MIDDLE EAST TECHNICAL UNIVERSITY
DEPARTMENT OF ELECTRICAL & ELECTRONICS
ENGINEERING

EE 463 - Static Power Conversion I - Term Project
Deadly Viper Assassination Squad Inc.

Development of a AC-DC Battery Charger for Rooftop Wind
Turbine Applications
Fınal Report

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Table of Contents

1. Introduction

Deadly Viper Assassination Squad Incorporation (D.V.A.S. Inc.) is established to provide practical solutions to the problems in the power electronics area. The main application areas in the power electronics field are AC to DC rectifiers and DC to DC converters.

In recent years, effects of climate change have started to show themselves at various locations of the world. Although we are at the beginning of the expected huge climate shift, we are already experiencing unusual meteorological events. In order to delay the effects of climate change, governments and companies have started to invest on renewable energy sources. Therefore, the share of renewables in the energy production industry is getting larger every year.

In addition to the conventional bulk power plants, distributed energy resources (DER), which is a new concept that appeared with the advancements in the renewables area, are being used in order to decrease the carbon emissions of the end user. Instead of large power plants in MW scale, the number of small power generation units located in the distribution level is increasing.

In this project, D.V.A.S. inc. proposes a solution for the interface between a small wind turbine located at the top of the EEE department of the METU and it's battery. First stage of the proposed solution includes AC to DC conversion of the wind turbine output whose frequency and amplitude varies randomly. Then, rectified variable-DC voltage is regulated to provide charging operation for the battery.

Project is completed in two steps. Preceding report was including the conceptual design discussion, simulation results and CAD model of the proposed solution. After submitting this report and getting feedback, development process is continued according to the feedback taken. This report represents the final version of the developed system including design, simulation, component selection, cost analysis, thermal analysis and PCB design parts.

2. Problem Definition

The main problem that yields us to work on this project is that the road next to the park of the EEE department needs to be illuminated continuously even in the nights. This action requires a large energy supply which is not available in that condition. For this reason, a small wind turbine is placed at the top of the roof. However, the speed and strength of the wind is not constant. Therefore, converted electrical energy must be stored in order to use at the evening hours for illumination. For storage, a battery is used at the output of the wind turbine. Proposed AC-DC charger design will convert variable AC to constant DC. Since the terminal voltage of the electrochemical battery would change with its state of charge, the charger must supply constant current DC independent of the terminal voltage of the battery. This definition intuitively shapes our design.

The system specifications for this project are defined as below.

- Open circuit voltage peak: 330 $V_{line-to-line}$
- Battery capacity: 13 Ah
- Battery nominal voltage: 24 V
- Output current: 2 A
- Output current ripple: %20 of average current.
- Inertia: 0.00027 kg.m^2
- Viscous Damping: 0.005024 N.m.s
- Poles: 2
- Voltage Constant: 110 $V_{peak_{l-l}/krpm}$
- Stator Resistance: 10.58 Ohm
- Armature Inductance: 16.7 mH

3. Topology Selection

In preceding chapter, problem definition is made, and the conceptual requirements are determined without entering the technical design discussion. In this step, possible topologies which satisfy the requirements defined above will be discussed and selected topology will be represented. According to the problem definition, we have determined that below topologies are suitable for this application.

- Three Phase Full Bridge Thyristor Rectifier
- Three Phase Full Bridge Diode Rectifier + Buck Converter (x2)
- Three Phase Full Bridge Diode Rectifier + Buck Converter

Using a three-phase full bridge Thyristor rectifier would be beneficial in order to decrease the size and number of the components. However, in this case 6 gates must be controlled at the same time. This would increase the cost because we need to feed 6 gate signals at the same time which requires 3 phase control drivers. Also, controlling 6 gates at the same time would increase the complexity of the controller and decrease the reliability of the system. For that reasons, a Thyristor rectifier is not preferred.

After eliminating the Thyristor rectifier, the team focused on the diode rectifier + buck converter topology. The given source in the project is a three-phase generator which means that we need to select a three-phase rectifier type. At this stage, three phase half wave/full wave diode rectifier topologies are considered. According to the output current specification, we need to feed the system with a high voltage so that we can reach 2A at the buck converter output. Therefore, a three-phase full bridge diode rectifier is determined as the best option for this application thanks to its larger voltage output.

Since the output voltage of the rectifier is large, whether a single buck converter would be capable of converting it for the battery or not is discussed. Note that the controller must operate at higher frequencies in order to convert such a high voltage to the 24V 2A DC. After conducting a short market research, it is found that there are plenty of analog controller ICs that can operate in such conditions. Therefore, a single stage buck converter is preferred in order to decrease the cost, number of components and volume of the design.

After determining the number of buck converter stages, control strategy is discussed. Batteries can be charged in constant voltage, constant current or constant current-constant

voltage modes of operation. Since the terminal voltage of the battery varies depending on its state of charge, the constant current charging method is adopted due to its simplicity. In the design, output current will be kept constant by an analog controller IC. Details of the controller will be discussed in detail later.

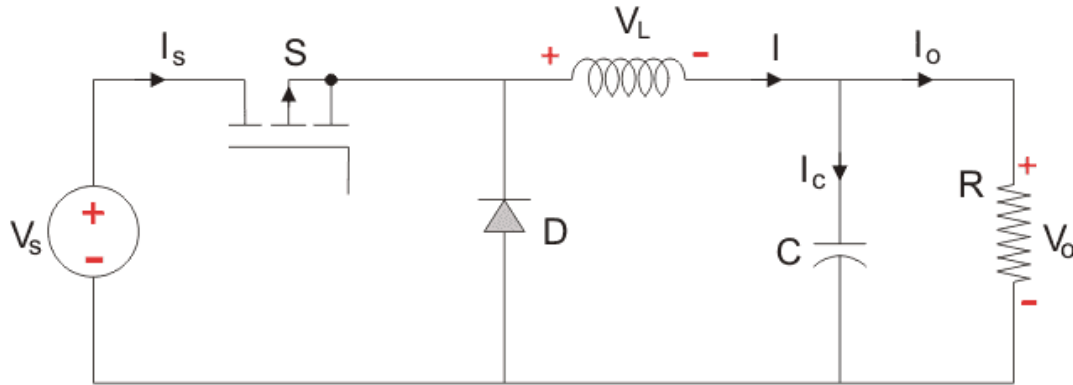A typical buck converter topology circuit diagram is given below.

Figure 1: Buck Converter topology

In order to increase the efficiency by decreasing the diode losses, diode D is changed with a MOSFET, and this configuration is known as synchronous buck converter. The synchronous buck converter circuit diagram is shown below.
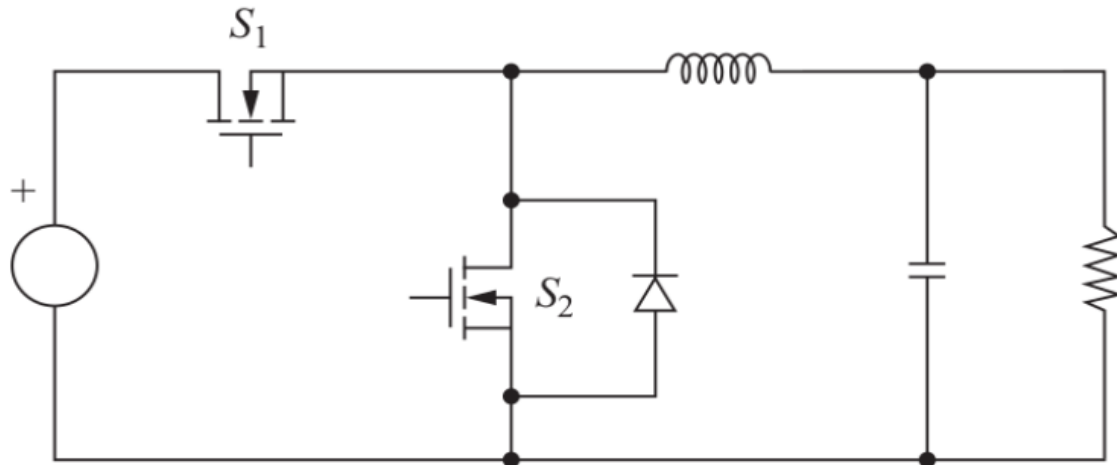

Figure 2: Synchronous buck converter topology

4. Design

In this part, values of capacitors and inductor are determined. Also, controller block is designed for simulations. Note there are two capacitors, one at the rectifier output and other one at the converter output. Also, value of inductance must be determined for buck converter.

First, capacitance at the rectifier output is determined. This capacitor decreases the output voltage ripple significantly. Since there is no specification about the rectifier output ripple, complete elimination of the ripple voltage was not the aim. Instead, an easy to find capacitor is selected and the result was satisfying (Given in simulation part). Therefore, a 470-microfarad capacitor is selected for rectifier. However, in order to decrease the size of the circuit, two series 270-microfarad capacitors are used. Their equivalent capacitance is 540-microfarad. Size is decreased and larger capacitance provides better ripple filtering.

Then, the inductor and capacitor values are determined for buck converter. Equations below are used for the calculations. Note that, equations include voltage and current ripple values. Therefore, allowable ripple values are also used and resulting capacitor and inductor satisfy this ripple values.

$$L_{min} = V_{out}.\frac{V_{in} - V_{out}}{\Delta I_L.f_s.V_{in}} \quad (1)$$

$$C_{out,min} = \frac{\Delta I_L}{8 * f_s * \Delta V_{out}} \quad (2)$$

After inserting circuit parameters to the equation (1), L_{min} can be found as below.

$$L_{min} = \frac{24x(300 - 24)}{0.4x200000x300} = 2.74x10^{-4}H$$

After inserting circuit parameters to the equation (2), C_{out} can be found as below.

$$C_{out} = \frac{0.4}{8x200000x0.5} = 0.5x10^{-6}\,F$$

These values are the minimum ones. For the sake of the reliability, the parameters were chosen larger than these minimum values which are presented in the above. For the buck converter, 1.5 microfarad capacitor and 1 milihenry inductor are used in order to obtain the required results. It can be also observed that for the chosen inductance value, system will work in the continuous conduction mode. The proof of this can be followed in the below derivations.

$$I_{LB} = \frac{I_{L_{peak}}}{2} = \frac{t_{on} * (V_d - V_o)}{2 * L} = \frac{D * T_s * (Vd - D * V_d)}{2 * L} = \frac{V_d * T_s * D * (1 - D)}{2 * L} \quad (3.1)$$

From here, inductance can be leave alone as below.

$$L_{min} = \frac{V_d * T_s * D * (1 - D)}{2 * I_{LB}} = \frac{V_o * T_s * (1 - D)}{2 * I_{LB}} = \frac{(1 - D) * R_L}{2 * f_s} \quad (3.2)$$

R_L can be calculated from the load characteristics, where there exists 24V nominal voltage with average 2A current. From here R_L can be calculated as.

$$R_L = \frac{24}{2} = 12\Omega \quad (3.3)$$

At the output of the rectifier, there exists an average of 250 V at the steady state. This output is sent to the input of the buck converter and converted to 24V. From here duty cycle can be extracted as below.

$$D = \frac{V_o}{V_d} = \frac{24}{250} = 0.096 = 9.6\% \; where \; V_d = V_{in} \quad (3.4)$$

Obtained variables in equations, in equation 3.3 and 3.4, can be inserted to the equation 3.2. The result is as below.

$$L_{min} = \frac{(1 - 0.096) * 12}{2 * 200 * 10^3} \; H = 0.271 \; mH$$

Mustafa Yıldız
Ali Belli
Mehmet Kılıç
                                  Final Report
                                 15/01/2021

As can be seen from the equation, the found inductance value for the CCM operation is the minimum value. Therefore, the one chosen in the above, 1mH inductance value, is guaranteed to work the Buck Converter on the CCM mode.

