EE 464
Static Power Conversion II
Hardware Project Final Report
Flyback Converter#3 Design

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1 Introduction

In this simulation project, we are assigned to simulate hardware project topology which is Flyback converter with following specifications.

- Minimum input Voltage: 24V
- Maximum input Voltage: 48V
- Output Voltage: 12V
- Output Power: 60V
- Output Ripple: %4

At the first part, we simulated the topology with ideal components. Then, we designed our transformer. After calculations, we added parasitic components and re-simulated the topology. For desired output characteristics, we determined related duty cycle values. After doing related calculations, we made some simulations to confirm our design. According to the simulation results, the components of the system are determined. After then we started to implement our circuit and made some tests. Finally we finished the project with a successful demonstration. This report includes design specifications, related calculations, simulation results and some test results.

2 Design Specifications

In order to facilitate our work in design process, we divided our circuit into three main parts these are transformer design, controller design and other parts of the system. The detailed information about this subsytems will be given in next parts of the report.

2.1 Transformer Design

For transformer design, we created a MATLAB code to facilitate our work. The code calculates Iprimary, Lmand turns ratio of the transformer. While creating this code Würth CookBook for Transformer Design Guideline is used. The MATLAB code can be seen from following figure.

```
Vo=10; % desired output voltage
Vin_min=24; % Minimum input voltage
Vin_max=48; % Maximum input voltage
Eff=0.9; % efficiency
fs=7815; % frequency
Po_max=65; % Maximum output power
Pin_max=Po_max/Eff; % Maximum input power

Io_max=6; % Load Current
D=0.45; % Maximum duty cycle


Lmax= (Vin_min^2*D^2*Eff)/(2*fs*Po_max); % calculation of L-mag

Ipeak= sqrt((2*Po_max)/(0.85*Lmax*fs*Eff)); % Peak primary current

Turns= (Vin_min*D)/((1-D)*(Vo+0.8)); % Turn ratio of transformer

%% Output capacitor selection

Vo_ripple=0.04*10;
C_out=Io_max*D/(fs*Vo_ripple);
```

After obtaining the Iprimary, Lmand turns ratio values we made some calculation in order to finalize procedure. The following calculations explains transformer design procedure;

$$L_m = 25uH$$

$$AL = 300nH/T^2$$

, where T is number of turns.

$$\frac{L_m}{AL} = T^2$$

, where T is found as 11.

$$n_{secondary} = 6$$

is chosen to have 1.8 turns ratio.
Total number of turns=17
Window area of selected core= $530mm^2$
Maximum Cable Size= 530
Considering the fact that current carrying capacity of AWG type wires AWG16 is used.

Path length of selected core is 147mm.
Total length of cable required for wiring is 147*17=2.5 meter.
Total resistance of the wire is $13.8m\Omega$.
Desired leakage inductance is % 3 of Lm.
After implementing our design, we found our transformer has;
Lm= 31uH
L(leakage)= 1,37uH (4.4% of Lm)
R (@ 31.375kHz) = 28mOhm
Lm was larger than our calculations, hence we add air gap simply using small paper between core. Then obtained the 26uH for Lm with same leakage. Test results are lost that's why we could not share them in our report.
To have less ripple at output we implemented 4*220uF capacitors

2.2 Controller Design

For controller part of the project, we used bang bang, i.e. hysteresis, control method. The main principle of this control is checking the output voltage and according to the instant value of the output opens switch or closes. For this purpose, we created the following control code.

```
float pwm=20;
void setup() {
  pinMode(3, OUTPUT);
TCCR2B = TCCR2B & B11111000 | B00000001; // for PWM frequency of 31372.55 Hz
Serial.begin(9600);
}
void loop() {

  int voltage = analogRead(A0);
  Serial.print ("voltage");
  voltage = map(voltage, 0 , 1023 , 0 , 100);
    if (voltage==0){
    pwm=20;
    analogWrite(3,map(pwm,0,100,0, 255));

      }

  else if (voltage<=45) {
    pwm=pwm+0.5;
    if(pwm<0){
      pwm=0;
      }
    if (pwm>60){
      pwm=60;
      }
    analogWrite(3,map(pwm,0,100,0, 255));

    }

  else if (voltage>45) {
    pwm=pwm-0.5;
    if(pwm<0){
      pwm=0;
      }
    if (pwm>60){
      pwm=60;
      }
    analogWrite(3,map(pwm,0,100,0, 255));

    }
   delay(200);

}
```

