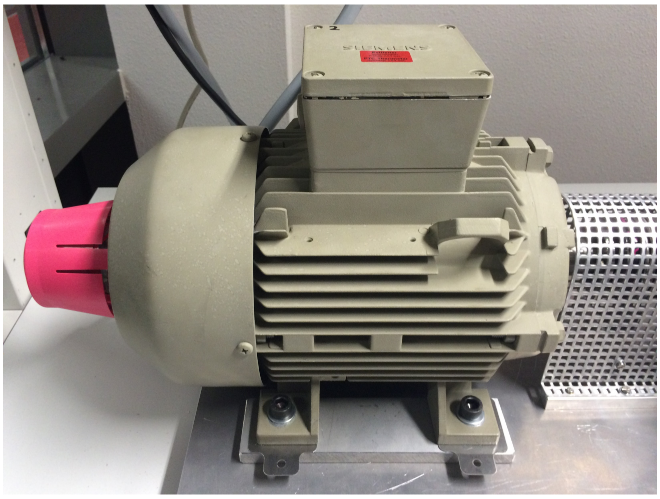
Eindhoven University of Technology
Department of Electrical Engineering
Group Electromechanics and Power Electronics

5LWE0 – Control of Rotating Field Machines

Lab Manual



Name:	
Student ID:	
Experiment Date:	
Setup Number:	
Group Partner:	

Responsible Lecturer: dr. K. Boynov.

October 4, 2018

Contents

Chapter 1

Introduction

The lab of the Control of Rotating Field Machines (5LWE0) consists of several experiments regarding control of the asynchronous induction machine (IM). Experiments include practical implementation of the control schemes (vector and scalar), performing system responses and obtaining torque-speed characteristic of the IM under different conditions on the test set-up. The set-up comprises a machine-set consisting of two electric machines – separately excited DC machine (DCM) and asynchronous induction machine, controlled by two voltage source inverters (VSIs). The experimental results are to be compared with the corresponding simulation results.

1.1 Goals and objectives

After successful completion of the lab experiments, students will be able to:

- Design and implement vector and scalar control of the IM on the experimental set-up.
- Perform step responses on the inner (current) and outer (speed) loops in the vector and scalar control modes.
- Compare step responses on the outer loop in the scalar control mode with the corresponding step responses for the vector control mode.
- Compare system behaviour obtained from experiments with corresponding simulations.
- Obtain torque-speed characteristics and analyse behaviour of the IM both in motor and generator modes, positive and negative speeds.

1.2 Preparation

- Study relevant parts of the book and lecture slides of 5LWE0
- Print and read this manual and answer the preparation questions in each chapter

IMPORTANT! Adequate preparation is considered necessary to complete work in the planned time. Insufficiently prepared students will be sent away!

1.3 Lab Submission and Assessment

The outcome of the lab is a paper. The paper should cover all parts of the lab experiments and should be written in accordance with the requirements to technical reports/scientific papers (e.g., IEEE style). Each student writes a paper individually. Papers must be submitted digitally on Canvas in the assignment section before the deadline set on **November, 11, 2018 at 23.59**. Together with the paper, related simulation files and experimental data should be put into a zip-archive with the name using the following format: **LastName_StudentNumber.zip**

1.4 Logging in to the Engineering PC

All the engineering PCs can be logged in using guest accounts, which grant the permission to run software needed to operate the set-ups. To log in on the Engineering PC use your TU/e account. Work files specific for the lab can be found in the following folder: `C:\5LWE0 Lab\`

IMPORTANT! Do not open any files unless it is stated in the lab manual.

1.5 Safety Rules

Working in the laboratory (GMN-N -1.23).

The following rules and regulations apply for working in the laboratory:

- It is mandatory to use hearing protection when using the machine set-up.
- It is not allowed to operate switches that are not part of the assignment and set-up. Exception on this rule are the emergency buttons that are located everywhere in the laboratory.
- Instructions for working with rotating machines are part of the rules and regulations.
- It is mandatory to follow up instructions given by people responsible for the safety in the laboratory.
- Do not touch moving parts of machines.
- Do not come near rotating parts with loose clothing or long hair.
- Do not modify connections of the set-up.
- Do not turn on/off switches of the set-up unless it is instructed during the lab.
- Do not press the emergency buttons without a reason.
- Do not change modes of operation and/or parameters of the machines unless it is stated in the instructions.

IMPORTANT! Always remember about safety and come prepared to the labs. You will be only allowed to the laboratory if you are prepared and know the safety rules well!

Chapter 2

Description of the Experimental Set-up

The experimental set-up depicted in Figure 2.1 is a combination of a machine-set and two voltage source inverters (VSIs) that supply the machines. The machine-set consists of a separately excited DC machine and an asynchronous induction machine. Each of the two machines in the set is powered by a VSI, and can either be operated in speed or torque (current) control modes.

