HACETTEPE UNIVERSITY

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

ELE613 - SWITCH MODE POWER SUPPLIES

TERM PROJECT REPORT

February 2, 2019

Design and Implementation of a Flyback Converter

1 INTRODUCTION

In this project, flyback converter with two output is designed and reported. Specifications of design are determined by the instructor. These specifications are given in further chapters in detail. In this report, design process are considered in details.

This report includes description of the system which includes design specifications, design steps, transformer design, component selection and control system. After description of system is given, simulation results are given. These simulation results are obtained by using MATLAB/SIMULINK. Then, hardware implementation is given. This part includes implementation steps and considerations, problems and experimental results.

2 Description of the System

In this part, general knowledge of the design is given.

2.1 Design Specifications

- Input Voltage (V_{in}): 85-265 V_{ac}
- Main Output Voltage(V_o): 24 V
- Auxiliary Output Voltage: 12 V
- Output voltage ripple should be smaller than 100 mV_{pp}
- Main Output Nominal Current(I_o): 2 A
- Overload Current= 2.2 A
- Auxiliary Output Current: 0.3 A
- Line Regulation: ±0.3%
- Load Regulation: ±0.5%
- Transient Response Peak Deviation: 10% of V_o (25% to 100% load step, 220 V_{ac} input)
- Transient response recovery: 200 μs (25% to 100% load step, 220 V_{ac} input)
- Continuous output power: 48 W (main output)
- Auxiliary Output Power: 4 W
- Efficiency at full load: 85%

2.2 Design Steps

2.2.1 Transformer Design

To design the transformer, initially magnetizing inductance value should be determined. Magnetizing inductance can be calculated using 2.1

$$L_{m,max} = \frac{V_{in,min}^2 D_{max}^2 \eta}{2 f P_{out}} \tag{2.1}$$

For our case, minimum input voltage is 85 Vrms, maximum duty cycle is 0.45, switching frequency is 40 kHz, expected efficiency is 90%, and output power is 48 W. Therefore, maximum magnetizing inductance is 686 μH.
Turns ratio of the transformer can be calculated using the equation 2.2, below.

$$\frac{N_s}{N_p} = \frac{V_{out}(1-D_{max})}{V_{in,min} D_{max}} \tag{2.2}$$

As a result of this calculation, primary to secondary turns ratio should be 4.
After a few numbers of core selection iteration, (reluctance and inductance calculation considering the effective magnetic path length of the core, cross sectional area of the core) transformer core is chosen to be ETD39 type.

The transformer design is validated using ANSYS PExprt toolbox, as given in Fig. 2.1.

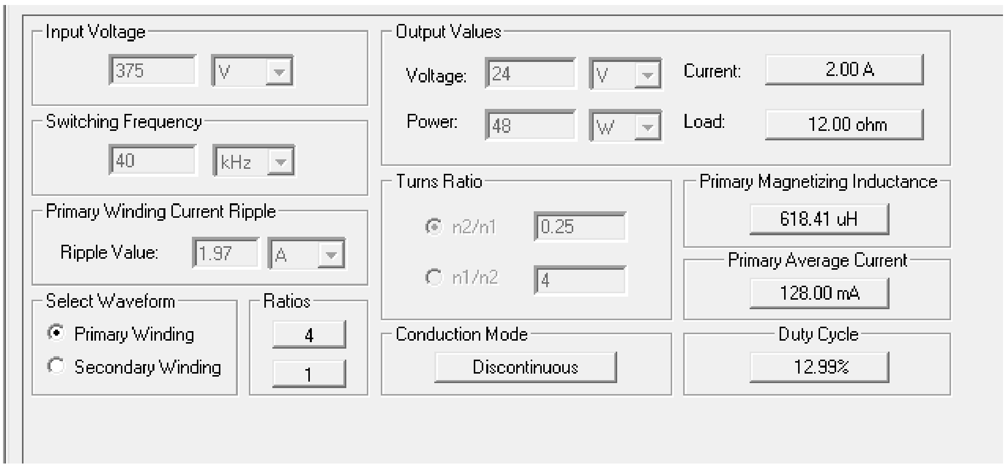

Figure 2.1: PExprt Validation

Also, to decrease the leakage inductance, sectioned transformer windings was planned to implement, following the scheme in Fig. 2.2.

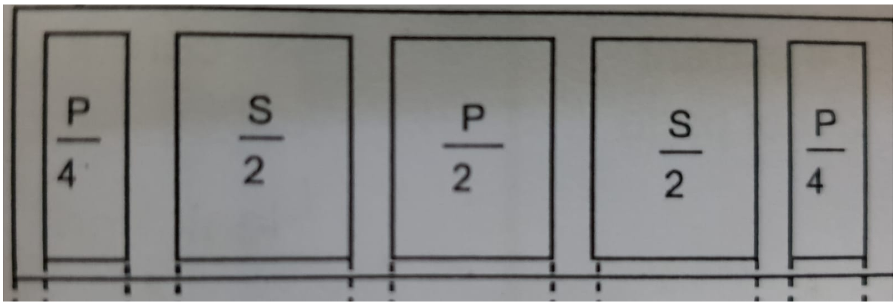

Figure 2.2: Sectioning Plan of the Transformer

Consequently, the specifications of the transformer can be summarized as follows:

- N_p = 56 turns (3 sections, AWG25 cables)
- N_s = 14 turns (2 sections, 2 parallel AWG20 cables)
- L_m = 600 μH (appx.)
- ETD39 ferrite core

2.2.2 Component Selection

In this part, component selection for project is explained. First component is single phase rectifier. This diode bridge voltage rate should be larger than maximum input voltage. Therefore voltage rating of rectifier is chosen as 1000 V and current rating is chosen as 4 A. Other consideration is filter inductor and filter capacitor now. Inductor is chosen radial and its inductance value is 44 μH. Two pieces of this inductor are bought and they are used in series. Thus, 44 microHenry is used in filter inductor. Other consideration is filter capacitor. Its voltage rating is 1000V as well.

