Homework 2: Resonant Converter

Hint: Work with this PDF and the questions in Moodle at the same time.

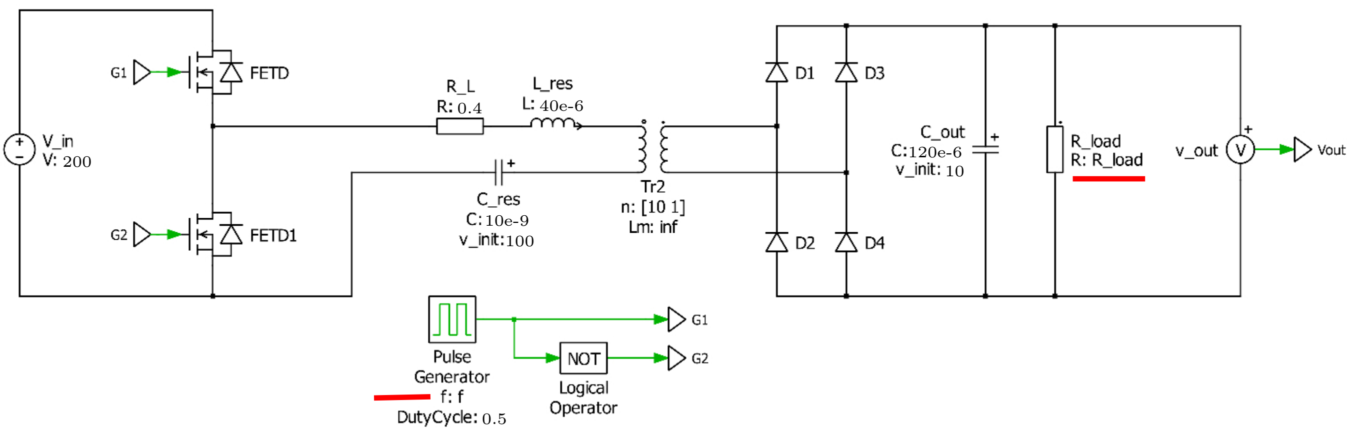

Figure 1: PLECS model of a series resonant converter

Build up the PLECS model of the series resonant converter (SRC) shown in Fig. 1. Use a MATLAB script to define the variables f and R_{load}. The following operating boundaries are given:

$$f = 250 - 350\,\text{kHz};\ R_{load} >= 1\,\Omega$$

Hint: For all tasks, use the stiff solver "ode23s", a relative tolerance of 10e-6 and a maximum step size of 50 ns.

1. Calculate the minimum value for C_{res} so that the voltage across the resonant capacitor does not exceed V_{in} at any time. The maximum RMS current which occurs in the resonant capacitor is 1.3 A.
   Hint: Assume the current in the resonant tank to be purely sinusoidal.
2. Calculate the resonant inductance L_{res} for a resonance frequency of 250 kHz.
3. Run the simulation with the calculated values for L_{res} and C_{res} for f = 250 kHz and R_{load} = 1 Ω. Consider the voltage across the resonant capacitor in steady state. Measure its average over one switching period and the amplitude of its AC component. Add your model to your ZIP file.

200 300

From now on, use $\mathbf{C_{res}} = \mathbf{10}\,\text{nF}$ and $\mathbf{L_{res}} = \mathbf{40}\,\mu\text{H}$. $f_n = 251.65$ KHz

4. For a switching frequency of 250 kHz, measure the average output voltage over one switching period, the RMS inductor current and the THD of the capacitor voltage in percent in steady state for $R_{load} = 1\,\Omega$ and $R_{load} = 10\,\Omega$.

5. Write a MATLAB script which runs the simulation for a load resistance of $10\,\Omega$, $2.5\,\Omega$, $1.5\,\Omega$ and $1\,\Omega$ each for frequencies from 250 kHz to 350 kHz with a step width of 5000 Hz. Plot the output voltage for each load resistance as a function of the frequency and add a legend to the plot. Add your model to your ZIP file.
   Hint: Use a "stop time" of 1 ms for each simulation to make sure that the steady state is reached.

The output voltage should be regulated to 9.3 V with the aid of the switching frequency. To answer the following two questions, use the plot you generated in task 5.

