Electromagnetic Energy Conversion
ELEC0431

Exercise session 5: Synchronous machines

11 March 2022

Florent Purnode (florent.purnode@uliege.be) – Nicolas Davister (ndavister@uliege.be)

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

Organisation point

Lab schedule and AC reminder class

The schedule for the lab sessions is available on the course webpage.

➔ More information on the labs and lab manual coming soon.

A small class about basics of AC circuits will be given during a lunchtime.

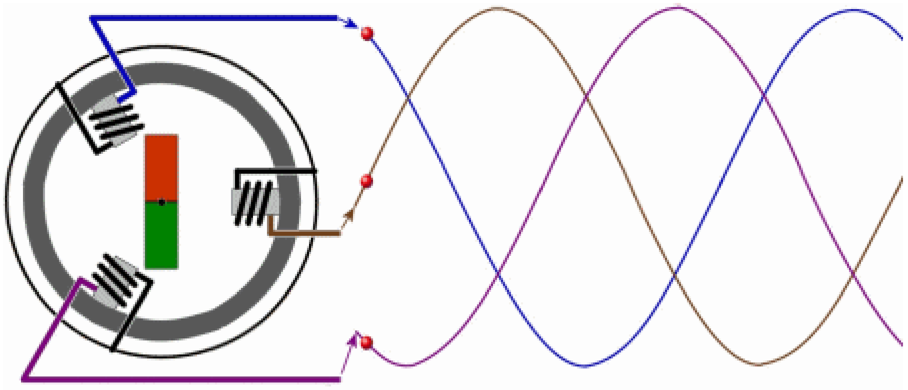
➔ If you are interested and you didn’t manifest yourself yet, please come meet me at end of the exercise session.

➔ If you have preferences for the day, please come meet me at end of the exercise session.

Reminders

Synchronous machine

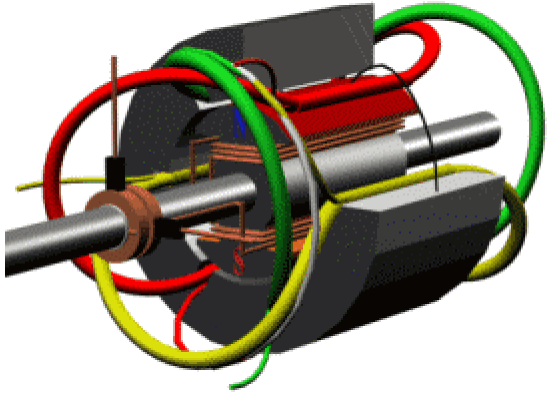
Synchronous generator – basic principle



The magnet is made to turn

➔ Varying flux at the coils

➔ e.m.f.

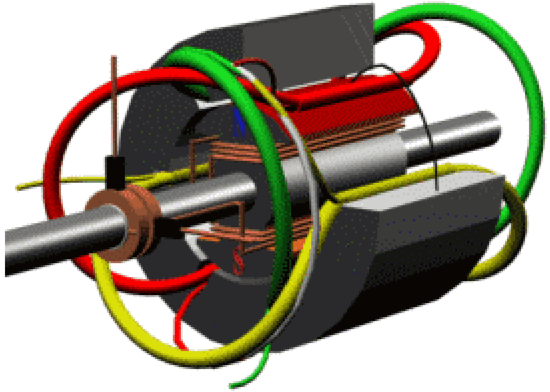


Faraday's law: $\varepsilon = -\frac{\partial \phi_B}{\partial t}$

- Higher speed leads to bigger time derivative
- Higher current in the rotor leads to higher B field

➔ $U \, \alpha \, \dot{\theta} \, I_E$

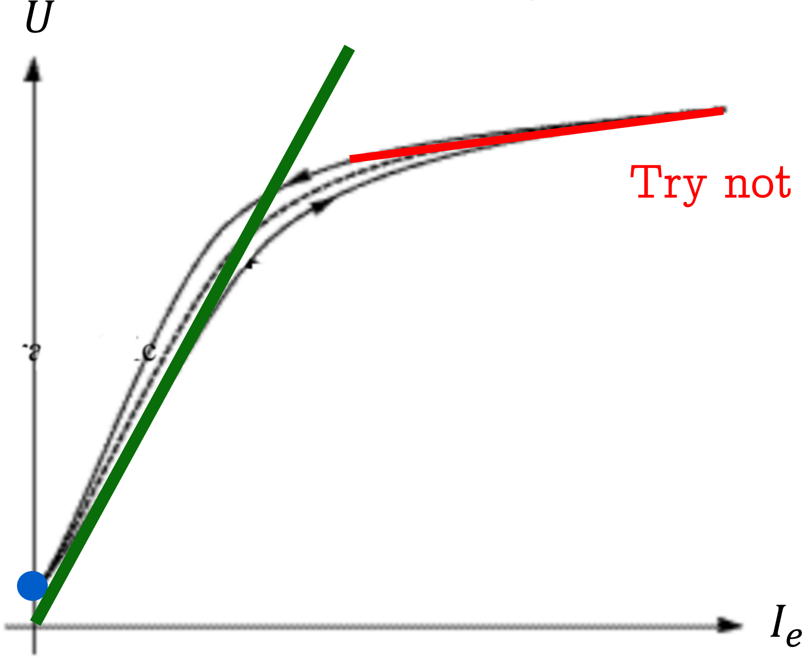
Synchronous generator – basic principle



~~$U \alpha \dot{\theta} I_E$~~ Yes but no.
The material exabits saturation and hysteresis.

The $\phi(I_e)$ relation is non linear

$$U \alpha \dot{\theta} \phi(I_E)$$



Approximation: linear relation
➔ $U = k I_e$

Try not to reach saturation

remanent state

Exercises

Exercise 16: Three-phase turbo-alternator

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 $P_n = 600\ MHz$

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 $R = 2.3\ m\Omega$.

Exercise 16: Three-phase turbo-alternator

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.

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

- 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.

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 $I_e = 3.2\,\text{kA}$;
3. Calculate the power losses for each of the tests.
4. Calculate the (unsaturated) synchronous reactance X_s of the turbo-alternator.

Using Behn-Eschenburg diagram with the experimental measurements

5. Neglecting resistive losses in the rotor, plot 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;