When going through the system , transformer and mosfet are faced to. Transformer design and core selection are mentioned previous sections. According to simulation results, current rating of Mosfet is chosen as 9 A and voltage rating is chosen as 900 V. Its drain to source resistance value is 2 Ohms. This resistance value should be smaller as possible as , since it affects conduction loss of Mosfet. If it is higher, conduction loss is higher as well and mosfet is overheated. Due to working principal of flyback converter, drain to source voltage of mosfet includes spikes with large peak value. These spikes should be filtered. For this purpose, snubber circuit is constructed. Snubber circuit includes a diode, a resistance and a capacitor. Resistance value is chosen high in order to decrease loss. It is chosen 68 kilo Ohms.

Capacitance rating voltage is chosen 250 V according to simulation results which is given in further sections. This value is 600 v and current rating is 5 A. Ultre fast diode is used in this project in order to response faster.

On the secondary side of transformer, a diode and a capacitor are encountered. Capacitor voltage rating is equal to main output voltage as well. Thus its voltage rating is chosen as 50V and capacitance value is chosen as 100 micro Farads. Diode voltage rating is chosen according to simulation results which is given in further sections.

2.3 Control System

As indicated in specifications, input to the system is not stable. It varies between 85 V_{ac} and 265 V_{ac}. However output voltage should remain constant which is 12 Volt. For this purpose, output should be controlled.

In this project, this is implemented by using Arduino Uno. As known, Arduino have a lot of pins. Some of these pins can read the voltage. However, maximum voltage that Arduino can read is 5.2 Volt. However, output voltage of the system is 24 V. In order for Arduino to read output voltage, voltage divider is implemented. This voltage divider divides the output twelve. Now, Arduino can read output voltage as 2 V. For this purpose, A5 pin of Arduino is used.

As mentioned above paragraph, Arduino now reads output voltage as 2 V. Thus , reference voltage should be 2 V as well. By arranging reference voltage, the fact that Arduino reads voltage in digital scale not analog scale. It reads voltage between 0 and 1023 digital values. That means that if the voltage is 5.2 V, Arduino reads 1023 and when tho voltage is 0, it reads 0. Thus, reference voltage should be scaled. In order to arrange reference voltage as 2 V, it should be applied 393 (scaled value).

At this point, output value is taken and reference voltage is obtained.Then controller should be implemented. For this purpose, PID library of Arduino is used. In order to obtain controller, PID function is used in this library. This function needs 6 inputs and one connection input. First input is the value which is controlled. In this project, it is scaled output voltage. Second one is output of controller that means what output gives as an output. In this case, it is duty cycle of PWM which is applied to mosfet's gate. Third one is the reference value which is reference voltage in this case. Other values are K_p, K_i and K_d values respectively. Direction input is either DIRECT or REVERSE. This determines the direction of output value.Other function which is used is SetMode. This function runs the PID function. Other function is Compute(), which takes the output value of PID function. Last function is SetOutputLimits. This function arrange maximum and minimum value of Arduino output. This is important since this function prevent from high duty cycle. In this project, minimum value of duty cycle is 0.05 and maximum value of duty cycle is approximately 0.2 to prevent from continuous conduction mode.

Controller is implemented and duty cycle is generated.Now, this duty cycle should be obtained as an output of Arduino. For this purpose, analogWrite function is used. This function applied any PWM output of Arduino Uno. Pwm pins of Arduino Uno is 3,5,6,9,10 and 11. In this project , 10 is used. On the other hand, duty cycle is scaled between 0 and 255 (8 bits). This means that when 0.5 duty cycle is applied, 0.5*255 should be applied to the output in this scale. As can be remember, SetOutputLimits function is mentioned and it is said that it determines limits which 0.05 and 0.2 in this project. These values are actually 0.05*255 and 0.2*255.

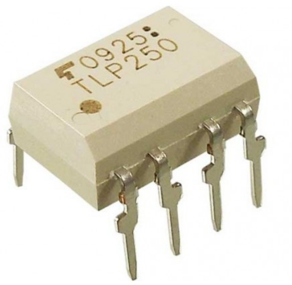

Figure 2.3: TLP250 view

Another issue is to apply generated PWM to mosfet's gate. For this purpose opto driver is utilized which can be seen figure 2.3. This device achieved isolation between supply and load. It includes infrared diode and photo transistor. It communicate with the help of light. In order to use this device, its circuit should be implemented. This circuit can be seen in Fig 2.4. In this project R1 is chosen 1 kilo ohms to prevent hing current from Arduino. R2 is chosen 10 ohms and C1 is chosen 470 μF. Arduino's PWM output is applied to 2 and its ground is applied to 3. The output PWM is taken between 5 and 6 pins. 5 is connected converter's ground as well.

