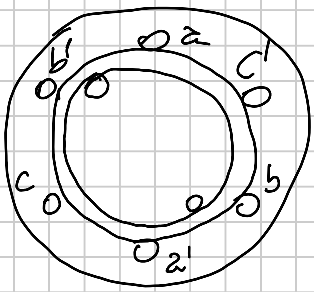
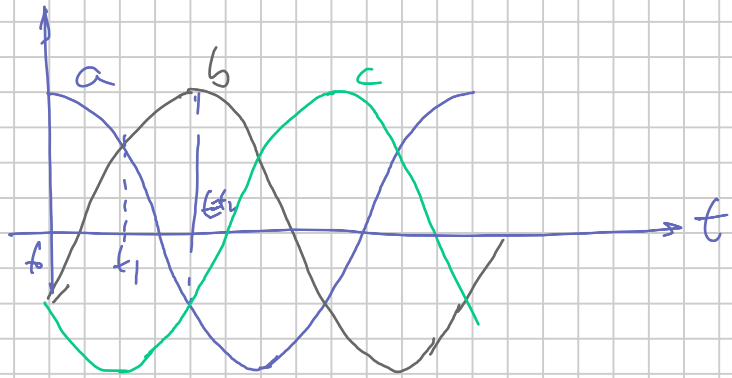
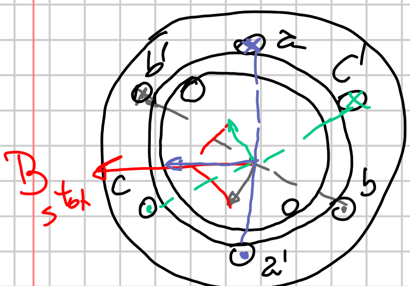
Control of induction machines

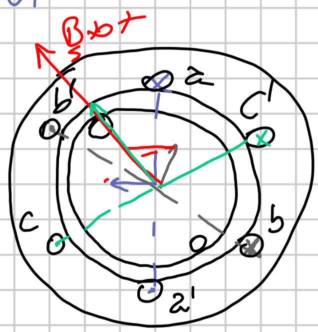
Note Title 11/19/2007

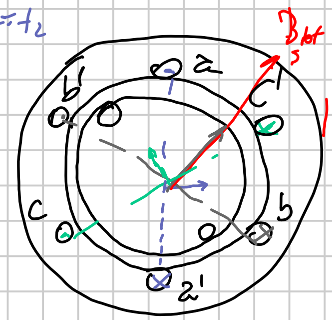




$t = t_0$ $t = t_1$ $t = t_2$







The 3-phase stator system creates a rotating field $\rightarrow \frac{d\vec{B}_s}{dt} \neq \vec{0}$

Rotor windings are under the action of a $\frac{d\vec{B}_s}{dt} \neq \vec{0}$

$\rightarrow$ They have area

$$V_r = \frac{d\lambda_r}{dt} \neq 0$$

Notice that

$|\vec{B}| = \text{constant}$

$\Downarrow$

what changes is the direction

Hence,

stator:

$$\begin{cases} v_{as} = r_s\, i_{as} + \dfrac{d\lambda_{as}}{dt} \\ v_{bs} = r_s\, i_{bs} + \dfrac{d\lambda_{bs}}{dt} \\ v_{cs} = r_s\, i_{cs} + \dfrac{d\lambda_{cs}}{dt} \end{cases}$$

Stator rotating $\vec{B}_s$

Rotor:

$$\begin{cases} v_{ar} = r_r\, i_{ar} + \dfrac{d\lambda_{ar}}{dt} \\ v_{br} = r_r\, i_{br} + \dfrac{d\lambda_{br}}{dt} \\ v_{cr} = r_r\, i_{cr} + \dfrac{d\lambda_{cr}}{dt} \end{cases}$$

Rotor rotating $\vec{B}_r$

I can reduce rotor "windings" to a 3 phase system

It is like having 2 magnets ⟹ the stator "magnet" tries to drag the rotor "magnet"

$$J\frac{d\omega}{dt} = T_e - T_{Load}$$

If the rotor rotates at the same speed than the stator $\vec{B}_s$

then $\left.\dfrac{d\vec{B}_s}{dt}\right|_{rotor} = \vec{0}$ and $v_r = 0$ so $\vec{B}_r = \vec{0}$

