

The Active Filter

Laboration 6

1. Before the lab, look through the manual and make sure you are familiar with all parts!
2. Bring the course book to the lab.
3. You are not allowed to do the lab if you have not submitted your home assignment for the Active Filter.

1 Introduction

In this lab a Shunt Active Filter (SAF) will be studied. The control system is a LabView based system using Compact RIO real-time hardware. The scope of the laboratory work covers a control of a three-phase converter, PWM modulation signal of three-phase symmetrized references, a vector control, a DC link voltage control and an active filter/a reactive power compensation. During the lab exercise the control of the active and reactive power and the active filtering fed from a frequency converter will be studied. The DC link voltage is controlled simultaneously so that the active filter does not need any other independent power source.

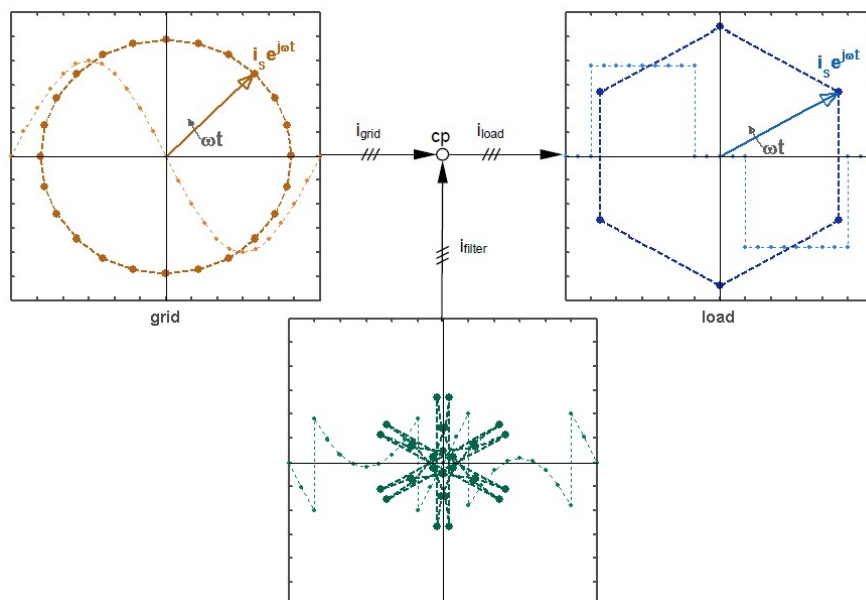


Figure 1.1: The Active Filter

2 The equipment

The laboratory set-up is shown in figure 2.1 below. Note that the actual setup in the lab might differ.

