Division of Electric Power Engineering
Department of Electrical Engineering
Chalmers University of Technology

Laboratory Instruction
Induction Machine Modeling and Operation

Name ______________________

Personal Number ______________________

Approval ______________________

Attention! This laboratory assignment is composed of 3 parts:

1. The home assignment in section 2 must be completed in order to be allowed to perform the measurements
2. The measurement part is performed either on 2019-09-23 Monday or 2019-09-26 Thursday (time booking on Canvas), the measurement tasks are described in Section 1.2.
3. The calculations of the induction machine parameters and the post processing of the measurements taken on the lab are performed and approved as home assignments for the first computer task, starting on 2018-10-03 Monday.

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Part I Practical Laboratory Instruction

This laboratory assignment does not have the "normal" layout of a recipe, first do this, then this and so on. For this assignment there is a description of what should be done, and in Appendix A, there is a description of the instruments that are available in the laboratory. To prepare and plan the laboratory assignment, you need to read through this instruction, and the Home Assignments in Section 2 must be done before the Lab Assignments in Section 3 carried out in the laboratory.

1 Introduction

The tasks for the laboratory exercise are to take the measurements needed to determine the parameters of the equivalent circuit of the induction machine (a no-load test and a locked rotor test), to measure the steady-state performance of the machine and to capture the direct start and a load step of the induction machine. The laboratory exercise is conducted on a 4 kW induction machine. The rating plate of the machine is shown in Figure 1. In Figure 2 the equivalent circuit of the induction machine, with the iron loss representing resistance ignored, is presented. Y-connection is applied in this assignment.

Figure 1. Photo of the rating plate of the induction machine.

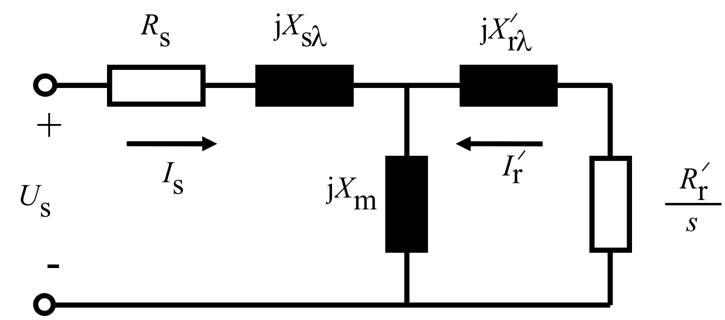


Figure 2. Equivalent circuit of the induction machine.

2 Home Assignments

Attention! These should be solved before the lab.

Home Assignment 1: Test Circuit

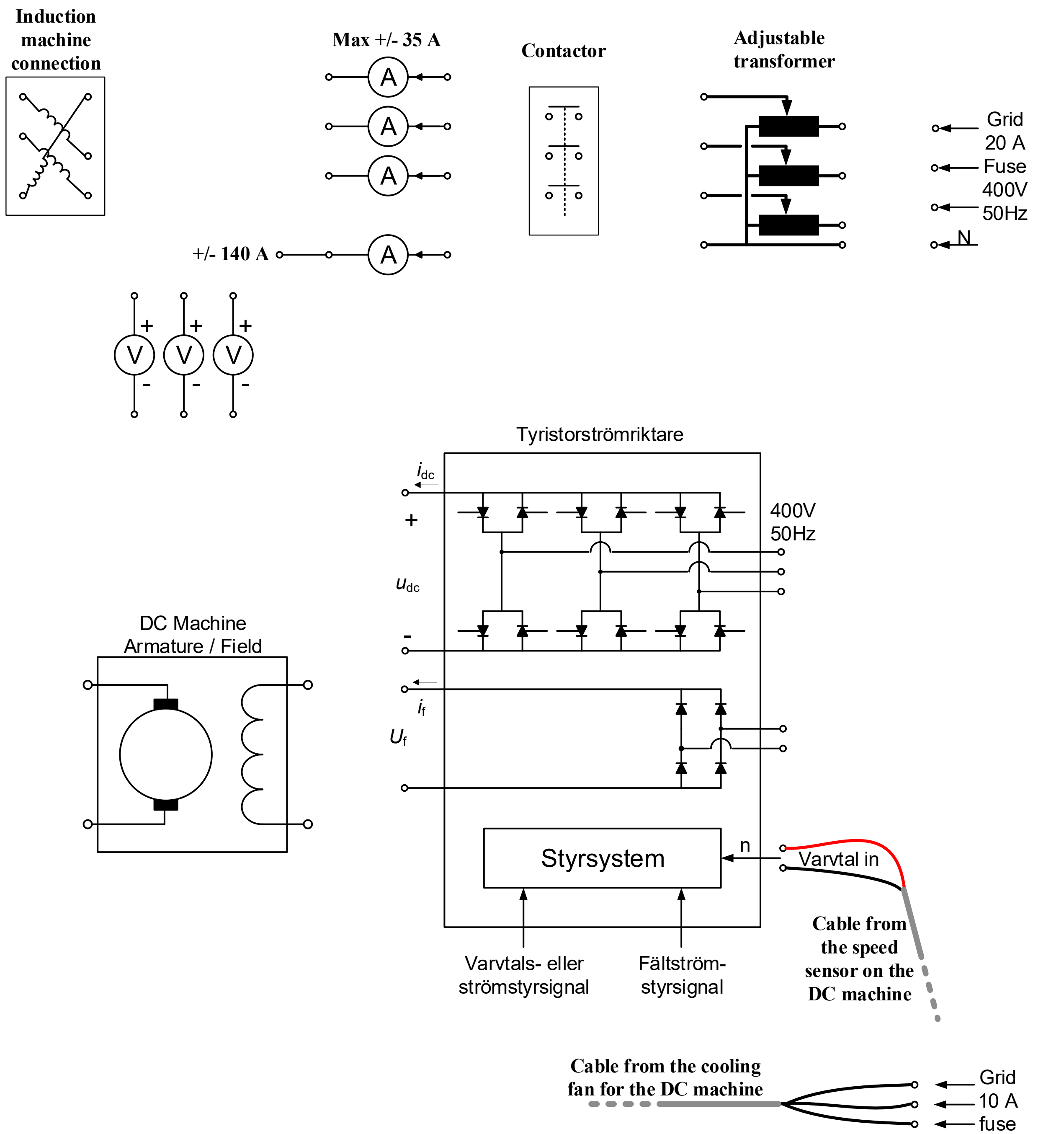
Describe how the parameters of the equivalent circuit, in Figure 2, can be determined from active and reactive power in locked-rotor and no-load tests. Please draw the circuit diagrams to illustrate.

