DC Motors

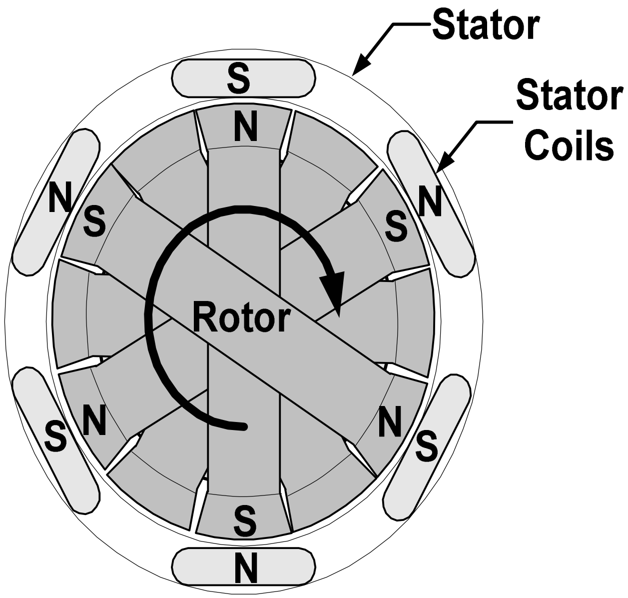
Electric Motors

- Electric Motor Classification / types
  - DC Motors
  - AC Motors
  - Stepper Motors
  - Linear motors
- Electric Motor Function
  - Power conversion - electrical into mechanical
  - Positional actuation – electrical signal to position

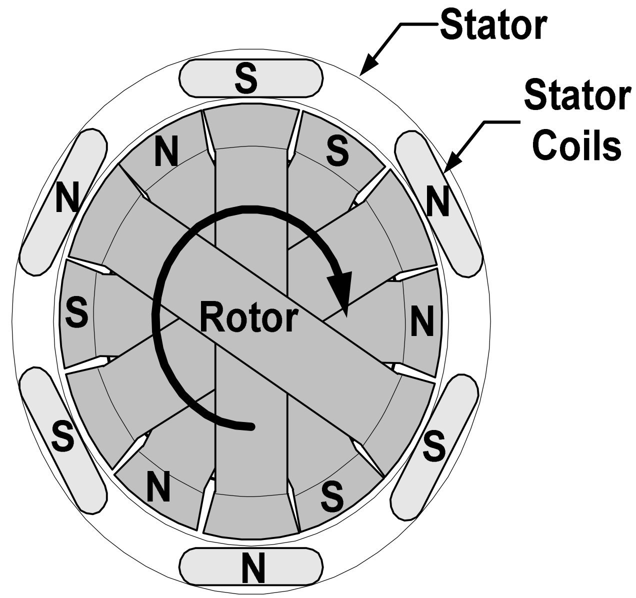
DC Motors

- DC Motors
  - Fundamental characteristics
    - Basic function
  - Types and applications
    - Series
    - Shunt
    - Combination
    - Torque characteristics
  - Modelling