3 Simulation Results

In order to verify our design, we created the following simulink schematic;

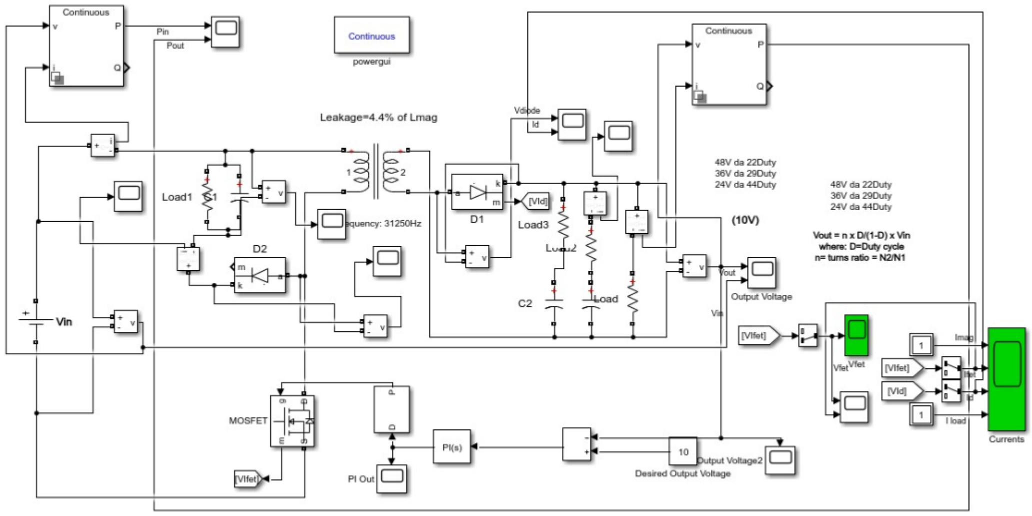

Figure 1: The overall simulink schematic of the system

The simulation results are indicated at following figures;

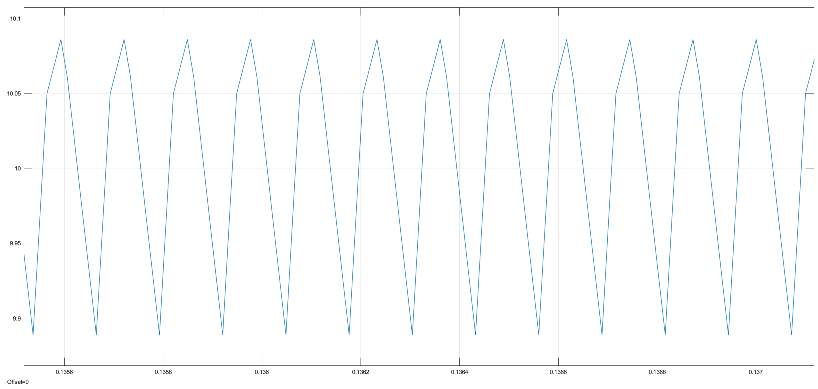

Figure 2: The Output Voltage Graph for 24V Input (Duty=0.44)

