Electromagnetic Energy Conversion ELEC0431

Exercise session 7: Asynchronous machines

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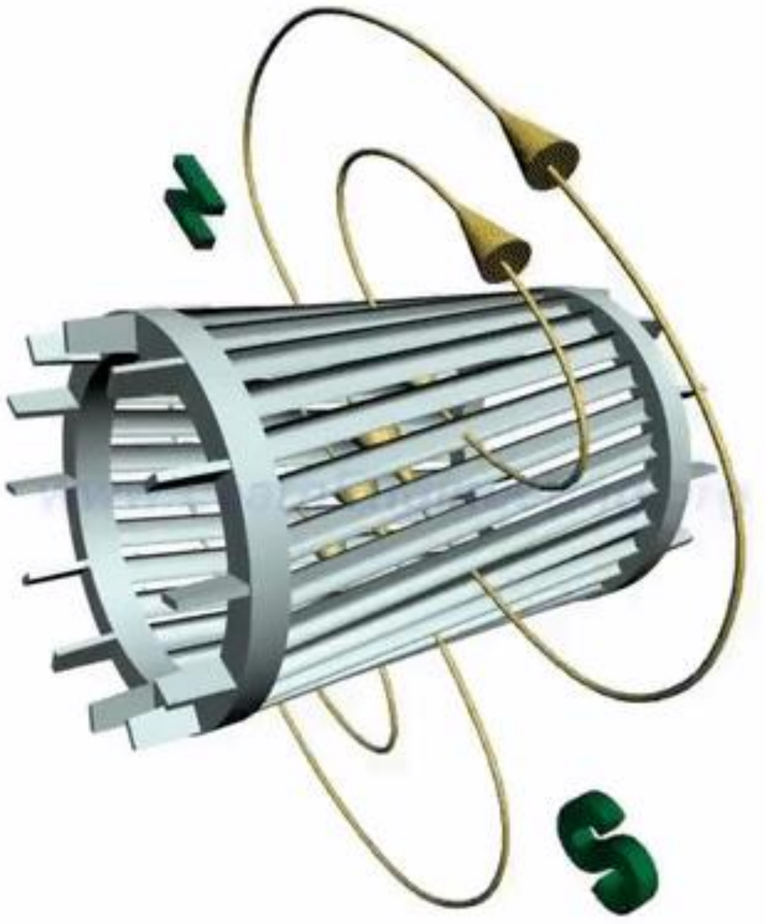
Reminders

The asynchronous machine

The asynchronous machine – working principle



1. The stator generates a rotating magnetic field.
2. Closed loop wire in the varying magnetic flux

   ➔ Faraday's law: e.m.f.

