EN 206: Power Electronics and Machines

Direct Current (DC) Machines

Suryanarayana Doolla

Department of Energy Science and Engineering
Indian Institute of Technology Bombay
email: suryad@iitb.ac.in

February 10, 2012

Lecture Organization - Modules

- Introduction and Power Semiconductor Switches
- Module 1: Transformers
- Module 2: AC/DC converter / Rectifier
- Module 3: DC machines and Drives
- Module 4: DC/DC converter
- Module 5: Induction Machine
- Module 6: DC/AC converter / Inverter
- Module 7: AC/AC converter / Cyclo converter
- Module 8: Synchronous Machine
- Module 9: Special Topics: Machines, HVDC, APF

Characteristics of a DC Generator

- The relation between basic quantities (V_t, I_a , I_f and n)

Characteristics of a DC Generator

- The relation between basic quantities (V_t, I_a , I_f and n)
- While determining the characteristic, speed of generator is held constant by the prime mover

Characteristics of a DC Generator

- The relation between basic quantities (V_t, I_a , I_f and n)
- While determining the characteristic, speed of generator is held constant by the prime mover
- Four Types:

Characteristics of a DC Generator

- The relation between basic quantities (V_t, I_a , I_f and n)
- While determining the characteristic, speed of generator is held constant by the prime mover
- Four Types:
  - No load characteristic or open circuit characteristic - E_a and I_f, speed is held constant

Characteristics of a DC Generator

- The relation between basic quantities (V_t, I_a , I_f and n)
- While determining the characteristic, speed of generator is held constant by the prime mover
- Four Types:
  - No load characteristic or open circuit characteristic - E_a and I_f, speed is held constant
  - Load characteristic or Load magnetization curve - V_t and I_f, both speed and I_a constant

Characteristics of a DC Generator

- The relation between basic quantities (V_t, I_a , I_f and n)
- While determining the characteristic, speed of generator is held constant by the prime mover
- Four Types:
  - No load characteristic or open circuit characteristic - E_a and I_f, speed is held constant
  - Load characteristic or Load magnetization curve - V_t and I_f, both speed and I_a constant
  - External characteristic - V_t and I_L, both speed and I_f constant

Characteristics of a DC Generator

- The relation between basic quantities (V_t, I_a , I_f and n)
- While determining the characteristic, speed of generator is held constant by the prime mover
- Four Types:
  - No load characteristic or open circuit characteristic - E_a and I_f, speed is held constant
  - Load characteristic or Load magnetization curve - V_t and I_f, both speed and I_a constant
  - External characteristic - V_t and I_L, both speed and I_f constant
  - Armature characteristic or regulation curve - I_f and I_a, both V_t and speed constant

Equations governing DC generator characteristics

The emf generated is given by

$$E_a = \frac{\phi ZNP}{60a}$$

In case of separately excited generator the emf generated in the armature is given by:

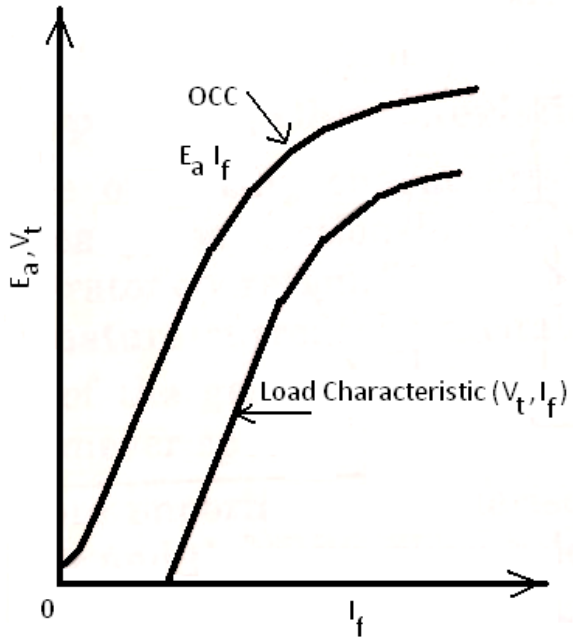
$$E_a = V_t + I_a R_a + brushdrop$$

Also,

$$E_a = K_a \phi \omega_m$$

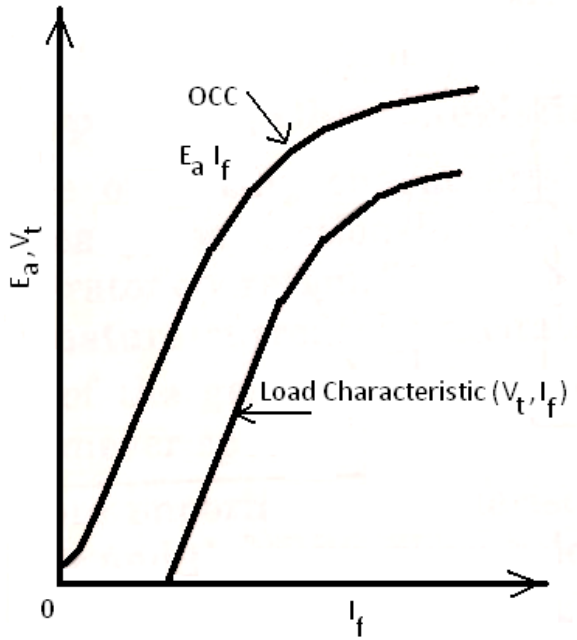
DC Separately excited generator - OCC

- Magnetization Curve or Open Circuit Characteristics Curve (OCC)



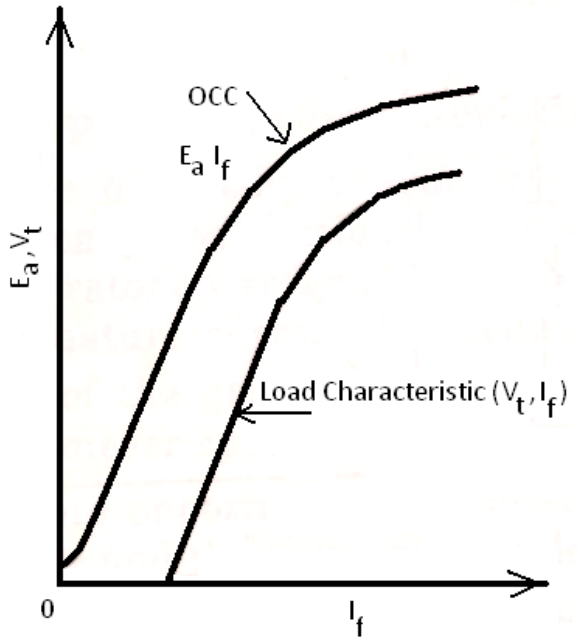
DC Separately excited generator - OCC

- Magnetization Curve or Open Circuit Characteristics Curve (OCC)
  - Relationship between air-gap flux (ϕ) and the field winding mmf or field winding current.



