Middle East Technical University

EE464 Power Electronics

"Turning Coffee into Electricity"

Hardware Final Report

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Ozan KEYSAN

Contents

1 Introduction **2**

2 PART I **2**

2.1 Converter Simulation 2

2.1.1 Open Loop Steady State Operation of the Converter 2

2.1.2 Closed Loop Steady State Operation of the Converter 5

2.2 Design Features and Magnetic Design 6

2.3 Component Selection 8

2.3.1 MOSFET Selection 8

2.3.2 Single Phase Full Bridge Diode Rectifier 8

2.3.3 Snubber and Output Diode Selection 9

2.3.4 Capacitor Selection 9

2.3.5 Gate Driver 9

2.3.6 Feedback Unit 9

2.3.7 Controller Unit 9

3 PART II **10**

3.1 Implementation and Considerations 10

3.2 Design Package 10

3.3 Problems Encountered and Proposed Solutions 11

3.4 Experimental Results 12

3.4.1 Requested 9V Output Voltage 12

3.4.2 Controller Response to a Change in the Reference Voltage 13

3.4.3 Efficiency 14

3.4.4 Transient Ripple in MOSFET and Output, Input Current Harmonics 14

3.4.5 Heating 15

4 CONCLUSION **16**

References **16**

1 Introduction

As Fiero Converters, we manufacture 230 V AC to 9 V DC, 10 W Flyback Converter with voltage feedback control using a Arduino Nano microcontroller. This documents shows the final product's manufacturing process with design considerations, packaging and experimental results in addition to simulations after the small changes in the design. The final product is shown in figure .

2 PART I

2.1 Converter Simulation

The design of the open loop converter is given in figure 1. There is snubber in order to reduce the current and voltage stress the MOSFET endures during operation. The resultant effect of the snubber is clearly observed in the simulations as well. The simulations were done synchronously with the implementation and hence the design parameters for the switch, diode and the transformer are taken from the implemented products.

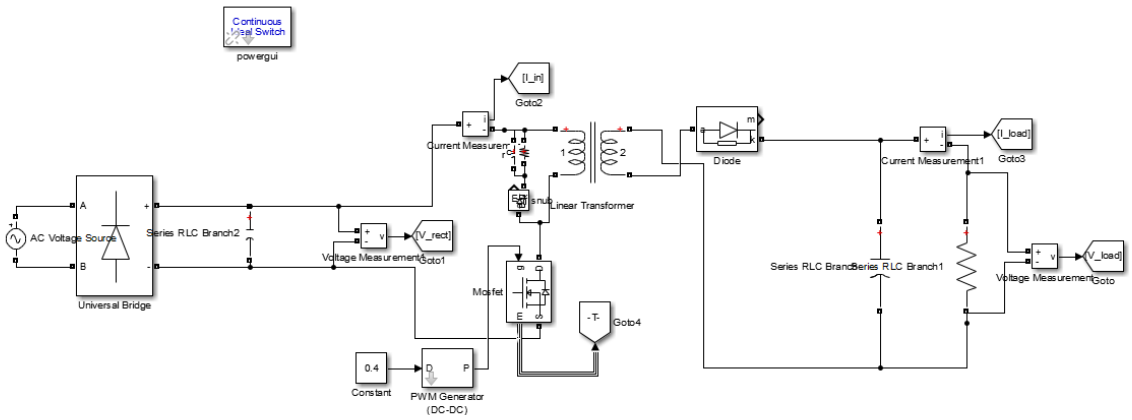

Figure 1: Flyback Design

2.1.1 Open Loop Steady State Operation of the Converter

The figures 2, 3, 4, 5 show the simulation waveforms and the resultant voltage, current and power outputs for the calculated values of maximum duty cycle, turns ratio, reasonable capacitor values and resistance for the ideal case.

