EE-362 ELECTROMECHANICAL ENERGY CONVERSION-II

Speed Control Techniques for Induction Machines

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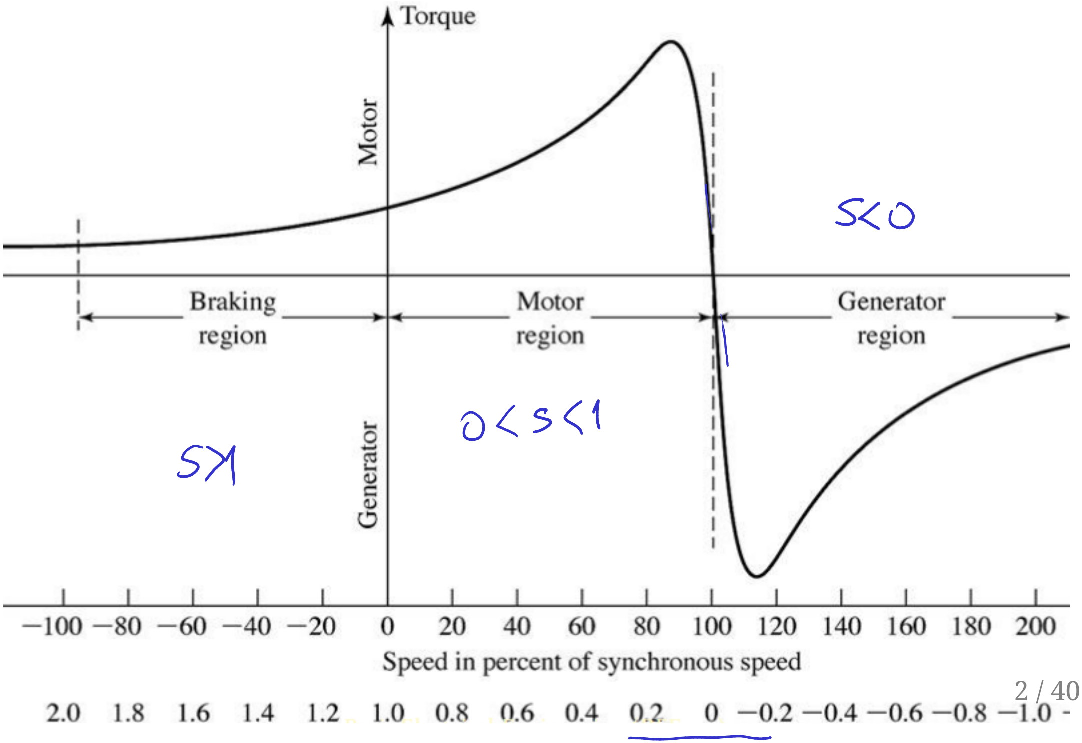
Full Operating Range of Induction Machines



Operation Modes of Induction Motors

1- Motoring

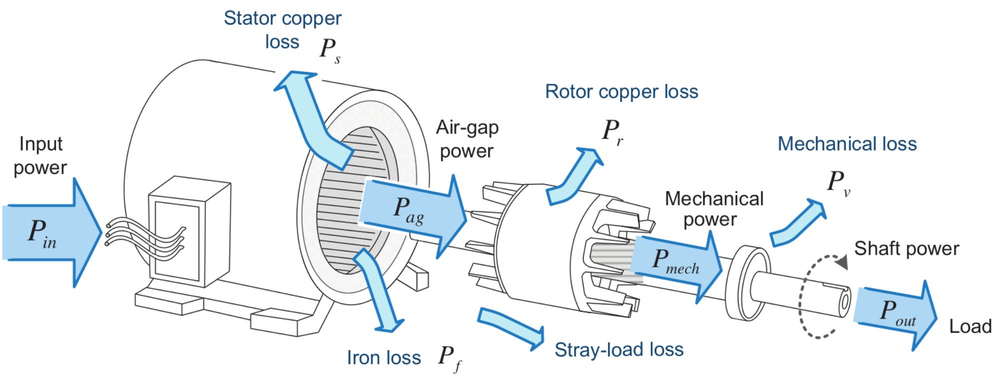
2- Generating

3- Braking (Plugging)

