Control of Electrical Drives

Home assignment 2:

Modulation and control of 3-phase voltage source converters.

Application to active filtering applications

Introduction

In this home assignment you will learn about modulation and current control of three phase 2-level converters, and apply that knowledge to active filtering. The assignment thus contains three parts:

1 *Modulation*. This part is focusing on the modulation of the three phase converter and the corresponding effect on the current ripple and the sound.

2 *Current control*. In this part you apply both sampled and direct current control to the three phase converter

3 *Active filtering*. In this part you apply the current control converter to active filtering in the power grid.

To get started, download the file “SED2.zip” from the course homepage and unpack it in your working directory. It contains the three Simulink files you need for the three parts of the assigment.

Note! If you run into trouble while performing the tasks, and suspect that there is a bug in the code - take a new look at the home page. We will present the latest version of the code there continuously. Remember

Lubarsky’s law on Cybernetic Entomology:

“- There is always another bug.”

The parameters you will need during the simulation are:

L=round(10000(0.003+rand/1000))/10000*;

R=0.4;

Ts=0.2083e-3;

Udc=250;

Upp=66.5;

Cdc=0.0011;

di=3;

Task 1 - Modulation

In this first part your task is to study the current ripple of the three different modulation methods. The top level of the code is given in figure 1.

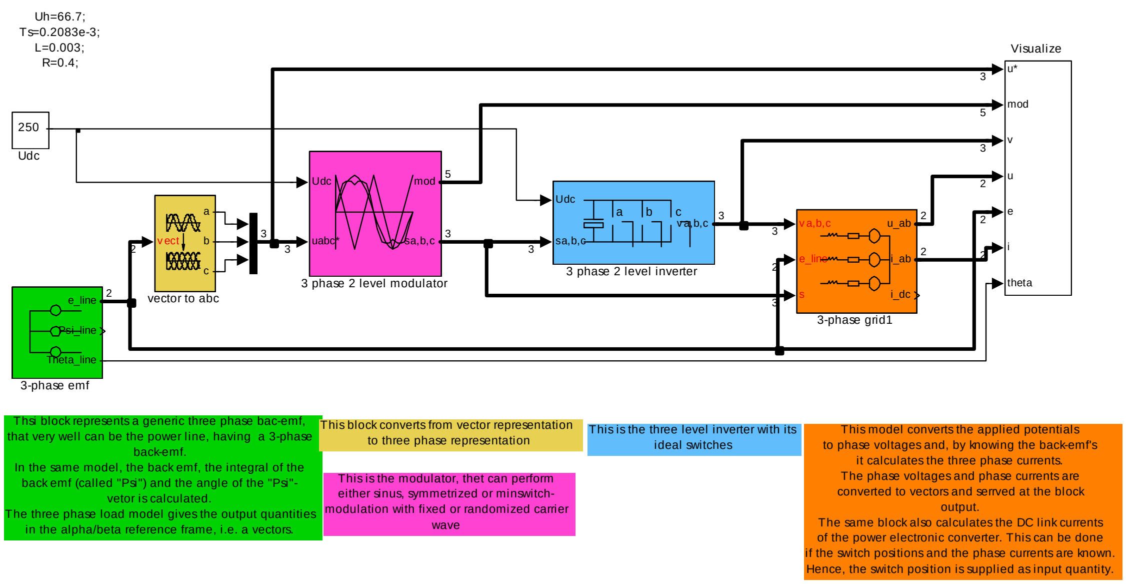


Figure 1. Top level of the code for the modulation task.

Note that the current is not controlled in this case. The thing that happens is that the converter is modulated to give exactly the same output voltage as the back-emf of the load. Thus, no current will flow, but the current will be zero, except for the current ripple.
The program should be run with **0.02 seconds simulation time** and with modulation settings according to Table 1. For each case, save the plot of the “Current” oscilloscope by pressing `"Fn"+"Ctrl"+"Alt"+"PrtSc"` on the keyboard when the oscilloscope is active.
NOTE, select only the time interval 16+/-0.5 ms, i.e. near the peak of phase *a* voltage u_a.