Home Assignment 2: Testbench Connection

Draw the connections you need for making the locked rotor experiment in the figure below, do not forget the sensors for measurements.

- Connect the machine to the output of the built-in adjustable transformer via the contactor. In this way the machine can be connected and disconnected from the control panel.
- Also make the necessary connections for the dc machine.
- For one phase you should measure the phase current with two current sensors in series, the 35 A and the 140 A sensor. **You can think about why this is needed.**

- For the no-load, steady-state and start measurements you only need to disconnect the adjustable transformer and connect the machine directly to the 400 V grid via the contactor.



3 Lab Assignments

Attention!

Please do the connections with cable in proper color-codes and proper lengths.

Please read through all the steps of each task before starting the task.

Task 1: Stator Resistance Measurement

Measure the stator resistance of the induction machine with the digital multimeter. Connect all three phases in series and measure the total resistance.

Why should you measure the resistance like this?

Why do you need to measure the stator resistance separately?

Attention for Task 2, 3, 4 and 5:

- **Three pieces of LabView programs located in the desktop folder *Lab Applications (server)* are used to sample the measurement data.**
    - ***Sample_EXPM* is used for Task 2 and 3.**
    - ***Lab2eng* is used for Task 4.**
    - ***Induction Machine Start with Torque Step* is used for Task 5.**
- **A piece of MATLAB post process code can be downloaded from Canvas, and from here on, the participants can use the code to check the waveforms at the end of each task.**
- **Please create a folder on the desktop and save all the measurement data in the folder together with the MATLAB post process code.**

Task 2: Locked-Rotor Test

For the locked rotor test, the DC Machine is used in speed control mode to keep the rotor at zero speed. The built-in adjustable transformer should be used to lower the voltage to the machine, in order to perform the experiment at rated current. **Observe** that when the locked rotor experiment is performed the supervisor should be present to monitor the experiment:

1. Make the connections from Home Assignment 2.
2. Also connect the signals to the inputs for the computer. The signals u_1, u_2, u_3, i_1, i_2, i_3, i_6 and n should be connected to the **Analogue Inputs** from AI0 to AI7 on the control panel. <u>YOU HAVE TO WRITE DOWN TO WHICH INPUT CHANNEL YOU CONNECT WHICH SIGNAL, SO YOU KNOW THIS WHEN YOU USE THE MEASUREMENTS</u>.

Signal	Analogue Input (from AI0 to AI7)
u_1	
u_2	
u_3	
i_1	
i_2	
i_3	
i_6	
n	

3. Check so that the adjustable transformer is on 0 output voltage by turning the knob in the direction of 0 V until you reach the end stop. Do not trust the indicator on the knob.
4. Check the control configurations
   - Set the Speed/Current Control in **Speed Control** mode (*sv: Varvtal*) and **Internal Control** (opposite to *sv: Extern Styrning*), that the speed reference is on 0.
   - Set the Field Current Control in **Internal Control** (opposite to *Extern Styrning*). Make sure the field current is set to 0 as well.
5. Get the connections approved by the supervisor.
6. AFTER approval, turn on the main switch and put the thyristor converter to operate and adjust the field current I_f to 1.5 A and adjust the speed to 0 by looking on the shaft.
7. Measurement will be done with the help of a LabView program *Sample_EXPM* (located in the folder "Lab Applications (server)" on the desktop). Open the LabView program.
   a. Turn on the contactor and increase the current to the rated current by turning the knob of the adjustable transformer. What is the rated current of the induction machine?
   b. Measure the stator voltage and currents and the rotor speed for the locked rotor test of the induction machine with the LabView program
8. Directly after you have got the question from the LabView program whether you want to save the file, turn down the knob to 0 again, disconnect the contactor, turn off the thyristor converter, and turn off the main switch.
9. Save the measurement file from the LabView and bring it with you. You need it for the calculation of the parameters.

Task 3: No-Load Test

1. The thyristor converter should be kept off in this test.
2. Modify your connections by disconnecting the adjustable transformer and connect the machine directly to the 400 V grid via the contactor.
3. Get the connections approved again.
4. Open the *Sample_EXPM* LabView program (located in the folder "Lab Applications (server)" on the desktop) for measurement.
5. Turn on the main switch and the contactor. The machine should start to rotate.

6. Check so that the direction of rotation is according to the arrow indicating positive direction. If it is not, turn off the system and make necessary changes and get it approved again. Start up the system again.
7. Measure the stator voltage and currents and the rotor speed for no-load operation of the induction machine.
8. Save the measurement file from the LabView program described in Appendix A1.4 and bring it with you. You need it for the calculation of the parameters.
9. Close the previous LabView program, click on “Don’t Save” if you get the question about whether you want to save the changes.
10. Turn off the contactor and the main switch.

Task 4: Load Test

Measure the steady-state performance of the induction machine between the rated current in motor mode to the rated current in generator mode.

1. Connect the cooling fan and keep it on during the test.
2. For this measurement you will use the same setup as in Task 3, so you do not need to change any other connection in the power circuit.
3. Open the LabView-program *Lab2eng – Shortcut* (located in the folder “Lab Applications (server)” on the desktop) and press the button “Show Overview Picture w. values” in the main menu.
4. Connect the analogue inputs according to the instructions on the screen.
5. Before you switch on the voltage, make sure that the thyristor converter control system on the instrument panel is positioned on **Current Control** (*sv: ström*) and **Internal Control** (opposite of *Extern Styrning*) and that the contactor control is on OFF (AV).
6. Switch on the main switch and push the “Offset Adjust” button on the screen.
7. After this, switch on the induction machine by changing the contactor control to ON (PÅ). The induction machine starts to rotate.
8. Before turning on the thyristor converter, adjust the “Speed Gain Adjust” on the screen so that the speed meter on the screen shows the same speed as the speed display on the control panel, see Figure 7 in Appendix 1.3.
9. Also before turning on the thyristor converter, make sure that the control by which you adjust the armature current I_{dc} is set to zero.
10. Turn on the thyristor converter by turning the control switch to Operate (*sv: drift*).
11. Adjust the armature current I_{dc} to zero and the field current I_{f} to 1.5 A.
12. Write down the value of the armature voltage for no-load operation in the table below, the speed values should be taken from the speed display on the control panel.
13. Change the DC machine armature current and take some more measurement points between the **rated current in motor mode** to the **rated current in generator mode** for the induction machine. Record the values in the table below.
14. Turn off the system. And please verify the measurements with the lab assistants.