1. The e.m.f. leads to a current.
2. Current in a magnetic flux

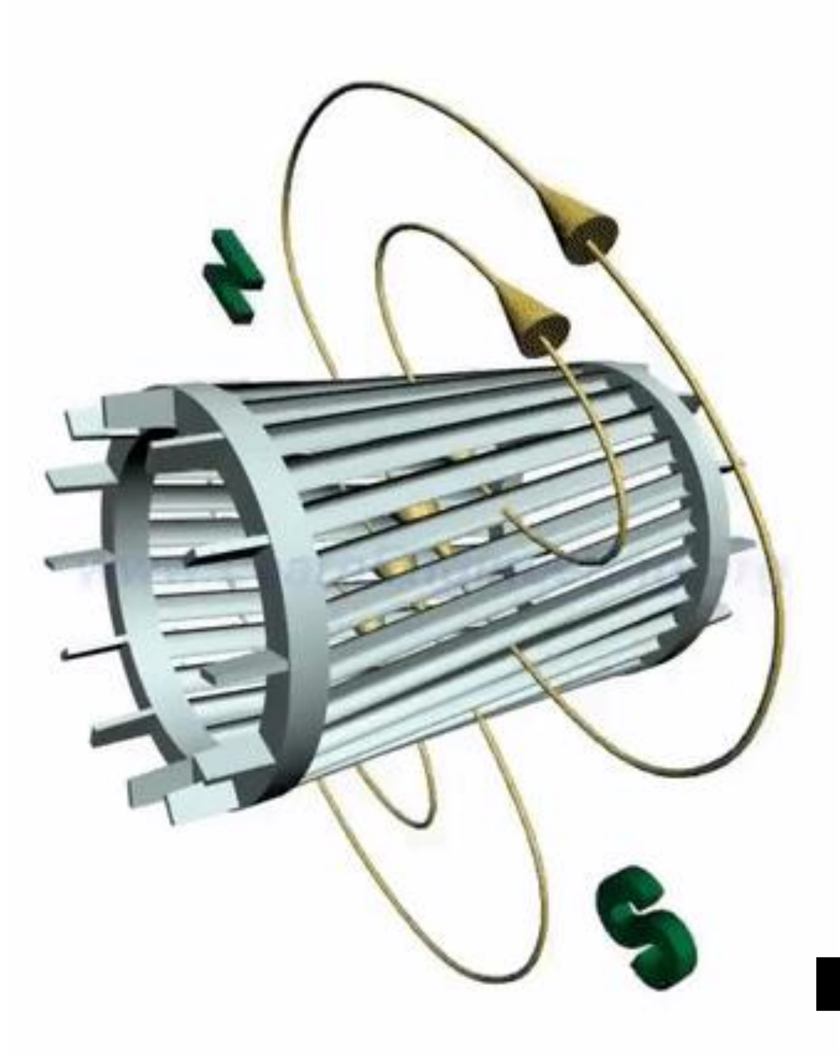
   ➔ Laplace: $\bar{F} = q\bar{v} \wedge \bar{B}$.

1. $\bar{F}$ makes the rotor rotate.

✓ Self starting

✓ brushless & no permanent magnet ➔ easy to build

The asynchronous machine – rotation speed



➔ The rotor doesn't move ➔ high varying fluxes ➔ high current ➔ big acceleration

No rotation ➔ The rotor accelerate

➔ The rotor rotates at the same speed as the magnetic filed ➔ no varying fluxes ➔ no force on the rotor ➔ deceleration due to mechanical losses

Rotor too fast ➔ The rotor decelerate

➔ The rotor will rotate at a speed lower than the one of the magnetic field (***A***synchronous)

The asynchronous machine – slip

➔ Speed of the magnetic flux $= \dot{\theta}_s$ = synchronous speed

➔ Speed of the rotor $= \dot{\theta}$

The slip g (“glissement” in French) links the two speeds:

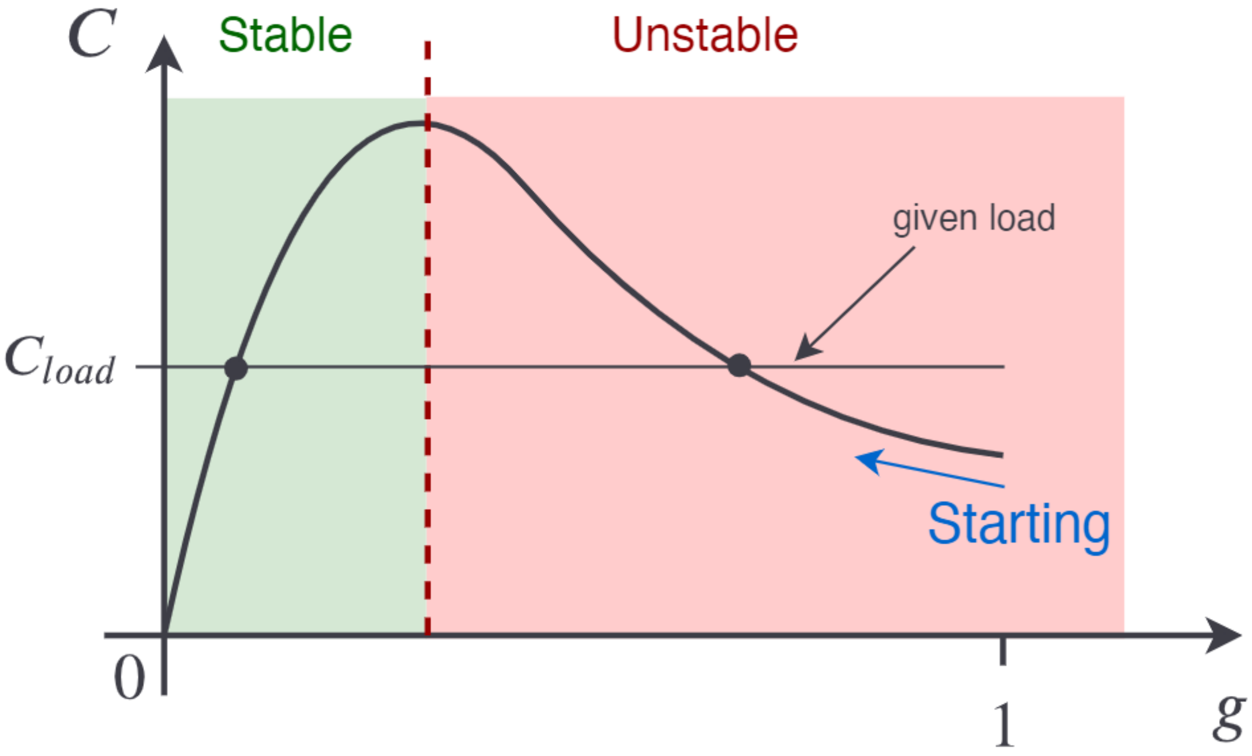
$$g = \frac{\dot{\theta}_s - \dot{\theta}}{\dot{\theta}_s}$$

Note:

- If the stator doesn’t move ➔ $\dot{\theta} = 0$ ➔ $g = 1$
- if the stator moves at the synchronous speed ➔ $\dot{\theta} = \dot{\theta}_s$ ➔ $g = 0$

The asynchronous machine – slip and torque

The relationship between the torque C and the slip g leads to the stable and unstable behaviours of the asynchronous machine.



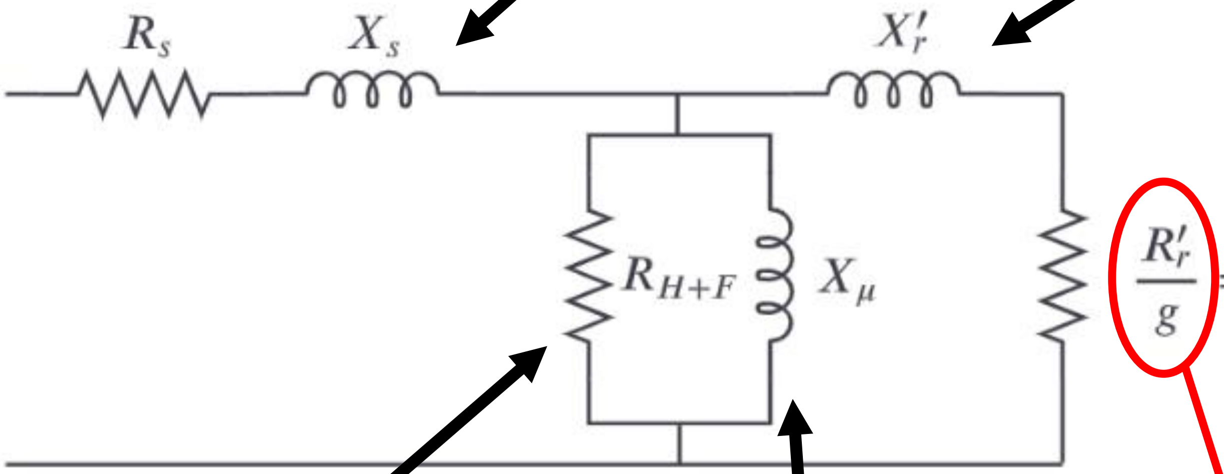
The asynchronous machine – equivalent model

