EE-362 ELECTROMECHANICAL ENERGY CONVERSION-II

Equivalent Circuit of Induction Machines

Ozan Keysan

keysan.me

Office: C-113 • Tel: 210 7586

Assume the rotor is stationary (s=1):

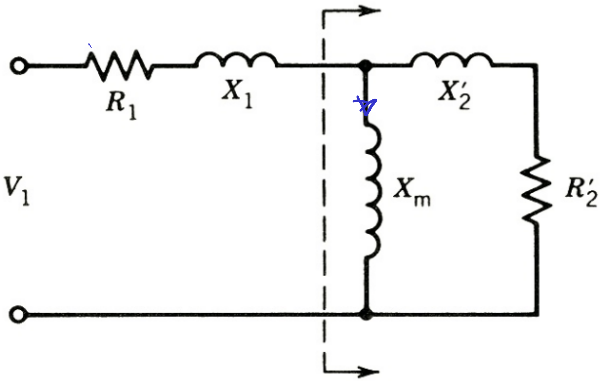
Then the frequency of rotor currents: $f_r = f_s$

Machine just behaves just like a transformer (secondary short-circuited)

- Stator winding: Primary winding of the transformer
- Rotor bars: Secondary winding of the transformer

Equivalent Circuit, Rotor Stationary (s=1)

Same as a transformer with secondary side short-circuited



$R_1 \Rightarrow$ stator winding resistance

$X_1 \Rightarrow$ stator winding inductance

$\left.\begin{array}{l} X_2' \\ R_2' \end{array}\right\}$ referred rotor winding parameter

$X_m \Rightarrow$ Magnetizing inductance

Assume now the rotor starts rotating (with N_r)

- Rotor induced voltage reduces (as the frequency difference between rotor and stator reduces)

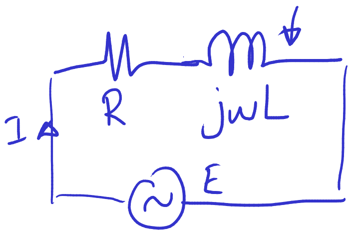
$e \propto \frac{d\phi}{dt}$

Assume now the rotor starts rotating (with N_r)

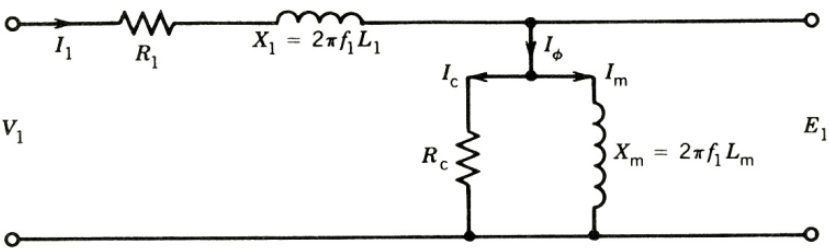
- Rotor induced voltage reduces (as the frequency difference between rotor and stator reduces)

- Therefore current reduces,

- but not that much, because the rotor side impedance reduces with reduced rotor current frequency (jwL)