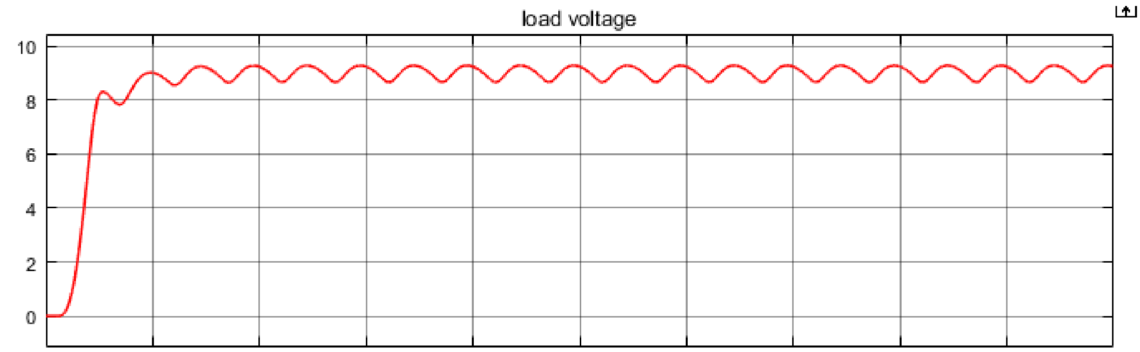

Figure 2: Load Steady State Voltage

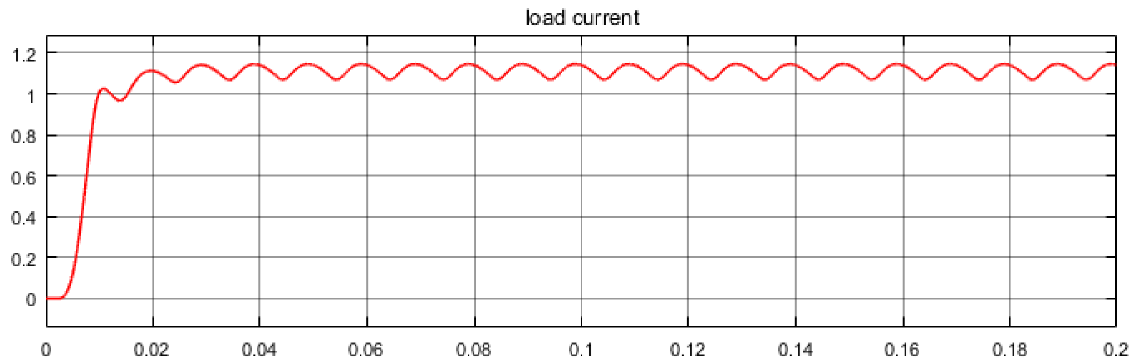

Figure 3: Load Steady State Current

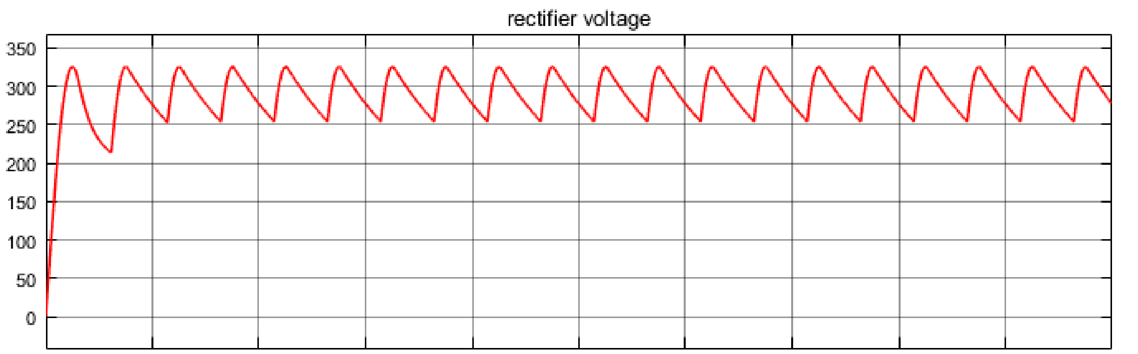

Figure 4: Rectifier Output Voltage at Steady State

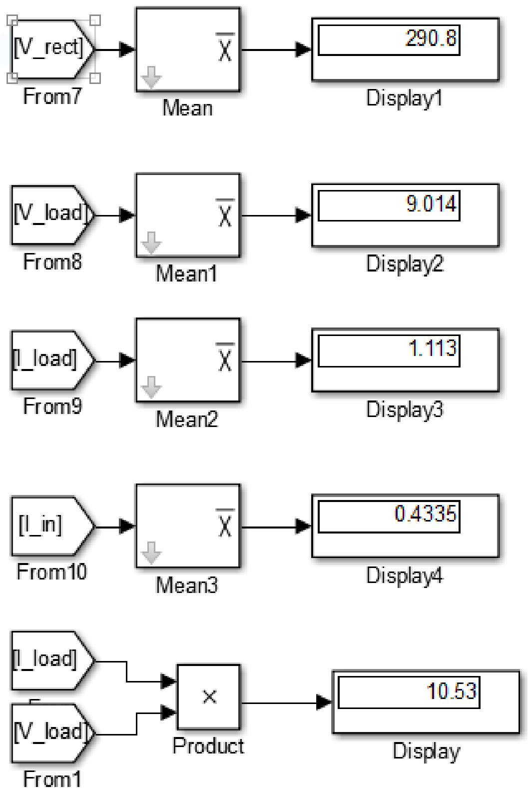

Figure 5: All voltage current display values

Moreover, we have also checked that the switch voltage and current remains in the tolarable range. As expected, the voltage across the switch will be twice the input voltage when it turns off. This can be seen in figure 6.