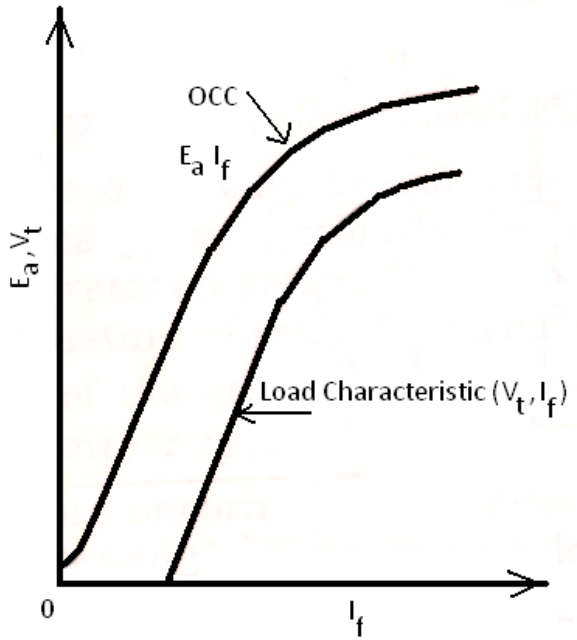
DC Separately excited generator - OCC

- Magnetization Curve or Open Circuit Characteristics Curve (OCC)
  - Relationship between air-gap flux (ϕ) and the field winding mmf or field winding current.
  - For constant speed (ω_m), the armature generated emf (E_a)at no-load is proportional to the air-gap flux only



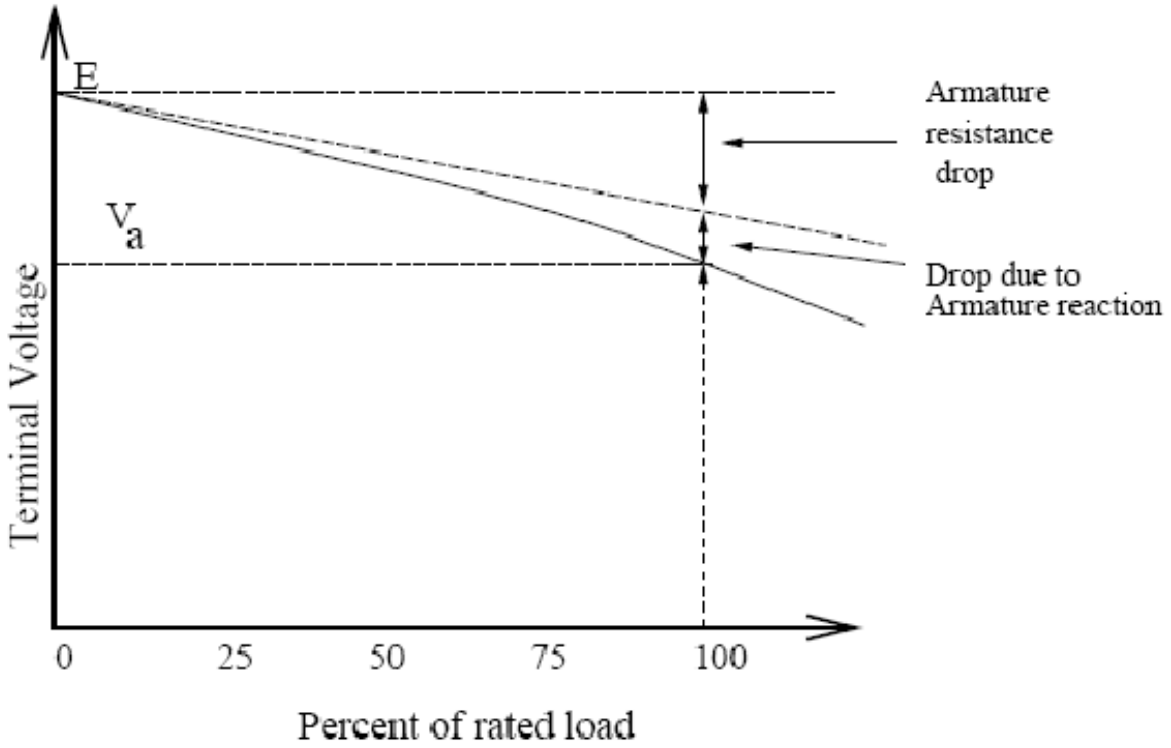
DC Separately excited generator - OCC

- Magnetization Curve or Open Circuit Characteristics Curve (OCC)
  - Relationship between air-gap flux (ϕ) and the field winding mmf or field winding current.
  - For constant speed (ω_m), the armature generated emf (E_a)at no-load is proportional to the air-gap flux only
- E_a is not zero when I_f is zero : Residual Magnetism

