Electromagnetic Energy Conversion ELEC0431

Exercise session 5: Synchronous machines

10 March 2023

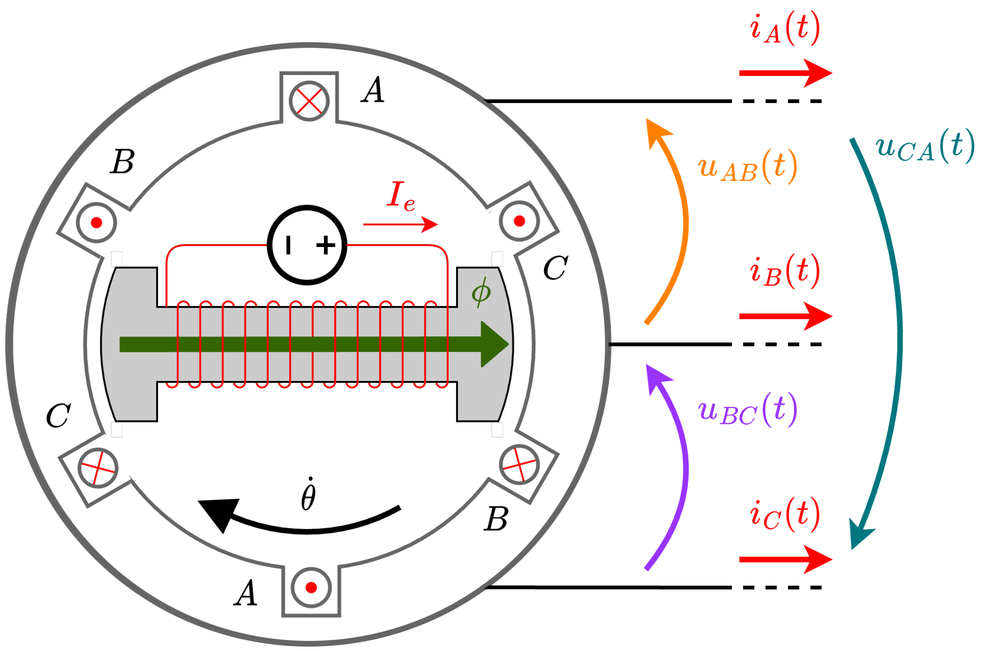
Florent Purnode (florent.purnode@uliege.be)

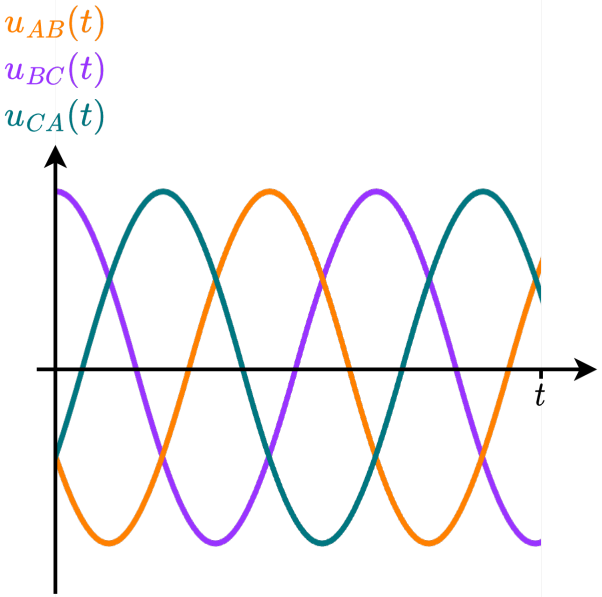
Montefiore Institute, Department of Electrical Engineering and Computer Science, University of Liège, Belgium