$\left.\dfrac{d\vec{B}_s}{dt}\right|_{rotor}$ → as seen by the rotor

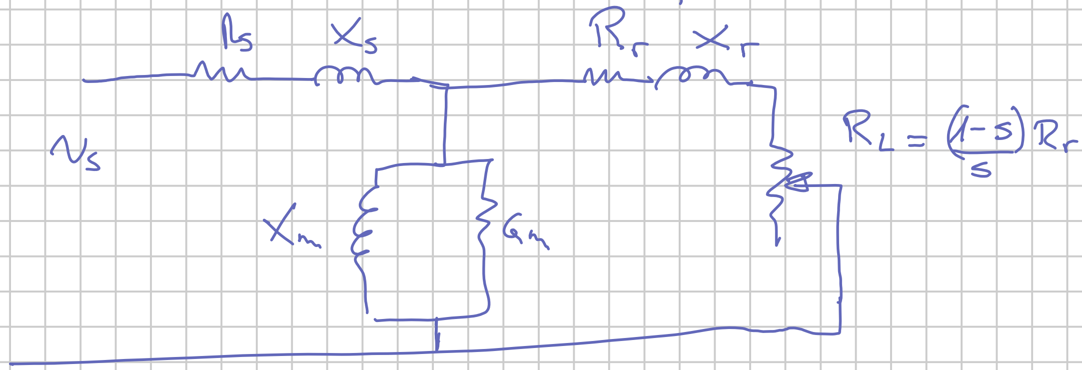
So, whenever the rotor "magnet" catchs up with $\vec{B}_s$, then $\vec{B}_r = \vec{0}$ so $\vec{B}_s$ can not drag $\vec{B}_r$ so the rotor losses speed

So $\left.\dfrac{d\vec{B}_s}{dt}\right|_{rotor} \neq \vec{0}$, so $\vec{B}_r \neq 0$ .....

↓

For this reason $\omega_r < \omega_s$

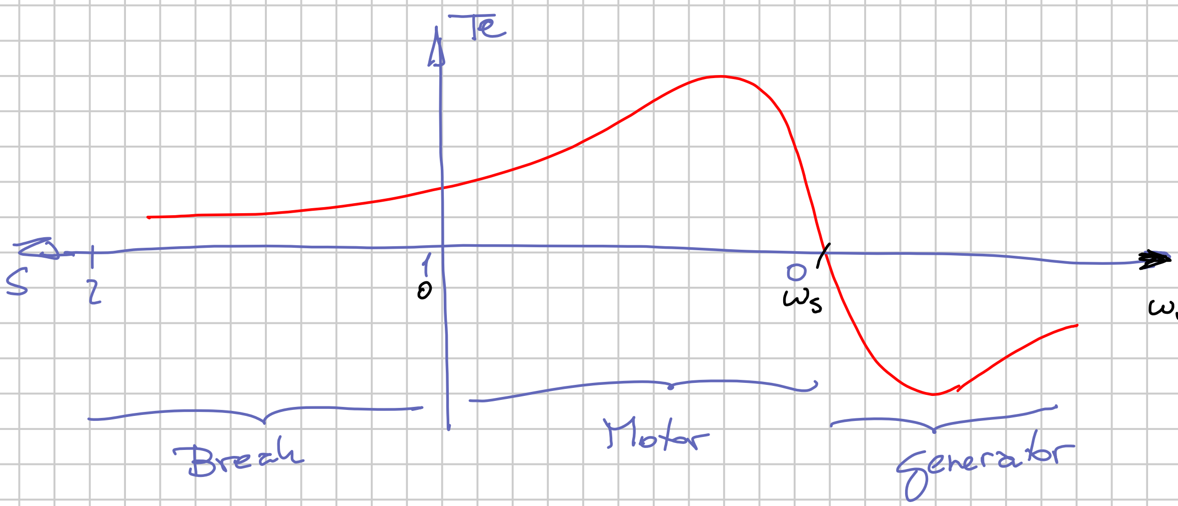
I can reduce the induction machine to the equivalent single-phase circuit



$$S = \frac{\omega_s - \omega_r}{\omega_s}$$ (everywhere I assume $p = 1$)

