MIDDLE EAST TECHNICAL UNIVERSITY
Electrical & Electronics Engineering

Simulation Project #2

EE 464 – Static Power Conversion - II

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Introduction

In our hardware project of the EE464 course, we are asked to design an Isolated Power Supply. In this project, the design and simulations are to be performed for hardware project. As Anca Inc. group, we have chosen the project designing an Isolated Flyback Converter. The specifications are as follows;

Minimum Input Voltage (V)	210 Vac
Maximum Input Voltage (V)	230 Vac
Output Voltage (V)	15
Output Power (W)	15
Output Volt. Peak-to-Peak Ripple (%)	5
Line Regulation (%)	3
Load Regulation (%)	3

Table 1: Flyback Converter Specifications

Question-1

a)

Our input voltage is AC voltage with 210 V rms. Firstly, we establish the single phase full bridge rectifier to convert AC to DC and the DC voltage is filtered by DC-Link Capacitor. Then, a Flyback Converter is established by PI controller. PI controller is required to adjust the output power 15 V for not considering input voltages change.

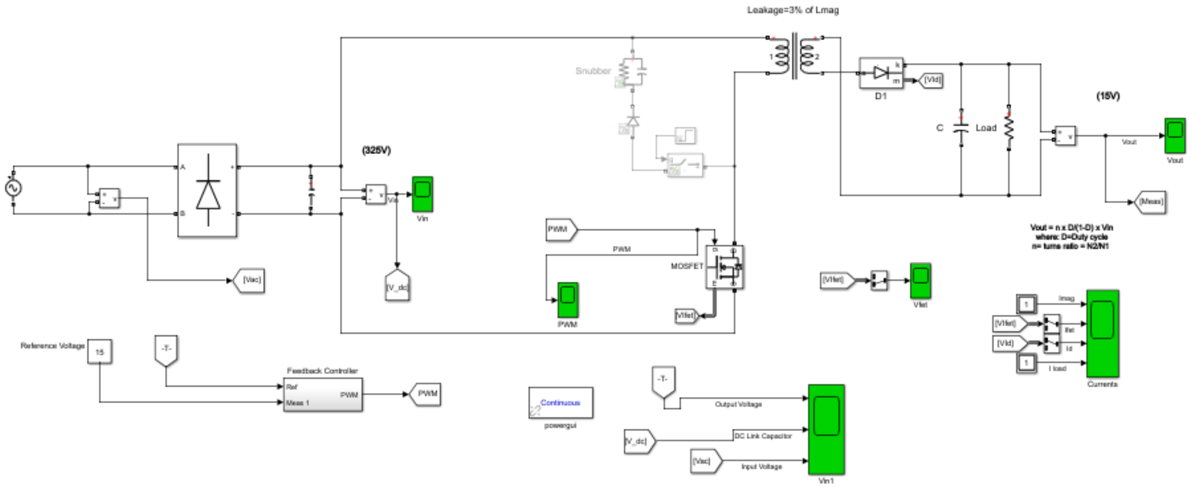

Figure 1: Simulink Setup of Flyback Converter

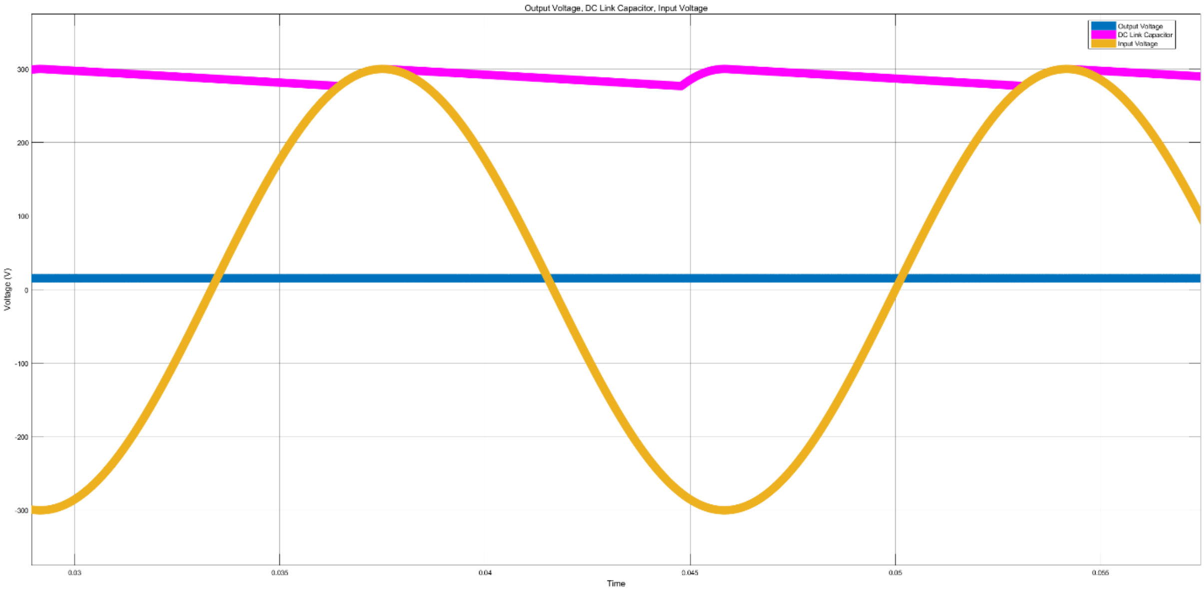

Figure 2: Inputs and Output Voltages of the Flyback Converter

b)

At this part, we are supposed that transformer design for our Flyback Converters. There are some properties that are important for designing such as permeability, saturation flux and core loss. Geometry and core type of the transformers determines the properties.

Transformer geometry toroid changes with respect to applications and some geometries are E-core I-core and Toroid core. E- cores are easier to wind and mount by using transformer core former. We chose the core geometry as E-core for that reason. Saturation flux depends on current ratings. Our current rating is small, 1A and we can choose saturation flux density as small. Also, permeability affects the magnetizing inductance which is very important to Flyback design because transformer is used for energy storage elements in Flyback. In addition to this, core loss is very important to determine switching frequency because of the efficiency consideration.