Then, the controller is designed with two outputs. At first, designed controller was taking output current as a measurement and comparing it with reference current. Then passing it through a P controller. Amplified P controller output was being compared with a constant frequency sawtooth waveform. If the difference between the amplified error and sawtooth is less or equal than zero, M1 was on and M2 was off. The system was working based on this process. Although this controller was be able to provide constant 2 A output current, inductor current ripple was weird, and reason could not be found. Then, according to the feedback taken in feedback session, a hysteresis (on-off) controller is designed. Such a controller operates as follows; a hysteresis band is determined and error between measured and reference currents is compared with the hysteresis bounds. If error exceeds upper limit, switch is off and vice versa. Figure 3 shows the old controller used in simulation report. Figure 4 shows the new controller.
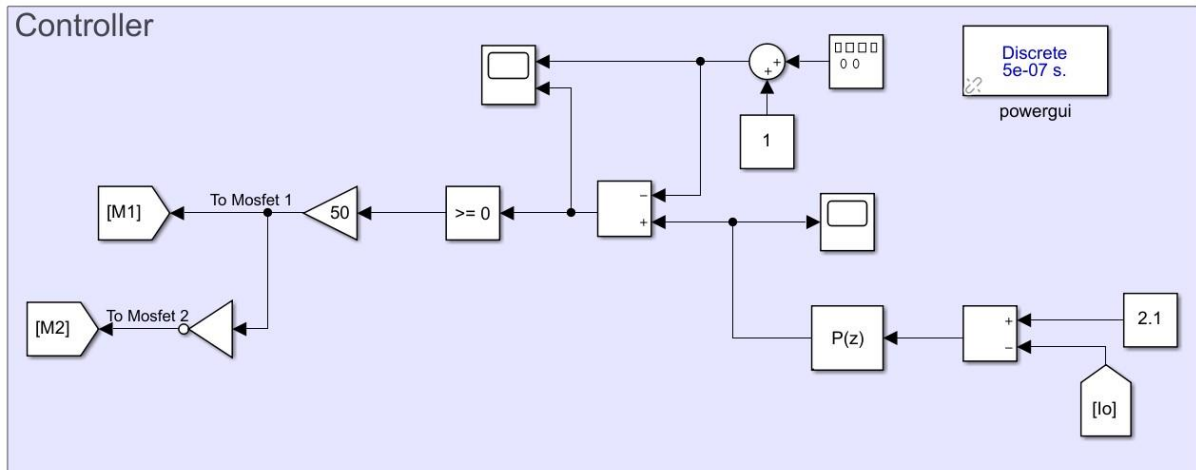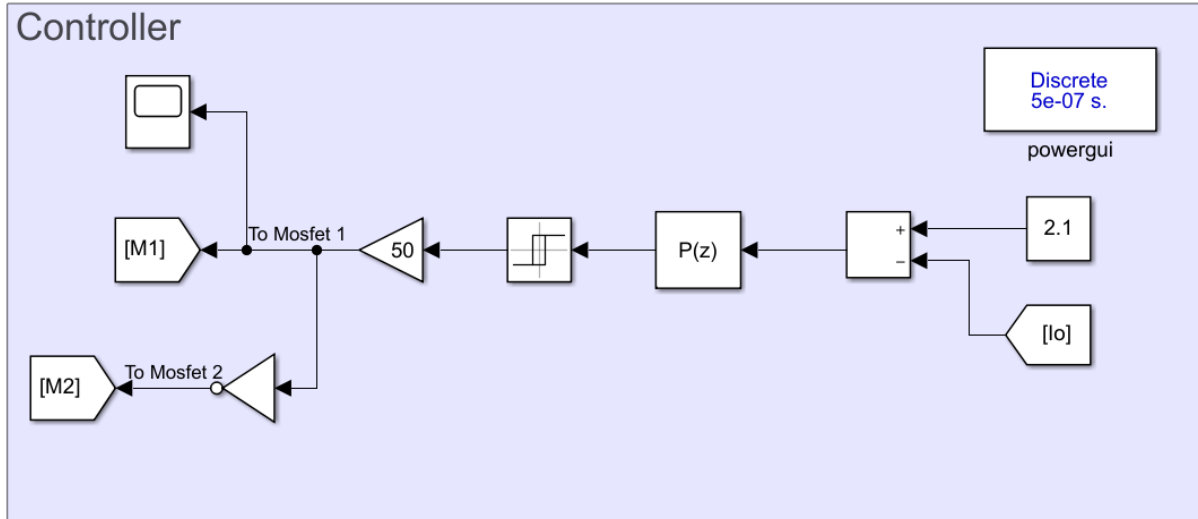

Figure 3: Controller block (old)

Figure 4: Hysteresis controller block (new)

Finally, overall system design is completed, and complete simulation model is constructed. In simulations part, results are represented. Figure 5 shows the overall system simulation results.
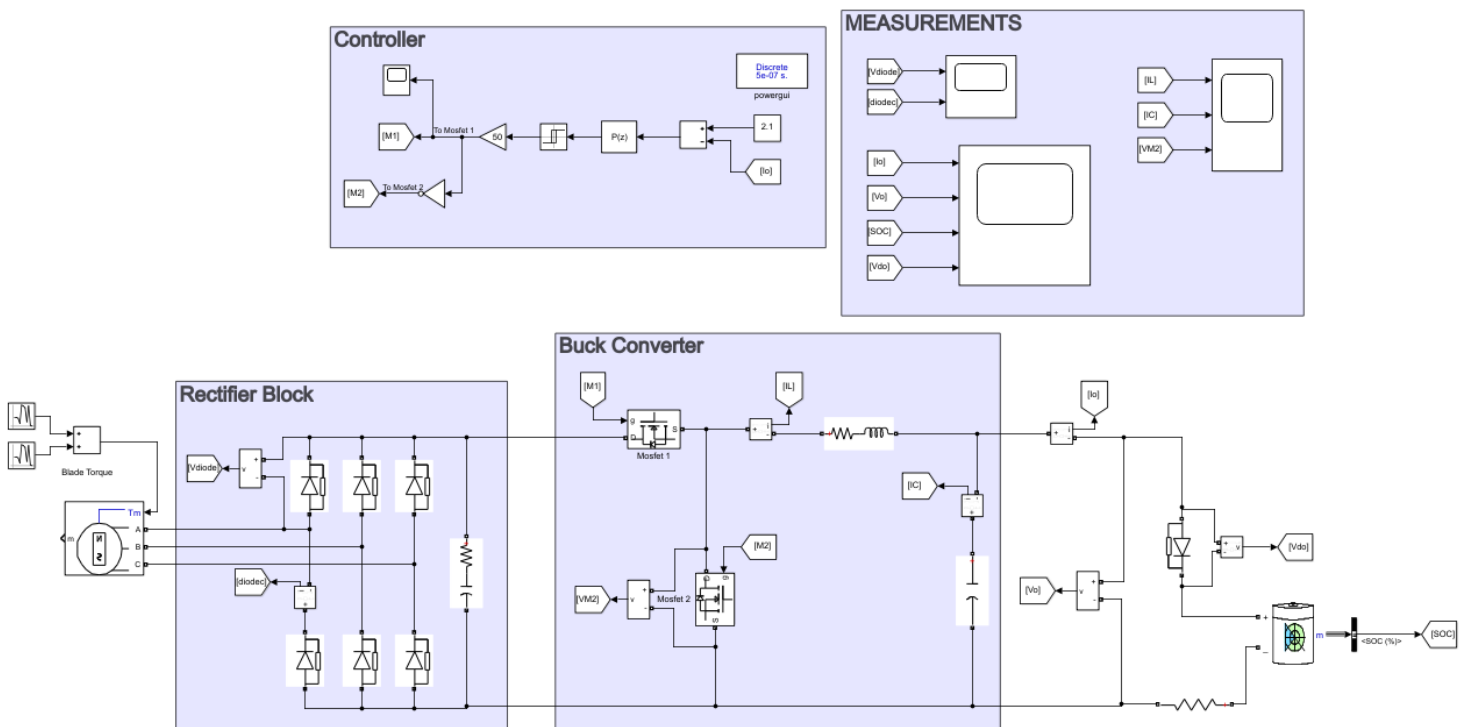

Figure 5: Overall system simulation model

5. Simulation Results

In this part of the report simulation results are represented. During the simulations, voltage drop and current of each component are measured. According to these measurements, ratings of the components are determined, and components are selected accordingly. Then, non-idealities of these components are included, and simulations are repeated. Results given in this report represent the non-ideal (final) case. First, diode rectifier simulations are presented.
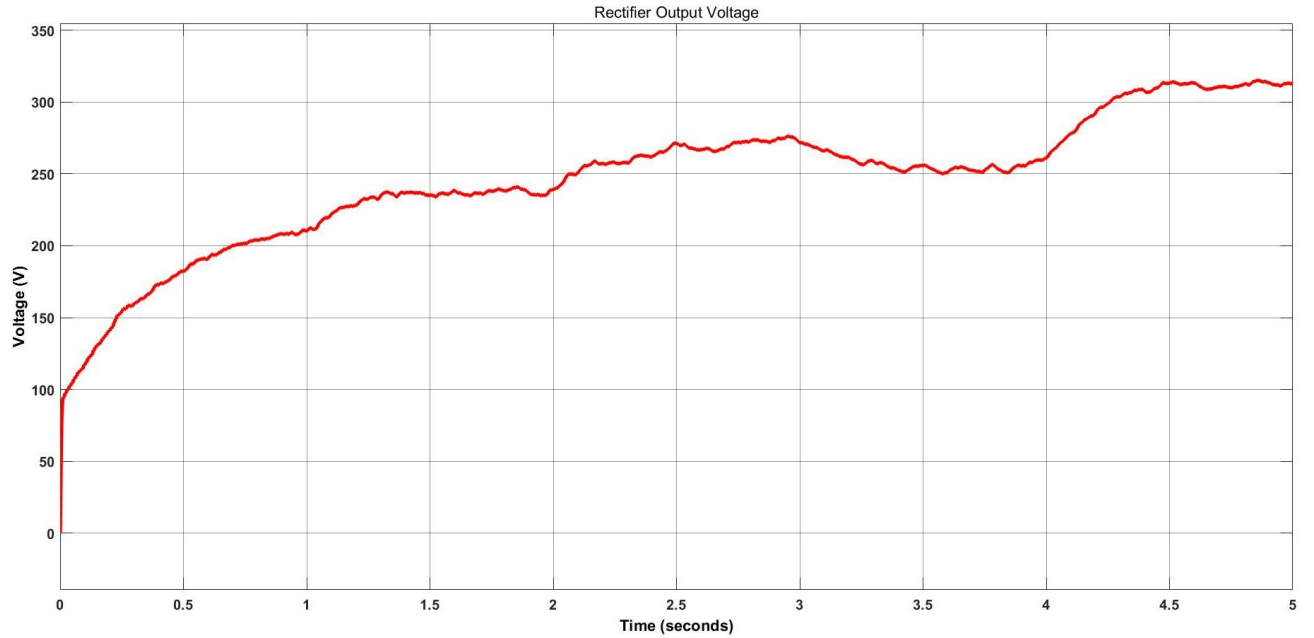

