EE-362 ELECTROMECHANICAL ENERGY CONVERSION-II

Starting Methods and Operating Modes of Induction Machines

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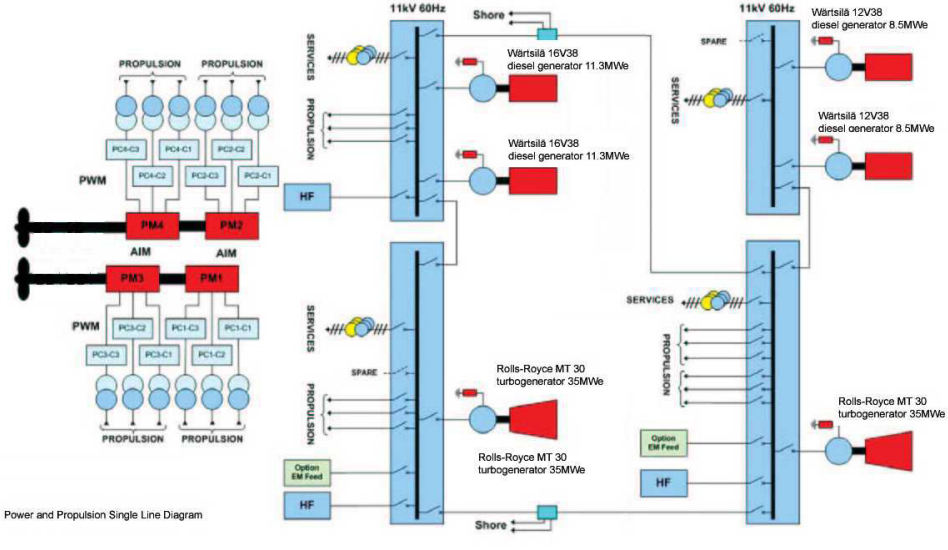
Induction Motors

