METU EE462 Utilization of Electric Energy

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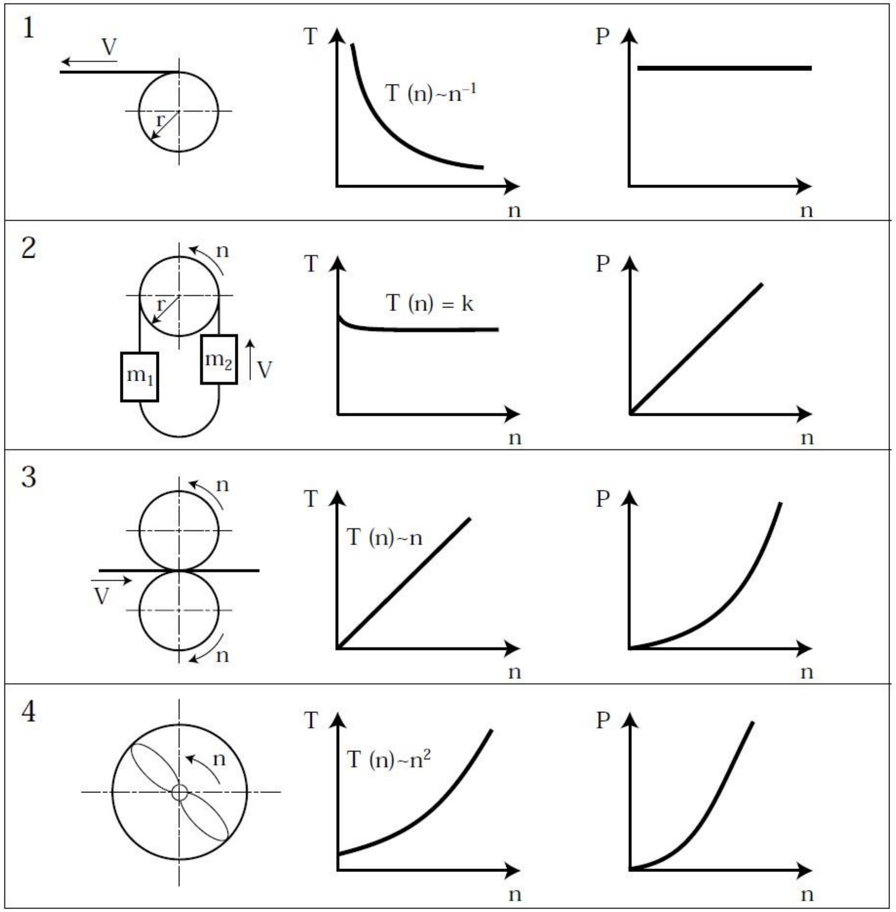
Office: C-107

Content

Load Types Overview



1. Machines for winding material under tension: This group includes, for example veneer cutting machines and machine tools.

2. Conveyor belts, cranes, positive displacement pumps, compressors as well as machine tools.

3. Hydraulic pumps, rollers, smoothing machines, and other processing machines.

4. Centrifugal force, such as centrifuges, centrifugal pumps and fans.

https://www.motorsystems.org/task-b/motor-and-load/load-types

Load Types

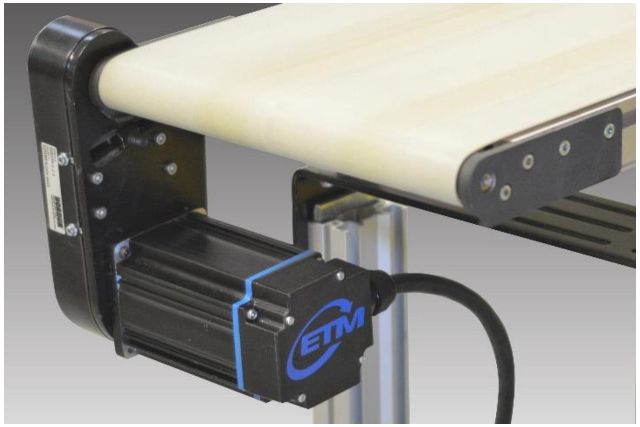
Constant Torque Loads

Compressors

Paper rolling machine

Constant tension should be applied at constant linear speed

Conveyors



Usually there is a high starting torque (to overcome static friction)

Crane Hoists

$$T_{load} = B\omega + T_{mech}$$

viscous friction force   load mass

Requires a four-quadrant drive

Load Types

Centrifugal Loads (Pump, Fan, etc)

$T_{load} = k\omega^2$

$P_{load} = k\omega^3$

Aerodynamic drag ~$v^2$and ~ω^2

Facebook Data Centers

https://thenextweb.com/facebook/2016/09/29/facebook-data-center-photos/

Vehicle as a Load

Aerodynamic drag

Grading resistance

$$(F_{tf} + F_{tr}) = \delta M \frac{dv}{dt} + (F_{rf} + F_{rr} + F_{\omega} + F_g)$$