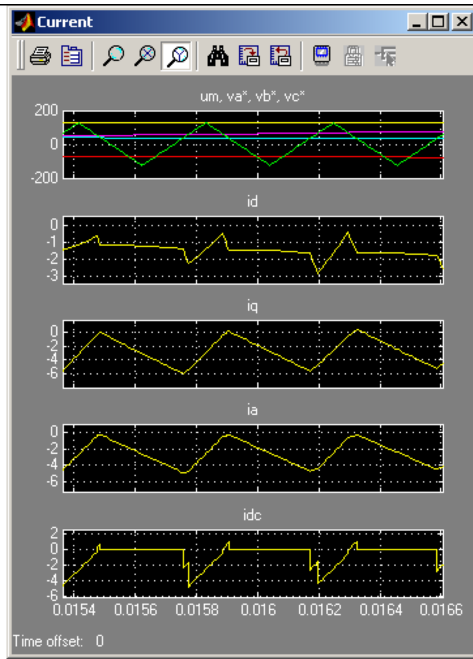
Report requirements:

Fill in Table 1 with the plots you have made, and the required comments. One example is given below, replace it with your own. The d/q current ripple can be taken from the “*Current in*

(d,q)” window.

Table 1 The five different cases to simulate

Case	**Modulation method**	**Modulation references**	**Plot of the “current window”**	**d-axis current ripple [A]**	**q-axis current ripple [A]**
1	Fixed frequency	Sinusoidal			

2	Fixed frequency	Minswitch			
3	Fixed frequency	Symmetric			
4	Random frequency	Symmetric			

In addition to filling in Table 1, make a sketch of the d- and the q-axis current around 16 +/- 0.5 ms for case 1 of Table 1 and explain in your own words the different slopes of the two current ripples. The sequence of voltage vectors as well as the line back emf vector should be in the explanation.

Task 2 – Current control

In this task you will study the three phase two level voltage converter with current control. The top level of the code is shown in figure 2.

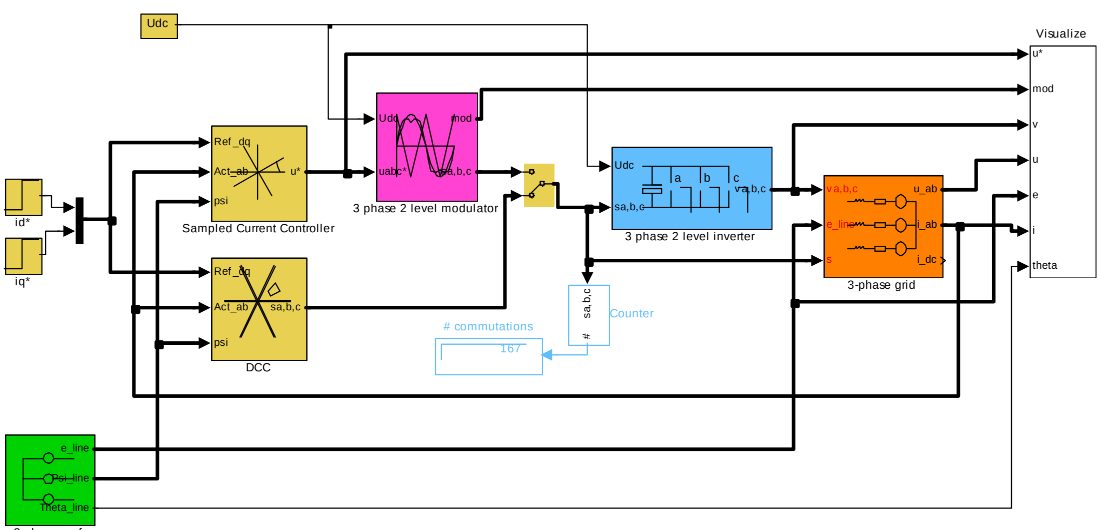


Figure 2. Top level of the code.

You are encouraged to examine the contents of the different blocks. You can select either the PIE- or the DCC controllers with the manual switch in the middle of the. The contents of the blocks are described in the code. Run 0.05 seconds simulation time only.

- Set the *q*-axis current reference to go from 0 to 10 A @ *t*=0.0055 seconds. Set the *d*-axis current reference to go from 0 to 10 A @ *t*=0.0105 seconds. The specific times are given for the reference to change in between two sampling time instants.
- Run the cases of Table 2. The *d*- and *q*-axis currents are saved to workspace. Plot them after the simulation with `"Fn"+"Ctrl"+"Alt"+"PrtSc"` when the "Current**s**" (NOT the Current) window is active.