20 MW Induction Motor for HMS Queen Elizabeth

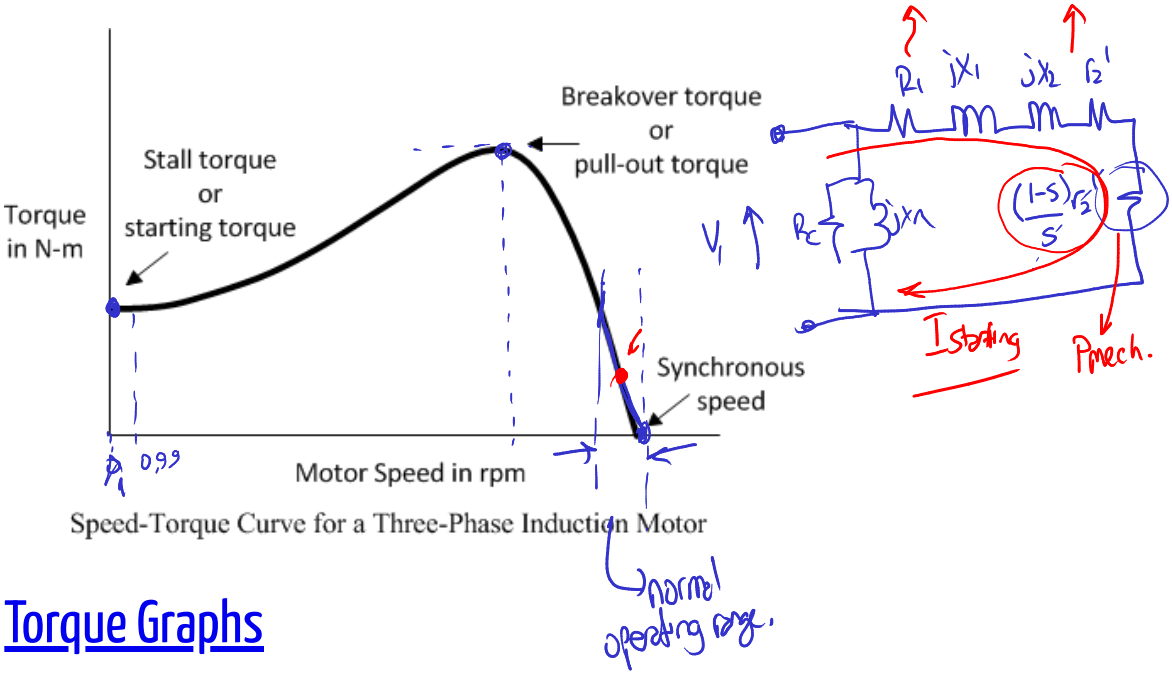
Induction Motors



Power and Propulsion Single Line Diagram

Single Line Diagram of HMS Queen Elizabeth Power System

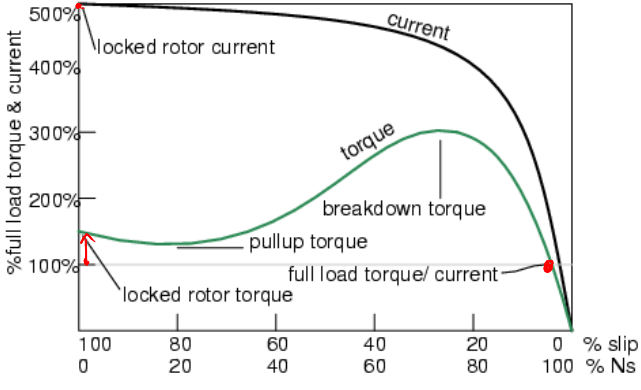
Typical Torque Curve of an Induction Motor



Torque Graphs

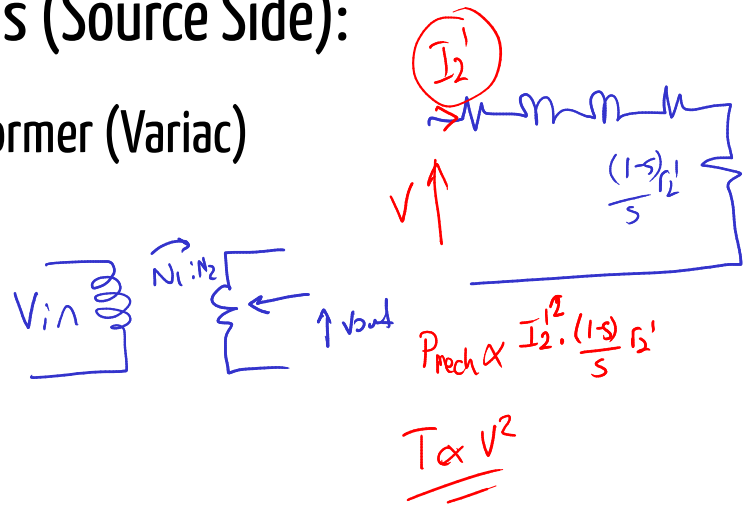
What is wrong with directly connecting motor to a constant voltage supply (i.e. grid)?

- High Start-up Current ✓
- Low(or high) Torque at Start-up ✓



Starting Methods (Source Side):

1- Use Auto-transformer (Variac)

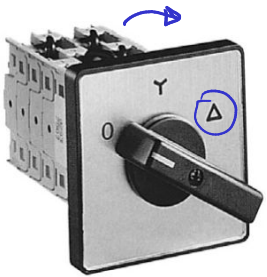


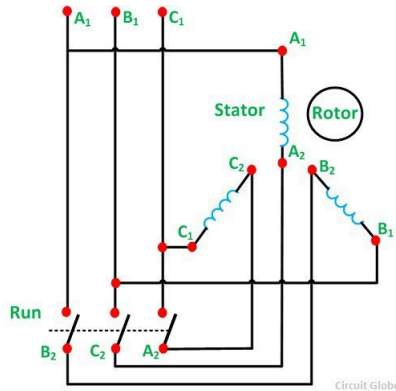
Apply a smaller voltage during start-up, and increase it gradually.

