Induction Motor Basics

Tuesday, October 22, 2019 5:40 PM

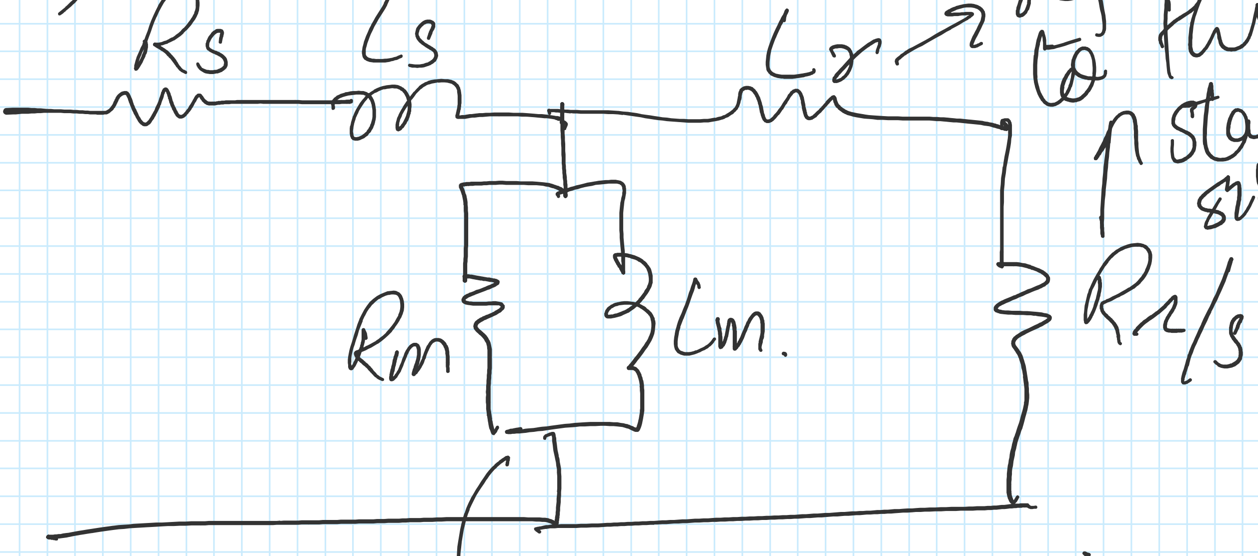
→ 3phase induction motor

→ Basics of Induction Motor

→ After that control will be studied.

→ Basics from the undergrad course

→ Equivalent cct is similar to transformer

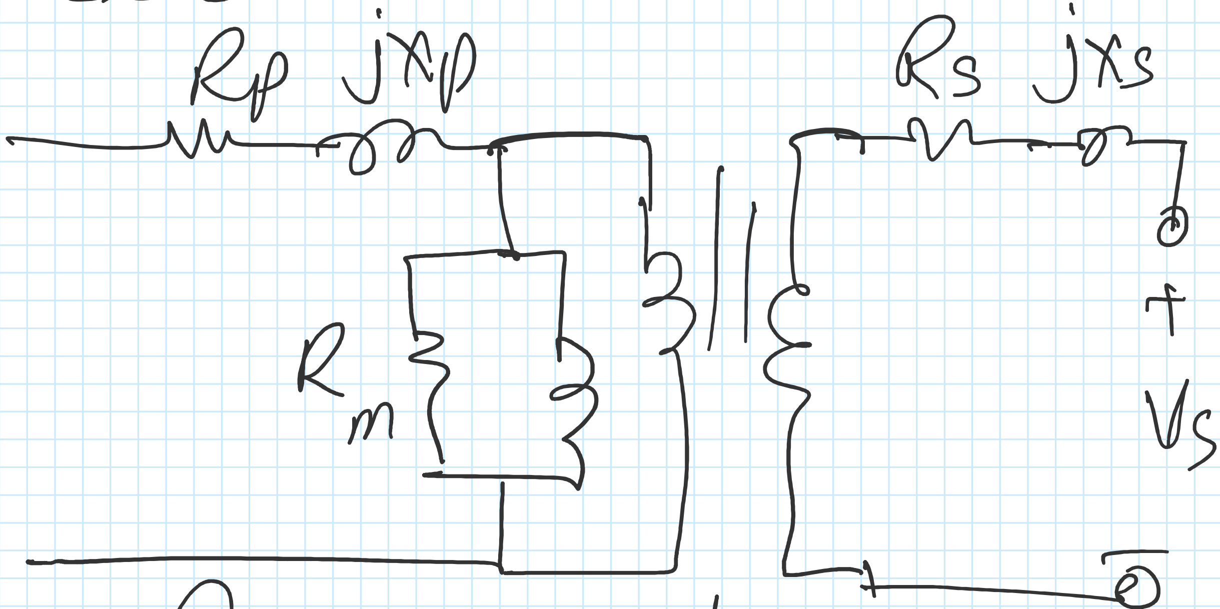
→


referred to the stator side.

→ Magnetizing

↳ Magnetizing branch

→ Transformer Equivalent ckt



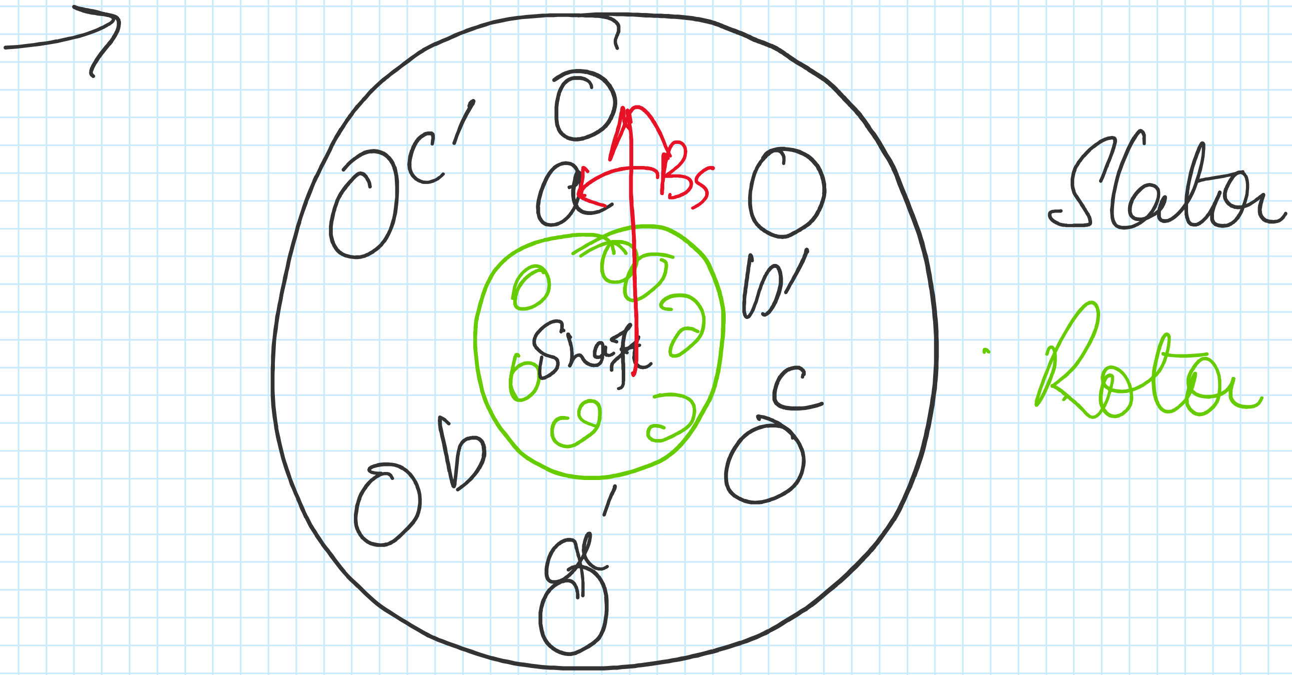
Primary side

ideal Trm

Secondary side

→ No frequency change in the trm as no relative motion b/w primary and secondary

primary and secondary.
But in case of motor
(basically it is a
transformer)