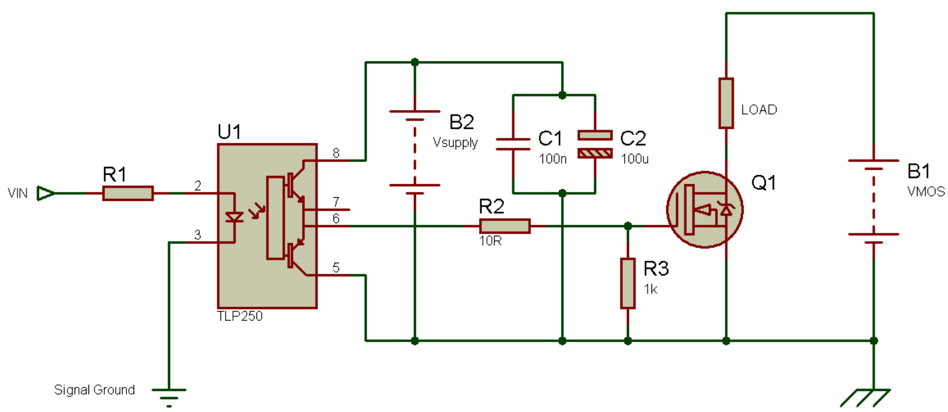

Figure 2.4: TLP250 circuit diagram

3 Simulation Results

Analytically designed circuit is modeled in Matlab/Simulink. Simulation model is provided in Fig. 3.1.

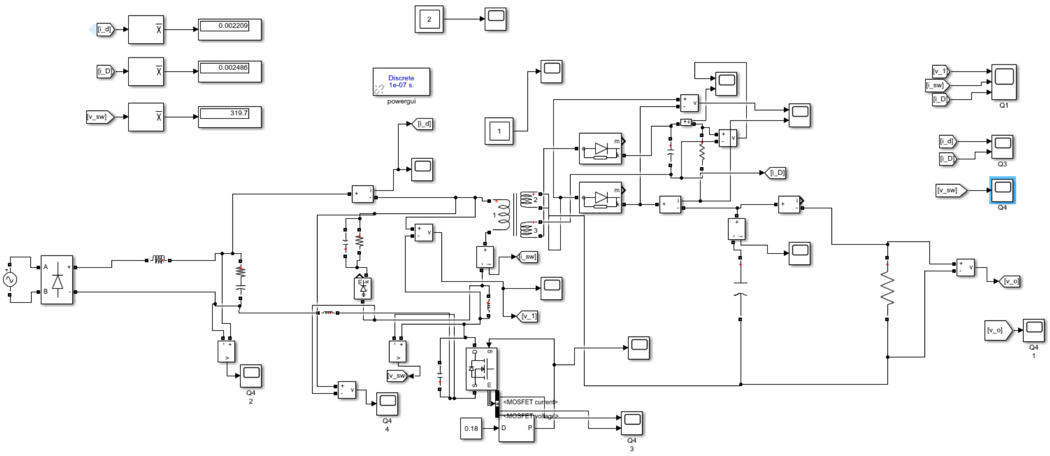

Figure 3.1: Simulation Model

While modeling the components, non-ideal effects such as internal resistance and capacitances, a moderate value of stray inductance in ground path have also been considered. Foreseeing such non-ideal effects is quite important for implementation process, since the devices must have chosen wisely, with safety margins. Voltage and current values of devices, output voltage and current, primary side voltage and current are shown on Figures 3.2-3.5 below. Please note that this simulation is made under rated conditions (V_{ac} = 220 V_{rms} and output load is 12Ω).