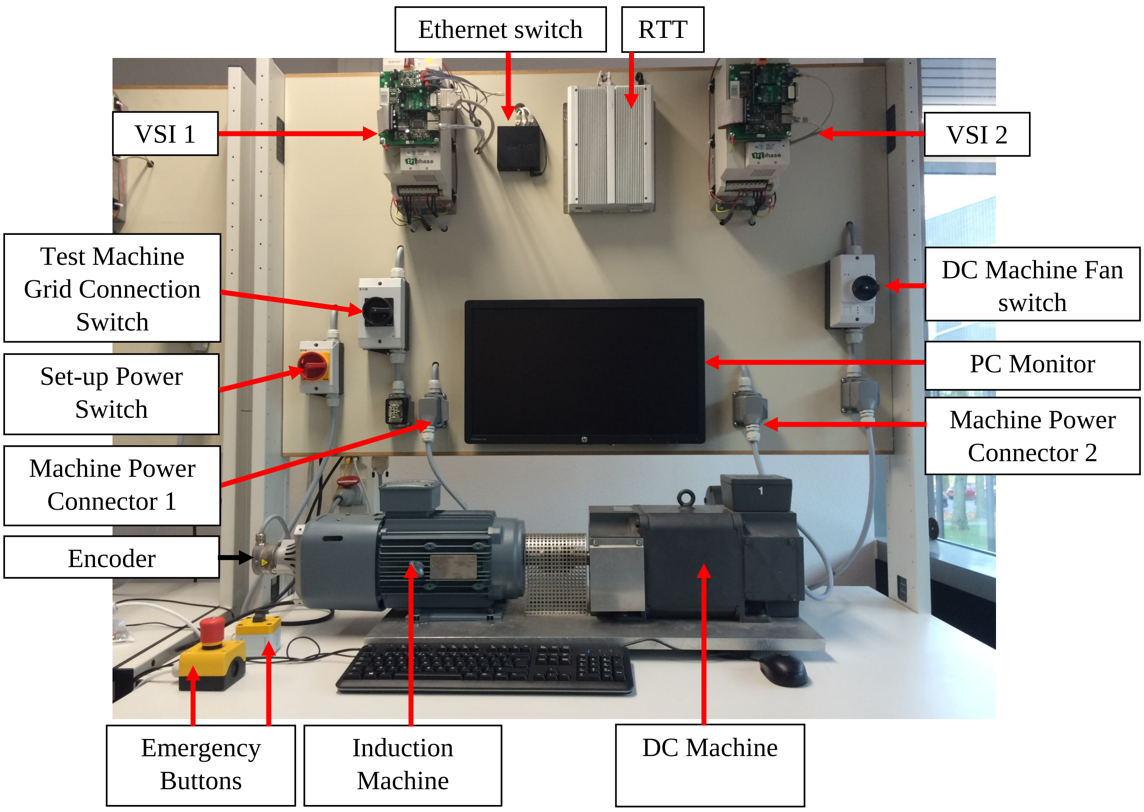


Figure 2.1: Experimental set-up.

The three-phase voltage source inverter VSI 1 (or VSI 2) shown in Figure 2.2 is a power electronic device that transform a nearly constant DC voltage to an AC voltage via three switching legs. Each of the switching legs consist of two semiconductor based switches that open and close according to a specific pattern to produce proper AC voltages.

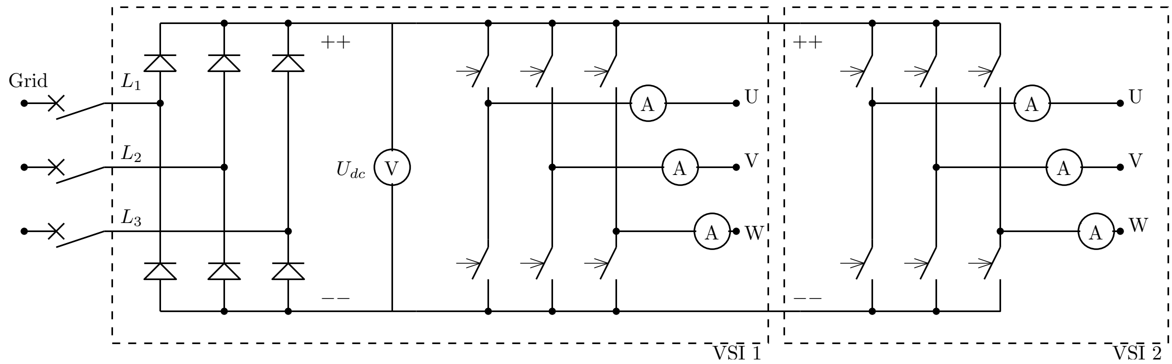


Figure 2.2: Three-phase voltage source inverters schematic.

The voltage source inverters VSI 1 and VSI 2 are powered from the grid via the set-up power switch. The passive rectifier in VSI 1 is used to charge the common DC bus to approximately 560 V. The DC voltage interconnections ++ (V_{++}) and −− (V_{--}) are connected to supply VSI 2 via the DC bus. In this case, VSI 1 is used to power the induction machine while the DC machine is powered by VSI 2. Inverters VSI 1 and VSI 2 are connected to the machines via the machine power connectors 1 and 2 respectively. The induction machine can also be connected directly to the grid using the test machine grid connection switch and corresponding connector. The set-up does also include a fan switch for the DC machine (see Figure 2.1).

The field winding of the DC machine is powered by one switching leg of the VSI 2 with respect to V_{--}. The other two switching legs are used in a full-bridge configuration to power the armature winding of the DC machine. Each switching leg of VSI 1 is connected to a phase-winding of the test machine. In order to measure the speed, the induction machine is equipped with an incremental encoder which is connected to the encoder interface module on VSI 1 (see Figure 2.1).