We, as Anca Inc Team, made a Matlab Script to determine the design parameters with respect to our requirements. The script is given as APPENDIX.

By using this script, we found that:

Requirement Magnetizing Inductance: 66mH
Np/Ns= 26.7721 (maximum duty is determined as 0.6) and minimum Np=30 turns.

And core is chosen as ‘00K6527E060’. It has Kool Mu core and the area of core is 540mm^2. The properties meet our specifications and requirements.

c)

There are 4 step to calculate the parameters to provide specification:

1- DC link capacitor determination for Single Phase Rectifier

DC link capacitor is determined by AC voltage and frequency with desired ripple at output of the single phase rectifier.

$$C_{dc} = \frac{2*V_{line}^2 - V_{Dc}^2}{P_{in}(1-D_{ch})f_l}$$

$$V_{line} = 210\ V\ (\,minimum)$$

$$V_{Dc} = 280\ V\ (\,minimum)$$

$$P_{in} = P_{out} * Efficiency$$

$$f_l = 50\ Hz\ and\ Dch = 0.2\ (\,charging\ duty)$$

The DC link capacitor is calculated easily as 33uF, 400 V.

2- Magnetizing Inductance is calculated by formula:

$$L_m = \frac{(\,V_{DC}D_{max})^2}{2P_{in} * f_s * K_{rf}}$$

Maximum duty can be selected for mode of converter. We want our converter to operates at continuous conduction mode. Thus, standard duty ratio is near the 0.5. Maximum duty is 0.6-0.7. Ripple factor (Krf) is 1 at DCM and it is between 0.2 and 0.5 at CCM. Switching frequency was determined as 45 kHz.

$$L_m = 66mH$$

3- Calculation of Peak Current of Switch

$$\Delta Ids = \frac{V_{dc}\,D_{max}}{L_m f_s}$$

$$I_{eds} = \frac{P_{in}}{V_{DC}D_{max}}$$

$$I_{ds}^{peak} = I_{edc} + \frac{\Delta I_{ds}}{2}$$

The calculation is important to determine the CCM and DCM mode. Change in switch current is equal to half of peak current or equals to I_eds.

4- Determination of primary side Turn number

$$N_p = \frac{L_m I_{ds}^{peak}}{B_{sat} * A_e}$$

Minimum turn number depends on core. The core area and saturation flux density. They are found at our core datasheet.

$$A_e = 540\ mm^2$$

$$B_{sat} = 1.05\ T$$

$$N_p = 29.558$$

5- Determination of primary side Turn number

$$N_s = \frac{N_p V_{Ro}}{V_{out} + V_d}$$

$$N_s = 1.119$$

Secondary side turn ratio depends on primary side voltage and secondary side voltage. Secondary side voltage includes output voltage and opening voltage of diodes.

