

## Exercise 4a: Control Design for Boost Converter – Current Control Loop

In this exercise a cascaded control structure, consisting of a voltage controller and a subordinated current controller, has to be designed for a boost converter. The standard topology of the boost converter is shown in figure 1:

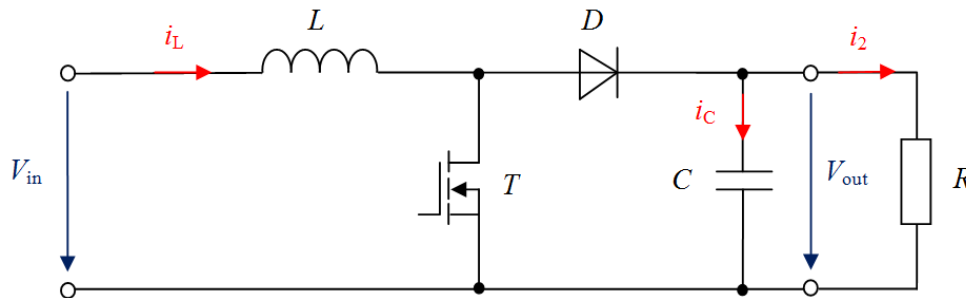


Figure 1: Topology of boost converter

The specification of the boost converter is given below:

Nominal input voltage:	$V_{in} = 50 \dots 300 \text{ V}$	Boost inductance:	$L = 1 \text{ mH}$
Nominal output voltage:	$V_{out} = 400 \text{ V}$	Output capacitor:	$C = 470 \mu\text{F}$
Nominal output power:	$P_{out} = 500 \text{ W}$	Switching frequency:	$f_s = 100 \text{ kHz}$

1. Draw the schematic diagram of a boost converter. Add a rudimentary block scheme of a cascaded control structure.
2. Set up the average value model of an ideal boost converter in continuous conduction mode (CCM) and draw the signal flow diagram.

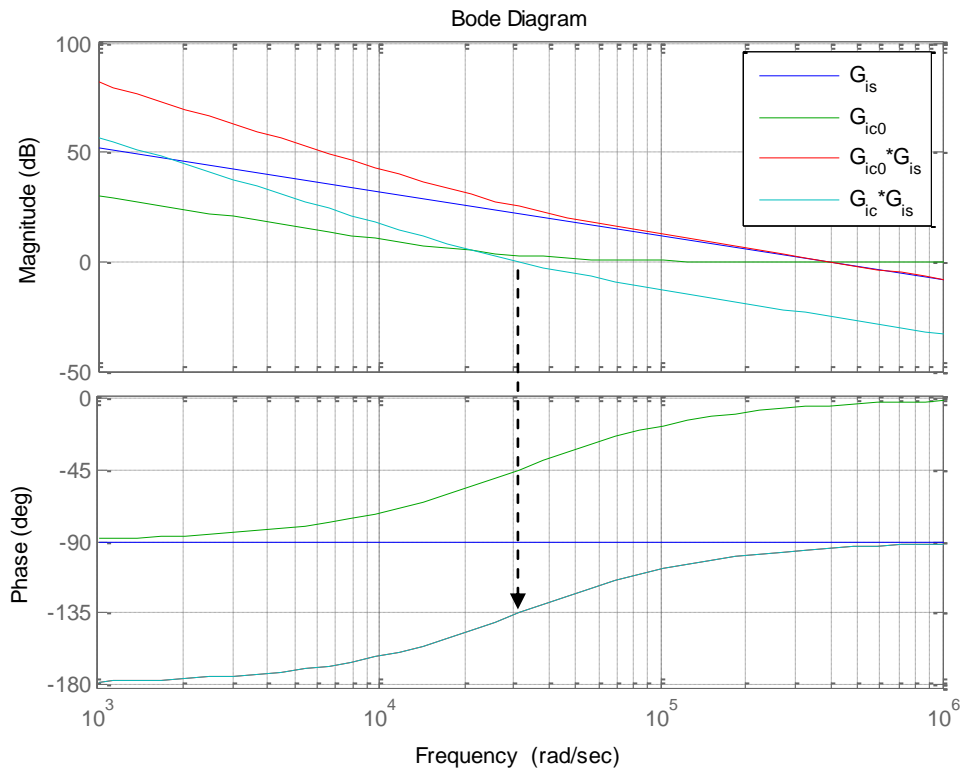
For the current control design the following assumption is made: the output voltage can be considered as ideally smoothed. The output capacitor and the load resistor can therefore be replaced by a constant voltage source.