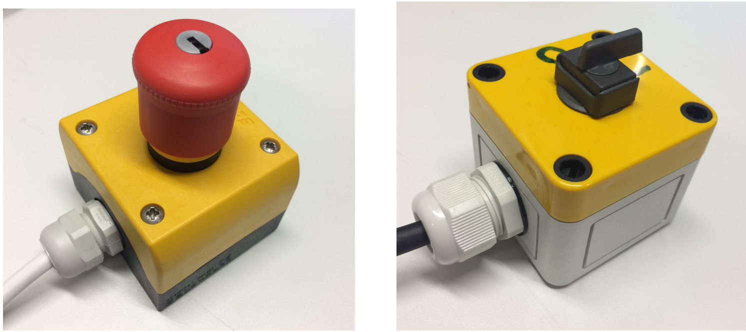
The sensors required to measure the machine-set behaviour are included in the VSIs. The output of each switching leg is equipped with a current sensor to measure each phase current. Voltage sensors installed on both VSIs give a possibility to measure output voltages of all switching legs. Signals from the incremental encoder are processed by the encoder interface board installed on VSI 1. The VSIs can both be operated as a voltage source and as a current source using the feedback of the current sensors.

Voltage source inverters are connected to a control unit called a Real-Time Target (RTT) through the Ethernet switch (Figure 2.1). The Real-Time Target is a multi-core PC with a real-time Linux/Xenomai-based operating system. Data communication between VSIs and RTT is realized with the EtherCat protocol, which is based on the Ethernet network protocol and allows for high-speed and reliable data transfer. Further, the RTT is linked to an Engineering PC. In order to control VSIs via the RTT, a MATLAB/Simulink model is built on the Engineering PC, which is then translated, compiled, built and activated on the RTT.

Note that the set-up is ready to operate, you will not have to or are allowed to change any connections.

IMPORTANT!There are two buttons per each set-up. The emergency button depicted in Figure 2.3 (a) is used to switch off the power of all set-ups in the

laboratory room completely. Make sure the emergency button is placed on the table where you can reach it easily. Please remember that it can also be used when something goes wrong with the set-up of your neighbours. The second button (Figure 2.3 (b)) is used to turn-off the switching legs of the inverters, but does not act as a total system shut-down emergency stop.



(a) (b)

Figure 2.3: Complete power off emergency button (a); The button to shut-down VSI switching legs (b).

Chapter 3

Parameters of the Experimental Set-ups

The laboratory provides two types of the separately excited DC machines and two types of the asynchronous inductions machines, which are coupled in four different combinations. The mechanical parameters of the set-ups, relevant parameters of the VSIs and the main parameters of the machines are listed below.

3.1 Mechanical Parameters of the Set-ups

Mechanical parameters of the coupled machine-sets, including shared inertia of both machines J, friction coefficient b_1, and static friction b_0 are presented in Table 3.1.

Table 3.1: Mechanical Parameters of the Set-ups

Parameter (Unit)	Set-up 1	Set-up 2	Set-up 3	Set-up 4
Inertia J, kgm^2	27.6e-3	33.7e-3	24.5e-3	24.4e-3
Friction Coefficient b_1, $\frac{\text{Nm}}{\text{rad/s}}$	15.1e-4	16.5e-4	19.3e-4	14e-4
Static Friction b_0, Nm	0.47	0.5	0.47	0.53

3.2 Parameters of the VSIs

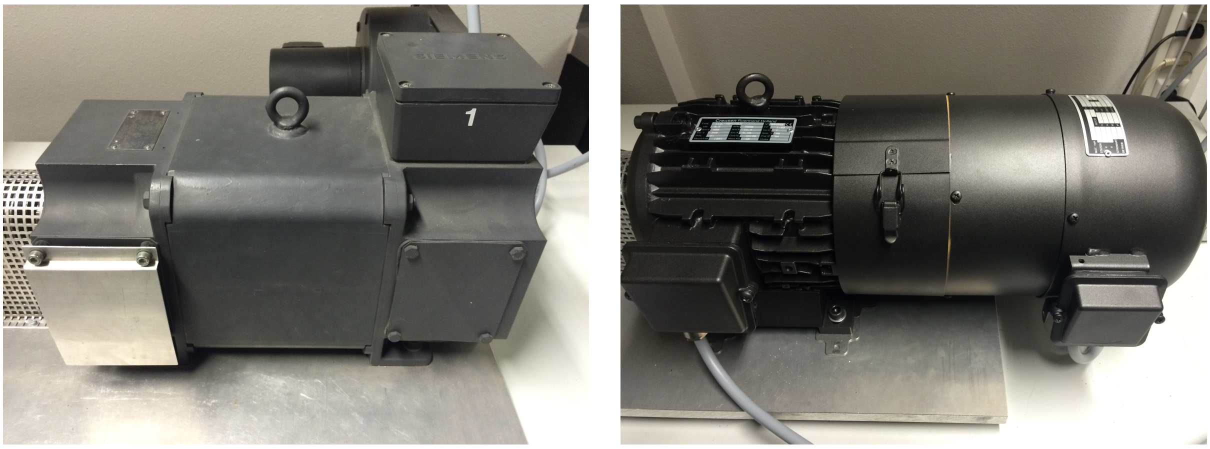
Maximum inverter current i_{max} and voltage v_{max} together with the time delay of the inverter can be shown in Table 3.2.

Table 3.2: Parameters of the VSIs

Parameter	Symbol	Value
Max Inverter Current	i_{max}	15 A
Max Inverter Voltage	v_{max}	400 V
Time Delay	T_{delay}	187.5 μ s

3.3 DC Machines Parameters

There are two models of DC machines used in the laboratory set-ups: 5.15 kW Siemens GG5104 shown in Figure 3.1 (a) and 5.5 kW Creusen 112L-4GM shown in Figure 3.1 (b).



(a) (b)

Figure 3.1: Siemens GG5104 DC machine (a); Creusen 112L-4GM DC machine (b).

Table 3.3 and Table 3.4 contain machine parameters of the Siemens GG5104 and Creusen 112L-4GM DC machines respectively. Both machines are separately excited DC machines.