Armature current	*Armature voltage*	*Speed from panel*	**Stator active power**	**Stator reactive power**	**Stator voltage**	**Stator current**	**Torque**
I_d (A)	U_d (V)	n (RPM)	P_{tot} (W)	Q (VAr)	U_s (V rms)	I_s (A rms)	T (N·m)
						8.8	
0							
						9.1	

Task 5: Direct Start and Load Measurements

Measure the stator voltage and currents and the rotor speed for a direct start and a load step.

1. For this measurement you will use the same setup as in Task 4, so you do not need to change the connections in the power circuit, keep the cooling fan on.
2. Close the previous LabView program, click on “Don’t Save” if you get the question whether you want to save the changes and open the LabView program *Induction Machine Start with Torque Step – Shortcut* (located in the folder “Lab Applications (server)” on the desktop).
3. Connect the analogue inputs, analogue output and digital output according to the instructions you find by clicking on “help” in the top left corner of the window, it is almost the same connections as in Task 4.
4. Before you switch on the voltage, make sure that the thyristor converter control system on the instrument panel is positioned on **Current Control** (*sv: ström*) and **External Control** (*sv: Extern styrning*) for the armature current and that the contactor control is on EXT …
5. Switch on the main switch and turn on the thyristor converter by turning the control switch to ‘drift’ (operate).
6. Adjust the field current to 1.5 A.
7. Set the slider for the armature current reference to the value that gave rated motor operation in Task 4.
8. Then press the start button. The program will then start to capture the values. After approximately 30 ms the contactor is turned on and the induction machine starts, the armature current reference is kept to zero during the start up. After 1 s from the start the armature current reference is stepped to the slider value and after additional 0.5 s it is stepped to zero again. After 2 s the measurement is stopped, and the contactor is opened.
9. Save the measurement file from the LabView program and bring it with you. You need it for the comparison with the simulated start and the simulated load step in the first project work assignment.

Task 6: Post Process

Since the machine parameters are needed to start the computer laboratory assignment, post process of the measured data needs to be done. A piece of post process code can be found in the Lab folder in Canvas. The participants are free to decide if they want to do the post process at home or in the laboratory. If the post process is done in the laboratory, then the lab assistants can help the students verify whether the results are within the correct range. Please

- Put all the measurement data file and the MATLAB code in the same folder on the desktop.
- In the import data process of the code, change the file names in the load syntax to the file names of the measurement data.
- Run the code and get the plots.
- Complete the formulas in the parameter calculation section of the code and get values of the parameters.

Task 7: Cleaning Up

Before you leave the lab make sure that you have the following measurements with you:

- The stator resistance.
- Measurements file for the locked rotor test.
- Measurements file for the no-load test.
- Measurements file for the direct start and load step.

Make sure that the voltage is turned off and disconnect everything and clean up.

Appendix A The Laboratory Equipment

As always in the grundkurslaboratoriet, the connections MUST be approved by the supervisor before the voltage can be switched on. As can be noticed in the laboratory the phases, neutral, positive and negative have different colors, when making the connections these should be followed. In Figure 3 an overview of the laboratory setup is shown.

1. First check that the switches on the supply panel are OFF
2. Make the connections including the signal connections.
3. Ask the supervisor to check the connections and discus with the supervisor how you have planned to do the measurements.
4. After approval block the experimental area with the “blocking rope”.
5. The main switch (located on the supply panel) for the laboratory setup can be turned ON and the measurements can be done.

If you suspect that something is wrong, push the emergency stop push button (Nöd Stopp) and ask the supervisor to check the experiment. Each time you have changed the setup you must get a new approval before the main switch is turned ON. In addition to the things shown in Figure 3 there is a digital multimeter available for additional resistance measurements. There is also a LabView program available that stores your measured data in a file that can be read from Matlab.

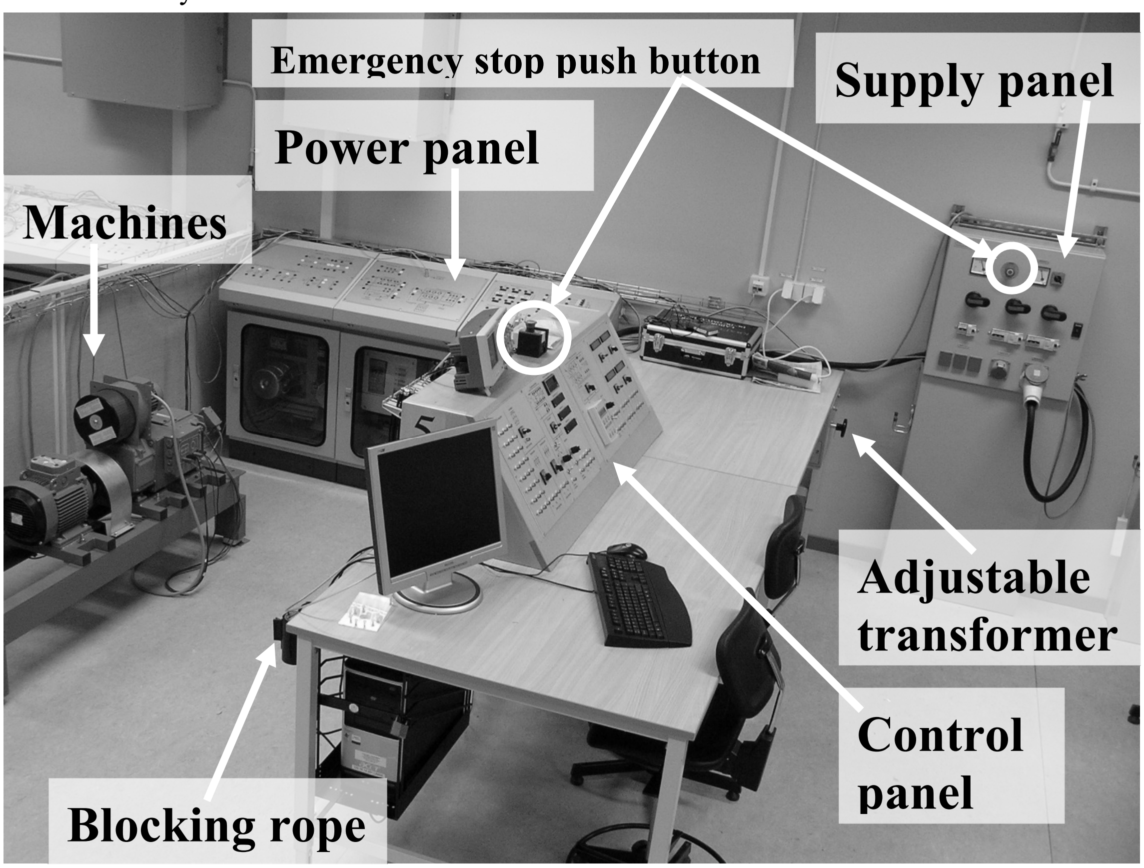


Figure 3. Overview of the laboratory setup.