Rolling resistive force of rear tires

Tractive force of front tires

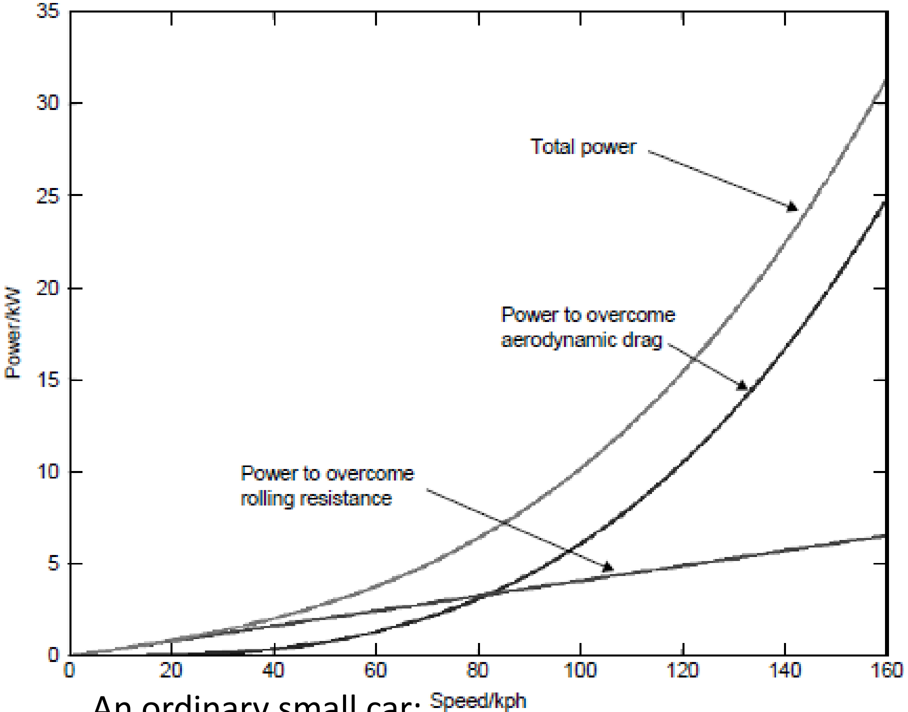
Tractive force of rear tires

Rolling resistive force of front tires

$$F_r = f_r M g\, cos(\alpha)$$

$$F_w = \frac{1}{2}\rho A_f C_d (V + V_w)^2$$

$$F_g = Mg\,\sin(\alpha)$$



An ordinary small car: C_d = 0.3, A_f=1.5 m^2, M= 1000 kg, and f_r = 0.015

Load Characteristics – Points of Equilibrium

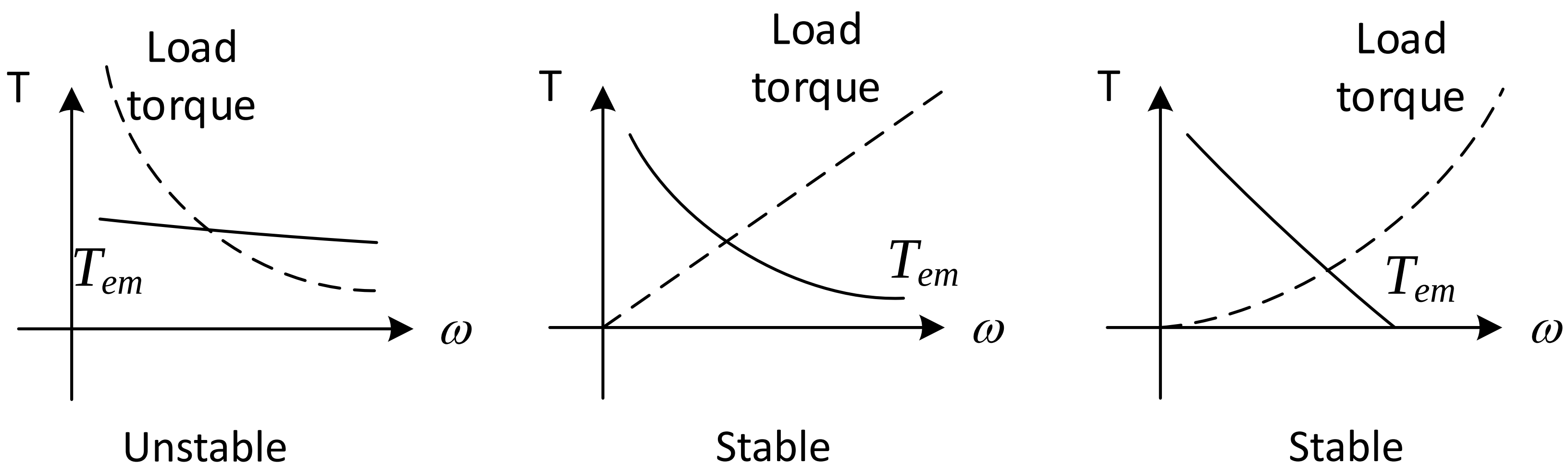
Equilibrium condition:

ω_m^* is an equilibrium if $\left.\frac{d\omega_m(t)}{dt}\right|_{\omega_m=\omega_m^*} = 0$