Table 3.3: Siemens GG5104 DC machine parameters

Parameter	Symbol	Value
Field Winding Resistance	R_f	276 Ω
Field Winding Inductance	L_f	58.4 H
Armature Winding Resistance	R_a	1.93 Ω
Armature Winding Inductance	L_a	10.8 mH
Maximum Field Current	$I_{f,max}$	0.8 A
Maximum Field Voltage	$V_{f,max}$	310 V
Maximum Armature Current	$I_{a,max}$	14.8 A
Maximum Armature Voltage	$V_{a,max}$	420 V
Rated power	P_{mech}	5.15 kW

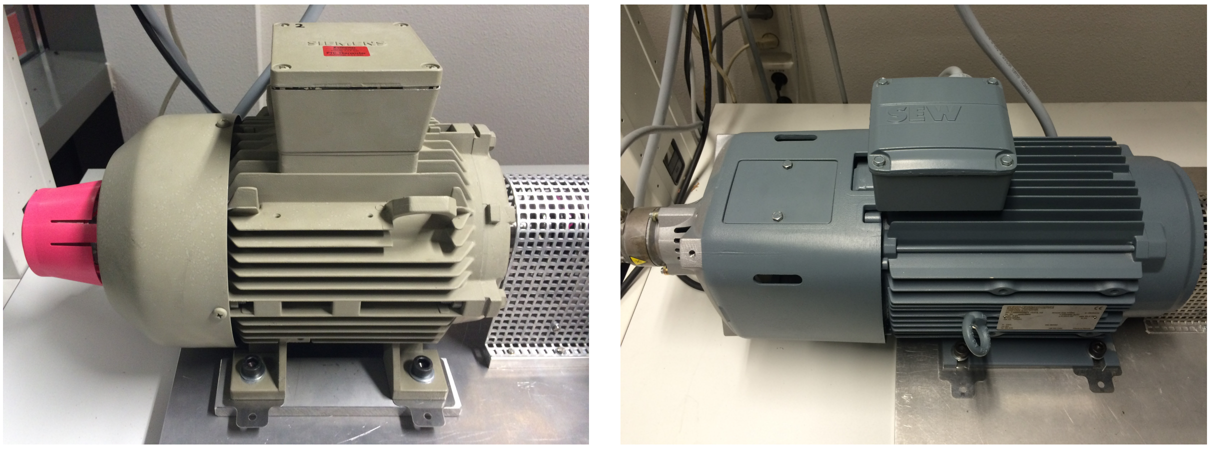
Table 3.4: Creusen 112L-4GM DC machine parameters

Parameter	Symbol	Value
Field Winding Resistance	R_f	561 Ω
Field Winding Inductance	L_f	60.7 H
Armature Winding Resistance	R_a	1.05 Ω
Armature Winding Inductance	L_a	4.3 mH
Maximum Field Current	$I_{f,max}$	0.48 A
Maximum Field Voltage	$V_{f,max}$	340 V
Maximum Armature Current	$I_{a,max}$	16.4 A
Maximum Armature Voltage	$V_{a,max}$	400 V
Rated power	P_{mech} $P_{a,max}$	5.5 kW

3.4 Asynchronous Induction Machines Parameters

There are two models of asynchronous induction machines used in the laboratory set-ups: 3.45 kW Siemens 1LA5105 shown in Figure 3.2 (a) and 3.0 kW SEW DRE100L2/FI/EV7C shown in Figure 3.2 (b).

Parameters of the induction machines are given in Tables 3.5 and 3.6. The machine parameters may be used to simulate the torque-speed characteristics of the machines.



(a) (b)

Figure 3.2: Siemens 1LA5105 induction machine (a); SEW DRE100L2/FI/EV7C induction machine (b).

Table 3.5: Siemens 1LA5105 Induction machine parameters

Parameter	Symbol	Value
Magnetizing Inductance	L_m	0.3744 H
Stator Leakage Inductance	L_{ls}	7.88 mH
Stator Resistance	R_s	1.75 Ω
Rotor Leakage Inductance	L_{lr}	11.82 mH
Rotor Resistance	R_r	1.54 Ω
Rated Per-Phase RMS Current	$I_{ph,max}$	6.3 A
Rated Phase RMS Voltage	$V_{ph,max}$	230 V
Rated rotational speed	ω_{rm}	2845 rpm
Rated power	P_{mech}	3.45 kW

Table 3.6: SEW DRE100L2/FI/EV7C Induction machine parameters

Parameter	Symbol	Value
Magnetizing Inductance	L_m	0.628 H
Stator Leakage Inductance	L_{ls}	7.882 mH
Stator Resistance	R_s	1.72 Ω
Rotor Leakage Inductance	L_{lr}	11.82 mH
Rotor Resistance	R_r	1.868 Ω
Rated Per-Phase RMS Current	$I_{ph,max}$	5.5 A
Rated Phase RMS Voltage	$V_{ph,max}$	230 V
Rated rotational speed	ω_{rm}	2850 rpm
Rated power	P_{mech}	3 kW

Chapter 4

MATLAB/Simulink Template

In order to implement control schemes of the IM on hardware, the MATLAB/Simulink template model is created. The top level model of the template is depicted in Figure 4.1.