A1.1 Machines

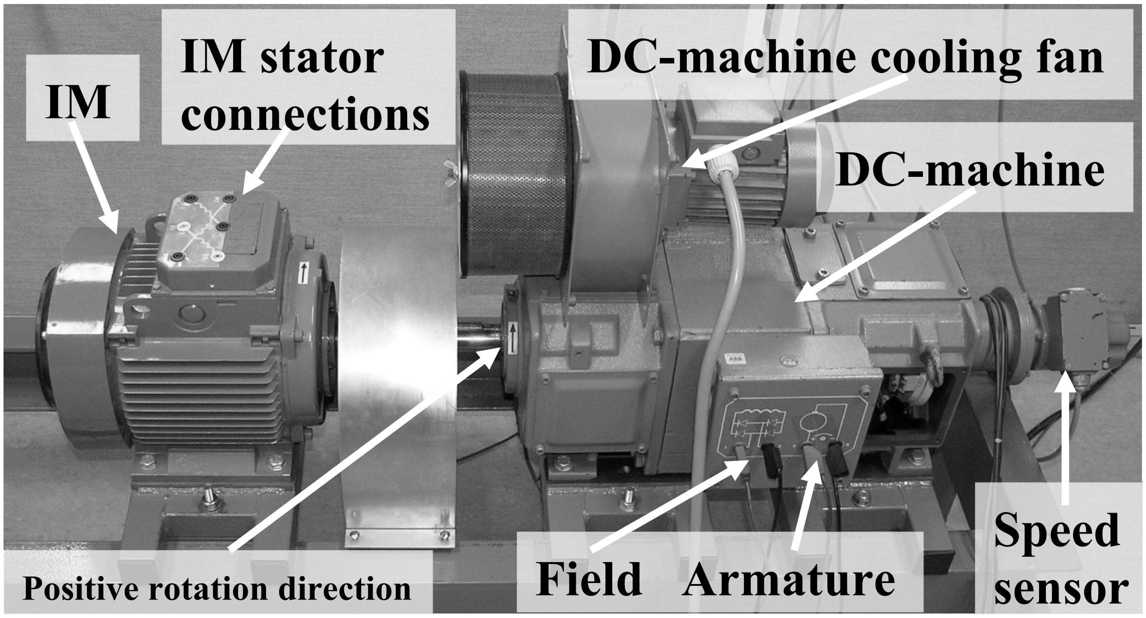


Figure 4. The machines and speed sensor.

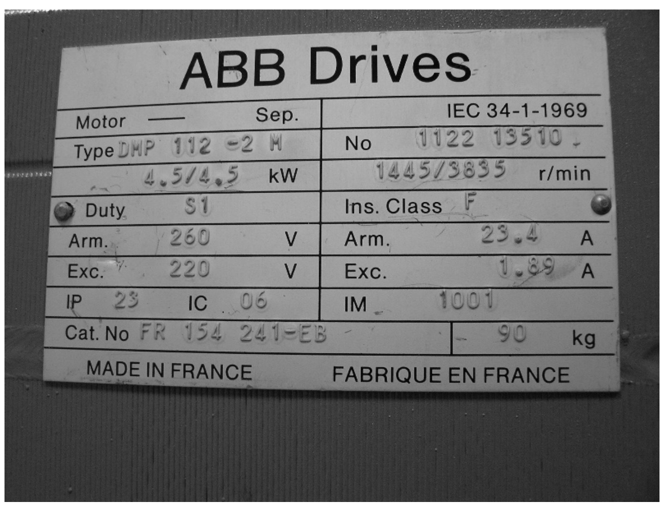


Figure 5. Photo of the rating plate of the dc-machine.

A1.2 Power panel

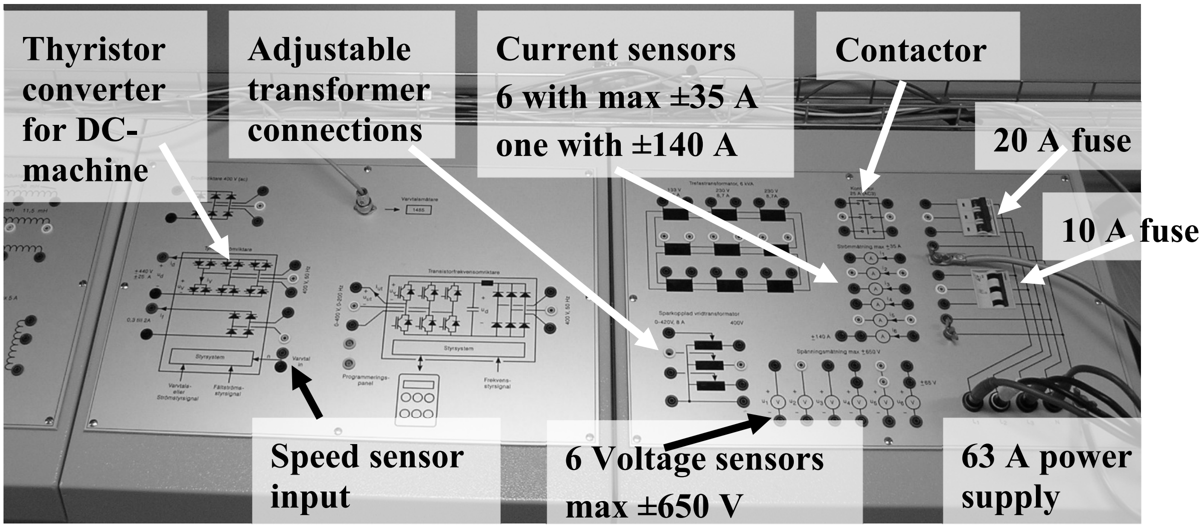


Figure 6. The power panel.