Fundamental characteristics of DC Motors



End view
Time 0

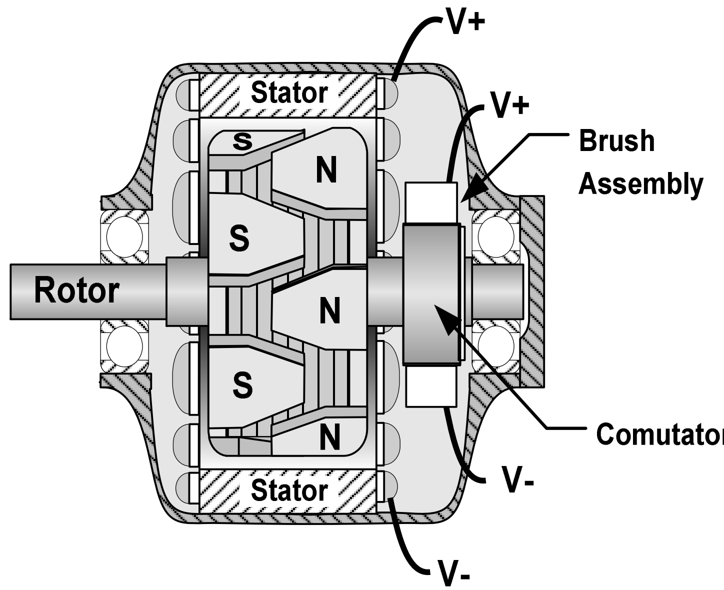


End view
Time 0+

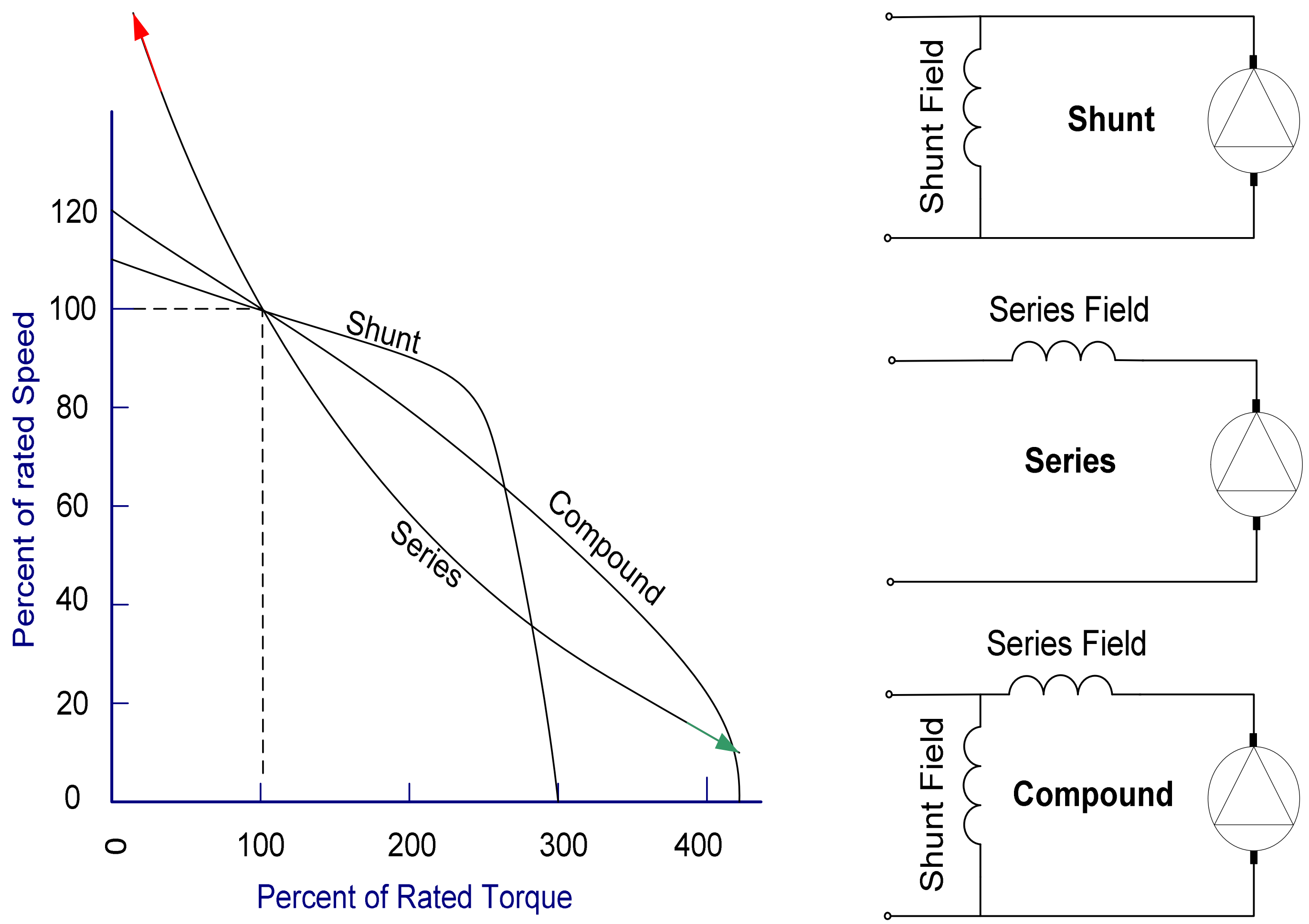
Shifting magnetic field in rotor causes rotor to be forced to turn