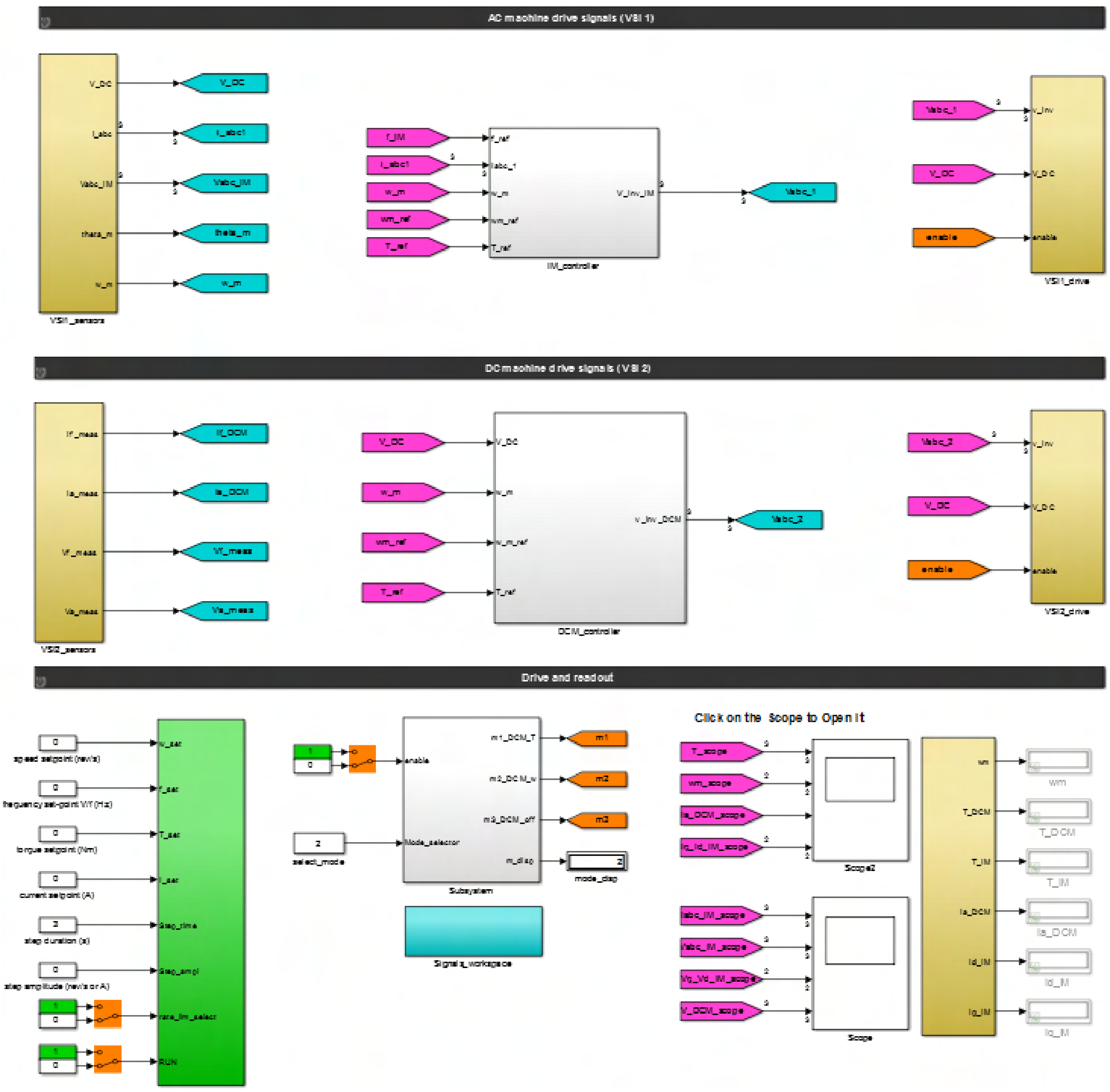


Figure 4.1: Top level of the MATLAB/Simulink template model.

The template consists of three main blocks (see Figure 4.1):

- the **AC Machine drive (VSI 1)** block (at the top)
- the **DC Machine drive (VSI 2)** block (at the middle)
- the **Drive and Read Out** block (at the bottom),.

The **AC Machine drive (VSI 1)** includes signals from sensors of the VSI 1 (left side), including the DC-bus voltage, IM phase currents and voltages, mechanical angle and speed. On the right side there is a subsystem that receives voltages generated by the control system, converts them to PWM signals and sends them to the switching legs of the VSI 1. **Note! You will be asked to develop and import the control subsystem of the IM (including vector and scalar control) into this part of the Simulink Template model**.

The **DC Machine drive (VSI 2)** block is similar to the one of the VSI 1. Signals from sensors comprise field and armature currents, field and armature voltages of the DCM. The block has also a subsystem with the complete control of the DCM. Furthermore, identically to the AC Machine drive (VSI 1), the block includes a subsystem that receives voltage signals from the control subsystem and generates the PWM signals that are subsequently sent to the switching legs of the VSI.

Finally, the **Drive and Read Out** block consists of the Set-Point Control subsystem, the Mode Selector subsystem, the Data Export subsystem, several scopes and displays for the main signals. The set-point control subsystem (green color in Figure 4.1) gives the opportunity to set a number of reference signals such as: speed, U/f frequency, torque, current setpoints and adjust the step parameters such as: step duration and step amplitude. To perform the steps, there is a RUN switch selection. When the RUN switch is turned on (set to 1), the desired step is performed after 1 sec. In addition, at the set-point control subsystem there is a rate limiter selection switch. The purpose of this switch is to apply limit at the rising and falling rates of the step signal.

The mode selector subsystem provides the opportunity to set the mode of operation of the **DC Machine** and additionally it contains the global Enable signal switch. Three operating modes of the DCM are listed below:

Mode 1 (m1) : DC machine in torque control (IM is expected to be operated in vector speed control or U/f control).