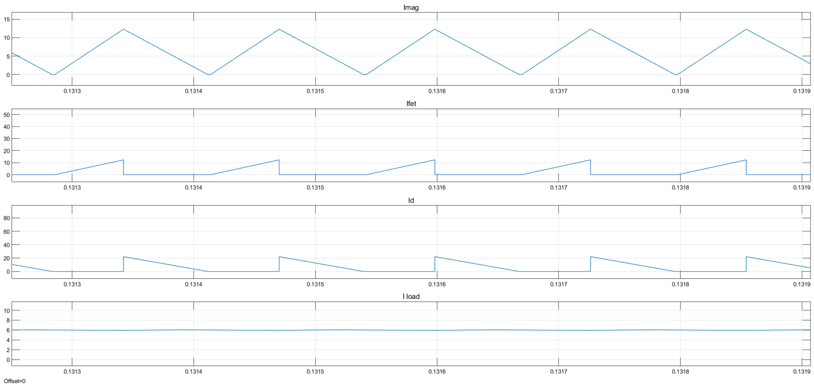

Figure 3: The Currents for 24V Input

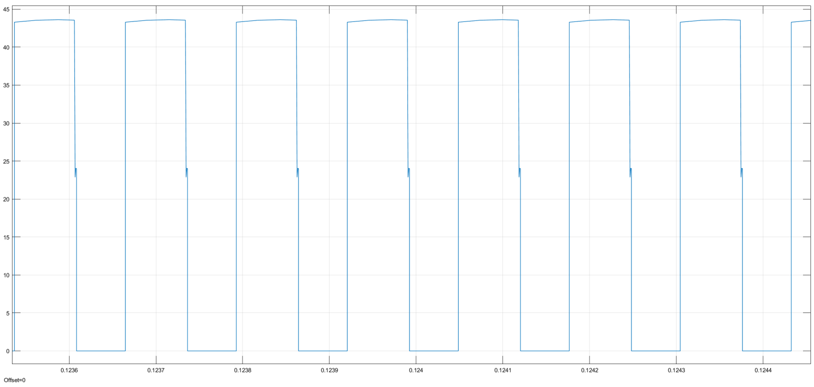

Figure 4: The Mosfet Voltage for 24V Input

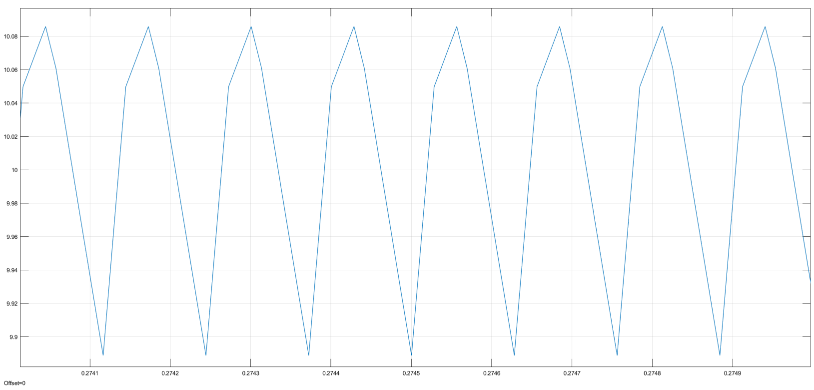

Figure 5: Output Voltage Graph for 48V input(Duty=0.22)

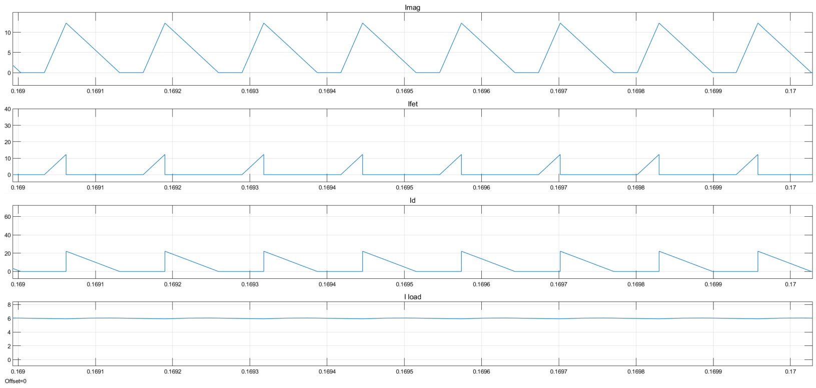

Figure 6: The Currents for 48V Input

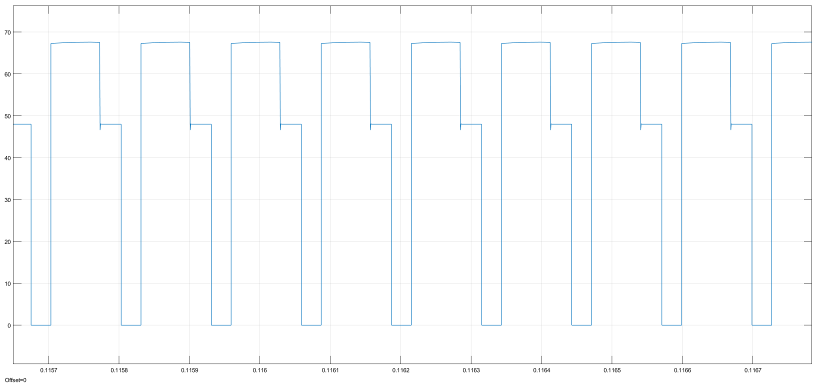

Figure 7: The Mosfet Voltage for 48V Input

4 Component Selection

4.1 Mosfet Selection

In order to select proper mosfet we looked at drain to source voltage rating and continuous current ratings. As seen Figure 7 at 48 volt imput mosfet voltage has 67 V peak value. Continuous current rating of mosfet is 13 A. From this calculations selected mosfet ratings are shown in Table 1.