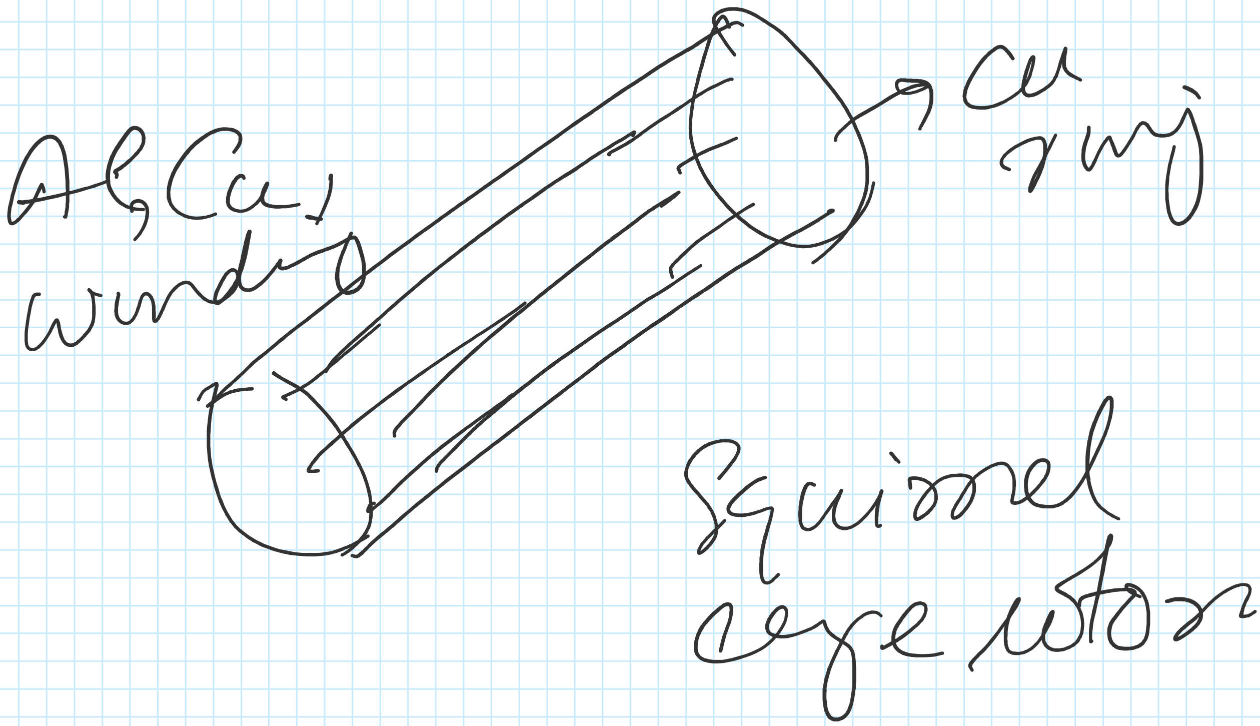


Three phase winding
produce a rotating
magnetic field of

$$N_s = \frac{120 f_e}{P} \text{ (rpm)}$$

It is not the physical speed. It is the speed of rotating magnetic field. This rotating field produces/ induces an emf in the rotor which is a short circuited metallic bar (squirrel cage rotor). The current of rotor has its own magnetic field which

magnetic field will
will try to chase the
stator magnetic field
i.e try to cancel its
cause according to
the lenz law. So, the
poles of induction
motor are rotating
~~according to~~ from
a static frame of reference
The chasing phenomena
of the rotor produces
the concept of slip



The rotor will not be able to allign itself to the stator. This is because of the fact that the power transferred to rotor is not equal to that of stator due to losses. If, for the

Sake of argument,
rotor aligns itself to
the stator, no relative
motion will be there
and no emf is induced,
So, rotor lags behind,
So, Relative motion
starts again. Hence, in
induction machine,
phenomena of induction
can't be avoided. In
case of synchronous motors,
a field is supplied to
the rotor. and by

the motor. and by controlling the field flux (in a certain range) we can control the machine. But it will be discussed later.

analogous to field control in DC machine.

99% of industrial motors are induction. Rest 1% is dominated by PMSM.

→ Line of Action

We shall derive the transfer function of AC machine for given input and given input and output. Rest is same as in case of DC motors

→ Two types of speed in ~~AC~~ machine

→ Electrical

→ Mechanical

Relation b/w the two are

$$\theta_e = \frac{P}{2}\theta_m$$

$$\frac{d}{dt}\theta_e = \frac{d}{dt}\left(\frac{P}{2}\theta_m\right)$$

$$\Rightarrow \omega_e = \frac{P}{2}\omega_m.$$

$\Rightarrow \quad \omega_e = P/2 \ \omega_m.$

Of $P = 2$

$\Rightarrow \omega_e = 2/2 \ \omega_m$

$= \omega_m$

Of $P = 4$

$\Rightarrow \omega_e = 4/2 \ \omega_m$

$= 2 \omega_m$

Of $P = 4$, space vector revolves two times but machine revolves one time in a cycle. So write

$$\omega_e = \frac{4}{2} \omega_m$$

$= 2\omega_m$

&

$\theta_e = 4/2\, \theta_m$

$= 2\,\theta_m$

→ Back to TRM

No relative motion in TRM. It is a static device. In induction, machine rotor moves. If the rotor is blocked and stator moves @ 1500 rpm, relative speed of rotor from stator point of view is not 0, it is 1500 rpm.

0, it is 1500 rpm in opposite direction. If rotor moves @ 750 rmp, from stator side the rotor speed is 750 rpm. ~~This~~ ~~From~~

$$e = N\frac{d\phi}{dt}$$

This is represented by "slip" concept.

$$\omega_{slip} = \omega_s - \omega_r$$

$$s = \frac{\omega_s - \omega_r}{\omega_s} \Big\} S\%$$

$$\text{slip} = \frac{\omega_s - \omega_r}{} \times 100\%$$

$$slip = \frac{\omega s - \omega r}{\omega s} \times 100\%.$$

$$= \frac{Ns - Nr}{Ns} \times 100\%.$$

As slip speed increases, more relative motion b/w stator and rotor, so, more emf is induces there according to