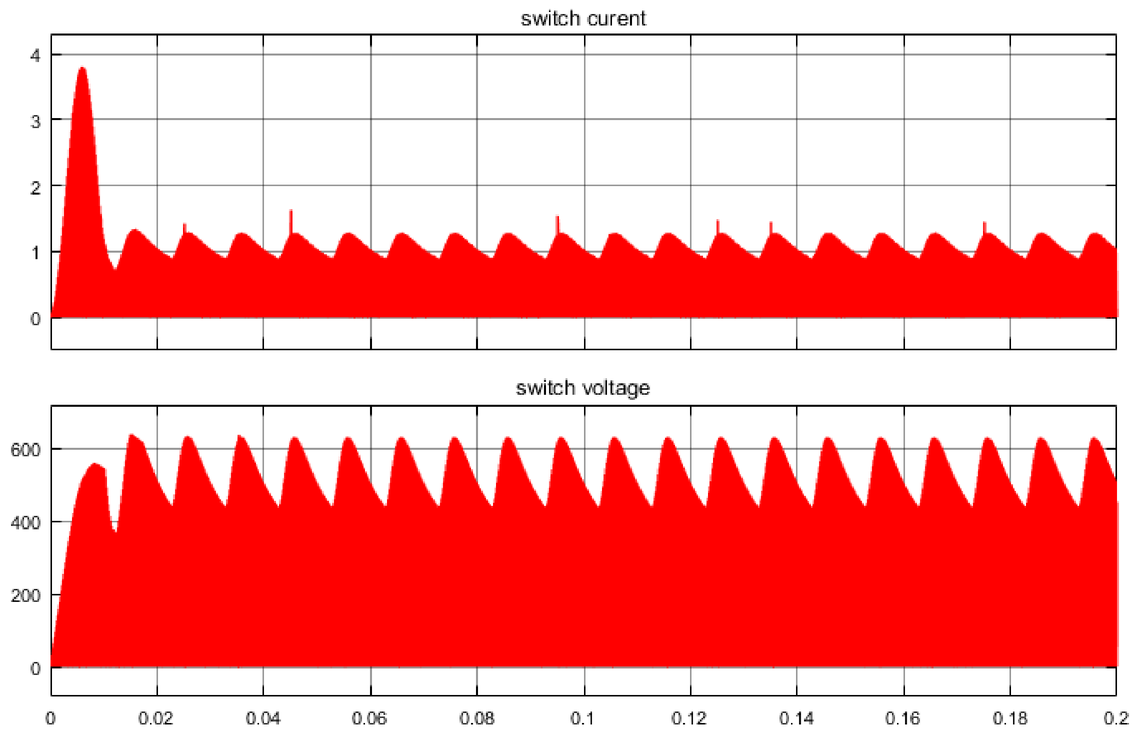

Figure 6: Current and voltage of the MOSFET during operation

2.1.2 Closed Loop Steady State Operation of the Converter

After obtaining properly working open loop converter design, voltage feedback control using Arduino was simulated.The closed loop control works fine and the system settles at the very desired point. The results are shown in 7 and 8.

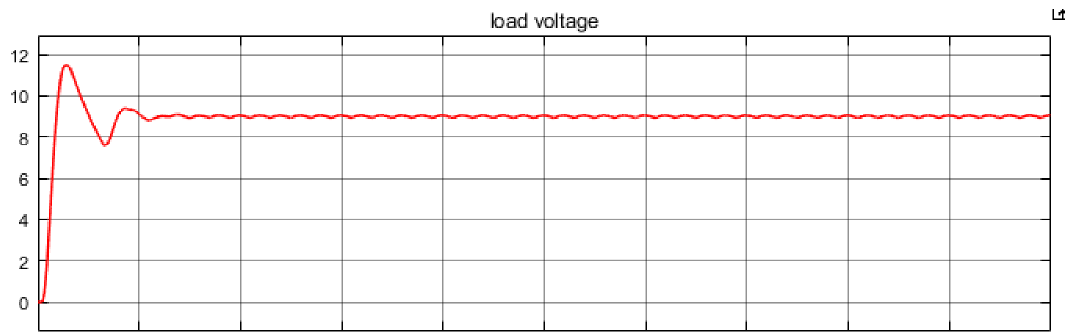

Figure 7: Controller output voltage

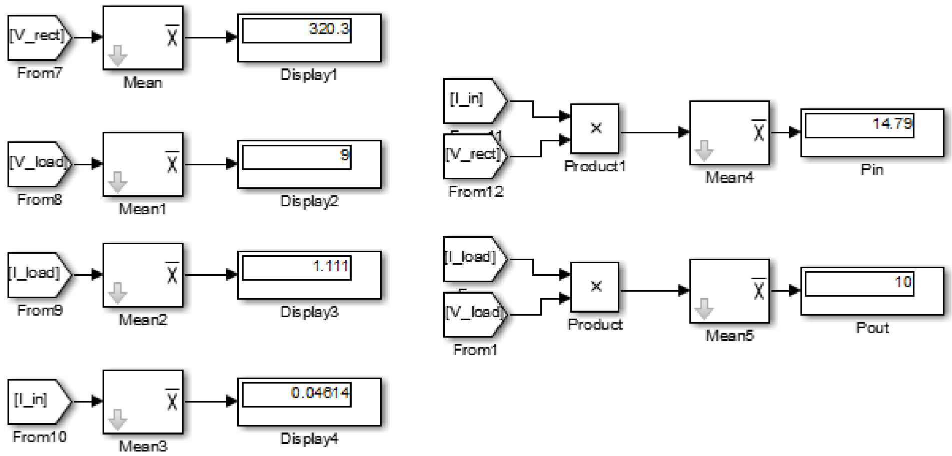

Figure 8: Controller output values

2.2 Design Features and Magnetic Design

[3],[2],[5] In this part of the report we will discuss our theoretical design and our actual design in the aspect of actual design data and magnetic core design. In the second project report we found the following values in Table 1 .

Table 1: Theoretical Design Values

Inpur Voltage	230V AC	Switching Frequency	62.5 kHz
Desired Output Voltage	9V	Maximum Duty Cycle	0.4
DC-link Voltage (mean)	300-330 V	Primary Turns	228 turns
DC-link Voltage ripple	%5	Secondary Turns	12 turns
Max Switch Voltage	900 V	Max output current	1.1A
Max Switch Current	500mA	Magnetizing Inductance	70 mH
Snubber resistance	30kohm	Snubber Capacitance	1nF

These designs calculations are made for a ETD39 Ferrite core.