3. Set up the simplified transfer function of the plant (small signal model). Draw the structure of the current control loop and draw the bode diagram of the plant.
4. Design a PI-controller with a gain crossover frequency of 5 kHz and a phase reserve of at least 45 degrees for nominal operation.

The following tasks will be presented in form of simulations in MATLAB/Simulink.

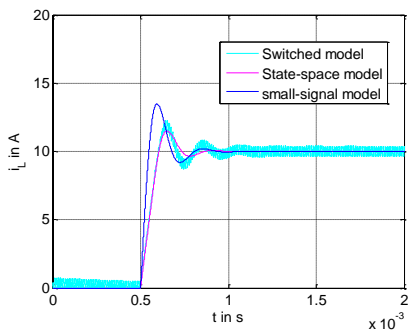
5. Open the simulation model, fill in the calculated controller parameters and initialize the model. Simulate the model and validate the functional principle of the current control loop.
6. Simulate input voltage steps and vary the control parameters. Observe the behavior of the inductor current.

Bode-plots of plant, PI-controller and open control loop:

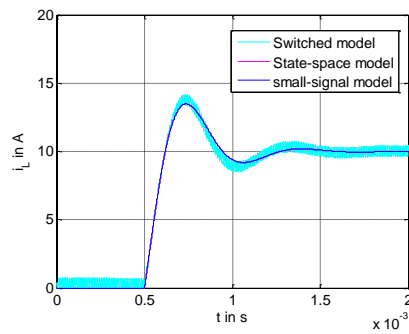


Simulation results of the designed current controller:

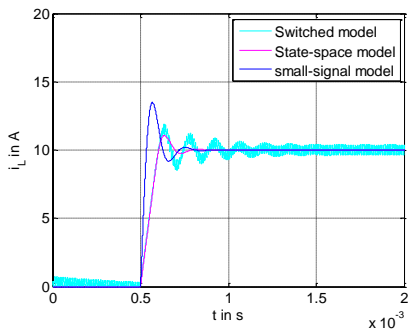
$V_{in} = 100 \text{ V}; V_{out} = 400 \text{ V}; f_c = 5000 \text{ Hz}$



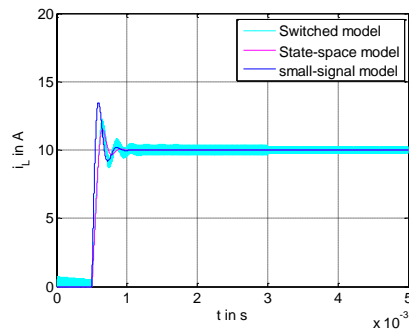
$V_{in} = 100 \text{ V}; V_{out} = 400 \text{ V}; f_c = 2000 \text{ Hz}$



$V_{in} = 100 \text{ V}; V_{out} = 400 \text{ V}; f_c = 7000 \text{ Hz}$



$V_{in} = 100 \text{ V} \rightarrow 50 \text{ V}; V_{out} = 400 \text{ V}; f_c = 5000 \text{ Hz}$



## Exercise 4b: Control Design for Boost Converter – Voltage Control Loop

As soon as the current control design is completed, the design process for the overlaid voltage controller can be started with. Its plant consists of the closed current control loop and the output capacitor. Figure 2 shows the simplified loop of the voltage control cycle:

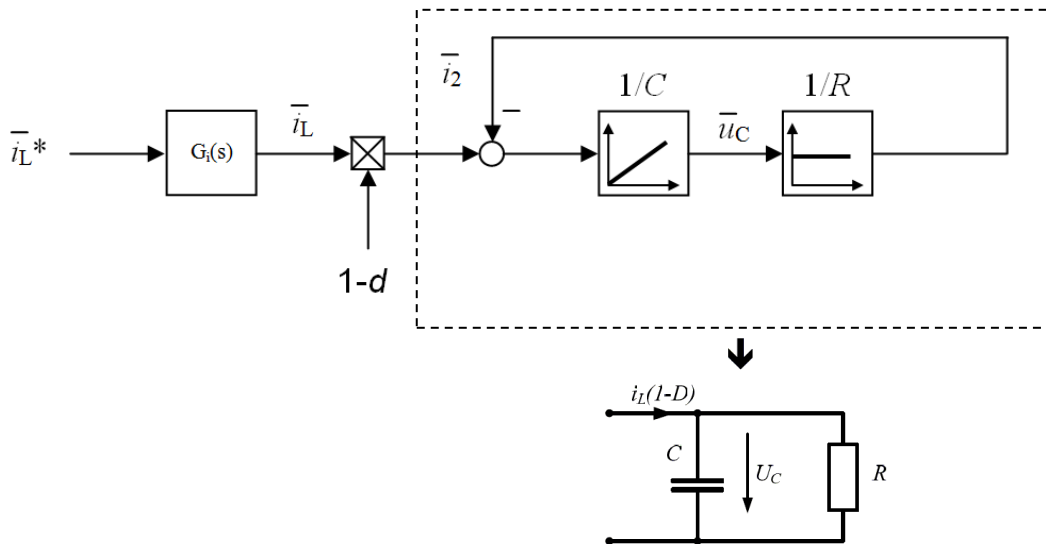


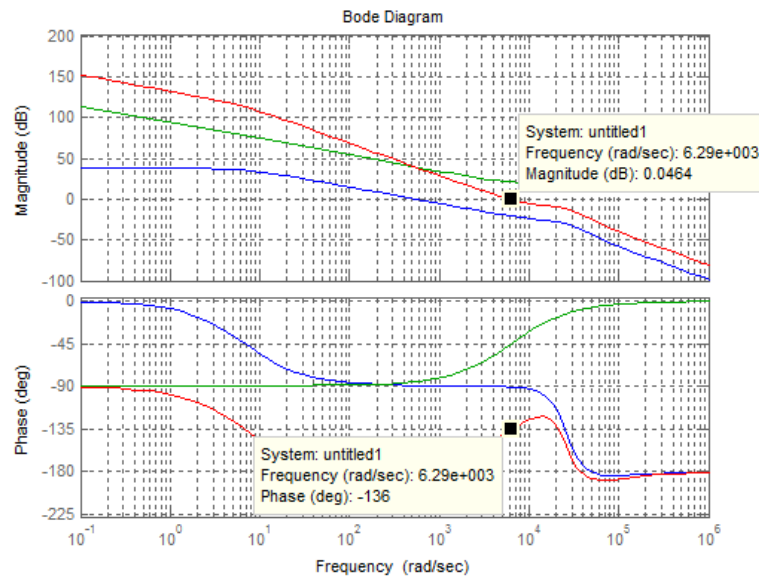
Figure 2: Voltage control plant, consisting of closed current control loop and output capacitor with resistive load

7. Set up the transfer function of the closed current control loop to determine the transfer function of the voltage control plant and draw the bode diagram of the whole plant.
8. Design a PI-controller with a gain crossover frequency of 1 kHz and a phase reserve of at least 40 degrees for nominal operation and an input voltage of 100 V.
9. Draw the bode diagram of the open voltage control loop for different input voltages and compare the resulting gain crossover frequencies and phase reserves.

The following tasks are again presented in form of simulations in MATLAB/Simulink.