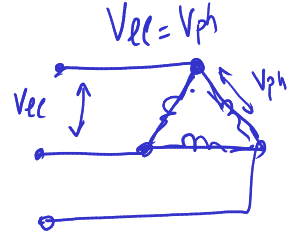
Remember: Torque $\propto V^2$

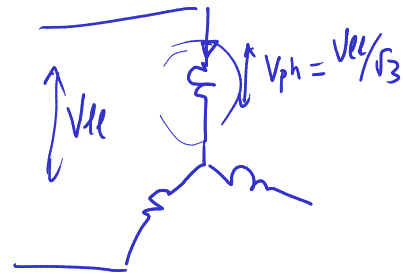
Starting Methods (Source Side):

2- Use ($Y - \Delta$) switch





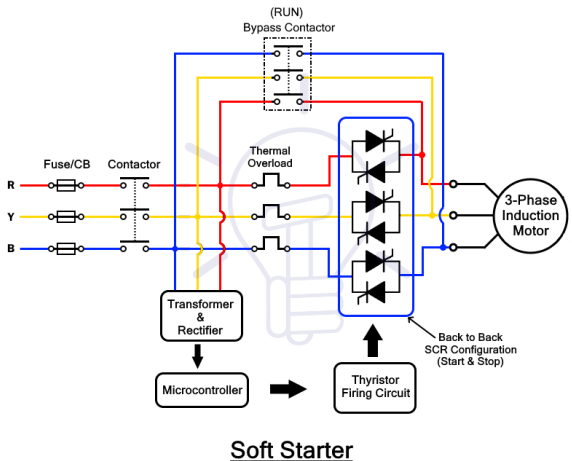




	Normal operation (Δ)	Y connection (During startup)
Phase voltage	Vll	Vll/√3
Phase Current	I_Δ	$I_\Delta/\sqrt{3}$
Starting Torque	T_Δ	$T_\Delta/3$

Starting Methods (Source Side):

3- Soft Starters

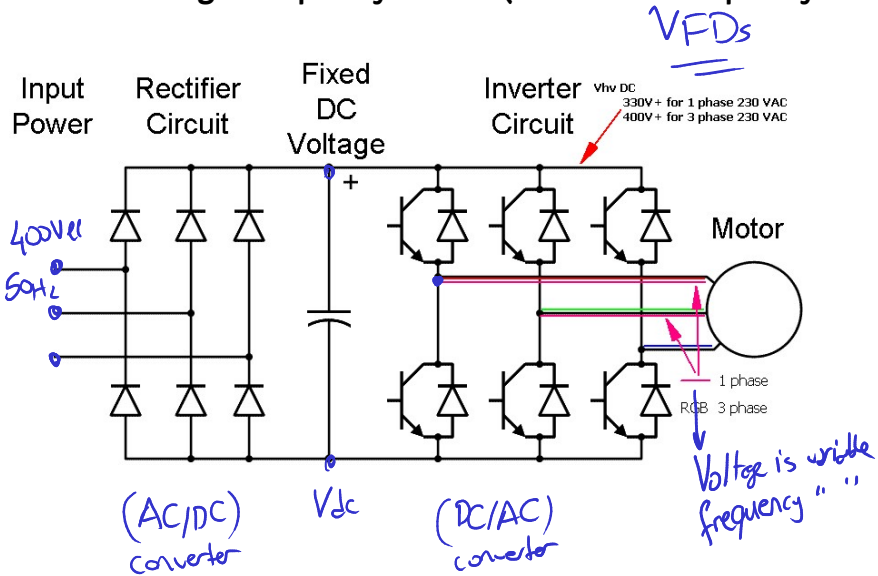


Soft Starters, Soft starter vs Motor Drive

Starting Methods (Source Side):

