EE 464
STATIC POWER CONVERSION-I
Spring 2022-2023

Homework 2
Complete Simulation Report

Mehmet Emre Doğan – 2374825

Metehan Küçükler – 2305068

Table of Contents

Introduction

This report explains the design decisions for the hardware project. Furthermore, it presents the details of the Magnetic Design of the Isolated Power Supply and the simulation results for the selected topology.

Topology Selection

The converter needs to be isolated. Therefore, the alternatives are listed below:

- Flyback converter
- Forward converter
- Push-Pull converter

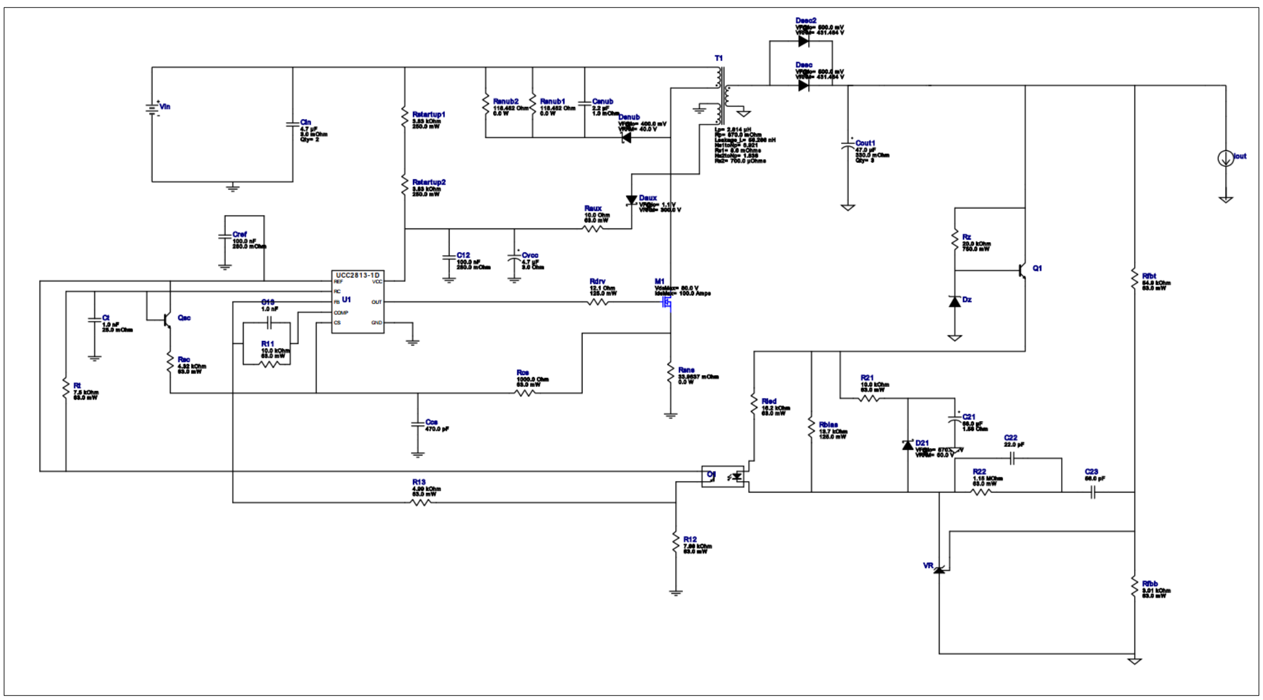

Figure 1: TI Webench design

Magnetic Design

a) The duty range of the converter is selected as [0.278 – 0.336] to match the design by the Ti Webench. According to the duty range determination, the turn ratio is calculated via the MATLAB code below.

```
clearvars
syms d turnsRatio
v_o = 48
d_min = 0.278; v_d_minduty = 18;
d_max = 0.366; v_d_maxduty = 12
turnsRatio_minduty = ( (d_min/(1-d_min)) * (v_d_minduty/v_o) )^-1
turnsRatio_maxduty = ( (d_max/(1-d_max)) * (v_d_maxduty/v_o) )^-1
```

According to the code above, the transformer turns ratio (N_s/N_p) is calculated as 6.93.

b)

1. The available cores and coil formers are investigated. Firstly, due to its available stock number is high, PCB5530-FA is selected as the coil former. Therefore, the compatible core 0P45530EC is selected as the transformer core. However, after calculations, it is seen that this core is overkill. Afterward, **79440A7 toroidal core is selected** due to its high stock number and wide window area. A wide window area makes the wounding procedure easier.
2. Using the MATLAB code below, the primary turn number is 13, while the secondary turn number is 87. The magnetizing inductance is 8 uH.

```
U_o = v_o;
v_t = d_max;
f_sw = 100e3;
i_out = 1;
i_avgSec = i_out/(1-v_t);
xformerCurrRipple = 0.5; % percent
L_sec = (U_o*(1-v_t))/(xformerCurrRipple*i_avgSec*f_sw)
L_pri = L_sec/(turnsRatio_maxduty^2)
% (turnsRatio_maxduty^2)*2.814e-6
```

```
syms priTurns secTurns
AL = 51e-9 % nH/T^2; minimal
priTurns = double(solve(L_pri == AL*priTurns^2))
secTurns = double(solve(L_sec == AL*secTurns^2))
% make sure core is not saturated
ampTurns = i_out*secTurns
```