$$e = \frac{N d\phi}{dt}$$

So, here

→ Voltage

and

→ Frequency / speed

of

speed

and

→ Current

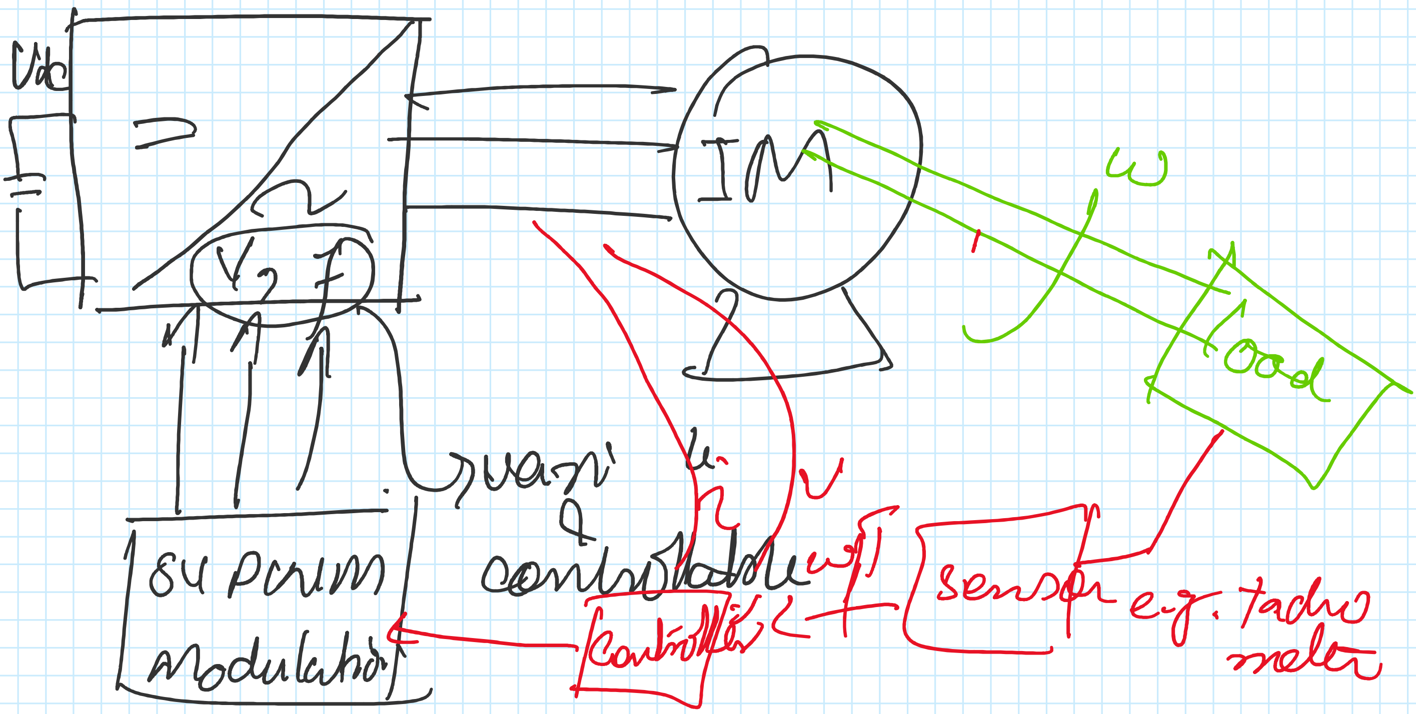
changes from stator to rotor side in contrast to transformer. So, voltage, current or impedance and frequency on rotor side depends on the relative speed which is described in terms of 'slip' concept. ~~In other words~~, In terms of transformer, turn ratio is now a function of slip speed. So, inductio motor can be transformed to an equivalent transformer mode with slip dependent co. turn ratio.

$$\rightarrow \vec{T} = \vec{B_r} \times \vec{B_s}$$

If $B_r \perp B_s$

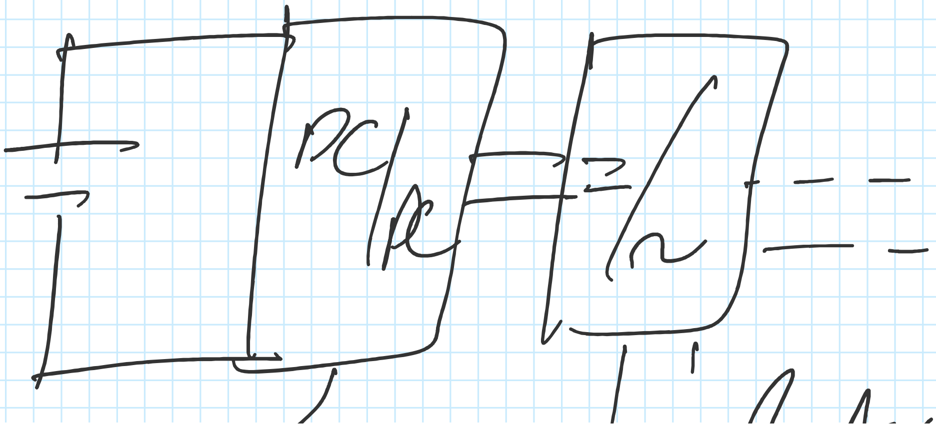
$$\Rightarrow \vec{T} = T_{max}.$$

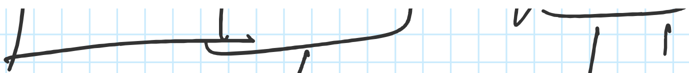
This is done by the controller. i.e 90° angle b/w B_r and B_s is maintained by the controller.



So, PWM is controlled in such a way that $B_s \perp B_r$ and hence $T = T_{max}$.

→ For controlling Vdc, a DC to DC converter can also be used if required





Rest is as above

→ will be studied if time permits. Basic intro is given already.

→ If Rotor is jammed or locked

slip = 1

and machine is pure transformer.

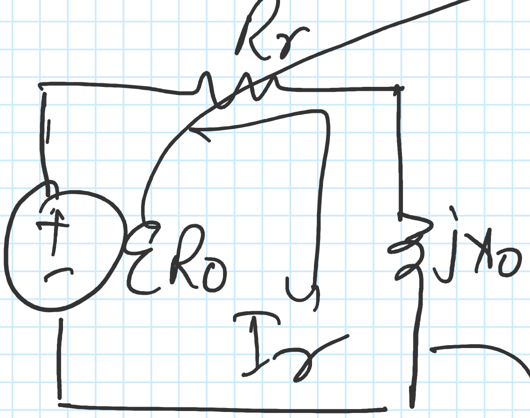
This happens at

→ very high load

→ at the start

of machine.

So,



→ induced emf from stator side.

$$I_r = \frac{E_{R0}}{R_r + jX_{R0}}$$

→ fig(1)

0 ⇒ $\omega_r = 0$ i.e stand still.

This happens at stand still

Now, motor starts. Here

$E_R = s E_{r0}$ → if $s = 0$ $E_r = 0$ locked. synchronously.

$X_R = s X_{R0}$ → $\boxed{\text{if } s = 0,\ f = 0 \Rightarrow X_R = 0}$ $s = 1 \Rightarrow E_r = E_{r0}$ → Blocked rotor

→ So,

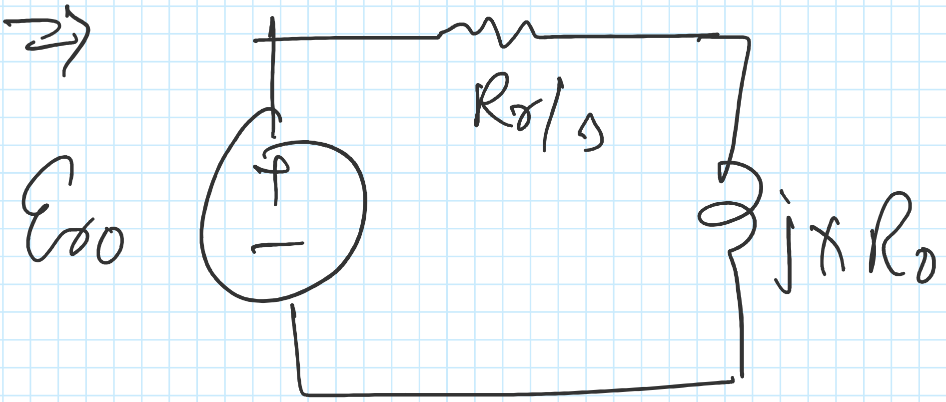
$$I_r = \frac{E_r}{\ldots}$$

$$I_r = \frac{E_r}{R_r + jX_r}$$

$$= \frac{s E_{r0}}{R_r + j s X_{R0}}$$

$$= \frac{E_{r0}}{R_r/s + j X_{R0}}$$

$\Rightarrow$



This circuit is equivalent to that of fig (1)

This is how R/s in the equivalent cct of induction equivalent ckt of induction motor comes. If s=1

⇒ Rotor is locked ⇒ emf is induced as there is relative motion.