4- Induction Motor Drives

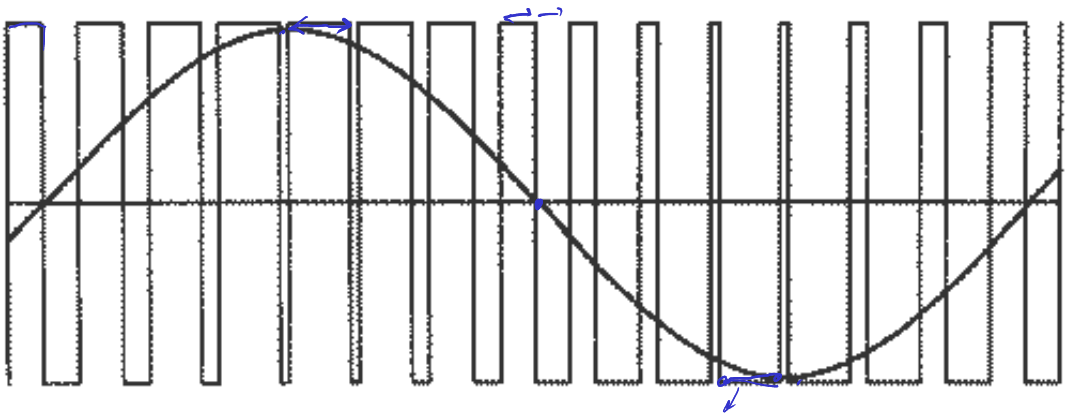
Variable Voltage-Frequency Source (or Variable Frequency Drives)



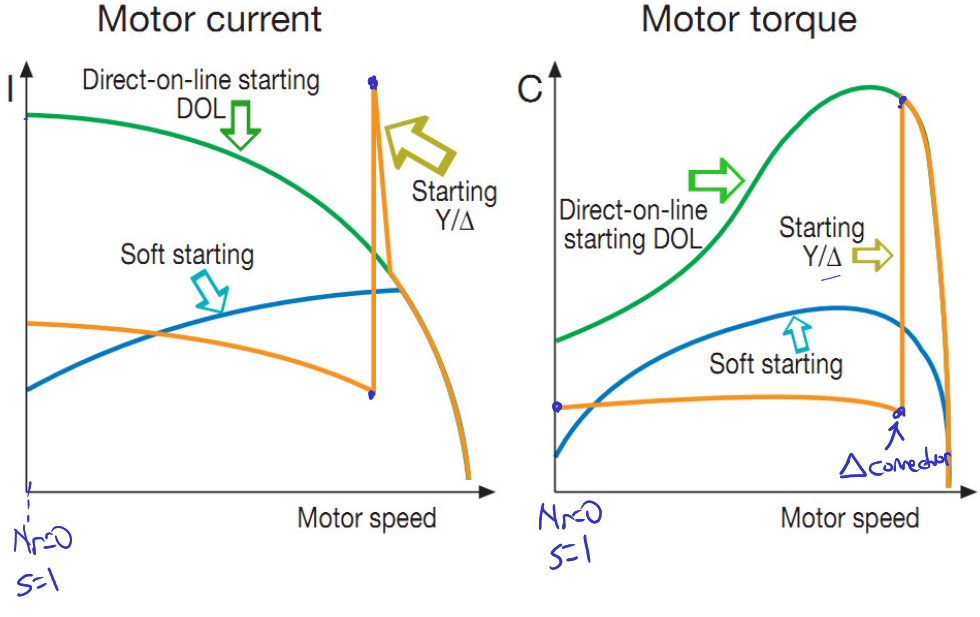
Starting Methods (Source Side):

4- Induction Motor Drives

Variable Voltage-Frequency Source (or Variable Frequency Drives)

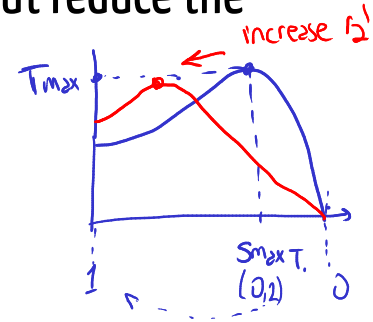


Starting Methods Comparison:



Starting Methods (Machine Side):

How to increase the starting torque, but reduce the starting current at the same time?