Product Code	MTP20N15E
Drain–Source Voltage	150 V (dc)
Drain – Continuous	20 A (dc) / 12 A @ 100°C
Operating and Storage Temperature Range	−55 to 150 °C
Gate–Source Voltage	± 20 V (dc)
Pruduct link	https://www.onsemi.com/pub/Collateral/MTP20N15E-D.PDF

4.2 Diode Selection

For the diode selection important parameters are peak inverse voltage and current capability.

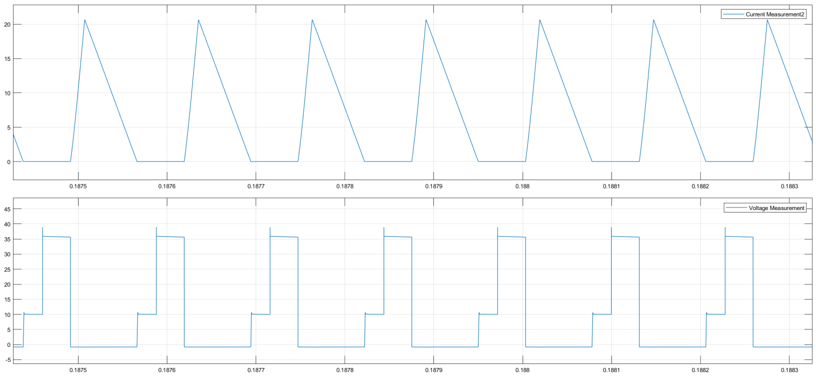

Figure 8: Diode voltage and current ratings

From Figure 23. We found peak inverse voltage as 40 V and continuous current as 22 A. Using these parameters a diode is selected and it's parameters shown in table 2.

Product Code	STPS30M100S
IF(AV)	30 A
VRRM	100 V
Tj (max.)	150 °C
VF (typ.	0.605 V
Product Link	https://www.st.com/content/ccc/resource/technical/document/datasheet/e4/43/ab/35/b9/4b/41/c9/CD00228906.pdf/files/CD00228906.pdf/jcr:content/translations/en.CD00228906.pdf

4.3 Filter Capacitor Selection

At the outpu capacitor wer calculated that we need 3 680 uF capacitor. It is also known that our output voltage rating is 10 V. After finding these parameters we selected our capacitor whose parameters is seen at Table 3.

Product code	PEG124MG368AQL1
Capacitance	680 µF
Voltage - Rated	63 V
Ripple Current @ High Frequency	7.5A @ 5kHz
Product Link	https://content.kemet.com/datasheets/KEM_A4011_PEG124.pdf

4.4 Snubber Elements

4.4.1 Snubber Capacitor selection

In the simulation we found capacitor voltage and current ratings which are indicated in Figure 24.

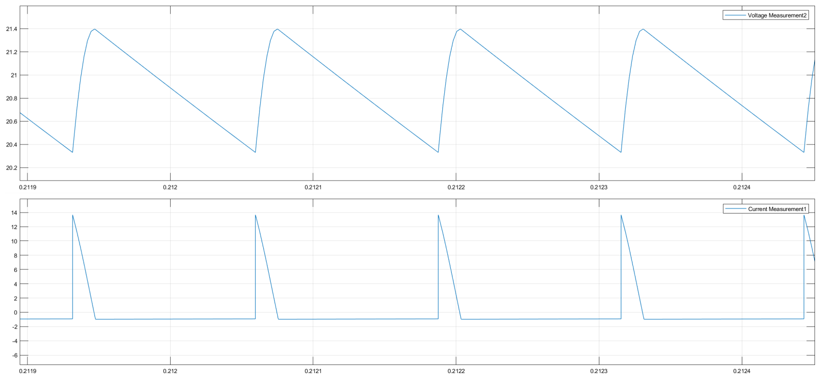

Figure 9: Snubber capacitor voltage and current ratings

After determining these values an aluminum electrolytic capacitor is selected as seen in table 4.