Joule losses in the stator winding

Leakage flux of the stator

Leakage flux in the rotor winding (seen from the stator)

Power transmitted to the shaft



$$\frac{R'_r}{g} = R'_r + \frac{1-g}{g}R'_r$$

Joule losses in the rotor winding (seen from the stator)

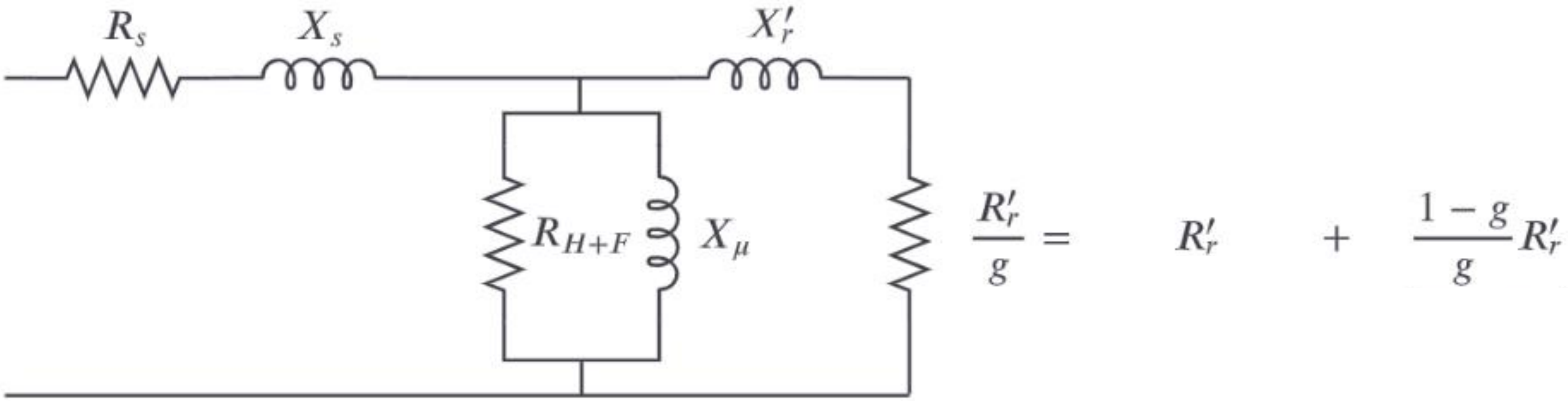
Magnetic losses in the core

Magnetizing reactance

Both joule losses and useful power

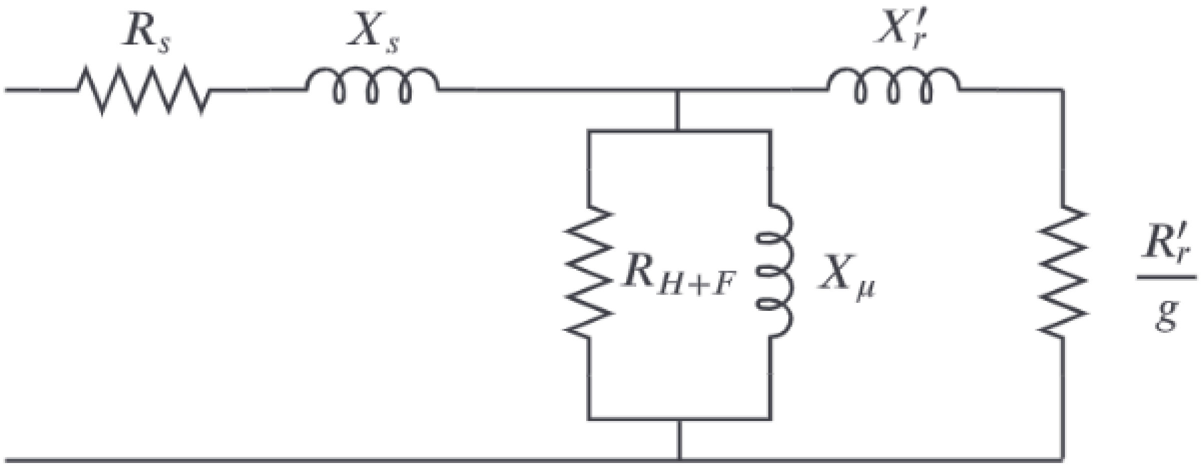
The asynchronous machine – equivalent model