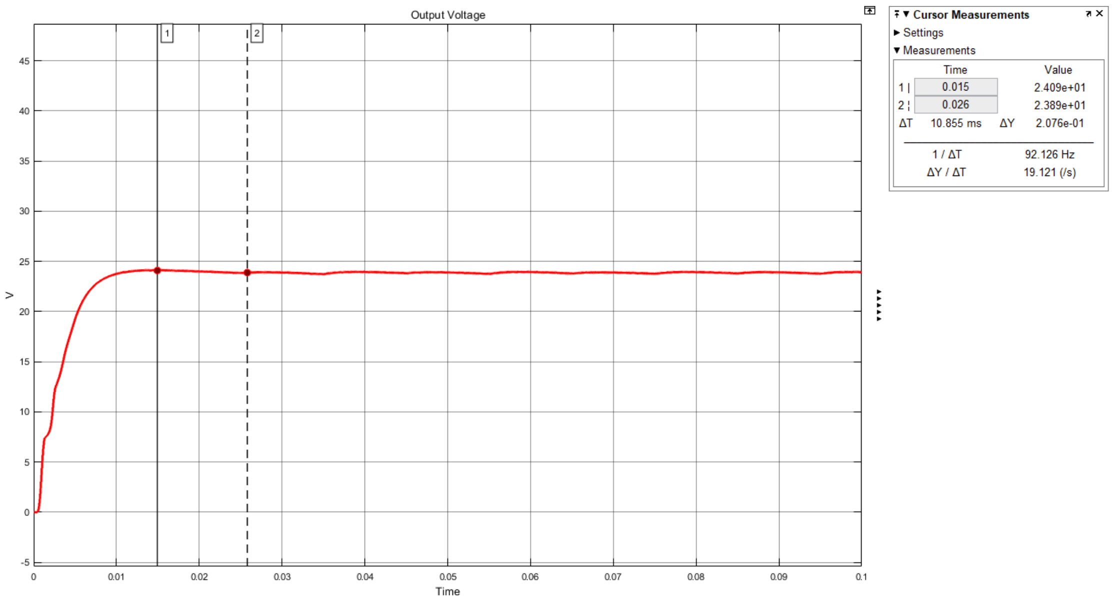

Figure 3.2: Output Voltage

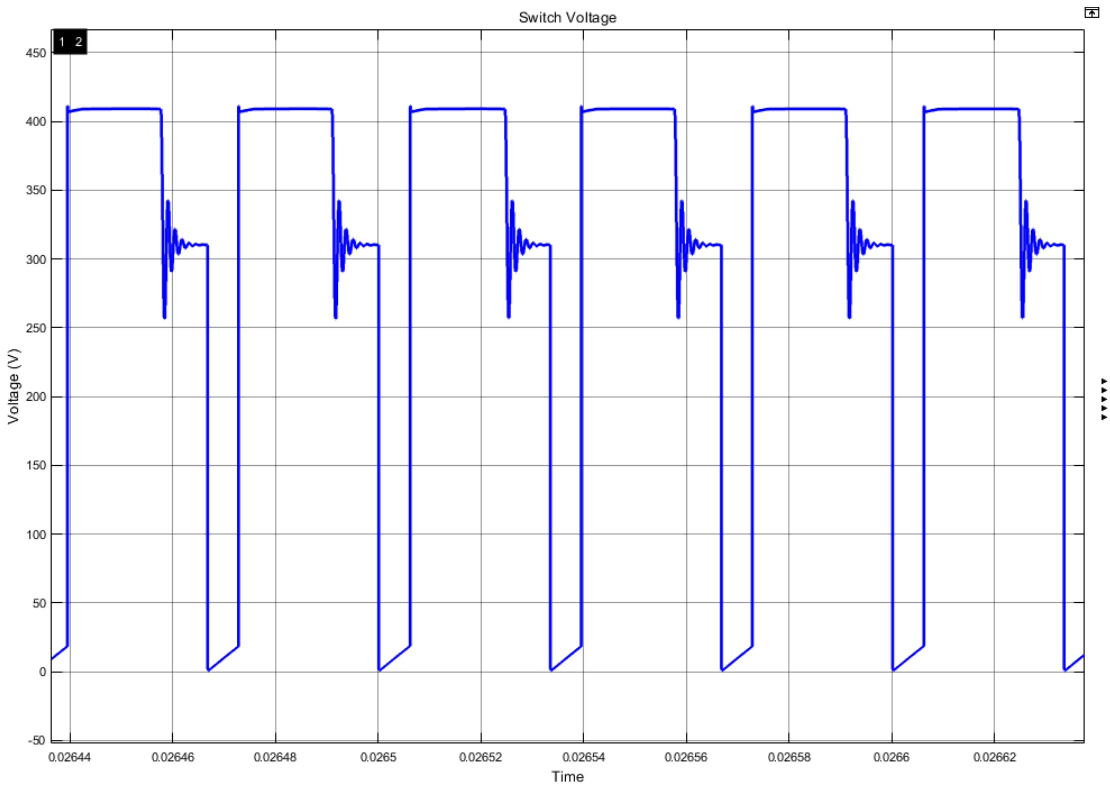

Figure 3.3: Switch Voltage

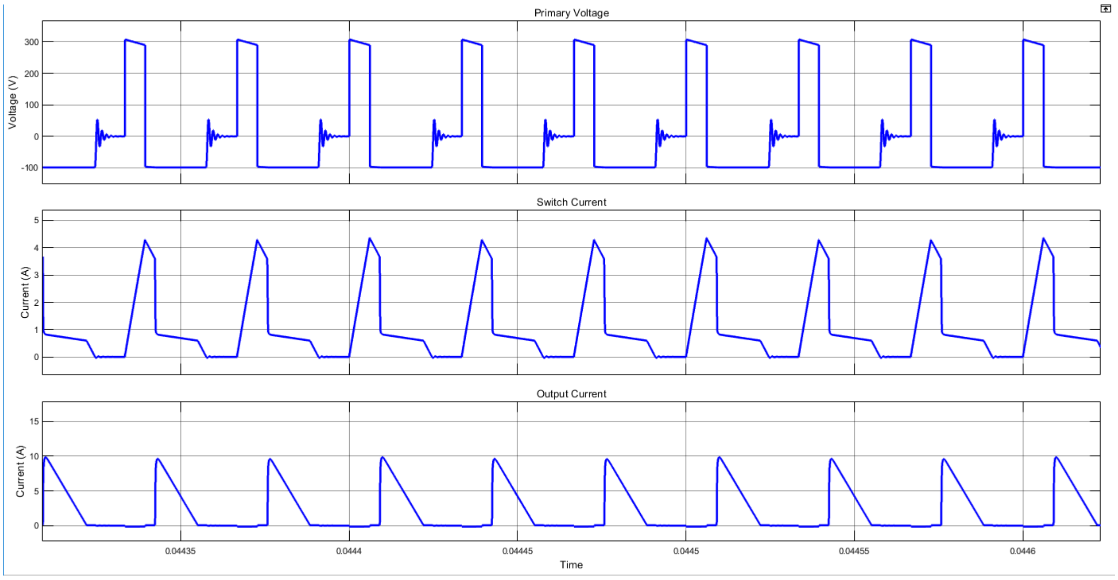

Figure 3.4: Switch and Output Currents, Primary Side Voltage

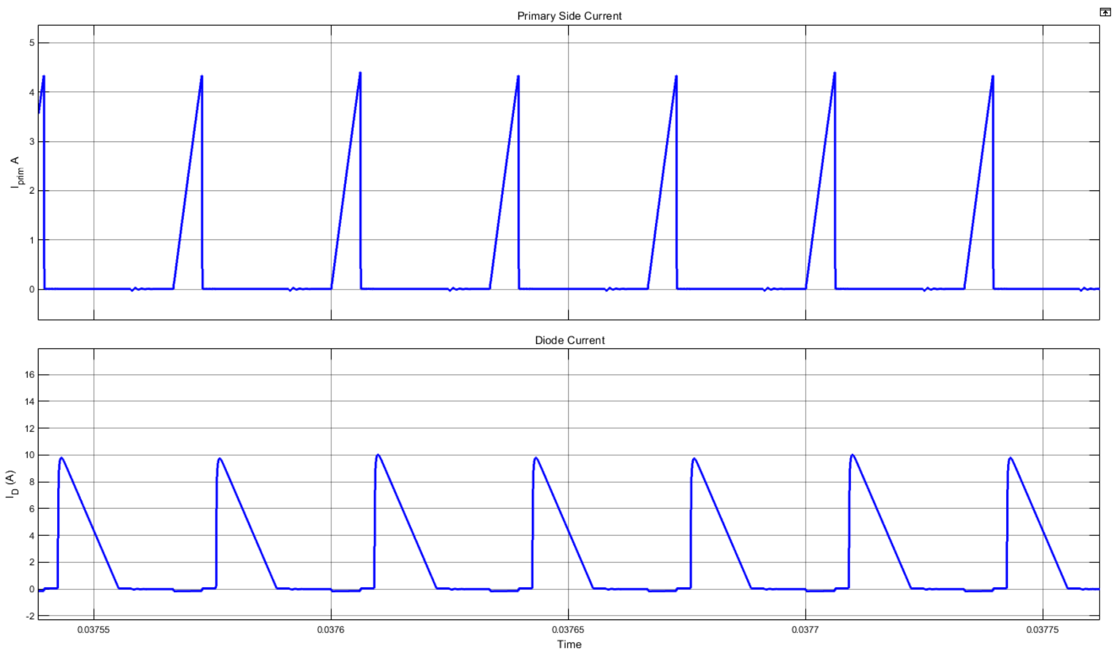

Figure 3.5: Primary Side and Diode Currents

4 Hardware Implementation

4.1 Implementation Steps and Considerations

In this part, implementations steps and considerations are considered. As known, most important thing is implementation steps. Even in the presence of the smallest error, all system can be damaged. Thus, implementation requires lots of attention.

Process starts with implementation of rectifier. As known input of rectifiers is AC voltage and output is rectified DC voltage. While its implementation, most important thing is orientation of pins. These orientation should be checked by inspiring data sheet of rectifier. As mentioned previous parts, single phase rectifier is used in this project. Another thing is filter implementation. The output of single phase rectifier have more harmonics. These harmonics should be filtered. In order to filter output of rectifier, LC filter is used. The most important thing in this step is polarity again since electrolytic capacitor has polarity.

New consideration is now transformer implementation. Design of transformation and considerations about design process is given previous parts. Thus it is not mentioned further. Transformer has three windings in this project. One is for primary, one is for main output voltage and other one is for auxiliary output voltage. The most important point is not to confuse about which winding is for which voltage. It means that windings should not be confused. Other thing is insulation of transformer windings.Any corruption of these cables causes short circuit. Short circuit causes several errors in the system. One of these is number of turn changes. Changing of turn numbers affects output voltage. Moreover, it changes the current drawing from source. It means that primary side current is affected as well. Thus, insulation of cables should be inspired carefully. Other consideration is air-gap. While transformer is implemented, air-gap of E-core is not affected. It should remain constant.