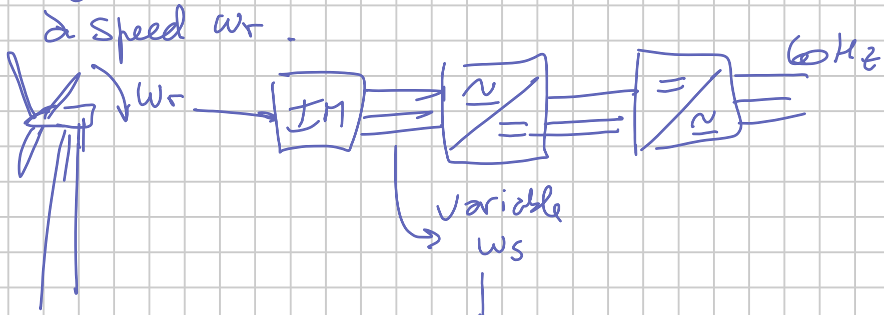
$$T_e = \frac{3 V_{s,rms}^2}{\omega_s} \frac{R_r / S}{\left[\left(R_s + \frac{R_r}{S}\right)^2 + (X_r + X_s)^2\right]}$$

$$P_{mec} = \omega_r T_e$$



- wind generator
- traction

In wind generator → The wind makes the machine to rotate at a speed ω_r.



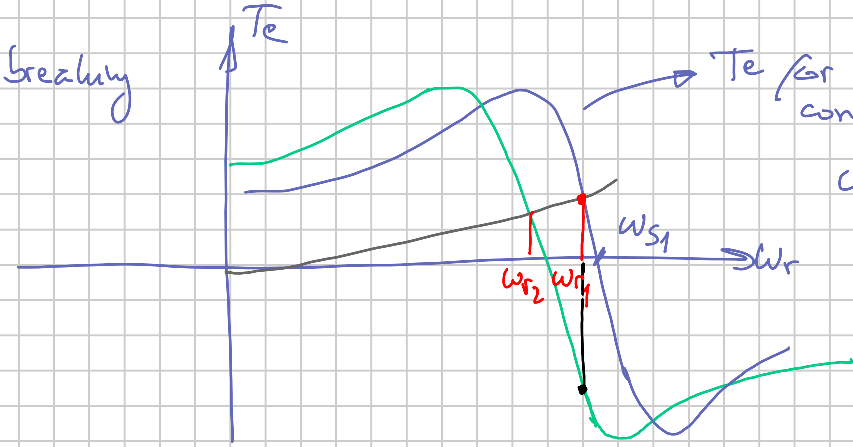
I set ω_s so $\omega_s < \omega_r$

Frequency of the voltage applied to the IM

Then the current flows "towards" the grid

↳ generator.

Regenerative breaking



To break: 1) I have $\omega_r(t=0^-) = \omega_{r_1}$

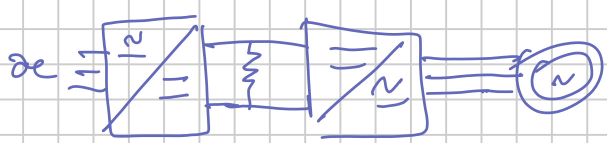
$\omega_s(t=0^-) = \omega_{s_1}$

2) In $t=0^+$, I chang $\omega_s(t=0^+) = \omega_{s_2}$

But $\omega_r(t=0^-) = \omega_r(t=0^+) = \omega_{s_1}$

3) Eventually, for $t=t_1$, ω_r reaches $\omega_r = \omega_{s_2}$

Brute force:



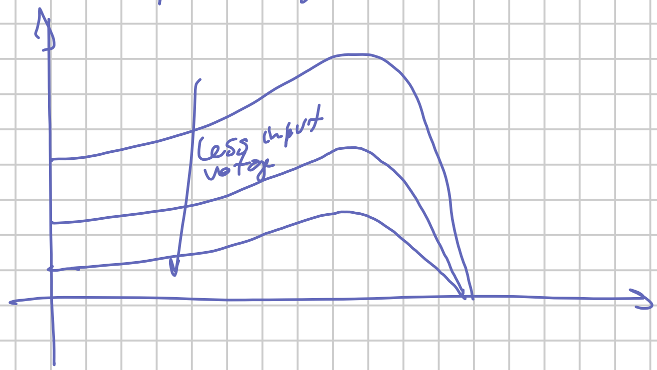
Efficient way → Hybrid Cars

Whatever is not used to charge batteris is lost in the wheel breaks.