As also mentioned in the second report we obtain a 9V output for a max duty cycle of 0.4. Therefore during practical design process we agreed to implement a flyback converter which can give a maximum of 15 V output for a maximum 0.35 duty cycle for further safety and flexibility.

We started our design by making a transformer for the DC-DC converter.

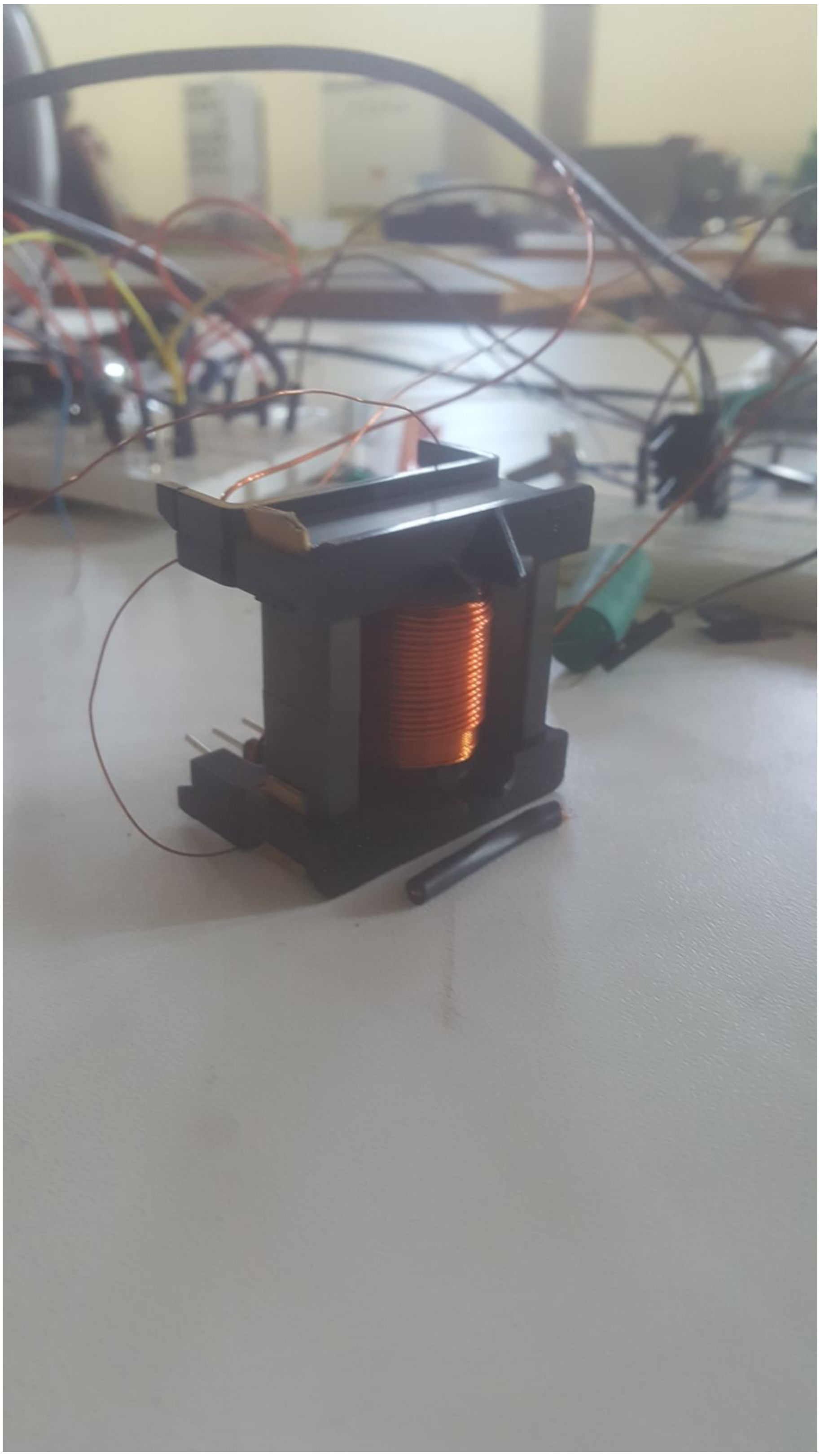

Figure 9: Transformer

The transformer in Figure 9 has 228 turns on the primary side and 19 turns on the secondary side to obtain a maximum of 15V output for a max duty cycle of 0.35 . The

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Table 2: Rated Voltage, Current and Reverse Recovery Time of K1120 MOSFET

Rated Voltage	1000V
Rated Current	8A
Reverse Recovery Time	100ns

core of the transformer is ETD39 ferrite core. In addition to our open loop system, we added a non-isolated closed loop to control the output voltage for wide range of input DC voltage.

After implementing the core the magnetising inductance was measured 91 mH and the leakage inductance as 10uH with the help of L-C meter.

2.3 Component Selection

In this section the component selection procedure will be explained. The components are selected according with both availability and rated values.

2.3.1 MOSFET Selection

In the second report the maximum switch voltage was calculated as 900 V including the safety margin. Also the maximum switch current was simulated and calculated as 500mA. While the rated values were important the response to high frequencies was also essential for proper component selection. With all of these considerations taken into account the switching semiconductor was selected as K1120 ultra-fast MOSFET. Some of the important specs. taken from the datasheet is in Table 2.