6. What is the boundary for the output current I_{load} if a switching frequency of approximately 315 kHz should not be exceeded?

7. What is the minimum switching frequency?

From now on, consider a dead time of 50 ns as shown in Fig. 2.

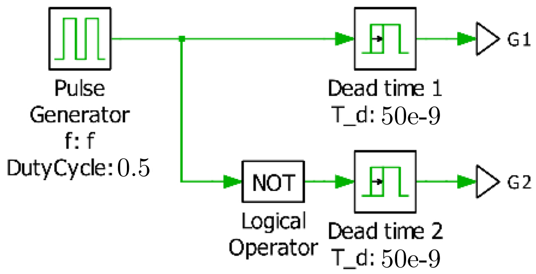

Figure 2: PLECS model of the modulator with dead times

For this task, please use a load resistance of $\mathbf{R_{load}} = \mathbf{0.1}\,\Omega$

8. Drag the correct switching behavior of the SRC at sub-resonant and super-resonant operation onto the switching transition and device.

Symmetric Snubber -- Lec 9
not necessary here

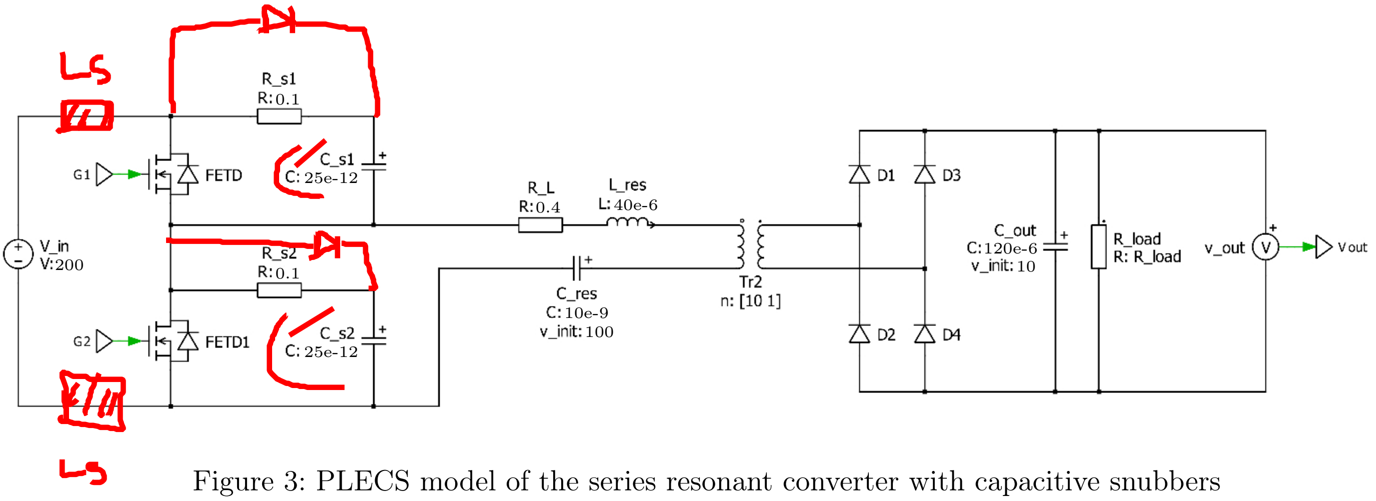

Figure 3: PLECS model of the series resonant converter with capacitive snubbers

Add snubber capacitors to the MOSFETS as shown in Fig. 3.

9. Do the snubber capacitors lead to decreased switching losses?
   Hint: Assume ZVS for turn-on.

From now on $f_{sw} = 326\,\text{kHz}$ and $R_{load} = 2\,\Omega$. The capacitances $C_{s1} = C_{s2}$ should be calculated so that the snubber capacitors are completely charged and discharged respectively within 30 ns during the turn-off process. Perform the following steps in order to do so.

10. Measure the inductor current at the turn-off instant for $C_{s1} = C_{s2} = 0$. How long is the time period between the turn-off event and the zero-crossing of the inductor current? Add your model to your ZIP file.

11. Use the results from the previous task to calculate C_{s1} and C_{s2}.
    Hint: Assume that the inductor current changes linear during the dead time and consider the MOSFETs to be ideal switches.