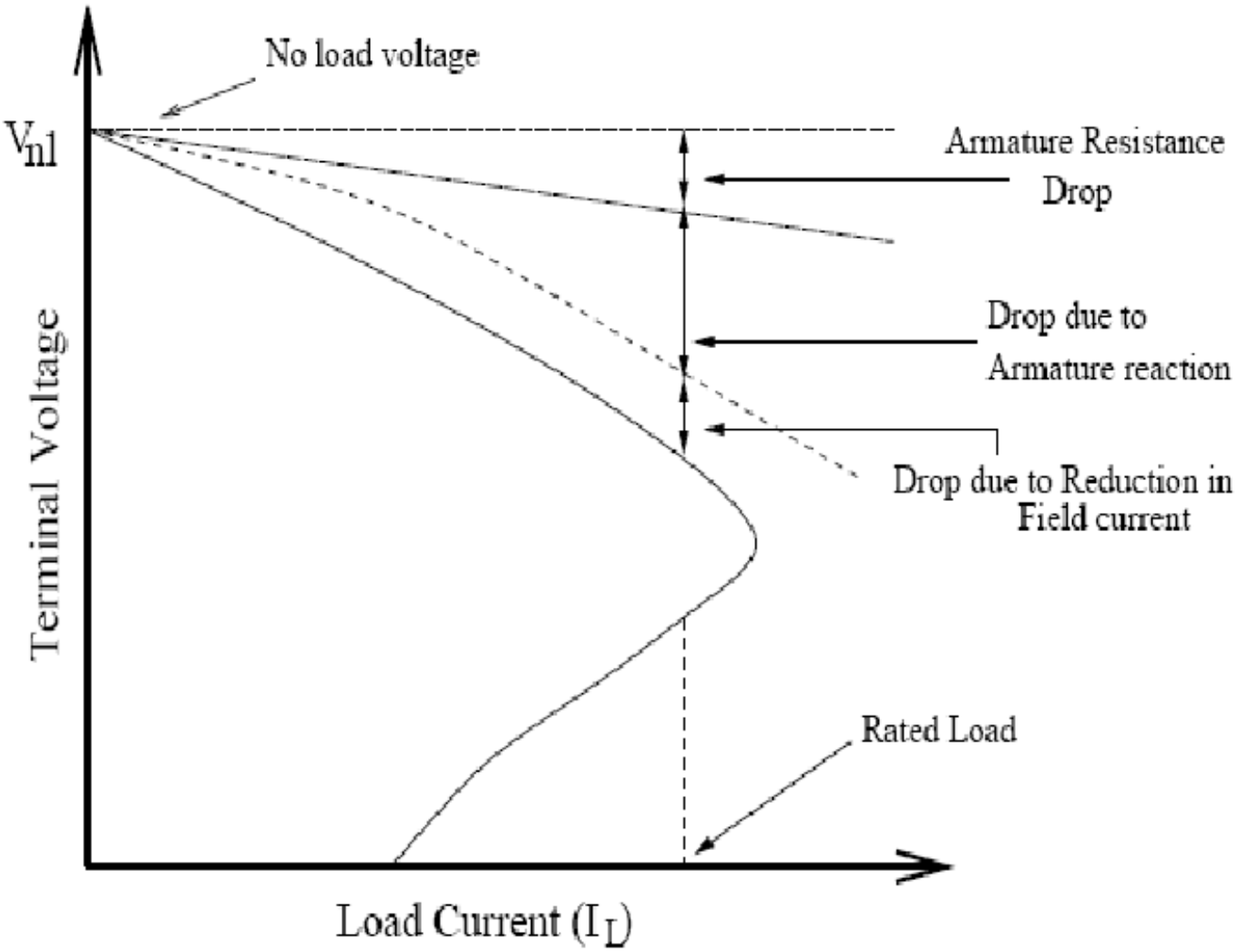


External Characteristics - DC Separately excited generator

- Terminal Voltage Vs Load Current
  $E_a = V_t + I_a R_a +$ Voltage drop due to armature reaction.

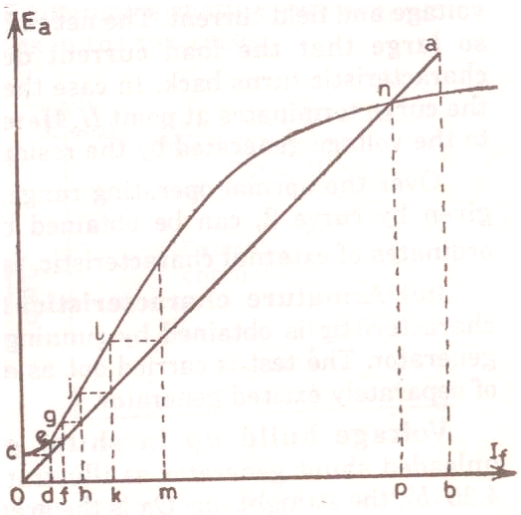


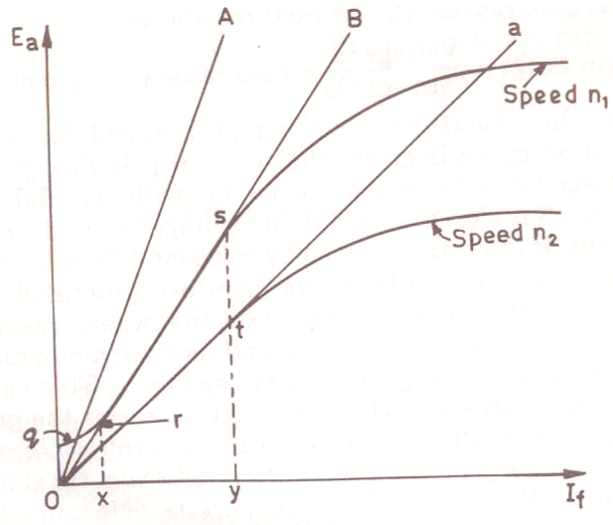
External Characteristics - Self excited generator



Voltage build up in a DC shunt Machine

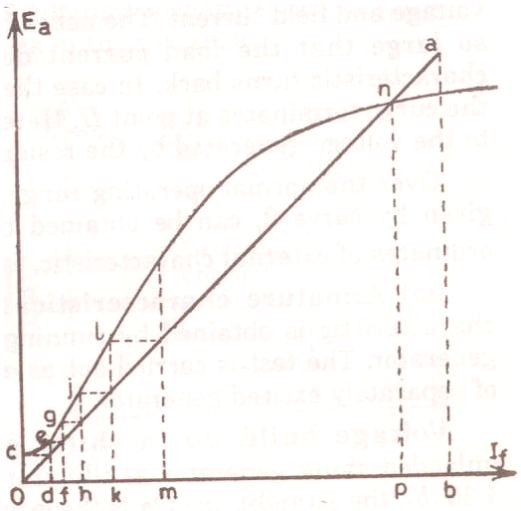
- Oa is graphical plot of ohm law of field circuit

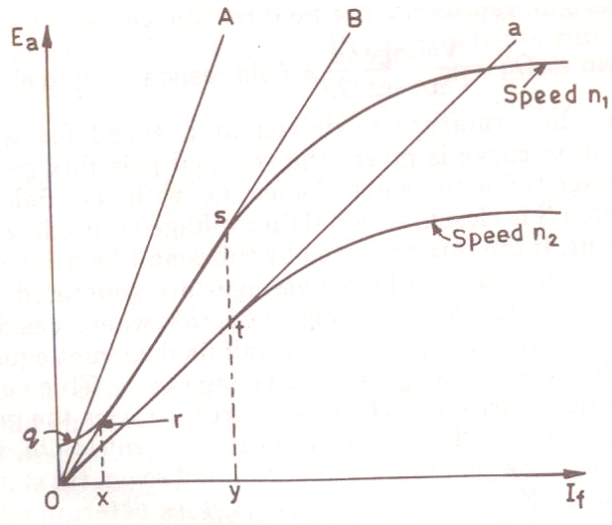




Voltage build up in a DC shunt Machine

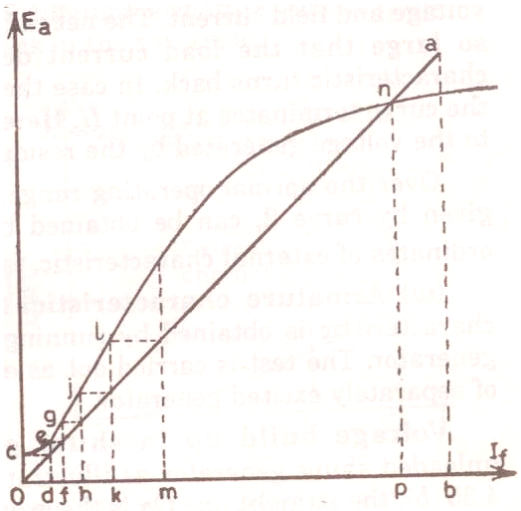
- Oa is graphical plot of ohm law of field circuit
- Stable point 'n' is the intersection of OCC and Oa