⇒ s=0 ⇒ synchronous locking, $R_R = \infty$ ⇒ No current flow

(Theoratical Justification of induction motor equivalent ckt)

→ Air gap Power

It is the stator deliverable power.

It is the power ideally available to rotor.

→ R_r/s is the fictitious resistance which resistance which accomodates the frequency dependency of X_R.

$\Rightarrow \quad P_{ag} = 3 I_R^2 \dfrac{R_r}{s}$

reason

$\Rightarrow \quad s P_{ag} = 3 I^2 R_r$

$= RCL$

$\Rightarrow \quad RCL = s P_{ag}$

↳ Rotor Copper losses

→ Power converted into mechanical form

$P_{mech} = \left(\dfrac{R_r}{s} - R_r \right) I_R^2$

Total resistance

Resistance accountable for losses $= R_r\left(\frac{1}{s} - 1\right) I_r^2$

resistance used for power conversion

OR

$$P_{mech} = P_{ag} - P_{RCL}$$

$$= I_R^2 \frac{R_r}{s} - I_R^2 R_r$$

$$= I_R^2 \left(R_r/s - R_r\right)$$

$$= I_R^2 R_r \left(1/s - 1\right)$$

OR

$$P_{mech} = P_{ag} - P_{RCL}$$

$$= P_{ag} - s P_{ag}$$

$= (1-s) P_{ag}$

Also

$$P_{mech} = T \, \omega$$

T → Maximum available torque from the machine

أكيد أقل من

effect of air friction etc

This . اللي

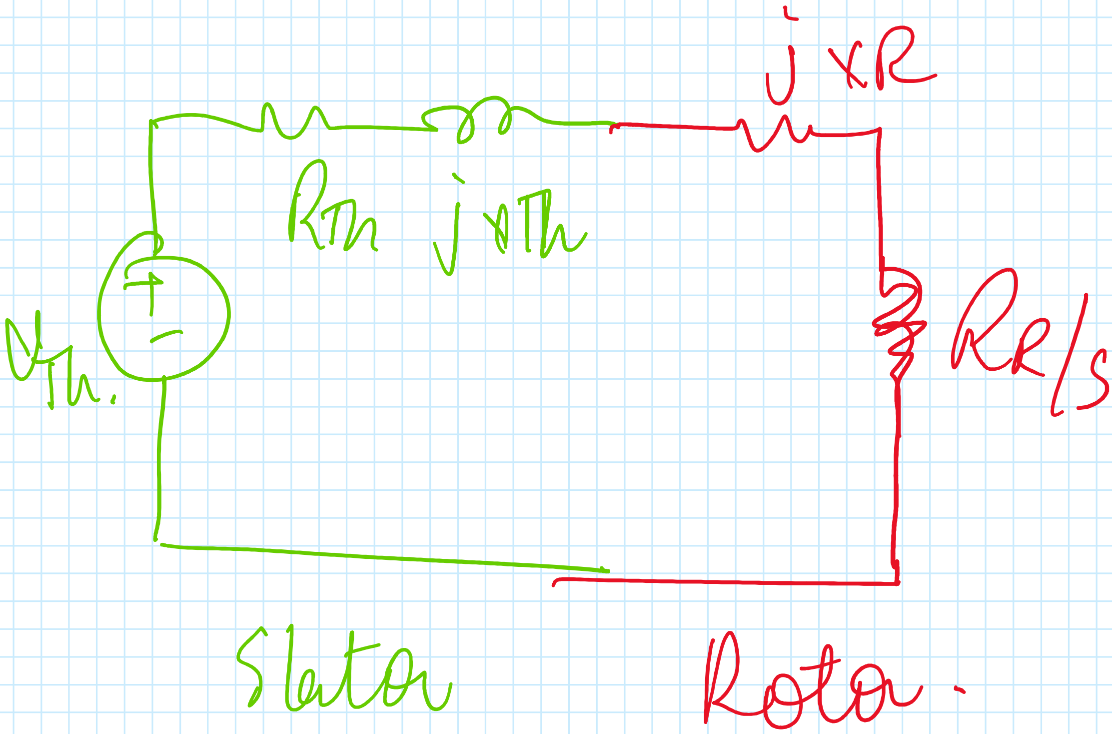
is not the load torque

ideally

ω → Actual load speed

ideally ! /

→ Back to main Point