Nature of commutation

- Power is applied to armature windings
  - From V+
  - Through the +brush
  - Through the commutator contacts
  - Through the armature (rotor) winding
  - Through the – brush
  - To V-
- Rotation of the armature moves the commutator, switching the armature winding connections
- Stator may be permanent or electromagnet



DC motor wiring topologies



Series Wound DC motors

- Armature and field connected in a series circuit.
- Apply for high torque loads that do not require precise speed regulation. Useful for high breakaway torque loads.
  - locomotives, hoists, cranes, automobile starters
- Starting torque
  - 300% to as high as 800% of full load torque.
- Load increase results in both armature and field current increase
  - Therefore torque increases by the square of a current increase.
- Speed regulation
  - Less precise than in shunt motors
    - » Diminished load reduces current in both armature and field resulting in a greater increase in speed than in shunt motors.
  - No load results in a very high speed which may destroy the motor.
    - » Small series motors usually have enough internal friction to prevent high-speed breakdown, but larger motors require external safety apparatus.

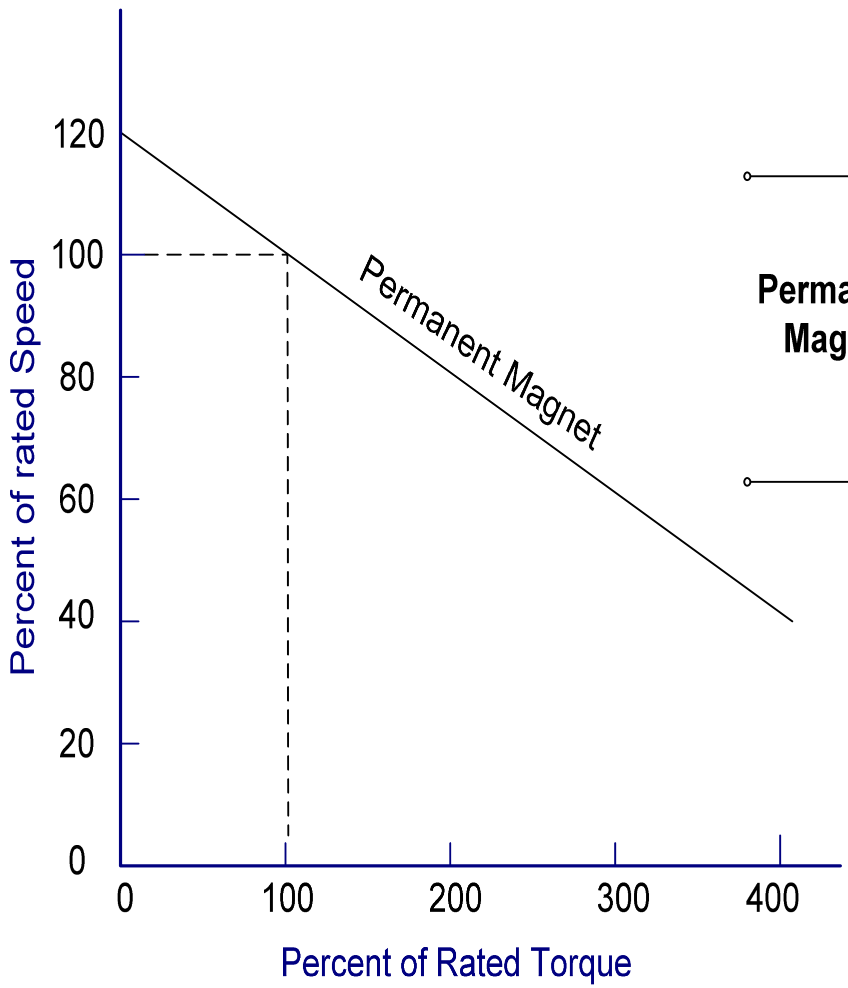
Shunt wound DC motors

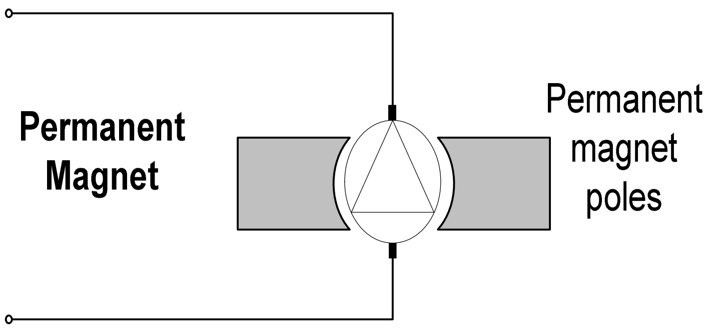
- Field coil in parallel (shunt) with the armature.
  - Current through field coil is independant of the armature.
    - Result = excellent speed control.
- Apply where starting loads are low
  - fans, blowers, centrifugal pumps, machine tools
- Starting torque
  - 125% to 200% full load torque (300 for short periods).

Compound wound DC motors

- Performance is roughly between series-wound and shunt-wound
- Moderately high starting torque
- Moderate speed control
- Inherently controlled no-load speed
  - safer than a series motor where load may be disconnected
    - » e.g. cranes

