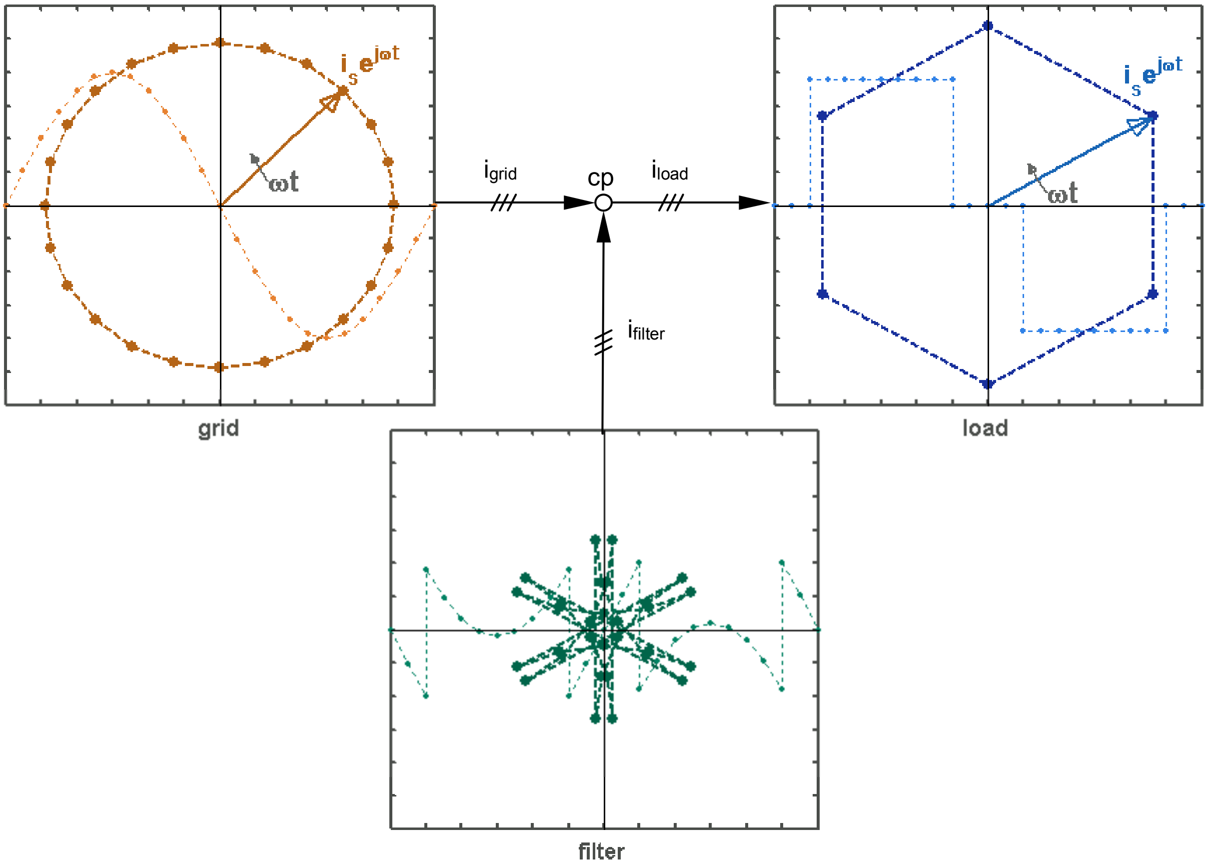
EIE 041 Control of Electrical Drives

Laboratory exercise 2

Active Filter Control



1. Introduction

In this lab a Shunt Active Filter (SAF) will be studied. The control system is a Simulink block diagram-based model that will be implemented in the dSpace real-time hardware. The scope of the laboratory work covers a control of a three-phase converter, a PWM modulation signal of three-phase symmetrized references, a vector control, a dc-link voltage control, an active filter/a reactive power compensation and an extra exercise is a dc machine drive connected to a voltage source converter (VSC). During the lab exercises 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 energy source.

2. Laboratory Set-Up

A three (one) phase rectified load is connected to a three-phase grid. A three-phase transformer (380/66.7V Y/Y) gives the suitable low voltage three-phase supply. A shunt active filter (SAF) is connected parallel to the load. The three-phase ac voltage source converter (VSC) is connected to the three-phase grid through three-phase inductances. This converter is back-to-back connected to a 2-level converter, which in turn feeds a dc-machine. The laboratory set-up is shown in figure 2.1 below.