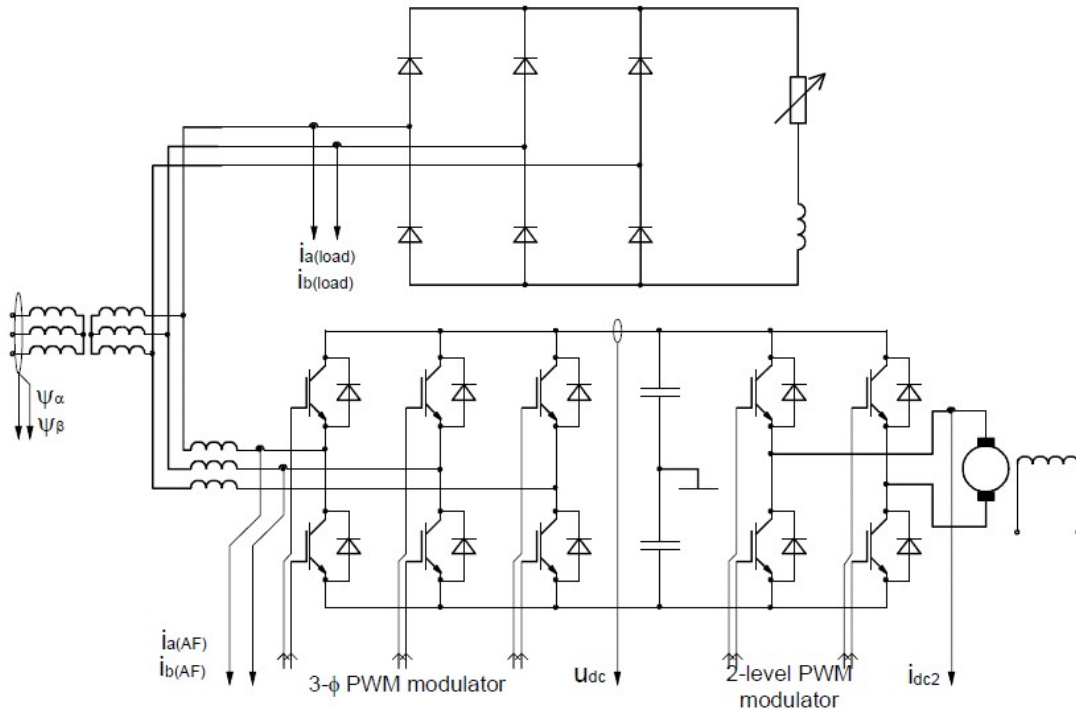


Figure 2.1: Principal diagram of the lab system

2.1 Laboratory set-up

A three-phase transformer (220/66.7 V, Y/Y) gives the suitable low voltage three-phase supply from the grid. A load is connected to the secondary side of the transformer (in the figure this load is a three [to one] phase rectified). A shunt active filter (SAF) is connected in parallel with the load. The three-phase ac voltage source converter (VSC) is connected to the three-phase grid through three-phase inductances. (The converter is back-to-back connected to a 2-level converter, which in turn feeds a DC machine – which is not used in this exercise)

The power circuits are shown in bold whereas the thin lines represent the control circuit I/O. The control system consists of I/O of the 3- ϕ VSC, inputs from a grid flux (linkage) integrator and the load. The control system is entirely implemented in LabView (figure 3.1).

2.2 System Data

The data of the power system necessary for the voltage source controlled shunt active filter (VSC SAF) is presented below in table 2.1. This data is used to design the PIE current controller and the PI DC link voltage controller.

Table 2.1: The SAF design data

Measure	Value
Line voltage (rpm, secondary)	$U_p = 66.7 \text{ V}$
Line inductance of the SAF	$L_{line} = 3.0 \text{ mH}$
Line resistance of the SAF	$R_{line} = 0.4 \Omega$
The capacitance of the dc-link capacitor	$C_{dc} = 1.1 \text{ mF}$
Sample time	$T_s = 0.2083 \text{ ms}$

3 The control system

3.1 The CompactRIO

The CompactRIO, *cRIO*, consists basically of three parts; a Field Programmable Gate Array, *FPGA*, a Real Time system, *RT*, and the Inputs and Outputs, *I/O*.

3.2 The FPGA

The FPGA is a programmable electrical circuit. This means that the program that has been written to it actually is built in hardware with logical gates. From the programs point of view this means that every part of it is executed simultaneously.

The FPGA is connected to both the RT system and the I/O-modules. It therefore acts as the bridge between the I/O- modules and the RT system. It can also make some or all of the signal processing, which will be utilized in this setup. Since the space on the FPGA is limited it is important to choose what to implement on it. The characteristics of things that should be implemented on the FPGA is that they need to execute fast, often and/or in parallel.

3.3 The RT

The real time system consists of an industry PC and a Real Time operating system. Programs on the RT system make things that do not have high demands on speed or tasks that are typical for a computer like read and write to files, talk over ethernet, display information and so on.

3.4 The I/O's

The cRIO is flexible unit where you can insert different I/O-modules, the cRIO used in the labs can take up to eight different modules. For example an eight channel TTL I/O is used to control the power electronics and a fast, simultaneously sampling four channel AD module is used to sample time critical signals, such as the current and the resolver signals.

3.5 Signal conditioning

Normally the I/O modules is intended to work with small signals, ie small voltages and currents. Since the power electronics is working with larger signals it is necessary to have some signal conditioning between them. This is done by a unit placed between the cRIO and the power electronics. The same unit also excites and interprets the resolver and provides some useful measuring points.

