The Active Filter

Home Assignment 4

Updated March 17, 2020

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.

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. This also serves as preparation for Lab 2, which deals with exactly the same situation.

Non-ideal loads

A non-ideal load is any three phase load that consumes power with anything else than a **symmetric** three phase current at **power factor of 1** (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, with the result that the current is not perfectly sinusoidal.
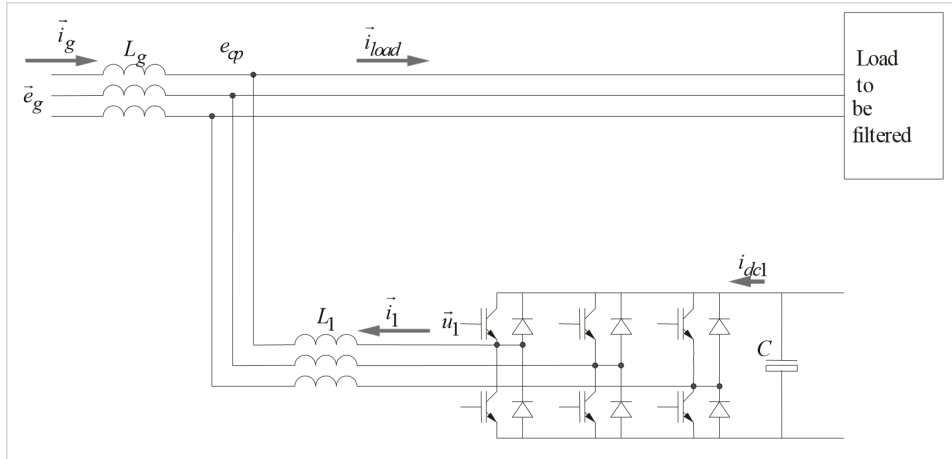
Figure 0.1: The active power filter connected to support a load.

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 the lab we will study the shunt active filter, SAF. Figure 0.1 shows how the filter is connected together with the load to be filtered.

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

1. No 3'rd harmonics. The APF in figure 1 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 too 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.

Report requirements

Report requirements are given more thoroughly in the DC Machine home assignment manual. In short:

- Submit via email and attach your report as a **PDF file**, with **the file name starting with AF_Yourlastname**.

- You must submit your home assignment report to be allowed to do the lab. The first report does not have to be perfect, but you should have made honest attempts to complete all tasks.

- One report per student.

- Anything unclear will be explained during the lab.

- You will receive your feedback after the labs are over.

- Try to finish all your feedback corrections before the exam for earlier Ladok results, or before the end of the summer to avoid having to redo the lab next year.

- There are no lab report for these labs, only the home assignment reports.

1 Modulation

In this first part your task is to study the current ripple of the three different modulation schemes. The top level of "ThreePhMod" is given in figure 1.1, with colorwise explanations of the blocks below.

This block represents a generic three phase back emf, like a power line, as vectors.

This block converts the vectors to three phase representation.

The Modulator that can perform sinus, symmetric or minswitch modulation, with fixed or random carrier wave frequency.

This is an ideal three level inverter.

This is a model of the grid connection and the load. It also calculates how much current is taken from the DC link.
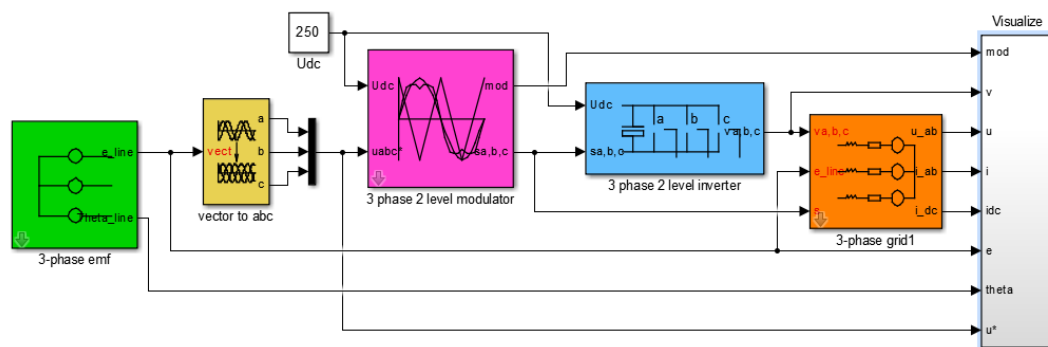

Figure 1.1: Top level of the Simulink model for the modulation task, ThreePhMod.