Table 2 Current control cases to study

Case	Current Control Method	Plot from the "Current" window	Your answer to question 1 and 2 below.
1	Sampled with Symmetric modulation		
2	Direct		
3	Sampled with Symmetric modulation With mistuned parameters		

1 Explain the difference in response time in the d- and q-axis currents and the difference between the PIE and the DCC cases for each current. You can use the magnifying glass in the plot window tool bar to examine the step responses.

2 Explain the reason for the drop in the *q*-axis current at the time of the *d*-axis step with the PIE controller.

3 Try out one new set of controller parameters by changing the parameter definition in the Vector Control block dialogue window to e.g. L*2 instead of L. This gives the controller the idea that the load inductance is twice the one it really is corresponding to a mistuned controller. Make your own choice of how mistuned the parameters should be. Chose a degree of mistuning that you consider realistic.

4 Run case 3 from table 1 above. Plot the with "dqplot" as before.

5 Comment on the apparent parameter sensitivity of the controllers.

Task 3 – active filtering

In this assignment you will study the characteristics of non-ideal loads and the application of Active Power Filters (APF's) for compensation of the non-ideal components of the load current flowing to the non-ideal load. The work done with this assignment also serves as preparation for Lab 2, which deals with exactly the same situation.

Non-ideal loads.

Any three phase load that consumes power with any other than a symmetric three phase current at unity power factor (no phase lag between voltage and current) and fundamental frequency is non-ideal. A non-ideal load current contains at least one of the following components:

- *Reactive current*. Loads containing inductive or capacitive elements consume reactive current components.
- *Asymmetric current*. Consumed by three phase loads that are not equal in all three phases.
- *Harmonics*. Consumed by non-linear loads, e.g. a diode rectifier.

The active power filter

There are two generic types of APF's, the series and the shunt active filter. Both are described in the book, but in this lab we will study the shunt active filter. Figure 3 shows how the filter is connected together with the load to be filtered.

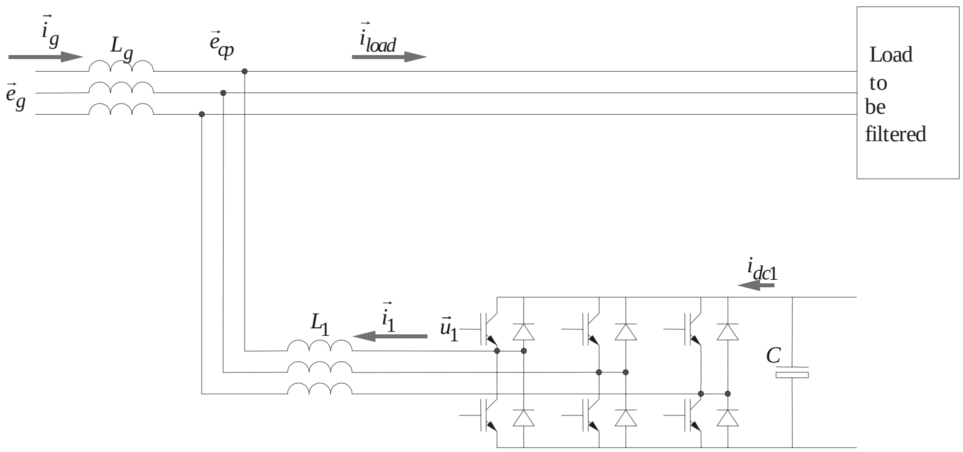


Figure 3. The active power filter connected to support a load.

There are two particular restrictions with a shunt active filter connected like in figure 3:

1 *No 3'rd harmonics*. The APF in figure 3 cannot supply currents that have the same phase position (zero sequence) in all three phase conductors, since then there would be no return path for those currents. This makes the filter in figure 1 unsuited to compensate loads that consume large amounts of 3'rd harmonics (3'rd harmonics get the same phase position for all three phase currents).

2 *No active power*. The APF, connected as in figure 1, is not able to support the load with a continuous flow of active power, since there is no source of energy on the DC side of the filter apart from the energy stored in the DC link capacitor. Any short time flow of active power between the DC and the AC side of the filter corresponds to a charge or a discharge of the DC link capacitor, depending of the direction of the power flow. In reality this means that with realistic sizes of the DC link capacitor, the APF can supply active power to the grid only for some millisecond, for longer times the corresponding change of the DC link voltage will be to big.

The two above discussed restrictions may both be eliminated. Restriction 1 can be eliminated by another Power Electronic connection that is able to support 3’rd harmonic currents. Restriction 2 can be eliminated if the DC link is connected to an external power source.