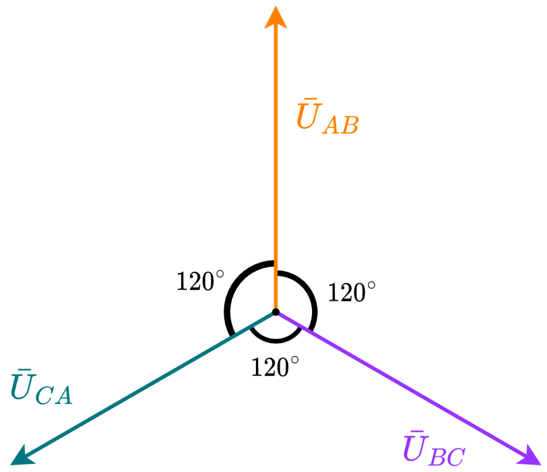
In this class…

- Synchronous three-phase generator
- Exercise 16: Three-phase turbo-alternator

Synchronous three-phase generator

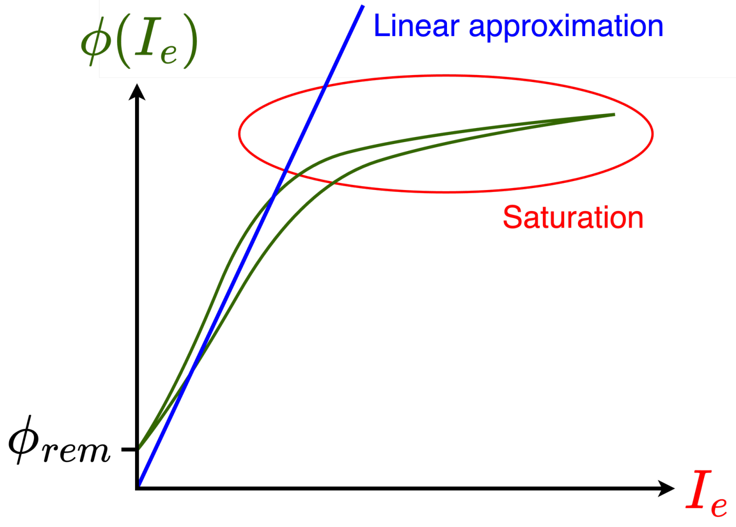






The voltage across a stator phase is $\boxed{E_v = \mathrm{k_e}\, \dot{\theta}\, \phi(I_e)}$

- E_v increases linearly with the stator speed of rotation $\dot{\theta}$ (and so does the frequency of the generated voltages).
- E_v increases linearly with ϕ.
- ϕ increases with I_e but exhibits saturation and hysteresis.



Exercise 16: Three-phase turbo-alternator

Turbo-alternators are alternators coupled to turbines allowing to convert the mechanical power of a moving fluid (steam or liquid) to electrical power. In this exercise the turbo-alternator has the following nominal characteristics:

- Power $P_n = 600\ MW$
- Frequency $f_n = 50\ Hz$
- Speed of rotation $\dot{\theta}_n = 3000\ RPM$
- Power factor $\cos\phi_n = 0.9$
- Line voltages $U_n = 20\ kV$
- Ferromagnetic losses $p_f = 543\ kW$
- Mechanical losses $p_m = 1.35\ MW$
- Rotor resistance $R_e = 0.17\ \Omega$
- Excitation system efficiency $\eta e = 0.92$
- Stator phase resistance $R = 2.3\ m\Omega$.

To characterize the turbo-alternator three tests have been performed:

- Using open stator windings, at the nominal speed of rotation $\dot{\theta}_n$, the RMS direct voltage values have been measured with respect to the RMS current intensity I_e flowing through the inductor (table on the right).
- Using short-circuited stator windings, at the nominal speed of rotation $\dot{\theta}_n$, using an excitation current of RMS value $I_e = 1.18\ kA$ has allowed a current flow in each phase winding of the stator reaching the half of the RMS nominal value.
- Using an inductive load, an excitation current of RMS value $I_e = 2.085\ kA$ has allowed a current flow in each phase winding of the stator reaching the half of the RMS nominal value. Also, the output voltage was measured as half the nominal voltage.

I_e [A]	E_v [kV]
400	5.2
700	9.1
963	11.5
1200	13
1450	14
1900	15

Exercise 16: Three-phase turbo-alternator

1. Calculate the nominal RMS intensity I_n of the stator currents.
2. Compute the total losses and the turbo-alternator efficiency at the nominal operating point, knowing the RMS excitation current value is $I_e = 3.2\ kA$ and that the alternator is in star configuration.
3. Calculate the needed mechanical power for each of the considered test.

Using Behn-Eschenburg diagram with the experimental measurements and neglecting resistive losses in the rotor:

4. Calculate the (unsaturated) synchronous reactance X_s of the turbo-alternator.
5. Plot the Behn-Eschenburg diagram for the nominal operating point.
6. Compute the RMS value E_v of the synchronous electromotive force.
7. Draw the internal lag δ_{int} angle and give its value.