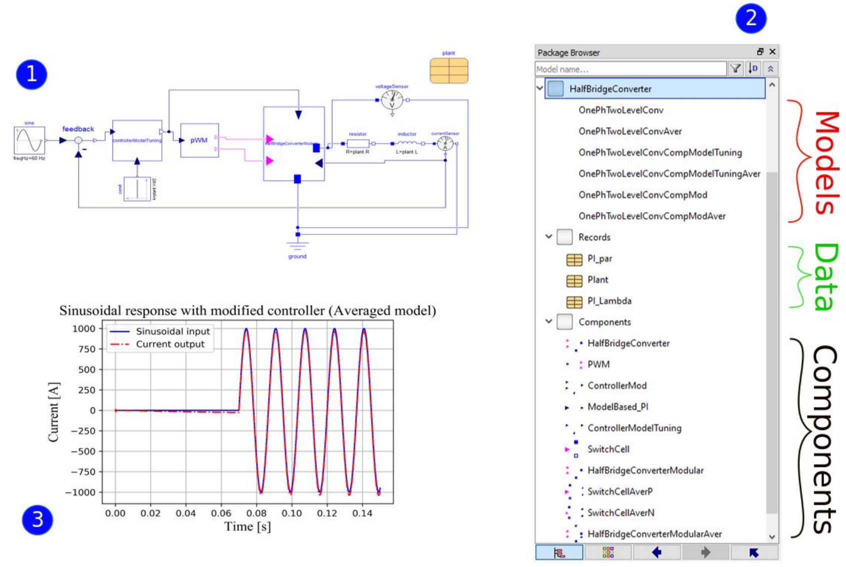

Object Oriented Modeling and Control Design for Power Electronics Half-Bridge Converter using Modelica

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Virtual American Modelica Conference 2020 | 22-24 September 2020

- Introduction
  - Motivations
  - Contributions
- Half-bridge converter applications and modeling
- Modelica model design and implementation
  - Modelica implementation
  - Control design
- Simulation results
- Conclusions
- Future Work

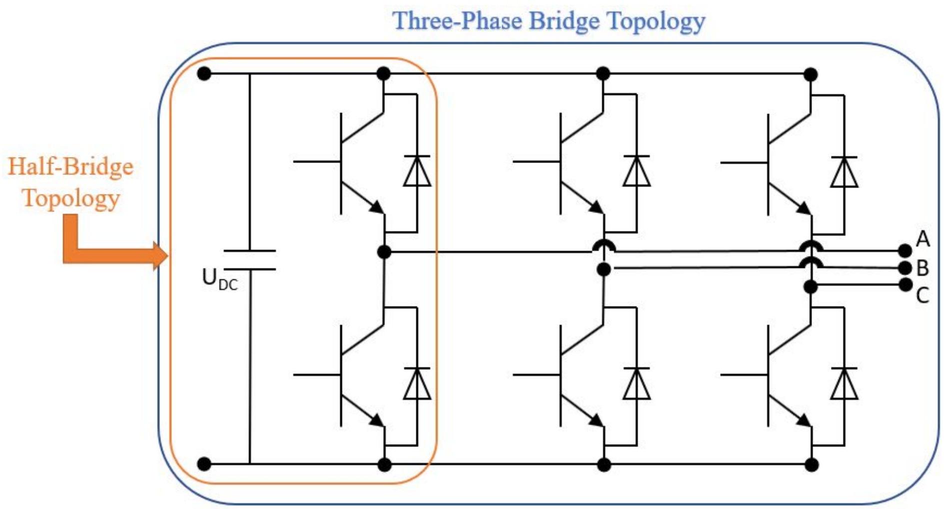
- Application of power electronics has been extended from traditional domestic and industrial applications to electric power systems for several reasons:
  - Continuously growing development of power electronics technology for electric power systems
  - Development of signal processing and control strategies
  - 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 (need for improving efficiency and reliability of the existent electric infrastructure)
- Why the choice of an half-bridge converter?
  - simple power electronic DC/AC converter: starting point for the implementation of more complex power electronics models (three-phase full STATCOM)
  - focus on the differences of a couple of output current control strategies and tuning depending on the considered model of the half-bridge converter if averaged or switching
- Why to use Modelica programming language for this type of work?
  - Modern object-oriented equation based programming language
  - It is possible to perform implementation and studies in the same field where traditional domain specific tools have been used

- To illustrate to the power engineering community the value of adopting Modelica for models implementation and typical control design tasks (use of records)

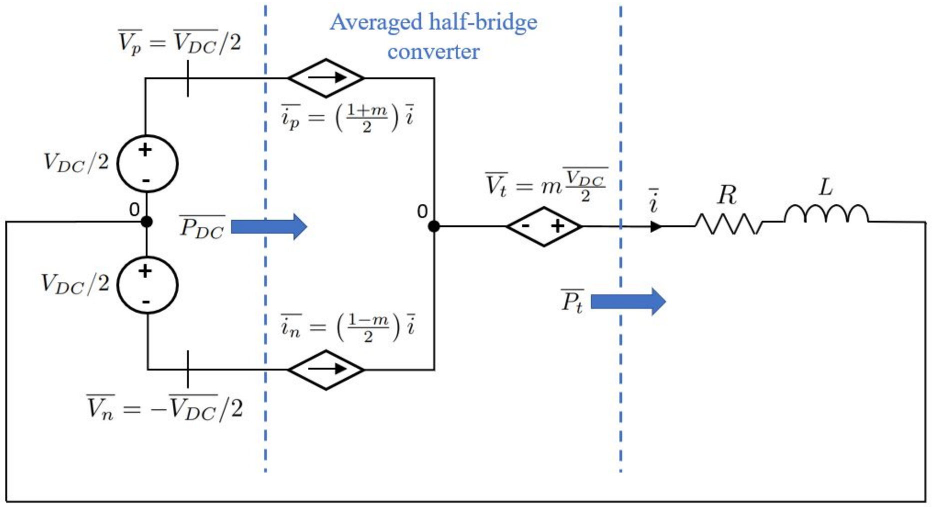
- Open access to the models of this work on GitHub to allow a novice to get familiar with Modelica language (https://github.com/ALSETLab/Modeling-Control-Design-Power-Electronics-Half-Bridge-Converter-Modelica)

- Advantage of using Modelica and the Modelica Standard Library is represented by the fact that the models can work in different software environments like OpenModelica, Dymola, Wolfram SystemModeler, SimulationX, etc. without the need to load external third party libraries (in contrast with the current tools used by the power engineering community)