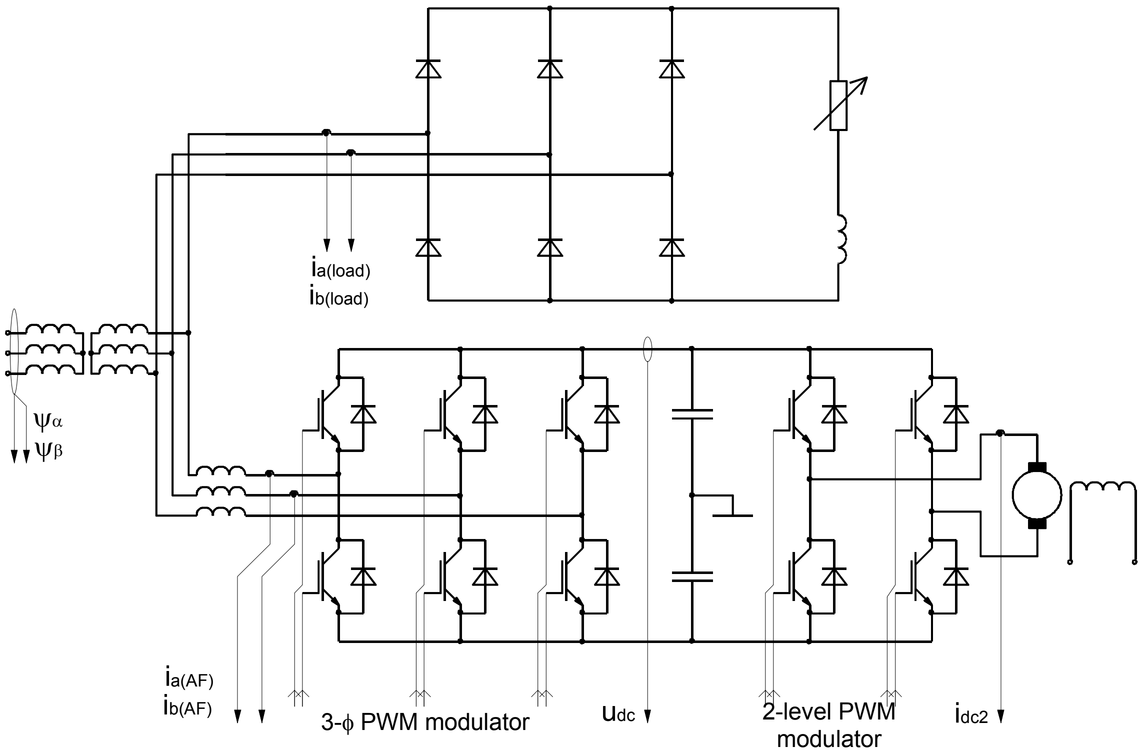


Figure 2.1 Principal diagram of the lab system

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 Simulink (figure 2.2).

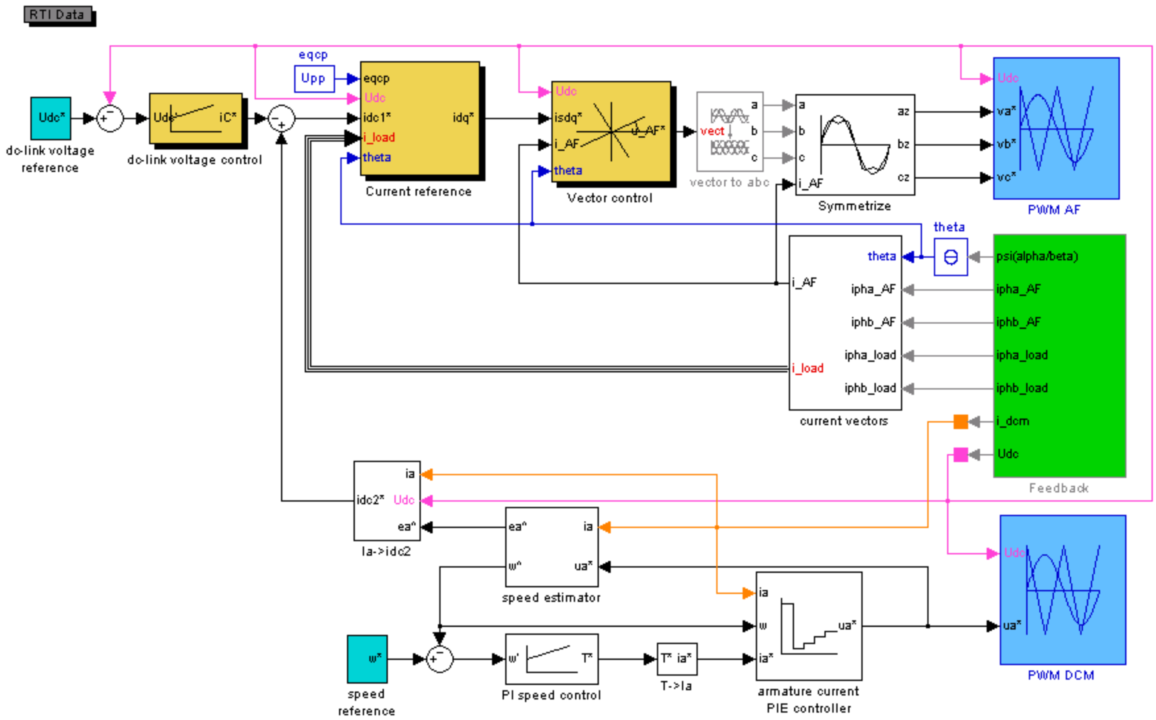


Figure 2.2 Control system implemented in Simulink RT-model

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. System Data

The data of the power system necessary for the voltage source controlled shunt active filter (VSC SAF) is presented below in table 3.1. This data is used to design the PIE current controller and the PI dc-link voltage controller.