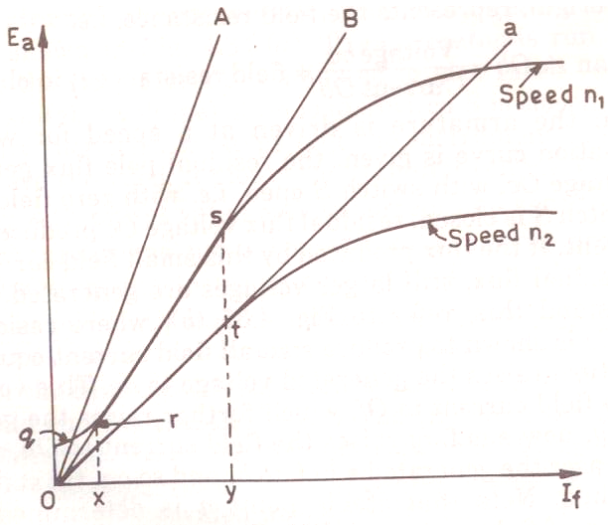




Voltage build up in a DC shunt Machine

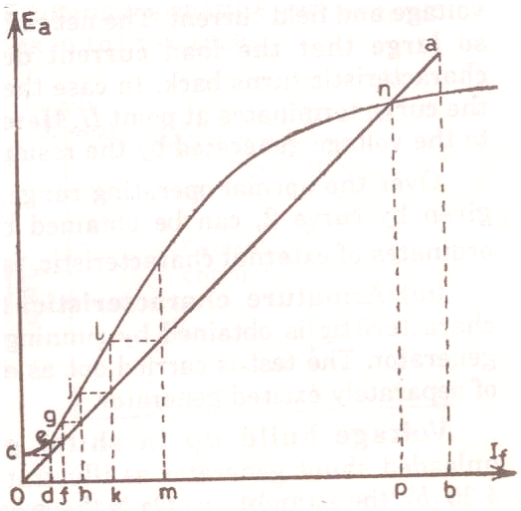
- Oa is graphical plot of ohm law of field circuit
- Stable point 'n' is the intersection of OCC and Oa
- OB - Slope of line is critical field resistance

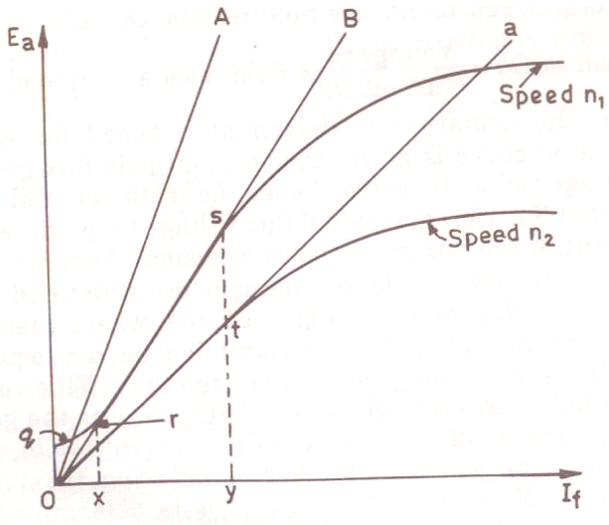




Voltage build up in a DC shunt Machine

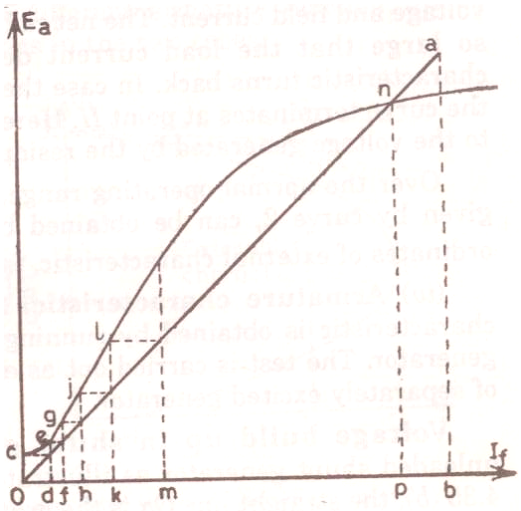
- Oa is graphical plot of ohm law of field circuit
- Stable point 'n' is the intersection of OCC and Oa
- OB - Slope of line is critical field resistance
- Speed n_2 - Critical speed

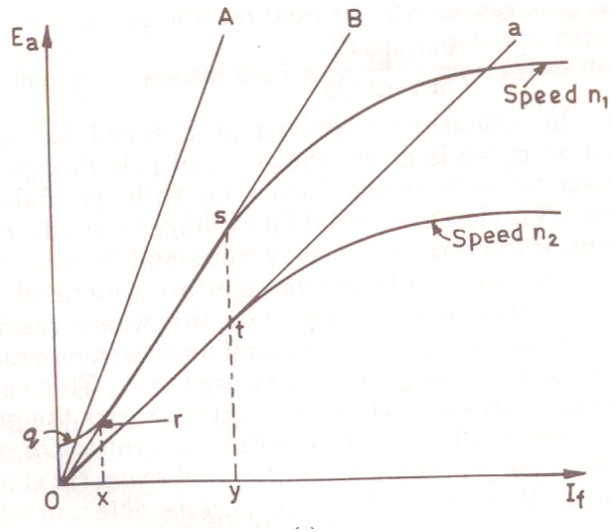




Voltage build up in a DC shunt Machine

- Oa is graphical plot of ohm law of field circuit
- Stable point 'n' is the intersection of OCC and Oa
- OB - Slope of line is critical field resistance
- Speed n_2 - Critical speed
- The process of connecting shunt field winding to a separate dc source for creating the necessary residual magnetism in the main poles is called field flashing





Equations governing dc motor characteristics

The speed of a dc motor is given by

$$\omega_m = \frac{E_b}{K_a \phi}$$

But, the back emf of a dc motor is given by:

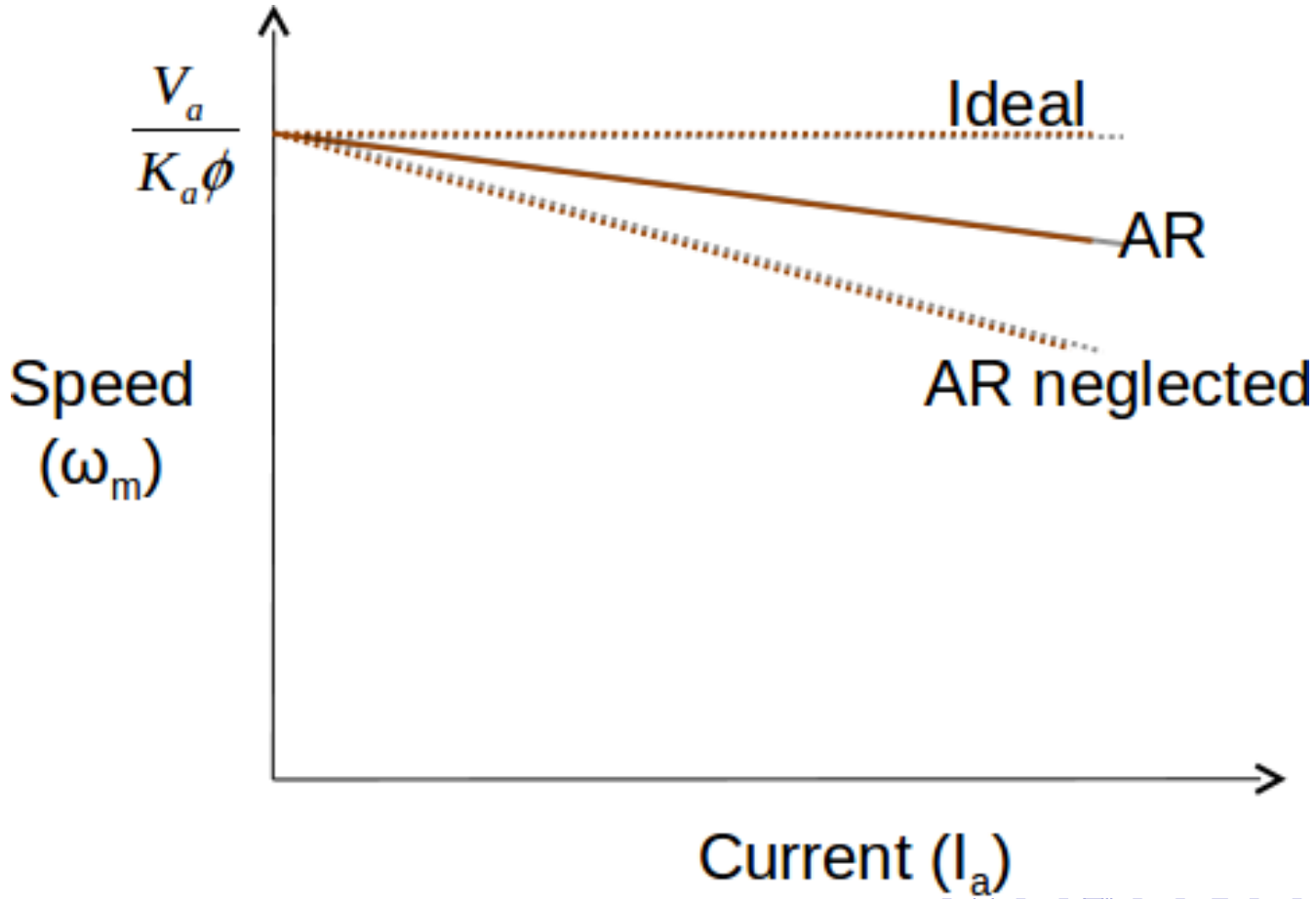
$$E_b = V_t - I_a R_a$$

$$\Longrightarrow \omega_m = \frac{V_t - I_a R_a}{K_a \phi}$$

$$\omega_m = \frac{V_t}{K_a \phi} - \frac{R_a}{(K_a \phi)^2} T_e$$

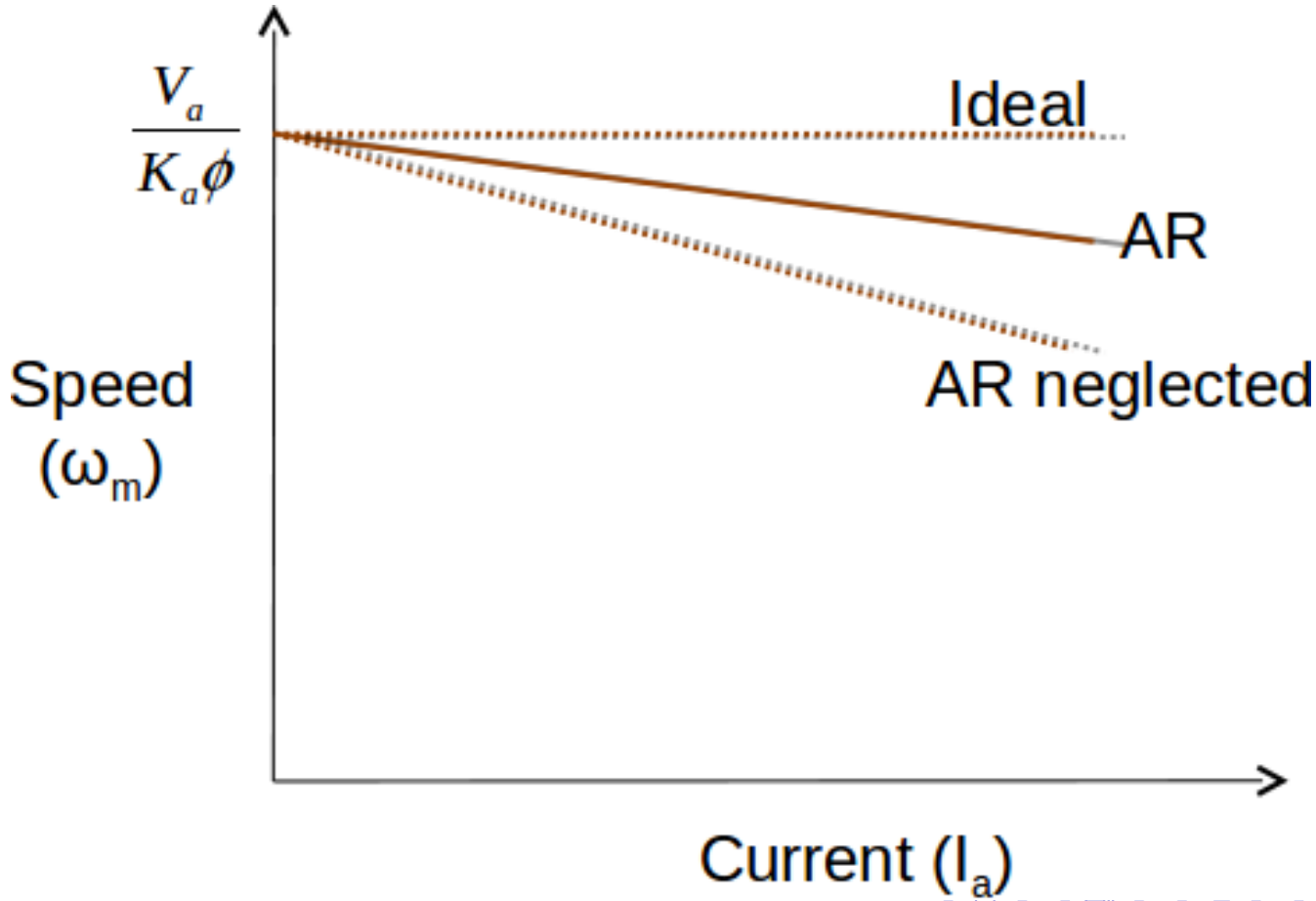
Characteristics of a Shunt Motor

- Speed Vs Torque



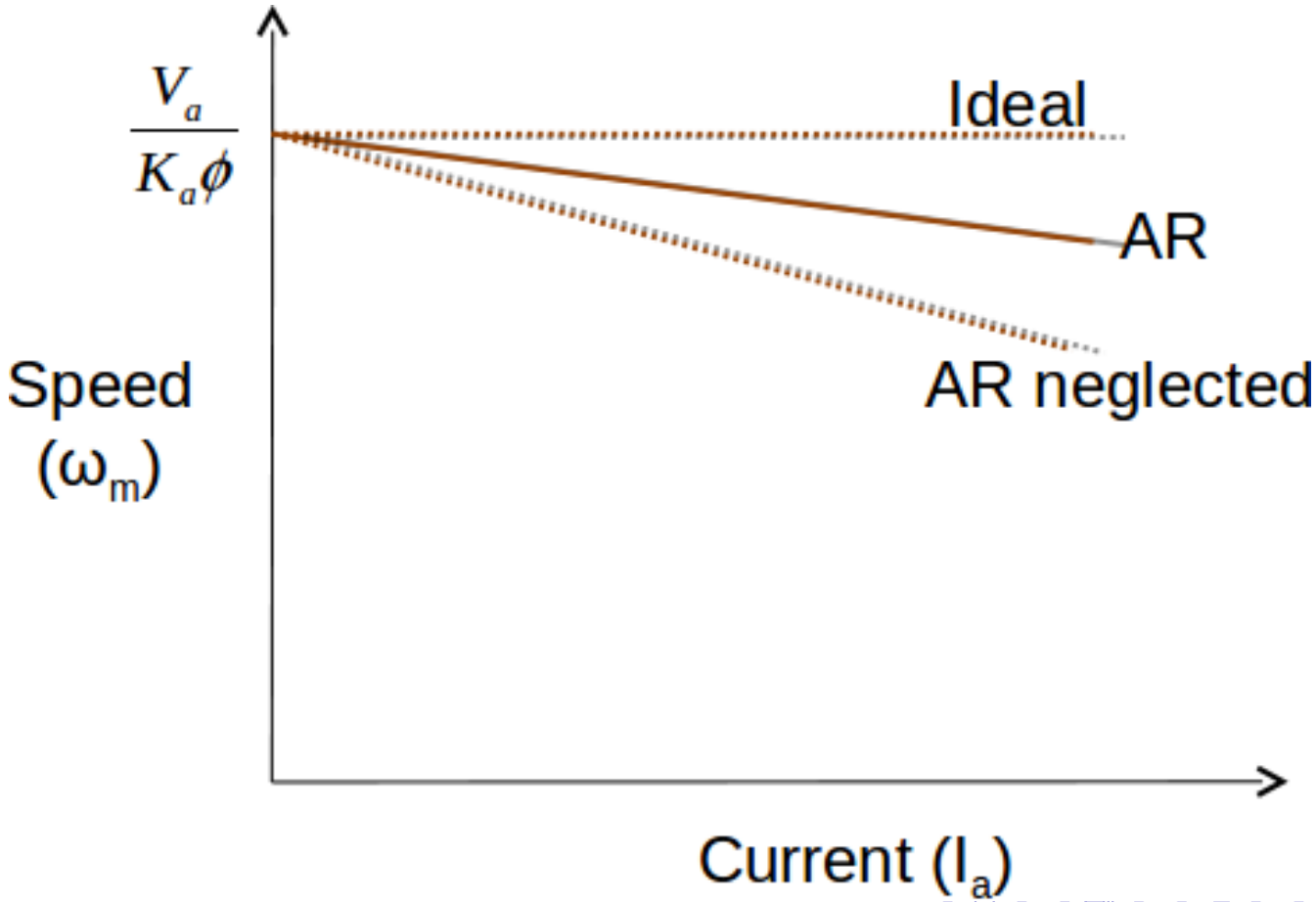