Product code	B41890A7107M
Capacitance	100µF
Voltage - Rated	35V
Product Link	https://www.tdk-electronics.tdk.com/inf/20/30/db/aec/B41890.pdf

4.4.2 Snubber Diode

Similar to snubber capacitor selection by looking at its voltage and current rating a diode is selected. Simulation results are shown in Figure 25.

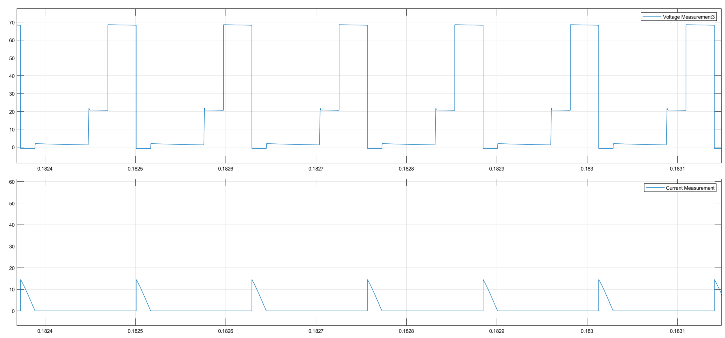

Figure 10: Snubber diode voltage and current ratings

Selected diode and its parameters indicated in Table 5.

Product code	TST40L 150CW
IF(AV)	20 A
VRRM	150 V
Tj (max.)	150 °C
VF (typ.	0.86 V
Product Link	https://www.taiwansemi.com/products/datasheet/TST40L100CW%20SERIES_B14.pdf

5 Demonstration Results

In the demonstration, we showed our converter from 24 V input to 48 V input. There was a little reference voltage problem in the controller code but it is told that it won't make any problems, so our output voltage results are taken as 10.5 V rather than 10 V. During demonstration we take input current and output voltage oscilloscope readings, input and output wattmeter readings for efficiency, thermal camera readings for 24 V, 36 V and 48 V input voltages.

5.1 24V Input Results

Input current and output voltage results are shown in Figure 11.

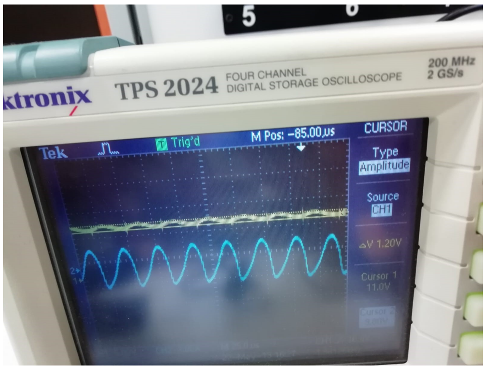

Figure 11: Input current (blue line) and output voltage (yellow line) vs. time results

It is not seen in the figure but our output voltage is around 10.5 V mean value. In the Figure 11 it can be seen that our peak to peak voltage 1.2 V. Normally we have designed our circuit to have ripple voltage less than 4%, however because of our control algorithm output voltage ripple value is more than our expectations.
In the Figure 12 input (on the left side) and output (on the right side) wattmeter result are shown. Using these results our efficiency is calculated as 64.3%, however because of he fluctuations resulting from our control code efficiency was changing during demonstration and when we take data belonging to the same second our efficiency was calculated 69

(a) Input voltage, current and power readings

(b) output voltage, current and power readings

Lastly our thermal camera photos indicated in the Figure 13. We were expecting our mosfet to be hottest equipment thus we placed a DC fan in front of out mosfet as a result of this we observed that our hottest equipments were snubber resistance and the core of the transformer.

Figure 13: Thermal readings for 24 V input voltage

5.2 36V Input Results

Input current and output voltage results are shown in Figure 14. When we compare these results with 24 V input results only our peak to peak voltage is increased slightly.

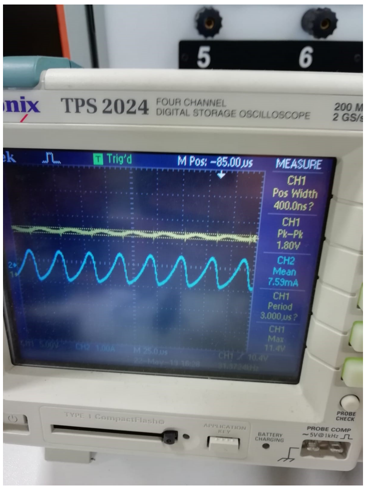

Figure 14: Input current (blue line) and output voltage (yellow line) vs. time results

In the Figure 15 input (on the left side) and output (on the right side) wattmeter result are shown. Our efficiency is calculated as 70% closer to the value we measured during demonstration.