Motoring

Slip: $0 < s < 1$

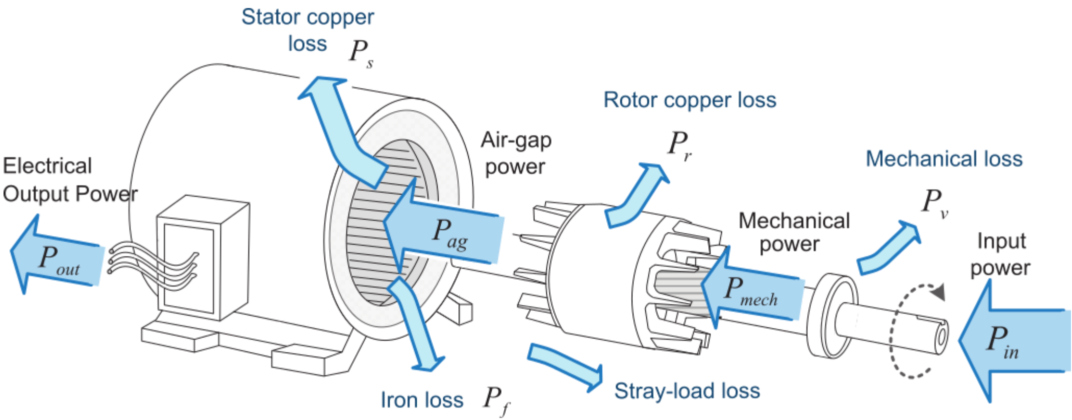
Power Flow: Electrical to Mechanical



Generating

Slip: $s < 0$

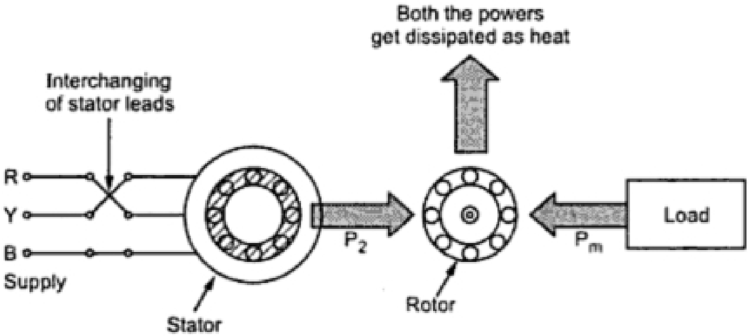
Power Flow: Mechanical to Electrical



Braking (Plugging)

Slip: $s > 1$

Power Flow: Mechanical+Electrical to Heat



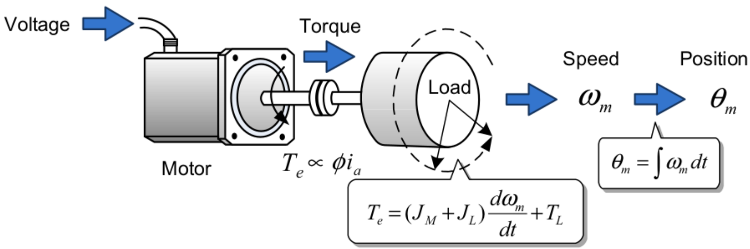
Plugging obtained by interchanging two stator phases

Machine Dynamics

Torque Balance Equation

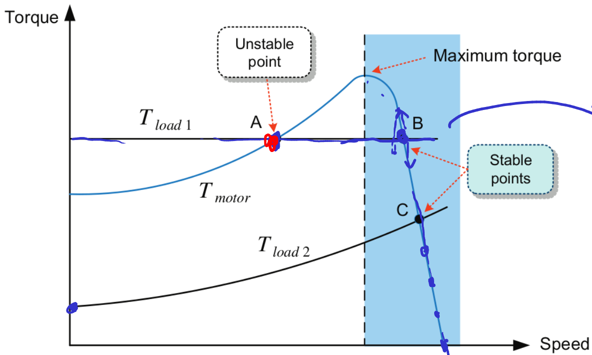
$$T_{elec} - T_{load} = J\frac{d\omega}{dt}$$

$$F = m\frac{dv}{dt}$$



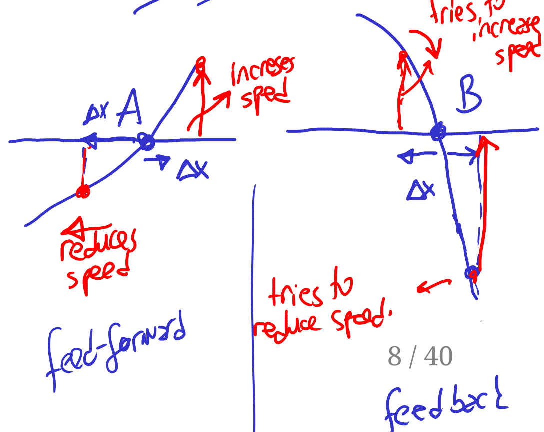
If there is no difference between the electrical torque and load torque, the machine operates at the steady-state