Stability:

$\frac{dT_e(\omega_m^*)}{d\omega_m} < \frac{dT_{load}(\omega_m^*)}{d\omega_m}$ ⇒ locally stable equilibrium

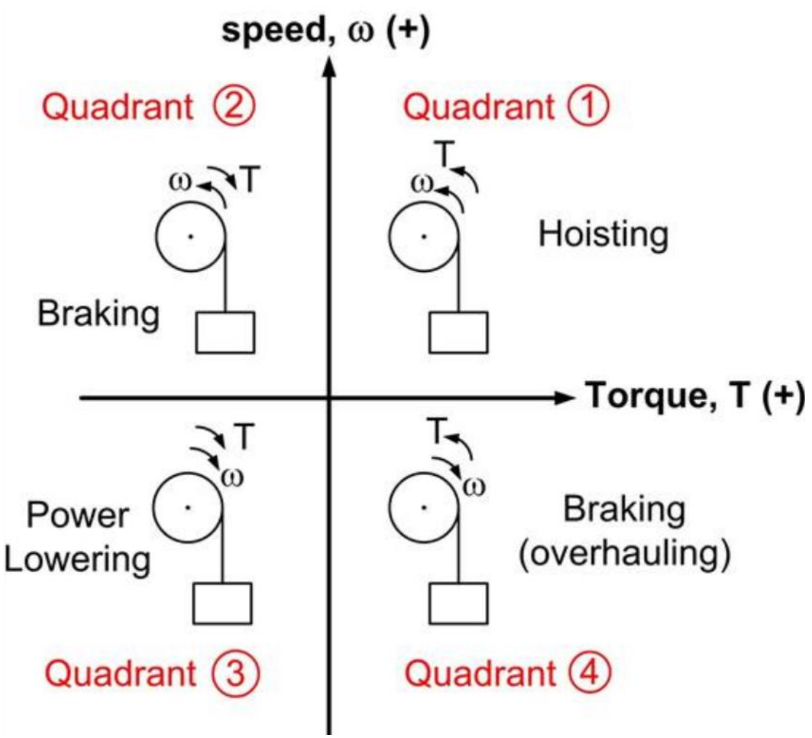
$\frac{dT_e(\omega_m^*)}{d\omega_m} > \frac{dT_l(\omega_m^*)}{d\omega_m}$ ⇒ locally unstable equilibrium

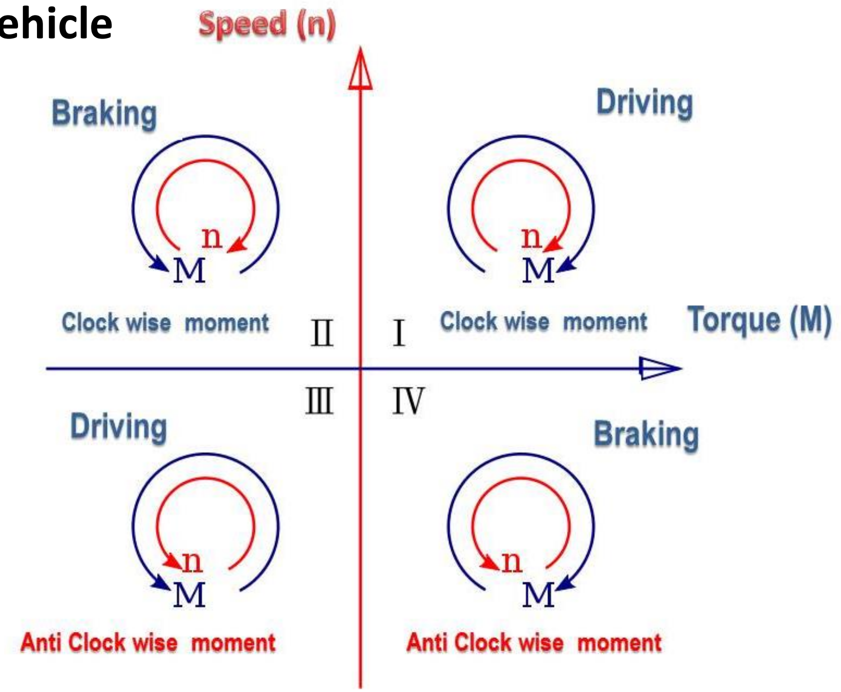


4-quadrant Operation

Example: Vehicle

Example: Crane Hoists:

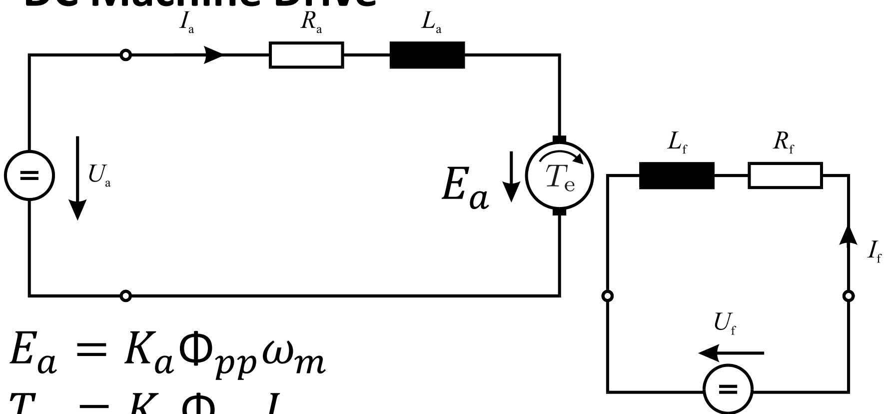




	Torque	Speed
Forward Driving	+	+
Backward Driving	-	-
Forward Braking	-	+
Backward Braking	+	-