The parameters you will need during the simulation are: (Copy and insert into Matlab console)

```
>> L = 0.003+round(10*rand)/1e4;
>> R = 0.4;
>> Ts = 0.2083e-3;
>> Udc = 250;
>> Upp = 66.5;
>> Cdc = 0.0011;
>> di = 3;
>> Tf = 1/(2*pi*50);
```

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.

Run all the cases below for 0.02 seconds and present the following for each of them in your report:

- Two screenshots of the "Currents" plot in the "Visualize" block:

– One of the whole time period (0 .. 0.02 s)

– One zoomed in to 0.0155 .. 0.0165 s

- The current ripple size (from "Currents in (d,q)" in "Visualize") in both d and q.

- A short comment on what you see (compared to the other cases).

Case	Modulation method	Modulation scheme
1.1	Fixed frequency	Sinusoidal
1.2	Fixed frequency	Minswitch
1.3	Fixed frequency	Symmetric
1.4	Random frequency	Symmetric

1.5 Theoretical questions - Modulation schemes

In chapter 2.6 in the text book, it is explained that the difference between the modulation schemes is the zero sequence signal that is added to the three phase reference waveforms. Since the converter has three phase outputs and no neutral line, the shape of the zero sequence signal will not be evident in the output currents.

What could then be the reason for the different modulation schemes? What differences do symmetric and minswitch (bus-clamped) do compared to sinusoidal?

1.6 Theoretical question - Current ripple in d-q

Look the d- and the q-axis current from 15.5 to 16.5 ms for case 1.1. Explain the following thoroughly. It may help making a sketch of the current, voltage vectors and/or modulation wave.

- Explain the different slopes in the shape of the d- and q-current ripples.

- How is the current ripple shape connected to the voltage vectors?

- How are the voltage vectors chosen?

2 Current control

In this task you will study the three phase two level voltage converter with current control. The top level of "ThreePhCurrentControl" is shown in figure 2.1.
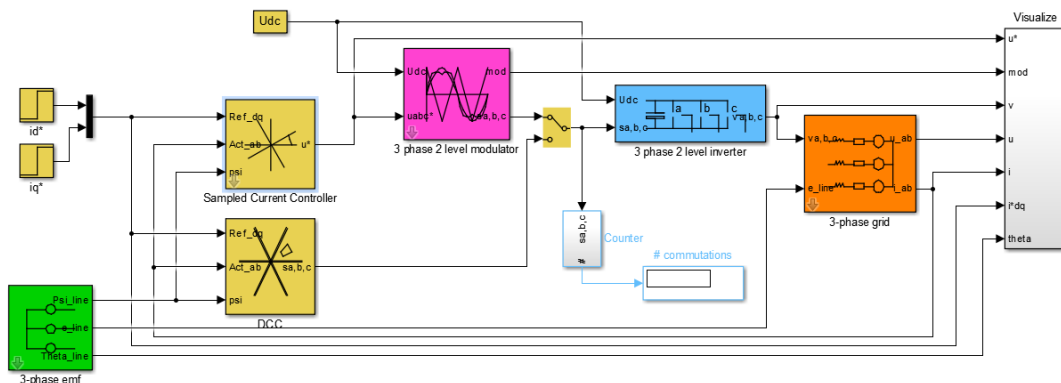

Figure 2.1: Top level of the Simulink model for the current control task, ThreePhCurrentControl.

Compared to the modulation model two controller blocks are added. You can select either the Sampled or the Direct Current Controller with the manual switch in the middle. Look under the mask of the controllers and try to understand what happens in them. The content of the PIE controller is thoroughly explained inside.

Run simulations of the cases below with the following settings:

- Simulation time 0.05 seconds.
- Q-axis reference step from 0 to 10 A at 0.0055 seconds.
- D-axis reference step from 0 to 10 A at 0.0105 seconds.

In your report, present the following:

- A screenshot of the "Currents" plot (not "Current").
- Your comments on how the step responses look.
- For Cases 2.1 and 2.2:
  - Compare the cases.
  - Why is there (or why is there not) a disturbance to the other current at the time a current makes a step response?
- For Case 2.3:
  - How much can the parameters be mistuned before the step responses are unstable?
  - Why is there (or why is there not) a disturbance to the other current at the time a current makes a step response?

Case	Current Control Method
2.1	Sampled with Symmetric modulation
2.2	Direct
2.3	Sampled with Symmetric modulation with mistuned parameters

In Case 2.3, either change the values for Resistance and Inductance in the "3-phase grid" block parameters to things like $R \cdot 2$ instead of just R, or change the values of the gain and integral time in the controller block. The controller parameters are calculated from the R and L values, but if those are different from the real grid values, the controller becomes mistuned.

3 Different loads

In this task you will look at the currents from different kinds of loads. The top level of "ThreePhAF" is shown in figure 3.1.

