

# Electromagnetic Energy Conversion ELEC0431

# Introduction to exercise sessions & Exercise session 1: Reminders

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Exercise sessions on Friday mornings from 10.30 to 12.30 am.

Slides/exercise manual will be uploaded on the on the webpage of the course.

# Laboratory sessions

4 sessions:

- Session 1: Transformers
- Session 2: AC synchronous machines
- Session 3: AC asynchronous machines
- Session 4: DC machines

The lab sessions are (so far  $\clubsuit$ ) organized face-to-face. The lab manual will be available on the webpage of the course. More information later...



# Phasors and power in sinusoidal steady state

# Introduction to the RMS value

• Dissipated power with DC current:

$$P = R I^2$$

• Dissipated power with AC current:

$$P(t) = Z i(t)^{2} \implies P_{mean} = R \frac{1}{T} \int_{0}^{T} i(t)^{2} dt = R \left( \sqrt{\frac{1}{T} \int_{0}^{T} i(t)^{2} dt} \right)^{2}$$
$$= R I_{RMS}^{2}$$

The Root Mean Square value (or effective value) is equal to the value of the constant direct current (voltage) that would produce the same power dissipation in a resistive load.

# RMS value and harmonic signal

$$F_{RMS} \coloneqq \sqrt{\frac{1}{T}} \int_0^T f^2(t) dt$$

For a harmonic function with frequency f, pulsation  $\omega = 2\pi f$  and period  $T = \frac{1}{f}$ :

$$f(t) = F_{max} \cos(\omega t)$$

$$F_{RMS} = \sqrt{\frac{1}{T}} \int_0^T F_{max}^2 \cos^2(\omega t) dt = \sqrt{\frac{F_{max}^2}{T}} \int_0^T \cos^2(\omega t) dt$$
$$= \sqrt{\frac{F_{max}^2}{T}} \frac{T}{2} = \frac{F_{max}}{\sqrt{2}}$$

#### Remark:

The following conventions will be used in the rest of the course for RMS and max/peak values:

$$F_{RMS} \Rightarrow F$$
  
 $F_{max} \Rightarrow F_{m}$ 

# Introduction to phasors



For a given frequency, the values of  $F_m$  and  $\varphi$  completely define the functions. The time evolution is not of interest  $\rightarrow$  higher level representation: the **phasor**.

$$f(t) = \sqrt{2} F \cos(\omega t + \varphi)$$
  
=  $\mathbb{R}(\sqrt{2} F e^{j(\omega t + \varphi)})$   
=  $\mathbb{R}(\sqrt{2} F e^{j\varphi} e^{j\omega t})$   
 $\overrightarrow{F}$ 

 $\overline{F}$  is the phasor of f(t). It is a complex number, with its amplitude and its phase angle.

# Phasor diagrams



The main assumptions of the phasor approximation are a constant frequency and linearity.

Linearity ensured as Kirchhoff's laws and differential equations are linear.

Time domain

Frequency domain



The concept of phasor can be applied to electrical quantities such as voltages and currents:

Time domain

Frequency domain

$$v(t) = \sqrt{2} V \cos(\omega t + \theta) \quad \longleftrightarrow \quad \overline{V} = V e^{j\theta}$$
$$i(t) = \sqrt{2} I \cos(\omega t + \psi) \quad \longleftrightarrow \quad \overline{I} = I e^{j\psi}$$

## Alternating voltages and currents – Phasor diagrams



## Product of 2 harmonic functions $\rightarrow$ instantaneous power

p(t) = i(t)v(t)

Development on the board

$$p(t) = I V \cos(\theta - \psi) + I V \cos(2\omega t + \psi + \theta)$$

## Product of 2 harmonic functions $\rightarrow$ instantaneous power



# Power components

$$p(t) = I V \cos(\theta - \psi) + I V \cos(2\omega t + \psi + \theta)$$
Development on the board
$$p(t) = I V \cos(\theta - \psi) \left[1 + \cos(2(\omega t + \theta))\right] + I V \sin(\theta - \psi) \sin(2(\omega t + \theta))$$
P, the active power
Q, the reactive power
Power in the frequency domain  $\Rightarrow$  complex power S
$$S = \overline{V} \overline{I}^*$$
Development on the board
$$S = I V \cos(\theta - \psi) + j I V \sin(\theta - \psi)$$

$$P = Re$$

## Power components

$$S = \overline{V} \,\overline{I^*}$$
$$= P + j \, Q$$

Based on that definition, one also defines the apparent power as the norm of the complex power:

$$|S| = \sqrt{P^2 + Q^2} = V I$$

# Power reference of the one-port ("le dipole")

The signal v(t) is the voltage accross the one-port.

The signal i(t) is the current through the one-port.





absorbed by the one-port.



## Consumer or producer



# Consumer or producer (solution)



# Complex power and phasors for a resistor

$$\overline{V} = Z \overline{I} \quad \& \quad Z = R$$



$$\Rightarrow S = \overline{V} \,\overline{I}^* = \mathrm{R} \,\overline{I} \,\overline{I}^* = R \,I^2$$



# Complex power and phasors for a capacitor



# Complex power and phasors for an inductance

$$\overline{V} = Z \overline{I} \quad \& \quad Z = j\omega L$$

$$\bigvee_{\overline{I}}^{\varphi} \overline{V}$$

$$\Rightarrow S = \overline{V} \,\overline{I}^* = j \,\omega L \,\overline{I} \,\overline{I}^* = j \,\omega L \,I^2$$



# Expressions relative to one-ports

$$\overline{V} = Z \,\overline{I} = (R + j \,X) \,\overline{I}$$

$$\overline{I} = Y \overline{V} = (G + j B) \overline{V}$$

Z : the impedance $[\Omega]$ R : the resistance $[\Omega]$ X : the reactance $[\Omega]$ 

$$S = Z I^{2}$$
 [VA]  

$$P = R I^{2}$$
 [W]  

$$Q = X I^{2}$$
 [var]

- Y : the admittance [S]
- G : the conductance [S]
- B : the susceptance [S]

$$S = Y^* V^2 \qquad [VA]$$
$$P = G V^2 \qquad [W]$$
$$Q = -B V^2 \qquad [var]$$

# Recap complex power basic components



The circuit of Figure 1 presents a resistive-inductive load powered with an AC generator of sinusoidal voltage (230 V, 50 Hz). Find the voltages accross R and L (magnitude and phase angle) and represent all the voltages on a phasor diagram.



Figure: Resistive-inductive circuit.

# Exercise 2: Reactive power compensation

Your colleague suggests to add a 50  $\mu$ F capacitor in parallel of the RL load. It is supposed to compensate the reactive power consumed by the inductive load. Is it a good idea ? If so, what would be the exact value of C needed ?



Figure: Inductive circuit with compensation capacitor.

# Exercise 3: one-port small quiz

Fill the cells of the table below with the most appropriate answer among :

$$=0$$
 <0 >0  $=1$  <1  $+\infty$   $-\infty$ 

