KTH Electrical Engineering

EG2040 Wind Power Systems
Assignment 2 – Power generation technology

Deadline for full credits: see the course webpage.

The assignments should be completed individually and the report containing all solutions should be submitted in the blue box marked EG2040, outside the student room at Teknikringen 33. If Matlab is used for completing the assignment the code should be included with the report.

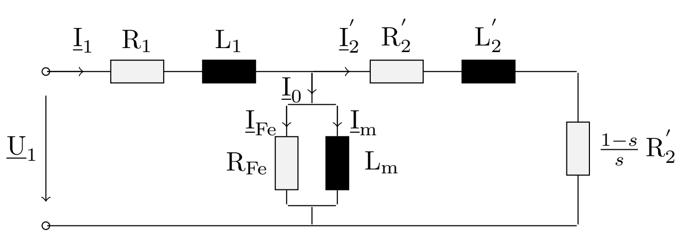
Solutions to the assignments should be well motivated and explained in detail. All equations used should be written clearly and all variables clarified. Figures and tables should be properly scaled and have captions. Write your name and student number on the front page of the assignment.

The teaching assistant will be available to answer questions during the scheduled course assistance hours.

Note

This assignment consists of one main task which you find in a grey text box at the very end. All questions before (indicated by ⇒) should help you and prepare you to fulfil the main task. All these preparing questions will not be marked, but we *highly* encourage you to briefly answer them hand-written *on this question sheet* and *return this sheet* along with your answer to the main task; because then, we can see what we should clarify during the exercise session. You will receive it back!

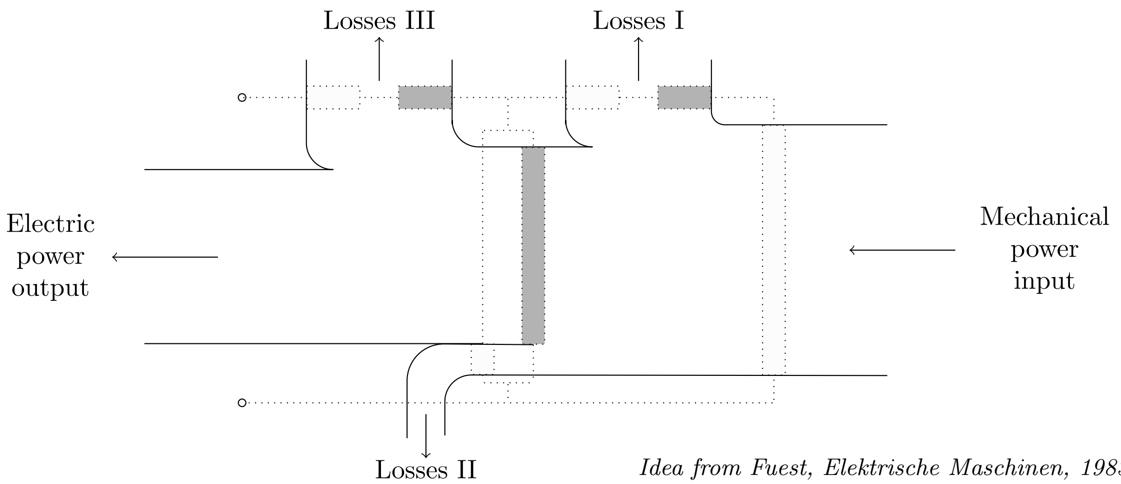
The following picture shows the equivalent circuit diagram of an induction machine.



The left side of the circuit represents the stator side (index 1), and the right side the rotor side (index 2) of the induction machine. $\underline{U}_1$ is the voltage at the machine terminals and $\underline{I}_1$ the current fed into the machine from the grid (_ indicates complex values). If the feeding grid is strong, the voltage $\underline{U}_1$ is not affected by the machine. R are ohmic resistances, while L symbolises inductive elements. Both rotor and stator are coupled through their magnetic fields represented by the main inductance L_m. Due to R_{Fe}, a part of the current $\underline{I}_0$ flows through R_{Fe} not magnetising L_m. To combine stator and rotor circuits in the same circuit diagram, rotor parameters are adjusted which is indicated by $'$. The resistance on the right hand-side represents the mechanical power input (generator mode) or output (motor mode). Here, s is the slip; if the machine is run in motor mode, all currents are directed as indicated, i.e. $\underline{I}_1 > 0$, $\underline{I}_m > 0$ and $\underline{I}_2' > 0$.