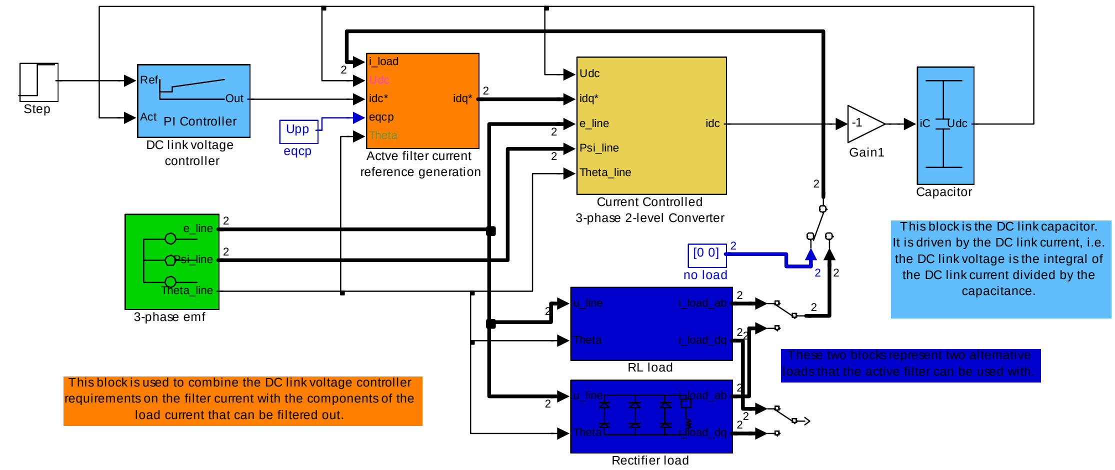


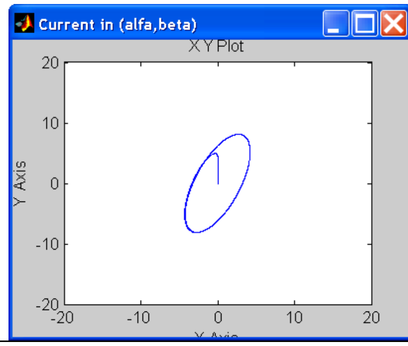
Figure 4 Active filter simulation program top level

Different loads

In the simulation program there are two load blocks. The first contains blocks that emulate the function of a two- or three-phase diode rectifier. The second contains an R-L-load where you can set the resistance and inductance of each phase individually.

Use these loads to study the following cases:

Case	Load and setting	Load current vector in alfa/beta	Load current vector in d/q	Your comment
1	RL Load Symmetric R=10 Ohm L=0.005 H Isat = 10 A			
2	Purely resistive symmetric load. R=10 Ohm L=0 H Isat = 10 A			

3	RL Load Assymtric, set the c-phase load to be: R=3 Ohm L=0.005 H Isat = 10 A			
4	Non linear symmetric load with saturation R=5 Ohm L=0.005 H Isat = 3 A			

Comment each case on the applicable of the following aspects:

- Phase position of the d/q-current relative to the load parameters. A purely resistive load should have zero phase lag relative to the emf-vector.
- Direction of rotation of the harmonic components in the d/q-frame. The asymmetry should result in a current rotating XX-wards in the d/q-frame.

The active filter

In this task you will run the Active Filter at no-load, i.e. without any filtering current references. The pure purpose is to study the dynamics of the DC current control. Run the following case:

Case	DC voltage reference and controller settings	DC link voltage and other quantities from window "Current" in the "visualize" block	Load current vector in d/q	Your comment
1	250-> 270 V @ t=5ms			

Comment

Task 3 – filtering

In this final task you will use the APF to support the load with all non-ideal current components possible. This means that the whole load current, with the exception of the DC-component of the q-axis load current is supplied by the APF. Then the APF does not provide any sustained active power (which it cannot!) but all reactive power components (= all d-axis load current components) and all AC-coupled q-axis load current components (= all variations in active power faster than a certain cut off frequency defined by T_f). Run the following cases:

Case	Load and setting	Load, filter, line currents and DC link voltage from the "Phase a" window in the "visualize" block	Load, converter and line	Your comment

		and all quantities from the “Current” block in the same window.	current vector in d/q	
1	Rectifier load			

Note how the filter current is trying to mimic all aspects of the load current except for the active power component in the q-axis, the average value of iq.

Dates and deadlines:

The report must be handed in on Friday evening, week 46 = 18/11.