Object Oriented Modeling and Control Design for Power Electronics Half-Bridge Converter using Modelica

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Abstract

In this paper the focus is on a particular type of converters that is the two-level VSC (DC/AC Voltage Source Converter). In this category the averaged model and the switching model of an half-bridge converter are considered. The half-bridge is a building block for multiphase and multilevel converters.

The implementation of the two models of half-bridge converter using Modelica language is described with the structure of the package developed in Dymola. Different control strategies are introduced showing different behavior of the models in the simulations. The goals of this paper are several. First of all the modeling choice was to use Modelica for this type of work, that is traditionally carried out with domain specific tools, to show that it is possible to perform implementation and studies in the same field where traditional commercial softwares have been commonly and extensively used, with additional benefits that the language provides. In addition to that, this paper shows that the control design studies for an half-bridge converter, typically performed using averaged value models, can result in a set of control parameters values that are not successfully applicable to switching models of the same power electronic device.

Keywords: VSC converters, half-bridge, averaged model, switching model, STATCOM, Modelica, Dymola, PI control, lead compensator, lag compensator, resonant control

1 Introduction

1.1 Motivations

With the enhancements of power semiconductors the application of power electronics has been extended from traditional domestic and industrial applications to electric power systems. The power-electronic converters for power systems are used especially for power compensation and power filtering. Such converters consist of a power circuit realized through different configurations of switches and passive components coupled with a control system (Yazdani and Iravani, 2010).

In the past, the applications of power-electronic converter systems in electric power systems were limited to the HVDC (High Voltage Direct Current) transmission systems and static reactive power compensators like SVC (Static Var Compensator). With time the application areas for generation, transmission and distribution of electric energy have been extended for several reasons. The main incentives are represented by:

- Continuosly growing development of power electronics technology for electric power systems
- Development of signal processing and control strategies
- Issues with power line congestions
- Growing of energy consumption leading to the utilization of the existent electric infrastructure at its technical limits (stability issues)
- Increasing penetration of renewable energy sources due to the economic feasibility and to environmental concerns

The use of power-electronic converters in power systems is also motivated by the need to improve the efficiency and reliability of the existent electric infrastructure for integrating large scale renewable energy sources and storage systems.

The main applications of power-electronic converters in power systems are:

- *Active filters*: they synthesize and inject specific components of current or voltage into the grid to improve the power quality (Rashid, 2017)
- *Compensation*: the aim is to improve the power transfer capability of the lines, the voltage stability, the power quality. In this category we have the STATCOM (Static Synchronous Compensator). The function of the STATCOM is to act as power compensator by injecting or absorbing reactive power from the grids (see Figure 1).
- *Power conditioning*: the idea is to allow for a power exchange between two electrical systems under control to meet specific requirements like frequency, voltage magnitude, etc. (Maza-Ortega et al., 2017)

This paper focuses on the implementation and design of a simple power electronic DC/AC converter, the half-bridge. The first modeling choice is to use Modelica for

$k_i \quad k_p R \quad r_{on}\ L \quad 1\ 176$. We can run a new simulation and the results are illustrated in Figure 21.

From Figure 21 we can see that now the system is able to settle at a final value corresponding to the step input value by using a PI controller. The initial negative overshoot of the current is due to the initial conditions of the system.

If we now consider the same conditions for the system with the switching model of the half-bridge converter, applying the same step without controls we get the results in Figure 23. Introducing the same PI control of the previous case we get the results in Figure 24. The value of the capacitance C at the output of the switching model of the converter can affect the output current ripple. There are also other requirements that need to be met, for example the admissible voltage ripple on the load and a reasonable value of the capacitance C. An example is shown in Figure 22 where the switching model of the half-bridge converter without any control has been used. It shows the impact of the variation of the capacitance on the output current.

Figure 22. Plot of the AC output current of the system with switching model without controls for different values of the output capacitance C.

Figure 23. Plot of the step input (blue curve) and AC output current (red curve) of the system with switching model without controls. Due to the difference of magnitudes between the two curves the step of 50A cannot be seen in the figure.

Figure 24. Plot of the step input (blue curve) and AC output current (red curve) of the system with switching model with PI controller.