3. According to the AWG table, the secondary should be wounded using 5 parallel 28 AWG wires. The primary, on the other hand, 18 parallel 28 AWG wires will be used.
4. According to the code below, the fill factor is 12.53%, which is reasonable.

```
windowArea_mm2 = 427;
priTurns = ceil(priTurns(priTurns>0))
```

```
secTurns = ceil(secTurns(secTurns>0))
num_of_paralles_pri = ceil(num_of_paralles_pri)
num_of_paralles_sec = ceil(num_of_paralles_sec)
cableArea_mm2 = 0.080;
primaryArea_mm2 = priTurns*num_of_paralles_pri*cableArea_mm2
secondaryArea_mm2 = secTurns*num_of_paralles_sec*cableArea_mm2
totalCableArea_mm2 = primaryArea_mm2 + secondaryArea_mm2
fillFactor_perc = 100*totalCableArea_mm2/windowArea_mm2
```

5. Cable resistance calculation is done by the code below:

```
windingLengthPerTurn_mm = 68.2
ohms_per_meter = 212.872 / 1e3
primaryLength_m = windingLengthPerTurn_mm * priTurns * 1e-3
secondaryLength_m = windingLengthPerTurn_mm * secTurns * 1e-3
primary_DC_resistance_ohm = ohms_per_meter * primaryLength_m /
num_of_paralles_pri
secondary_DC_resistance_ohm = ohms_per_meter * secondaryLength_m /
num_of_paralles_sec
```

The DC and AC resistances of the transformer are assumed equal thanks to the skin depth being greater than the radius.

Primary Resistance: 10.5 mOhm

Secondary Resistance: 252 mOhm

6. Copper losses are calculated by the code below:

```
diameter_mm = vpa(0.32004*u.mm)
radius_mm = diameter_mm/2
skinDepth_cm = vpa(7.5/sqrt(f_sw)*u.cm)
skinDepth_mm = unitConvert(skinDepth_cm, u.mm)
% skin depth is greater than radius.
% Therefore, AC reistance equals DC resistance
DC_to_AC_ratio = 1
primary_AC_resistance_ohm = primary_DC_resistance_ohm*DC_to_AC_ratio
secondary_AC_resistance_ohm = secondary_DC_resistance_ohm*DC_to_AC_ratio
resistancePri_ohm = vpa(primary_AC_resistance_ohm * u.Ohm)
resistanceSec_ohm = vpa(secondary_AC_resistance_ohm * u.Ohm)
copperLossPri = vpa(unitConvert((i_in_max*u.A)^2 * resistancePri_ohm, u.W))
copperLossSec = vpa(unitConvert((i_out*u.A)^2 * resistanceSec_ohm, u.W))
copperLoss_W = copperLossPri + copperLossSec
```

Total Copper Losses: 0.42 W

7. Core losses are calculated by the code below:

```
permeability = 26;
mu_zero = 1.25663706212e-6;
pathLength_m = 107e-3;
fluxDensity_Tesla = mu_zero * permeability * ampTurns / pathLength_m
% using graph above, 0.03 Tesla @ 100 kHz corresponds to
wattLoss_mW_cm3 = 60*u.mW/u.cm^3
volume_mm3 = 21300;
volume_cm3 = vpa(unitConvert(volume_mm3*u.mm^3, u.cm^3))
coreLoss_w = vpa(unitConvert(wattLoss_mW_cm3 * volume_cm3, u.W))
```

Core Loss: 1.27 W

The core loss is comparable with the copper loss. Hence, the design is good. No need to iterate more.

c) The open-loop flyback design is simulated on Simulink as shown in Figure 2. The circuit is simulated at its edges, namely, 12V input voltage and 0.366 duty and 18V input voltage and 0.278 duty. The simulation results are shown in Figures 3-6 for 0.278 duty and Figures 7-10 for 0.366 duty.