A1.3 Control panel

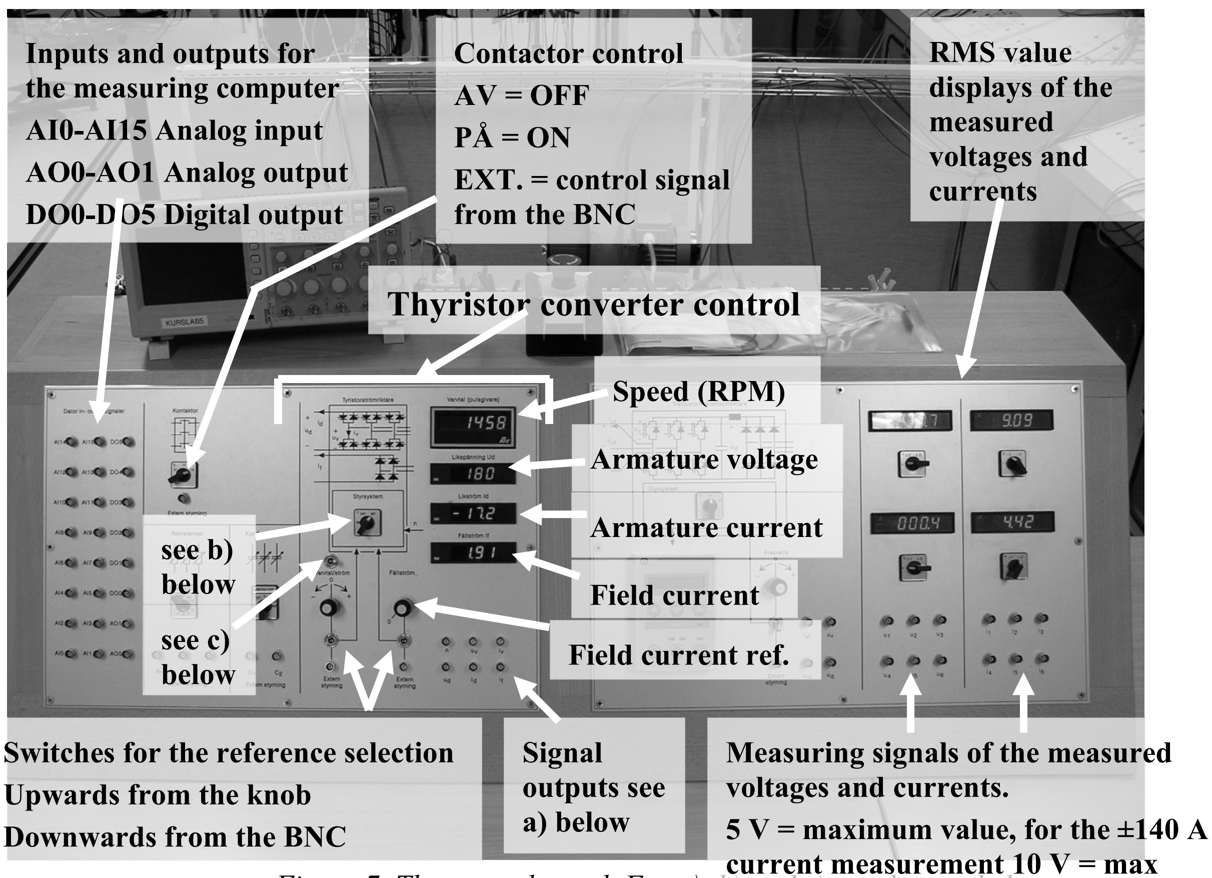


Figure 7. The control panel. For a), b) and c) see the text below.

a) Measuring signals from the thyristor converter.
n = speed
u_v = voltage across one valve
i_v = current through one valve
u_d = Armature voltage
i_d = Armature current
i_f = Field current

b) Switch for turning the thyristor converter on and off
FRÅN = OFF
STOPP = STOP, the converter is on but in stand by
DRIFT = OPERATE, the converter is on.

c) Switch for selecting the control method for the dc-machine
Left (Varvtal) = Speed control
Right (Ström) = Armature current control

A1.4 LabView program for locked rotor and no-load tests

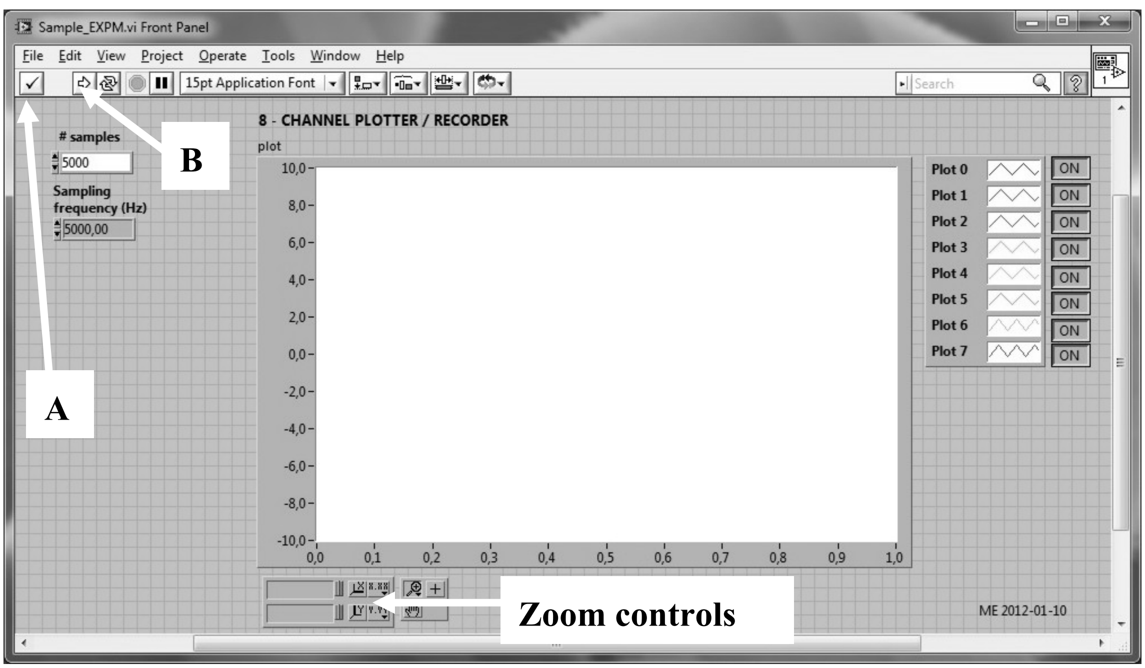


Figure 8. LabView program for capturing time traces of voltage, current and speed.