Characteristics of a Shunt Motor

- Speed Vs Torque
- Speed Vs Load Current

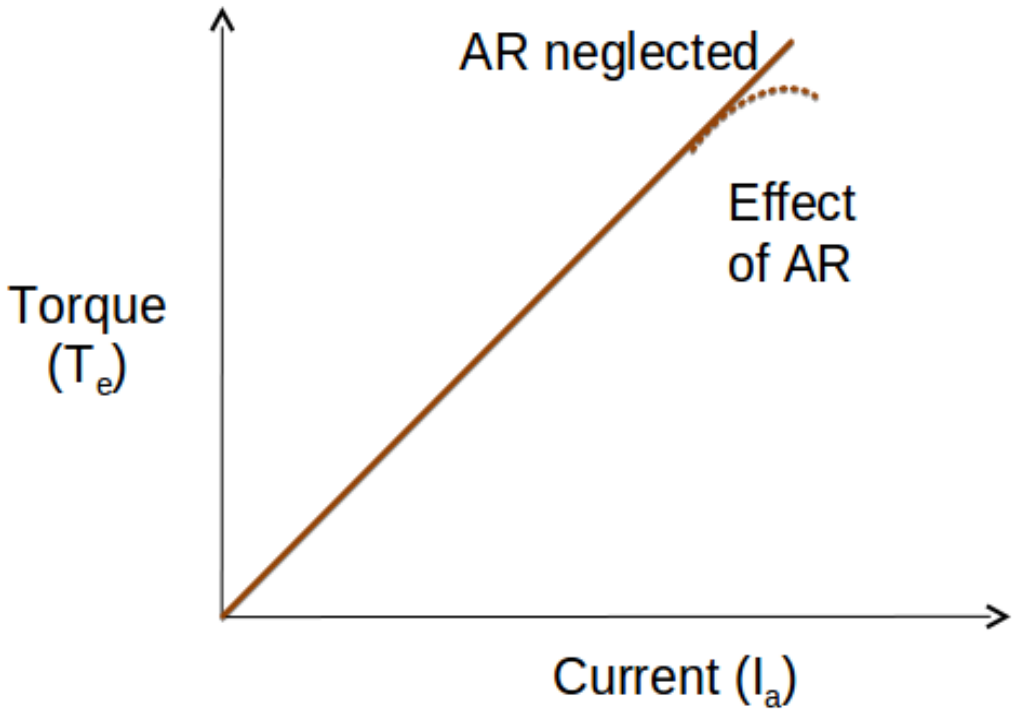


Characteristics of a Shunt Motor

- Speed Vs Torque
- Speed Vs Load Current
- Torque Vs Load Current

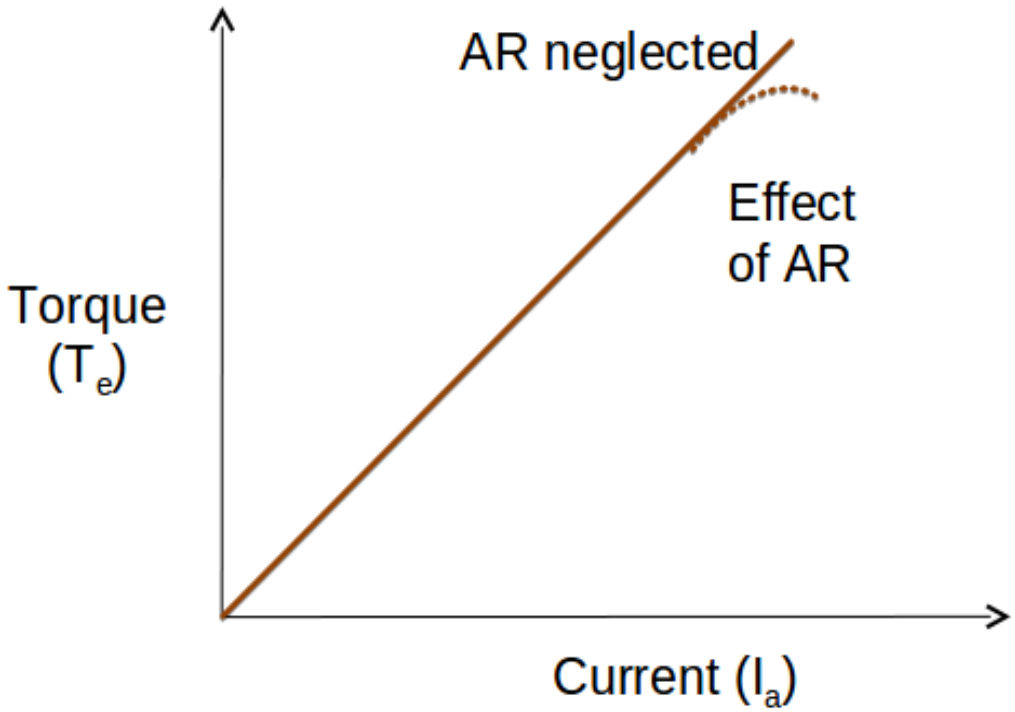


Torque - Current Characteristics