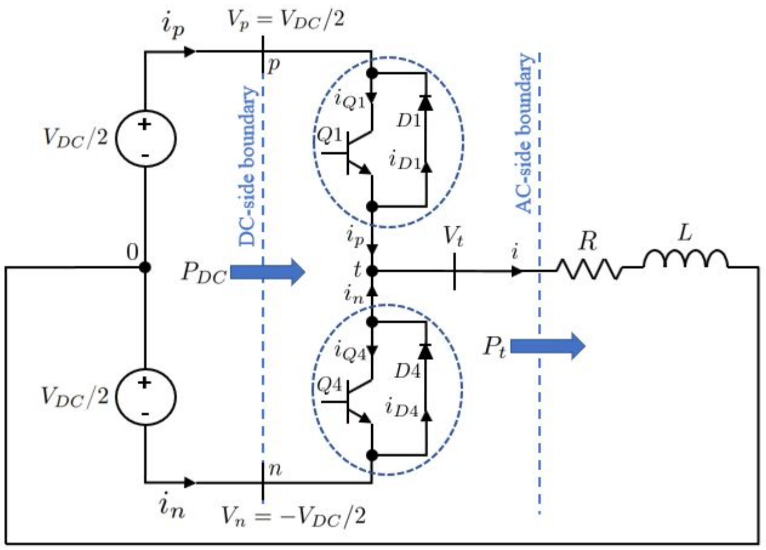
- The half-bridge converter can be seen as basic building block used to model more complex power electronics systems
- For example, it can be used to implement either three phase VSCs (Voltage Source Converters) through parallel combination or multi module VSCs through parallel/series combination



- Two models of the half-bridge converter are used in this work:



Averaged equivalent circuit



Switching equivalent circuit

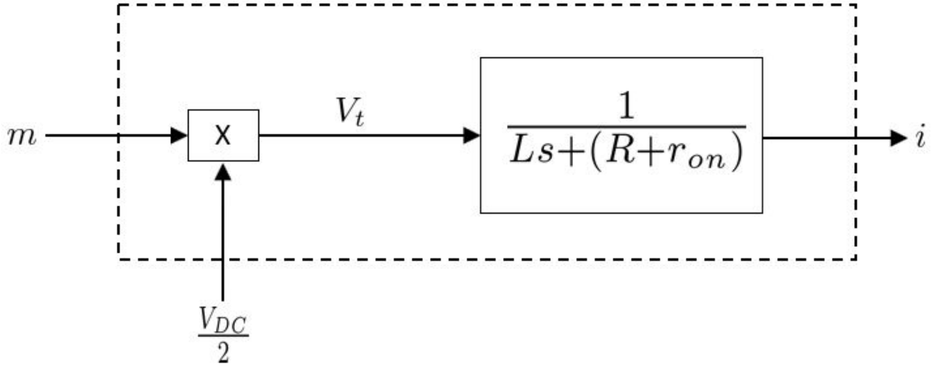
- The non ideal effect of the on-state resistance of the switches (current generators for the averaged model and transistors for the switching model) has been considered
- Implementation of the models using Modelica language has been performed in the software environment Dymola

- From the averaged equivalent circuit of the half-bridge converter, the dynamics of the AC output current can be described as:

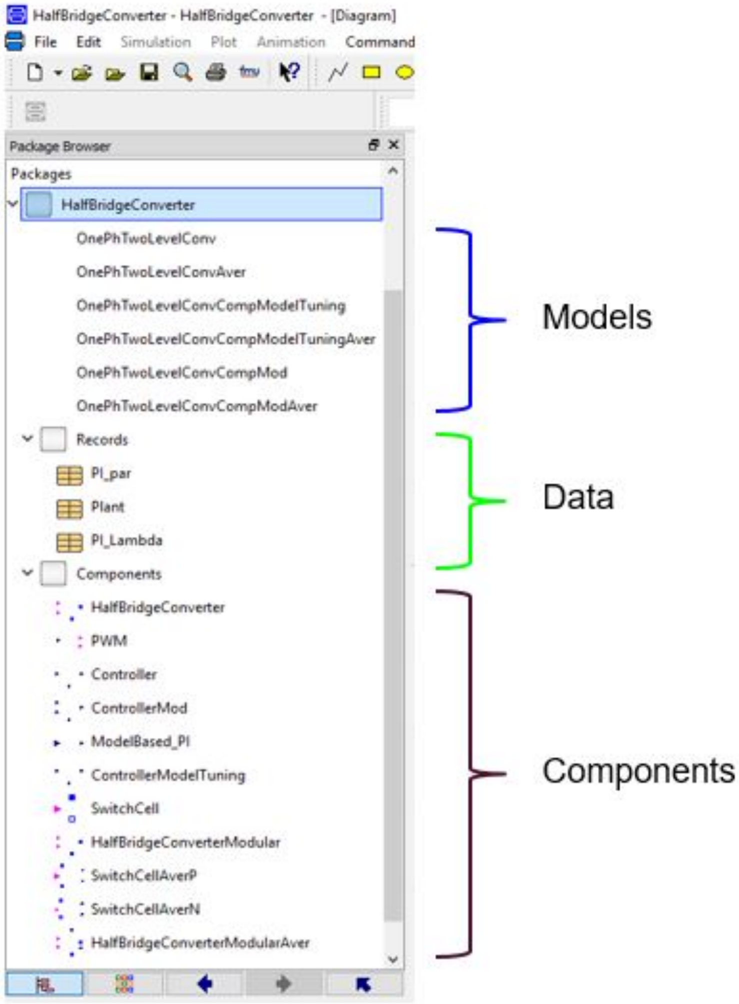
$$L\frac{di}{dt} + (R + r_{on})i = V_t$$

where *R* and *L* are the parameters of the AC system to which the converter is connected to and r_{on} is the on-state resistance of each switch of the converter.