Logon with your CID on the lab computer. The LabView program can be found in the folder "Lab Applications (server)" on the desktop, double click on the shortcut "Sample_EXPM - Shortcut". In the field "# sample" the number of samples per channel that should be stored is specified, default is 5000, and in the field "Sampling frequency (Hz)" the sampling frequency can be changed, default is 5 kHz. When something in these two fields is changed, button A is shown, to enter the new value you must click on it. To start the measurement, click on button B, after all samples are collected a new window will pop up asking where to save the file. Name the file so you remember which experiment it was, for example "Locked_Rotor.txt". It is only the specified channels that are stored in the file, the time vector you have to create in MATLAB.

The voltage and current sensors shown in Figure 6 scales the measured quantity to a low voltage signal, which value is proportional to the measured quantity. The low voltage signals you can access on the control panel, see in the lower right corner of Figure 7. The used signals should be connected to the analog inputs of the measuring computer, left side of Figure 7. What is shown in the LabView program and what is stored in the measurement files are the values of the low voltage signal. To obtain the value of the measured quantity these values needs to be multiplied with the scaling constant, which you can obtain from Figure 7.

A1.5 Scaling Factor in the Saved Data File in Task 2, 3, 4 and 5

In this section it is shown how we calculate the scaling factors for different sensors, such as current, high current, voltage and speed. The values are also available on the shelf door of the lab.

Current scaling factor:

The current sensors with the accuracy of max 35 A to measure, should be multiplied by **35/5** = 7.

The high current sensors with the accuracy of max 140 A to measure, should be multiplied by **140/10 =** 14.

Voltage scaling factor:

The voltage sensors with the accuracy of max 650 A to measure, should be multiplied by **650/5** = 130.

Part II Computer Laboratory Instruction

1 Introduction

This computer lab is a modeling practice. The parameters of an induction machine have been calculated from the measurement in the practical lab, and now in this lab

- A mathematical model of the induction machine is going to be derived (in Home Assignments) and implemented in Simulink (Lab Assignments).
- Thereafter, verification of the model needs to be done as well with comparisons between the simulated and experimental direct-start performances.
- In the end, some parameters, e.g. inertia and viscous damping factor, will be adjusted to improve the participants' understanding of electric drive system.

2 Home Assignments

Home Assignment 1: Induction Machine Parameter Calculation

Calculate the parameters of the induction machine from the lab measurements. From the no-load and locked rotor measurements, calculate the parameters and fill the values in the table below.

	No-load	**Locked rotor**		
$\boldsymbol{U}_{\mathbf{s.rms}}$			$R_\mathrm{s} =$	$R'_\mathrm{r} =$
$\boldsymbol{I}_{\mathbf{s.rms}}$			$L_\mathrm{sl} =$	$L'_\mathrm{rl} =$
$\boldsymbol{P}_{\mathbf{s}}$			$L_\mathrm{m} =$	
$\boldsymbol{Q}_{\mathbf{s}}$				

Please note that, since the parameters are referred to the stator side, the turns ratio becomes 1:1, which means the magnetizing inductance share the same value as mutual inductance, i.e. $L_\mathrm{Mag} = \frac{N_1}{N_2} L_\mathrm{m} = L_\mathrm{m}$.

Home Assignment 2: Induction Machine Dynamic Modeling

Derive the state-space equations of the dynamic T-equivalent circuit of the induction machine in αβ-coordinates and the matrices needed for the implementation of the dynamic model. Separate the electrical and the mechanical states for the implementation (see the induction machine modeling tutorial). Implement the electrical states by using matrices and the mechanical states by using separate equations.

The six state variables should be:

- Stator currents in the αβ-frame
- Rotor currents in the αβ-frame
- Electrical rotor speed
- Electrical rotor position.

The model should be implemented using amplitude invariant transformation. And a diagram of the model can be described as shown in Figure 9.

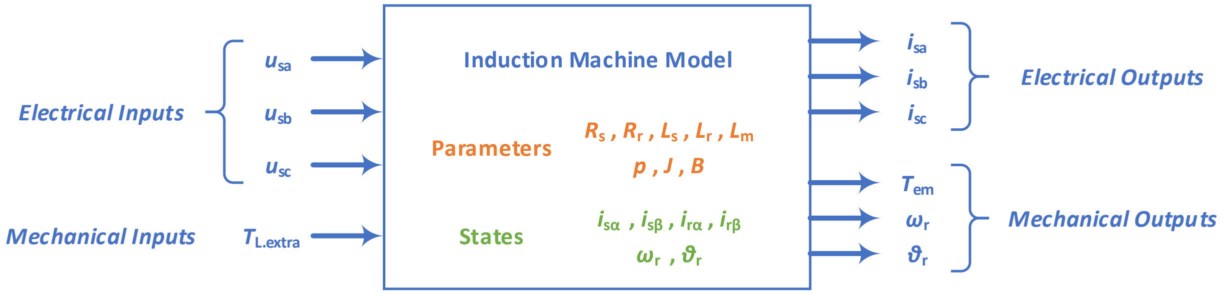


Figure 9. Dynamic model of induction machines.

The inputs to the dynamic model should be:

- Stator voltages, in Phase A, B and C.
- The extra load torque $T_{\mathrm{L,extra}}$.

The load torque, T_{L}, shall consist of two parts:

- A speed dependent part determined by the parameter B and
- A direct extra load torque input $T_{\mathrm{L,extra}}$

The complete load torque should be implemented as

$$T_{\mathrm{L}} = B\Omega_{\mathrm{r}} + T_{\mathrm{L,extra}} = B\frac{\omega_{\mathrm{r}}}{p} + T_{\mathrm{L,extra}}$$

Please observe that Ω_{r} is the mechanical speed in rad/s and ω_{r} is the electrical speed rad/s of the rotor.