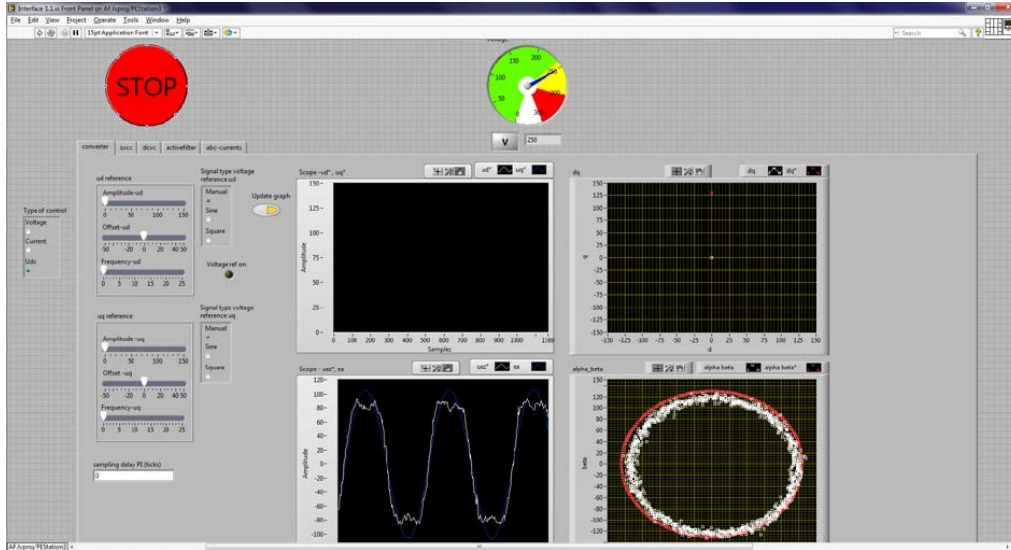


Figure 3.1: Control system first page view

3.6 The interface

The interface is mainly a tab-based interface. The idea is to save space on the control panel and to only show necessary controls, graphs, etc. Some of the control elements are always good to keep within reach, such as the stop button or the DC-link voltage. They are placed on upper part of the panel.

There are a number of boxes where you can enter variables; these are normally saved when you press enter after entering them, even if you leave the tab. However some setting, reference generators for example, are turned off when leaving a tab.

3.7 Converter modulation

This tab (figure 3.1) is meant to show the modulation methods that can be used and how the relation between the voltage references and the grid voltage.

The 3- ϕ converter is modulated with symmetrized references. The voltage references are calculated by a current control and the current references are given from the load current filter and the dc link voltage controller. All in accordance with the textbook material on shunt active filter control.

3.8 Sampled vector current control

This tab (figure 3.2) lets you set the current references (in d and q) and see how the converter controls the current.

3.9 DC voltage control

In order for the supply of the active filter to be disconnected from the grid, the converter has to control the DC voltage. This tab (figure 3.3) is used to set the reference and control parameters for the DC voltage control. As long as U_{dc} is chosen as Type of control (see the buttons to the far left), this control will continue as set in this tab, even if you switch to other tabs in LabView.