(i.e. the intersection point at between the motor torque line and the load torque line).



from C to B
↳ $T_{load} > T_{elec} \Rightarrow \frac{d\omega}{dt} < 0$

B ⇒ $T_{load} = T_{elec}$



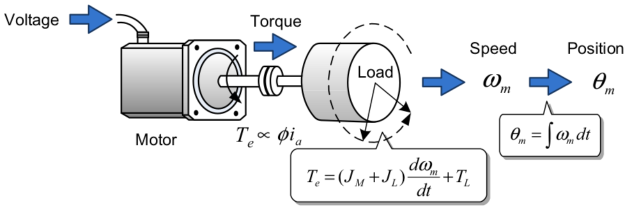
but beware of unstable intersection points.

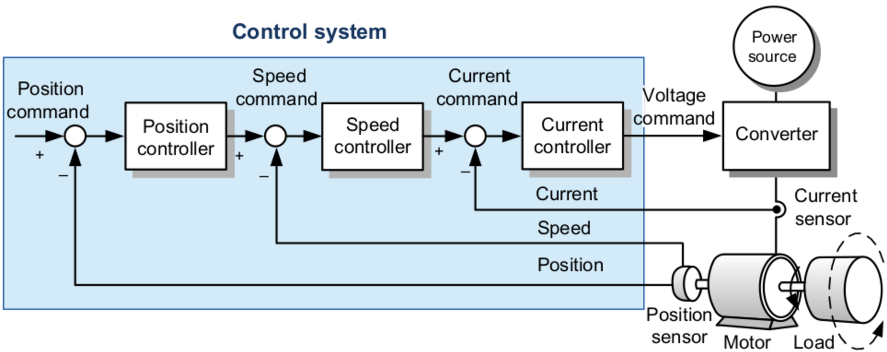
Speed Control Problems

- Load constant, speed reference is changed
- You want the speed constant, but load torque is varying
- Both speed reference and load variable

We need to modify machine characteristic

Closed Loop Control of an Electrical Machine

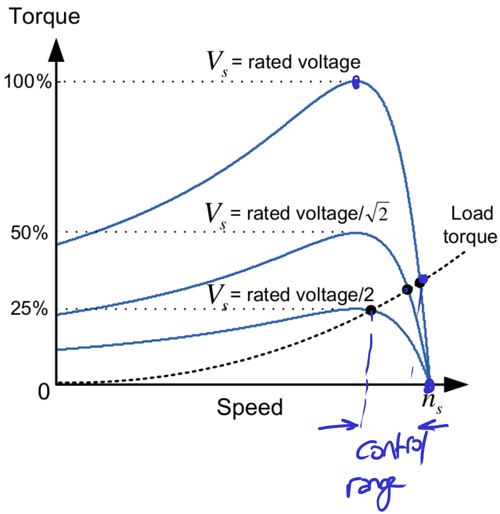




Speed Control Methods

Variable Voltage Control: $T_e \propto V^2$

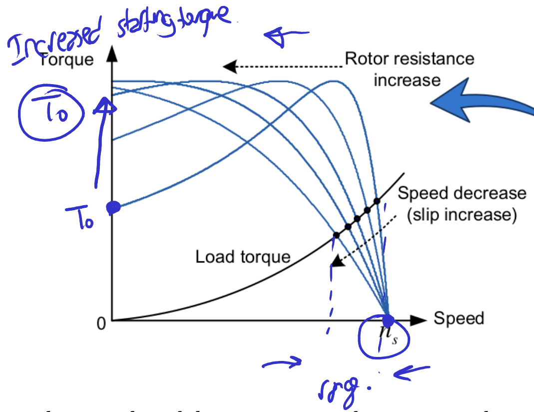
Control is limited to a small range as Ns is constant

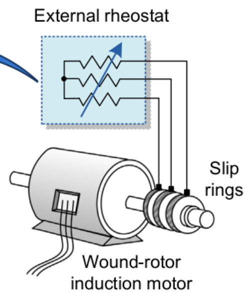


Speed Control Methods

Rotor Resistance Control:

Not very efficient, but can create a large startup torque



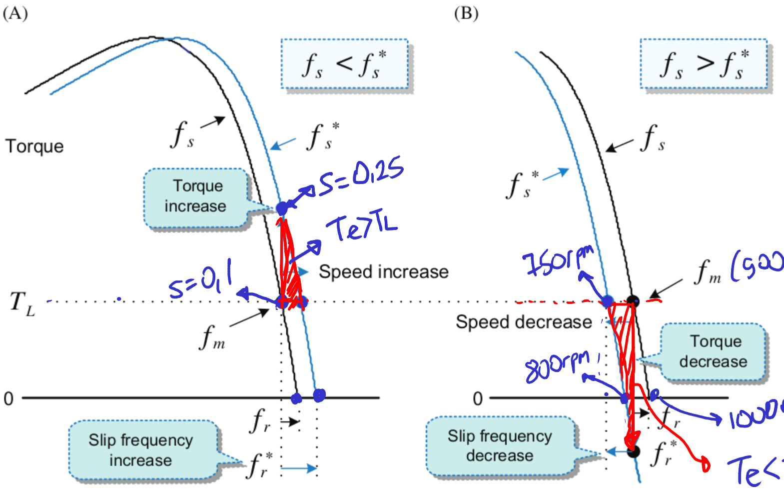


Only applicable to wound rotor induction machines

Speed Control Methods

Variable Stator Voltage Frequency

What happens if we change the synchronous speed by changing the stator voltage frequency?



s=0,125
Te>TL
s=0,1
750rpm
800rpm
fm (900rpm)
1000rpm
Te<TL
dw/dt<0

increasing speed

decreasing speed.

a) Initially Ns=1000rpm (50Hz)
Nr=900rpm
↳ Ns=1200rpm (60Hz)
Nr=900rpm

b) Initially
s=0,1 (Nr=900rpm) Ns=1000rpm)
↓
Ns=800rpm
Nr=900rpm
↳ s=-0,125

Linear Approximation of Torque

Accurate torque expression

Valid for all values of slip

$$T_e = \frac{3V_{th}^2}{(R_{th} + \frac{r_2'}{s})^2 + (X_{th} + X_2')^2} \frac{r_2'}{s\omega_s}$$

However, under steady-state conditions, slip is usually very small (<5%)

Linear Approximation of Torque

$$s < 0.05$$

$$\frac{r_2'}{s} >> R_{th}, X_{th}, X_2'$$

Torque equation becomes

$$T_e \approx \frac{3V_{th}^2 s}{r_2' \omega_s}$$

k

Linear Approximation of Torque

$$T_e \approx \frac{3V_{th}^2 s}{r_2' \omega_s}$$

$$T_e \approx ks$$

(only valid for small values of s)

Variable Stator Voltage Frequency

What happens if we reduce f, with constant V?

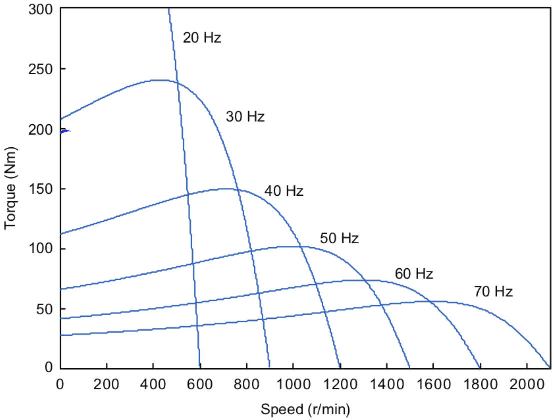
$$E = 4.44 f_s N_s \Phi$$

$E = N \cdot \frac{d\phi}{dt}$

Motor core starts saturating which is not desirable!

Variable Stator Voltage Frequency

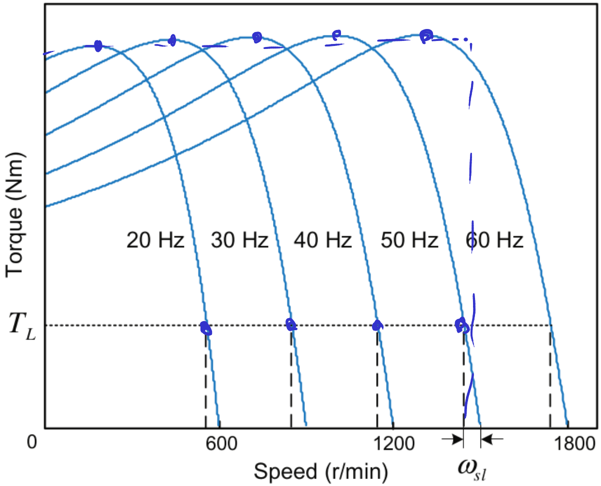
Alternatively, if the frequency is increased by keeping the voltage constant, motor cannot produce enough torque.



