ELG4139: DC Drives

- **Types of DC Motors**: Shunt; Series; Compound; Separately; excited; Switched reluctance motors.
- **Motor Selection**: Cost; Thermal capacity; Efficiency; Torque-speed profile; Acceleration; Power density, volume of the motor; Ripple, cogging torque; Peak torque capability.
Motor Drives
Speed is determined by Armature Voltage
Torque is determined by Armature Current
DC Motor Example

- $V = 12$ volts
- Max current = 4 A
- Max power out = 25 W
- Max efficiency = 74%
- Max speed = 3500 rpm
- Max torque = 1.4 N-m
- Weight = 1.4 lbs
- Forward or reverse (brushed)
Torque Equation: Motor Drives

\[ T_e = T_L + J \frac{d\omega}{dt} \quad \text{or} \quad T_e - T_L = J \frac{d\omega}{dt} \]

\( T_e \): motor torque (Nm) \hspace{1cm} \( T_L \): Load torque (Nm)

\[ T_e - T_L > 0 \quad \text{Acceleration} \]

\[ T_e - T_L < 0 \quad \text{Deceleration} \]

\[ T_e - T_L = 0 \quad \text{Constant speed} \]
Equivalent Circuit of DC Motor

\[ v_t = R_a i_a + L \frac{di_a}{dt} + e_a \]

\[ v_f = R_f i_f + L \frac{di_f}{dt} \]

\[ T_e = k_t \phi i_a \quad \text{Electromagnetic torque} \]

\[ e_a = k_E \phi \omega \quad \text{Armature back e.m.f.} \]
Torque-Speed Characteristics

Armature circuit:

\[ V_a = R_a i_a + L \frac{d i_a}{dt} + e_a \]

In steady state,

\[ V_a = R_a I_a + E_a \]

Therefore speed is given by,

\[ \omega = -\frac{R_a}{(k_T\phi)^2} T_e + \frac{V_a}{k_T\phi} \]

Three possible methods of speed control:

Armature resistance \( R_a \)
Field flux \( \Phi \)
Armature voltage \( V_a \)
DC Motor Drives

Methods of speed control

Armature voltage control

Variable voltage source

Phase-controlled Rectifier

Switch-mode converter (Chopper)

1Q-Converter

2Q-Converter

4Q-Converter
DC Drives

• **DC Drives:** Electric drives that use DC motors as the prime movers.

• **DC motor:** industry workhorse for decades.

• **Will AC drive replaces DC drive ?**
  – Predicted many years ago
  – DC strong presence; easy control; huge numbers
  – AC will eventually replace DC; at a slow rate.

• **Advantage:** simple torque and speed control without sophisticated electronics.

• **Limitations:** Maintenance; expensive and heavy; the problem of sparking!
Power Electronic Converters in Electrical Drive Systems

DC Drives
- AC Source
  - AC-DC
  - AC-DC-DC
- DC Source
  - DC-AC-DC
  - DC-DC

AC Drives
- AC Source
  - AC-DC-AC
  - AC-AC
  - Const. DC
  - Variable DC
  - NCC
  - FCC
- DC Source
  - DC-AC
  - DC-DC-AC
AC-DC Drive

Field Supply

3 Phase AC Power

T1 T3 T5

Gate

SCR

DC Armature

T2 T4 T6

Shunt Field

Firing Circuit

Regulator

Current Feedback

Operator Control Station
AC-DC-DC Drives
Switch Mode Converter: 1Q Converter or Class A

\[ V_a = D I_s \quad P_o = V_a I_a \quad I_s = D I_a \quad R_i = V_s / I_s \]

\[ \Delta I_{\text{max}} = \frac{V_s}{R_m} \tanh \frac{R_m}{4fL_m} \]

- When chopper is ON, supply voltage \( V \) is connected across the load.
- When chopper is OFF, \( v_o = 0 \) and the load current continues to flow in the same direction through the freewheeling diode.
- The average values of output voltage and current are always positive.
  - It is used to control the speed of dc motor.
Switch Mode Converter: 2Q Converter

Q1 → T1 and D2
Q2 → D1 and T2
DC-DC: Two-quadrant Converter

T1 conducts $\rightarrow v_a = V_{dc}$

Diagram showing the circuit with T1, D1, D2, and switches Q1 and Q2.
Quadrant 1: The average voltage is made larger than the back EMF
DC-DC: Two-quadrant Converter

\[ + \quad V_{dc} \quad - \]

\[ + \quad D1 \quad T1 \quad i_a \quad T2 \quad D2 \quad - \]

\[ D1 \text{ conducts} \quad \rightarrow \quad v_a = V_{dc} \]
**DC-DC: Two-quadrant Converter**

Quadrant 2: The average voltage is made smaller than the back EMF, forcing the current to flow in the reverse direction.

- T2 conducts $\rightarrow v_a = 0$
- D1 conducts $\rightarrow v_a = V_{dc}$

$V_{dc}$ conducts $\rightarrow v_a = 0$

$V_{dc}$ conducts $\rightarrow v_a = V_{dc}$
Switch-Mode Converter: 4Q Converter