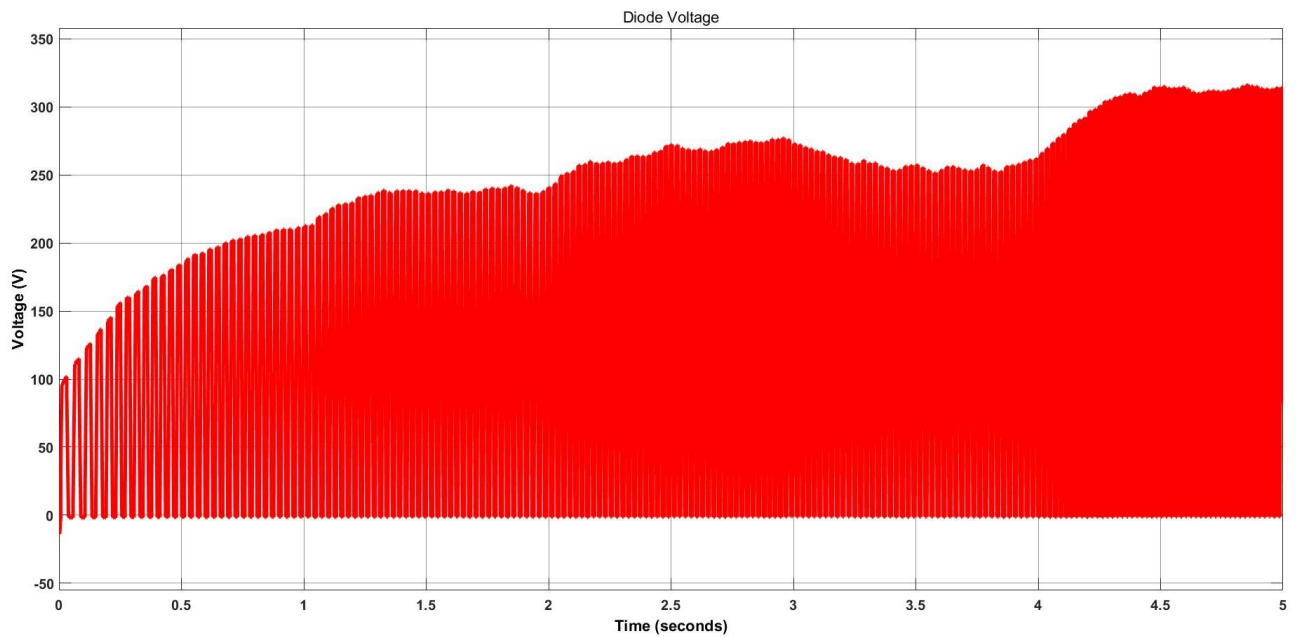*Figure 6: Rectifier output voltage, C=540 µF*

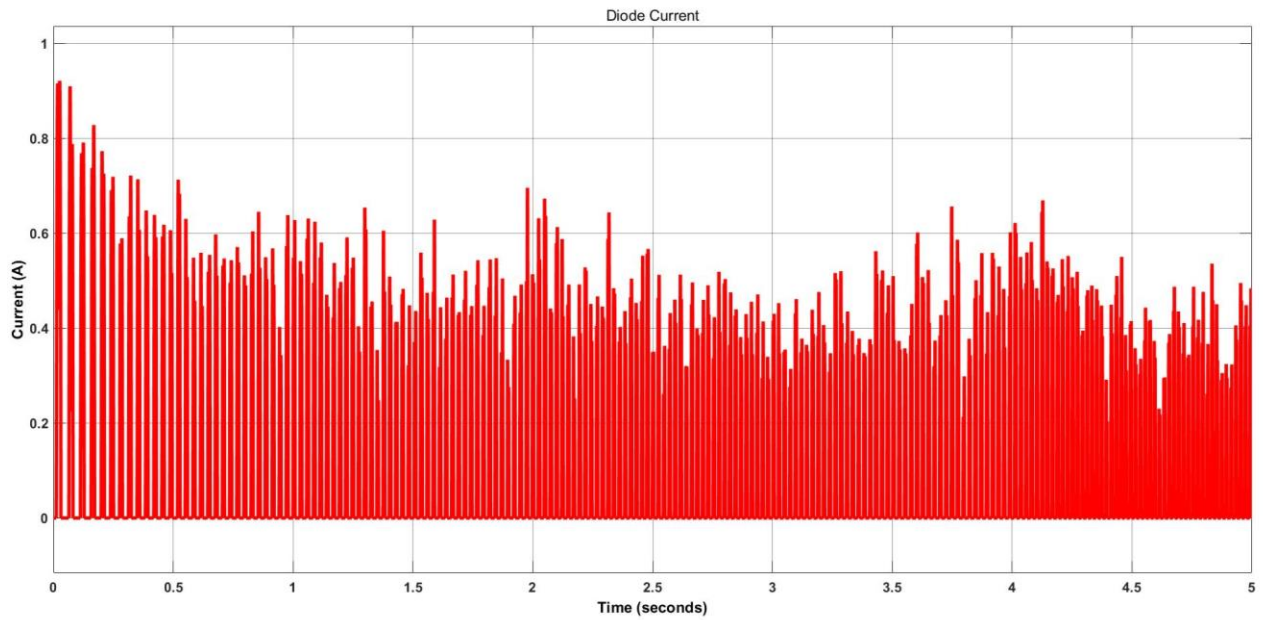

Figure 7: Rectifier diode voltage

Figure 8: Rectifier diode current

Figure 6 shows the output voltage of the rectifier. Increasing the capacitor value could decrease the ripple value. However, since the controller of the buck converter would adjust the output voltage automatically, dimensions of the capacitor become the most important parameter. Since the selected capacitor provides enough filtering with relatively small volume, there is no need for larger capacitors. Figure 7 and 8 show the diode voltage and current measurements. Diodes of rectifier are chosen according to these values. Detailed discussion is provided in the component selection part.

Buck converter simulation results are given below. Figures 9 and 10 show the inductor current and inductor current ripple. Note that, controller guarantees constant current operation with deviations between approximately 2.2 A and 1.8 A. Therefore, selected inductor satisfies 0.4 A ripple current condition, which is used while determining the minimum inductor value in design part. Moreover, settling time is also satisfactory. Figure 11 shows the current flows through the output capacitor. Note that, this current value is negligibly small. Therefore, it is safe to assume inductor current is equal to output current. Figure 12 shows the output current. Note that the difference between inductor current and output current is not even visible in this scale.
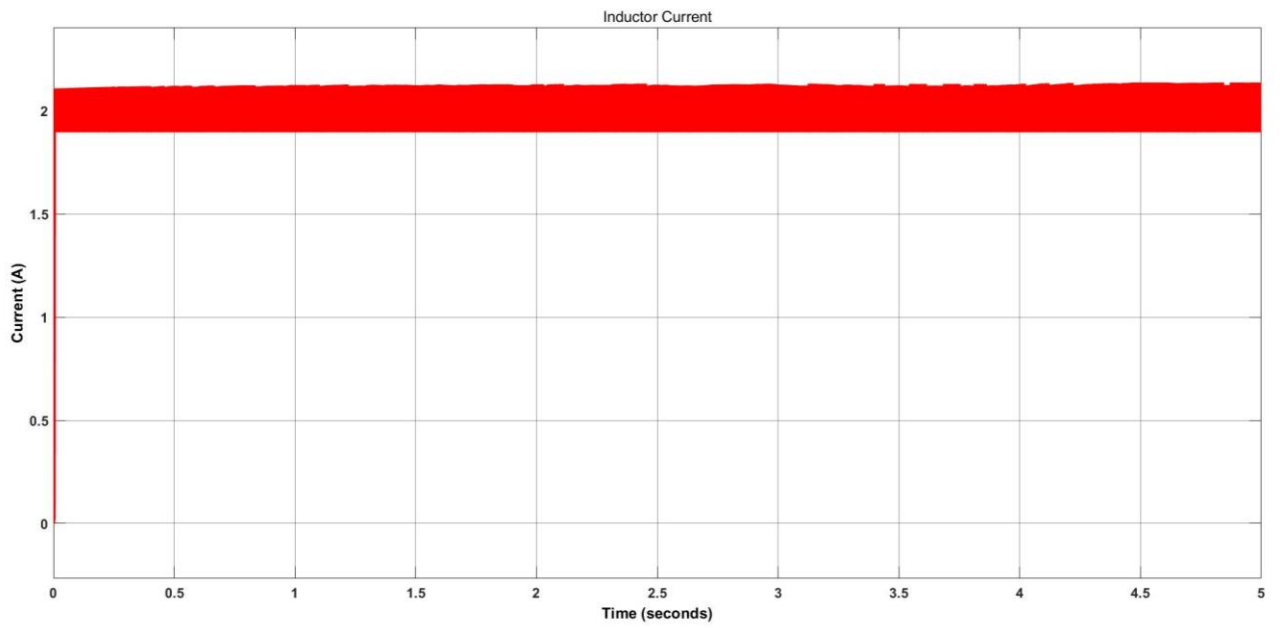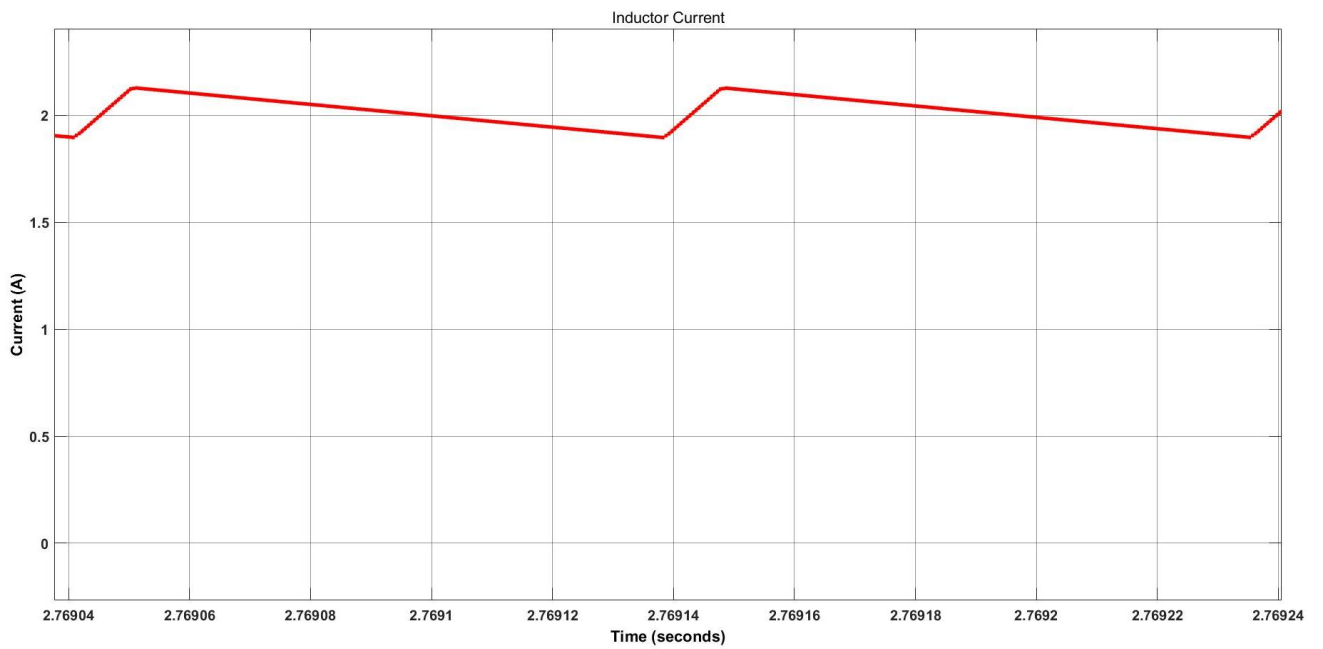
Figure 9: Inductor current