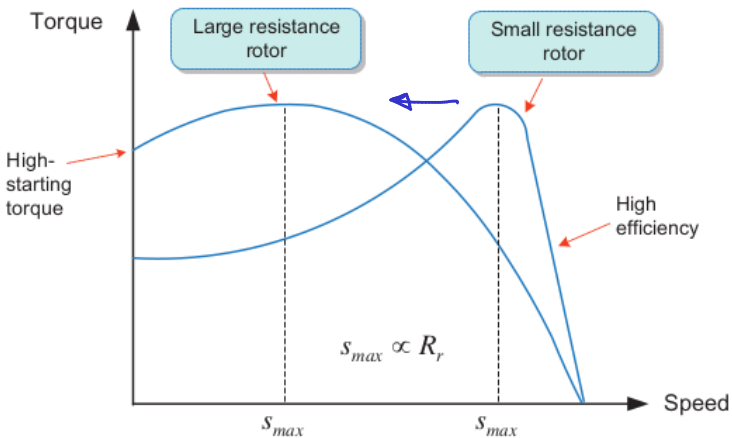


$$s_{maxT} = \frac{r_2'}{\sqrt{R_1^2 + (X_1 + X_2')^2}}$$

$$T_{max} = 3\frac{0.5V^2}{\omega_s}\frac{1}{(R_1 + \sqrt{R_1^2 + (X_1 + X_2')^2}}$$

Starting Methods (Machine Side):

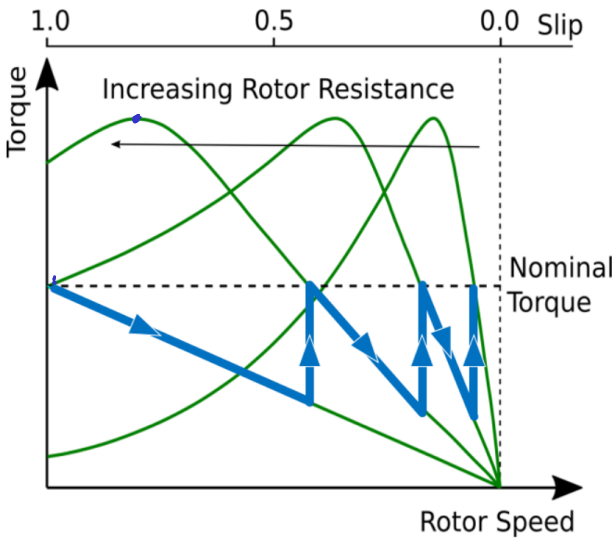
Increase rotor resistance (r_2')



[Torque Graphs]

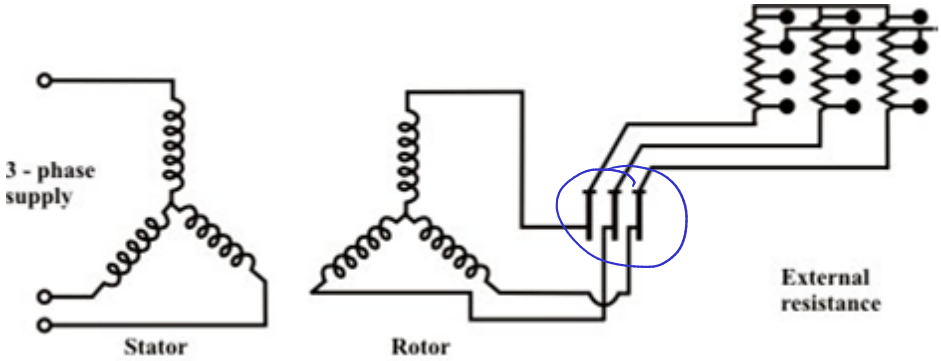
Starting Methods (Machine Side):