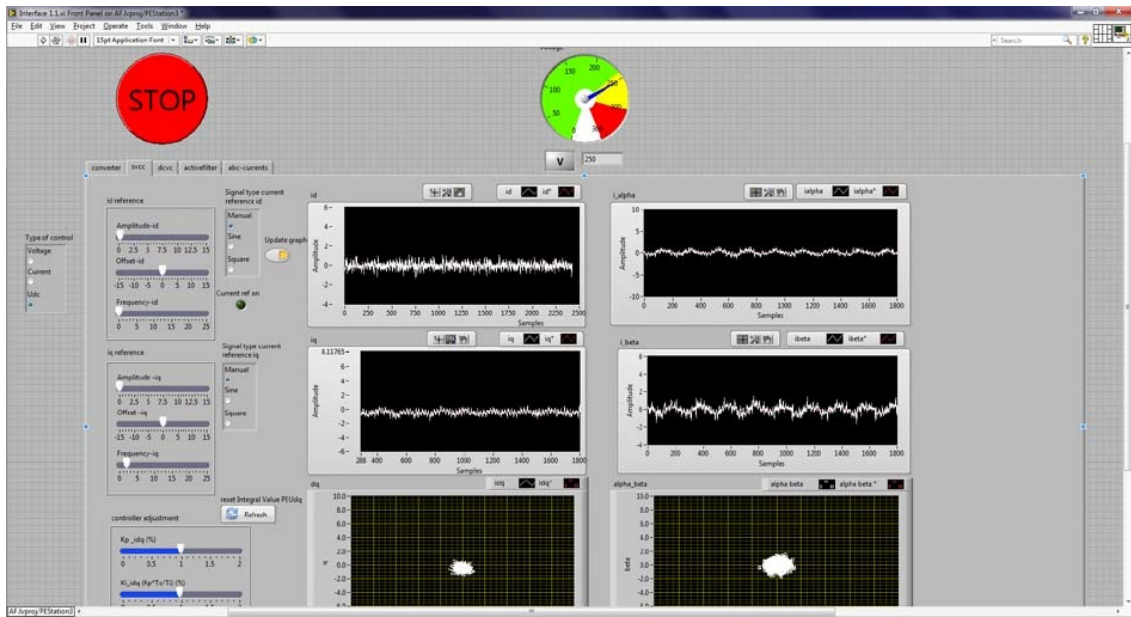


Figure 3.2: Control Desk layout for the sampled current control

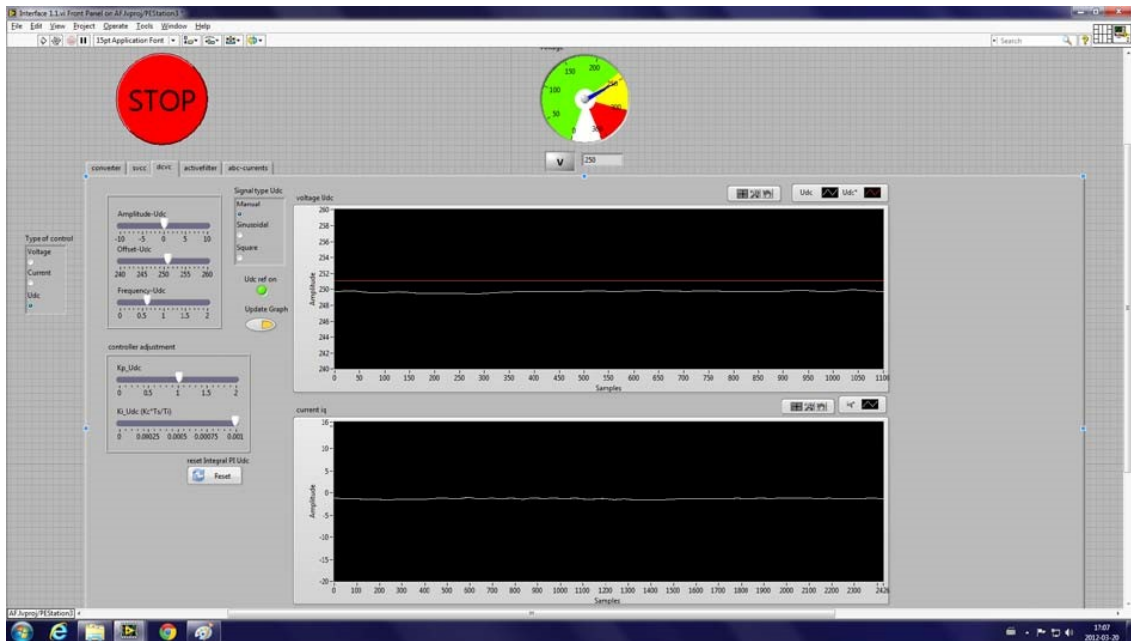


Figure 3.3: Control desk layout for the dc-link voltage controller

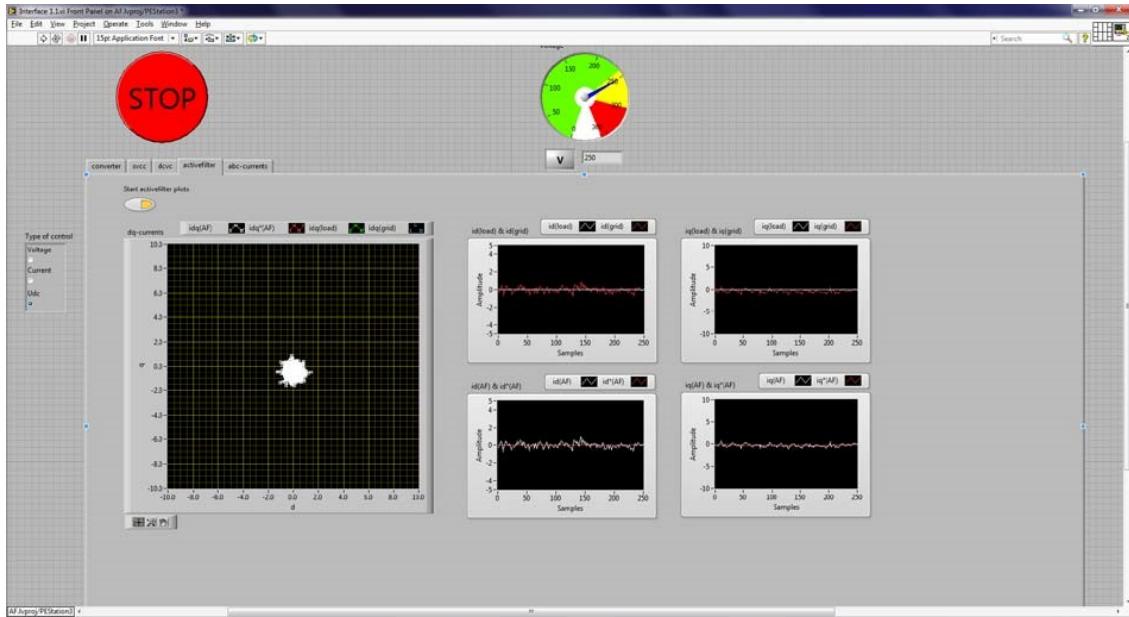


Figure 3.4: The layout for the active filtering

3.9.1 Active filter

In this tab (figure 3.4), the grid current, the load current, the filter current reference and the output filter current for phase a can be seen.

3.9.2 abc currents

This tab shows the currents (grid, load, filter) currents for all three phases (a, b, c), which is useful when the symmetry is under study. Note that only phase a and b are actually measured, but since no neutral return line is present within the system, phase c can be calculated from the measured currents.

3.10 Safety

Unlike the previous lab, the DC Machine lab, this lab does not allow jumping back and forth between tabs and control methods without thinking. Follow the instructions carefully and ask the lab supervisor if you have to go back to a previous step!

Also, as before, have in mind that it is quite much power you are controlling with this equipment. Connectors, etc. is as far as possible protected against human contact, but since it is lab equipment it is not as safe as the electrical equipment you buy at the shop. **Be careful!**

The DC link voltage should always be the last thing to turn up during start up and always the first thing to turn down during turn off.

4 Lab assignments

4.1 Getting started

1. Start the program National Instruments LabVIEW 201x. A *Getting Started* window will open.
2. Open the file C:\Labview\Active Filter Lab VI\AF.lvproj. The Project Explorer for the Active Filter will open.
3. Expand the *cRIO* item named PEstation# and then the RT folder in the navigation tree under *Items*.
4. To open the control interface double click on **Interface 1.1.vi**.
5. To start the **Interface 1.1.vi** click on the run button in the upper left corner of the toolbar.
6. If everything works the icon of the run button changes and the control system is executed in the cRIO system.
7. Make sure that everything else, such as the signal conditioning and the control system in the power electronics is running.

4.2 Goal

The ambition with this lab is that you shall get "hands on" experience of the following:

- Modulating a 3-phase converter that is not connected to the load, just to see the output voltages.
- Controlling the current to the three phase load by means of a Carrier Wave based Current Controller (No Direct current Control in this lab). The load is the electric power grid as shown in figure 1.
- Controlling the DC link voltage by means of the line side active current control as described in lectures and the textbook.
- Using the thus developed system as an Active Filter to compensate non-ideal currents draw by a load with a diode rectifier.