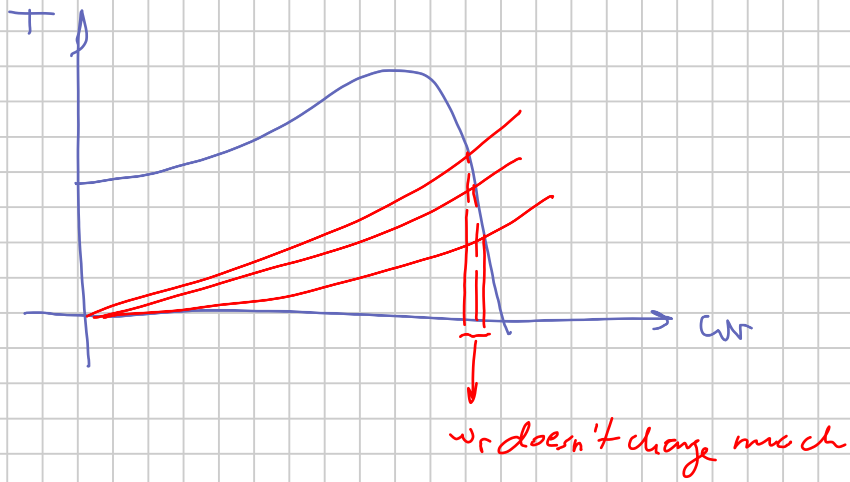
Maximum energy that can be transfered to the batteris is

$$U = \frac{J(\omega_{r_1}^2 - \omega_{r_2}^2)}{2}$$

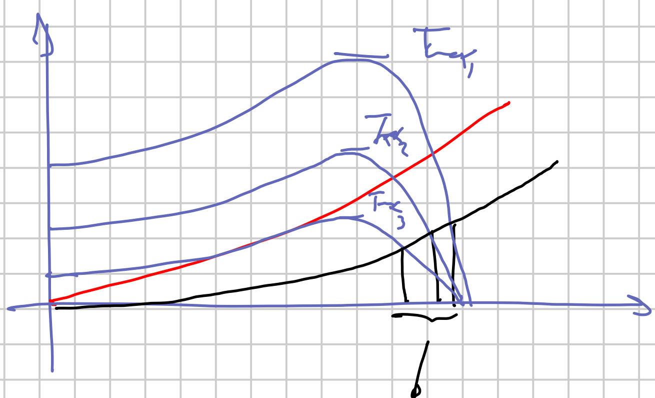
Change in Torque with input voltage :



Speed control



Bad idea → change input voltage



- Not much change either
- what is worse → Tmax decreases

So, for the bottom curve and the red load it won't work

Better idea:

From $T_e = \frac{3V_{s,rms}^2}{\omega_s} \frac{R_r/s}{\left[\left(R_s + \frac{R_r}{s}\right)^2 + (X_r + X_s)^2\right]}$