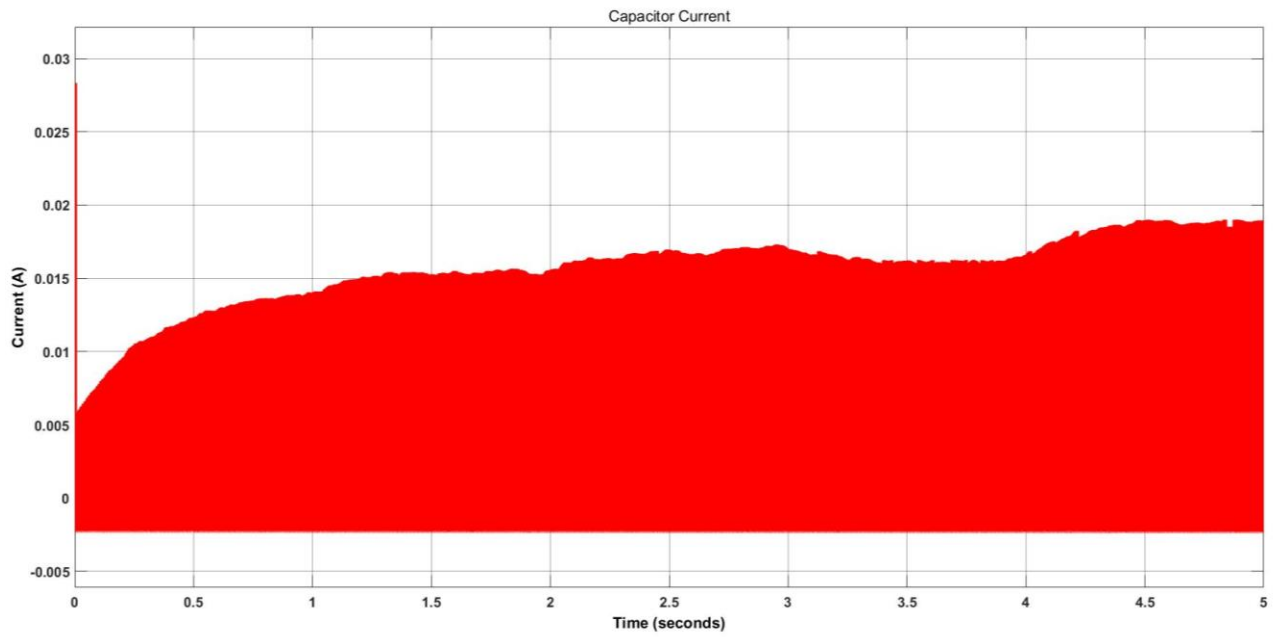*Figure 10: Inductor current ripple*

Figure 11: Output capacitor current

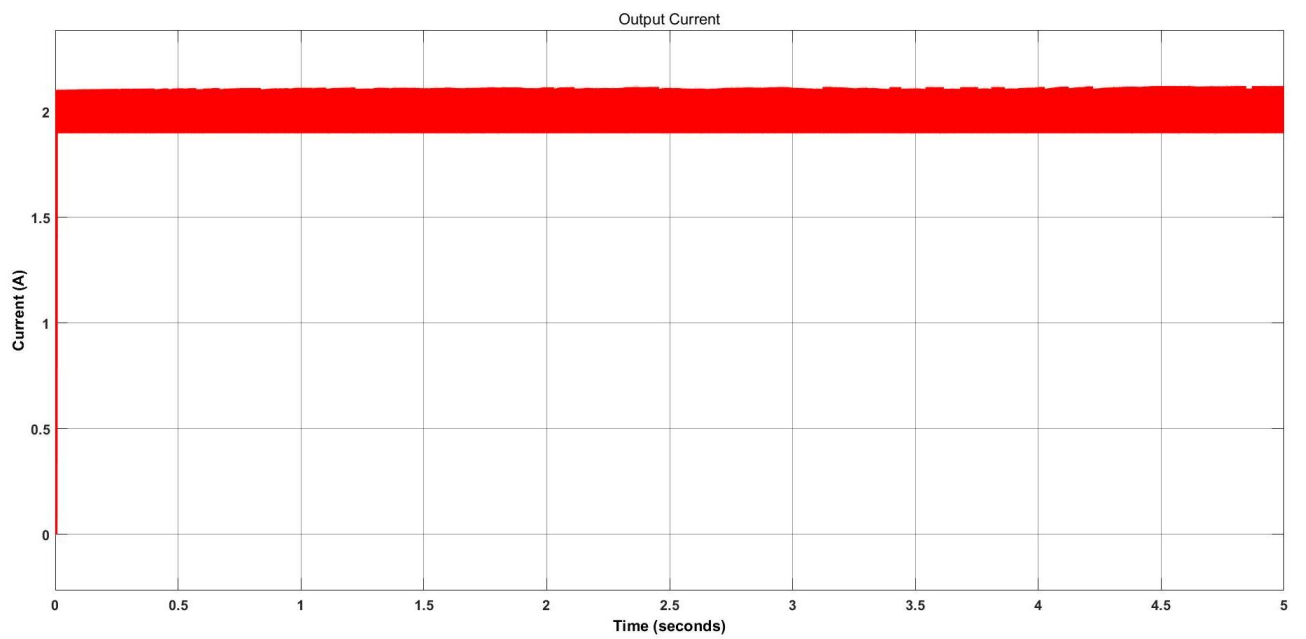*Figure 12: Output current.*

Figures 13 and 14 show the output voltage and battery state of charge. Normally, output voltage is expected to increase as the battery SOC increases. However, supplying 2A for 5 seconds cannot charge the battery significantly. Therefore, output SOC and output voltage are almost constant during the simulation.
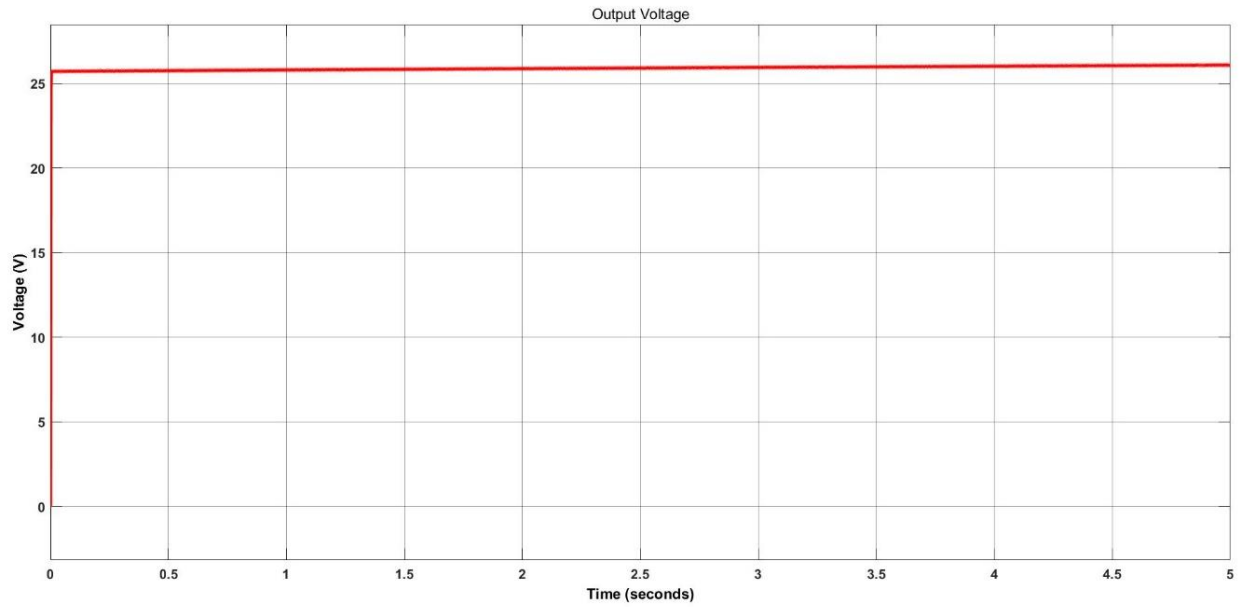

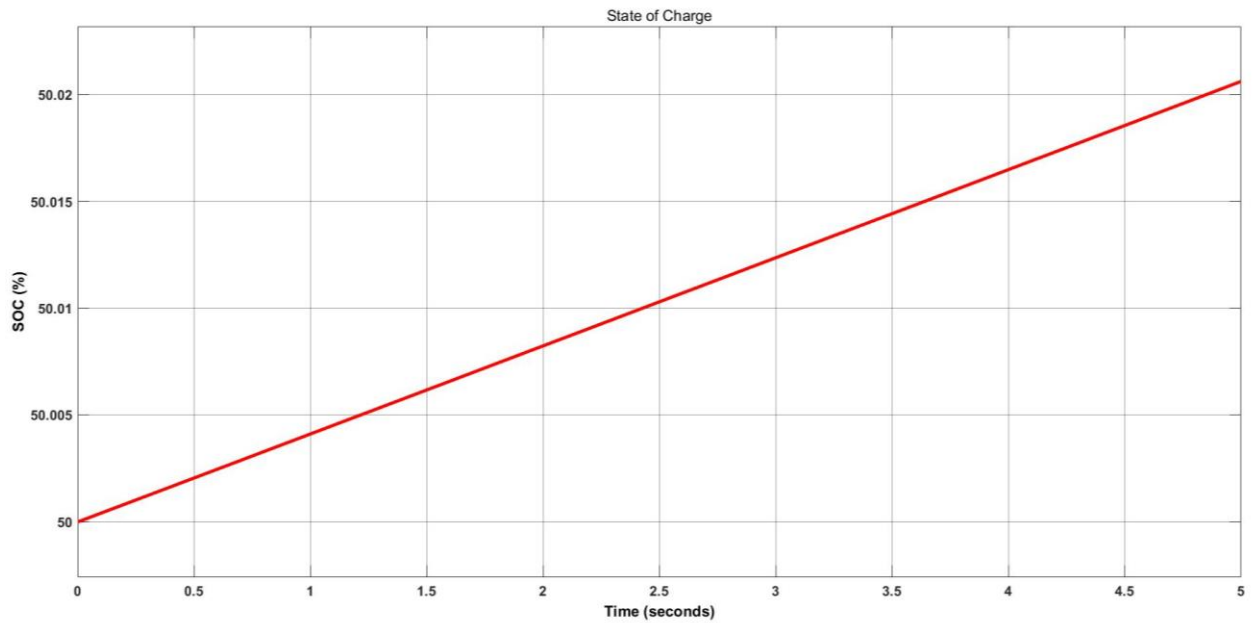*Figure 13: Output voltage*

Figure 14: Battery State of Charge

As figure 14 shows, initial battery SOC is 50% and it becomes 50.02 percent at the end of the simulation. Since the battery is charged initially, it is expected to see a current flow from battery to the output capacitor of buck converter. Note that the output capacitor of the buck converter is not charged initially. Therefore, battery expected to discharge into that capacitor. In order to avoid this effect, a diode is added at the output side. This diode blocks the current flow from battery to the capacitor. Figure 15 shows the voltage on the output diode. Note that, voltage becomes negative at the beginning of the simulation. This means that the hypothesis was valid. Now, this diode blocks the reverse current at the beginning of the operation.
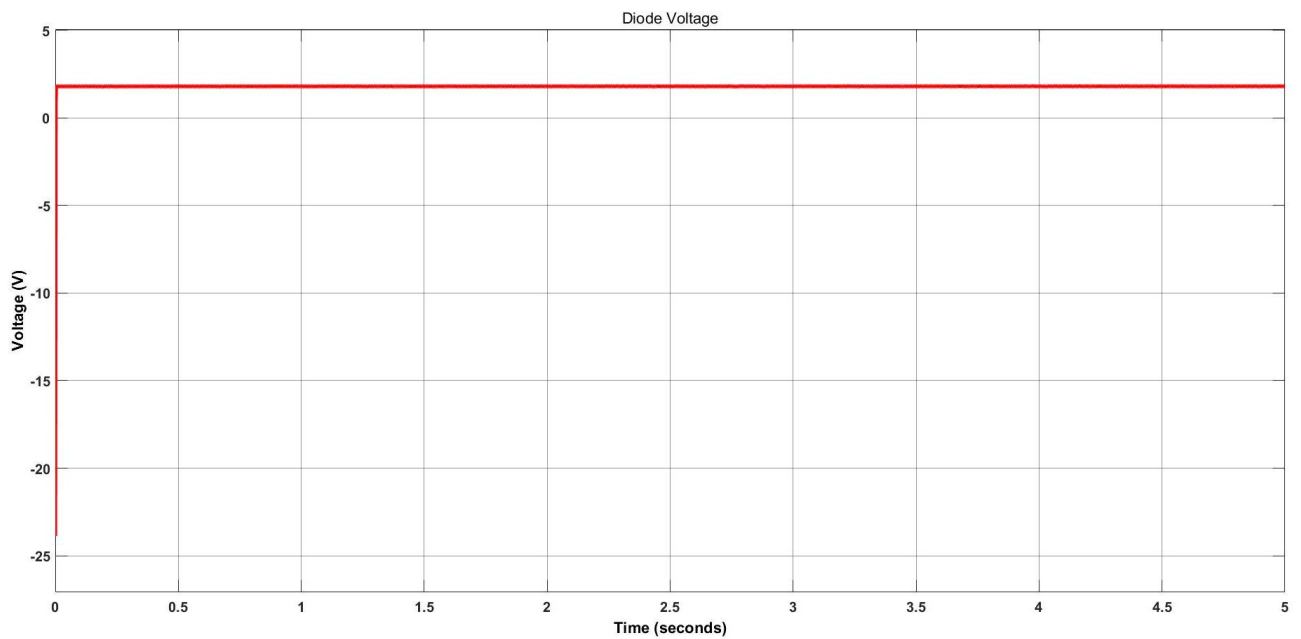
Figure 15: Output diode voltage