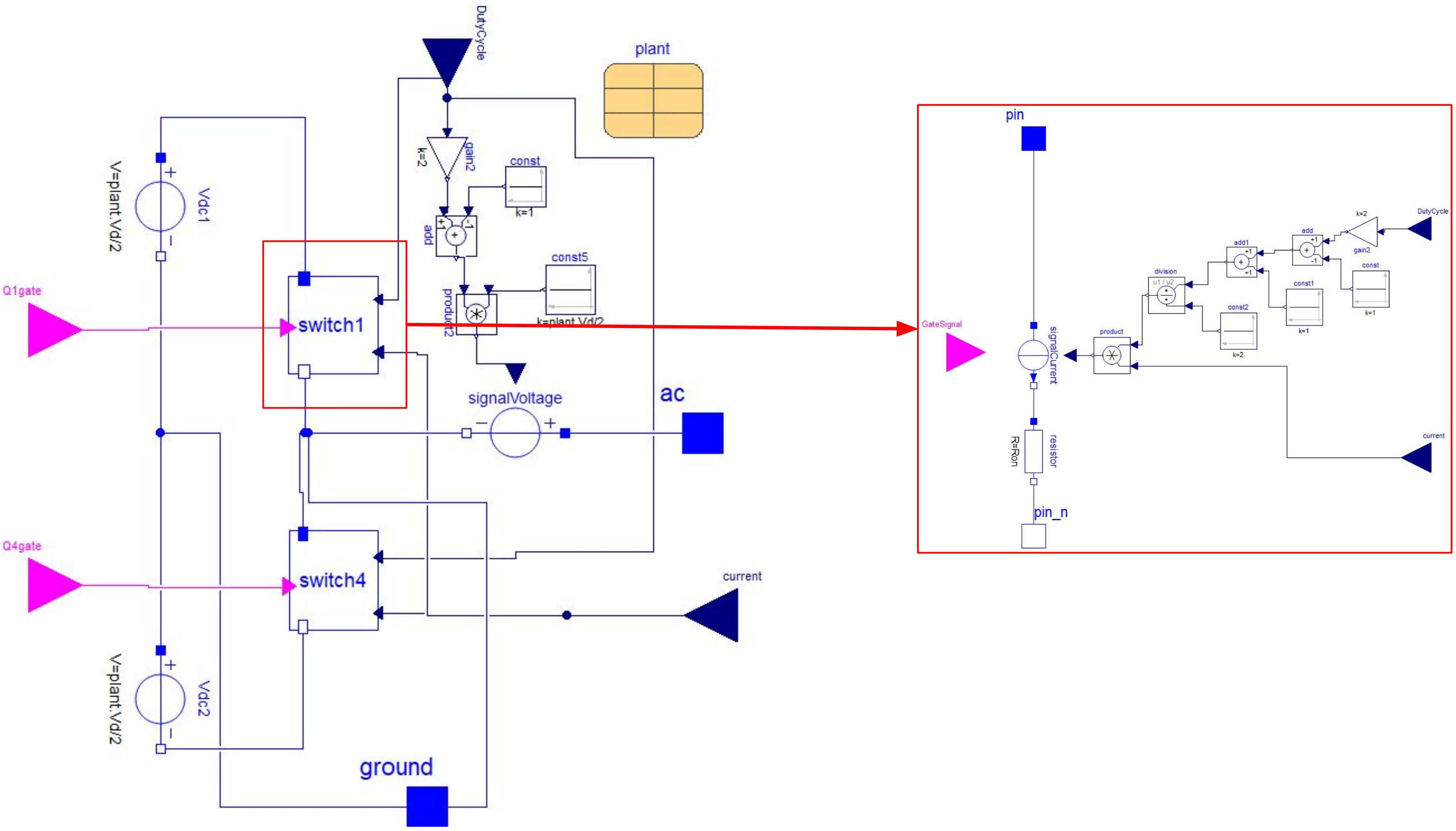
- The AC current *i* can be considered the state variable and $V_t = m*V_{DC}/2$ the control input since it can be changed by varying *m*, the modulating signal



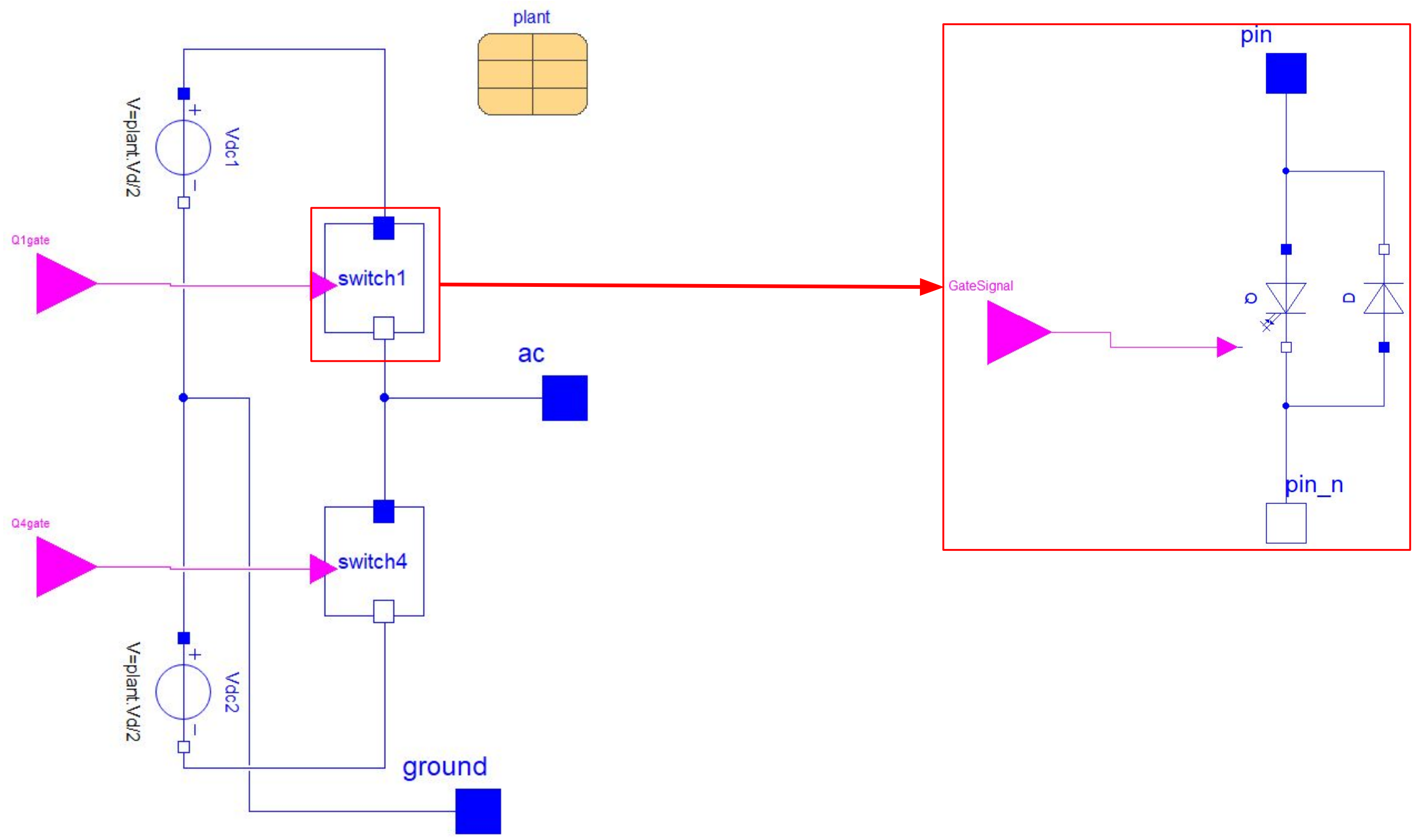
- The structure of the package created in Modelica to model all the components and systems is the following