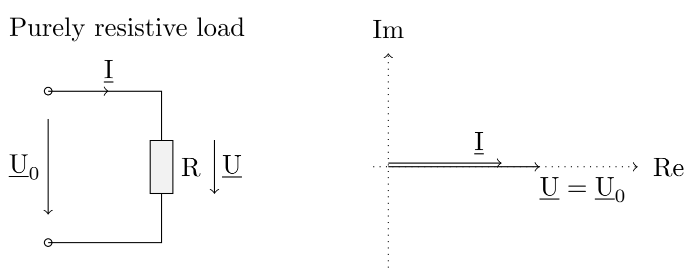
In the next figure, you see a sketch for an induction machine running in generating mode. The sketch is not drawn to scale (in practice losses tend to be smaller).

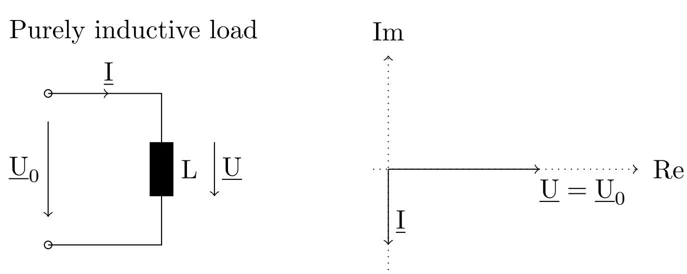
⇒ What are the reasons for the indicated losses? Draw a similar sketch for the case where the induction machine works as a motor. In which range will the slip s be in that case?



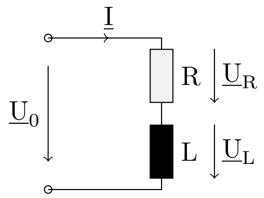
Idea from Fuest, Elektrische Maschinen, 1983.

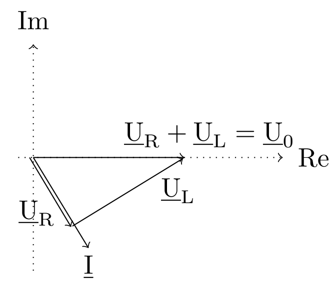
In case you are not familiar to phasor diagrams, the following sketches might give you some guidance to understand what follows. $\underline{U}_0$ is the applied voltage.



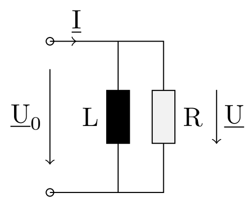


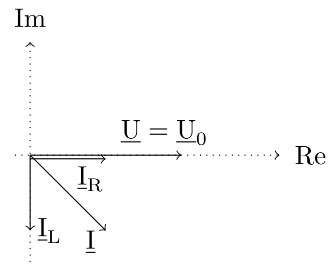
In series



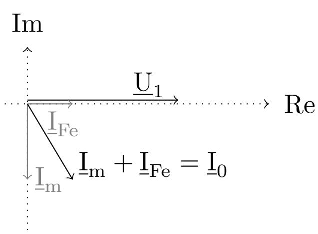


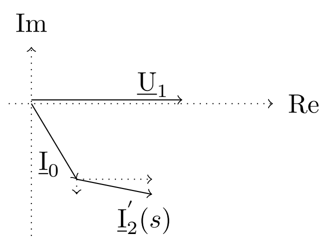
Parallel

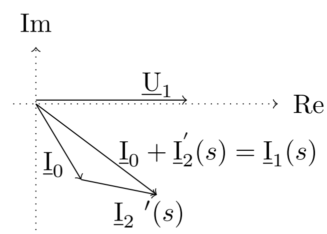




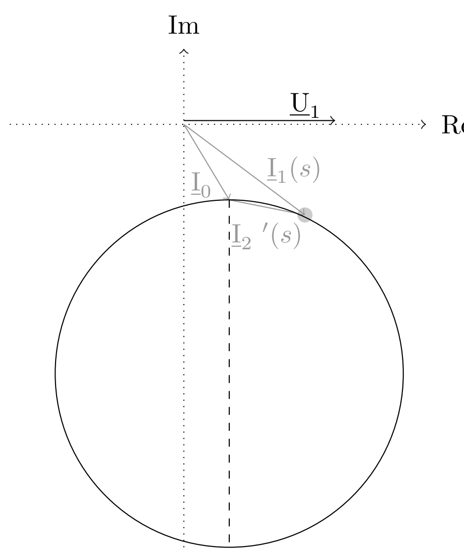
Based on the equivalent circuit diagram in the introduction, the phasor diagram can be constructed:

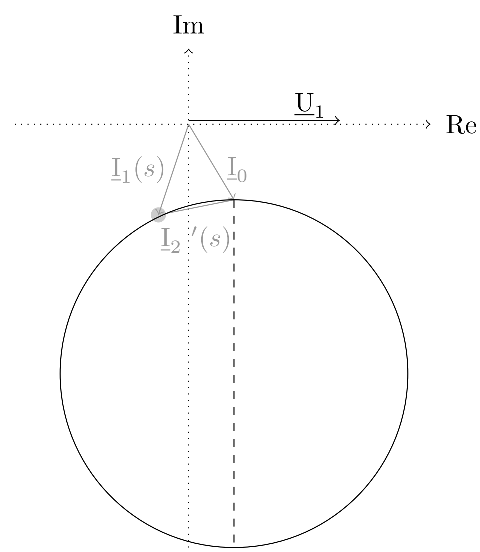






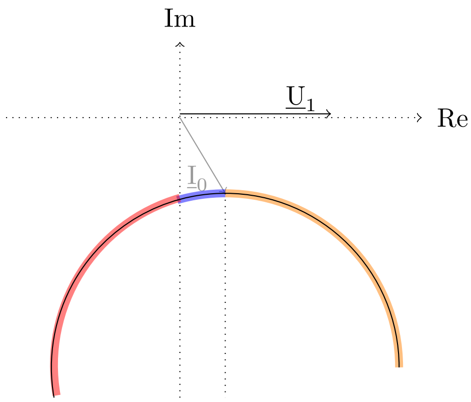
The current $\underline{I}_2^{'}(s)$ is a certain function of the slip s; therefore, the machine cannot be run at all arbitrary operating points. Feasible operating points lie on a circle (so-called *Heyland diagram* or *Ossanna circle*) as indicated in the following diagram. Observe that for induction machines, $\underline{I}_0$ is not dependent on s.





Because the slip s is usually very small, we focus on the operating points on the upper part of the circle.

⇒ Have a look at the coloured ranges in the figure below and indicate whether the real parts of $\underline{\mathrm{I}}_2^{'}$ and $\underline{\mathrm{I}}_1$ are > 0 or < 0 for operating points within the range. Then, think about whether $s > 0$ or $s < 0$, whether the machine works in generator or motor mode and whether it is producing or consuming active power from the grid ($P > 0$ or $P < 0$). Add all your results in the table.



Range	$\mathrm{Re}(\underline{\mathrm{I}}_2^{'})$	$\mathrm{Re}(\underline{\mathrm{I}}_1)$	s	Mode	P

⇒ What happens in the blue range?

Finally, observe that induction machines are always consuming reactive power Q independent of whether they generate or consume active power P:

$$\mathrm{Q} = \mathrm{Im}\{\underline{\mathrm{S}}\} = \mathrm{Im}\{\underline{\mathrm{U}}_1 \underline{\mathrm{I}}_1^*\},$$

where the apparent power $\underline{\mathrm{S}} = \mathrm{P} + j\mathrm{Q}$ and $\underline{\mathrm{I}}_1^*$ marks the conjugate of $\underline{\mathrm{I}}_1$, i.e. $\underline{\mathrm{I}}_1 = \mathrm{Re}\{\underline{\mathrm{I}}_1^*\} - j\,\mathrm{Im}\{\underline{\mathrm{I}}_1^*\}$. Due the choice of $\underline{\mathrm{U}}_1$ as reference voltage with zero phase angle: $\mathrm{Im}\{\underline{\mathrm{U}}_1 \underline{\mathrm{I}}_1^*\} = |\underline{\mathrm{U}}_1|\,\mathrm{Im}\{\underline{\mathrm{I}}_1^*\}$ we get:

$$\mathrm{Q} = \mathrm{U}_1\,\mathrm{Im}\{\underline{\mathrm{I}}_1^*\} = \mathrm{U}_1(-\,\mathrm{Im}\{\underline{\mathrm{I}}_1\}) > 0,$$

which holds for all operating points as you can see in the Heyland diagram above.

Main task

Explain in detail how a squirrel-cage induction machine works in generator mode feeding active power into the grid. Use sketches which can be drawn free-hand.

We do not want you to spend too much time on drawing sketches or typesetting basic equations. Therefore, we want to encourage you to hand in a hand-written answer. Your answers do, of course, have to be readable ☺.

Be careful not to plagiarise! And observe that copy-pasting figures from another source without stating the reference counts as plagiarism as well!