Since our switching frequency is 62500kHz its 1 period is 16000ns. Therefore we can say that this MOSFET can be choosen for proper operation.

2.3.2 Single Phase Full Bridge Diode Rectifier

As indicated in Table 1 our input is single phase 230V AC while our output DC-link voltage varies between 300 and 330 V. Also the maximum current drawn from the AC-supply is the same with the MOSFET which is 500mA. Hence a full bridge single phase diode rectifier was chosen. VS-2KBP06 was chosen as the unit (600V-2A) however due to availability KBP210G was chosen as the rectification unit.(1kV-2A).

2.3.3 Snubber and Output Diode Selection

During the implementation process we once had a problem with burning snubber diode. A burnt out snubber diode resulted in reverse charging of the capacitor and also shorted the MOSFET. Hence we picked a diode which has a high current capability and high speed. So we chose STTH3R04RL which has 3A rated, 400V rated and 35 ns reverse recovery time.
As for the output diode we choose BYW29 which has a high current capability of 4A, a voltage rating of 200V and 20ns reverse recovery time.

2.3.4 Capacitor Selection

In the whole design we used in total of 4 capacitors.

- 100uF 400 V DC-link capacitor is used to rectify the AC source (Aliminum Electrolitic Capacitor).
- 0.1nF 600V capacitor is used as the snubber diode (Polyester capacitor).
- 10 uF capacitor is used in the TLP250 gate driver circuit.
- 3800uF 50V capacitor is used in the output.

2.3.5 Gate Driver

As for the gate driver we used TLP250 optocoupler gate driver in order to isolate the Arduino-Nano from the actual circuit.

2.3.6 Feedback Unit

In order to have a closed loop control we tried but failed to implement an voltage sensing with isolation. So we used 150kohm and 300 kohm resistors in order to bring the feedback voltage level between 0-5V range. Then LF355N operational amplifier is used as a buffer for further protection.

2.3.7 Controller Unit

In order to process the feedback voltage and obtain a varying duty cycle which has a frequency of 62.5 kHz we used Arduino Nano.

3 PART II

3.1 Implementation and Considerations

3.2 Design Package

Our package contains a box for coverage and the design is fully compact with a single piece on a Printed Circuit Board (PCB). Throughout the project, we have implemented the circuit on bread board to begin with. Seeing a high ripple content at the output we have decided to pass to the next stage where we need a more compact design with shorter component legs, smaller high frequency AC loops and leakage eliminating (snubber) circuit parts.This way we aimed to reduce the transient ripple at the MOSFET and output so that we can reduce the stress on our transistor and get a smooth output DC waveform as well.

The PCB is drawn in Proteus as seen in figure 11. We have successfully printed and soldered the circuit ourselves.