12. Measure the actual duration of the charging process for the values calculated in task 11.
    Hint: If you did not solve task 11, use $C_{s1} = C_{s2} = 25\,\text{pF}$.

13. Why is the value measured in task 12 smaller than 30 ns?

In the following use $C_{s1} = C_{s2} = 25\,\text{pF}$. A short circuit at the output of the SRC is considered. Therefore, the load resistance is reduced to $R_{load} = 0.05\,\Omega$. The frequency is $f = 270\,\text{kHz}$.

14. Measure the average short-circuit current at the output over one switching period as well as the RMS inductor current in steady state.

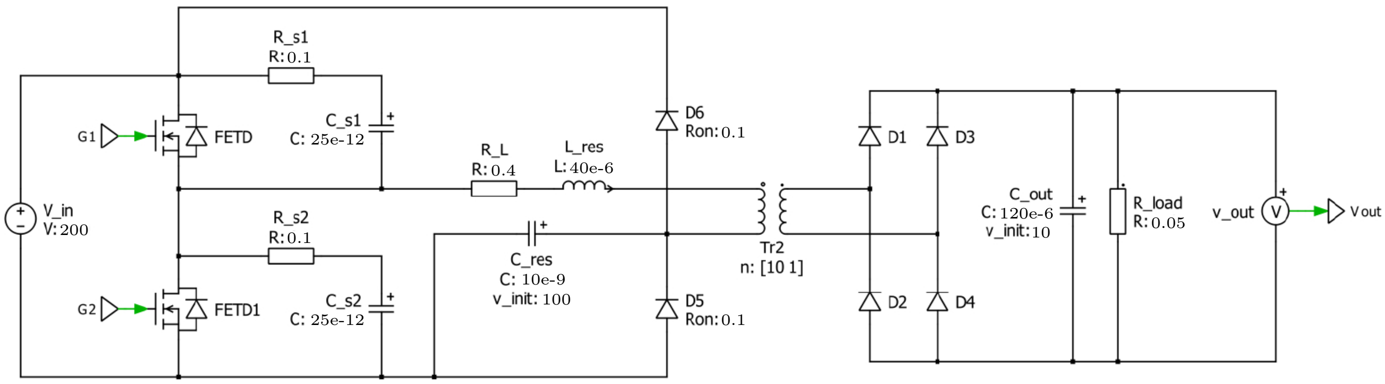

Figure 4: PLECS model of the series resonant converter with capacitive snubbers and clamping diodes

To reduce the short-circuit current at the output, add the clamping diodes shown in Fig.4.
Hint: Consider the on-resistance and the connection points of the clamping diodes.

15. What is the average short-circuit RMS inductor current in steady state with clamping diodes? To what percentage is the average short-circuit output current decreased? Add your model to your ZIP file.

Submission Information All numerical values should be submitted in RWTHmoodle. As RWTHmoodle does not support the English decimal separator, you have to enter the German decimal separator (,) instead. Please only enter values with three significant digits. You will find the submission mask under sections → Homework.
You have to create a ZIP file including the following objects:

- Task_3.slx
- Task_5.fig and Task_5.m and Task_5.slx
- Task_10.slx
- Task_15.slx

Please use the following convention for naming your zip file:

- Excercise{No}_Solution_{MatrNo}_{LastName}_{Firstname}.zip
- For Example: Excercise1_Solution_007007_Mustermann_Max.zip

The ZIP file should be uploaded into RWTHmoodle.

Simulation Settings The following settings should be set when you simulate (stock settings):

Parameter/Setting	Value/Setting
Diode turn-on threshold	1e-3
Type	Continuous state-space
Number of consecutive gate signal changes	100
Advanced->Tolerance	1e-6

Table 0.1: PLECS Settings

Parameter/Setting	Value/Setting
Solver Type	Variable-step
Solver selected	ode23s (stiff/Mod. Rosenbrock)
Relative tolerance	10e-6
Absolute tolerance	auto
Min step size	auto
Max step size	50e-9
Initial step size	auto
Shape preservation	Disable All
Number of consecutive min step	1
Zero-crossing control	Use local settings
Algorithm	Non adaptive
Time tolerance	10*128*eps
Number of consecutive zero crossing	1000
boxes	unchecked

Table 0.2: Simulink Settings