Permanent magnet DC motors



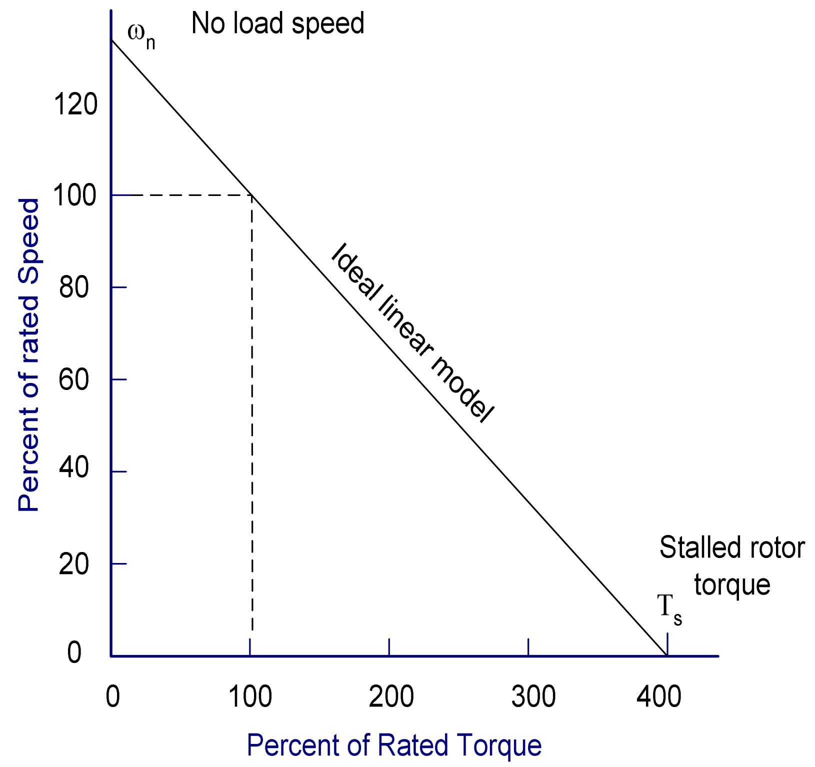


Permanent Magnet DC Motors

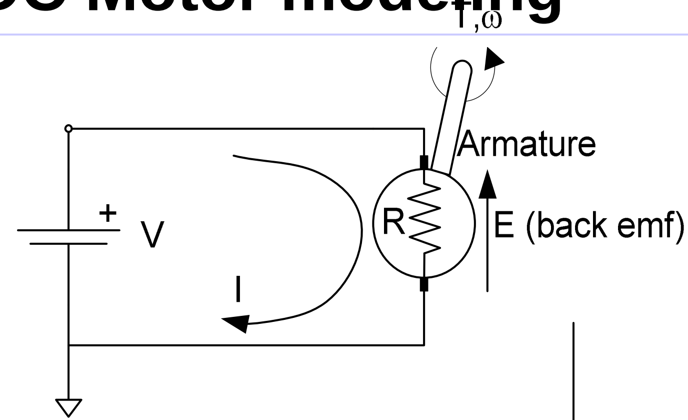
- Have permanent magnets rather than field windings but with conventional armatures. Power only to armature.
- Short response time
- Linear Torque/Speed characteristics similar to shunt wound motors. Field magnetic flux is constant
  - Current varies linearly with torque.
- Self-braking upon disconnection of electrical power
  - Need to short + to – supply, May need resistance to dissipate heat.
- Magnets lose strength over time and are sensitive to heating.
  - Lower than rated torque.
  - Not suitable for continuous duty
  - May have windings built into field magnets to re-magnetize.
- Best applications for high torque at low speed intermittent duty.
  - Servos, power seats, windows, and windshield wipers.

Modeling DC motors

- A linear speed/torque curve can be used to model DC motors. This works well for PM and compound designs and can be used for control models for narrow ranges for the other configurations