Table 3.1 The SAF design data

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

The necessary files are in the work directory: ***C:/SED_lab/filter/***

- The RT Simulink model setup and the model – ***saf_setup.m, saf_lab.mdl***;
- The dSpace experiment and the user interface – ***saf_exp.cdx***;

If necessary, refer to the previous lab handout for the details on opening files and using the software.

System I/O is summarized in the table below:

Table 3.2 System Input/Output

Input	**dSpace Interface**	**symbol**	**source/measurement**
Flux linkage (alpha)	ADC1	psi_al	Flux linkage estimator
Flux linkage (beta)	ADC2	psi_be	Flux linkage estimator
Armature current	ADC3	ia	C&V measurement card
dc-link voltage	ADC4	Udc	C&V measurement card
Filter current phase a	ADC5	ipha_AF	C&V measurement card
Filter current phase b	ADC6	iphb_AF	C&V measurement card
Load current phase a	ADC7	ipha_L	LEM in circuit breaker
Load current phase b	ADC8	iphb_L	LEM in circuit breaker
Output	**dSpace Interface**	**symbol**	**source/measurement**
2φ PWM	PWM7 PWM8	va vb	DS1104SL_DSP_PWM
3φ PWM	PWM1 PWM3 PWM5	va vb vc	DS1104SL_DSP_PWM3
Reference current on quadrature axis*	DAC1	iq*	RT Simulink model
Feedback current on quadrature axis	DAC2	iq	RT Simulink model
Predicted current on quadrature axis	DAC3	iq^	RT Simulink model
Reference voltage on quadrature axis	DAC4	uq*	RT Simulink model
Flux linkage (alpha)#	DAC5	psi_al	RT Simulink model

* The axis of the dq-frame can be selected in vector control block.

An extra measurement cable is connected for flux linkage ($\psi_\alpha=\psi_a$) measurements.

4. The Laboratory Exercises

The content of the laboratory exercises are divided into four parts:

1 Studying the output of the 3-ϕ converter;

2 Investigating the principle of sampled vector current control;

3 Studying the principle of the dc-link voltage control;

4 Studying active filtering for the different loads;

4.1. 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 SAF is supplied with DC link voltage from an external source and is not connected to the grid. The dc voltage (Udc=250V) will be converted to the alternating voltages of the three-phase system.

The corresponding user interface – ***converter*** is shown in the figure 4-1.

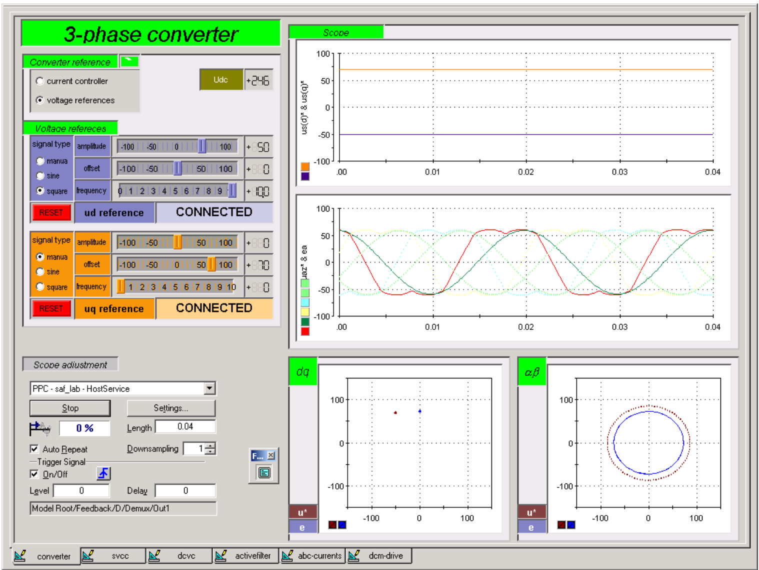


Figure 4.1 User interface to study the 3-ϕ converter

You can vary the d- and q-axis voltage references, and simultaneously look at the line voltage and converter voltage vectors in both the d/q-frame and as time functions. Use this possibility to investigate:

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

Draw the corresponding flux linkage vector for the voltage space vector below ($u_s(\omega t)=k*Um*e^{j\pi/6}$), show the position of d-q frame and draw the time functions of 3φ phase voltage for phase b (u_b), phase b potential for symmetrized references (v_b) and zero sequence potential (v_z). Indicate the corresponding switching states of the VSC.