4.3 Output voltage of the Active Filter

In this first part of the lab, the input of the 3- ϕ PWM modulator is connected to a reference block where the output voltage (phase, amplitude) of the 3- ϕ converter is a function of voltage references that you set manually in the direct and quadrature (d,q) axes. The Active filter is supplied with DC link voltage from an external source and is not connected to the grid, but the control system is sensing the grid voltage and using that as reference to define the orientation of the (d,q)-reference frame. The DC link voltage will in this part of the lab be converted to the alternating voltages of the three-phase system as defined by you when you set the d- and q- axis components. You will be able to compare the converter output voltage to the grid voltage, even if these are not electrically connected yet.

- Make sure all the cables between the inductances and converter are disconnected.
- Turn on the green switch on the front panel of the Active Filter VSC and the corresponding red/yellow switch.

- With the adjustable transformer on the bench, slowly increase the DC link voltage to 250 V. Measure with the voltmeter. Remember that some transformers are very sensitive, so be careful!
- Make sure that the 'converter' is open and that 'Voltage' is selected in the 'Type of control' block (the radio buttons at the far left in LabView).
- Play around with the u_d and u_q reference offsets and look at the four graphs until you understand how to interpret ALL of them.

Look at the circles in the bottom right graph and increase the u_d^* amplitude to about half the size of the grid voltage circle. Then increase the u_q^* amplitude until the circles coincide. Now, are the reference voltage and grid voltage in phase?

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Where (in the d/q reference frame, top right graph) must the voltage reference vector be positioned for the phase voltage references to coincide with the line voltages?

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To understand why the d-q-frame is defined this way, we will look at a machine, even though there are no machines in this lab. The grid voltage on this lab can be interpreted as the back emf from a rotating machine (which is in fact how most of the power in the grid is generated). In the machine figure 4.1):

- Draw the d-axis and q-axis (direct and quadrature)
- Considering the induced voltage $e = L \frac{d\Psi}{dt}$ in a rotating machine, where will the largest back emf be induced?

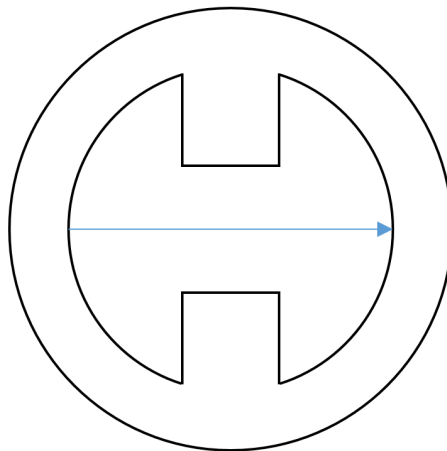


Figure 4.1: Draw the d-axis and q-axis. Where will the largest back emf be induced?

4.4 Sampled Vector Current Control

In the next step of the lab you will connect the Voltage Source Converter (VSC) to the grid. Before you can do this you need to connect the cables from the converter output to the phase inductances. To figure out which phase goes to which inductance, do the following:

- Stay in the converter tab.
- Decrease the DC link voltage to 90 V.
- Set u_d^* offset and amplitude to 0 V.
- Look at the PWM signal from the VSC in the oscilloscope and increase u_q^* until the signal is over-modulated.
- With the other channel of the oscilloscope, look at the different phases on the secondary side of the transformer (behind the VSC rack) and find the phase that coincide with the over-modulated signal.
- Turn off the red/yellow switch on the front panel of the VSC.
- After consulting the lab supervisor, connect the transformers second side with the corresponding filter inductances. Connect the cable in the converter side first and then the transformer side.

In this second part of the lab, the Voltage Source Converter (VSC) will be connected to the grid. The DC link will still be supplied from an external source, but the current controllers will now calculate the phase voltage references.