Mode 2 (m2) : DC machine in speed control (IM is expected to be operated in torque control or U/f control).

Mode 3 (m3) : DC machine in switched off.

To change the mode during the operation of the set-up, the following procedure should be performed:

1. Make sure that all set-points are put to zero.
2. Turn off the "Enable" switch on the main front panel.
3. Change the mode using corresponding toggle on the main front panel. Check if the mode is applied using the mode indicator.
4. Turn on the "Enable" switch on the main front panel.

IMPORTANT! Do not change modes of operation if the "Enable" switch is on.

The data export subsystem (cyan color in Figure 4.1) collects at Workspace the main signals, such as: the IM q- and d- axes currents and voltages, the actual mechanical speed and its reference, the DCM armature current and time. Furthermore, scopes are used to monitor behaviour of the main signals in time, and displays to observe instantaneous values of the main signals.

IMPORTANT! The MATLAB/Simulink template model lab_5LWE0_Template.slx can be located on the Engineering PC using the following path: `C:\5LWE0 Lab\Template` .

Chapter 5

Lab 1: Step Responses of the Induction Machine using Vector Control

The goal of the **First Lab Session** is to obtain step responses of the induction machine (IM) by using vector control. To evaluate the vector control, two lab experiments should be performed. The first experiment includes step changes in torque of the IM and the second experiment includes step changes in speed. It is important to mention that the experimental tests are to be performed on cold machines.

5.1 Preparation of the First Lab Session

As mentioned in section 1.2, adequate preparation is necessary to complete the lab experiments of the first lab session in the planned time. Instructions to conduct successfully the experiments are presented below.

Modeling in MATLAB/Simulink:

- Create the complete control model of the IM, including the large signal model of the IM in the *dq* reference frame, cascaded control, and subsystem of estimation of the electrical angle.
- Using sisotool of MATLAB, mechanical parameters from Table 3.1, electrical parameters from Table 3.5 or Table 3.6, design the speed and current PI-controllers for the IM.

  IMPORTANT HINT! In the process of controller design for the inner loop (current) make sure that the stator voltage is as close as possible to $V_{ph,max}$ and for the outer loop (speed) – the stator current is as close as possible to $I_{ph,max}$. Moreover, ensure that the gain margin is more than 6 dBs and the phase margin is more than $45°$.
- Perform step responses on the inner (torque) and outer (speed) loops and save the system responses. For the inner loop, save also the stator voltage response, and for the outer loop - stator current response.

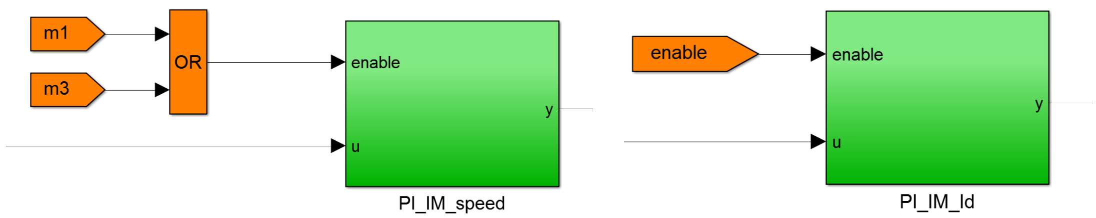
- Additionally implement subsystems with *abc-dq* and *dq-abc* transformations and estimation of the electrical angle (to be used in the lab).

Import of the Control Model Subsystem:

- Navigate to the folder `C:\5LWE0 Lab\Template`.
- Open the Simulink Template file **lab_5LWE0_Template.slx**.
- Insert the vector control model (current and speed) of the IM as a subsystem into the block **AC Machine drive (VSI 1)** of the template. Inputs to the subsystem should include: **i_abc_1** (AC machine phase currents), **w_m** (mechanical speed), **wm_ref** (reference speed), and **T_ref** (torque reference). Output of the subsystem should be the three-phase inverter voltages **v_inv_IM**.

Required contents of the control model subsystem:

- Cascaded control model of the IM with speed and current (I_d and I_q) controllers.
- Transformation blocks (*abc-dq* and *dq-abc*).
- Electrical angle estimation subsystem.
- Speed controller should have an enable signal based on the mode of operation (see Figure 5.1 (a)), and the current controllers must be enabled by the global **Enable** signal (see Figure 5.1 (b))
- Saturation blocks for the signals that must be limited for safety reasons (currents, voltages, speed). For the values of signal limits refer to the Chapter 3.
- Torque set-point for the current controller. **Tip: Check the DCM control subsystem for the implementation**.
- Sink blocks (from the Simulink Library) for the following signals (use the signal names as stated further): slip speed (**w_slip**), torque of the IM (**T_IM**), d- and q- stator currents (**id_s_IM** and **iq_s_IM**), d- and q- stator voltages (**Vd_s_IM** and **Vq_s_IM**).



(a) (b)

Figure 5.1: Mode enabled system (a); System enabled by the global **Enable** signal (b).