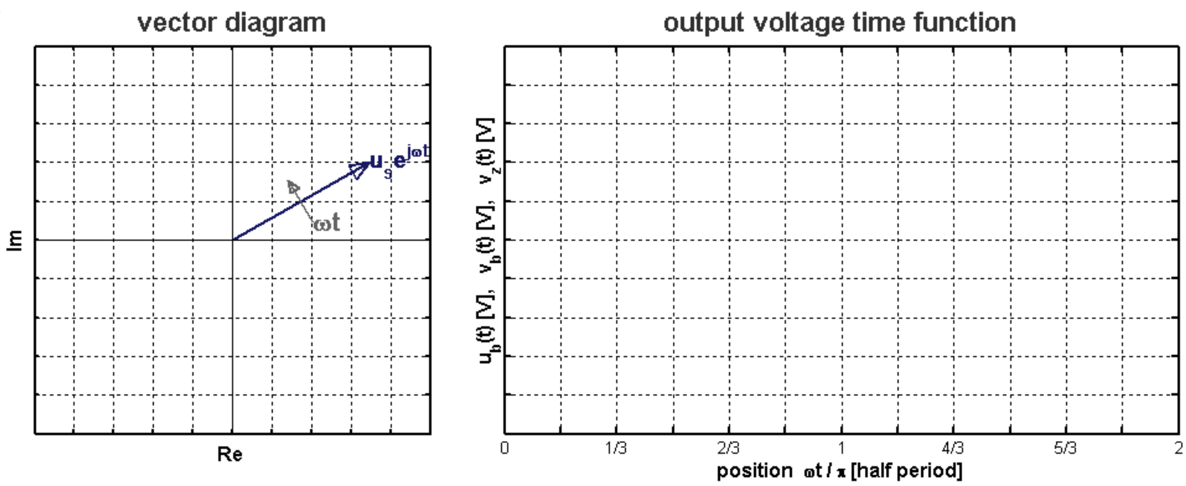


Figure 4.2 output voltage vector diagram and time functions for phase b

How does a step change (apply a square wave) in the d-axis reference influence the amplitude and phase of the phase voltage references if the q-axis reference is constant approximately equivalent to the line voltage? Make sure you understand how the variation in the vector plane and the time plane relate! Indicate the influence of the step change to the previous graph (fig. 4.2).

What happens if you let the d-axis reference be zero and increase the q-axis reference higher than the DC link voltage can supply? Look with a voltage probe on a phase potential on the converter output.

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In the next step of the lab you will connect the 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:

1 Set a DC link voltage to about 90 V.

2 Set the d-axis voltage reference to zero and the q-axis reference to such a high value that the modulator is over-modulated.

Look at the phase voltage of the line ($e_a = e_\alpha = d\psi_\alpha/dt$) and converter phases with a differential probe (available at the lab table). The phase voltage and converter output that coincide in phase belong together. **DO NOT connect the cables before you have switched off the converter output power switch!!!** Just note what phases belong together and how VSC suppose to be controlled that it can be safely connected to the power grid. Check with the teacher that you have done it right before you go ahead.

4.2. *Sampled Vector Current Control*

In this 2'nd 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. It is important that the "current references" is selected in the top left corner of the interface layout. Otherwise the DC-link voltage controller will compete with the external DC link supply.

A new interface layout is going to be used. It is called ***svcc*** and it is shown in the figure 4.3.

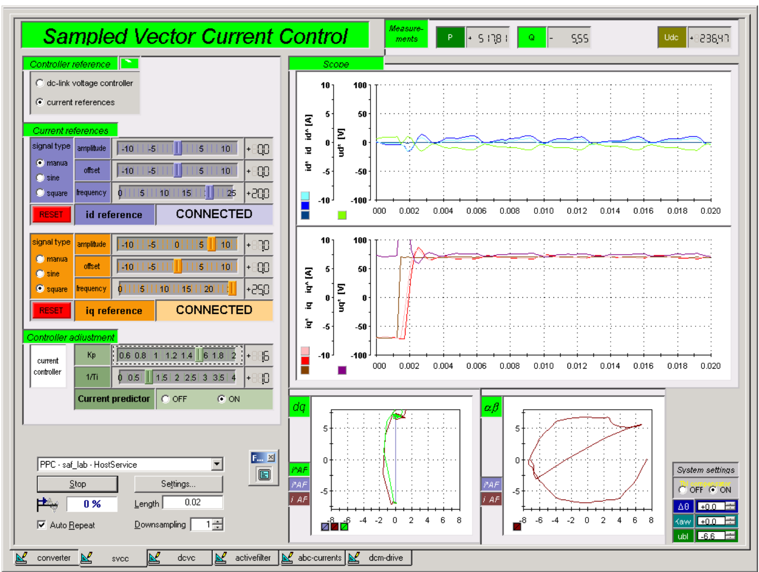

Figure 4.3 Control Desk layout for the sampled current control

Set the reference currents in the d- and q-axis to zero, then it is safe to switch the VSC to the grid with the red and yellow switch on the lower of the two converters. Now do the following:

Vary the d- and q-axis current components one by one and note the active and reactive power reading from the screen display. Do these two orthogonal current components influence the active and reactive power as you expected?

