**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 3](#_Toc133878989)

[Topology Selection 3](#_Toc133878990)

[Magnetic Design 4](#_Toc133878991)

[Complete Simulations 12](#_Toc133878992)

[Conclusion 12](#_Toc133878993)

# 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

diyagram içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : TI Webench design

# Magnetic Design

1. 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 (Ns/Np) is calculated as 6.93.

2. 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.
3. 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

1. 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.
2. 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

1. 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**

1. 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**

1. 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.

1. 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.

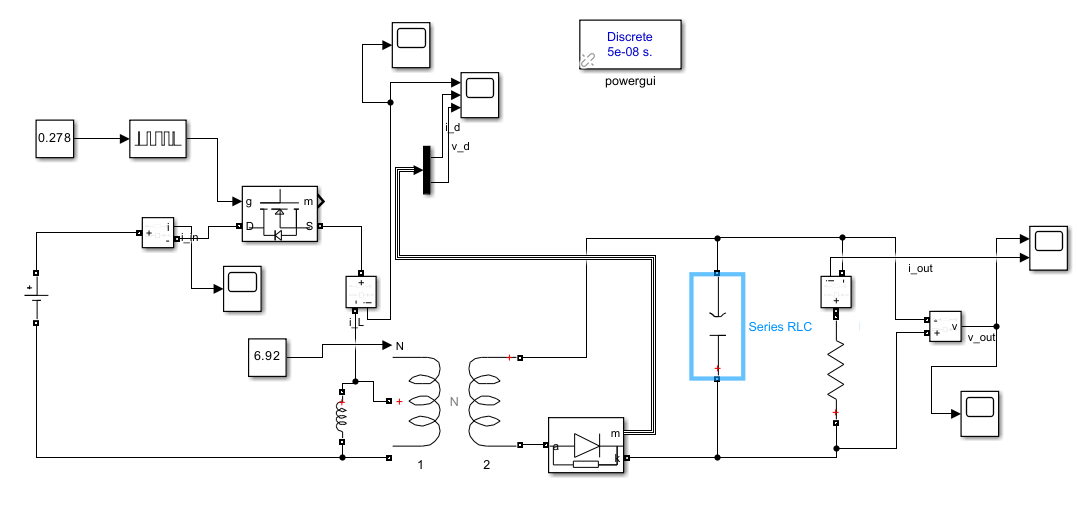


Figure : The Flyback converter in Simulink

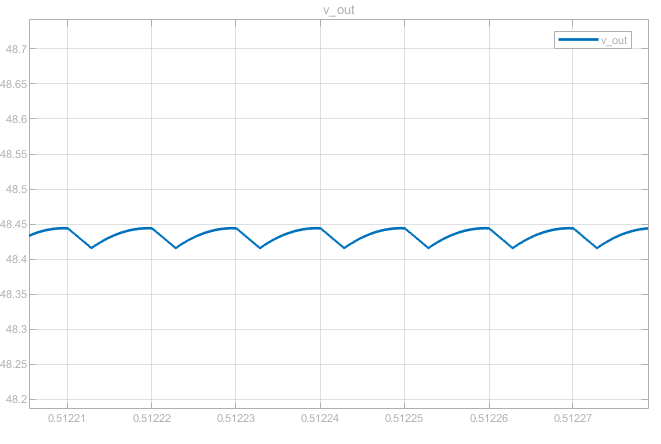
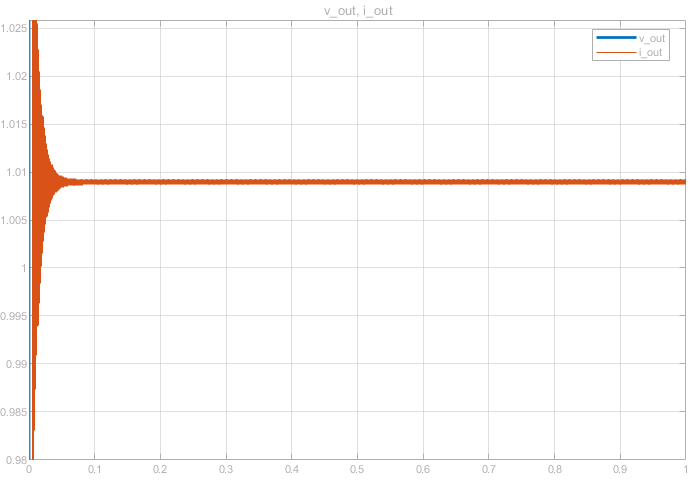


