**Two basic equations:**

\[
E_a = K_a \Phi \omega_m \quad \text{Generator: Generated voltage}
\]
\[
\text{Motor: Back emf (Lenz's law)}
\]

\[
T = K_a \Phi I_a \quad \text{Motor: Generated torque}
\]
\[
\text{Generator: Retarding torque (Lenz's law)}
\]

\[
E_a I_a = T \omega_m \quad \text{(Neglecting losses)}
\]

◆ 機電整合主導公式
◆ 馬達及轉換器之象限:
  - Forward driving and regenerating braking
  - Backward driving and regenerating braking
Torque in DC Motor

- Torque generating capability of a DC Motor is the best, since the flux and armature conductor current are kept in quadrature in nature.
Efficiency: \[ \eta = \frac{\Delta}{P_o / P_{in}} \]

**Generator**

\[ P_o = V_t I_t (= P_{elec}) = P_{shaft} (= P_{in} = P_{mech}) - P_{rot} - I_a^2 R_a - I_f^2 R_f - I_t^2 R_{sr} \]

**Motor**

\[ P_o = (P_{shaft} = P_{mech}) = P_{in} (= V_t I_t = P_{elec}) - I_t^2 R_{sr} - I_f^2 R_f - I_a^2 R_a - P_{rot} \]
Torque-Speed Characteristics

以它激馬達為例:

$\omega_m = \frac{V_t - I_a R_a}{K_a \Phi} = \frac{1}{K_a \Phi} V_t - \frac{R_a}{(K_a \Phi)^2} T$

$V_t$: Control  $T$: Load torque (Disturbance)

電樞反應效應 (Armature reaction (AR) effect): 去磁:

Motor: $Load \uparrow \Rightarrow \Phi \downarrow \Rightarrow \omega_m \uparrow$

Generator: $Load \uparrow \Rightarrow \Phi \downarrow \Rightarrow E_a \downarrow$
Speed control

\[ \omega_m = \frac{V_t - I_a R_a}{K_a \Phi} = \frac{1}{K_a \Phi} V_t - \frac{R_a}{(K_a \Phi)^2} T \]

- \( V_t \) control (Constant-torque region, constant-flux),
- \( \Phi \) control (Constant-power region, field weakening),
- \( R_a \) control
（機電特性）

$T=0$  $T_1$  $T_2$

$\omega_m$

$V_t$

$T_L$

$\Phi$

$\Phi$

$I_a$

$E_a$

Rated

Constant torque
(constant flux)
(Vt control)

Constant power
(Field weakening)
(I_f control)

$T=\text{定值}$，且設$I_a$維持定值
各式直流馬達之轉矩速度特性比較：

![Graph showing different motor types: Series motor, Separately excited, Differential compound, and Cumulative compound.](image)
Series Motor

- Universal motor: AC and DC are all okay.
- Large developed torque (large starting torque): \( T = K_t I_a^2 \)

- Speed will be dangerously large at light load.

\[
\omega_m = \frac{V_t}{\sqrt{K_{sr} \sqrt{T}}} - \frac{R_a + R_{sr} + R_{ae}}{K_{sr}}, \quad K_a \Phi = K_{sr} I_a
\]

\( \omega_m \propto 1/\sqrt{T}, \ T = 0 \ (No\ load) \Rightarrow \omega_m \to \infty \)