Set a step change (square wave) as reference for the two currents, one by one. Look at the current response and adjust the preset gain and integration constant with the levers called "Controller adjustment". The adjustment factors are scaling the gain and the inverse of the current controller time constant. Try also to include the current predictor and note that you can use a higher gain when the predictor is active. What are the suitable parameters for the current controller? What are the theoretical values (Ts=0.2083ms) of the proportional gain and the integral time constant?

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Compare the controller response with the simulations and draw (figure 4.4) the converter current response for i_q*=|5| A 25Hz square waveform.

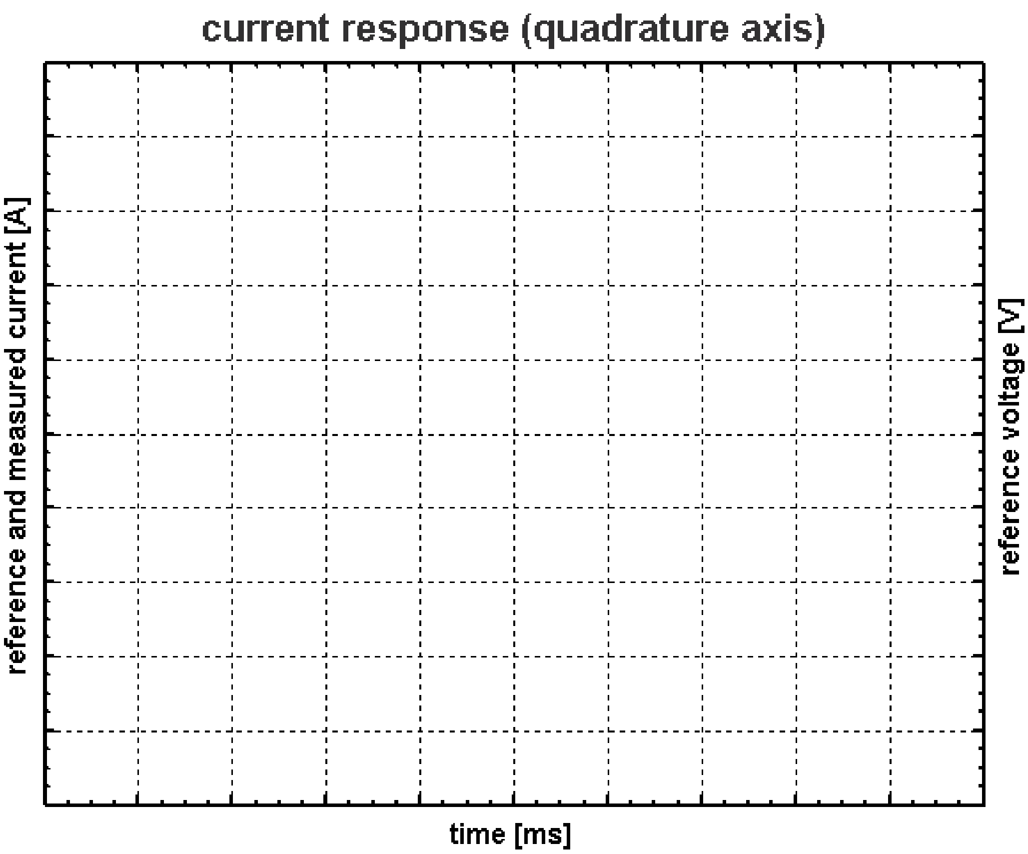

Figure 4.4 Current response on quadrature axis

4.3. DC-Link Voltage Control

Until now, the dc-link was connected to the external direct voltage source. Switch off the converter, disconnect the dc-link from the external dc-supply and include the dc-link voltage controller in the control circuit (setting in top left corner of figure 4.3). Now the DC link voltage controller is used to calculate the current references (the current reference settings on the screen are disregarded).

For a the successful start of the VSC SAF, reduce the proportional gain for the current controller, increase the proportional gain and the integral time constant for the PI dc-link voltage controller. Look at the current reference setting from the DC link voltage controller and don't switch on the power switch until this setting is lower than 10 A.

The new layout for the dc-link voltage control is shown in figure 4.5.