Figure : Output voltage ripple for 0.278 duty

Figure : Output current waveform for 0.278 duty

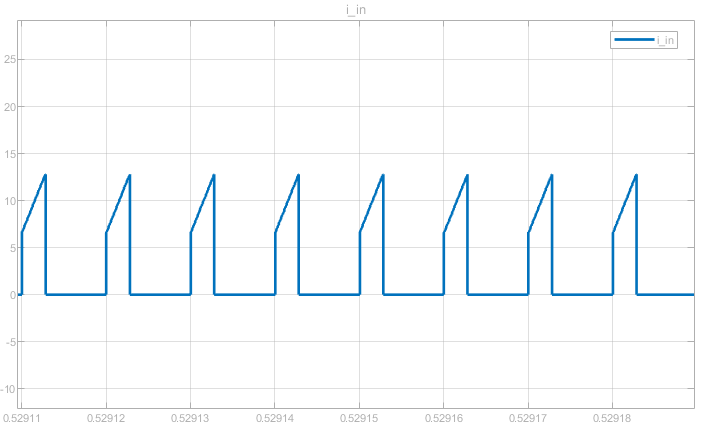


Figure : Input current waveform for 0.278 duty

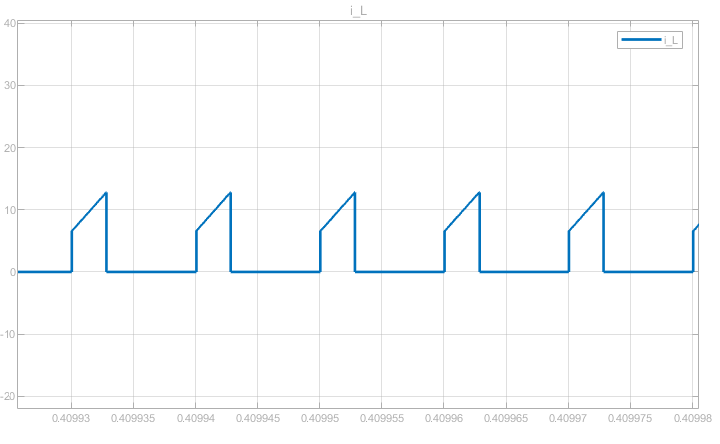


Figure : Transformer primary current waveform for 0.278 duty

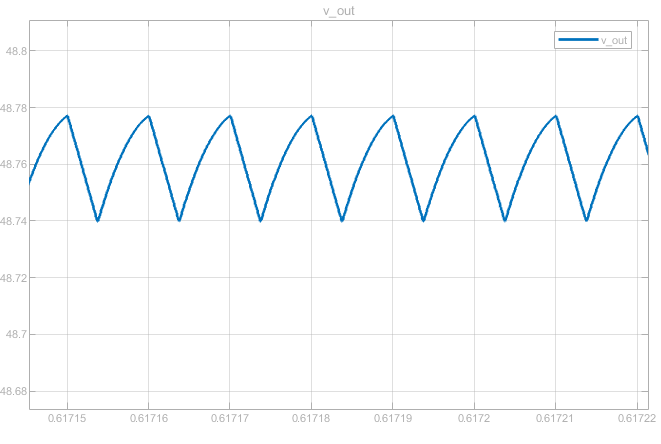


Figure : Output voltage ripple for 0.366 duty

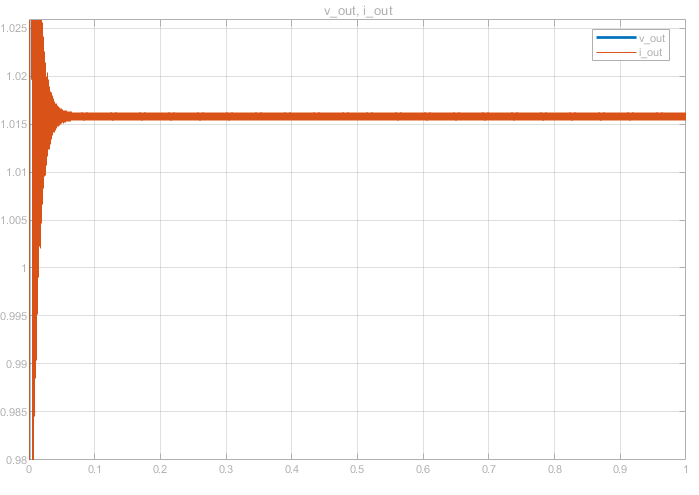


Figure : Output current waveform for 0.366 duty

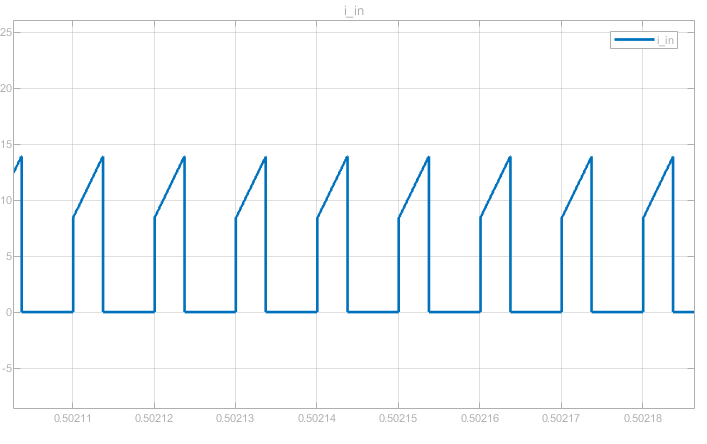