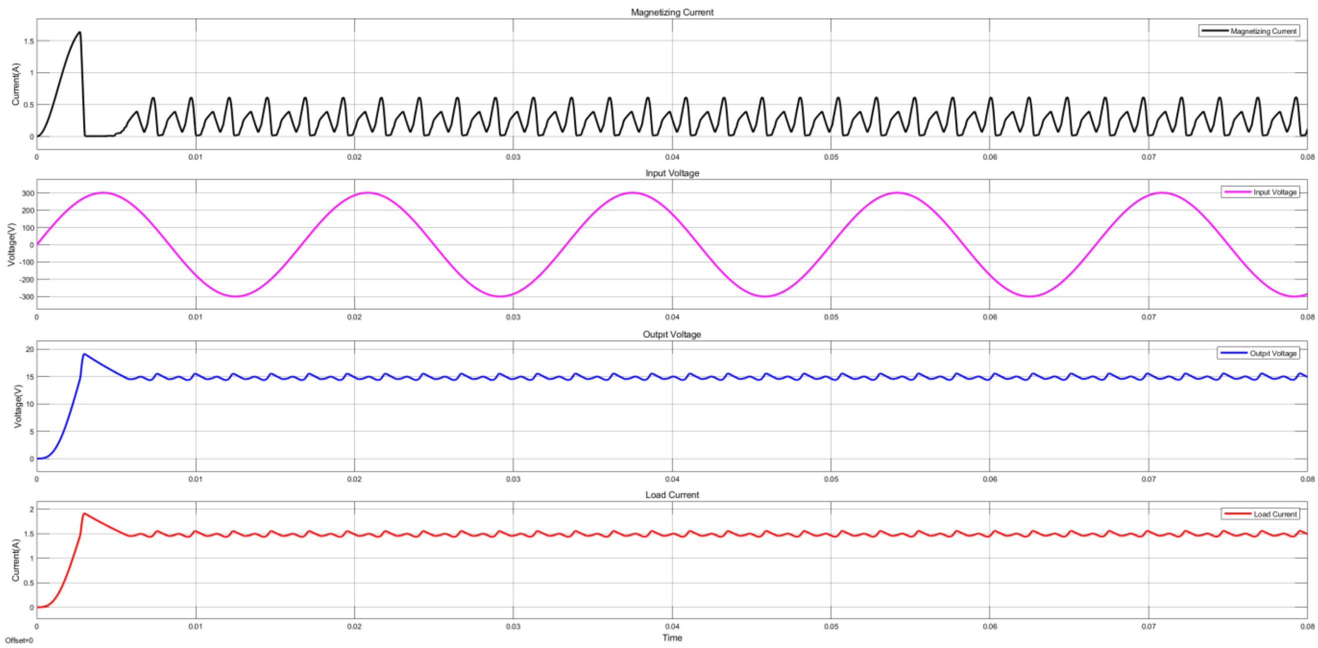

Figure 3: Corresponding waveforms with ideal switches and elements

d)

Passing through DCM and CCM gives the minimum current of load. At question 3, half of peak current of switch current change in current.

$$I_{eds} = \frac{P_{in}}{V_{DC}D} = \Delta Ids = \frac{V_{DC}\,D}{L_m f_s}$$

$$D = 0.52$$
$$P_{in} = 8.9\,Watt$$
$$P_{out} = 6.55\,Watt$$
$$I_{min} = 0.43\,A$$
$$n = 26$$

Transformer current calculated by turns ratio:

$$I_p^{min} = \frac{I_{min}}{n} = 0.016A$$
$$I_p^{max} = \frac{I_{max}}{n} = 0.038A$$

$$I_n^{min} = 0.43A$$

$$I_n^{max} = 1A$$

e)

Leakage inductance is taken as 3 percentage of magnetizing inductance. The mosfet conduction resistance is 10 ohms, and diode conduction resistance is 5 ohms. Switch Voltage and Switch current are taken at only conduction time.