4-quadrant Operation

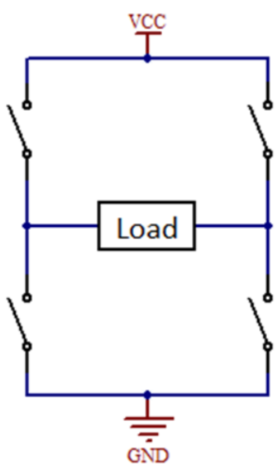
DC Machine Drive



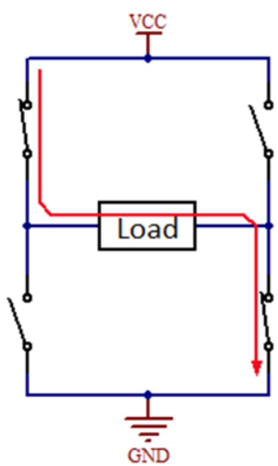
$$E_a = K_a \Phi_{pp} \omega_m$$
$$T_e = K_a \Phi_{pp} I_a$$

What kind of a power electronic circutry can we use for 4-quarant operation?

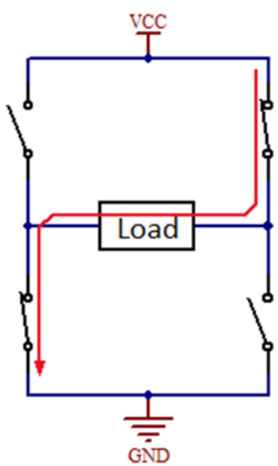
H bridge topology

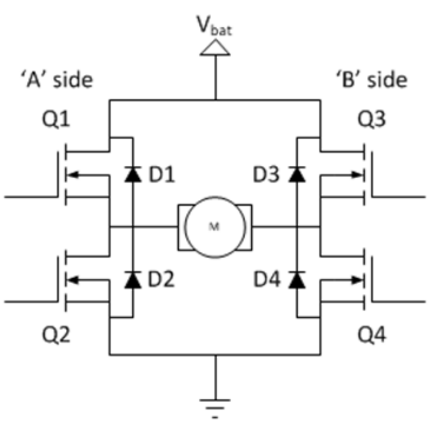


Connecting the load in one direction

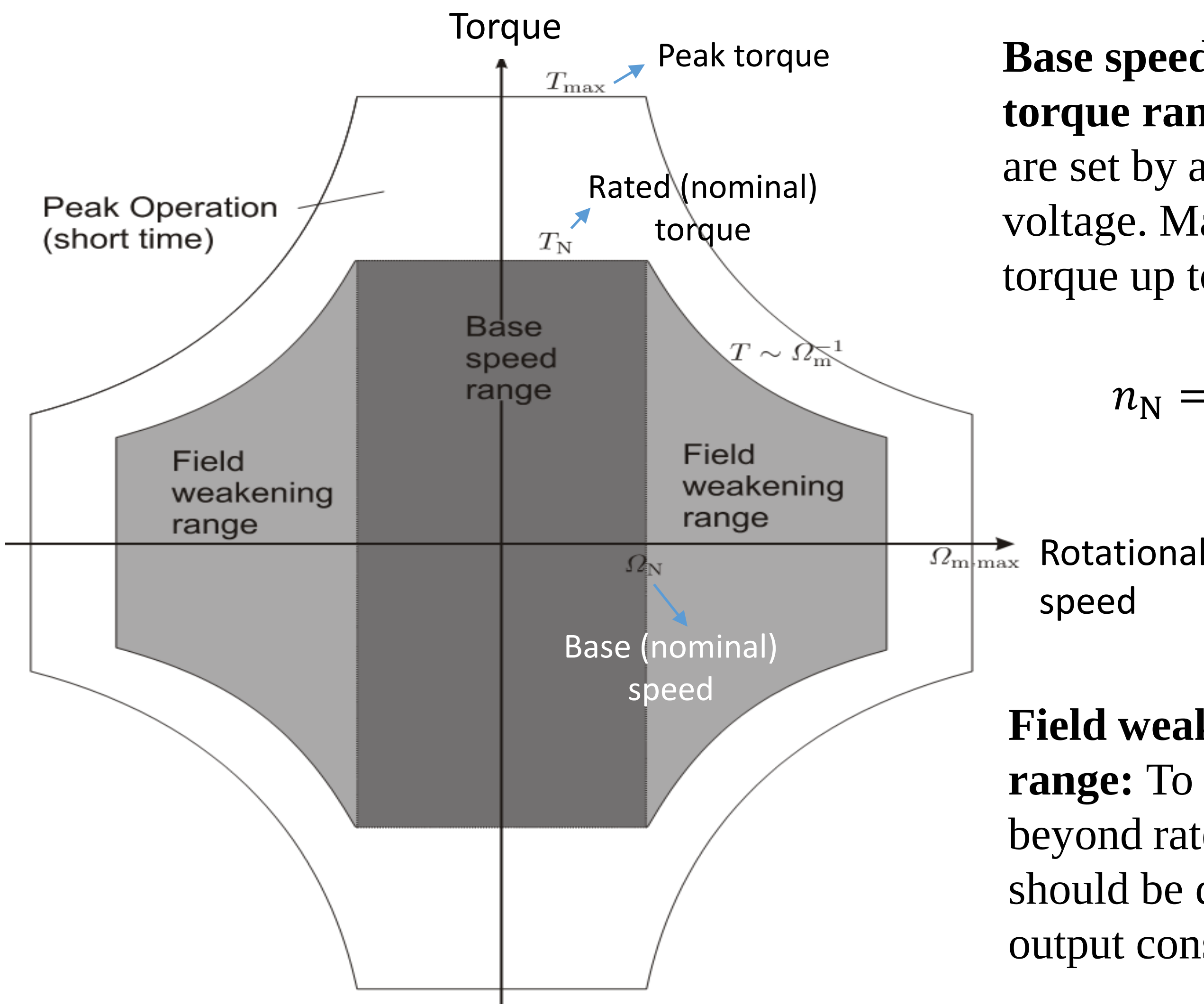


Connecting the load in the other direction





Operating Limits



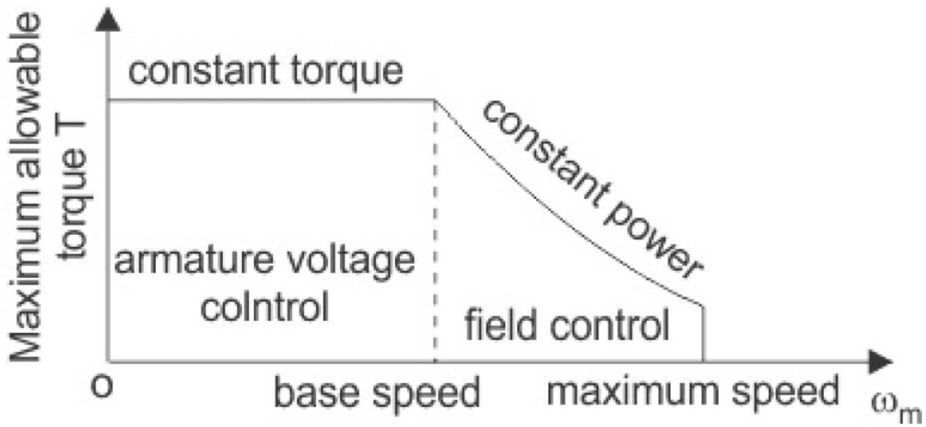