Figure : Input current waveform for 0.366 duty

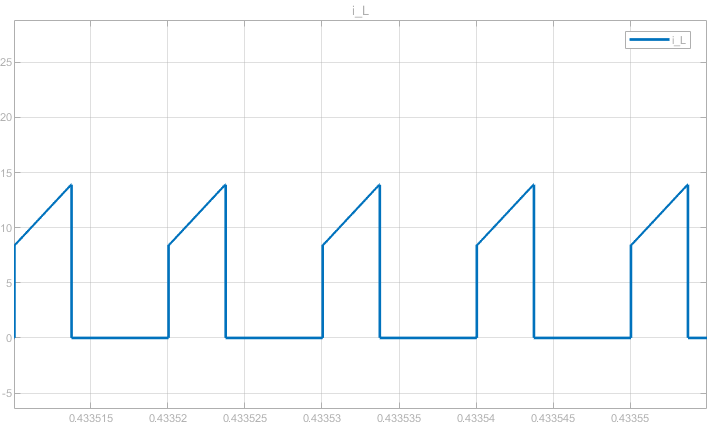


Figure : Transformer primary current waveform for 0.366 duty

1. 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.

diyagram, şematik içeren bir resim

Açıklama otomatik olarak oluşturuldu

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

# 

Figure : 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.

The flyback converter is simulated with parasitic elements and non-ideal switching devices as shown in Figure 13.