- Press the 'reset references' button in the converter tab.
- Choose Current in the Type of control block.
- Select the SVCC tab.
- Make sure that the d- and q-current references are set to zero.
- Increase the DC link voltage back to 250 V.
- Switch on the red/yellow switch on the front panel of the converter.
- Vary the d- and q-axis current reference amplitudes one at a time and answer the next question.

Which of the currents produce active and reactive power (see at the far right side in LabView). Does it seem right?

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To tune the control parameters of the current controller, do the following to the d- and q- current, one at a time.

- Set reference type from manual to square.
- Set the current reference frequency to approximately 10 Hz.
- Set the amplitude to ± 2.5 A.
- Adjust the controller parameters and look at the step response.
- Reset and look at the other current.

What are the suitable parameters for the current controller?

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- Press the 'reset references' button.

What are the theoretical values ($T_s=0.1$ ms) of the proportional gain and the integral time constant?

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4.5 DC-Link Voltage Control

Until now, the dc-link was connected to the basement generator as an external voltage source. We will now disconnect it by doing the following (Read carefully!):

- Switch off the red/yellow VSC switch.
- Keep the current controller running and make sure the DC link voltage is approximately 250 V.
- Choose U_{dc} in the Type of control block.
- Open the DCVC tab in LabView.
- Adjust the Offset U_{DC} reference to be equal to the measured DC link voltage (so that the lines coincide on the screen).
- Switch on the converter red/yellow breaker.
- Switch off the external DC supply (ask supervisor to locate the switch).

You will now hear a strange sound, but if everything works out it will only last for a couple of seconds. If it continues, turn the external DC supply back on.

- Check if the control works by changing the U_{dc} reference offset slightly and seeing if U_{dc} follows.

If it does – Great, it works! The SAF is now running without external power supply. We will now tune the U_{dc} controller.

- Set the U_{dc} reference offset to 250 V.
- Change type of reference from manual to square.
- Set the frequency to 1 Hz.
- Set the amplitude to ± 5 V.

Which of the d/q-current references is used by the DC link voltage controller? Make sure that you understand the sign of the capacitor current reference and the current reference in the d-q-frame.

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Play around with the PI parameters and see how they affect the step response. What are the suitable parameters for the voltage controller?

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What are the theoretical values ($T_s = 0.1$ ms) of the proportional gain and the integral time constant?

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- Set the u_{dc}^* frequency and amplitude to 0, and the signal type of the reference back to manual.

4.6 Active Filtering

In this section of the lab you will finally do what the Active Filter is meant for – active filtering. The current reference filters are already in operation, but up to now there has not been any load current to filter.

- Switch on the symmetric, nonlinear load.
- Under the "abc currents" tab and the "Active filter" tab, look around and make sure you understand what all the graphs mean. Note that the text is to the LEFT for the different colors in the description of the graphs.
- (Tip: In the 'abc currents' tab, use the 'Start abc-currents' button to pause the graphs)
- (Tip: In the 'abc currents' tab, reassign the scales of the a-, b-, and c-currents respectively to the same scale, e.g. ± 5 A, 0..2000 samples)

The connected load will draw nonlinear current. The harmonics from the odd shaped load current that the six-pulse rectifier will result in, may damage other equipment on the grid.

Look at the graphs in the two proposed tabs (abc currents and Active filter). How can you see that the load current is nonlinear? What can you say about the SAF's ability to filter harmonics?

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- Disconnect the symmetric nonlinear load.
- Switch on the asymmetric reactive load.

The connected load will draw asymmetric currents.

Look at the graphs in both proposed tabs. How can you see that the load currents are asymmetric? What can you say about the SAF's ability to improve the symmetry in the grid currents?

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- Switch both loads on.

Both loads will consume reactive power.

Look at the graphs in both proposed tabs. How can you see that the load current has a reactive component? What can you say about the filter's ability to compensate for reactive load currents?

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- Check with the supervisor that you have passed the lab.
- Disconnect both loads.
- Turn off the red/yellow, then the green switch of the VSC.
- Turn U_{dc} down.
- Press the 'Stop' button in Labview.
- At the inductance's side, disconnect the VSC-to-inductance cables.
- Turn off the grid voltage (ask supervisor).
- Have a nice day.