Reduction of torque under constant voltage with increasing frequency

Constant V/f Operation (or Constant Flux)

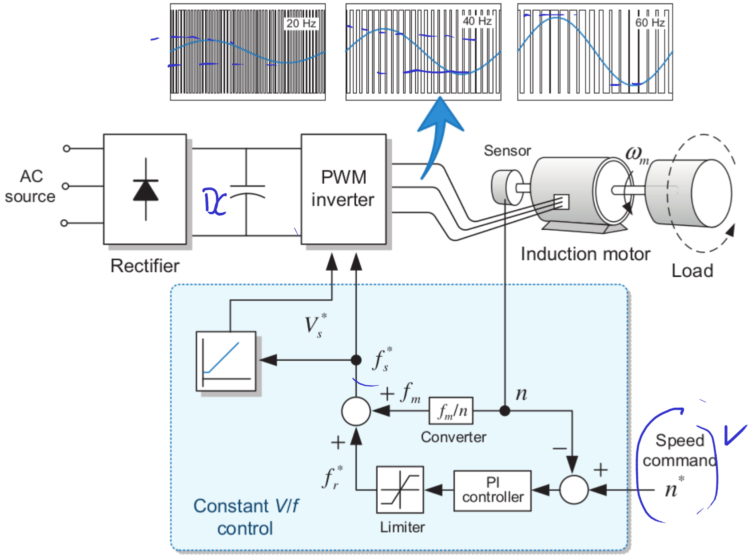
Change the voltage with stator frequency to keep the flux constant



Stator voltage is varied with frequency to eliminate torque reduction

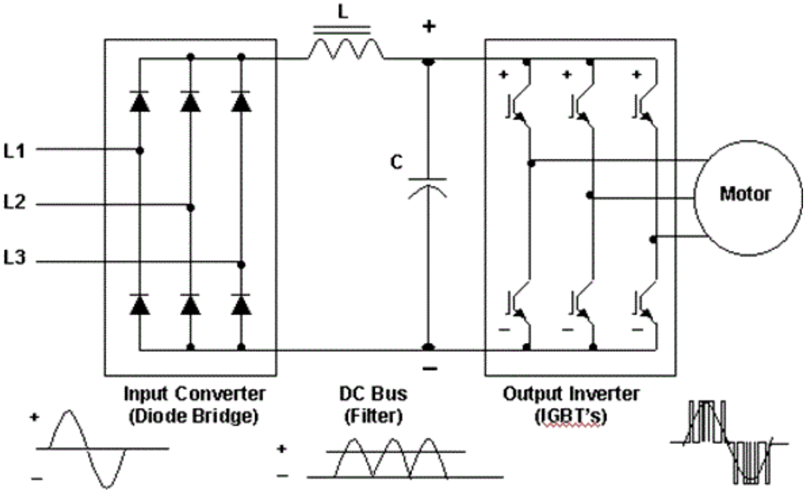
Constant V/f Operation (or Constant Flux)

Use a Variable Voltage-Frequency Drive (VFD)



Constant V/f Operation (or Constant Flux)

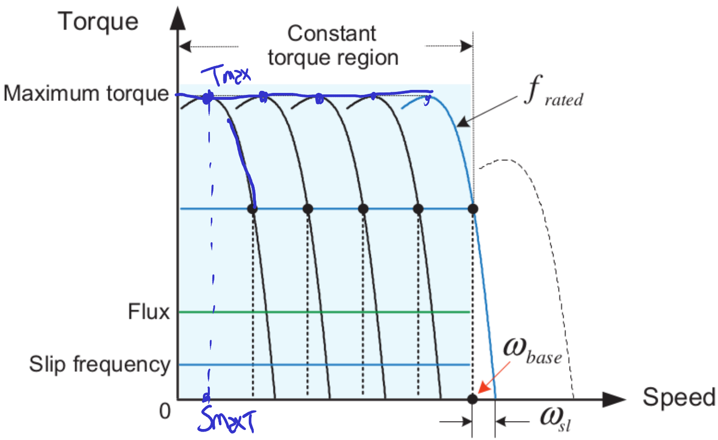
Use a Variable Voltage-Frequency Drive (VFD)



For curious students: [Variable Frequency Drive](), [What is VFD?](), [Basics of the Inverter](), [How Inverters Work?]()

Constant V/f Operation (or Constant Flux)

Constant torque can be achieved during acceleration



If we set the slip to the point where max torque is produced (s_{max-T}), the machine can be accelerated quickly.