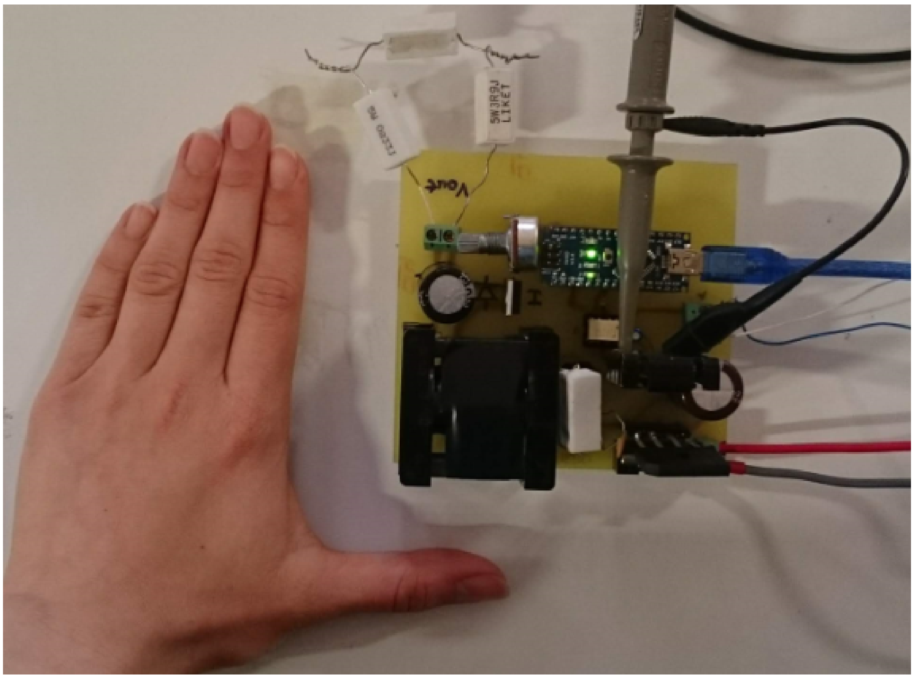

Figure 10: First PCB

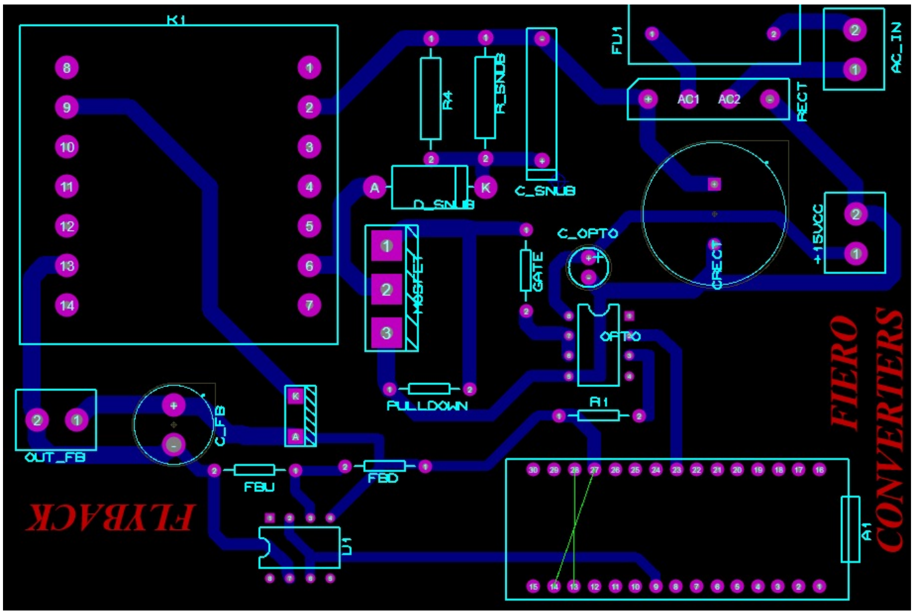

Figure 11: Last PCB schematic

Figure 12: Last PCB

3.3 Problems Encountered and Proposed Solutions

During the implementation we have come across a number of problems which include:

1. Ripple at the output of load side and at the MOSFET Drain-Source Voltage Waveform in figure 13.

This problem was tried to be eliminated with better PCB design with shortened legs of components, better snubber design [4], addition of an LC filter at the output [4] and a new transformer with a smaller core and using a faster diode with no reverse recovery (schottky). Yet, none of these could diminish the transient ripple occuring simultaneouly with MOSFET turn-offs. Hence, considering the order of the ripplefrequency (6-32 MHz) and the order matching/similarity of the frequency that the output capacitance of MOSFET (some μF) and the leakage inductance (generally some nH) introduce, we have concluded that this ripple is either due to measurement devices or the MOSFET.

2. The microcontroller requires a stable current voltage source. We encountered the problem of optocoupler voltage drop dramatically anddrawing high current for high-input voltages. Moreover, the computer slowed down.
   We used a 5V-2A power bank to power Arduino.

3.4 Experimental Results

3.4.1 Requested 9V Output Voltage

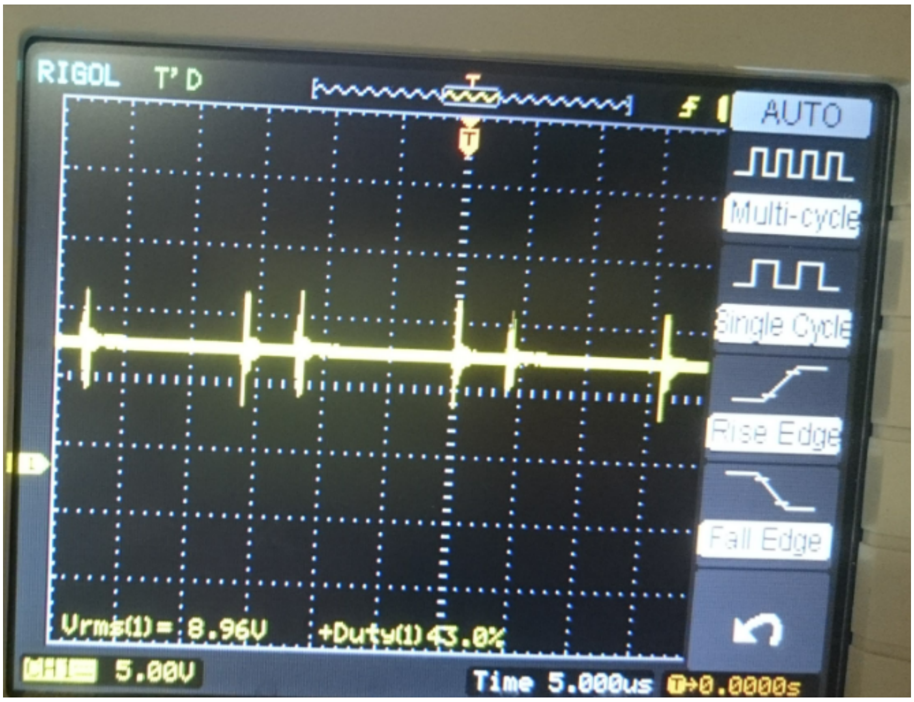

Figure 13: 9 V set output result

3.4.2 Controller Response to a Change in the Reference Voltage

For controlling the output voltage, our first trial was with a current mode controller LT3845. After some trials and not being quite an expert on this controller, we decided to move on and complete the rest of the design with a microcontroller so that after some progress on the project, we could revise the design and consider implementing current mode controller for output voltage control.

We used Arduino Nano [1] for our controller. The major drawback in using Arduino is the frequency restriction and dependency on code generating and power consumption of the microcontroller. Nonetheless, we used one of the digitalpins of Arduino and configured it to the topmost frequency that Arduino can provide, which is approximately 62.5 kHz.