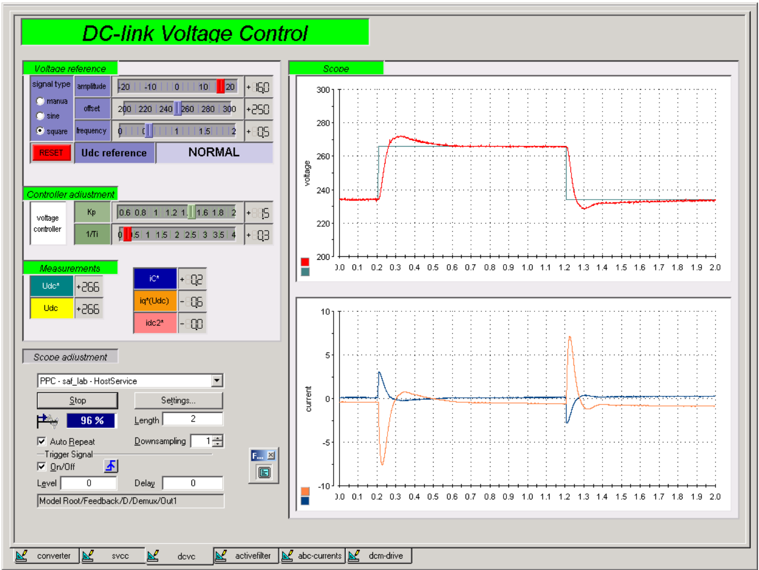

Figure 4.5 Control desk layout for the dc-link voltage controller

In order to study the response of the PI dc-link voltage controller use the signal generator implemented on the user interface. Note that the voltage step should be no more than 10-20 Volts around the average value of 250V at the switching frequency about 1Hz. Explore the voltage response and the possibilities for the further improvements. Compare the response with simulations and make sure that you understand the sign of the capacitor current reference and the current reference in the d/q-frame. Draw dc-link voltage response and the corresponding current reference for the current controller.

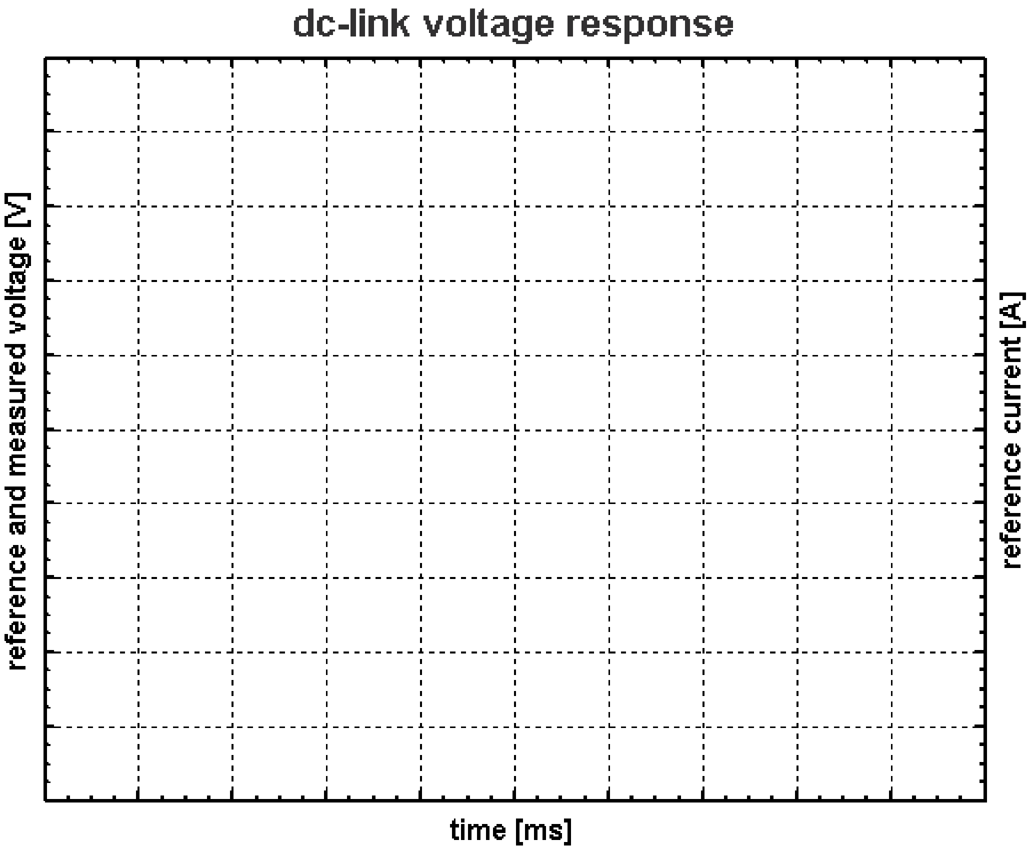

Figure 4.6 The control action of the dc-link voltage controller

Which of the d/q-current references is used by the DC link voltage controller?