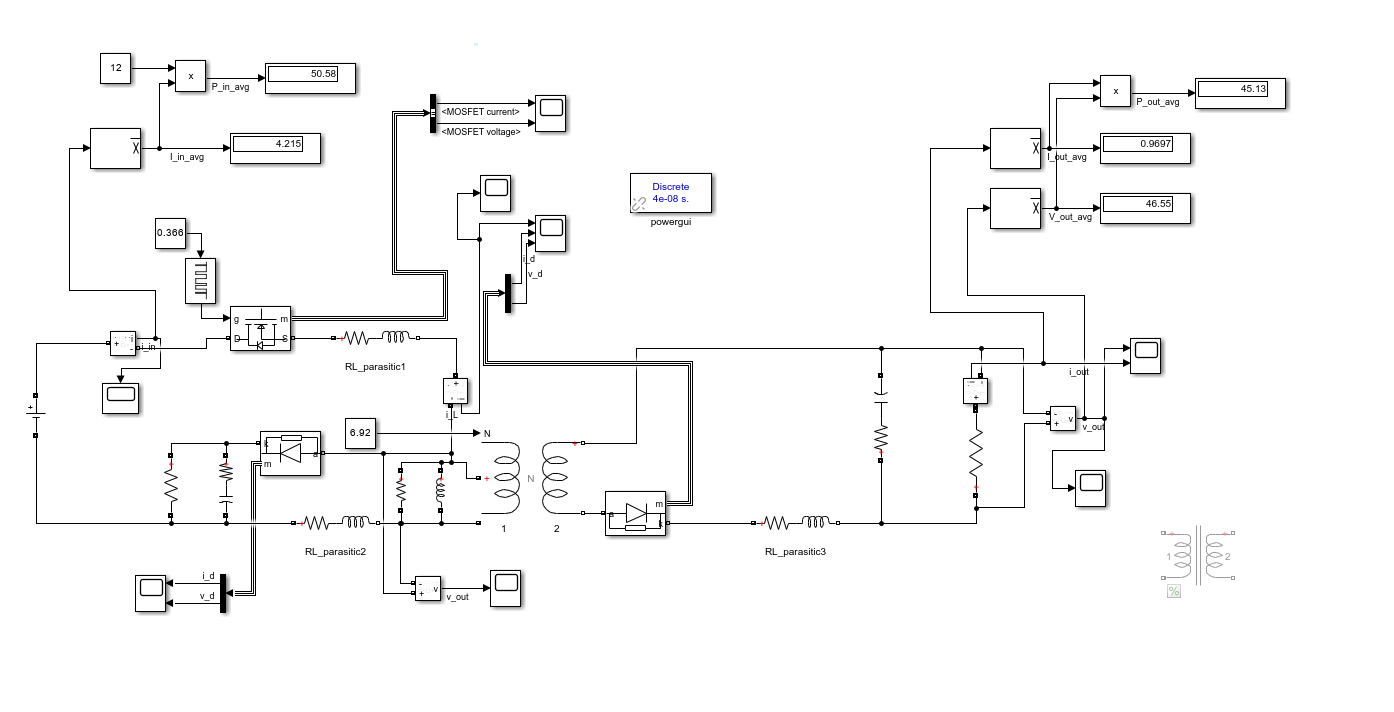


Figure : Simulation design for efficiency test.

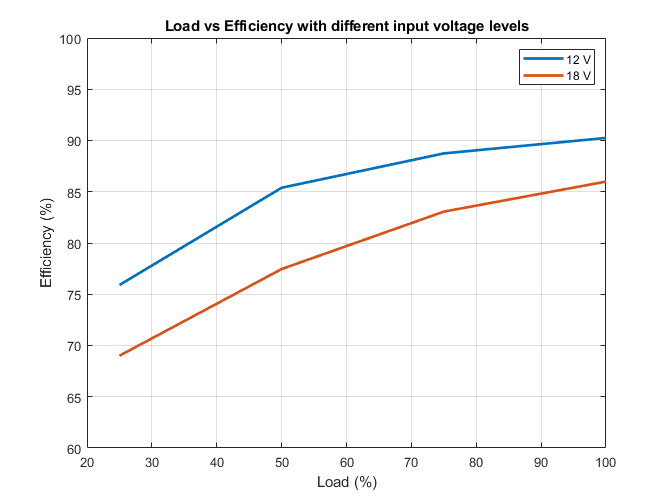


Figure : Efficiency vs Load curves for different voltage input levels.

Table : Simulation result of efficiency values for different

input voltage and load conditions.

|  |  |  |
| --- | --- | --- |
| Load (%) | Efficiency (%) | |
| 12V | 18V |
| 25 | 75.9 | 69 |
| 50 | 85.39 | 77.46 |
| 75 | 88.74 | 83.06 |
| 100 | 90.25 | 85.99 |

Table : Calculated efficiency values without snubber losses.

|  |  |  |
| --- | --- | --- |
| Load (%) | Efficiency (%) | |
| 12V | 18V |
| 25 | 87.7 | 87.89 |
| 50 | 92.78 | 93.03 |
| 75 | 94.3 | 94.62 |
| 100 | 94.94 | 95.33 |

Efficiency of the flyback converter decreases with less load since core loss and snubber losses become dominant. Also, when the input voltage increased, the losses on switching device increase quadratically; thus, converter becomes less efficient with higher input voltage. Lastly, how inefficient is snubber can be seen by comparing two results.

# Complete Simulations

# Conclusion