Figure 16 show the switching characteristics of two MOSFETs. Since this is a synchronous buck converter, switches become ON and OFF synchronously. Figure 17 show the voltage between drain and source terminals of MOSFET 2, which is used instead of the freewheeling diode. This voltage measurement is used in component selection process. Detailed discussions are provided in component selection part.

Figure 16: Switching characteristics of MOSFET's.

Figure 17: Voltage on the freewheeling MOSFET

Since the simulation model includes the non-idealities and real parameters of selected components, it is possible to measure the efficiency. However, real efficiency would be smaller due to the switching losses of MOSFETs and other losses that can not be obtained in the simulation. In this simulation, internal resistance of switches, series resistances of capacitors and inductors are includ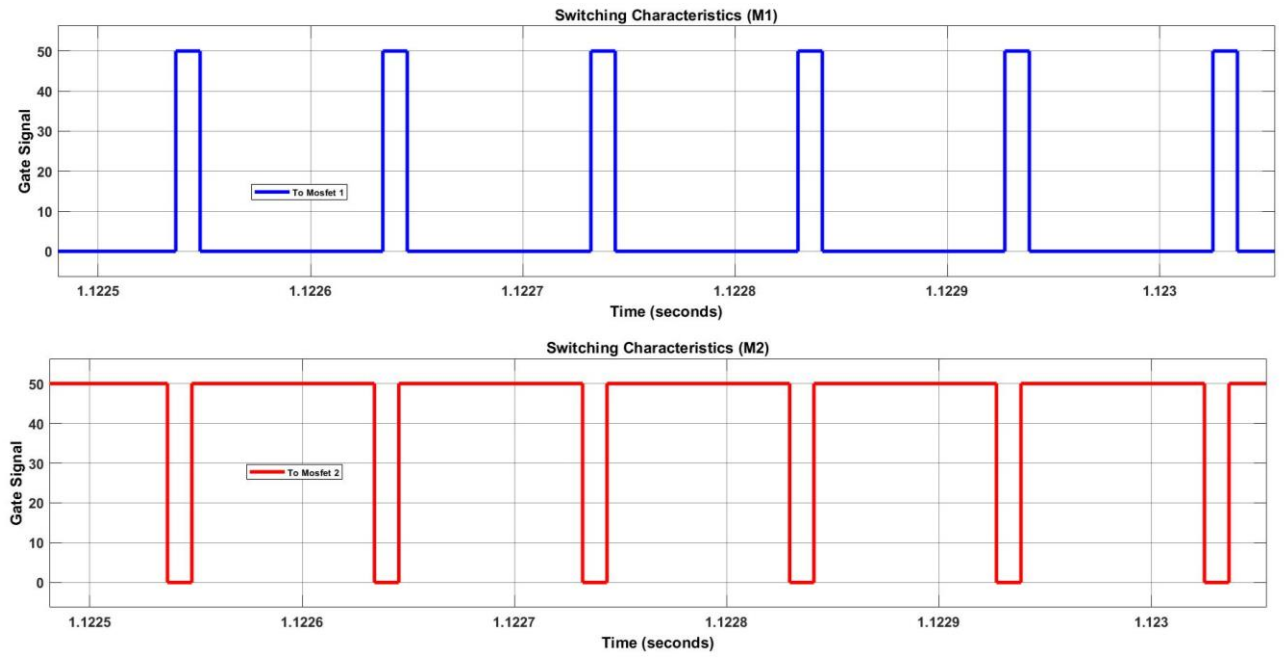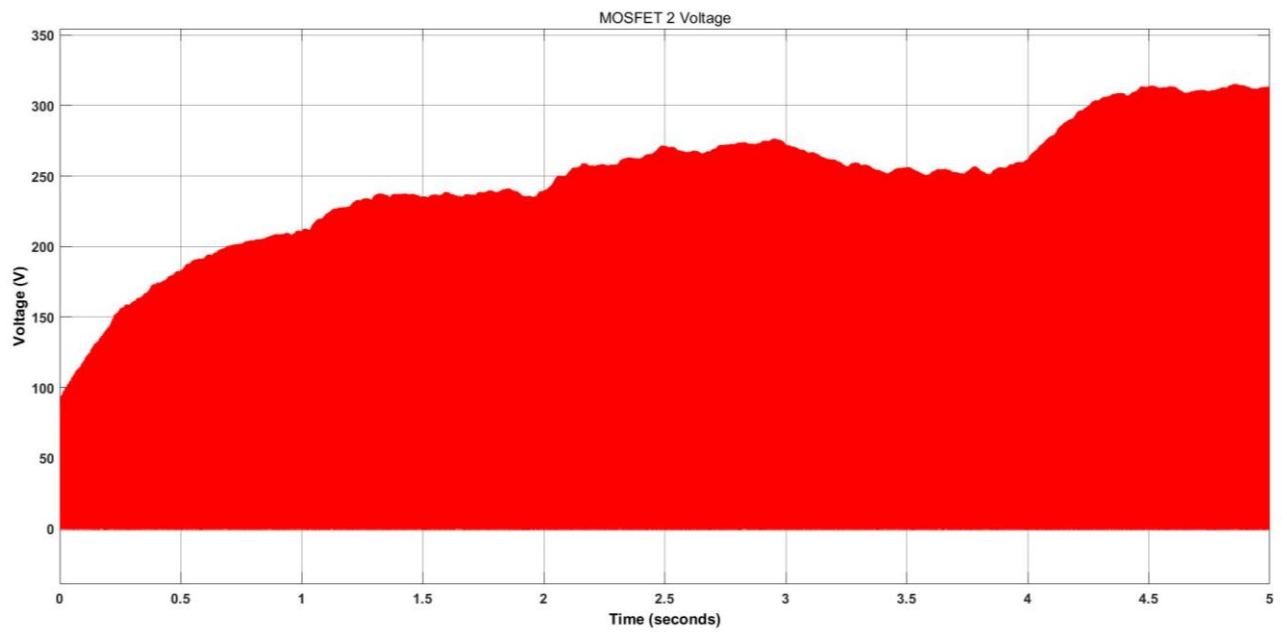ed. Also, effect of current sense resistor is also included. Figure 18 shows the efficiency measurement block. Simulation efficiency is found as 91.22%.
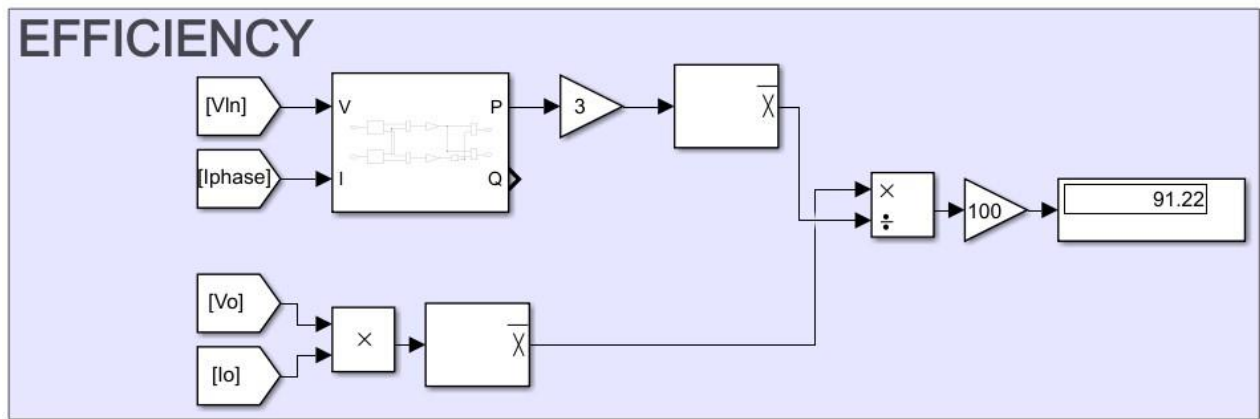
Figure 18: Efficiency measurement

6. Component Selection

In this part of the report, the component selections are presented. The followed roadmap for the component selection is measuring the related voltages and currents for the analyzed component. According to the stresses over them the related components are selected. In this report the selections starting from the rectifier stage to the end stage are presented orderly.

6.1. Rectifier Stage

In the rectifier stage there are two components: diodes and capacitor. The voltage and current measurements for the rectifier diodes are given in figure 7 and 8 in simulations part. For safety of the design, components need to be selected with 1.5 multiples of the measurements. The voltage over diodes will be measured as approximately 325V, and the currents as maximum 0.9A. Then, according to the extreme points, selected diode is presented in Table 1.

Table 1. Rectifier stage power diode parameters

Component Code	AS4PJ
I_F	4.0 A
V_{RRM}	600 V
$T_{j_{max}}$	175 °C
V_F	0.92 V
Package	SMPC (TO-277A)

The table 1 shows important parameters for the diode. The maximum repetitive reverse voltage that this diode can carry is 600V and forward current is 4A. These ratings are at least 1.5 multiples of the actual stresses shown in figure 7. The next component is the capacitor. It is selected according to the voltage over it. It sees output voltage, and rectifier output voltage characteristics are shown in figure 19.

	Value	Time
Max	4.407e+02	4.470
Min	0.000e+00	0.000e+00
Peak to Peak	4.407e+02	
Mean	4.226e+02	
Median	4.405e+02	
RMS	4.232e+02	

Figure 19: Rectifier output voltage characteristics

The capacitor is faced with at most 441V peak. Therefore, the capacitor needs to be selected accordingly its rated voltage which should be larger than 441V. Since these types of circuit components are dangerous for the health of the circuit board, these selections should be made at least 1.5 multiples of the capacitor maximum voltage level in order to prevent it from exploding. However, selecting one capacitor that can carry almost 500-600V increases the product size effectively. It is not desired for this project design point of view. It is desired to design a product that is cheapest and smallest.

For that purpose, capacitor can be divided into smaller size capacitors, and can be connected in parallel. By selecting the size and the number of capacitors in the optimum point, the requirements for this stage can be met. According to these explanations, 2 identical aluminum capacitors are selected, and their properties are given in table 2. With these discussions, rectifier side components selection is completed.