After transformer is implemented, mosfet is implemented. The most important thing is again pins of mosfet. These pins should be inspired. Any mistake can cause damage of all system. Other consideration is thermal design of mosfet. Its switching losses and conducting losses can cause increase of mosfet's temperature. This increase can cause damage of mosfet. Thus, thermal design should be done well. For this purpose, loss should be calculated and suitable heat sink should be chosen. While heat sink and mosfet are combined, thermal paste should be used. It provides fully interaction of mosfet and heat sink. The important point is that source is connected to ground. This should be reminded. After mosfet implementation, gate driver implementation should be considered. Optocoupler has 8 legs and some of them are not connected to anywhere. Most important thing is to avoid short circuit in this case, since legs of optocoupler is so close. Implementation should be done carefully. Other thing is whether optocoupler circuit works or not. It should be tried independent of over all system. The most important thing is that grounds of optocoupler should be district. It means that ground of Arduino and over all system should be district. This provides isolation.

In this part, snubber implementation is considered. Due to working principal of flyback converter, mosfet voltage drop includes spikes. These spikes should be prevented from. For this purpose, snubber circuit is implemented parallel to the transformer. It includes resistance, capacitance and diode. Only thing should be considered in this case is polarity of diode. Other things is straight forward.

At this point, primary side is completed. Now, secondary side is implemented. Secondary side includes one diode, one capacitor and load. Actually, this implementation step is straight forward as well. Other thing in secondary side is voltage divider. This is parallel to the load. It divides the output voltage twelve in order for Arduino to able to read it. It includes three resistance whose values are 1k,1k and 10k respectively. These resistances are connected in series. Reference voltage is taken from the resistance which is in the middle due to ground consideration.

4.2 Problems

In this part, problems which are faced during the implementation and test process are considered. Moreover, solution of these problems are considered.

First problem is faced while first measurement is done. After implementation of single phase rectifier is completed, its output is tried to viewed. For this purpose, oscilloscope is used. However, it is not isolated. Thus, it draws high current values even if low voltage is applied to the rectifier. This problem is solved by using isolated oscilloscope.