Base speed range or constant torque range: All operating points are set by adjusting the terminal voltage. Machine can operate at any torque up to T_N (T_{max}) in this area.

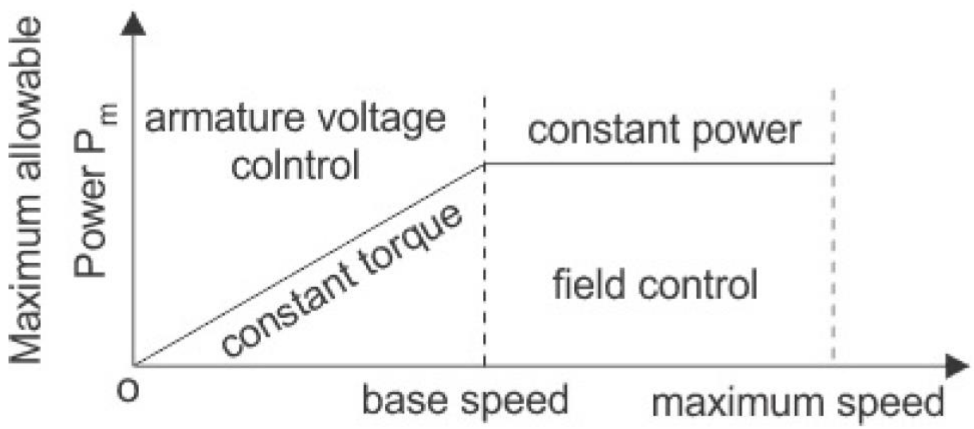
$$n_N = \frac{P_N}{2\pi T_N}$$

Speed at which machine delivers rated torque and rated power.

Field weakening or constant power range: To be able to increase speed beyond rate speed, maximum torque should be decreased to keep power output constant.

Operating Limits





Discussion of DC machine operating range:

- When do we reach base speed?
- How can we increase speed beyond base speed?