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4.4. 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 there has up to now not been any load current to filter.

Switch on the load current by turning on the two fuse-switches on the front on the control electronics modules (ask the teacher if you are not sure). A six-pulse rectifier together with a RL load is thus connected to the grid. The plot of the user interface for the active filtering is shown in figure 4-6.

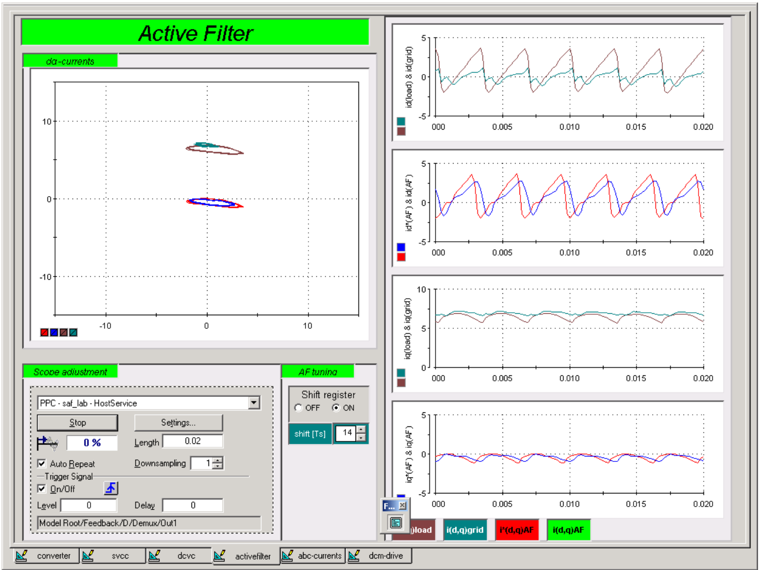

Figure 4-6 *The layout for the active filtering*

Study the outcome of the active filtering. There are several things you can do:

1 Run just the 3-phase diode rectifier and study the load currents, AF-currents and line currents as time functions of phase or vector component quantities and as vector quantities.

2 Switch of one of the phase switches to the load. Now it becomes a 1-phase rectifier connected between two phases. This is an unsymmetrical load also consuming harmonic currents.

3 There are two inductors rated 32 mH each that you can series connect in between two line phases. Now the load is asymmetrical and also consumes reactive power.

Play with these opportunities. Create cases that resemble to the simulations you have made, and compare performance. Comment on the action and quality of the active filtering and draw the different cases (figure 4.7 – 4.9).

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Explore different aspects like reactive load compensation, load symmetrization and filtration of the high order harmonics.

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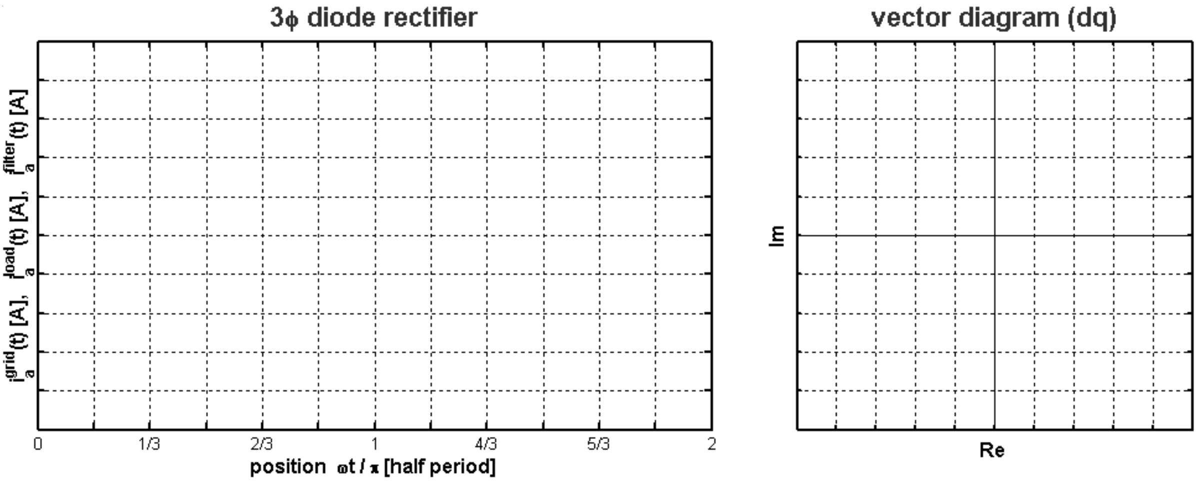