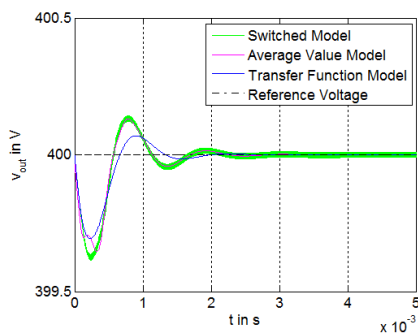
10. Complete the simulation model with a PI-controller and insert the control parameters from task 2) and replace the voltage sink by a 400 V charged capacitor. Update the model and check the behavior of the controlled system.
11. Vary the input voltage in the given range and observe the output voltage and the inductor current.
12. Simulate load steps (double load and half load) and observe the behavior of the controlled system
13. Simulate a voltage reference step of 400 V with an initial capacitor output voltage of 0.5 V. How has the controller structure to be extended to achieve a stable startup?

Bode diagram of plant (blue), voltage PI-controller (green) and open control loop (red):

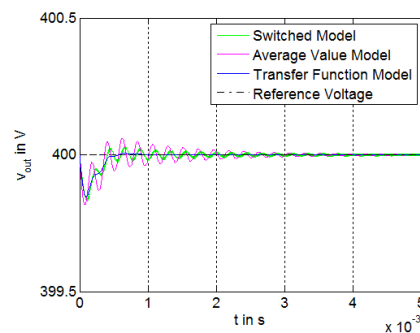


Simulation results of the designed voltage controller:

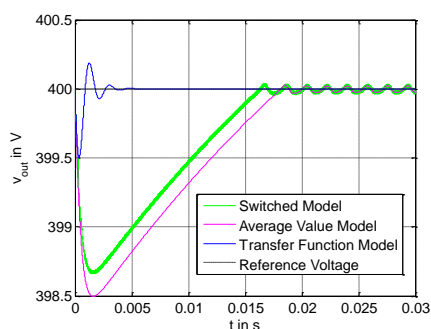
$V_{in} = 100 \text{ V}; V_{out}^* = 400 \text{ V}; V_{out_0} = 400 \text{ V}; R = 320 \Omega$



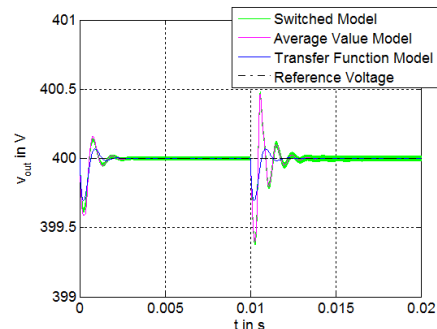
$V_{in} = 300 \text{ V}; V_{out}^* = 400 \text{ V}; V_{out_0} = 400 \text{ V}; R = 320 \Omega$



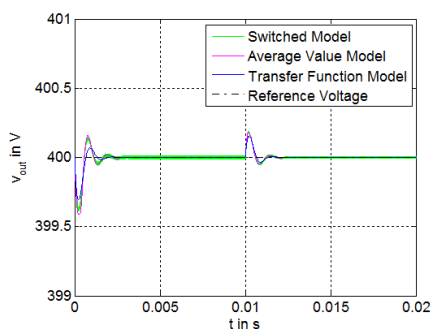
$V_{in} = 50 \text{ V}; V_{out}^* = 400 \text{ V}; V_{out_0} = 400 \text{ V}; R = 320 \Omega$



$V_{in} = 100 \text{ V}; V_{out}^* = 400 \text{ V}; V_{out_0} = 400 \text{ V}; R = 320 \Omega \rightarrow 160 \Omega$



$V_{in} = 100 \text{ V}; V_{out}^* = 400 \text{ V}; V_{out_0} = 400 \text{ V}; R = 320 \Omega \rightarrow 640 \Omega$



$V_{in} = 100 \text{ V}; V_{out}^* = 400 \text{ V}; V_{out_0} = 0.5 \text{ V}; R = 320 \Omega$