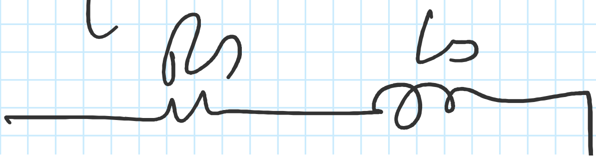


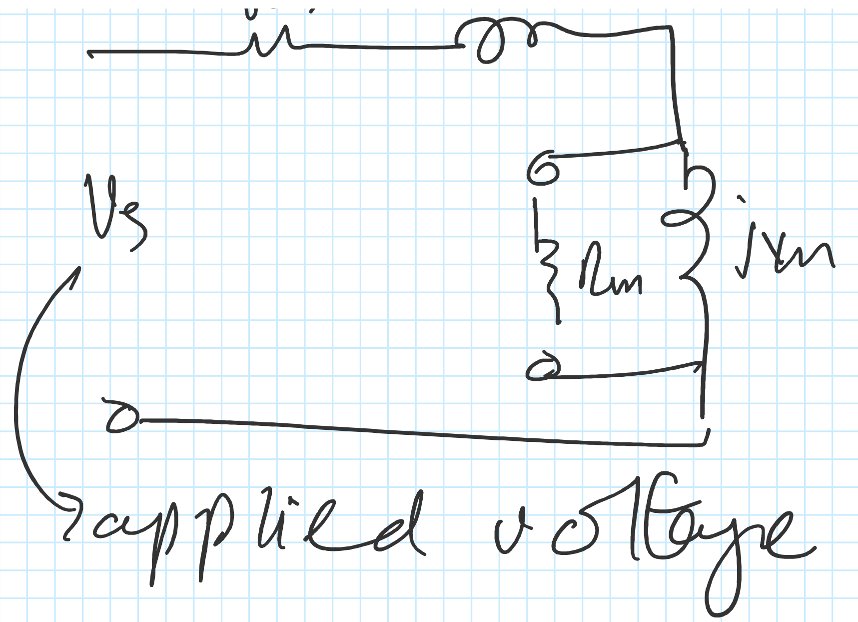
In induction Motor

$R_m >> X_m$

$\Rightarrow \quad R_m \| X_m \simeq X_m$

So, equivalent ckt is





$$\Rightarrow \quad V_{Th} = \frac{jX_m}{R_s + jX_s + jX_m} V_s$$

$$= \frac{X_m}{\sqrt{R_s^2 + (X_s + X_m)^2}} V_s$$

Here

$$R_s < (X_s + X_m)$$

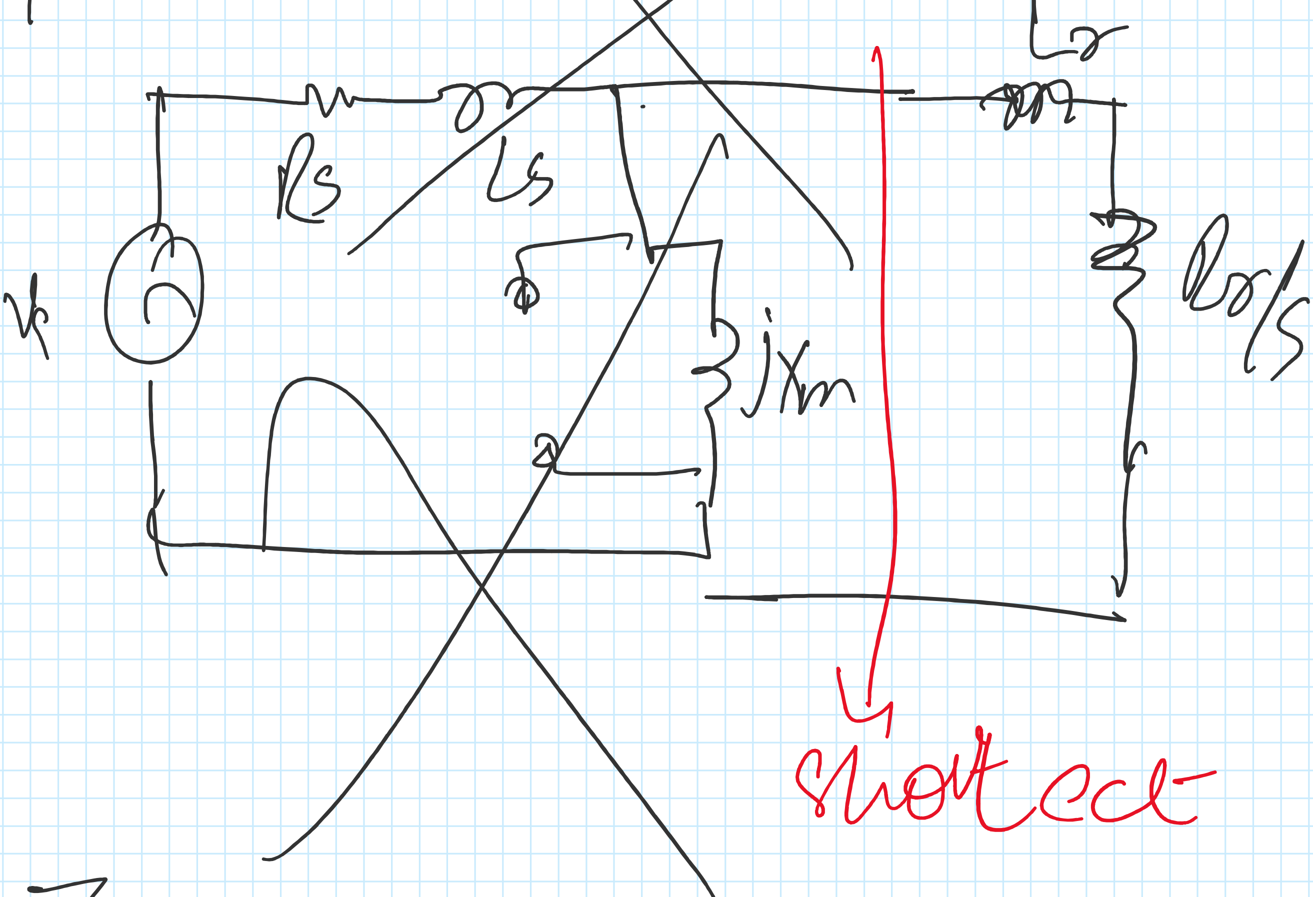
So,

$$R_s^2 \ll (X_s + X_m)^2$$

$$\Rightarrow \quad V_{Th} \approx \frac{X_m}{X_m + X_s} V_s$$

~~Cir~~

~~if stator circuit is short~~



$Z_{Th} =$

Similarly

Similarly

$$Z_{Th} = (R_s + jX_s) \parallel jX_m$$

$$= \underbrace{\left(\frac{X_m}{X_m + X_s}\right)^2 R_s}_{R_{Th}} + j\underbrace{X_s}_{X_{Th}}$$

$$= R_{Th} + jX_{Th}.$$

So,

$$I_R = \frac{V_{Th}}{\left(R_{Th} + R_R/s\right) + j\left(X_{Th} + X_R\right)}$$

$$I_R = \quad V_{Th}$$

$$I_R = \frac{V_{Th}}{\sqrt{\left(R_{Th} + R_r/s\right)^2 + \left(X_{Th} + X_R\right)^2}}$$

$$\Rightarrow P_{ag} = I_R^2 \frac{R_r}{s}$$

$$= \frac{V_{Th}^2}{\left(R_{Th} + R_2/s\right)^2 + \left(X_{Th} + X_R\right)^2}$$

Also

$$P_{ag} = T_{em}\, \omega_s$$

↳ electromagnetic or induced torque

induced torque

$$\Rightarrow \tau_{em} = \tau_{ind}$$

$$= \frac{V_{TH}^2 R_2/s}{\omega_s \sqrt{(R_{TH} + R_2/s)^2 + (X_{TH} + X_R)^2}}$$