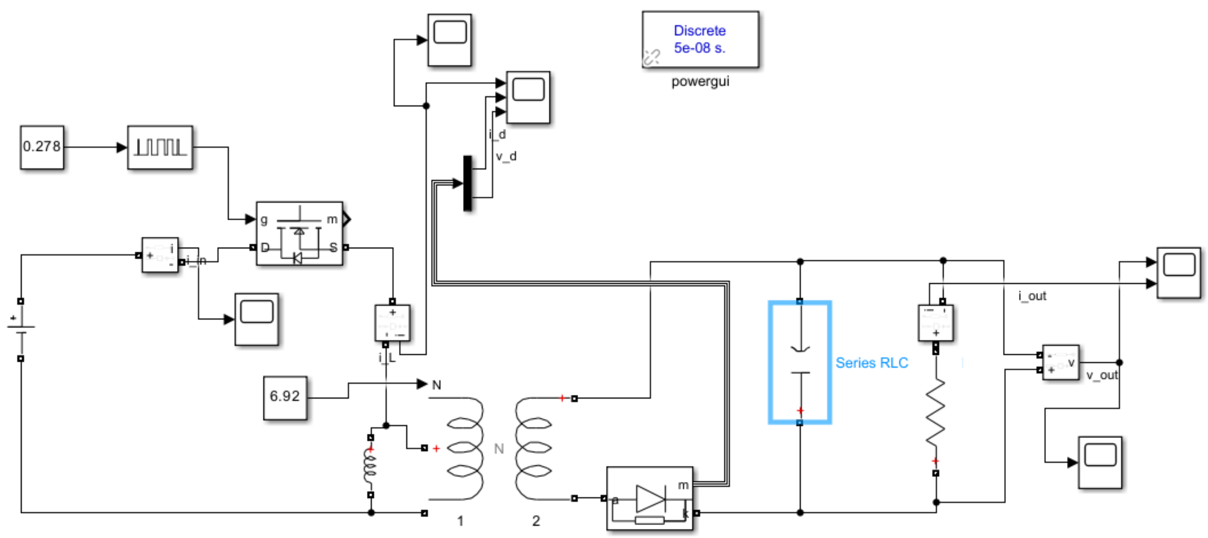

Figure 2: The Flyback converter in Simulink

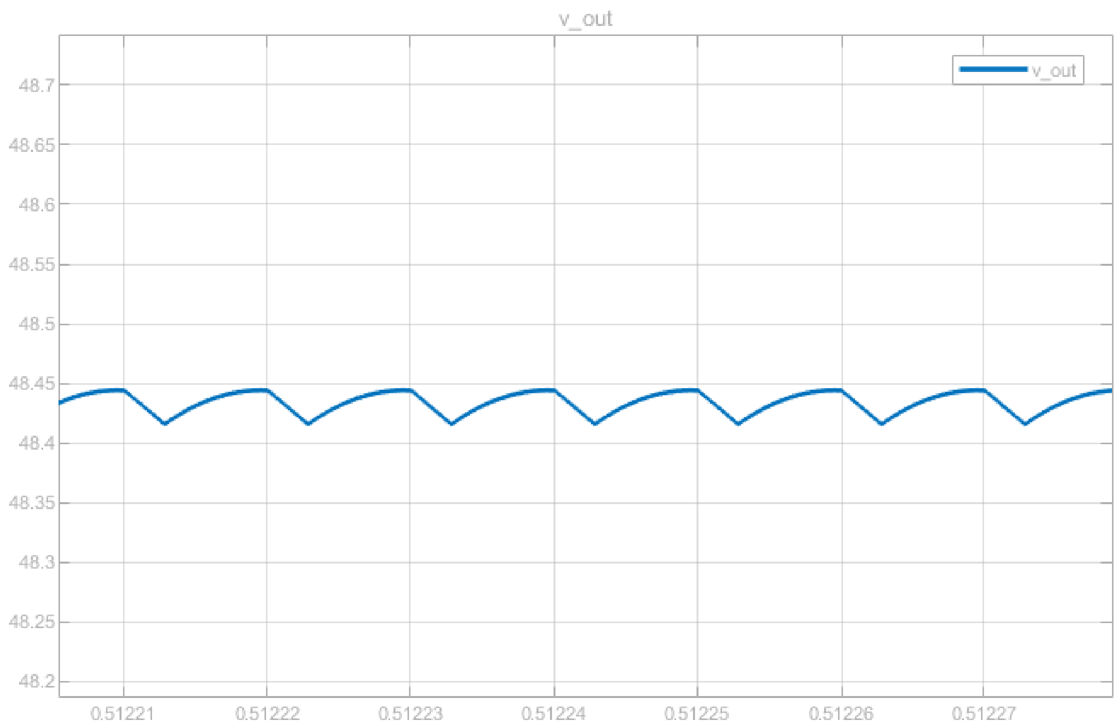

Figure 3: Output voltage ripple for 0.278 duty

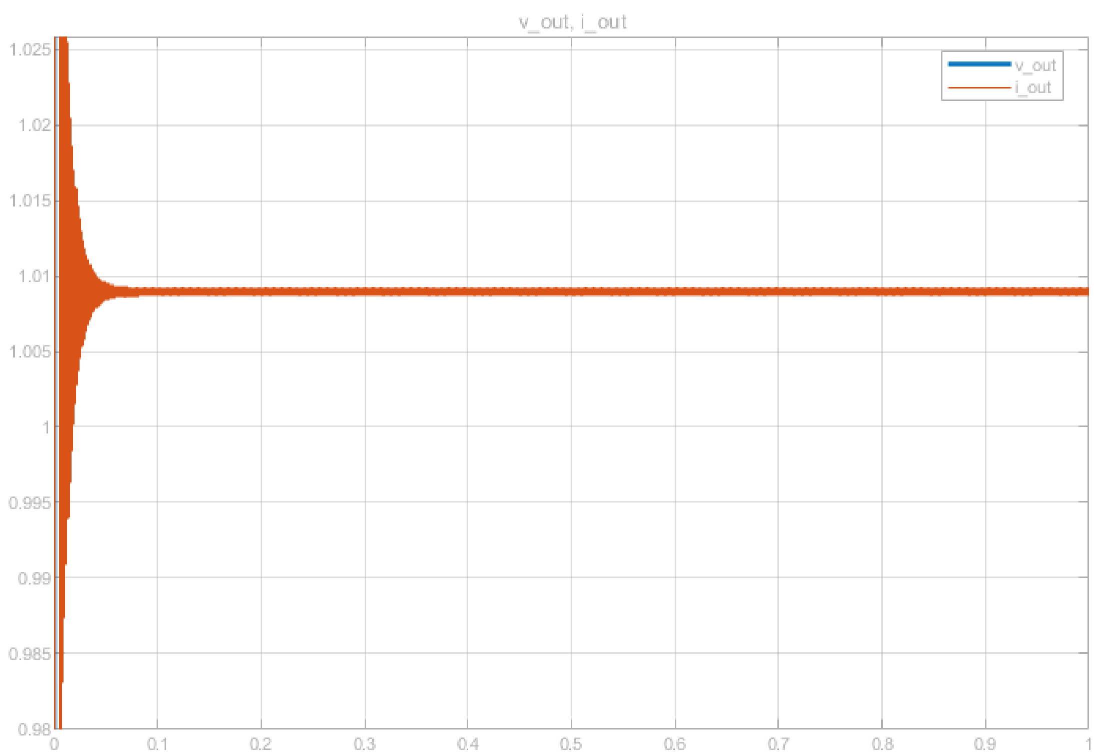

Figure 4: Output current waveform for 0.278 duty

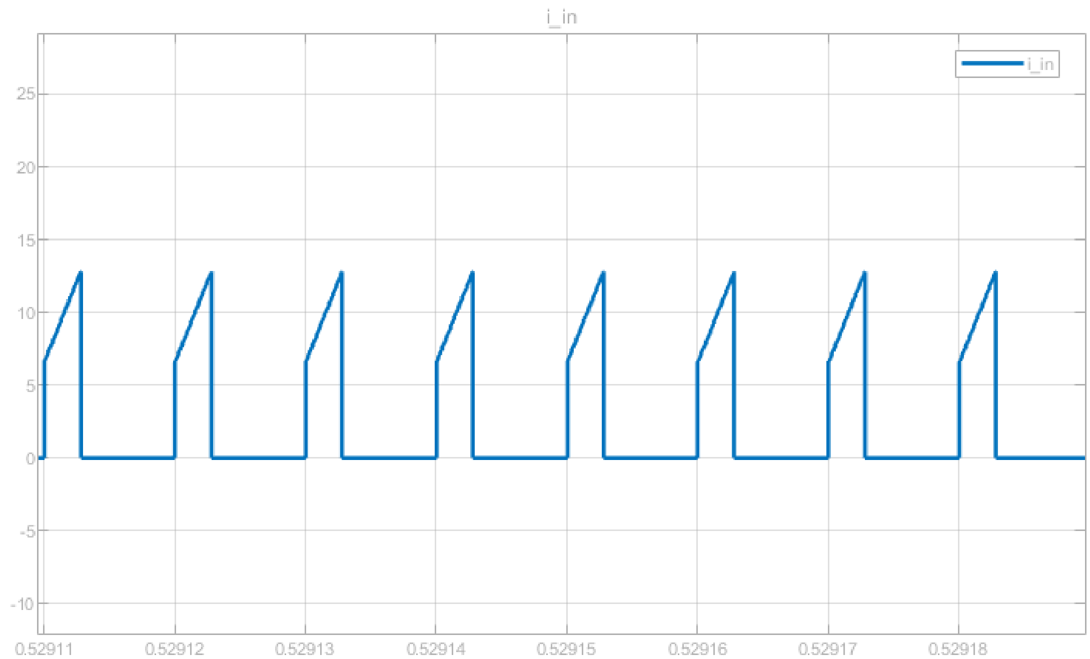

Figure 5: Input current waveform for 0.278 duty