- Model will assume!
  - Linearity
  - Constant thermal characteristics
  - No armature inductance
  - No friction in motor



DC Motor modeling



From the circuit

$$V = IR + E_b$$

Motor equations

$$E_b = K_e \omega$$

$$T = K_t I$$

Substituting the above:

$$V = \frac{T}{K_t} R + K_e \omega$$

$$\omega = \frac{V}{K_t} - \frac{T}{K_e K_t} R$$

For stalled rotor torque

$$T_s = \frac{K_e V}{R}$$

And no-load speed

$$\omega_n = \frac{V}{K_t}$$

In terms of no-load speed torque/speed equation is:

$$\omega = \omega_n - \left(\frac{R}{K_e K_t} \right) T$$

Power is:

$$P = T\omega = T\omega_n - \left(\frac{R}{K_e K_t} \right) T^2$$

Max power is:

$$P_{\max} = \frac{V^2}{4R}$$

Units:

$$K_e = [Vs/rad]$$
$$K_t = [Nm/A]$$

Application

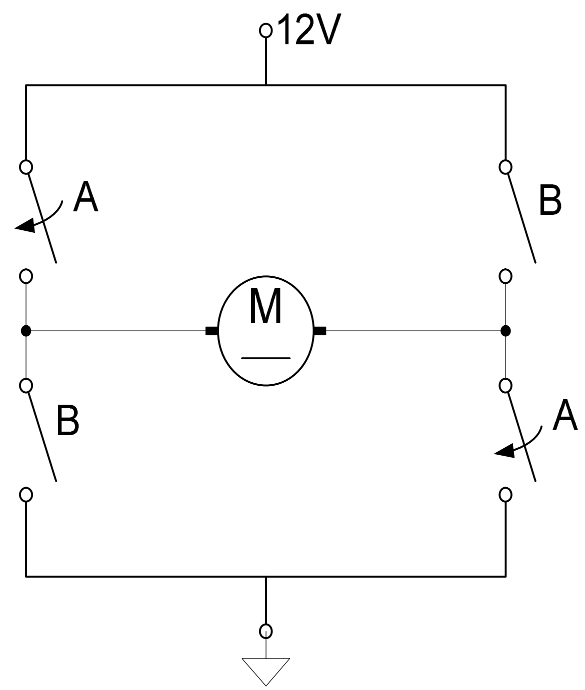
- Use motor voltage and no-load speed to calculate K_t
- $K_t = K_e$ in SI units
- Use stalled rotor torque, V, and K_e to find R
  - Note, R varies with speed and cannot be measured at rest
- See web download for explanation of K_t, K_e:

http://biosystems.okstate.edu/home/mstone/4353/downloads/

Development of Electromotive Force.pdf

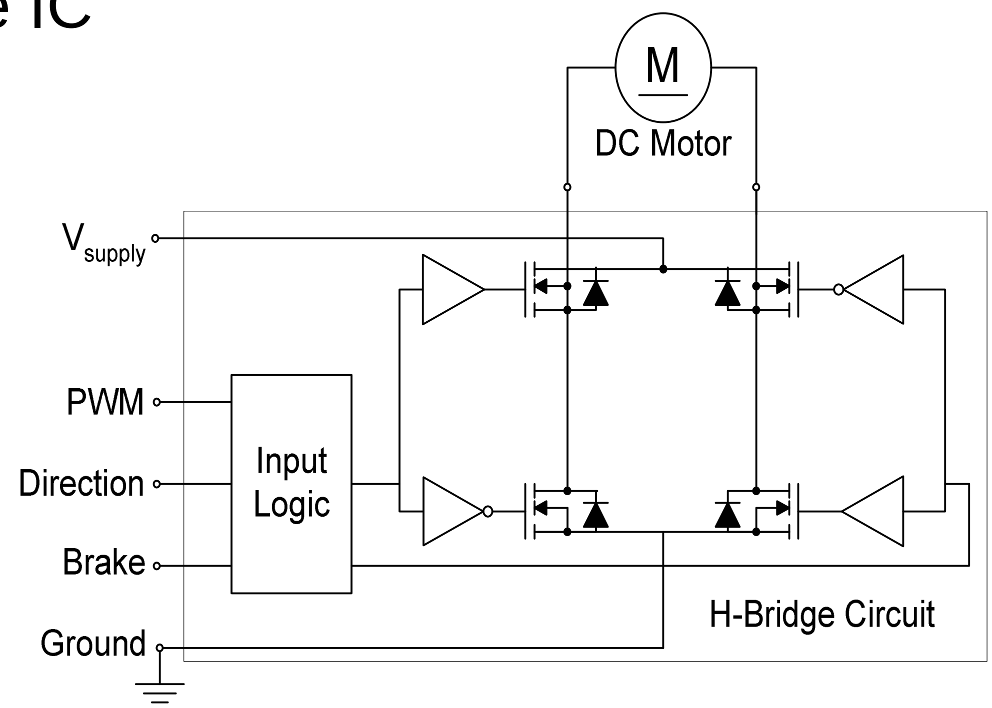
DC motor control – H-bridge

- Switches control direction
  - “A” switches closed for clockwise
  - “B” switches for counter-clockwise
- PWM for speed control
  - “A’s” duty cycle for clockwise speed
  - “B’s” duty cycle for counter-clockwise speed
- Can be configured to brake
  - Bottom “B” and “A” to brake