The equivalent circuit of the asynchronous machine is close to the circuit of the transformer.



Indeed, the induction machine behaves as a transformer with its secondary short-circuited. The important difference is that the rotor, as it is a moving part of the machine, sees a frequency $g \cdot f$ different than the stator nominal frequency f.

The asynchronous machine – equivalent model



The asynchronous machine is built to minimize the losses

➔ $R_s,\ R_r' \ll R_{H+F}$

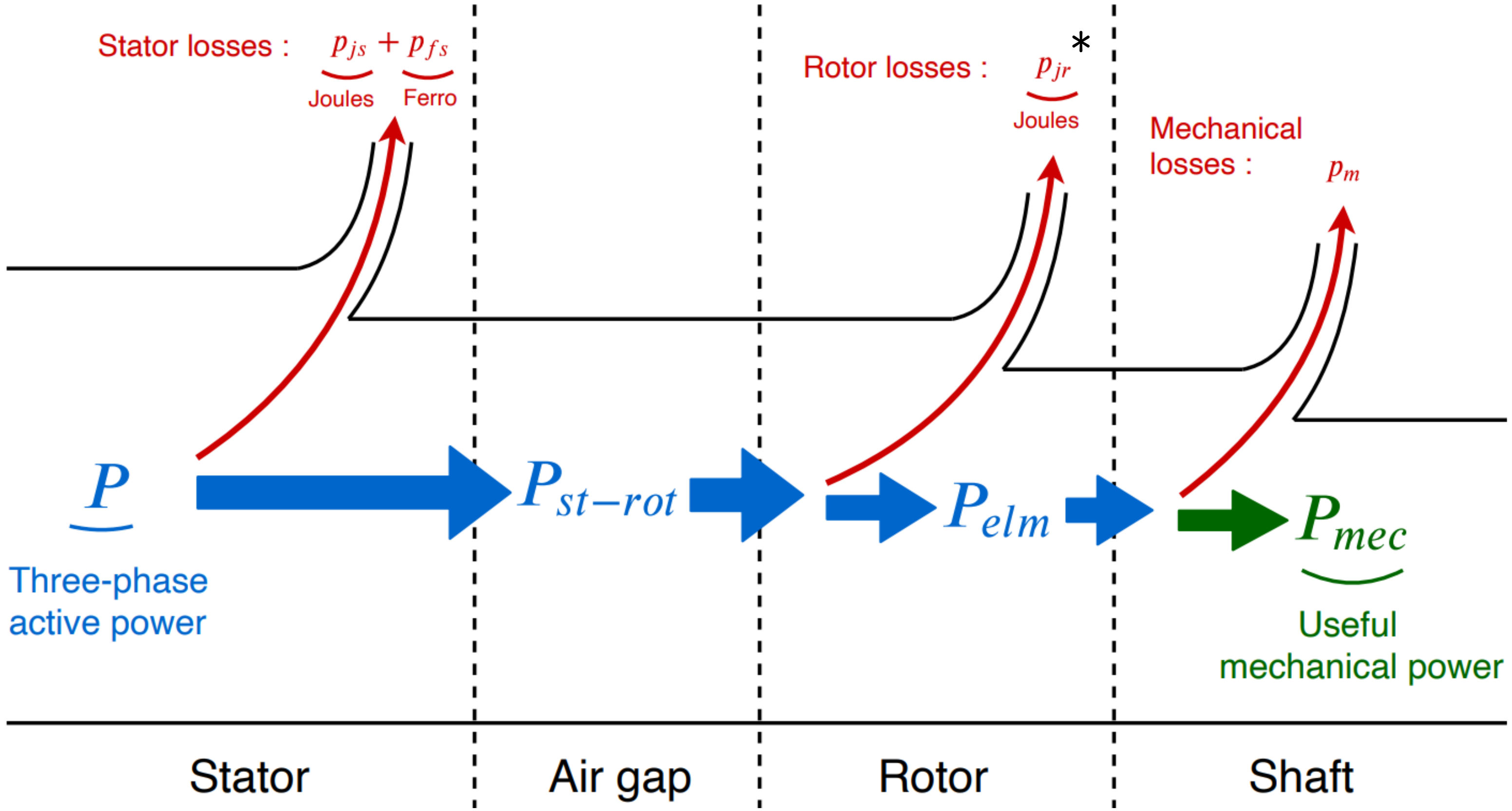
➔ $X_s,\ X_r' \ll X_\mu$

(same as for the transformer)

The parameters R, X, R_{H+F} *and* X_μ can be determined in the same way as for the transformer: short circuit and open circuit tests.

➔ Short circuit obtained by taking $g = 1$ ➔ the rotor is set to the synchronous speed.
➔ Open circuit obtained by taking $g = 0$ ➔ the rotor is forced not to move.

The asynchronous machine – Power balance



* Ferromagnetic losses in the rotor can be neglected since the rotoric current frequency is much smaller than the grid frequency

Exercises

Exercise 19: Asynchronous motor for washer cleaner

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A star-shaped asynchronous motor of a high-pressure washer cleaner has the following nominal characteristics:

- Power $P_n = 5.5\,\text{kW}$,
- RMS composed voltage value $U_{sn} = 400\,\text{V}$,
- Frequency $f_n = 50\,\text{Hz}$,
- RMS line current intensities $I_{sn} = 11\,\text{A}$,
- Speed of rotation $\dot{\theta}_n = 1460\,\text{RPM}$.