The outputs of the dynamic model should be:

- Stator currents, in Phase A, B and C.
- Electromagnetic torque
- Mechanical rotor speed
- Mechanical rotor position

Please formulate your dynamic model with all necessary equations and steps.

Home Assignment 3: Coordinate Transformations

- Describe how the physical rotor current (in 3-phase, assuming turns ratio as 1:1) from your αβ-induction machine model can be determined. Which frequency should the currents have?
- Describe how the stator and rotor currents from your αβ-induction machine model can be transformed to dq-coordinates.
- From the dynamic T model of the induction machine in αβ-coordinates derive the steady-state model in dq-coordinates, and the equivalent circuit.

If you want to start before you have calculated the equivalent circuit parameters, you can use the following approximate values until you have done it

$$R_{\mathrm{s}} = 1.33\ [\Omega]$$
$$L_{\mathrm{s}\lambda} = 8.1\ [\mathrm{mH}]$$
$$R'_{\mathrm{r}} = 1.24\ [\Omega]$$
$$L'_{\mathrm{r}\lambda} = 8.1\ [\mathrm{mH}]$$
$$L_{\mathrm{m}} = 135\ [\mathrm{mH}]$$
$$J_{\mathrm{IM+DCM}} = 0.051\ [\mathrm{kg}\cdot\mathrm{m}^2]$$

3 Lab Assignments

Task 1: Model Implementation

Download the file *Computer_Lab_IM_Model.zip* from the course web page on Ping-Pong and unzip it. Then, please

- Fill in the measured parameters in the main code. The inertia of the system can be set as $J_{\mathrm{IM+DCM}} = 0.051\ [\mathrm{kg \cdot m^2}]$ and the viscous damping factor can be set as $B = 0\ [\mathrm{N \cdot m \cdot s/rad}]$
- Complete the induction machine dynamic model by filling the derived equations in the Home Assignments into the "*MATLAB Function - Induction Machine -*" block in the Simulink file.
- Run the simulation and get the plots.

Task 2: Model Verification with Measurements

In this task, the behavior of the induction machine measured in the laboratory assignment should be simulated and compared with the measurements. The task is divided into five steps, from Task 2A to Task 2E. The plots for comparison will be generated and analysis will be performed in the final step 2E, and before that can be achieved, loading data and some necessary calibrations need to be done in steps from 2A to 2D.

Task 2.A Load Data

In the text file from the lab the channel list is:

1. time [s]
2. Stator voltage Phase A [V]
3. Stator voltage Phase B [V]
4. Stator voltage Phase C [V]
5. Stator current Phase A [A]
6. Stator current Phase B [A]
7. Stator current Phase C [A]
8. Armature voltage of the DC machine [V]
9. Armature current of the DC machine [A]
10. Field current of the DC machine [A]
11. Rotor speed [rad/s]
12. Stator current measured with the high current sensor [A]

You can load the measurement file into the MATLAB memory and extract the channels as:

```
data = load('Task_5_IM_Direct_Start');
time_m   = data(1,:);
u1_m     = data(2,:);
u2_m     = data(3,:);
u3_m     = data(4,:);
i1_m     = data(5,:);
i2_m     = data(6,:);
i3_m     = data(7,:);
ua_m     = data(8,:);
ia_m     = data(9,:);
ifeild_m = data(10,:);
speed_m  = data(11,:) * 30 / pi;            % To get the speed in RPM
i3high_m = data(12,:);
```

Please place this code at the end of the post process MATLAB script: *post_process_code.m*.

Task 2.B Speed Calibration and Voltage Step Matching

To be able to make a comparison between the measured speed and the simulated speed, the speed measurement needs to be calibrated. The measured speed signal usually contains a DC offset, i.e. the speed is not zero before the machine is started and the no-load speed after the start is not equal to the synchronous speed. The following MATLAB code can be used to calibrate the speed measurement signal:

```
temp      = time_m < 0.047;                % To finds elements for time < 0.047 s
Speedoff  = mean(speed_m(temp));           % Offset for the speed
speed_m   = speed_m-Speedoff;              % To Remove the offset

temp      = (time_m > 0.6)&(time_m < 0.9); % To finds elements for 0.6 < time < 0.9 s
SpeedGain = 1500 / mean(speed_m(temp));    % Gain adjust for the speed
speed_m   = speed_m * SpeedGain;
```

This code assumes that the start of the induction machine is happening after 47 ms and that the machine is in no-load steady state operation between 0.6 and 0.9 s with the speed 1500 RPM. You have to plot the measurements first to verify this and if needed, change the times so they fit your measurements.

Please observe that the simulation should be performed as the measurement was done. This means that you should step the stator voltage from zero to the same voltage magnitude as was used in the lab measurement and the step should be synchronized with the measurement. Specifically, you have to change the value of the voltage step, the frequency and the time for the step to match your measurements. You can use the average value of the no-load voltage magnitude calculated in Home Assignment 1.

Task 2.C Torque Steps

The value of the load torque step can be calculated from the armature current, field current and the flux constant of the DC machine. The flux constant can be calculated from the no-load armature voltage from the Practical Laboratory Assignment Task 3.

```
Temp      = (time_m > 1.1)&(time_m < 1.45);
Ia_m_mean = mean(ia_m(Temp));
Ua_m_mean = mean(ua_m(Temp));

psi_DCM   = Ua_m_mean / (1500*pi/30);        % DC machine flux linkage
T_em_DCM  = Ia_m_mean * psi_DCM;             % DC machine load torque
```

You have to tune the step times so that the steps in the measurements and simulations appear on the same time. **Observe** that for this simulation the speed dependent load torque should be zero, i.e. put the parameter B in the main file to zero, $B = 0$.

You should also create a load step similar to the load step in the lab. This can be done by low pass filter the output of two step functions as is shown in Figure 10, and the low pass filter (LPF) models the closed loop bandwidth of the current controller in the thyristor converter. The transfer function of a first order low pass filter can be described as

$$G(s) = \frac{\alpha_{\text{LPF}}}{s + \alpha_{\text{LPF}}}$$

The cutoff frequency of the low-pass filter should be put to $\alpha_{\text{LPF}} = 110$ [rad/s].The block used for the LPF is a transfer function block that you will find under “Continuous” in the Simulink Library Browser.