Stator Side Equivalent Circuit



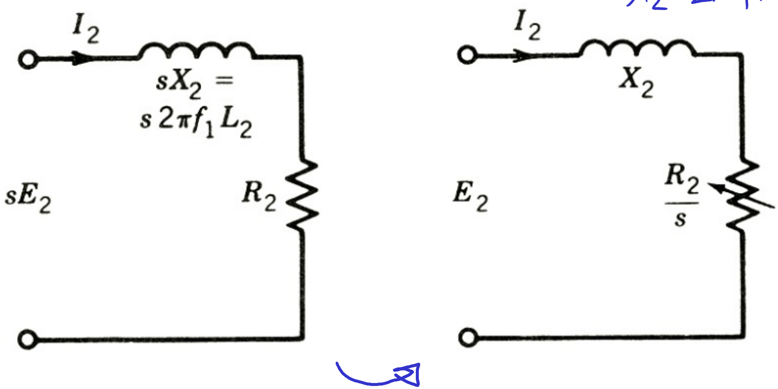
$\Rightarrow$ rotor side

Rotor Side Equivalent Circuit

$j\omega L$

f_1 = stator frequency

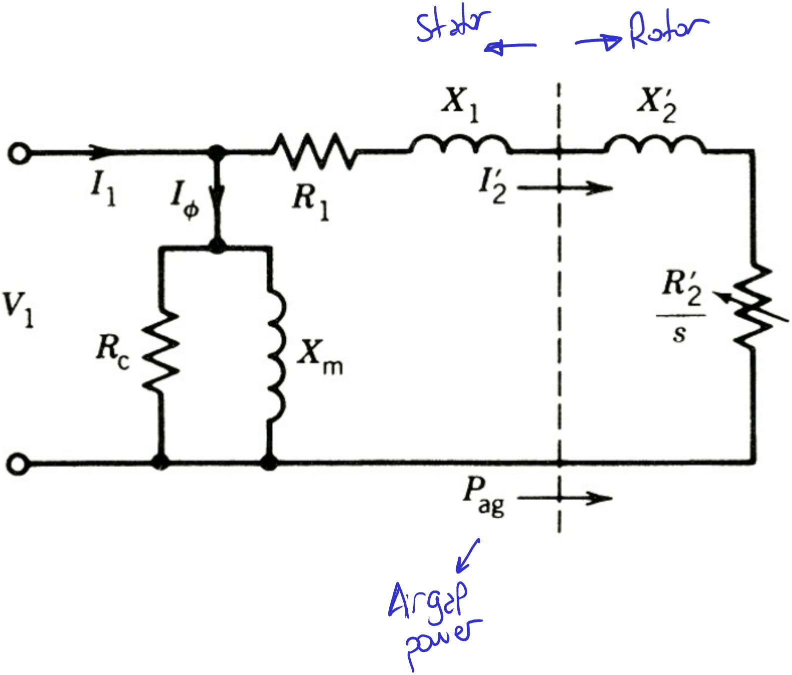
$X_2 = 2\pi f_1 . L_2$



Rotor side impedances can be modified to transfer these to the stator side

For curious students: P.C.Sen, Principles of Electrical Machines and Power Electronics, Section 5.7, Derivation of the equivalent circuit of induction machines

Equivalent Circuit with Referred Rotor



Determination of Equivalent Circuit Parameters

Equivalent tests for induction machines:

- Open-circuit Test = No-Load Test
- Short-circuit test = Locked Rotor Test

Locked-Rotor Test

Rotor kept stationary with a mechanical locking system

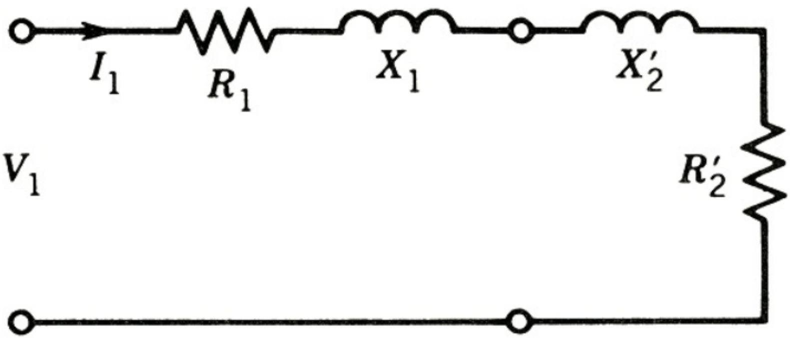
$$n_r = 0 \rightarrow s = 1$$

Apply a small voltage (10-15% of the rated) to obtain rated current and measure:

- Input Power
- Input Voltage
- Current

Locked-Rotor Test

Neglect the parallel branch and s = 1, the circuit becomes:



Locked-Rotor Test

- $P_{phase} = \frac{P_{total}}{3} = I_1^2(r_1 + r_2')$
- Measure $r_{1(dc)}$ using an ohm-meter, assume $r_{1(ac)} = 1.1r_{1(dc)}$
- $\frac{V_1}{I_1} = Z_{eq} = \sqrt{(r_1 + r_2')^2 + (X_1 + X_2')^2}$
- Assume $X_1 = X_2'$