Assume that the stator reactance X_s is equal to the stator resistance R_s. Using a single-phase equivalent model of the asynchronous motor when needed,

1. Calculate the synchronous speed of rotation $\dot{\theta}_s$, the number of pair of poles of the motor and the nominal slip g_n;
2. Determine the value of the stator resistance R_s given that a current of RMS value $I_0 = 10\,\text{A}$ flows when a voltage of RMS value $U_0 = 20.6\,\text{V}$ is applied;

Exercise 19: Asynchronous motor for washer cleaner

3. At the nominal operating point, without mechanical load, the motor draws a current of RMS value $I_{so} = 3.07$ A for an active power $P_{so} = 245$ W. Calculate the overall losses and calculate the resistance modelling ferromagnetic losses R_{HF} and the magnetizing inductance L_{μ}, asumming that mechanical losses equal ferromagnetic losses;

Consider that the machine operates at nominal speed and produces the nominal mechanical power P_n to the mechanical load. The nominal mechanical power can also be denotted P_{mec}.

4. At the nominal operating point, calculate the transmitted power from the stator to the rotor and the Joules losses in the stator p_{js} and deduce the total consumed power P;

5. Calculate the rotoric resistance R_r' and the leak inductance L_r' seen from the stator;

6. At the nominal operating point, calculate the mechanical torque Γ_{un} and the electromagnetic torque Γ_n, the power factor $\cos\phi_n$ and the efficiency η_n;

7. Compute the RMS value I_s of the line currents, and the power factor $\cos\varphi$ at a rotation speed of 0 RPM.