Other problem occured by checking controller. Controller can not arrange output value due to mistake in code. The mistake is that reference voltage is analog value while read voltage value is digital. Thus, controller can not arrange output value of system.

Another problem is about transformation and this problem can not be solved fully. Transformer is saturated while system is working. This situation causes overheating of transformer. At full load, it is a problem. To solve it , two solution is applied. first one is to increase air-gap. By increasing air-gap, energy capability of transformer is increase. However, magnetized inductance decreases and this causes increase of primary side current. Other solution is to use fan. It partially decreases temperature of transformer.

4.3 Experimental Results

In this part, simulation results are given for three distinct input value which are 97 V, 122 V and 152 V. For these values, supply voltage, output waveform and multimeter value, gate to source voltage and drain to source voltage waveforms are given

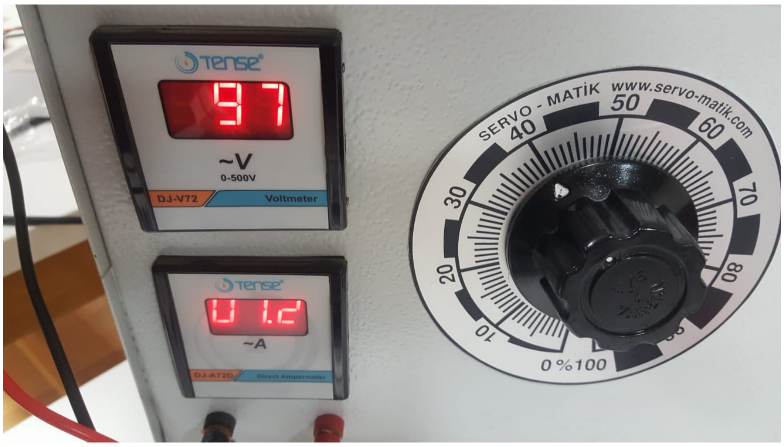

Figure 4.1: Supply voltage view for 97 V input