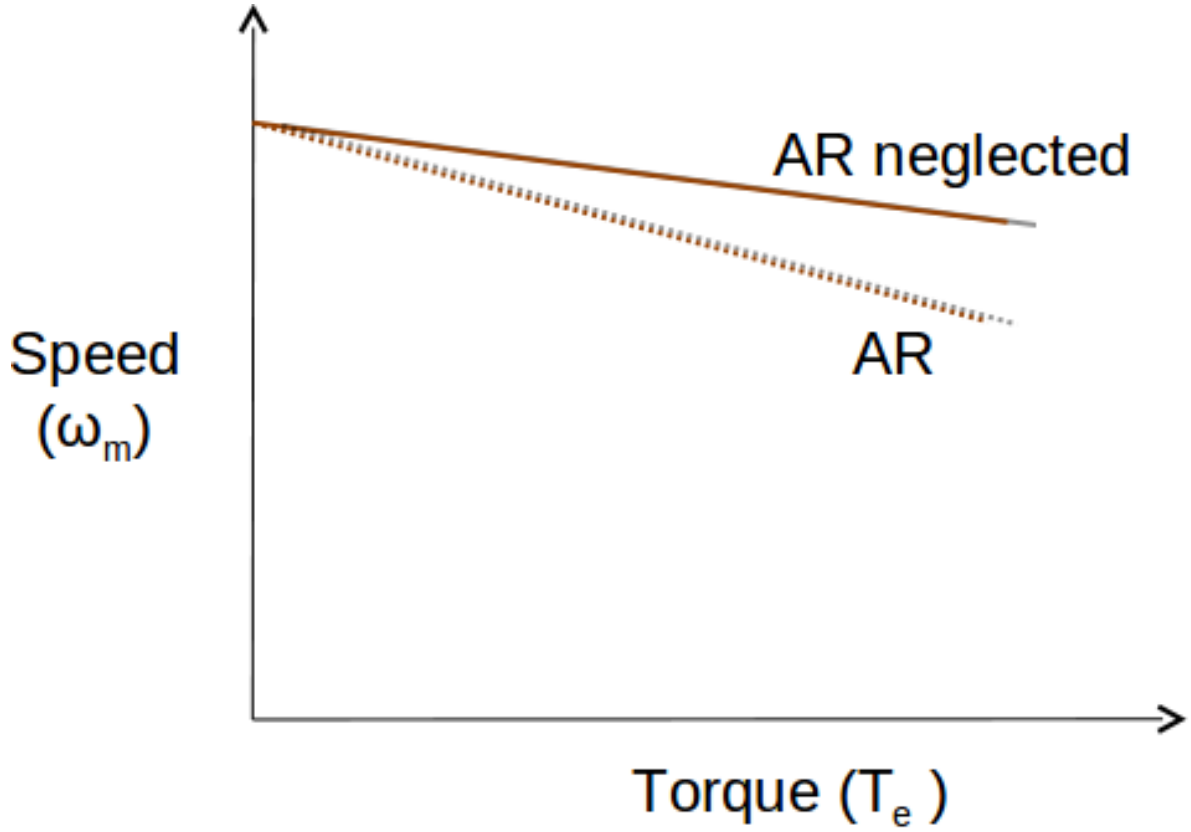
- The effect of armature reaction is neglible for low values of current

Torque - Current Characteristics



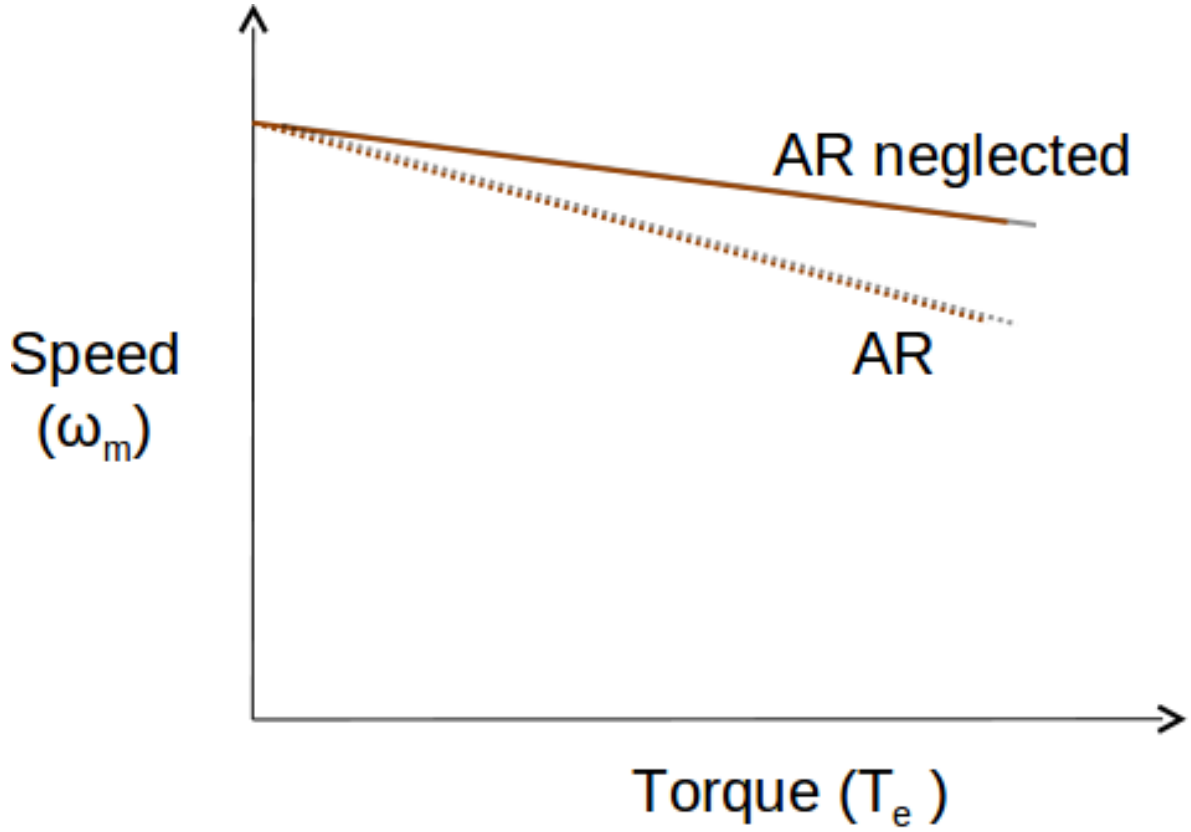
- The effect of armature reaction is neglible for low values of current
- At high values of current the torque current deviates from straight line