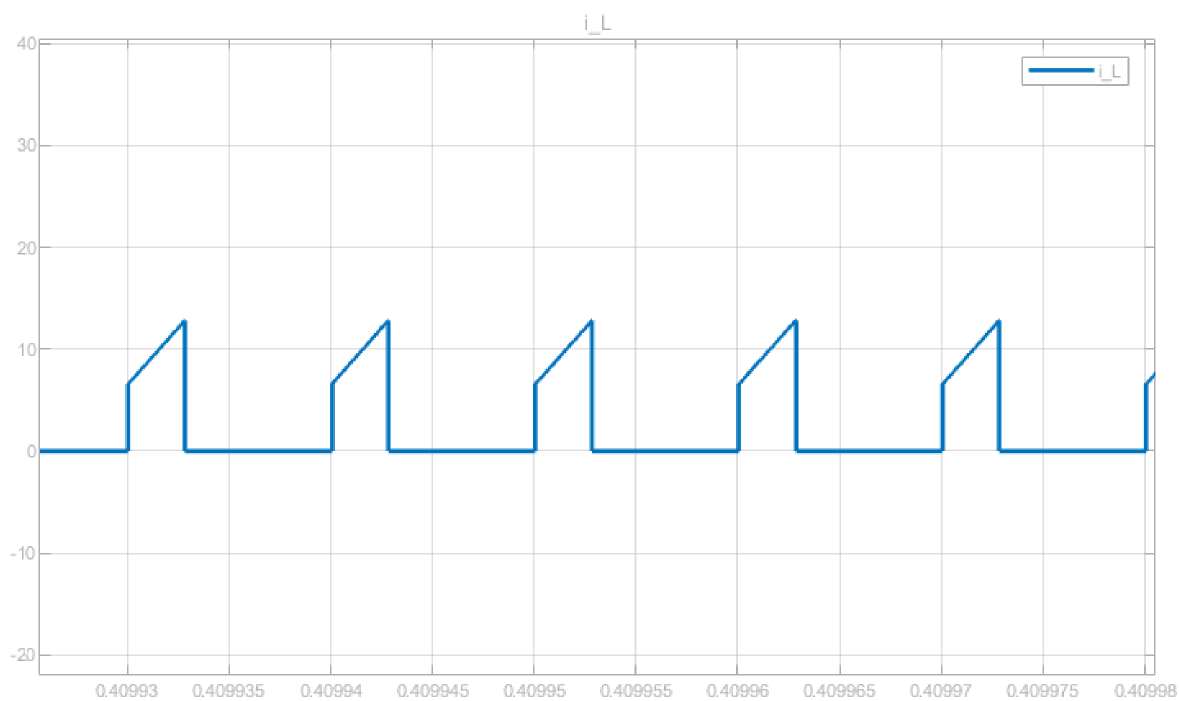

Figure 6: Transformer primary current waveform for 0.278 duty

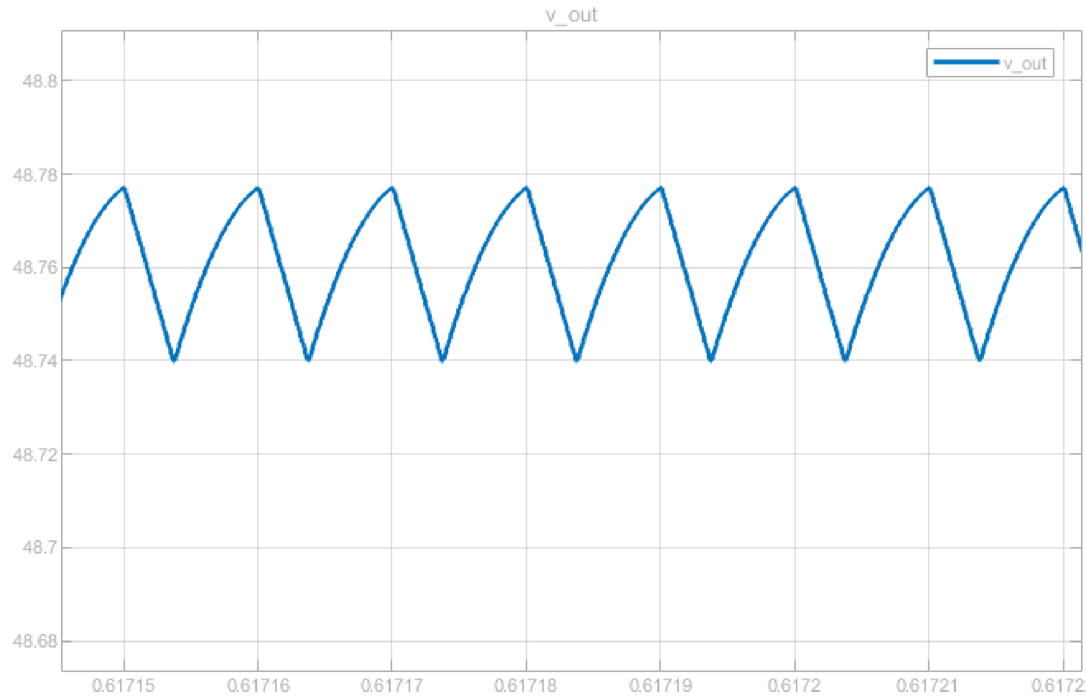

Figure 7: Output voltage ripple for 0.366 duty

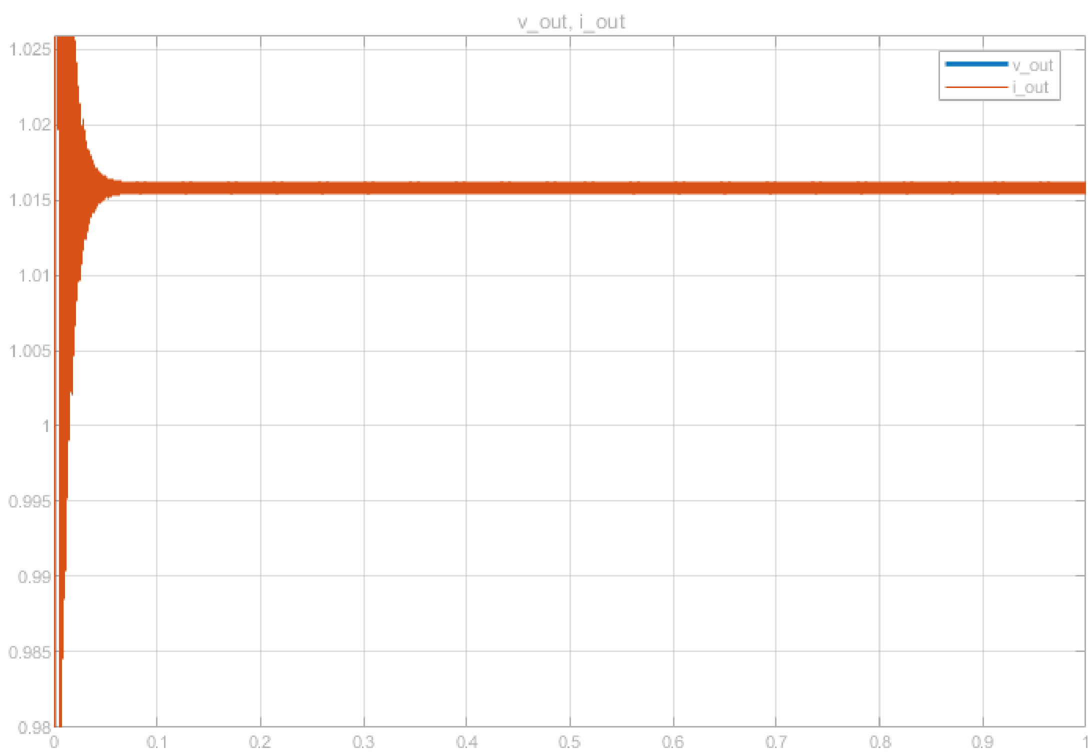

Figure 8: Output current waveform for 0.366 duty

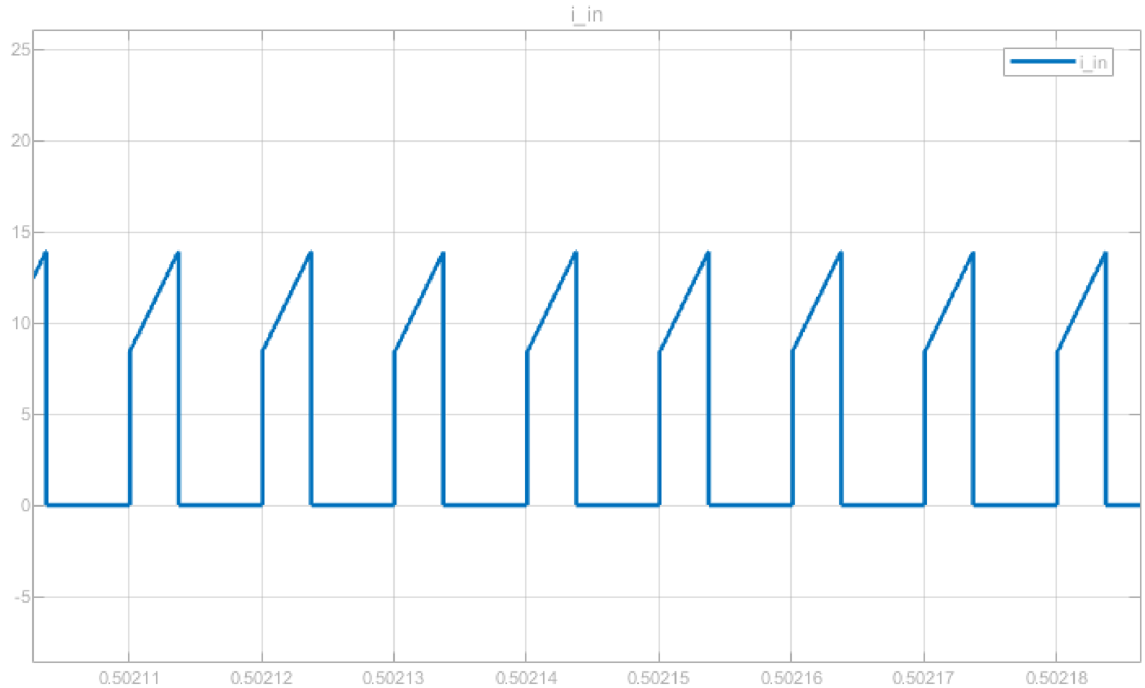