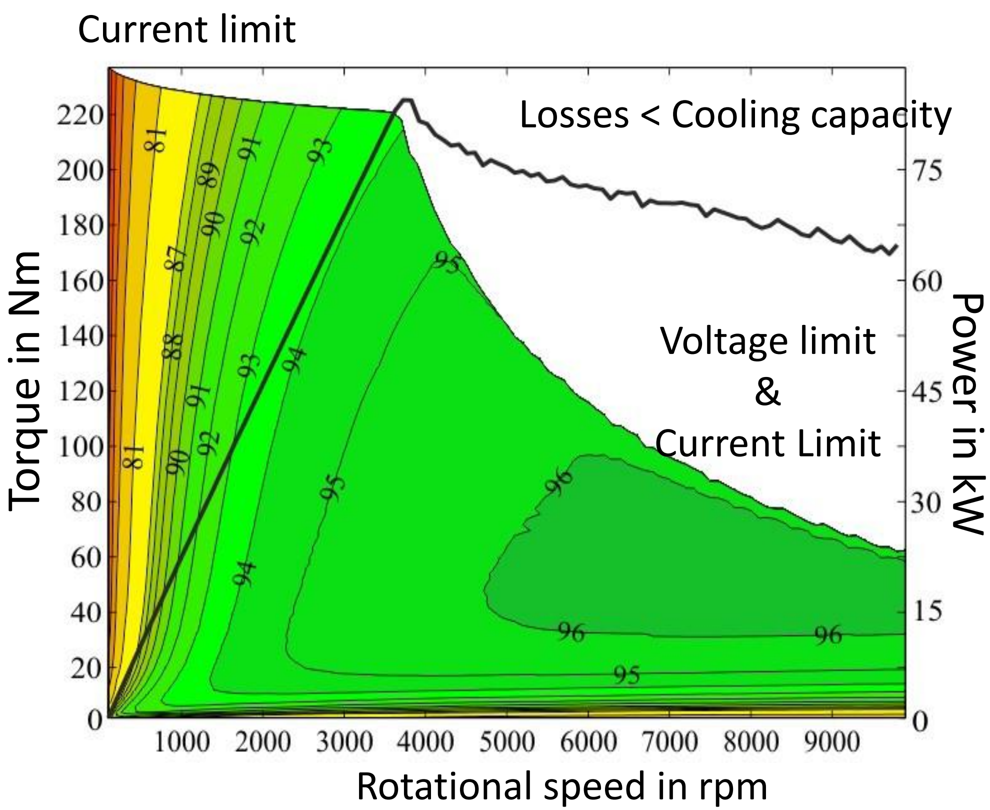
Operating Limits

Limiting Factors:

- DC-link voltage
- Current capability (EM + PE)
- Temperature (Cooling capability)
- Mechanical stability

➢ If the machine is operated beyond the limits the machine might be **thermally damaged** by overload currents or high torque could lead **mechanical destruction**.

➢ At speeds beyond the limits, the rotor bearings reach a thermal boundary which shortens the **lifetime** or even lead to mechanical destruction. Moreover, rotor can be **damaged** due to centrifugal force.



http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6556123

Basic Control Loops

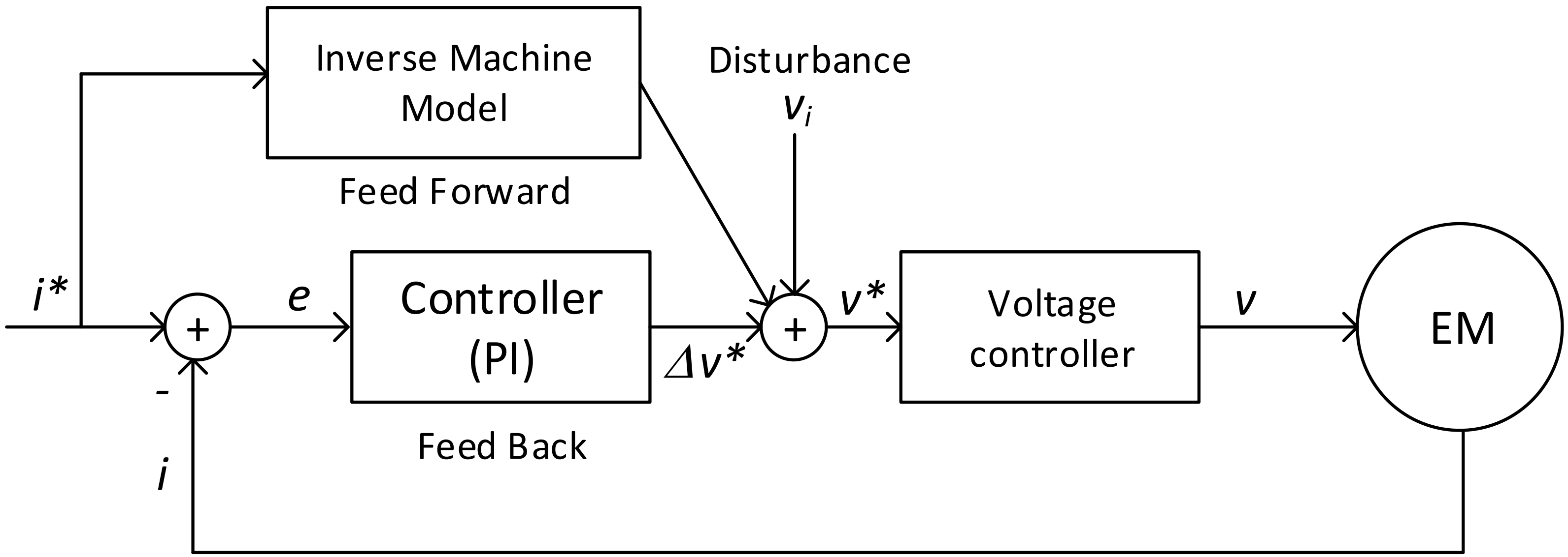
Depending on the required profile, different mechanical quantities of an electric machine have to be controlled: torque, speed and position.