[Tesla Insane Mode](), [Tesla Insane Mode- Slow Motion](), [Tesla Model S P100D](),
[Tesla Model S Plaid]()

EVBite.com

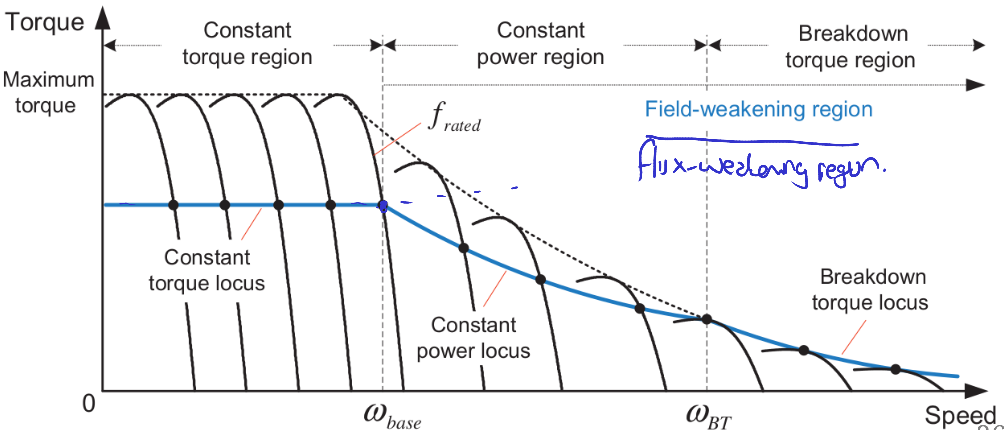
	Tesla Model S Plaid	Lucid Air Grand Touring	Porsche Taycan Turbo S
	196" L x 77" W x 57" H	TBD	195" L x 77" W x 54" H
0-60 MPH	< 2 s	3 s	2.6 s
Top Speed	200 mph	168 mph	161 mph
Range	520+ mi	517 mi	192 mi
Battery	TBD	113 kWh	93.4 kWh
Power	1,100 hp	800 hp	750 hp
Cargo Space	28 cu ft	26 cu ft	16 cu ft
Seats	5	5	5
Charging	TBD	300+ kWh	270 kWh
MSRP	$139,990	$139,000	$185,000

[Tesla Insane Mode](), [Tesla Insane Mode- Slow Motion](), [Tesla Model S P100D](), [Tesla Model S Plaid]()

Flux Weakening Range

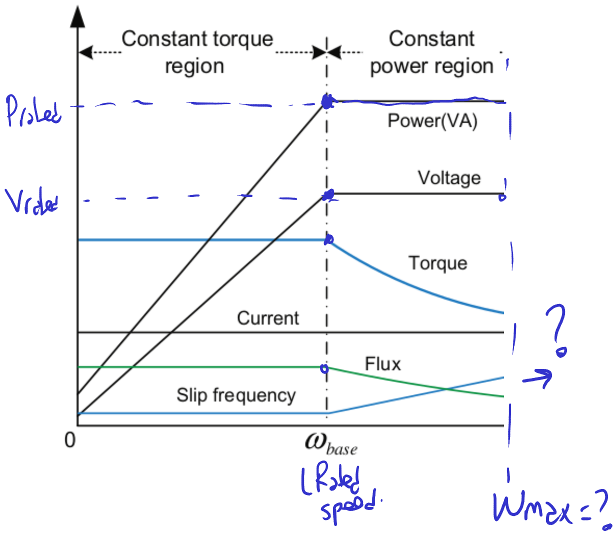
Voltage cannot be increased beyond the rated voltage

If the torque is kept constant at high speeds, power limit will be exceeded.



Flux Weakening Range

Operation of an induction machine is determined by: phase voltage, magnetic flux, phase current, cooling capability, mechanical constraints



$P = T \cdot \omega$

↑ ↑

constant V/f

$\omega \propto f \propto V$

$P = T\omega$

↓ ↑