Figure 9: Input current waveform for 0.366 duty

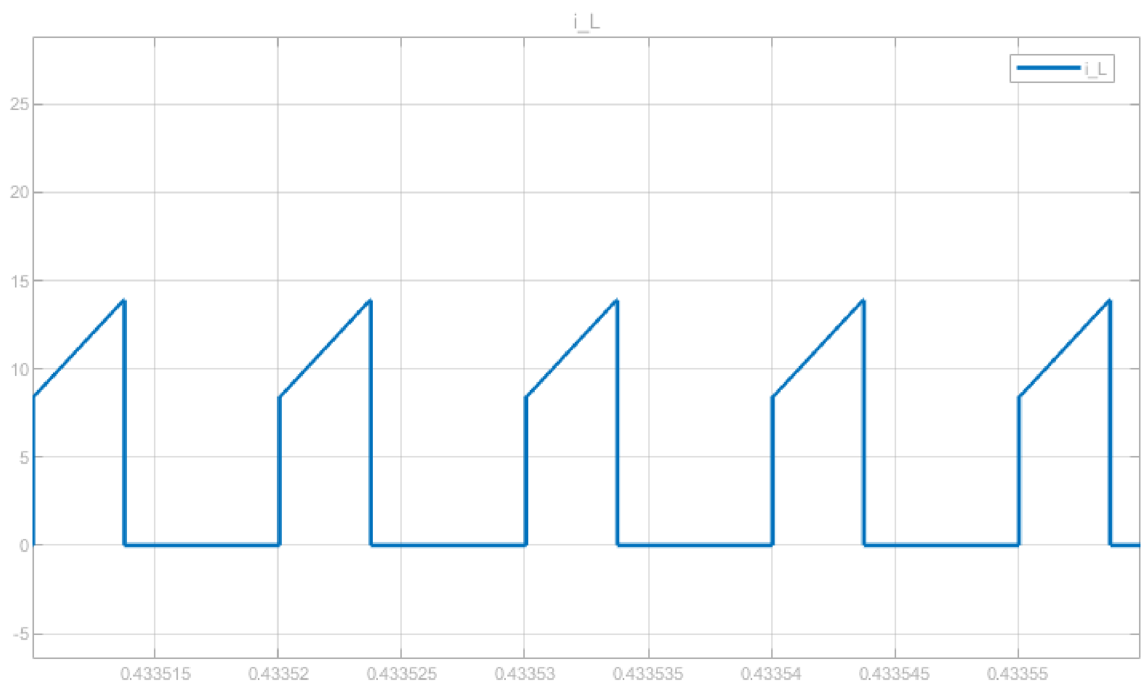

Figure 10: Transformer primary current waveform for 0.366 duty

d) The minimum load current to avoid from DCM is calculated with code below:

```
Lm = 8*10^-6; f_sw = 100*10^3;

% DCM
% for Vs = 12V
Vs = 12; D = 0.366;
deltaI_lm = Vs*D/(Lm*f_sw);
P_min = Vs^2 * D^2 / (2*Lm*f_sw);
I_load_min = P_min / 48

% for Vs = 18V
Vs = 18; D = 0.278;
deltaI_lm = Vs*D/(Lm*f_sw);
P_min = Vs^2 * D^2 / (2*Lm*f_sw);
I_load_min = P_min / 48
```

Minimum load current to operate in CCM when input is 12V = 0.251mA
Minimum load current to operate in CCM when input is 18V = 0.326mA

The maximum current that can flow through transformer is calculated with code below:

```
% max I_Lm current occurs when input voltage is 12V and at 100% load
Vs = 12; D = 0.366;
turnsRatio = 6.92; R = 48;
deltaI_lm = Vs*D/(Lm*f_sw);
P_out = Vs^2 * D^2 * turnsRatio^2 / ((1-D)^2 * R);
I_Lm_max = deltaI_lm/2 + P_out/(Vs*D)
```

Current can rise up to the 13.645A while converter is working with 100% load and 12V input voltage.

e)