A current control is usually preferred instead of torque control, since it is difficult to measure torque directly.

- Current Control
  - Current control by voltage regulation
  - Hysteresis current control
- Speed Control
- Position Control

Basic Control Loops

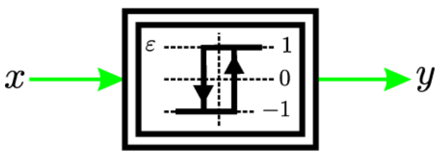
Current control by voltage regulation

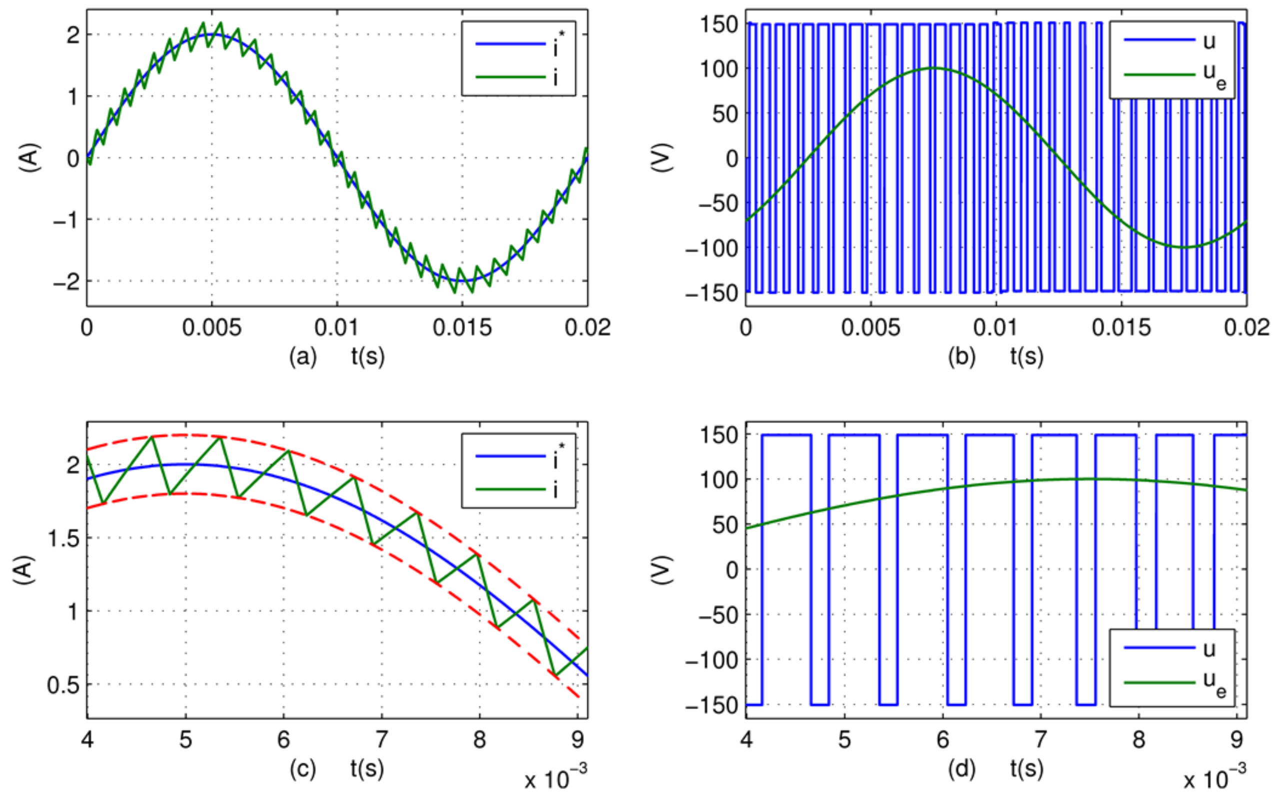


We know the relationship between torque and current, therefore we regulate current instead of torque. Since, it is common to use voltage source type converters, we can regulate current by regulating voltage.