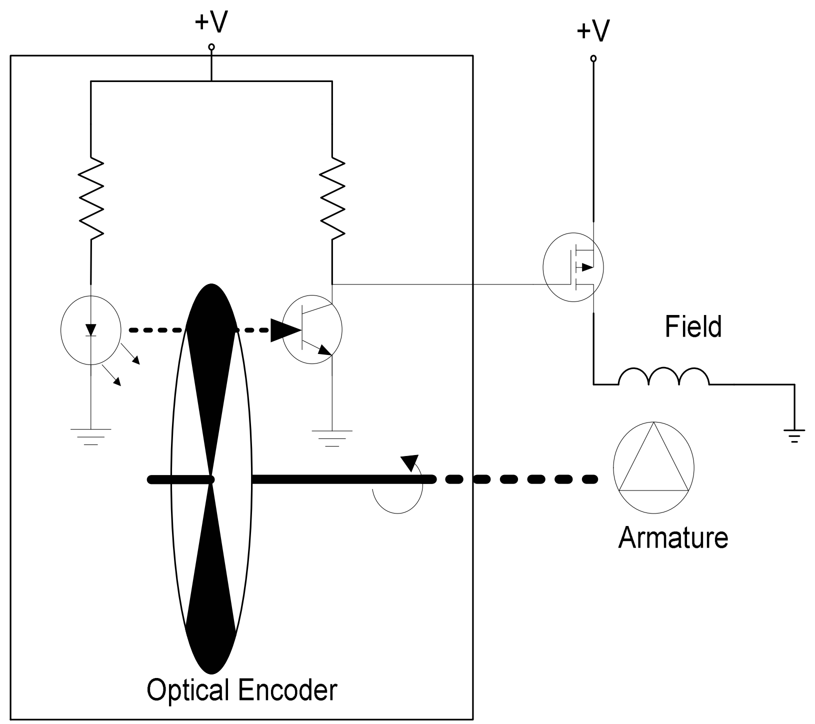
H-Bridge implementation

- Elements in box are available as single IC



Brushless designs

- Commutation is done electronically
  - Encoder activated switching
  - Hall effect activated switching
  - Back EMF driven switching
- PM armature
- Wound/switched fields
- Application
  - Few wearing parts (bearings)
  - Capable of high speed
  - Fractional HP
    - Servos
    - Low EMC



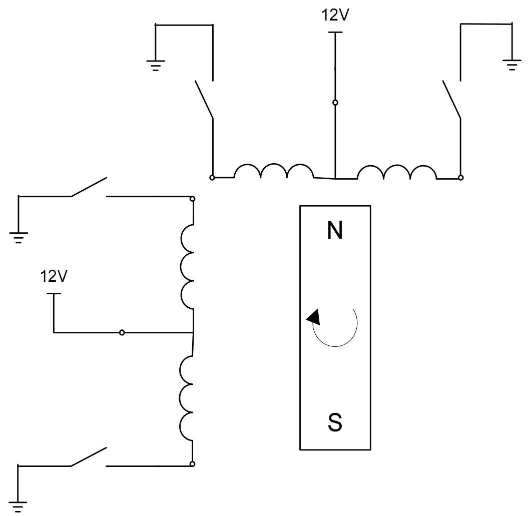
Encoder activated switching

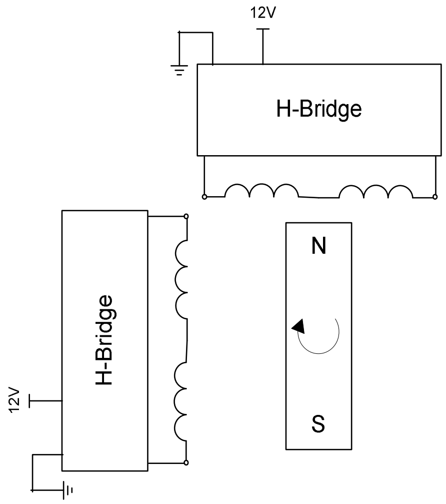
Stepper Motors

- Description
  - Generally a two phase motor
  - permanent magnet rotor and wound fields
  - Rotor normally has many poles
    - 200 poles = 1.8 degrees per step
  - Used primarily for position or velocity control
  - Typically no position feedback
    - Torques are managed so that an intended step is always achieved
      - Accelerations, decelerations and loads must be managed intelligently
- Two general types of windings
  - Unipolar
  - Bi-polar

Winding configurations

- Bi-polar design
  - 6 wire





- Unipolar design
  - 4 wire