Table 2. Rectifier Capacitor Rated Values

Component Code	Rubycon MXH Series
Rated Voltage Range	400-550 V_{dc}
Selected Capacitor Rated Voltage	450 V_{dc}
Size	270 μF
Operating Temperature Range	-25°C - 105°C
Size of Capacitor	30x30 mm

6.2. Converter Stage

For the converter side switching element (MOSFET), inductor and capacitor should be selected. In simulations part, figures 9, 11 and 17 show the inductor current, output capacitor current and freewheeling MOSFET voltage.

As can be seen in figure 9, inductor current reaches to approximately 2 amperes. Therefore, an inductor should be selected such that it can carry that much current over it. Accordingly, the PM2120-102K-RC inductor which can carry 2.5Amperes current should be selected. The size of the inductor was determined according to the output current ripples. For this scenario, 1mH inductor is enough to filter ripples up to the limited regions. The selected inductor is shown in figure 13.

Figure 20: Buck converter PM2120-102K-RC inductor

On the converter side switching elements need to be selected. For this application, MOSFET as a switching element is selected due to its capability of carrying 300-350V applications and speed related advantages. As can be seen on figure 17, high side MOSFET is faced with 300-350V voltage through the drain and source terminals. Therefore, FQD6N50C-D MOSFET is selected, which can carry 1.5 multiples of the voltage stress over MOSFET for safety regarded issues. Its ratings can be seen in Table 3.

Table 3. Converter Side Mosfet Parameters

Component Code	FQD6N50C-D
V_{DS}	500 V
I_D	4.5A
Operating Temperature Range	-55°C - 150°C
$R_{\theta JC}$	2.05 °C/W
$R_{\theta JA}$	110 °C/W
Package	D-PAK FQD Series

Last component that needs to be chosen based on figure 11 is the buck converter output capacitor. Since the battery is connected to the output, the capacitor is faced with 24V nominal battery voltage. The capacitor should be selected according to this criterion. Since this application does not require higher rated voltages tantalum capacitors will be enough for this type of application. The selected capacitor is 293D155X9050C2TE3. It has 1.5 microfarad capacitance and is capable of 50V voltage. These properties are enough for this type of application.

Table 4. Buck Output Capacitor

Component Code	Rubycon MXH Series
Rated Voltage Range	50 V_{dc}
Size	1.5 µF
Operating Temperature Range	-55°C - 125°C
Size of Capacitor	7.3x4.3 mm

6.3. Battery Stage

When the MOSFET 1 is off, there will be no current that charges the capacitor. However, at that time the capacitor is charged from the battery. In order to prevent this action, a diode in the direction of the positive battery terminal can be placed. After inserting this diode, the battery will not feed the buck converter capacitor. Diode will prevent this action, and system efficiency also the battery charge oscillations is improved. For this operation, the diode given in Table 5 is selected.

Table 5. Battery Input Diode Parameters

Component Code	
I_F	3.0 A
V_{RRM}	50 V
$T_{j_{max}}$	150 °C
V_F	0.90 V
$Package$	SMC (DO-214AB)

6.4. Controller & Driver Selections

The system is fed from the wind turbine generator torque. Therefore, its input voltage is not constant. It yields a requirement to use a controller in the output, so that system stabilize its output current in the desired range. For that purpose, TL594 PWM Control Circuit is selected according to the system requirements.

6.4.1. Controller Parameters

In order to implement TL594 controller component to the circuit, it is required to select the passive components that run the controller in the desired application form.

At that stage, from the data sheet typical application circuit is analyzed. Its components are rearranged such that it suits this project application. The selected components in this stage can be found in Table 6.

Table 6. TL594 Controller Passive Components

Component	Component Name	Piece
PWM Controller	TL594	1
1kΩ Resistance	RCA06031K00JNEA	2
2.5 kΩ Resistance	RN732ATTD2501B25	1
23.5 kΩ Resistance	MCT06030C2352FP500	1
48 kΩ Resistance	CPF0805B48K7E	1
5.1 kΩ Resistance	CRCW04025K10JNED	2
9.1 kΩ Resistance	CRCW04029K10JNED	1
51 kΩ Resistance	CRCW040251K0FKED	1
510 Ω Resistance	CRCW0603510RJNEA	1
5 kΩ Resistance	MCT06030C2352FP500	1
Current Sense Resistance	RCWE0612	1
1 nF Capacitor	C1608JB2A102K080AA	1
2.2 µF Capacitor	C1005X5R0J225K050BC	1

In the selection of the passive components given in Table 5, the Figure 27 in Appendix is referred. There are several components that need to be changed according to this project requirement.

First of all, R_T and C_T components are arranged for satisfying the oscillation frequency based on the below formulations.

$$f_{osc} = \frac{1}{R_T * C_T}$$

In order to find the required R_T and C_T, there exist 3 parameters with only 1 one of them is known, which is f_{osc}. Thus, the strategy is taking 1 parameter suitable, then find the rest. The capacitor value is taken as in the datasheet example (1nF). Then, the rest is as follows.

$$200 * 10^3 = \frac{1}{1 * 10^{-9} * R_T}$$
$$R_T = 5 \, k\Omega$$
$$C_T = 1 \, nF$$

In the circuit, there is a current sense resistance, which has 1W power rating and has capability of current sense up to 10mV, in at the load side. The voltage drop over sense resistor is compared with the reference voltage in the TL594. In pin 15, there is a voltage division with 2kΩ and 48kΩ resistances. They convert 5V reference voltage to 0.2V and limits output current with 20% deviation. That is the acceptable error in the output current waveform. There is another comparator between pin1 and pin2. In there, in order to obtain 2.5V from the 26V output voltage there exists another voltage division. 2.5 kΩ and 26 kΩ resistances are used in here. Circuit checks whether there the voltage is larger than 2.5V or not. If there is, then it closes. If less, it opens.

6.4.2. Driver Parameters

In order to give the controlled signal to the gate of the MOSFETs as a closed loop system form, gate drivers are preferred. By arranging the duty cycle of the PWM signals according to the load characteristics, the desired output waveforms can be obtained. For the NCP5181 gate driver, the possible application circuit can be found in Appendix Figure 28.

For this design, it is required to select only 3 components: 2 Capacitor and 1 Diode. For capacitors, it is enough to choose small ceramic capacitors. There are not high voltage ratings over them. Therefore, selecting 0.2 µF 25V ceramic capacitor is enough for this operation. For the diode selection again as an optimum selection can be done. Thus, 60V 3A power diode is selected in order to satisfy the possible stresses in the circuit. Components are given in table 6.

Table 7. Gate Driver Components

Component	Component Name	Piece
Mosfet Gate Driver	NCP5181	1
Power Diode	SBR3U60P5-7	1
0.2 µF Capacitor	12063C204KAT4A	2

7. Thermal Analysis

In the circuit, there are some components that creates heat. The heated components have some temperature limits, such that after that temperature components will damaged. Therefore, the overall circuit will be useless. In order to take into account this effect, the thermal analysis of the circuit is required.

In analysis part, there are 4 components that need to be considered in thermal view. These are rectifier diodes, converter MOSFETs and battery diode which disables charging the capacitor from the battery.

Over MOSFETs, there are 2 types of losses; switching losses and conduction losses. The calculations for these losses can be seen in below equations.

Switching losses are calculated by;

$$P_{sw_{loss}} = V_{in} * I_o * f_{sw} * (t_r + t_f)$$

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Conduction losses can be calculated for high side MOSFET by;

$$P_{Cond_{loss}} = R_{DS_{ON}}^2 * I_{out}^2 * D_1$$

$$P_{cond_{loss}} = 0.514^2 * 2^2 * 0.096$$

$$P_{cond_{loss}} = 0.1W$$

Conduction losses can be calculated for low side MOSFET by;

$$P_{Cond_{loss}} = R_{DS_{ON}}^2 * I_{out}^2 * (1 - D)$$

$$P_{cond_{loss}} = 0.514^2 * 2^2 * 0.904$$

$$P_{cond_{loss}} = 0.955W$$

Switching losses can be calculated for high side MOSFET by;

$$P_{sw_{loss}} = 300 * 2 * 200 * 10^3 * 80 * 10^{-9}$$

$$P_{sw_{loss_{highside}}} = 9.6W$$

Switching losses can be calculated for low side MOSFET by;

$$P_{sw_{loss}} = 24 * 2 * 200 * 10^3 * 80 * 10^{-9}$$

$$P_{sw_{loss_{lowside}}} = 0.768W$$

For the diode losses, it can be calculated for the rectifier side as;

$$P_{loss} = V_F * I_F * D$$

$$P_{loss} = 0.92 * 2 * \frac{1}{3} = 0.613W$$

For the input diode of battery, it can be calculated as;

$$P_{loss} = V_F * I_F * D$$

$$P_{loss} = 0.9 * 2 = 1.8W$$

For temperature increase of high side MOSFET;

$$T_{junction} = T_{ambient} + R_{JA} * \left(P_{cond_{loss}} + P_{sw_{loss}}\right)$$

$$T_{junction} = 25 + 110\frac{C}{W} * (9.6W + 0.1W) = 1092 \; Celsius$$

For temperature increase of low side MOSFET;

$$T_{junction} = T_{ambient} + R_{JA} * \left(P_{cond_{loss}} + P_{sw_{loss}}\right)$$

$$T_{junction} = 25 + 110\frac{C}{W} * (0.955W + 0.768W) = 214.53 \; Celsius$$

For temperature increase of rectifier diodes;

$$T_{junction} = T_{ambient} + R_{JA} * (P_{loss})$$

$$T_{junction} = 25 + \frac{80C}{W} * (0.613W)$$

$$T_{junction} = 74.04 \; Celsius$$

The maximum operating temperature of this diode is 175 Celsius. Therefore, there is no requirement for thermal design for this diode.

$$T_{junction} = T_{ambient} + R_{JA} * (P_{loss})$$

$$T_{junction} = 25 + 47 * 1.8$$

$$T_{junction} = 109.6 \; Celsius$$

The maximum operating temperature of this diode is 150 Celsius. Therefore, there is no requirement for thermal design for this diode.

As can be seen from the calculations, it is only required to select heatsink for the MOSFETs because their temperature increase is very high. If this precaution is not taken, then

the overall system will burn. In order to select a heat sink, such that it can capable of handling such a high temperature, it is required to select very big heatsink and also a fan. However, the aim of this project is to design the smallest and cheapest design. Therefore, it is not applicable from this perspective.