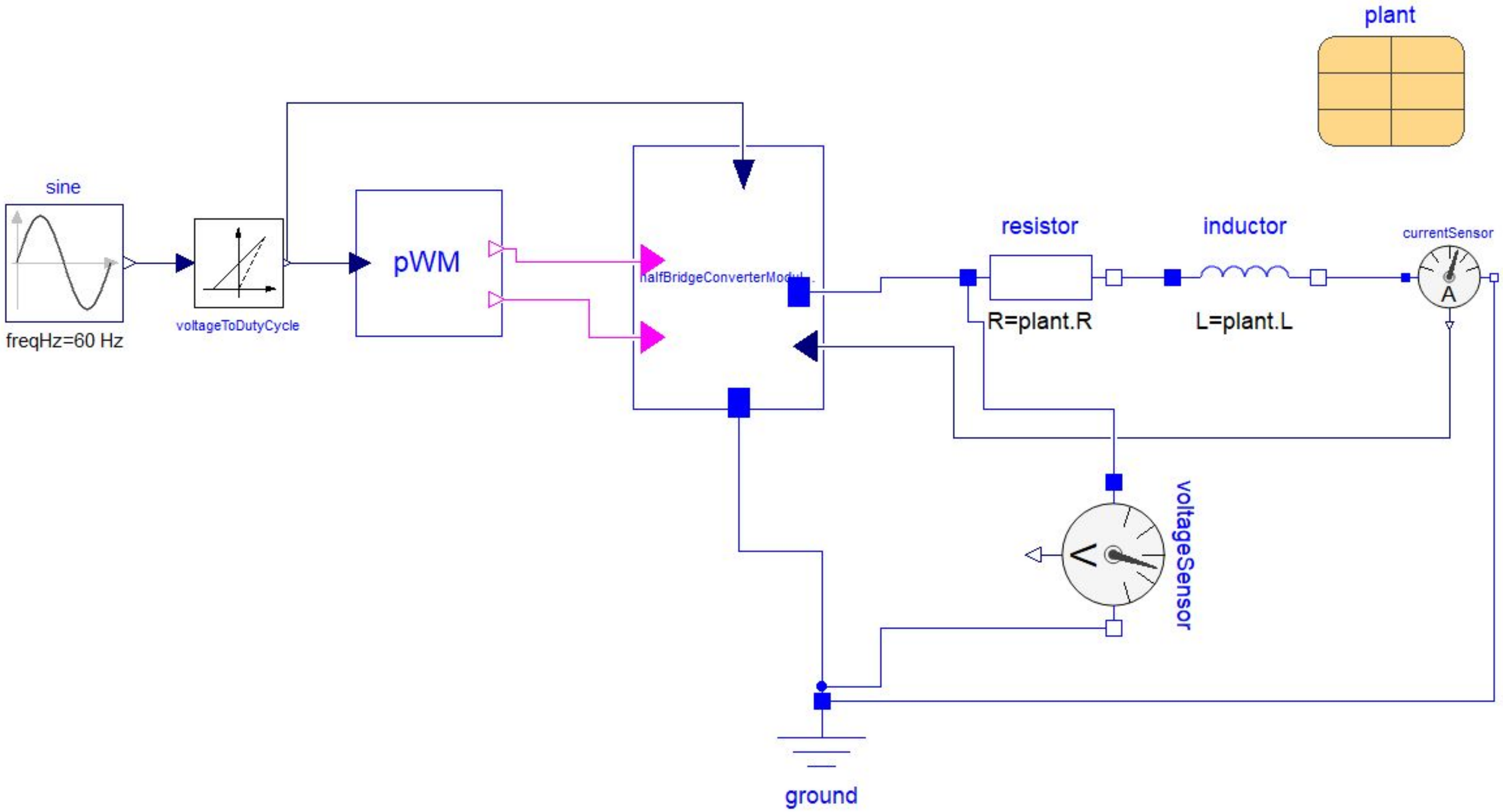
- The averaged model of the half-bridge converter in Modelica



- The switching model of the half-bridge converter in Modelica

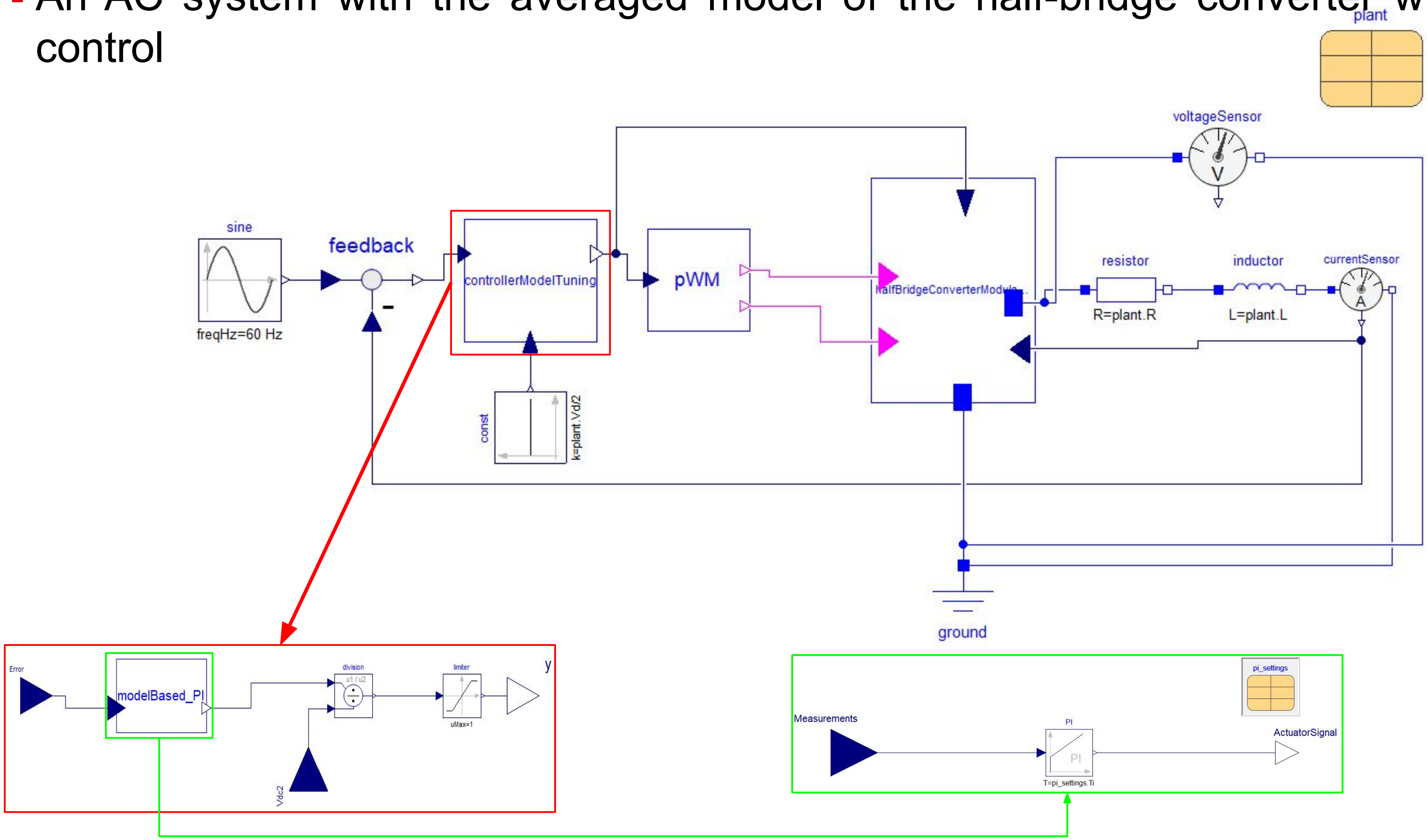


- An AC system with the averaged model of the half-bridge converter without control