From Figure 20 and Figure 23 we can see that without any control the output current is not able to track the step reference either with the averaged model or with the switching model. Introducing a PI controller, from Figure 21 and Figure 24, the results are better even if we have a large negative overshoot for the system with the averaged model of the half-bridge converter and some oscillations of the output current at the initialization of the system with the switching model when the step is applied.

The next test consists of changing the source of the reference signal with a sinusoid of amplitude 1000 and frequency 60Hz starting at $t \quad 0\ 07$s. Running a simulation we get the results in Figure 25 for the system with the switching model without any control.

Figure 25. Plot of the sinusoidal input (blue curve) and AC output current (red curve) of the system with the switching model without controls.

For the system with the averaged model without any control we get the results in Figure 26.

From Figure 25 and Figure 26 the behavior of the systems with the switching model and the averaged model without any control looks very similar but not able to track the reference signal.

When introducing the same PI controller with the sinu-

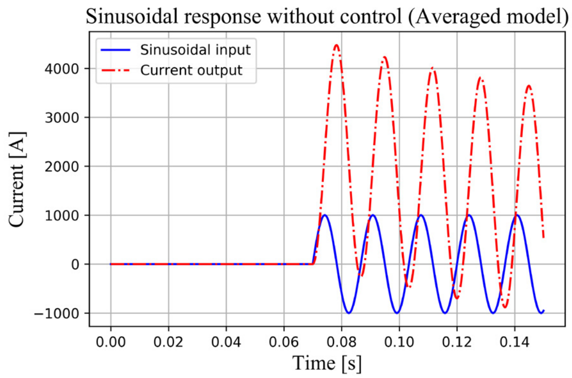

Figure 26. Plot of the sinusoidal input (blue curve) and AC output current (red curve) of the system with the averaged model without controls.

soidal reference signal we get the results in Figure 27 for the system with the switching model and the results in Figure 28 for the system with the averaged model.

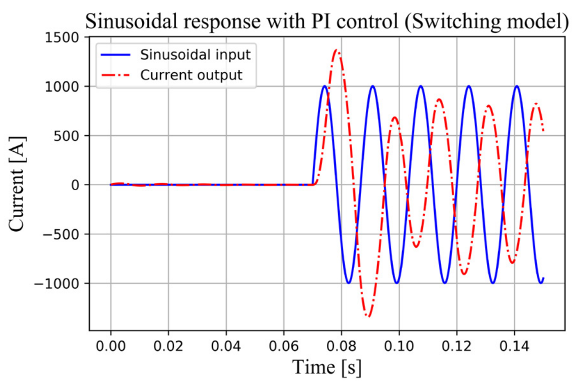

Figure 27. Plot of the sinusoidal input (blue curve) and AC output current (red curve) of the system with the switching model with PI controller.

From Figure 27 and Figure 28 we can see that the behavior of the system is better with the averaged model of the half-bridge converter than with the switching model. They both present errors in amplitude and phase compared to the reference but the averaged model looks like more aligned with the reference.
Then introducing a more elaborated control strategy described in 3.1 a new simulation with the sinusoidal reference can be performed. The results for the system with the switching model are in Figure 29 and for the system with the averaged model in Figure 30.

From Figure 29 and Figure 30 the behavior of the system with the switching model is better than the one with the averaged model since the tuning of the control parameters has been performed on the switching model.
In order to get a similar behavior of the system with the averaged model, like in Figure 31, the gain of the controller has been increased from a value of 8680 to 450000.

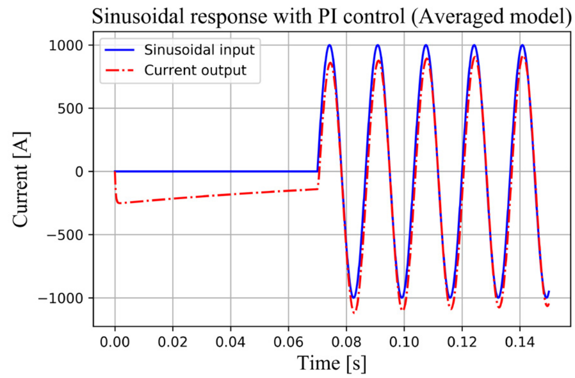

Figure 28. Plot of the sinusoidal input (blue curve) and AC output current (red curve) of the system with the averaged model with PI controller.