For the overall design, an Al 1060 alloy box is designed over CAD program, and overall PCB will be mounted on the box. The surface of the components and box will be touches each other. Such a large Al alloy can capable the thermal requirements of this circuit. Its thermal conductivity is 200W/m-K. At the end, it will be painted with black colour, which will increase the thermal conductivity of Al very critical. All of the semiconductor devices are touching to the Al alloy box, so that they are also be in safe side.
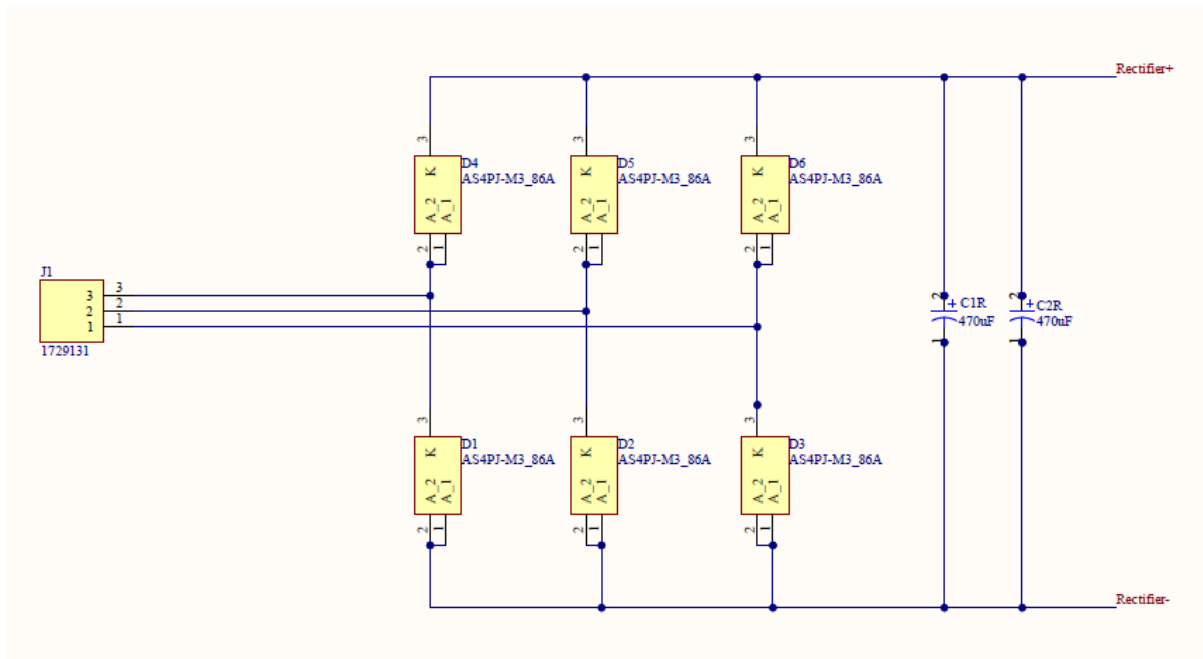
8. PCB Design

Figure 21. Rectifier schematic

Figure 22. Buck Converter Schematic
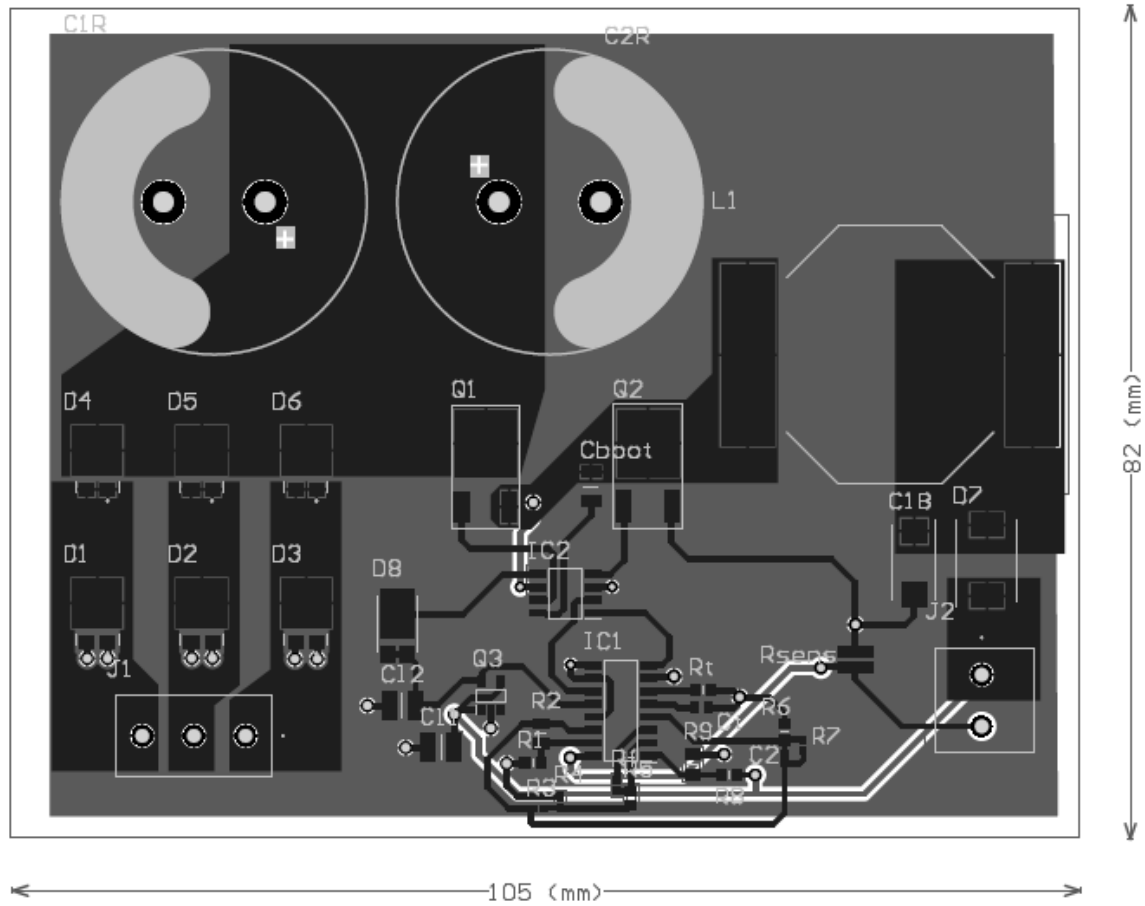

Figure 23. Controller Schematic

Figure 24. PCB Layout of Overall Circuit

For the high current passing routs, polygon planes are preferred so that system will be completely in safe. However, there were some connections which could not be applicable for polygon plane. For them, online layout trace width calculator was used, and for the safe two amperes current passing route, the width has been calculated as at least 0.68mm. It is preferred to use 0.7 trace width for 2 amperes current. For the other connections, such as connections of driver passive elements, 0.6 trace width was selected. All of the components were placed on to the top layer. In addition, although most of the connections were made on the top layer, some of the connections were routed at the bottom layer. The connection between the top layer and bottom layer were satisfied by using Via's. Finally, since the ground connection is the most common used one, rest of the bottom plane was coated with a ground polygon plane.
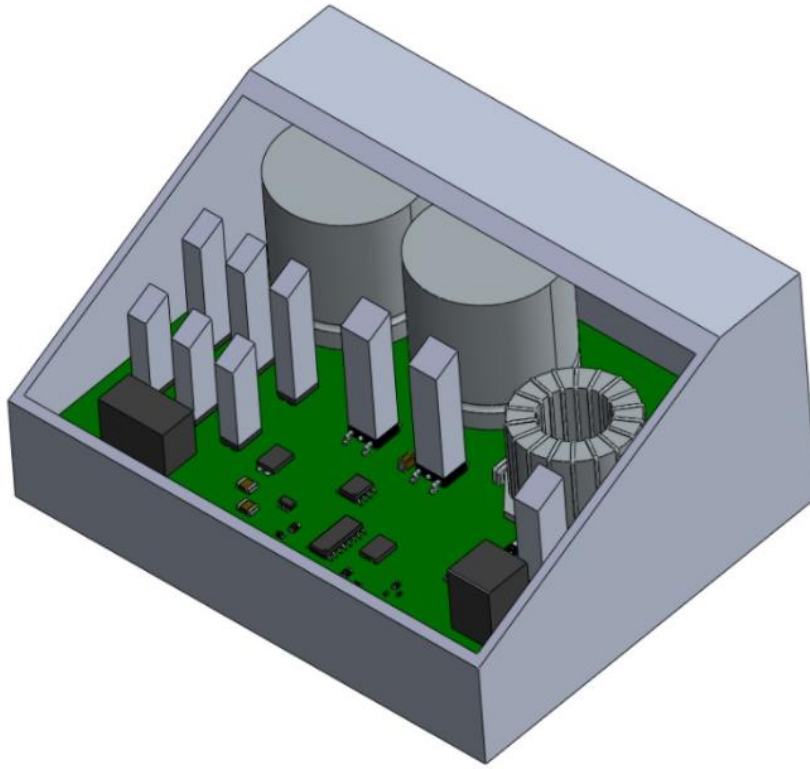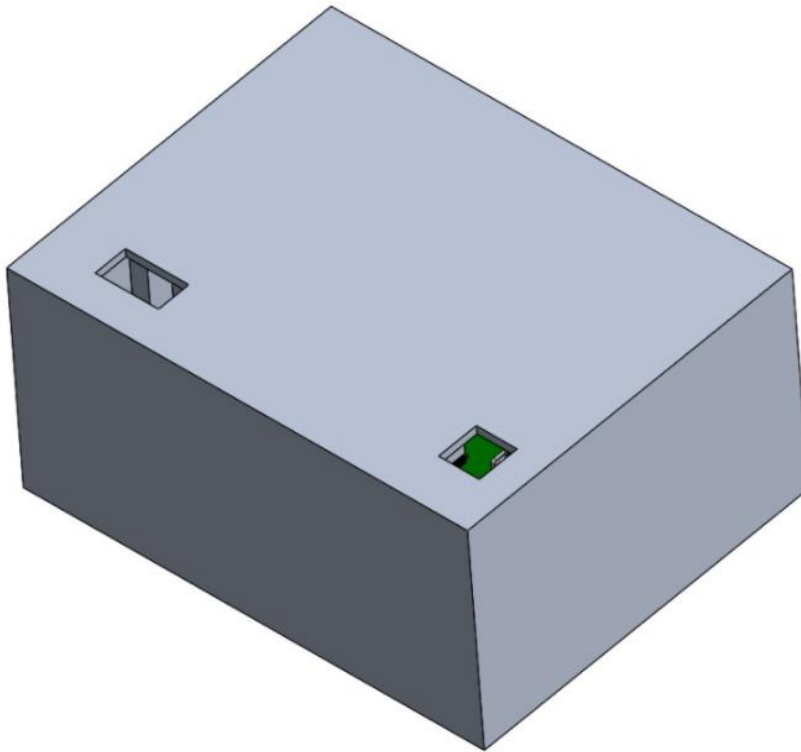
Figure 25. 3D Box Design Open Form

Figure 26. 3D Box Design Closed Form

9. *Cost Analysis*

Table 8. Overall System Cost Analysis

Cost Analysis of the Project			
Component Code	**Unit Price**	**Required Unit**	**Total Cost**
Rectifier Stage			
AS4PJ	$0.36	1	$0.36
Rubycon Mxh Series 270 µF	$3.37	2	$6.74
Converter Stage			
PM2120-102K-RC	$1.57	1	$1.57
FQD6N50C-D	$0.41688	2	$0.83376
293D155X9050C2TE3	$0.34291	1	$0.34291
Battery Stage			
ES3B	$0.14280	1	$0.14280
Controller Components			
TL594	0,326 €	1	0,326 €
RCA06031K00JNEA	$0.011	2	$0.022
RN732ATTD2501B25	$0.087	1	$0.087
MCT06030C2352FP500	$0.01581	1	$0.01581
CPF0805B48K7E	$0.10578	1	$0.21156
CRCW04025K10JNED	$0.00511	2	$0.01022
CRCW04029K10JNED	$0.00511	1	$0.00511
CRCW040251K0FKED	$0.00596	1	$0.00596
CRCW0603510RJNEA	$0.00511	1	$0.00511
MCT06030C2352FP500	$0.01581	1	$0.01581
RCWE0612	$0.17350	1	$0.17350
C1608JB2A102K080AA	$0.0121	1	$0.0121
C1005X5R0J225K050BC	$0.4225	1	$0.04225
Driver Components			

NCP5181	0.829 €	1	0.829 €
SBR3U60P5-7	$0.24278	1	$0.24278
12063C204KAT4A	$0.11453	2	$0.22906
Physical Connectors			
277-1263-ND	$0.94350	1	$0.94350
277-1248-ND	$1.173	1	$1.173
Thermal Component			
573400D00010G	$1.01279	2	$2.02
PCB Order			
PCB	$1.013	1	$1.013
Total Cost			$15.13

In the cost analysis of the project, stage by stage analysis may simplify the understanding budget distribution. In the following Table 8, overall system cost analysis can be found stage by stage. These cost analyses are done by referring price per 1000 unit according to the project bonus specifications.