- A similar system has been used with the switching model of the half-bridge converter

- An AC system with the averaged model of the half-bridge converter with PI control



- A similar system has been used with the switching model of the half-bridge converter

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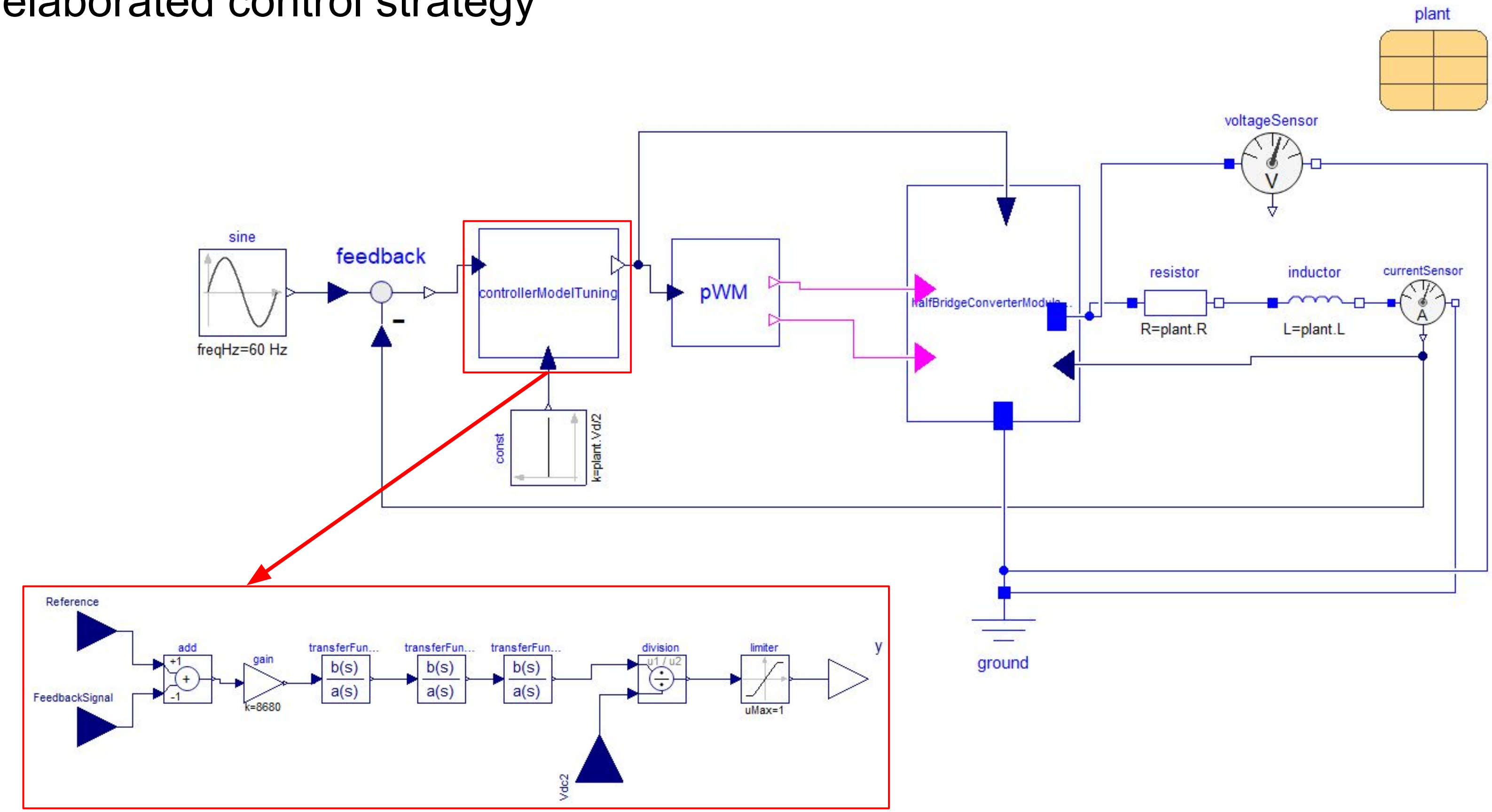
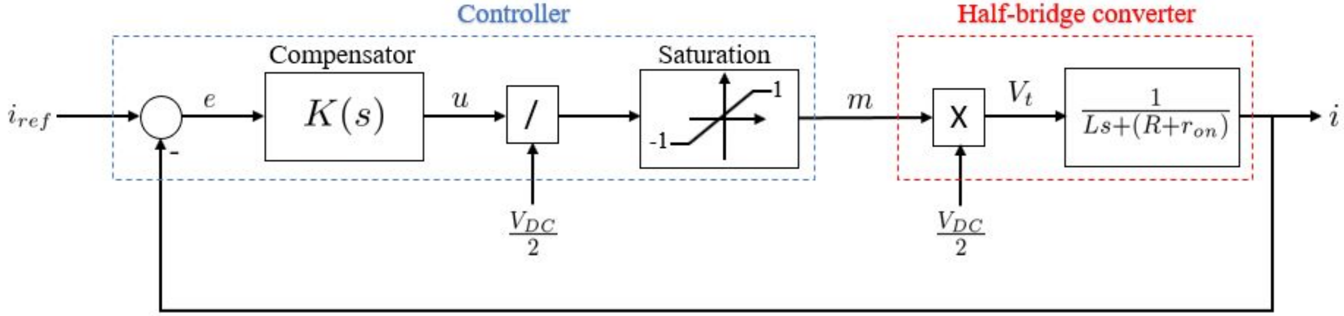
- An AC system with the averaged model of the half-bridge converter with more elaborated control strategy



- A similar system has also been used with the switching model of the half-bridge converter

- The control of the output current can be obtained as follows:



- Depending on the reference signal and the performance to match, different compensators may be used
- In case of a step function as reference signal, a proportional-integral (PI) compensator can be considered: $K(s) = \frac{k_p s + k_i}{s}$
- Open-loop transfer function: $$G_{open}(s) = K(s)G(s) = \left(\frac{k_p}{Ls}\right)\left(\frac{s+\frac{k_i}{k_p}}{s+\frac{R+r_{on}}{L}}\right)$$
- The open-loop system has a stable pole at: $p = -(R+r_{on})/L$
- For the typical values of R, r_{on} and L, the pole p is quite close to the origin giving a slow natural response. So to improve the open-loop frequency response the pole p can be cancelled by the zero of the PI compensator