We have generated our code to prevent the duty cycle go above 0.5. We sensed the voltage at the output. Since Arduino can analog read voltages between 0-5V range, we divided the voltage with large valued resistors and put this voltage point into the buffer. The buffer circuit was fed from the output as well. The buffer was used as a means of isolation before the microcontroller. The output value then, was kept within the reference range with a simple control. The control was kept simple in order to see the accuracy, efficiency and pace of this control method. In the case of an unsatisfactory result, we would increase the order of the controller. Another major reason of not using a more complicated control mechanism was the dependency of arranging the parameter values only by trial and error in which we could not dare to endanger the pcb or some components to blow/burn out.

The simplicity of the control mechanism lies in arranging the duty cycle such that if the reference value exceeds the real scaled output value, the duty cycle is decreased by some amount and vice verse. The speed and the addition of some miliseconds delay creates a hysteresis band for the control and this decreases the effort for fine tuning the reference constant we use for real voltage to Arduino scaled voltage etc.

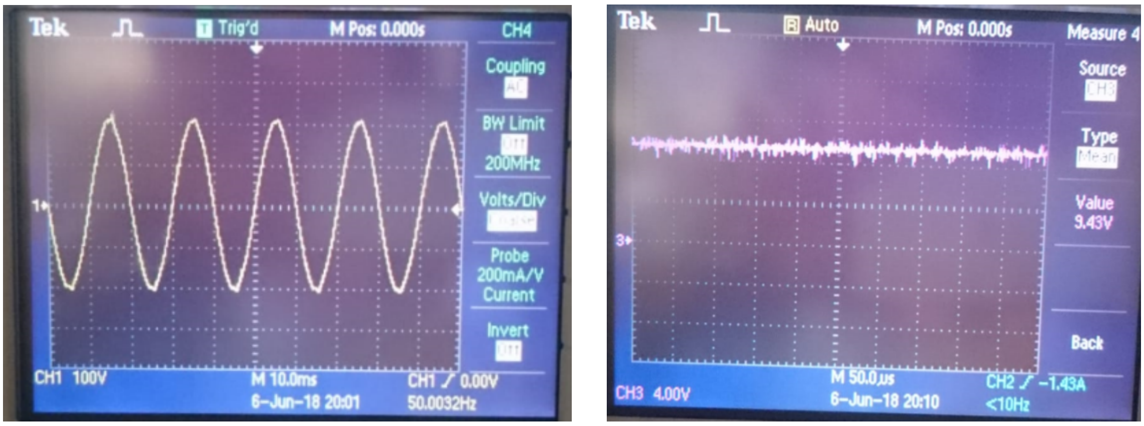

Figure 14: Input single phase AC to 9V DC voltage flyback operation

3.4.3 Efficiency

3.4.4 Transient Ripple in MOSFET and Output, Input Current Harmonics

The ripple seen in figure13 has 6 MHz to 32 MHz high frequency component as stated in 3.3. The ripple is equivalent to that seen in MOSFET switching moments.

When we examine the AC input side current in figure 15, 3rd order harmonic content is highly observed. In order to eliminate this 3rd order harmonics, we need to make the 3phase input side inductive such that the current is smoothed. Line boost inductors should be added in order to eliminate 3rd order harmonics.THD acquisition was intervened due to some unknown reason, we could not achieve to see the THD graph on oscilloscope screen and the current was lost. Yet, we expected a high 3rd order component. Considering the rectified output as nearly pure DC, since we had selected the capacitor value such that the voltage waveform follows the peak of the rectified wave with a small peak to peak ripple and we operate in continuous conduction mode, the rectified current waveform would be an undulant rising and falling periodically wave as long as the input wave magnitude exceeds the nearly constant output wave. Since output wave is following the peak and has a high average value, the time the current can flow is limited and the amount of current to flow then should be large in order to conserve the power. That is why we see large peaks at the input for small times. We know that the odd harmonics have 1/n decreasing amplitudes. Therefore, we expected to see high order 3rd and following that 5th harmonics at the output 16.