Figure 4.7 The active filtering action for the B6 with RL-load

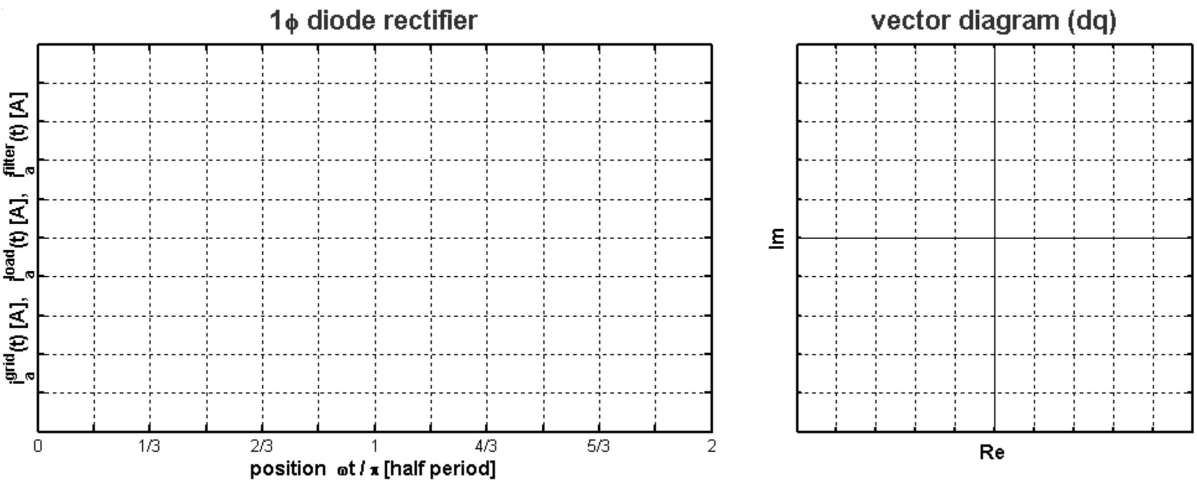

Figure 4.8 The active filtering action for the B2 with RL-load

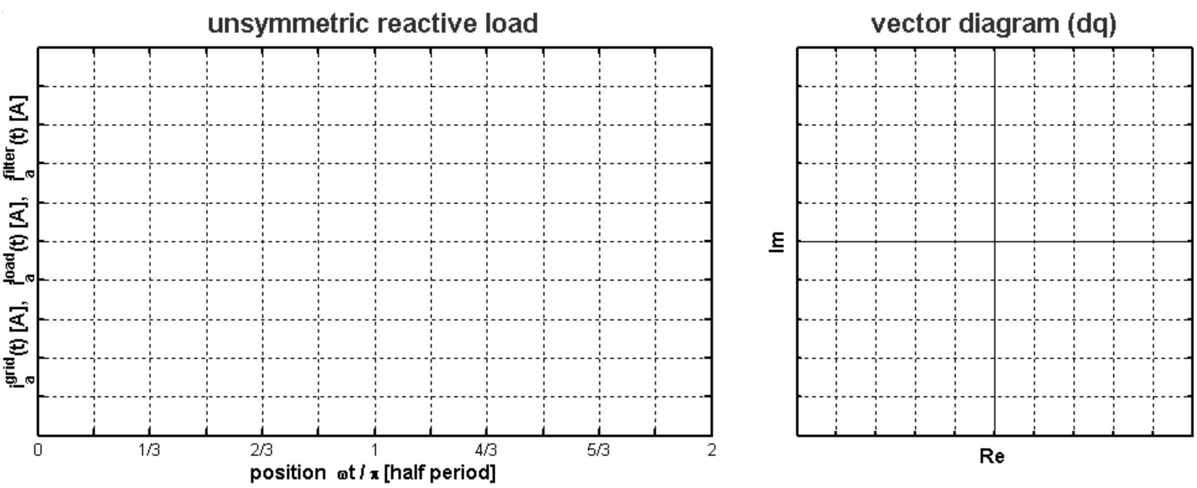

Figure 4.9 The active filtering action for the reactance between the phases

4.5. DC machine drive fed from the DC link

This is an extra assignment if you have time left when you have finished the previous tasks. There is a speed controlled drive connected to the same DC link as the Active Filter. It is almost exactly the same drive as you worked with in the previous lab. You can switch that on, and let the DC machine run e.g. back and forth in speed with a square wave speed reference. Look at the DC link voltage and the line current (especially vector component in the q-axis).

Explore the control action and the corresponding power flow in the system. Make sure that you understand the way the DC link voltage and the q-axis line current react to the speed variations in the DC machine. It may be helpful to disconnect the non-linear load to make the signals stricter.

4.6. Finally

Consider what you have done. When all systems have been running you have used the three phase vector controlled converter to control the AF current, filter the load current, control the DC link voltage and supply the DC machine with power. In addition you have used the 4-quadrant DC converter to control the current and speed of the DC machine. This is a rather complex power electronic control challenge, executed with 5 power electronic switch branches and a well thought through code for the control. Our hope is that this may have given you an impression of what can be done with power electronic control.