5.2 Lab Experiment 1 – Step changes in Torque using Vector Control

Procedure Steps:

1. Perform the instructions of the **"Import of the Control Model Subsystem"** section (see section 5.1).
2. Press **Code** → **External Mode Control Panel** → **Signal & Triggering**. Highlight the **TriggerScope** signal from the **Signal selection** list and press the **Trigger Signal** button on the right side of the window. In the **Trigger options** menu choose **signal** from the **Source** list. Press **OK**.
3. Press **Triphase** → **Build Model** (or just a shortcut **Ctrl + B**), and wait approximately 30 sec until the model is built. Then press **Triphase** → **Activate**, **Triphase** → **Connect**, and finally a **Run** button. Inverters will start working.
4. Choose **Mode 2** from the **Mode Selector** and turn on the "Enable" switch. Now the DCM works in the speed control, and the IM is supposed to be operated in the torque control.
5. Obtain step responses on the inner control loop (torque). Set desired values of the step size, step duration and step amplitude using corresponding constant value blocks connected to the **Set-Point Control** subsystem. You can set the initial values of the speed (for DCM) and torque (for IM) using the **speed set-point (rev/s)** and **torque set-point (Nm)** constant blocks. Turn on the **Run** switch. Once the step response is finished turn off the **Run** switch, disable the global "Enable" switch, press **Triphase** → **Disconnect** and immediately **Connect** again (that will allow to save the data array to the workspace under name **MeasurementData**). Save the array as a separate .m file if needed. Repeat the torque steps for two different reference values of d-axis current: $2i_{ds}$ and $0.5i_{ds}$.

Results:

Process the measurement data and compare the obtained step responses with the corresponding simulation results. Discuss the results and make conclusions.

5.3 Lab Experiment 2 – Step changes in Speed using Vector Control

Procedure Steps:

1. Choose **Mode 1** from the **Mode Selector** and turn on the "Enable" switch. Now the DCM works in the torque control, and the IM is supposed to be operated in the speed control.
2. Perform step responses on the outer control loop (speed). Set desired values of the step size, step duration and step amplitude using corresponding constant value blocks connected to the **Set-Point Control** subsystem. You can set the initial values of the speed using the **speed set-point (rev/s)** constant block. Turn on the **Run** switch.

Once the step response is finished turn off the **Run** switch, disable the global "Enable" switch, press **Triphase** → **Disconnect** and immediately **Connect** again (that will allow to save the data array to the workspace under name **MeasurementData**). Save the array as a separate .m file if needed. Repeat the step for other parameters of the speed step (if necessary).

Results:

Process the measurement data and compare the obtained step responses with the corresponding simulation results. Discuss the results and make conclusions.

IMPORTANT HINT! Prepare the desired values of the step size-duration-amplitude that you are going to apply, as well as the initial values of the speed and torque (think about the limits of the speed and torque). Also, take into account the values of the simulation experiments in your decisions.

Chapter 6

Lab 2: Step Responses and Torque-Speed Characteristic of the Induction Machine using Scalar Control

In the **Second Lab Session**, two lab experiments are to be performed. The goal of the first experiment is to obtain the step responses of the IM and the goal of the second experiment is to obtain the Torque-Speed characteristic of the IM. In both cases, the scalar control (known also as U/f control) is used.

6.1 Preparation of the Second Lab Session

In the U/f control, the ratio between the supply voltage U_s and frequency f is kept constant. This is an open control scheme without the speed feedback present, which is discussed in the lecture slides. The scalar control should be compared with the vector control schemes of the IM performing steps on speed. Speed step responses from scalar and vector control schemes with the limited stator current should be compared with respect to settling time. Instructions to conduct successfully the lab experiments are presented below.

Modeling in MATLAB/Simulink:

- Use the large signal MATLAB/Simulink model of the IM that was built in section 5.1 .
- Design the scalar control model of the IM and connect it to the the large signal model of the IM. **Note**: For calculation of the value of the U/f factor use machine parameters from Chapter 3.
- Perform speed step responses with the same step sizes that were used for the vector control in Lab 1. Observe responses of speed and stator current and compare them to the corresponding ones from the vector control.
- Implement the rate limiter on the input frequency. Adjust the rate of change of the frequency in such a way that the stator current during the speed step response does not exceed motor rated value.

- Simulate speed step responses and save them. Additionally, save stator current responses.
- Compare speed step responses of the scalar control with the corresponding step responses of the vector control with respect to settling time and overshoot.
- Using the motor parameters build the steady-stare torque-slip characteristic of the investigated IM.

Import of the Control Model Subsystem:

- Navigate to the folder `C:\5LWE0 Lab\Template`.
- Open the separate MATLAB/Simulink Template file **lab_5LWE0_Template.slx**.
- Insert the scalar control model of the IM as a subsystem into the block **AC Machine drive (VSI 1)** of the MATLAB/Simulink template. Input to the subsystem is the synchronous frequency **f_ref** and the outputs of the subsystem are the three-phase inverter voltages **v_inv_IM**.

6.2 Lab Experiment 3 – Step changes in Speed using U/f Control

Procedure Steps:

1. Perform the instructions of the **"Import of the Control Model Subsystem"** section (see section 6.1)
2. Press **Code** → **External Mode Control Panel** → **Signal & Triggering**. Highlight the **TriggerScope** signal from the **Signal selection** list and press the **Trigger Signal** button on the right side of the window. In the **Trigger options** menu choose **signal** from the **Source** list. Press **OK**. **Note: Not necessary to perform this step if it was done for the previous experiment**
3. Press **Triphase** → **Build Model** (or just a shortcut **Ctrl + B**), and wait approximately 30 sec until the model is built. Then press **Triphase** → **Activate**, **Triphase** → **Connect**, and finally a **Run** button. Inverters will start working.
4. Choose **Mode 1** from the **Mode Selector** and turn on the "Enable" switch. Now the DCM works in the torque control, and the IM is supposed to be operated in the U/f control.
5. Enable the built-in rate limiter of the reference signal by switching on the **rate_lim_select** switch of the **Set-Point Control** subsystem. The built-in rate limiter is implemented for safety reasons to avoid overcurrents while performing speed steps in the scalar control mode. Figure 6.1 shows the Rate Limiter block from the Simulink library. The values of rising and falling slew rates are set by default for this measurement at 5*2*pi $\frac{rad/s}{s}$ and -5*2*pi $\frac{rad/s}{s}$ correspondingly. It means that the reference speed of 10 rev/s (10*2*pi rad/s) will be reached in 2 seconds.
6. Disable the built-in rate limiter by switching of the **rate_lim_select** switch of the **Set-Point Control** subsystem. Implement your own rate limiter block and adjust the