Increase rotor resistance (r_2')



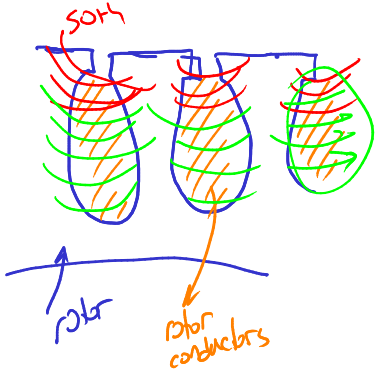
How to modify (r_2')?

1 - Add External Resistor: Easy for wound rotor induction motors by using external resistance



How to modify (r_2') for squirrel cage motors?

2 - Use Deep Rotor Bars: Utilize rotor resistance change with skin effect



$N_r = 0$

$f_s = 50Hz$

Rotor bar currents $\Rightarrow$ 50Hz current

$N_r = 900rpm$

$N_s = 1000rpm$

$s = 0,1$

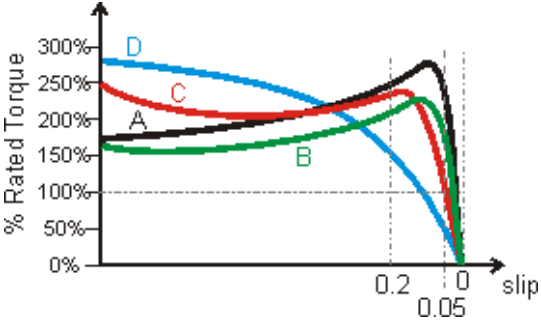
$f_s = 50Hz$

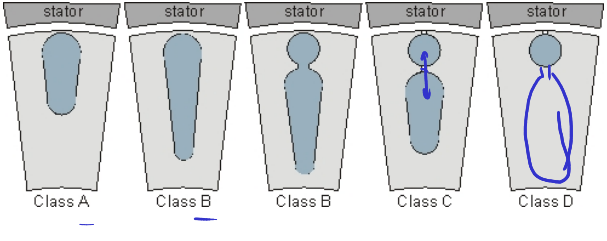
Rotor bar currents $\Rightarrow$ 5Hz

How to modify (r_2') for squirrel cage motors?