$$\Rightarrow \tau_{ind} \propto V_{TH}^2 \propto V_s^2$$

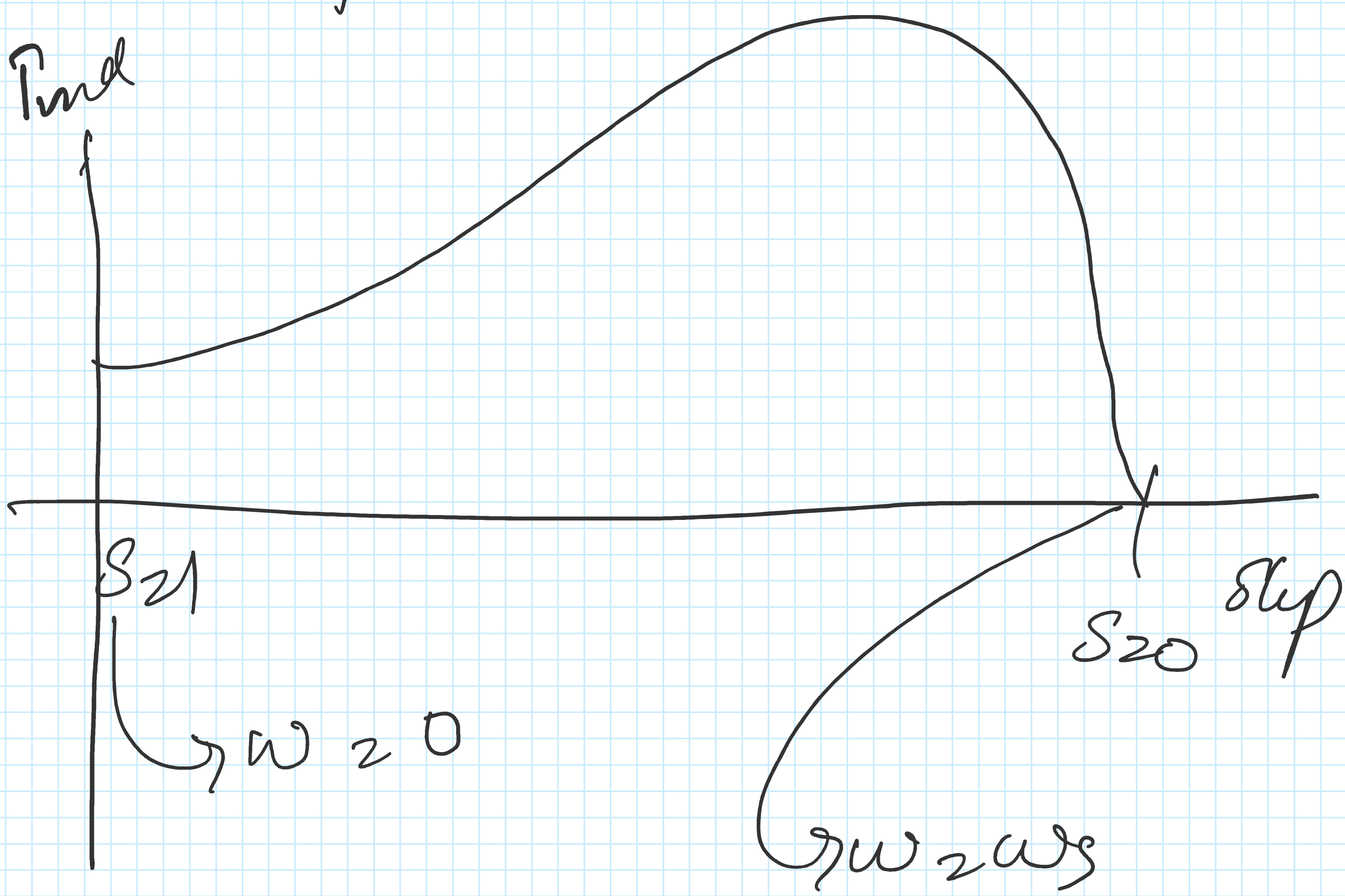
↳ per phase voltage

Also

$$\tau_{ind} \propto \frac{1}{f_s}$$

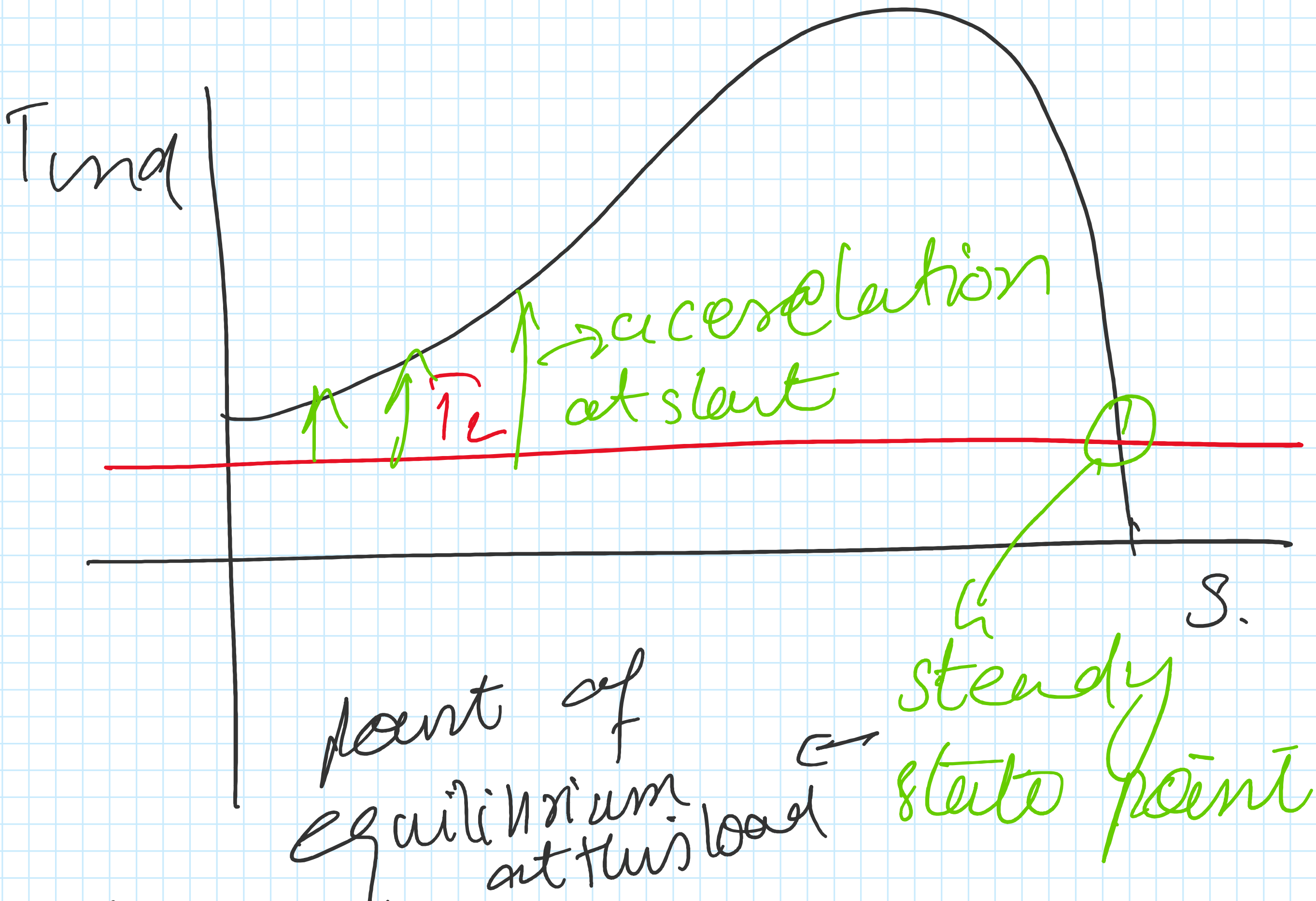
i.e torque can be controlled by the applied vol e (V_s) and synchronous speed (f_s/ω_s)

→ Torque slip curve at at constant V_{Th} and frequency is fixed.

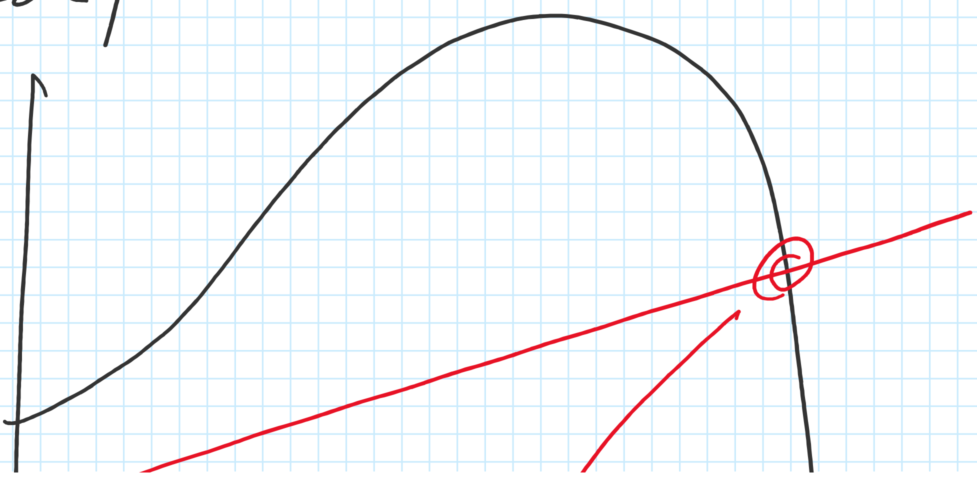


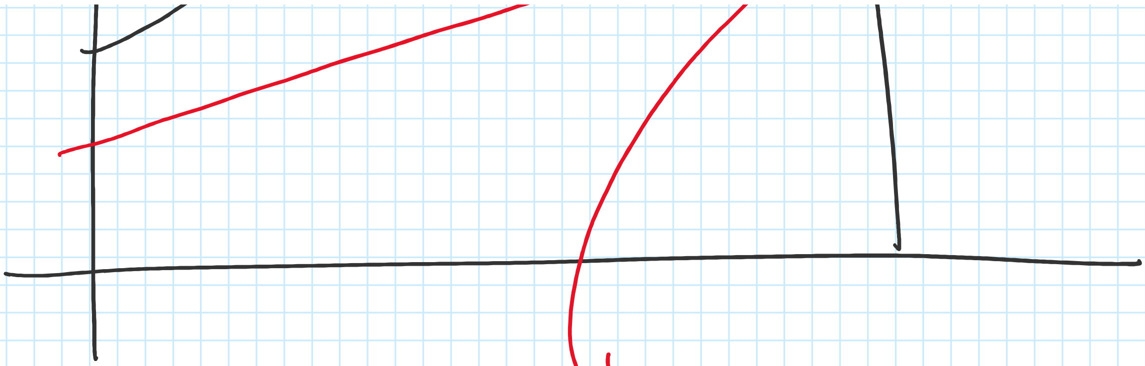
but this is at fixed voltage and fixed frequency

Now consider the case



Now consider an increased load,





New equilibrium point at a "wer" speed.

