Chapter 5: DC Motors
Reversing the Rotation Direction

- The direction of rotation can be reversed by reversing the current flow in either
  - the armature connection
  - the shunt & series field windings

(base)                       (reversed)                      (reversed)
Motor Starting

- Full voltage applied to a starting motor can:
  - burn out the armature
  - damage the commutator and brushes due to heavy sparking
  - overload the supply feeder
  - snapping off the shaft due to mechanical shock
  - damage the mechanical load

- Means must be provided to limit the starting current to reasonable values (between 1.5 & 2 pu of full-load current)
  - connect a rheostat in series with the armature
    - as speed increases, the counter $emf$ increases
    - the resistance can be reduced as the counter $emf$ increases
  - use power electronics to drive the armature current
Motor Starting

• Manual face-plate starter for a shunt motor
  – contacts connect to current-limiting resistors
    • contact arm in off position (m)
    • manually move arm to position (n) to start
    • supply voltage causes full filed current flow
    • armature is limited by four resistors
    • as speed increases, $E_0$ builds
    • when acceleration ceases, arm is move to the next contact, where the motor begins to accelerate
    • at last contact, electromagnet holds arm in place
Stopping the Motor

- Stopping a dc motor is a nontrivial operation
  - large motors coupled to a heavy inertia load may take an hour or more to halt
  - braking action is often required: apply a braking torque to ensure rapid stop
    - mechanical friction
    - electrical braking - reverse power flow
      - dynamic braking: transfer the armature circuit to a load resistor
      - Plugging: reversing the flow of armature current
Dynamic Braking

- The armature of a shunt motor is connected to a DPDT switch that connects the armature to either the line or external resistor $R$
  - in normal operation the armature is connected to the source
  - opening the switch, the armature current $I_a$ drops to zero and the rotor will spin until friction and windage losses brake the rotation
    - the machine operates as a generator with no-load
  - closing the switch onto the resistor, the induced voltage causes a reverse current to flow in $R$, creating a counter torque
    - the value of $R$ is selected for twice the rated motor current, braking at twice the drive torque
Dynamic Braking

- The braking torque is proportional to the braking resistor’s current, $I_a$
  - as the motor slows down, $E_0$ decreases as well as $I_a$
  - consequently the braking torque becomes smaller
  - the torque goes to zero as the rotor halts
  - the speed drops quickly at first and then more slowly
  - dynamic braking is an exponential decay
Plugging

- The motor can be stopped more rapidly by plugging
- Plugging is the sudden reversing of the armature current
  - accomplished by reversing the terminals to the armature circuit
  - under normal motoring conditions
    \[ I_a = \frac{(E_s - E_0)}{R_a} \]
    - sudden reversing the terminals causes the net voltage acting on the armature circuit to become \((E_s + E_0)\), resulting in a large reverse current (50x)
    - a limiting resistor in series is used to control the current to twice full-load current
Plugging

- The braking torque is proportional to the armature current, $I_a$
  - initially, the torque is twice the full-load torque and is limited by the current-limiting resistor
  - a reverse torque is developed even when the armature comes to a stop
  - the reverse torque at zero speed is half of the initial braking torque
  - as soon as the motor stops in two time-constants, the armature circuit must be opened
Mechanical Time Constants

- Dynamic braking causes the speed to drop exponentially

\[ T = \frac{J n_1^2}{(30/\pi)^2 P_1} \]

- \( T = \) mechanical time constant
- \( J = \) Moment of inertia
- \( n_1 = \) initial speed
- \( P_1 = \) initial power to the braking resistor

- \( T_0 = \) time for the speed to decrease by 50% of its original value:

\[ T_0 = 0.693T = \frac{J n_1^2}{131.5 P_1} \]

- the equation neglects the extra braking effects of windage and friction
Dynamic Braking

• Example
  – 225 kW, 250 V, 1280 rpm dc motor has windage, friction, and iron losses of 8 kW
  – drives a large flywheel with 177 kg m² moment of inertia
  – motor is connected to a 210 V dc supply and operating at a speed of 1280 rpm
  – a 0.2 ohm braking resistor is used
  – calculate: $T_0$, time for the motor speed to drop to 20 rpm, and time for the motor speed to drop to 20 rpm if there is no dynamic braking
Plugging

• Example
  – the motor is plugged using a current-limiting resistor of 0.4 ohm resistor
  – calculate: the initial braking current and power and the stopping time
Basics of Variable Speed Control

- The most important outputs of a motor are speed and torque
  - useful to determine the machine limits as speed increases
- the rated values of armature current, armature voltage, and field flux must not be exceeded

- Assume that the machine is an ideal separately excited with negligible armature resistance
  - consider the per unit values of $E_a$, $I_a$, $\Phi_f$, $I_f$, and $n$
  - the per unit approach renders a universal torque-speed curve

- the per-unit torque is given by the per-unit flux times the per-unit armature current
- the per-unit armature voltage is given by the per-unit speed times the per-unit flux
Basics of Variable Speed Control

• The per-unit equations of torque and induced voltages are:

\[ T = \Phi_f I_a \]

\[ E_a = n \Phi_f \]

– to reduce speed below base, reduce armature voltage while keeping rated current and flux constant (constant torque mode)

– to increase speed above base, reduce flux, but as current cannot exceed base, torque decreases (constant power mode)

• DC machines can operate anywhere within the limits of the torque-speed curve
Homework

• 5-14, 5-15, and 5-17