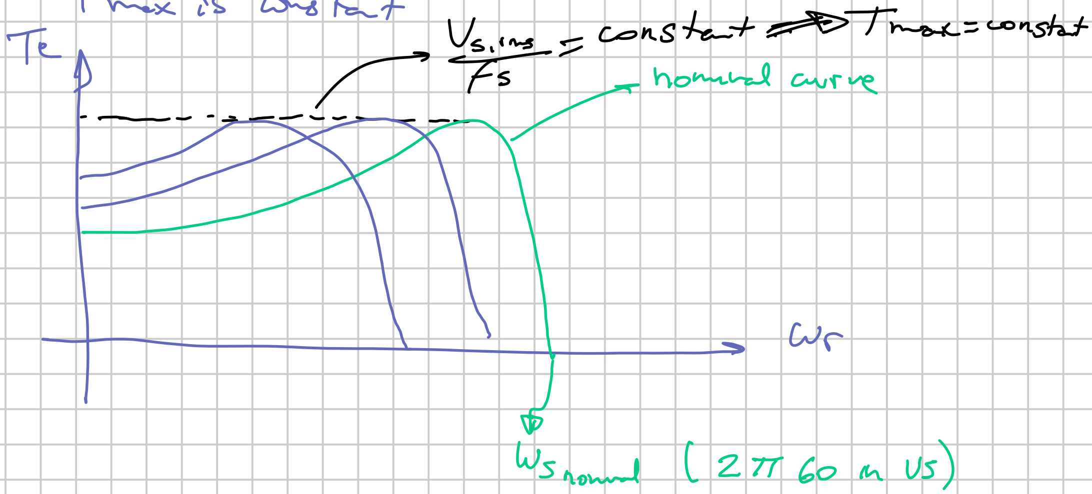
$$s_{T_{max}} \simeq \frac{R_r}{X_s + X_r}$$

$$T_{max} \simeq \frac{3 V_{s,rms} \; (X_r + X_s)}{\omega_s \left[(\underbrace{R_s + X_r + X_s}_{\simeq X_r + X_s})^2 + (X_r + X_s)^2\right]}$$

Hence $T_{max} \simeq \frac{3V_{s,rms}^2}{\omega_s (X_r + X_s)} = \frac{3 V_{s,rms}^2}{\omega_s^2 (L_r + L_s)}$

Hence, if $\frac{V_{s,rms}}{\omega_s}$ is constant (V/f is constant) the

T_{max} is constant



For $\omega_s > \omega_{sn}$ ⟶ Consider $T_e = \frac{P_n}{\omega_s}$ ⟶ maximum steady state power

Can be exceeded only for short periods of time.

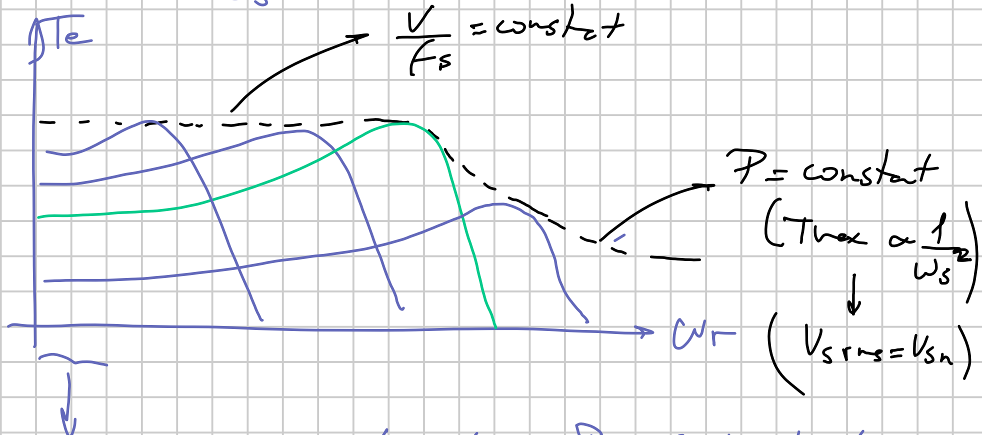
If T_{max} is kept constant and ω_r is increased the P should be increased again, going beyond P_n

Since P_n can not be exceeded then when w_r is increased T_{max} is decreased so P doesn't exceed P_n

Since $T_{max} \propto \frac{V_{s\,rms}^2}{\omega_s^2}$ and $\omega_r \simeq \omega_s$

and $P \simeq \frac{V_{s\,rms}^2}{R_L} \longrightarrow$ If $P = \text{constant} \Rightarrow V_{rms} = \text{constant}$

then $T_{max} \propto \frac{1}{\omega_s^2}$ then:



We assumed that $X_r + X_s \gg R_s$ but that is not true for low frequencies. then