Now

As $T_L > T_{start}$:

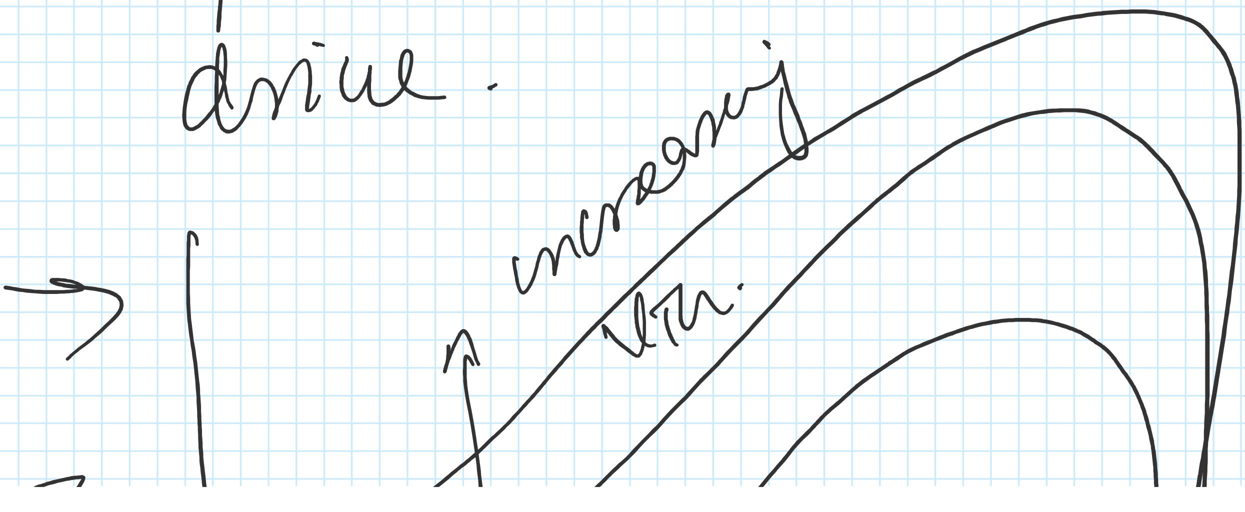
motor will not start by itself. So, a

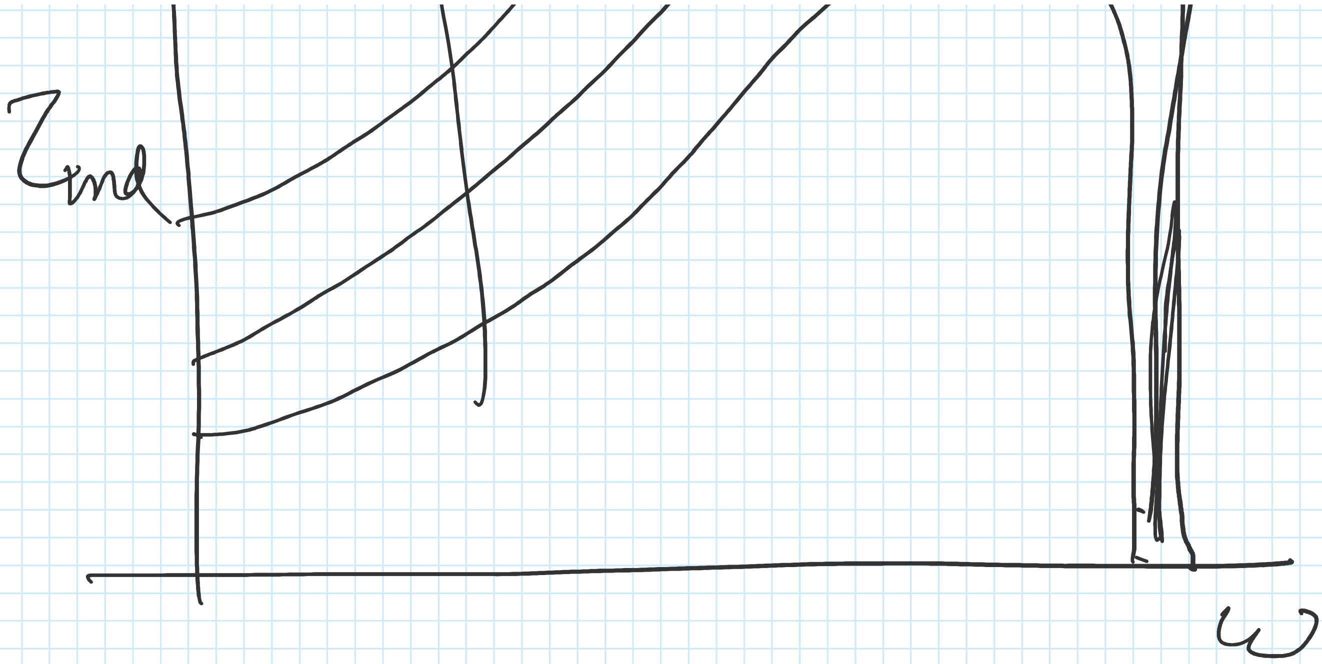
drive is needed (some

drive is needed here

If voltage is increased, Torque speed curve is shifted up (shown by yellow).

→ Similarly, we can get a required slip at a given load torque by varying the torque speed curve with the drive.