This block (in the middle) contains the current controller from the previous task.

These blocks represent the loads. The first contains an R-L-load where you can set the resistance and inductance of each phase individually. The second contains blocks that emulate the function of a two- or three-phase diode rectifier. Don't forget to flip the switches to run your simulations with the correct load.

This block controls the DC link voltage. The DC link voltage will change as current is taken from it when the filter is working, so this controller will borrow reactive power from the grid to keep the voltage.

This block looks at the grid voltage, the load current and the DC link voltage to calculate the reference current for the current controller.
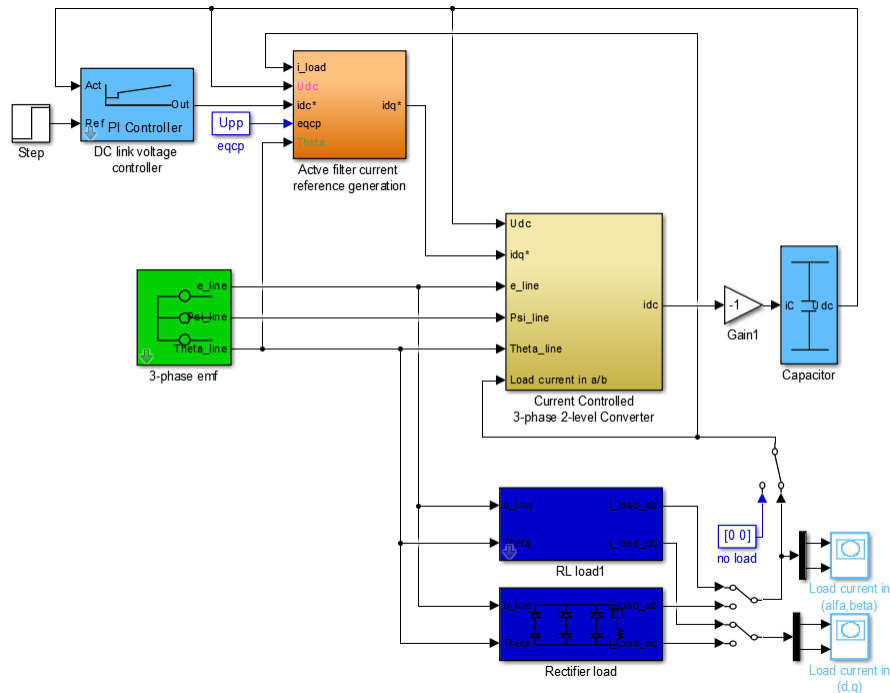
Figure 3.1: Top level of the Simulink model for the active filter.

In this task, use the settings of the RL Load only (not the rectifier load), to study the cases below. Make sure the DC link voltage reference step is turned off.

Present the following for each case:

- Screenshots of "Load current in (alfa,beta)" and "Load current in (d/q)".
- What does the position in the d-q-frame tell you?
- What does the shape of the alfa-beta-current tell you?
- Compare the cases.

Case	Load type	Load settings
3.1	Symmetric RL Load	$R = 10\ \Omega$ $L = 0.005$ H $I_{sat} = 10$ A
3.2	Purely resistive symmetric load	$R = 10\ \Omega$ $L = 0$ H $I_{sat} = 10$ A
3.3	Asymmetric RL Load Set phase A and B like Case 1 Set phase C as described to the right:	$R = 3\ \Omega$ $L = 0.005$ H $I_{sat} = 10$ A
3.4	Non-linear symmetric load with saturation	$R = 5\ \Omega$ $L = 0.005H$ $I_{sat} = 3$ A

4 DC link voltage control

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 simulations and

tune T_f between $\frac{1}{2\pi 50}$ and $\frac{1}{2\pi 300}$ until you are happy with the DC link voltage step response.

Present the following in your report:

- A screenshot of Current controller converter $\rightarrow$ Visualize $\rightarrow$ "Current".

- Your choice of value for T_f.

- How are the d- and/or q-currents to control the DC link voltage chosen?

(Tip: The simulations are a lot faster if you close the alfa-beta and d-q-plot windows!)

Case	DC link voltage reference	Load
4.1	Step from 250 to 270 V @ 5 ms	No load

5 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 it does provide all reactive power components (d-axis load current) 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 case and present the following

- Screenshots of Current controller converter $\rightarrow$ Visualize $\rightarrow$ "Phase a" and "Current"

- Why are there spikes in the line current? Can we get rid of them?

- What are the d- and q-currents from the filter used for respectively?

Case	Settings	Load
5.1	No DC link reference step	Rectifier load