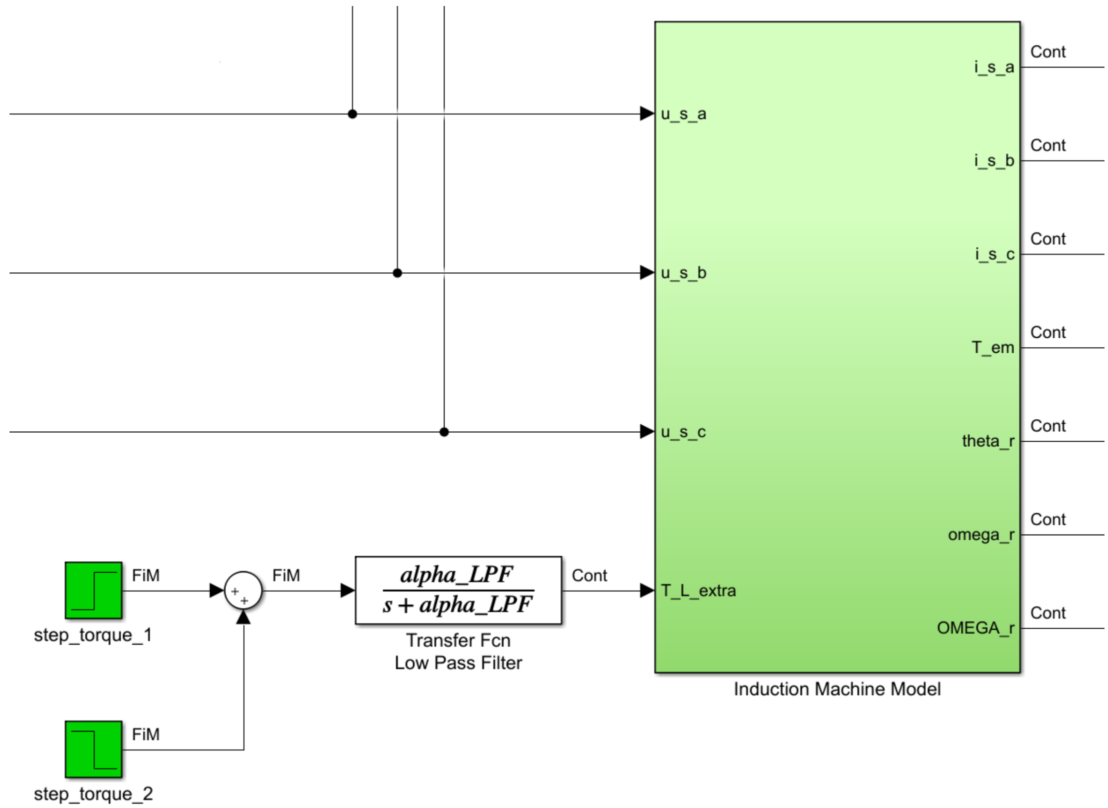


Figure 10. Low pass filter for the torque steps.

Task 2.D Moving Mean of the Speed Measurement

The speed measurement is quite noisy, and a moving mean is therefore needed to filter out the noise.

```
k_avg = 50;
speed_m_avg = movmean(speed_m,k_avg);
```

Task 2.E Comparison and Analysis

Please generate a new figure and place the following subplots inside at the end of the post process MATLAB script: *post_process_code.m*

Due to that the measurements have noise in them, put them first in the plot command and the simulated values in the end. In this way the simulated values are on top of the measured values and can be seen.

<table>
<tr><td>subplot (3,3,1)
Rotor Speed [rev/min]
both measurement (the one filtered by moving mean) and simulation</td><td>subplot (3,3,2)
Three-Phase Rotor Current [A]
0 – 2 s simulation only
(entire range)</td><td rowspan="2">subplot (2,3,3)
DQ Stator Current [A]
simulation only</td></tr>
<tr><td rowspan="2">subplot (3,3,4)
Stator Current [A]
both measurement (the one with high current sensor) and simulation (one phase is enough)</td><td rowspan="2">subplot (3,3,5)
Three-Phase Rotor Current [A]
0.25 – 0.5 s simulation only
(transient from start to no-load)</td></tr>
<tr><td rowspan="2">subplot (2,3,6)
DQ Rotor Current [A]
simulation only</td></tr>
<tr><td>subplot (3,3,7)
Active, Reactive and Shaft Power [kW] [kVar] simulation only</td><td>subplot (3,3,8)
Three-Phase Rotor Current [A]
1 – 1.25 s simulation only
(transient from no-load to load)</td></tr>
</table>

Compare the measured values with the simulated ones in subplots (3,3,1), (3,3,4) and (3,3,7). Then explain the differences in the between:

1. For the start of the induction machine, why is there a difference in the **stator current magnitude** and in **the time it takes to get the speed up to synchronous speed**? To study the measured starting current, which signal should you use? What is the peak starting current compared to the rated current? (Hint, can the difference depend on one of the assumptions made in the derivation of the model?)
2. Compare the **active and reactive stator power and the shaft power in steady-state** for the **no-load and loaded case**. The shaft power in the load case can be calculated from Task 5 in the practical lab by multiplying the torque and the mechanical speed in rad/s together.
3. How are the stator currents matching?
4. For the **steady-state operation at load**, why is there a difference in the **rotor speed**? The machines (simulated and measured) are operating with the same stator voltage and approximately the same stator current. (Hint, can the difference depend on one of the assumptions made in the derivation of the model?)
5. Is the model a good representation of an induction machine?

For the quantities from simulation, please answer the questions below:

1. Study the physical rotor currents in subplots (3,3,2), (3,3,5) and (3,3,8). Are they behaving as expected? What is the frequency of the currents for the different operation modes of the machine?
2. Study the stator and rotor currents in dq-coordinates in subplots (2,3,3) and (2,3,6). Why is the d-component of the rotor current zero in steady-state? Why is the q-component of the stator and rotor currents almost the same, except for the sign? (Hint, look in the equivalent circuit of the induction machine)

Task 3: Change of Inertia

After you have compared the start with our measurements you should remove the inertia for the DC-machine. Now assume that the inertia of the induction machine is 25 % of the value you measured in the laboratory exercise.

Rerun the simulation with the reduced inertia and use $B = 0.08$. Reduce the extra load torque step ($T_{\mathrm{L,extra}}$) so that approximate the same total load torque is applied after the load step. For this simulation you do not need to have the measurements in the plots. Study the plots in the base figure created in Task 1. What have changed? What is the starting time now? What is the torque produced by the induction machine at 0.7 s?