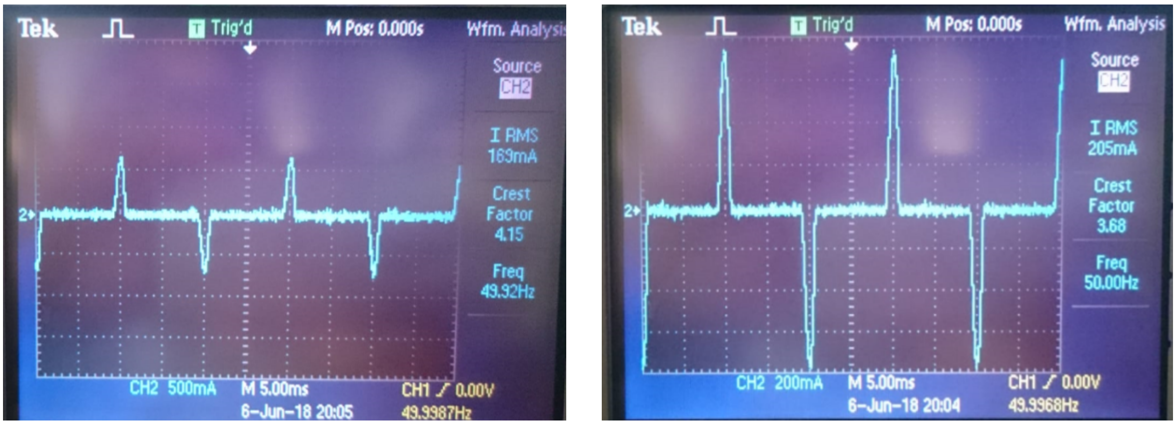

Figure 15: Input Current Harmonic Distortion

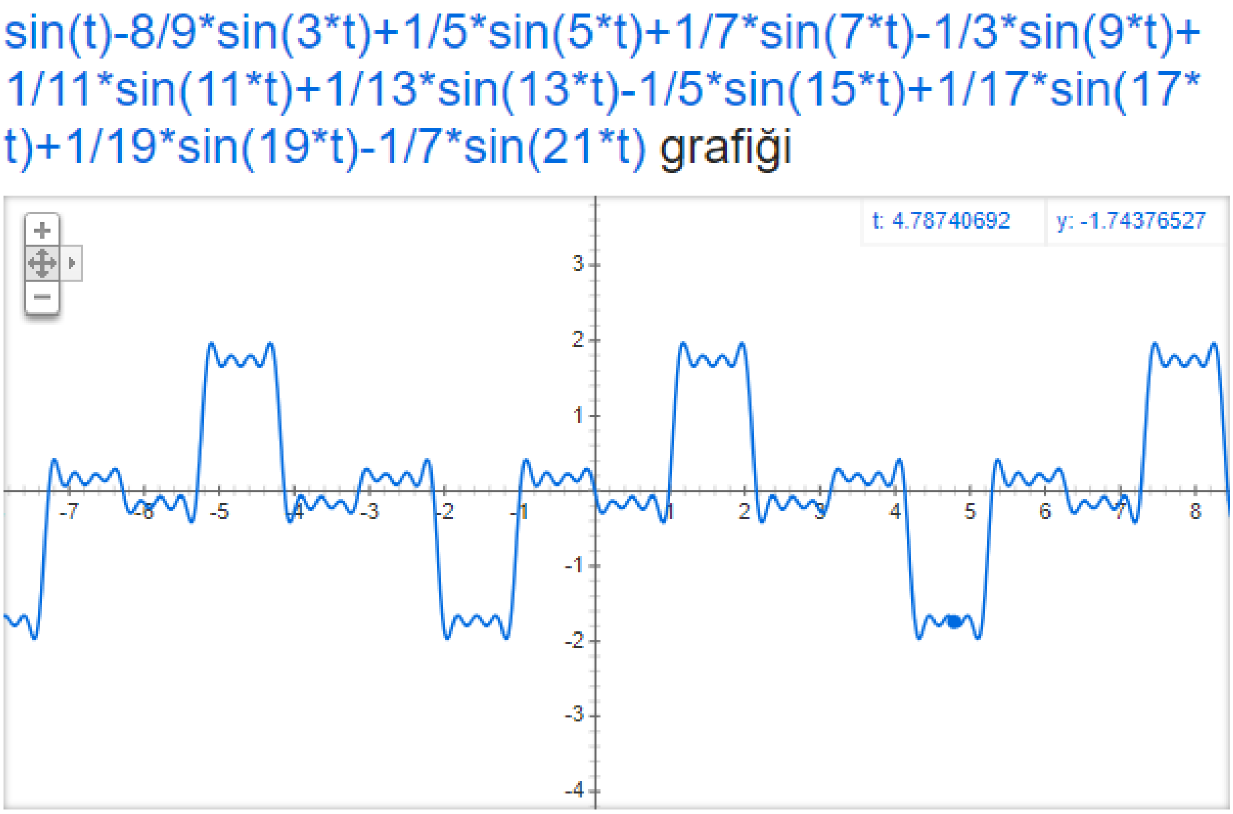

Figure 16: Googled Trial for a similar Input Current Harmonic Distortion

3.4.5 Heating

During full load operation (9V , 10W) the component temperatures were about 40-50 degrees. After 2 minutes the output diode had a temperature of 55 degrees(full load steady state temperature) while the MOSFET had a temperature of 45 degrees.

4 CONCLUSION

To sum up, in this project 230V AC to 9V DC, 10W Flyback Converter has been designed. Voltage feedback controller with Arduino Nano was also implemented. In the early steps of the project, theoretical calculations together with computer simulations were completed.By following Wirth Elektornik Cookbook[3], necessary calculations were held hence a transformer with proper primary and secondary turns ratio was obtained. For the all other component selections, simulation in Simulink has been used. According to critical voltage and current values, required speed of those components, proper ones were bought from Konya Sokak.

During implementation process, we firstly tried to achieve a converter with current sense microcontroller. However, after not being successful at PWM generation,we decided to use Arduino Nano. Afterwards, we have implemented all circuit on breadboard to see if its working properly. Then, to obtain compact and robust design, PCB drawings and necessary processes were done. Thanks to minimum distances on PCB minimum EMI was obtained.

References

[1] Arduino. from https://www.arduino.cc.

[2] Lisa Dinwoodie. *Design Review: Isolated 50 Watt Flyback Converter Using the UCC3809 Primary Side Controller and the UC3965 Precision Reference and Error Amplifier.* Unitrode.

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