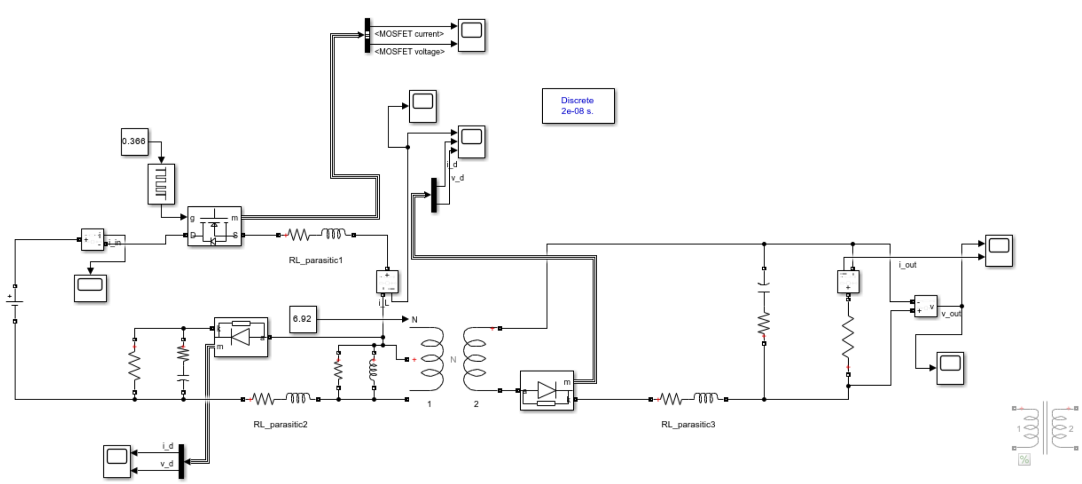

Figure 11: Simulation of the converter with parasitic elements of transformer and switching device.

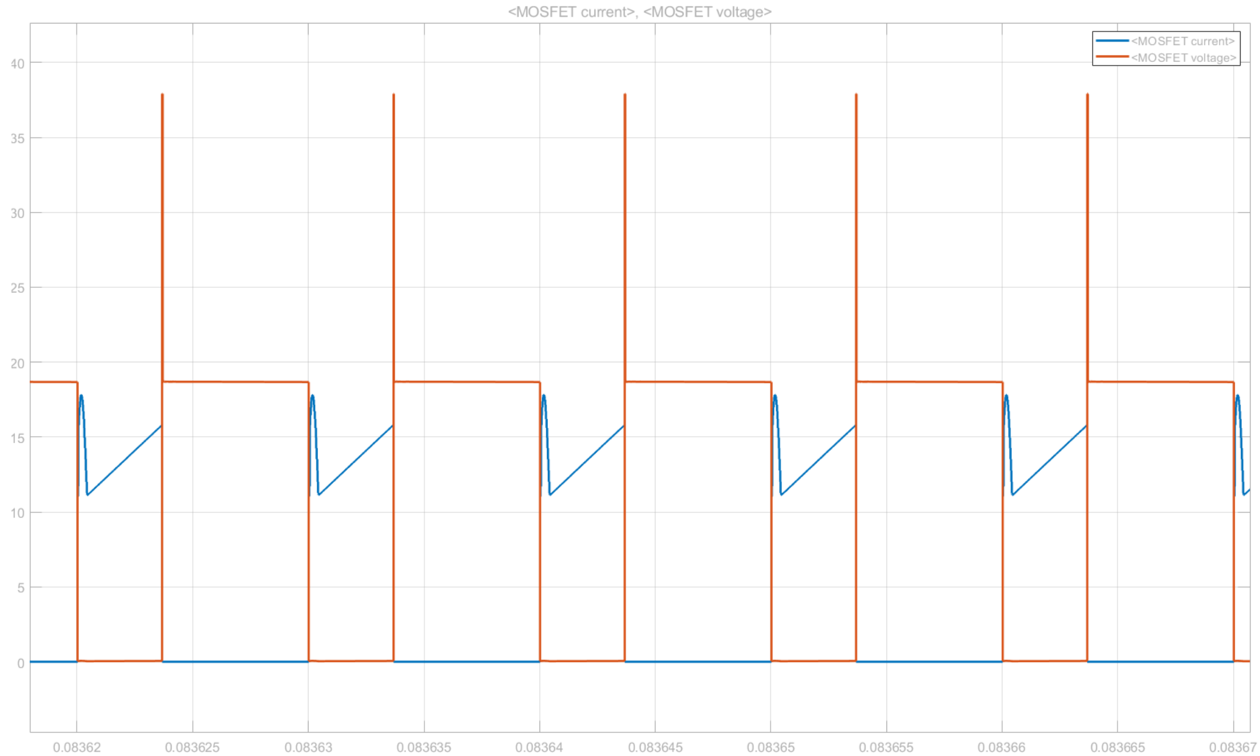

Figure 12: Voltage and current waveforms of MOSFET with parasitic elements.

In figure 12, it can be seen that, due to parasitic inductances, there are voltage spikes on MOSFET while switching. Because of leakage inductance, snubber must be used to discharge the leakage inductance. Snubber design is taken from the recommended design of Webench.

Complete Simulations

Conclusion