(a) Input voltage, current and power readings

(b) output voltage, current and power readings

5.3 48V Input Results

Input current and output voltage results are shown in Figure 16. The results are similar with 24 V results and 36 V results. This time our peak to peak voltage smaller than we measured in 36 V input and slightly larger than the 24 V input voltage results.

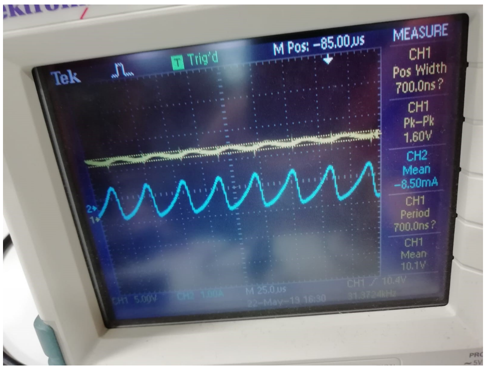

Figure 16: Input current (blue line) and output voltage (yellow line) vs. time results

In the Figure 17 input (on the left side) and output (on the right side) wattmeter result are shown. Our efficiency in this case is calculated as 69%. It is same as what we observed during demonstration

(a) Input voltage, current and power readings

(b) output voltage, current and power readings

Our thermal camera photos indicated in the Figure 18. Same equipments mentioned in the 24 V result part are the hottest equipments this their temperature values increased since this step was the last step and converter worked for more than 5 minutes.

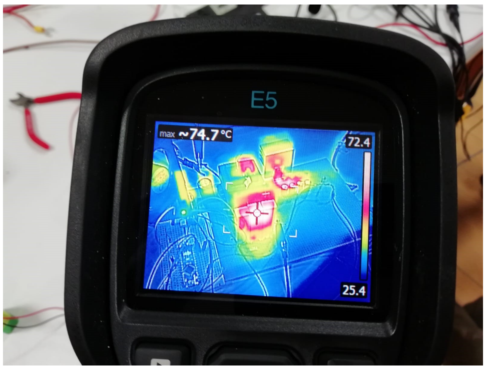

Figure 18: Thermal findings for 48V

We also take the mosfet drain to source voltage results during demonstration which is shown in the Figure 19.

Figure 19: Mosfet drain to source voltage

Before placing a snubber we had observed a 250 V peak voltage at the mosfet. As seen in the Figure 19 this peak voltage is decreased to 134 V after placing the snubber.

5.4 Evaluation and Comments about Demonstration

During the demonstration first we showed that our design has soft start since we had a controller that increase or decrease the voltage with small steps by comparing measured voltage with reference value. We had used a digital controller with Arduino Nano and there has been a slight mistake about reference voltage so our demonstration results are taken with 10.5 V output voltage instead of 10 V. After that when we reached our target output voltage for 24 V input voltage we measured the efficiency and it was 69%. Most of our losses resulted from snubber resistance. In order to have better efficiency we should have designed our snubber better. Furthermore, we had 4.4% leakage inductance that decreases our efficiency but we don't want to speed too much time with wrapping the core again and again. Then, we checked output voltage ripple and as explained before because our step increase and decreases resulting from controller we had relatively large ripple value. We observed similar results for different input voltage values for efficiency and peak to peak ripple voltage. For the load regulation sudden change in the loading increased our output voltage nearly to 30 volts. Since our controller was slow our load regulation was not good enough. Lastly, we checked the thermal design of the converter during its operation and we did not have problems about thermal constraints.

6 Cost Analysis

Product Name	Cost
UF640L-TA3-T MOSFET	৳2.50
DSA60C150PB DIODE	৳5.36
SNUBBER CAPACITOR	৳13.37
ARDUINO NANO	৳25.00
FILTER CAPACITORS	৳2.40
OTHER COMPONENTS	৳10.00
TOTAL	৳58.63

7 Conclusion

With this project, we have learned so many things about isolated power converters especially flyback converters. Designing transformer and controller systems are some of them. In addition to that we learned how some real life situation affects operation of the converter. Such as distance between gate and optocoupler output, snubber effect, switching frequency effect. Although we faced too many challenging situations during design,implementation and test process, we learned so much thing about real life engineering and this project will be a guide for us in our professional life.