- The compensator can be chosen such that its parameters are:

$$k_i/k_p = (R + r_{on})/L \qquad\qquad k_p/L = 1/\tau_i$$

where τ_i is the desired time constant of the closed-loop system

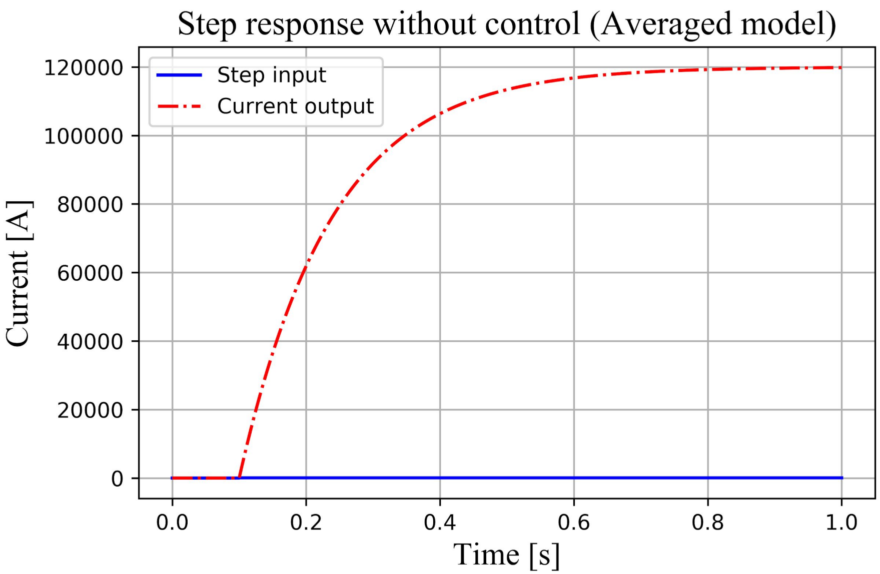
- Closed-loop transfer function:

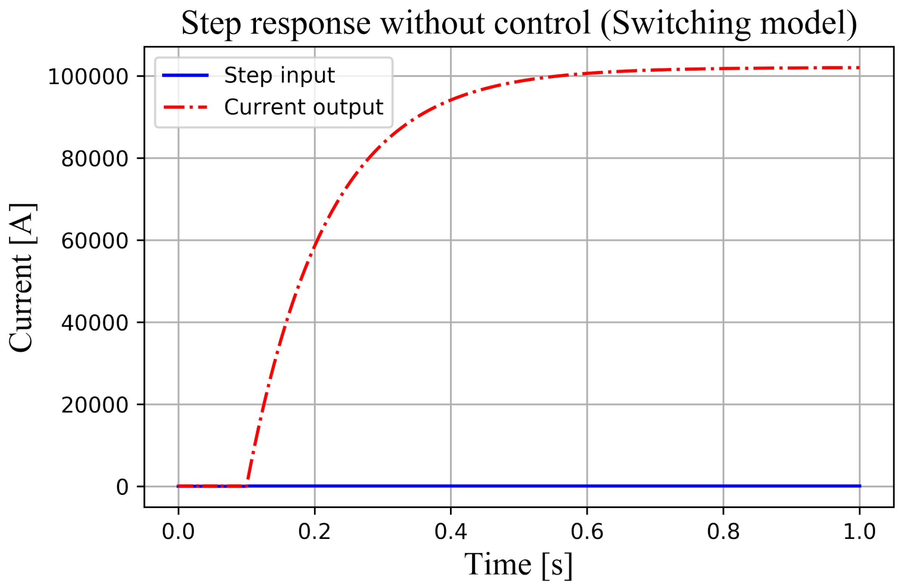
$$G_{closed}(s) = \frac{K(s)G(s)}{1+K(s)G(s)} = \frac{i}{i_{ref}} = \frac{1}{\tau_i s+1}$$

- τ_i should be small enough to have a fast response of the current control
- $1/\tau_i$ should be smaller than the switching frequency of the half-bridge converter
- Usual range of τ_i is 0.5 - 5ms and it can vary depending on the application of the converter and its switching frequency

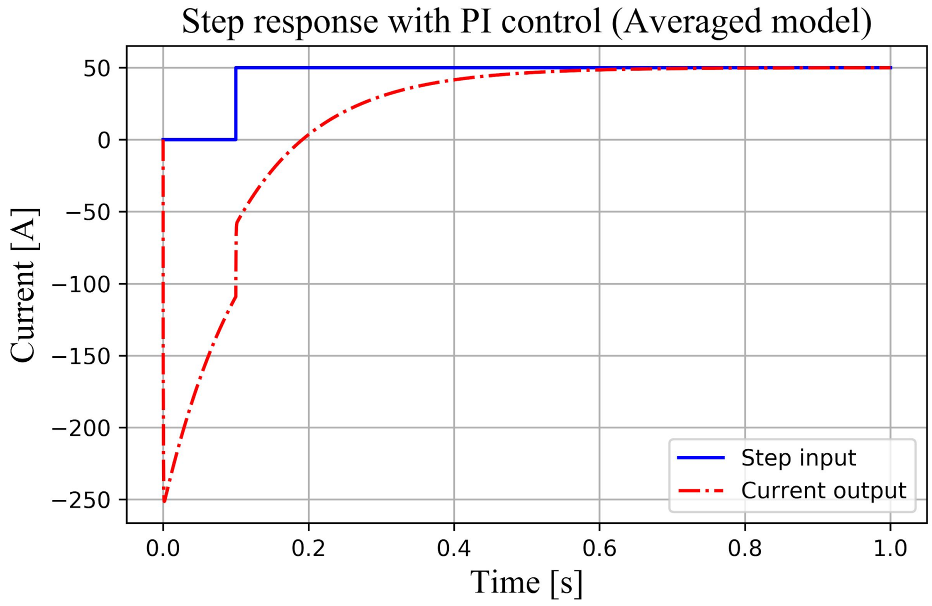
- Application example with the following parameters:
  - $L = 690\mu H$
  - $R = 5m\Omega$
  - $r_{on} = 0.88m\Omega$
  - $\tau_i = 5ms$