Without Snubber Circuit:

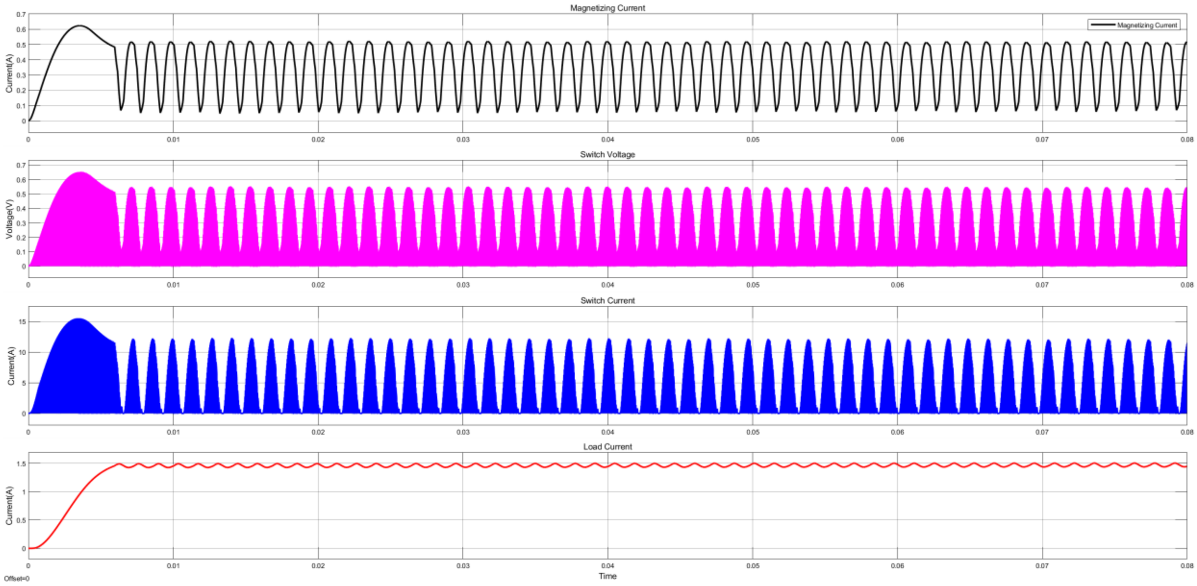

Figure 4: Corresponding waveforms without snubber circuit

With Snubber Circuit:

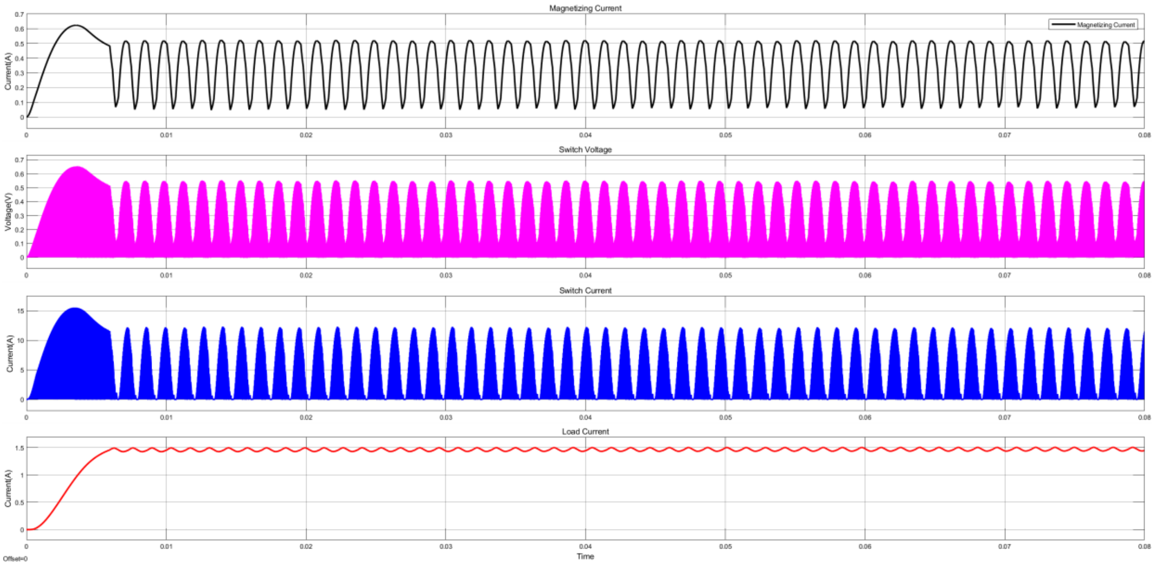

Figure 5: Corresponding waveforms with snubber circuit

Without snubber circuit, the energy storage is not transferred to load. Load current decreases and output voltage is not provided successfully.