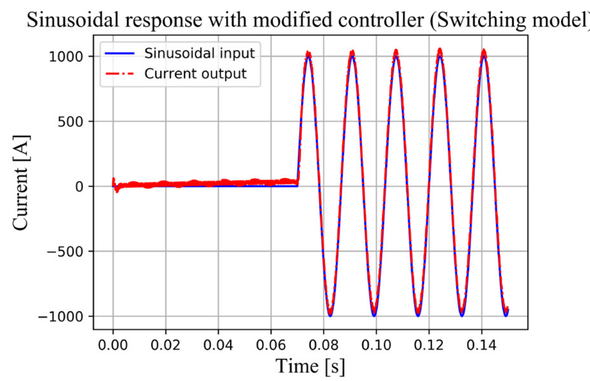

Figure 29. Plot of the sinusoidal input (blue curve) and AC output current (red curve) of the system with the switching model with modified controller.

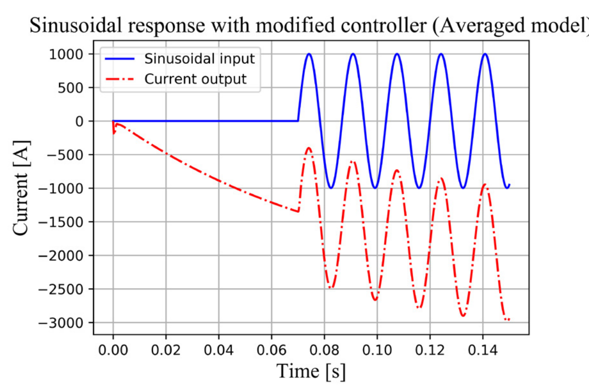

Figure 30. Plot of the sinusoidal input (blue curve) and AC output current (red curve) of the system with the averaged model with modified controller.

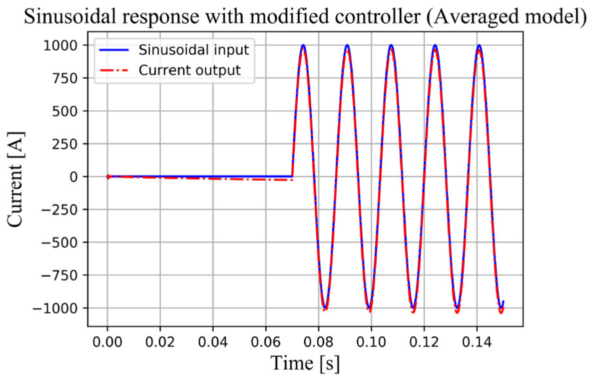

Figure 31. Plot of the sinusoidal input (blue curve) and AC output current (red curve) of the system with the averaged model with modified controller.

The voltage distortion due to voltage drop at grid's R-L due to non-sinusoidal currents of switching converter has not been shown because the focus of the paper is on the control of the output current of the half-bridge converter. There are also other aspects that can be analyzed starting from what has been presented like voltage distortion, THD content, other control strategies and so on. They can be studied in a future work.

5 Further Work and Conclusions

The modularity of blocks of components and records allows for an easy reuse in different models. This allowed to run simulations very quickly. One of the objectives of this paper is to communicate to the power system analysts the benefits of Modelica language features, such as the replaceable and redeclare features. In most power system tools, the user would have to set up different system models when using different representations. In future work, the authors plan to illustrate how we can use these features by changing from detailed component models, to the ideal switches, to the averaged value model. Simplifying model development and management.

The simulations show that the introduction of a feedback control improves the reference tracking. A specific combination of control parameters can work for a system with the switching model of the half-bridge converter but not for the one with the averaged model or viceversa. This will also be the case if we consider a more detailed or less detailed model of the switches, which will be illustrated in a future work. So for the tuning of the controls other tools can be considered for the estimation of their parameters. Other control strategies can be analyzed, for example, to reduce the initial overshoot of the output current of the system with the averaged model of the half-bridge or the initial oscillations of the system with the switching model. They represent an additional stress for the components of the converter.

The implementation of a three-phase converter will follow this work that is an initial step. So different control strategies can be taken into account for this more complex case.

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