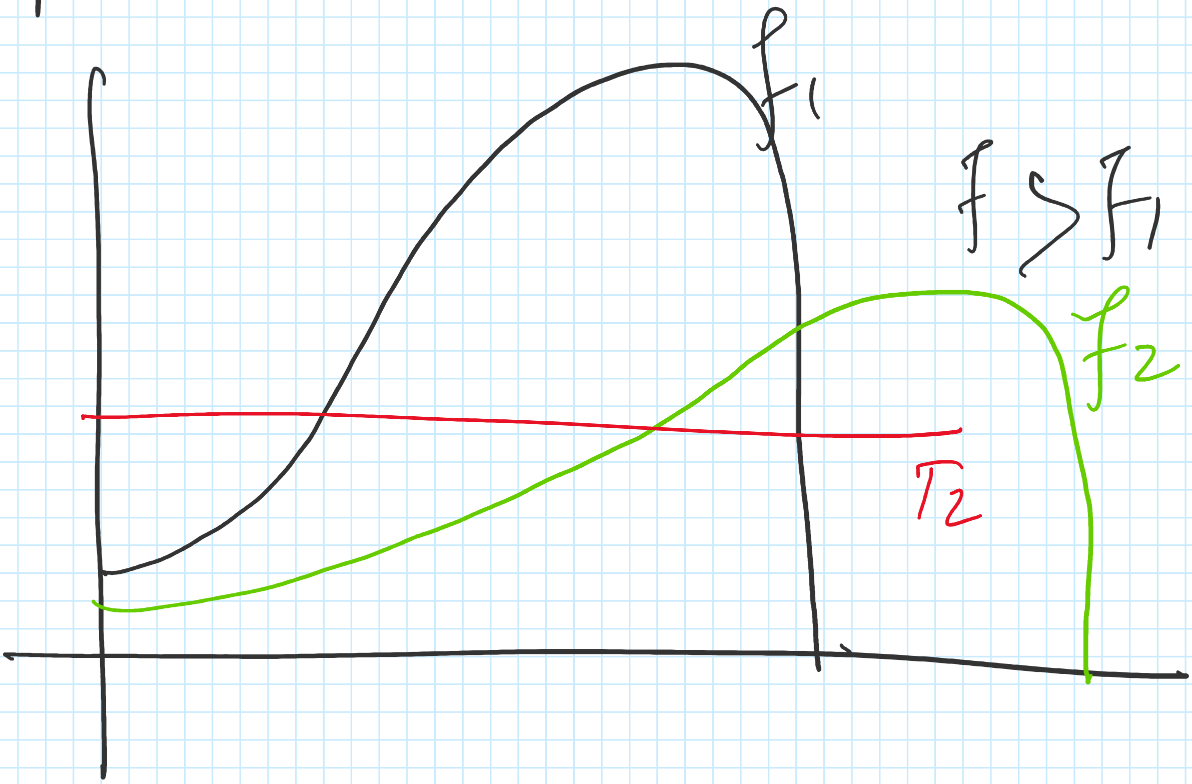


If changing V_{Th} is not capable to give required torque, you can shift to frequency control as well.

→ Every motor can be operated above its rated values for some time depen-

ding on its class
(A, B, C, D etc)

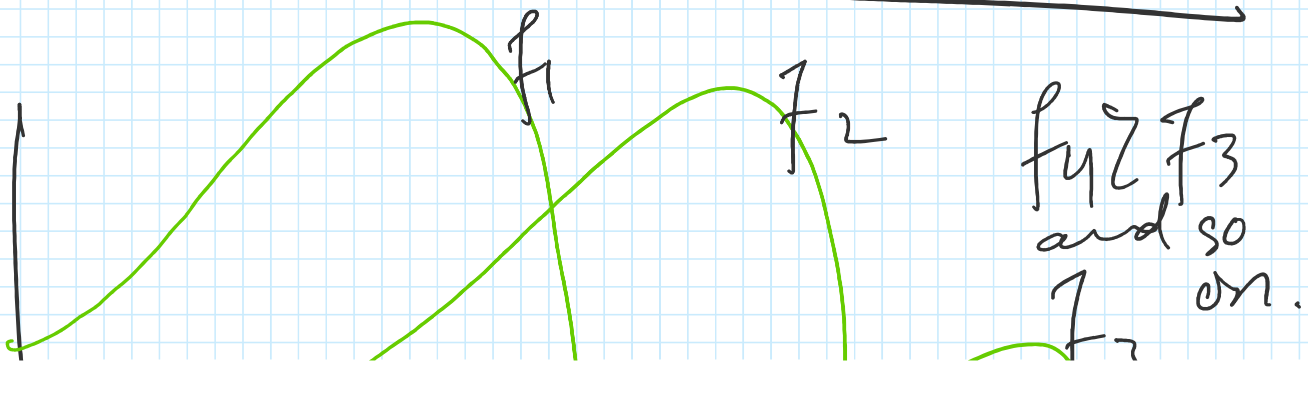
→ Controlling V, f,
Shifts τ_{ind}-ω curve
up and down.



At $f_2 > f_1$,
Pullout Torque decreases
and shifts to right.

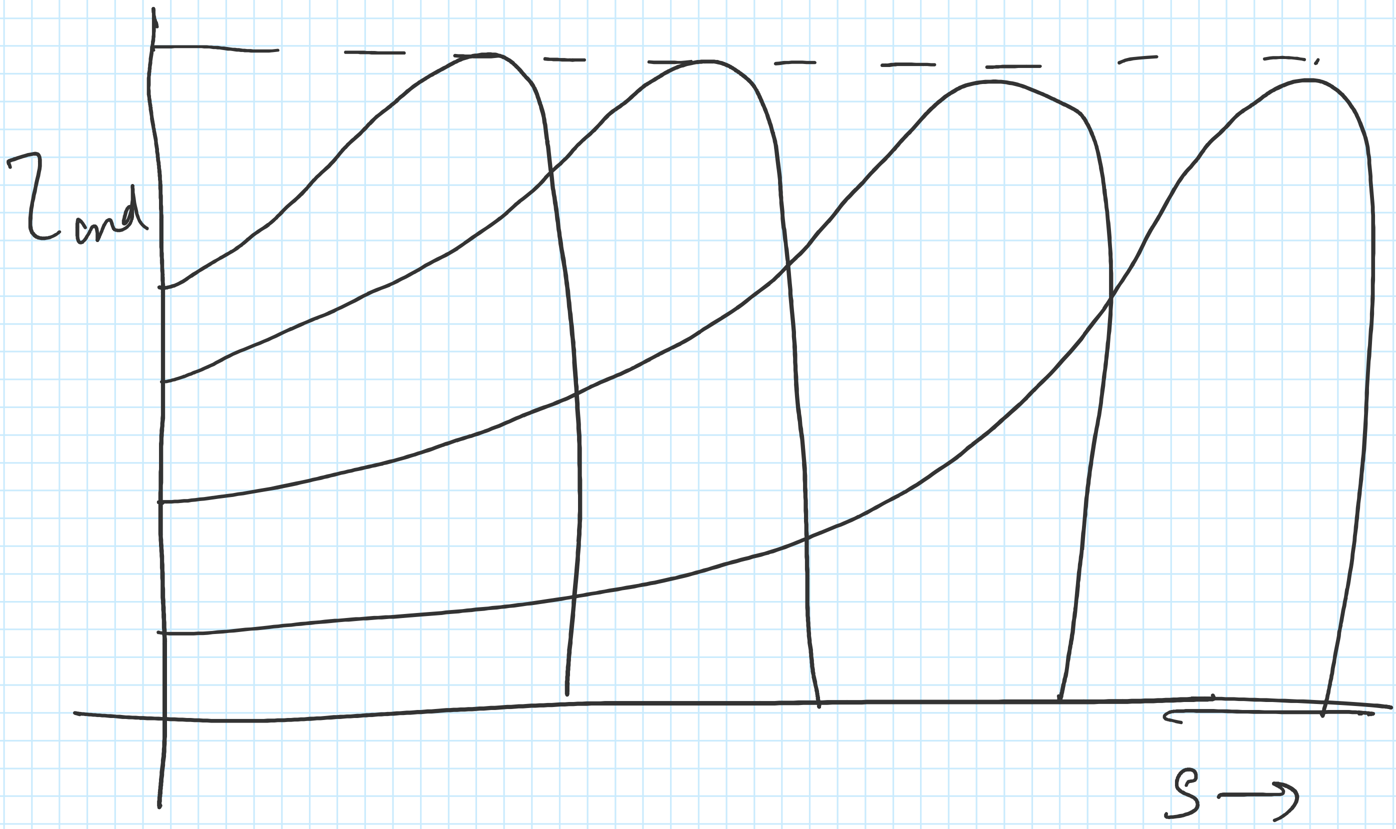
and shifts to right.
Also, ω_s moves to right.

At the given T_L, motor cannot be started at f_2. So, it will be started at a lower frequency and then frequency is gradually decreased in such a way that motor keeps accelerating



→ $T_L < T$ at the given frequency so that motor keeps on accelerating.

→ If V^2/f = constant



→ Torque speed curve is the most important point. Controller is a mapper finding a particular point on this curve.

——— End ———