2 - Use Deep Rotor Bars: Utilize rotor resistance change with skin effect

Rotor Bar Shapes

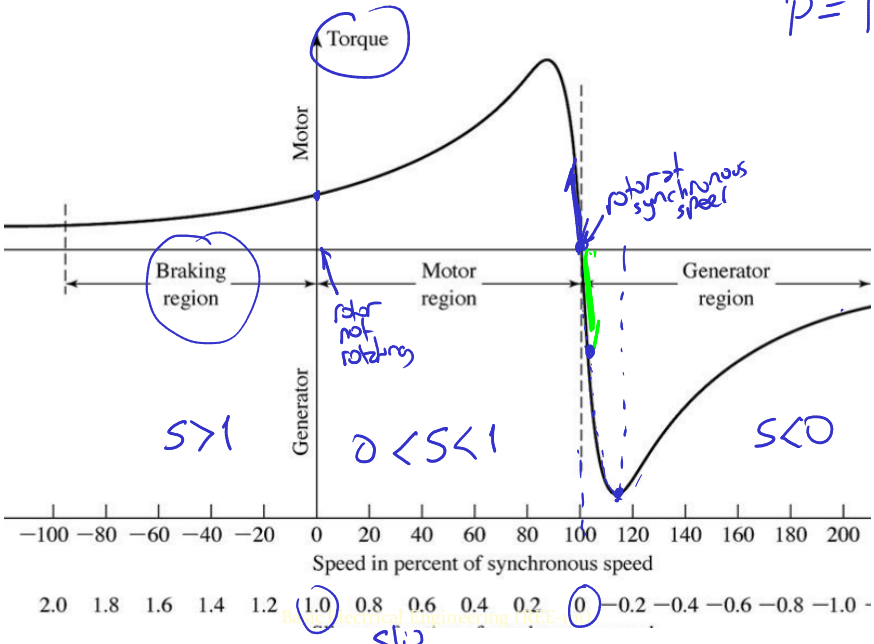




For curious students: Rotor design, Motor design classes

Complete Torque Characteristics

Can slip be larger than 1, or can it be less than 0?



Operation Modes of Induction Motors

1- Motoring

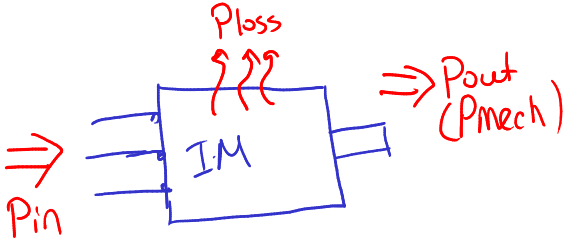
2- Generating

3- Braking

Motoring

Power Flow: Electrical to Mechanical

Slip: $0 < s < 1$ $0 < N_r < N_s$

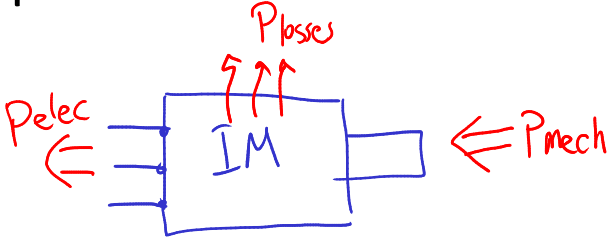


Generating

Power Flow: Mechanical to Electrical

Slip: $s < 0$

$N_r > N_s$ $P = T\omega$



Braking (Plugging)

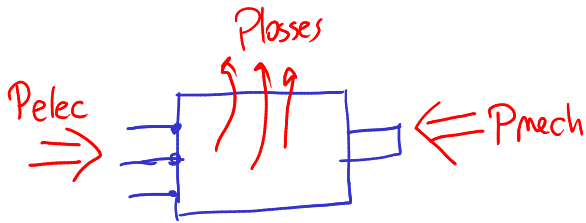
Power Flow: Mechanical+Electrical to Heat

Slip: $s > 1$

$N < 0$

$P = T \cdot \omega$

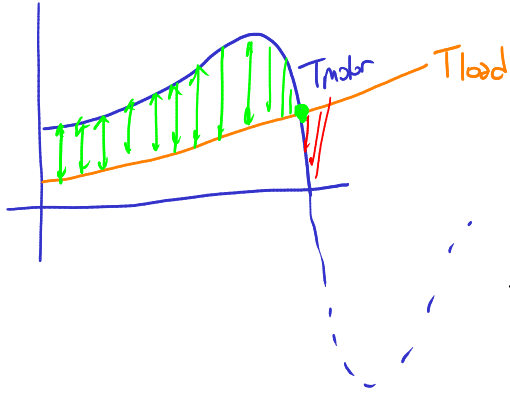
(+) (−)



Machine Dynamics

Torque Balance Equation

$$T_{elec} - T_{load} - T_{friction} = J\frac{d\omega}{dt}$$



$0 = J\frac{d\omega}{dt}$

$\frac{d\omega}{dt} = 0 \Rightarrow$ Speed is constant

Four-Quadrant Operation