rate of changing of frequency in such way, that the stator current is close as possible to the rated value. Perform iteratively a set of responses to reach the optimum value of the rate limiter. **IMPORTANT! Adjust values of rising and falling slew rates of the rate limiter by small steps and never exceed the limit of 300** $\frac{rad/s}{s}$**.**

7. Perform a step response with the optimal rate limiter value by turning on the **Run** switch. Observe the step responses on the corresponding Scope. Once the step response is finished turn of the **Run** switch, disable the global "Enable" switch, press **Triphase** → **Disconnect** and immediately **Connect** again (that will allow to save the data array to the workspace under name **MeasurementData**). Save the array as a separate .m file if needed. Repeat the step for other torque/speed steps (if necessary). **IMPORTANT! In this test the reference value for the synchronous frequency of the IM should be set with the speed set-point (rev/s) of the Set-Point Control subsystem**.

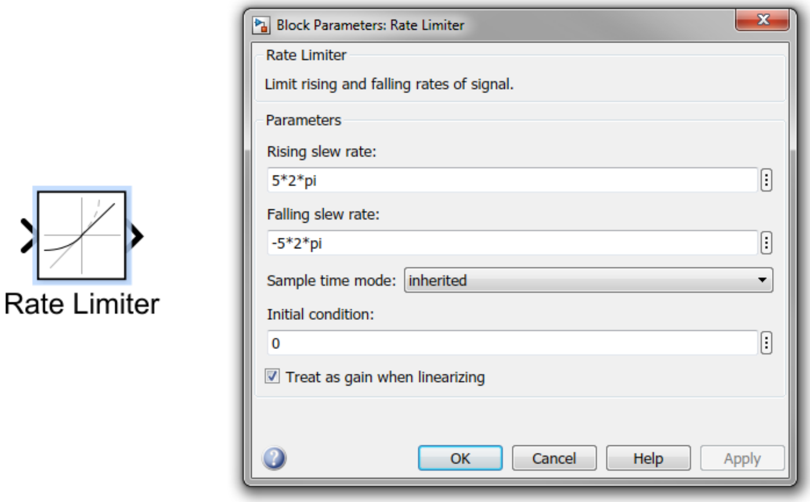


Figure 6.1: Rate Limiter block of the Simulink Library.

Results:

Process the measurement data perform the following analysis:

- Compare the experimental speed step responses to the corresponding simulations mentioned in the **Preparation** section of the current Chapter.
- Compare the experimental speed step responses of the scalar control scheme to the corresponding experimental speed step responses of the vector control.

Discuss the results and make conclusions.

6.3 BONUS Experiment – Torque-Speed Characteristic of the Induction Machine

The outcome of this lab experiment should be the export of the Torque-Speed characteristic of the IM. The IM is able to operate both in motor and generator modes, positive and negative speeds, using U/f control, whereas the DCM operates in speed control.

IMPORTANT! Since the DCM operates in the speed control and at the same time we set the reference synchronous frequency for IM, a special start-up procedure should be conducted. At first, we set the speed set-point of the DCM, then, the set-point of the synchronous frequency of the IM with the zero voltage component of the U/f ratio, and afterwards gradually increase the voltage from 0 to the desired value.

Procedure Steps:

1. Perform the instructions of the **"Import of the Control Model Subsystem"** section (see section 6.1)
2. Press **Code** → **External Mode Control Panel** → **Signal & Triggering**. Highlight the **TriggerScope** signal from the **Signal selection** list and press the **Trigger Signal** button on the right side of the window to **deselect** the signal. In the **Trigger options** menu choose **manual** from the **source** list. Press **OK**. **Note: Not necessary to perform this step if it was done for the previous experiment**
3. Press **Triphase** → **Build Model** (or just a shortcut **Ctrl + B**), and wait approximately 30 sec until the model is built. Then press **Triphase** → **Activate**, **Triphase** → **Connect**, and finally a **Run** button. Inverters will start working.
4. Choose **Mode 1** from the **Mode Selector** and turn on the "Enable" switch. Now the DCM works in the torque control, and the IM is supposed to be operated in the U/f control.
5. Set synchronous speed of the IM using**speed set-point (rev/s)** constant block connected to the **Set-Point Control** subsystem to the desired value.
6. Set the torque of the DCM using the **torque set-point (Nm)** constant block connected to the **Set-Point Control** subsystem from the range [-10; 12] Nm.
7. Open the corresponding scopes and observe the signals. Using the .xlsx template file **Torque Speed Characteristic table.xlsx** located in the work folder write down main parameters of the experiment (speed, reference torque, DCM armature current).
8. Set the torque of DCM back to zero.
9. Set reference speed of the IM to zero.
10. Turn off the **Run** switch, disable the global "Enable" switch, press **Triphase** → **Disconnect**.

Results:

- Process the measurement data and plot the torque-speed characteristic of the IM.
- Find the steady-state operating points of the previous experiments (scalar and vector control) on the torque-speed characteristic.
- Discuss the results and make conclusions.