RCD snubber circuit is established. The value of components can be found by considering reverse voltage.

$$V_{ro} = \frac{D}{1-D} V_{in}$$

R=1k ohm
C= 47 nF

f)

	Input Power (W)	Output Power (W)	Efficiency (%)
%100	21.12	14.98	71
%75	17.6	11.24	63
%50	12.1	7.48	60
%25	8.3	3.74	45

Table 2: Efficiency calculation with different load characteristics

As the load is decreased, the efficiency is decreased as well as shown in Table 2. The reason for that is the losses in transformer stays constant although the changes in output and input powers. Transformer losses have bigger portion in the loss calculations in that case. Therefore, efficiency is decreased with decreasing load. Also, the controller and converters are designed considering %100 load. Therefore, the efficiency is expected to be lower than designed circuit with different load characteristics.

g)

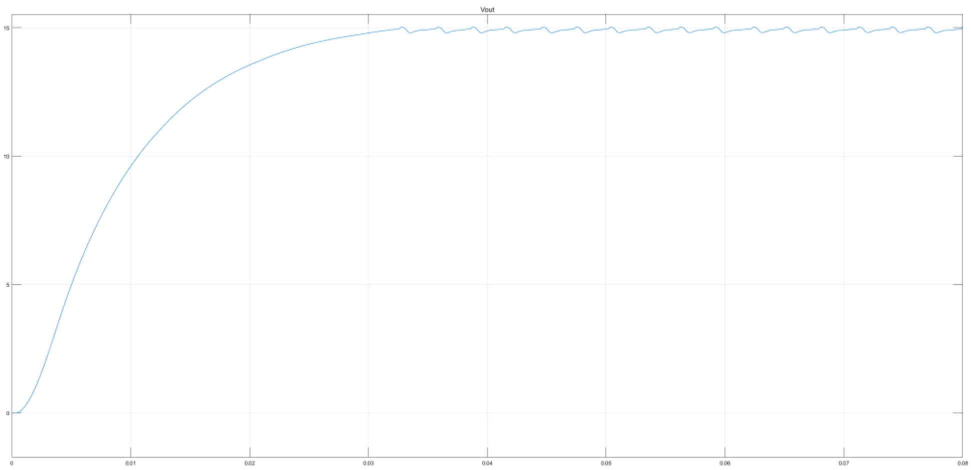

Figure 6: Output waveform with input voltage 210 Vac

%1.3 ripple at 210 Vac is observed in the output voltage waveform which is a reasonable value with desired ripple value less than 5%.

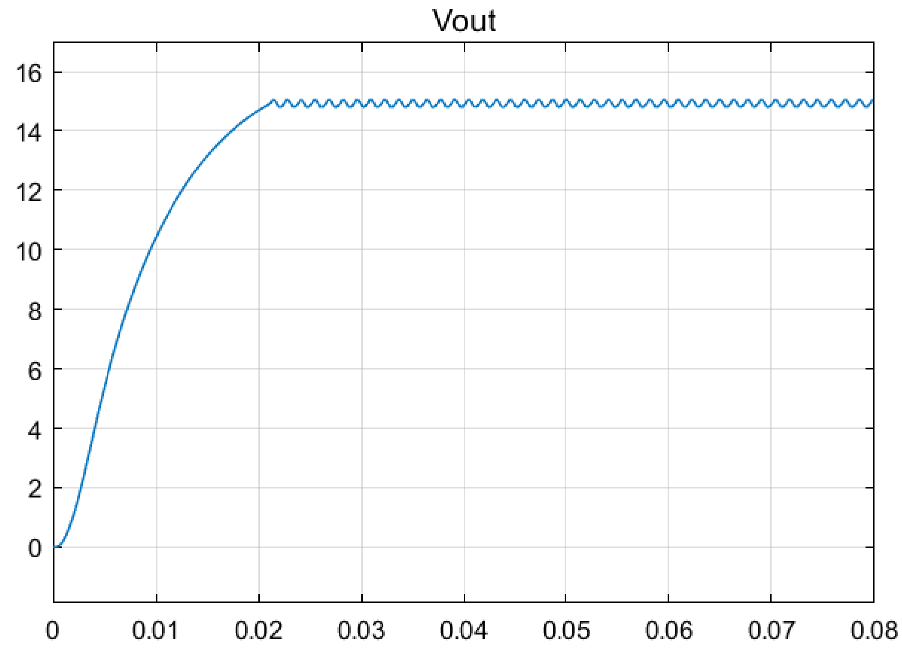

Figure 7: Output waveform with input voltage 230 Vac

%1.6 ripple at 230 Vac is observed in the output voltage waveform which is a reasonable value with desired ripple value less than 5%. Figures 6 and 7 show that the output ripple condition is satisfied with the designed converter design.