Basic Control Loops

Hysteresis current control





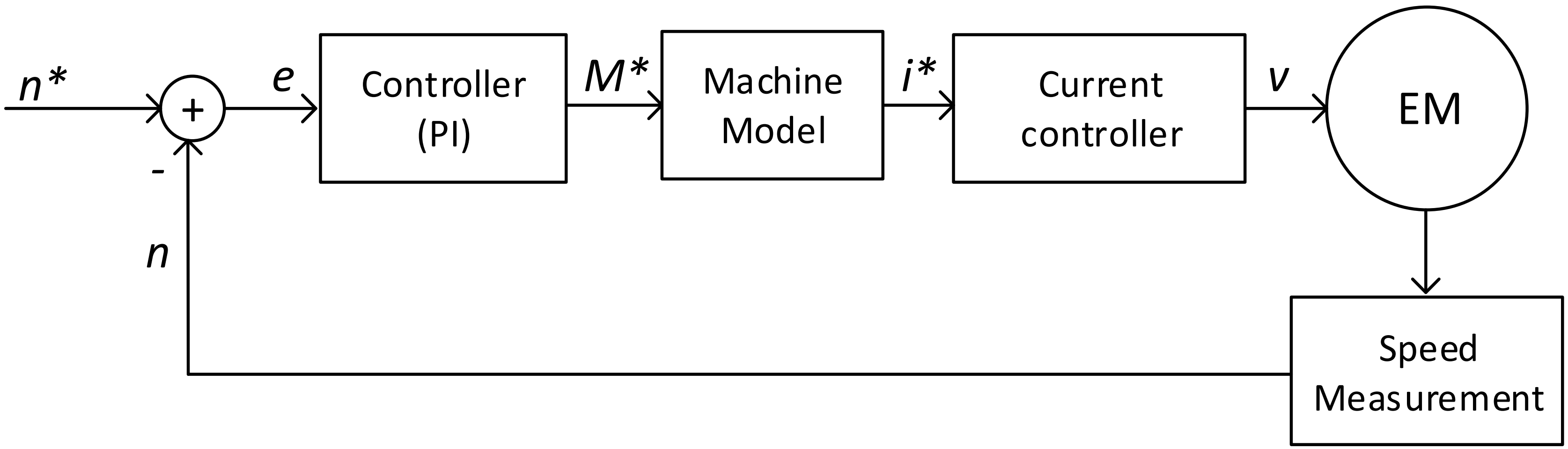
Single-phase hysteresis control example

Basic Control Loops

Speed Control

$$T = J\frac{d\omega}{dt} + T_{load}$$

We can control speed by regulating torque!

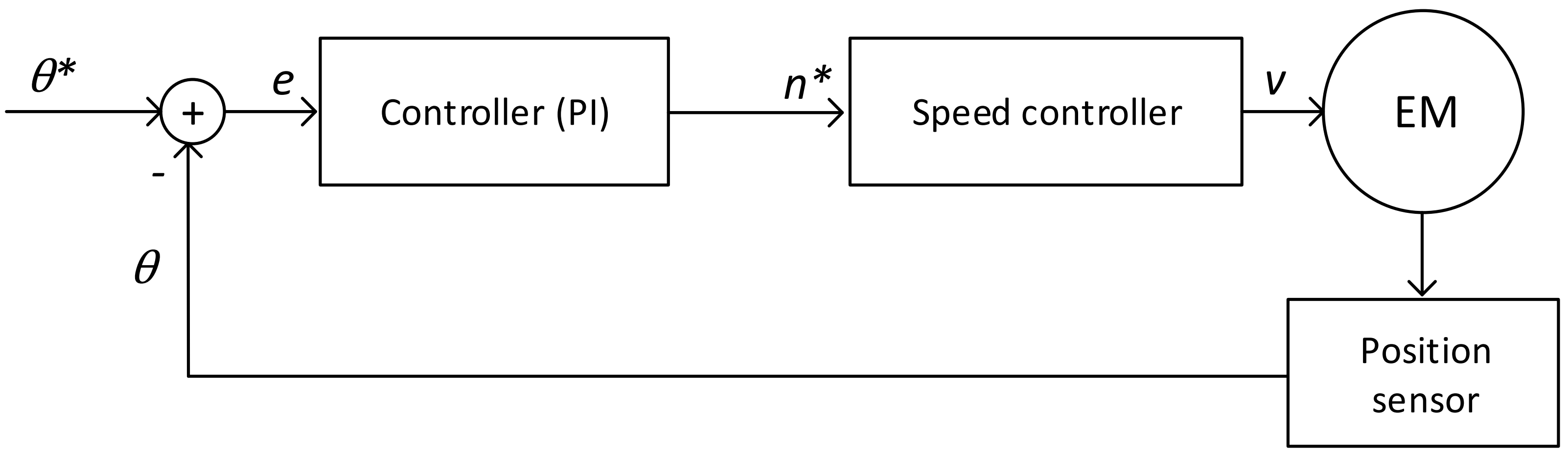


Block diagram of a speed controller with a cascaded current controller

Basic Control Loops

Position Control

$$\frac{n}{60}2\pi = \frac{d\theta}{dt}$$



Block diagram of a position controller