Speed - Torque Characteristics



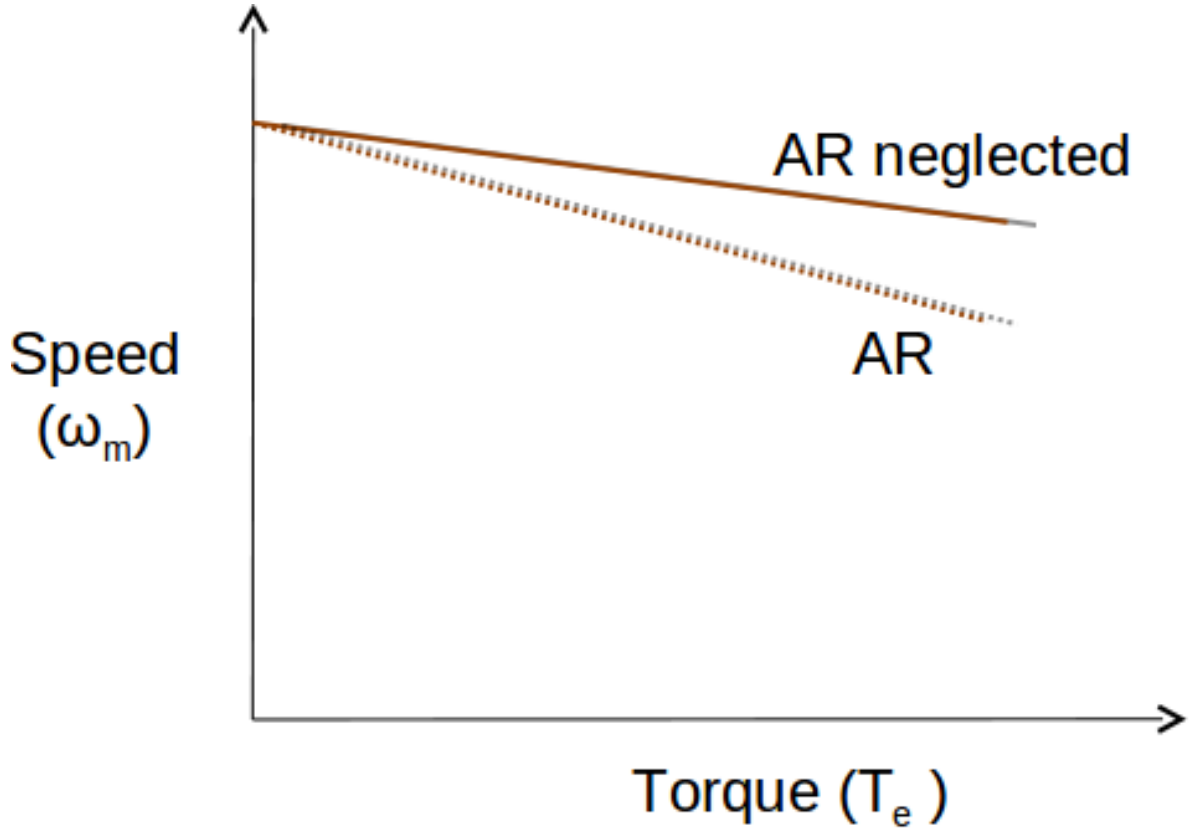
- As the torque increases speed drops

Speed - Torque Characteristics



- As the torque increases speed drops
- For larger values of Te, large will be Ia which reduced due to saturation and armature reaction

Speed - Torque Characteristics



- As the torque increases speed drops
- For larger values of Te, large will be Ia which reduced due to saturation and armature reaction
- Speed drops more rapidly

Characteristics of Series Motor

- The main flux is proportional to load current or armature current, if saturation and armature reaction are neglected.

The speed of a dc motor is given by

$$\omega_m = \frac{E_b}{K_a \phi}$$

The back emf of a dc series motor is given by:

$$E_b = V_t - I_a(R_a + R_s)$$

$$\Longrightarrow \omega_m = \frac{V_t - I_a(R_a + R_s)}{K_a \phi}$$

$$\omega_m = \frac{V_t}{K_a C I_a} - \frac{R_a + R_s}{K_a . C}$$

Characteristics of Series Motor

- With saturation and armature reaction neglected, the speed-current characteristic of a dc series motor is a hyperbola.

If saturation and armature reaction are neglected,

$$I_a = \sqrt{\frac{T_a}{K_a.C}} and \omega_m = \frac{V_t}{\sqrt{K_a C T_e}} - \frac{R_a + R_s}{K_a C}$$

Characteristics of Series Motor

- With saturation and armature reaction neglected, the speed-current characteristic of a dc series motor is a hyperbola.
- For larger load currents, the air gap flux tends to remain constant because of saturation and armature reaction and hence speed-current characteristic of a series motor approaches a straight line for larger values of armature current.

If saturation and armature reaction are neglected,

$$I_a = \sqrt{\frac{T_a}{K_a.C}} and \omega_m = \frac{V_t}{\sqrt{K_a C T_e}} - \frac{R_a + R_s}{K_a C}$$

Characteristics of Series Motor

- With saturation and armature reaction neglected, the speed-current characteristic of a dc series motor is a hyperbola.
- For larger load currents, the air gap flux tends to remain constant because of saturation and armature reaction and hence speed-current characteristic of a series motor approaches a straight line for larger values of armature current.
- The dc series motor should not be operated at no load speed.

If saturation and armature reaction are neglected,

$$I_a = \sqrt{\frac{T_a}{K_a.C}} and \omega_m = \frac{V_t}{\sqrt{K_a C T_e}} - \frac{R_a + R_s}{K_a C}$$

Characteristics of Series Motor

- With saturation and armature reaction neglected, the speed-current characteristic of a dc series motor is a hyperbola.
- For larger load currents, the air gap flux tends to remain constant because of saturation and armature reaction and hence speed-current characteristic of a series motor approaches a straight line for larger values of armature current.
- The dc series motor should not be operated at no load speed.
- The torque-current characteristic of a dc series motor is a parabola. For large values of Ia the torque-current characteristic approaches a straightline.

If saturation and armature reaction are neglected,

$$I_a = \sqrt{\frac{T_a}{K_a.C}} and \omega_m = \frac{V_t}{\sqrt{K_a C T_e}} - \frac{R_a + R_s}{K_a C}$$