h)

As calculated from part b, we found the capacitor value as 33 µf. We decided to use electrolytic capacitor since 33 µf is large value.

For switching and controller, we found an integrated circuit which is called TNY267[1]. This component has its mosfet and PWM generator with respect to feedback value. Also, we calculated Vds as 625 and the reverse voltage of the component is 700V. Ids is 0.12A in the calculation. Ids value of the component is 0.72 A. This component is proper for our application.

For diode selection, we calculated Vro value in the part b and that is 400V. On the output side, maximum current will be 1 A. On the internet, we found a diode which is called 10A10[2].

For the output capacitor, 1mF is need and output voltage is 15 V. We can use more than capacitor to obtain that value.

Conclusion

In this project, the design of a Flyback converter with the specified input and output characteristics are discussed. Firstly, the simulations are performed at the steady-state operation. Then, transformer design with related calculations are done accordingly. After that, the effects of ideal switches and transformers are compared with the non-ideal ones. Also, DCM/CCM boundary is calculated. Then, the performance of converter with different load characteristics are observed and compared. Having that, output ripple values are illustrated and compared with design requirements. Finally, preliminary component selection is done according to related simulation results. This project plays crucial role in hardware design. Hardware implementation will be performed according to these design knowledge and waveforms.

References

[1] Controller datasheet: http://html.alldatasheet.com/html-pdf/139806/POWERINT/TNY267PN/5077/13/TNY267PN.html

[2] Diode datasheet: http://html.alldatasheet.com/html-pdf/56900/BYTES/10A10/124/1/10A10.html

APPENDIX

Matlab Script for Calculations:

```
%%
clear all;
clc;
%% Flyback Parameters
V_line_minimum= 210; % V rms
V_line_max=230 ; % Vrms
V_dc_min= 280; % 5 percentage ripple
V_dc_max=sqrt(2)*V_line_max;
Output_power= 15; % Watt
Efficiency= 0.95 ; % between 0-1
Input_power= Output_power/Efficiency;

%% DC Link Capacitor Calculation
D_ch=0.2; % for capacitor charging duty
F_line= 50; % Line frequency

C_DC = (Input_power*(1-D_ch))/ ...
   (F_line*((2*V_line_minimum^2)-V_dc_min^2));

fprintf(' %f microFarad \n',C_DC*1e6);



%% Determination of Maximum Duty Cycle
D_max= 0.6 ; % for CCM mode, it is bigger than 0.5
V_Ro= (D_max/(1-D_max))*V_dc_min;
V_ds= V_dc_max+V_Ro;

%% Lm Determination
f_s= 45000; % Switching Frequecny Hertz
K_f= 0.3; % for ccm 0.25-0.50
L_m= (( V_dc_min*D_max)^2)/(2*Input_power*f_s*K_f)...
   *1e3; % mili Henry
fprintf('% f mH \n', L_m);
L_m=L_m*1e-3;

%% Calculation of peak current of FSP( mosfet, IGBT)
I_edc= Input_power/(V_dc_min*D_max); % average ...
... switching amplifier
Delta_Ids= (V_dc_min*D_max)/(L_m*f_s);
Ids_Peak=I_edc+(Delta_Ids/2);
Ids_rms=sqrt((3*I_edc^2) + ((Delta_Ids/2)^2*D_max/2));
fprintf('%f %f \n',Ids_Peak,Ids_rms);

%% Primary Side Turns Determination
Ae=540*1e-6; % m^2
B_sat=1/2 ; %Tesla
N_p= ((L_m*Ids_Peak)/(B_sat*Ae));
fprintf('%f \n', N_p);

%% Secondary Side Turn Ratio


N_s= N_p/((V_Ro)/(15+0.7));
fprintf('%f \n', N_s);
```