bug

(Ladder diagrams to show how devices are to be physically wired in the field.)



Correction for Voltage Feedback



Ladder Diagram