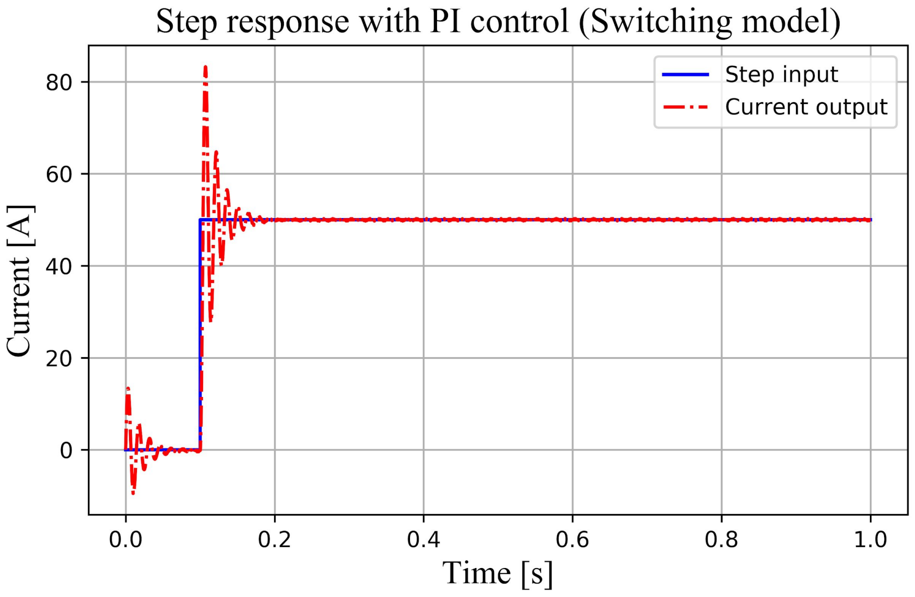
- Consider a step of amplitude 50A applied at 0.1s as reference input of the half-bridge converter



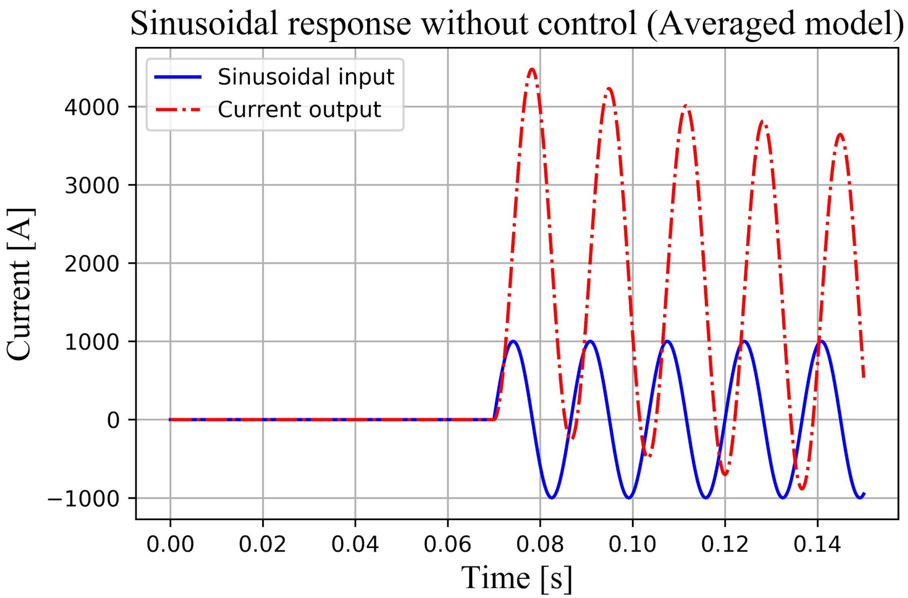


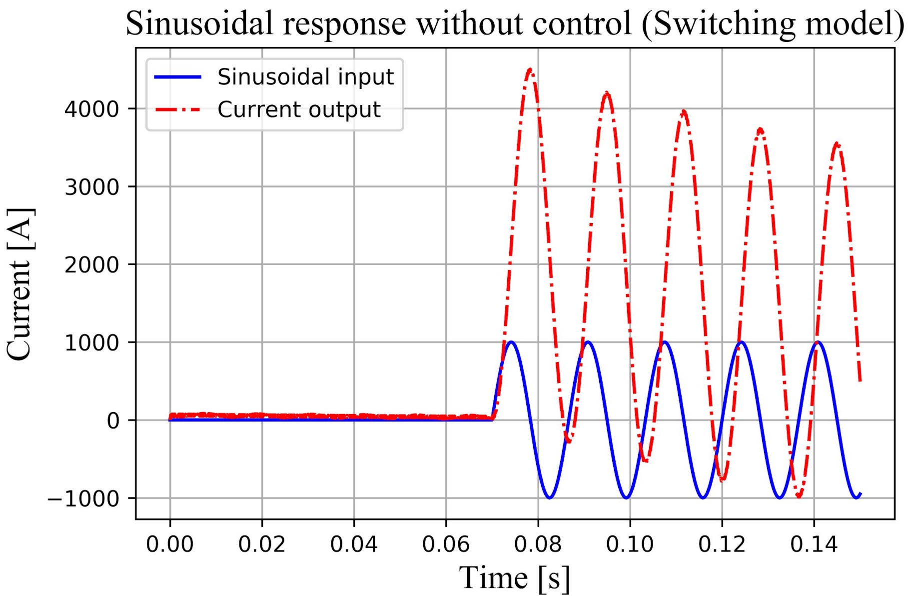
- Using the same step reference and parameters as in the previous example:
  - $k_p = L/\tau_i = 0.138$
  - $k_i = k_p(R + r_{on})/L = 1.176$