No-Load Test

Run the motor at no-load, applying rated voltage

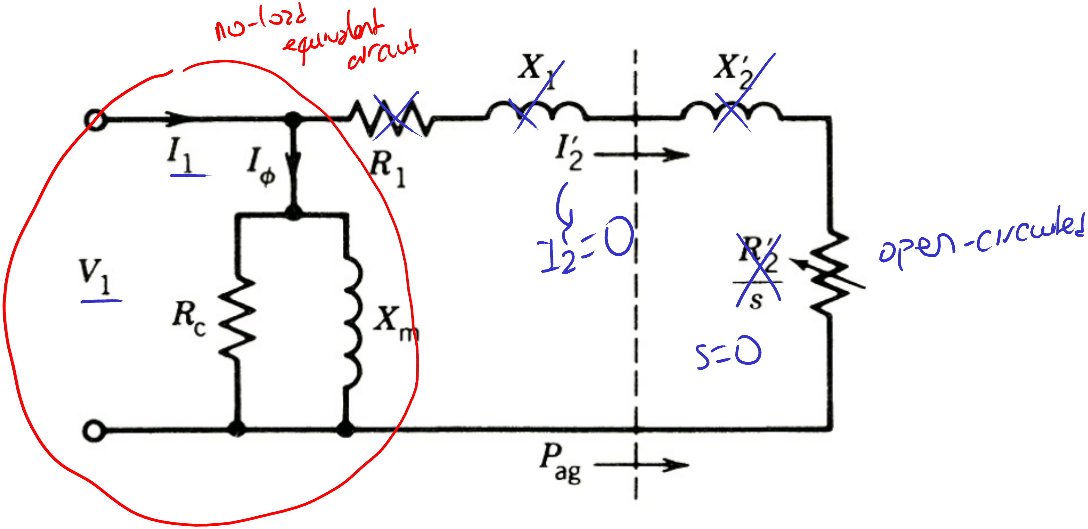
$$n_r \simeq n_s \rightarrow s \simeq 0$$

Again measure:

- Input Power
- Input Voltage
- Current

No-Load Test

Rotor-side is open-circuited (s=0), the series branch (R1,X1) can also be neglected:



No-Load Test

- $P_{phase} = \frac{P_{total}}{3} = \frac{V_1^2}{R_c}$, find R_c
- $\frac{V_1}{I_1} = Z_{eq} = R_c // X_m$, find X_m

But, how about mechanical friction and windage losses?

Get a few measurements at different voltages and speeds to estimate the friction.

Example:

Estimate the parameters of a 30 kW, 50 Hz, Delta-connected, 415 V, 3-phase machine, if the test results are as follows:

Locked-Rotor Test:

- Input Power: 6.4 kW
- Line Current: 77 A
- Line Voltage: 130 V
- Resistance between two lines: 0.293 Ω

Example:

Estimate the parameters of a 30 kW, 50 Hz, Delta-connected, 415 V, 3-phase machine, if the test results are as follows:

No-Load Test:

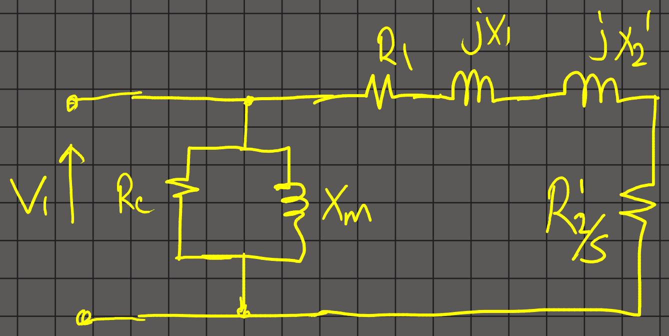
- Input Power: 1.65 kW
- Line Current: 22.8 A
- Line Voltage: 415 V
- Friction and windage losses: 1.15 kW

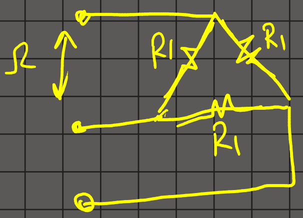
Assume $X_1 = X_2'$

Estimate the parameters of a 30 kW, 50 Hz, Delta-connected, 415 V, 3-phase machine, if the test results are as follows:

Locked-Rotor Test:

- Input Power: 6.4 kW
- Line Current: 77 A
- Line Voltage: 130 V
- Resistance between two lines: 0.293 Ω



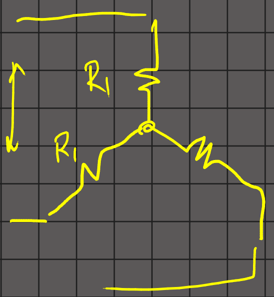


resistance between two lines $\Rightarrow R_1 // (R_1 + R_1) = \frac{2R_1}{3} = 0{,}293\,\Omega$

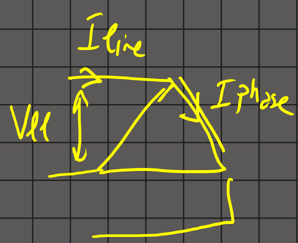
$R_1 = 0{,}44\,\Omega$ (DC resistance)

$R_{1(ac)} = 1.1 \cdot R_{dc}$

$R_{1(ac)} = 0{,}48\,\Omega$



resistance between two lines $\Rightarrow 2R_1$



Equivalent circuit in the locked rotor test

$$Z_{eq} = \frac{130}{77/\sqrt{3}}$$

$$Z_{eq} = 2{,}92\,\Omega$$

$$P_{ph} = \frac{6.4\,kW}{3} = I_{ph}^2 \cdot (R_1 + R_2')$$

$$= \left(\frac{77}{\sqrt{3}}\right)^2 \cdot (R_1 + R_2')$$

$R_{eq} = R_1 + R_2' = 1{,}08\,\Omega$ (per phase)

$$\boxed{\begin{aligned} R_1 &= 0{,}48\,\Omega \\ R_2' &= 0{,}6\,\Omega \end{aligned}}$$

$$Z_{eq} = \sqrt{R_{eq}^2 + (X_1 + X_2')^2} \Rightarrow X_{eq} = X_1 + X_2' = \sqrt{2{,}92^2 - 1{,}08^2}$$

$$= 2{,}71\,\Omega$$

Assume $X_1 = X_2' = \boxed{1{,}36\,\Omega/ph}$

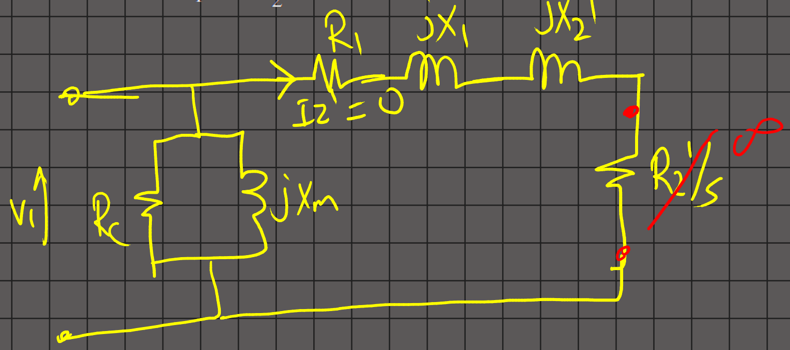
Estimate the parameters of a 30 kW, 50 Hz, Delta-connected, 415 V, 3-phase machine, if the test results are as follows:

No-Load Test:

- Input Power: 1.65 kW
- Line Current: 22.8 A
- Line Voltage: 415 V
- Friction and windage losses: 1.15 kW

Assume $X_1 = X_2'$

At no load $s \cong 0$



$$Z_{nl} = \frac{V_{ph}}{I_{ph}} = \frac{415}{(22.8/\sqrt{3})} = 31,53\ \Omega/ph.$$

$P_{noload} = 1,65\,kW$ $\quad P_{friction} = 1,15\,kW \Rightarrow P_{core} = 1,65 - 1,15 = \underline{500\,W}$

$$P_{core} = \frac{3 . V_1^2}{R_c} = 500 \Rightarrow \underline{R_c = 1033\ \Omega}$$

$$Z_{nl} = (R_c // X_m) = 31,53\ \Omega \qquad \left(\frac{1}{X_m}\right)^2 + \left(\frac{1}{R_c}\right)^2 = \left(\frac{1}{Z_{nl}}\right)^2$$

$$\underline{X_m = 31,54\ \Omega}$$