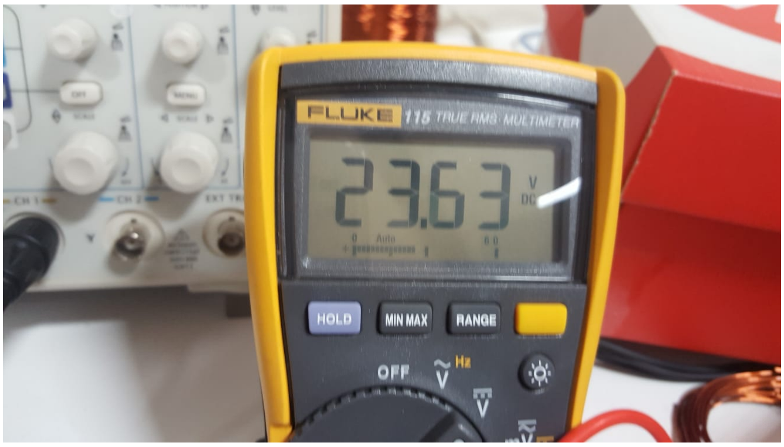

Figure 4.2: Output voltage view for 97 V input

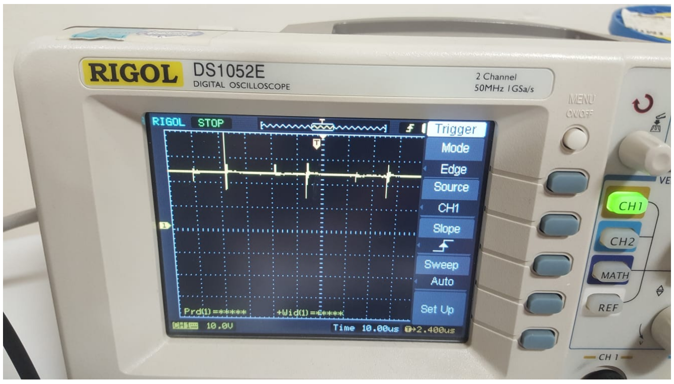

Figure 4.3: Output voltage waveform for 97 V input

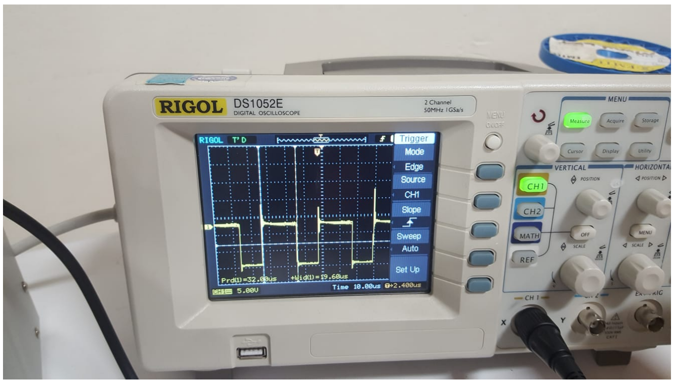

Figure 4.4: Gate signal for 97 V input

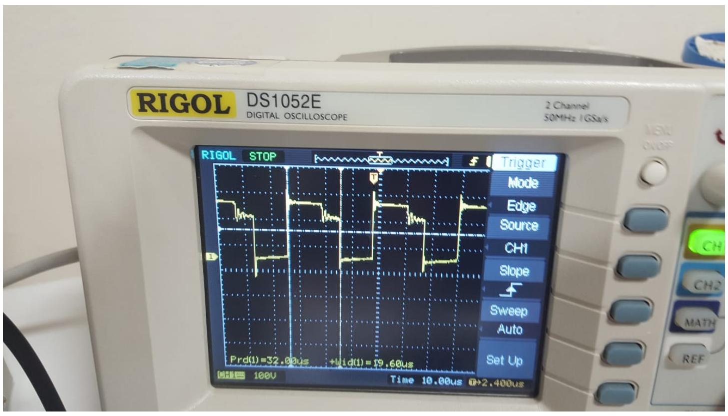

Figure 4.5: Drain to source voltage waveform for 97 V input

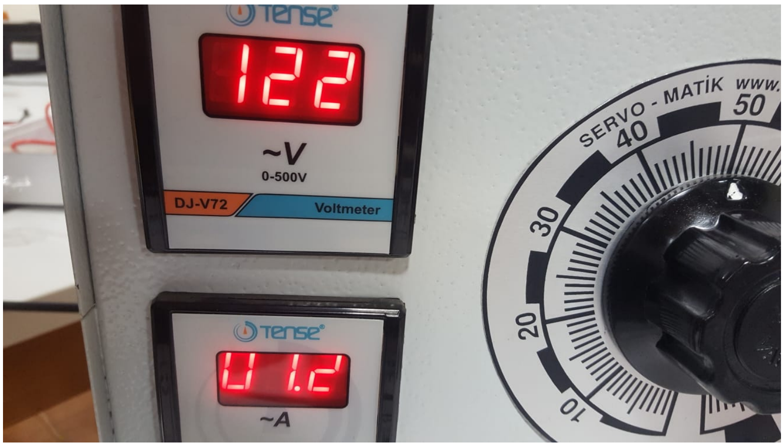

Figure 4.6: Supply voltage view for 122 V input

Figure 4.7: Output voltage view for 122 V input

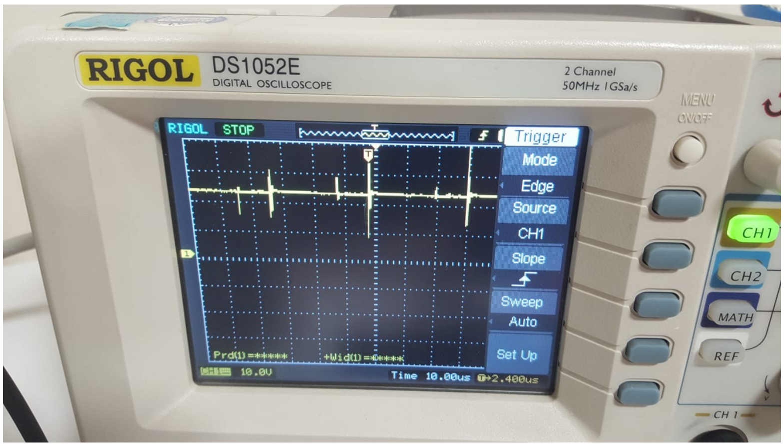

Figure 4.8: Output voltage waveform for 122 V input

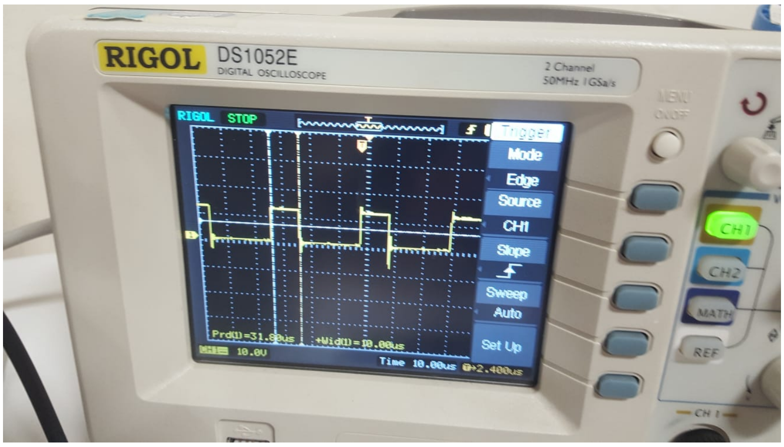

Figure 4.9: Gate signal for 122 V input

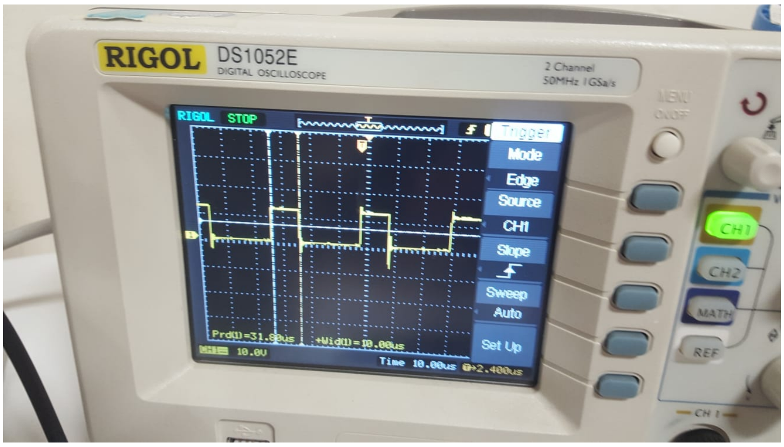

Figure 4.10: Drain to source voltage waveform for 122 V input

Figure 4.11: Supply voltage view for 152 V input

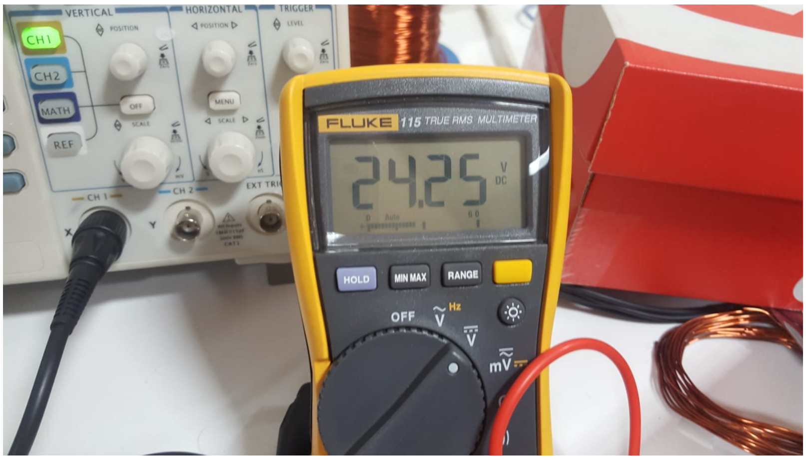

Figure 4.12: Output voltage view for 152 V input

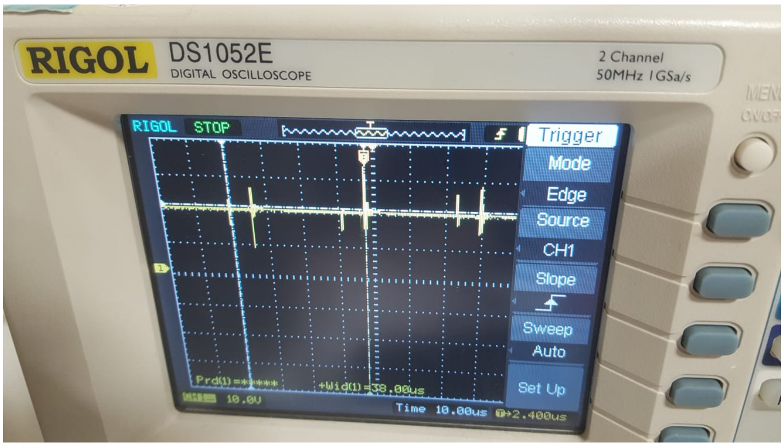

Figure 4.13: Output voltage waveform for 152 V input

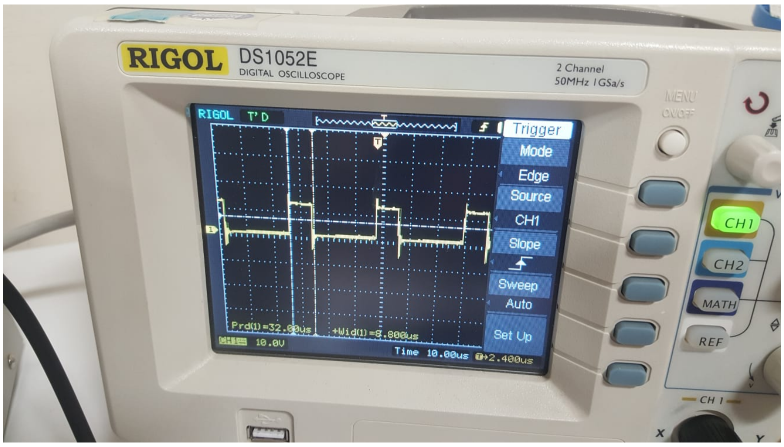

Figure 4.14: Gate signal for 152 V input

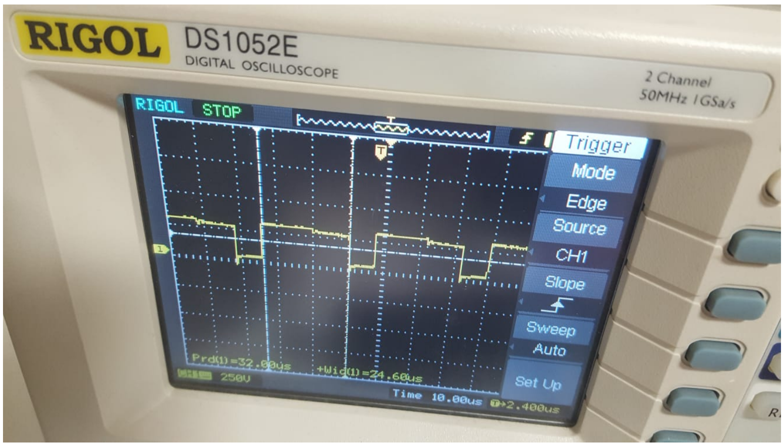

Figure 4.15: Drain to source voltage waveform for 152 V input

5 CONCLUSION

In this project, flyback converter with two output is designed. For this purpose, given specifications are tried to maintain. While it is doing, the first thing which is done is to make research on flyback converters. Its working principal is examined well. Relevant formulas are derived and relevant parameters are calculated as well. After it is done, work is carried to simulation area. For this purpose, MATLAB/SIMULINK is used. By using calculated parameters and knowledge about flyback converter, simulations are completed. According to simulation results, components are selected. After component selection is done, implementation of system starts. (Detailed knowledge about implementation process is given in previous sections). Then, experimental works are done and results are observed. According to these results, errors are determined and these errors are tried to resolved.
While this project is done, knowledge from lectures and knowledge which is reached after some research are combined and used. This project contributes to theoretical and experimental experience.