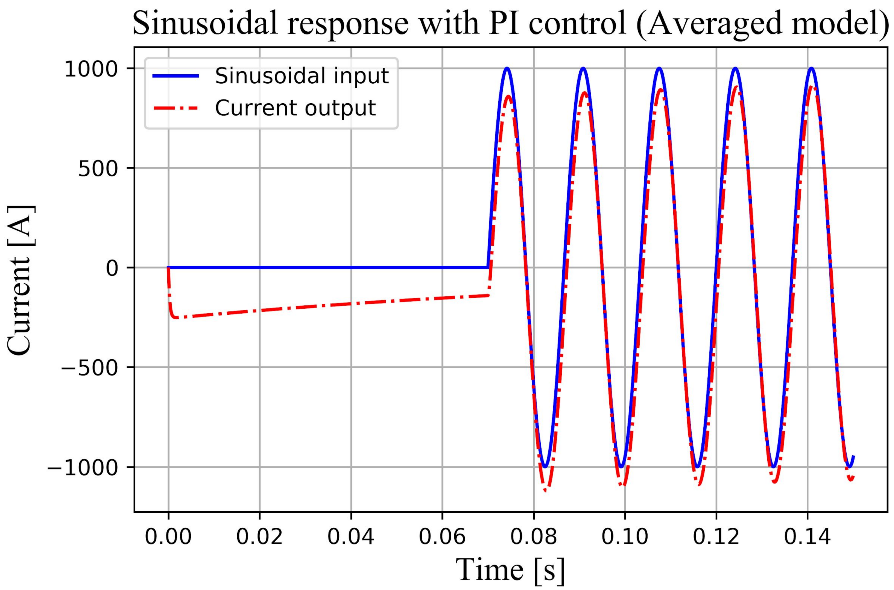


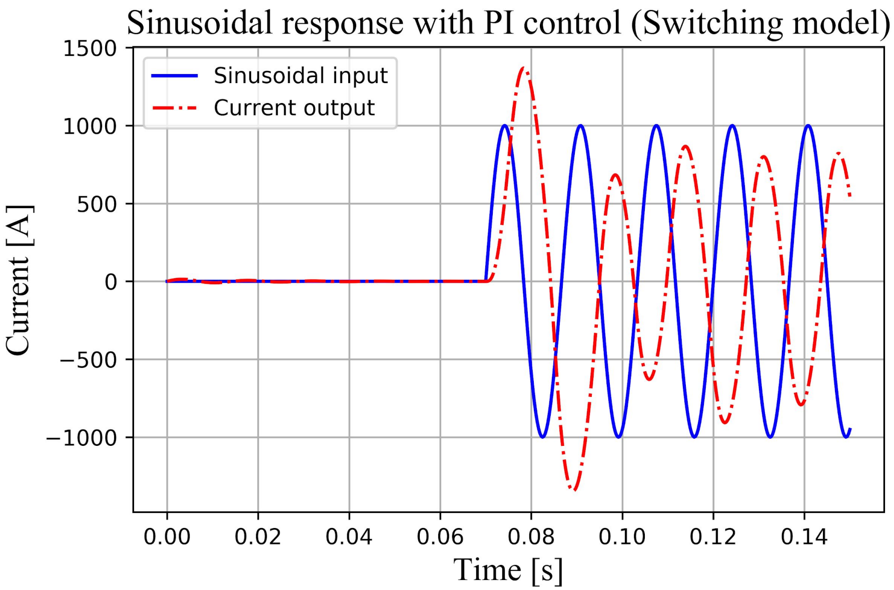
- Changing the source of the reference signal with a sinusoid of amplitude 1000A, frequency 60Hz and starting at t=0.07s:



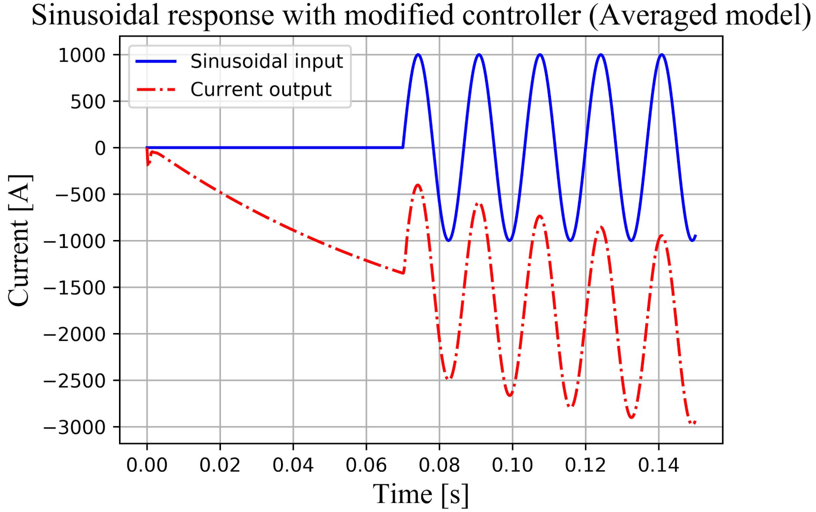


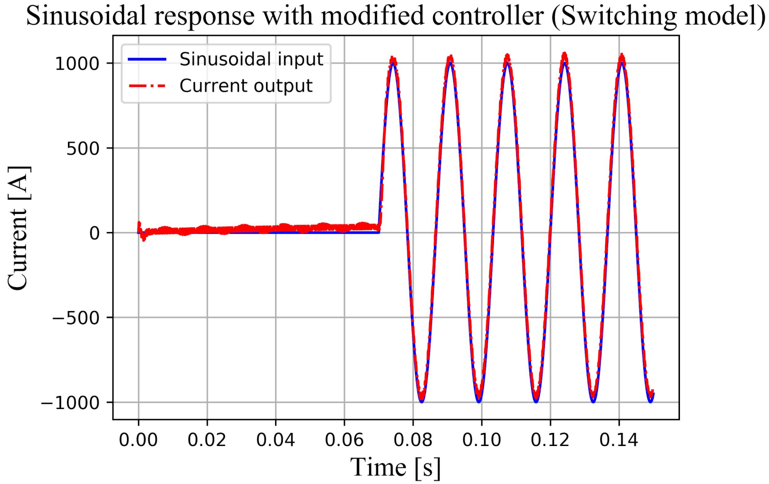
- Using the same sinusoidal reference signal as in the previous example:



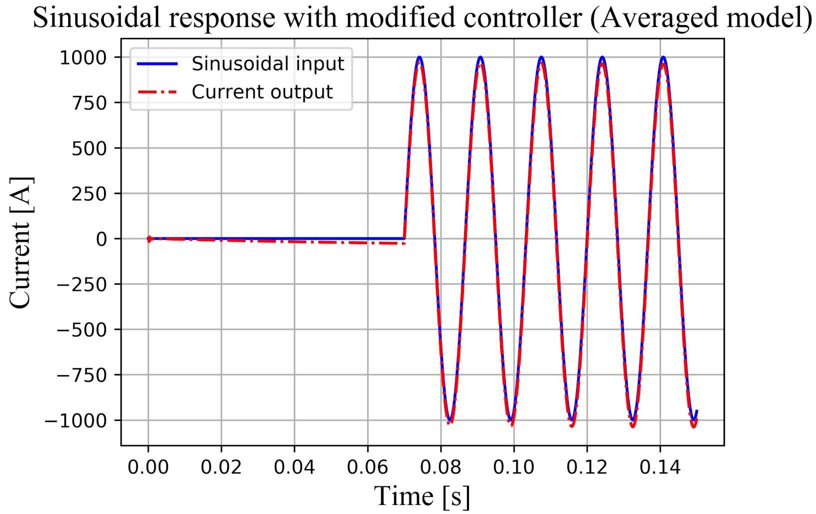


- Using the same sinusoidal reference signal as in the previous example:





increasing the gain of the controller by about 50 times



- The modularity of blocks of components and records allows for an easy reuse in different models and, consequently, running quick simulations
- 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 vice versa
- Some benefits of Modelica language are “replaceable” and “redeclare” features because there is no need to set up different models for the same system when using different representations (simplified model development and management)

- For the tuning of the controls other tools can be considered for the estimation of their parameters
- Other control strategies and other aspects like voltage distortion, THD content, grid synchronization, etc. can be analyzed
- The implementation of a three-phase converter will follow this work that represents an initial step

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