As can be understood from Table 8, overall system budget is $12.46755. Except 2 components, the rest is found in Digikey. The related bill of materials can be found in **Appendix B.** For the two components, which are controller and driver, they are ordered from Mouser. For this order, related chart is attached in **Appendix B** also.

10. Conclusion

In this report, the development process of an AC-DC battery charger is represented. First, the problem is defined and requirements are determined. Since the power supply is a wind turbine, frequency and amplitude of the generated electricity varies randomly. Therefore, the designed product should be capable of converting variable frequency and variable amplitude AC to constant current DC with determined specifications of the project. According to the problem definition and requirements, conceptual design is completed. Without diving into deep technical discussions, capabilities that product must have are determined. After the conceptual design stage, technical discussions are conducted and topology selection is made. In this stage, different topologies are compared and the best option is determined. Designed topology is simulated with ideal components and the operation conditions that the real components must be capable to work under are determined. According to the determined values, real components are found from the market, and these are inserted to the simulation environment. Effect of selected components are observed on the simulation except for the controller and drivers. Since their models are not reachable on Simulink or LTSpice, their simulations cannot be observed.

After simulation presentations, feedbacks taken about the upcoming points are noted. Then accordingly, controller is revised, and with a new approach a controller is designed. It is observed that it can give better results as can be understood from the waveforms.

In the design of PCB stage, first the passive components of the controller and driver are selected as explained in the component selection section. After selecting them, overall system components are determined. Their cost analysis are extracted, and it is observed that the total project cost is $15.13.

As a summary, in this project the basic topics in AC to DC and DC to DC converters are learned. Besides the design process, also the component selection steps are experienced which is very crucial in the professional engineering life. Moreover, the technical drawing for the power cards is applied and experienced.

References
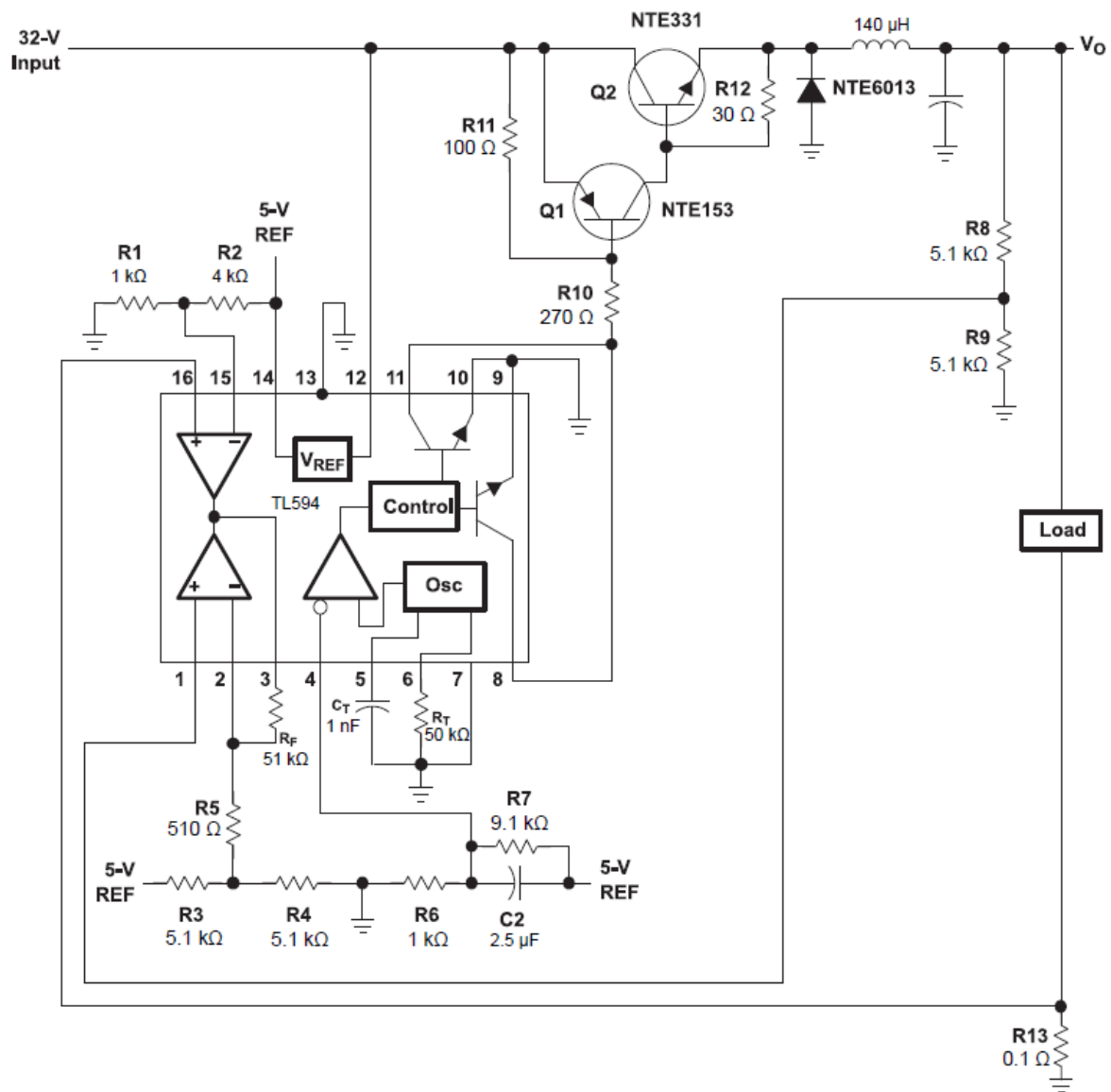
For the component selections;

https://www.digikey.com/

https://eu.mouser.com/

For the PCB order;

https://www.pcbway.com/

Appendix A

TL594 Controller application circuit can be seen in figure 27.

Figure 27.Typical TL594 Application Circuit

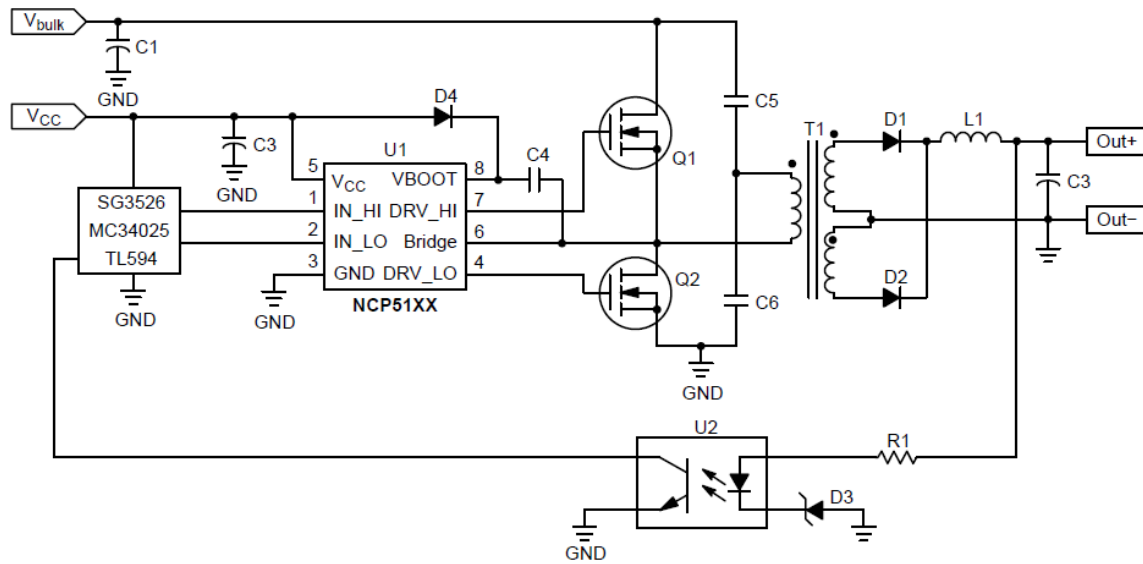Driver application circuit can be seen in figure 28.

Figure 28.NCP5181 Typical Application Circuit

Appendix B

Controller and Driver components were not found in Mouser. They cannot found in Digikey, but added to the cost analysis.

Sort	Product Detail			Description	Quantity	Availability	Unit Price (EUR)	Ext. Price (EUR)	
1		Mouser No: Mfr. No: Mfr.: Customer No:	595-TL594IN TL594IN Texas Instruments Customer No	Switching Controllers PWM Controller RoHS Compliant QuickView	1	1 Dispatches Now	0,771 €	0,77 €	🗑
2		Mouser No: Mfr. No: Mfr.: Customer No:	863-NCP5181DR2G NCP5181DR2G ON Semiconductor Customer No	Gate Drivers HV MOSFET DRIVER RoHS Compliant QuickView	2 Packaging: **Cut Tape	2 Dispatches Now	1,74 €	3,48 €	🗑

By submitting your order you agree to these terms and conditions.
For additional information on availability, click on the Mouser Part No.

Merchandise: 4,25 €

Figure 29. Mouser cost analysis

SHOPPING BASKET

This is not an invoice.

Sort	Product Detail			Description	Quantity	Availability	Unit Price (EUR)	Ext. Price (EUR)
1		Mouser No: Mfr. No: Mfr.: Customer No:	595-TL594IN TL594IN Texas Instruments Customer No	Switching Controllers PWM Controller RoHS Compliant	1000	1.000 Dispatches Now	0,326 €	326,00 €
2		Mouser No: Mfr. No: Mfr.: Customer No:	863-NCP5181DR2G NCP5181DR2G ON Semiconductor Customer No	Gate Drivers HV MOSFET DRIVER RoHS Compliant	2000 Packaging: **Cut Tape	2.000 Dispatches Now	0,829 €	1.658,00 €

By submitting your order you agree to these terms and conditions.
For additional information on availability, click on the Mouser Part No.

**All MouseReel™ items are non-cancellable and non-returnable.

Incoterms: DDP is available to customers in EU Member States.
All Prices include duty and customs fees on select shipping methods.

Merchandise:		1.984,00 €
Shipping:	FedEx International Priority	0,00 €
	+ More Delivery Options	
Subtotal:		**1.984,00 €**

Figure 30. 1000 Pieces order bill

Manufacturer Part Number	Digi-Key Part Number	Quantity	Unit Price	Extended Price	Net Price
AS4PJ-M3/86A	AS4PJ-M3/86AGICT-ND	1000	0.36668	$366.68	$366.68
PM2120-102K-RC	M8801-ND	1000	1.575	$1,575.00	$1,575.00
FQD6N50CTM	FQD6N50CTMCT-ND	2000	0.41688	$833.76	$833.76
450MXH270MEFCSN3	1189-1995-ND	2000	3.37633	$6,752.66	$6,752.66
RCA06031K00JNEA	541-2213-1-ND	2000	0.011	$22.00	$22.00
RN732ATTD2501B25	2019-RN732ATTD2501B	5000 1000	0.08704	$435.20	$87.04
MCT06030C2352FP50	MCT06030C2352FP500-	5000 1000	0.01581	$79.05	$15.81
CPF0805B48K7E	CPF0805B48K7E-ND	5000 1000	0.10578	$528.88	$105.78
CRCW04025K10JNED	541-5.1KJCT-ND	2000	0.00511	$10.22	$10.22
CRCW04029K10JNED	541-9.1KJCT-ND	1000	0.00511	$5.11	$5.11
CRCW040251K0FKED	541-51.0KLCT-ND	1000	0.00596	$5.96	$5.96
CRCW0603510RJNEA	541-510GCT-ND	1000	0.00511	$5.11	$5.11
MCT06030C2352FP50	MCT06030C2352FP500-	5000 1000	0.01581	$79.05	$15.81
RCWE0612R200JNEA	541-2502-1-ND	1000	0.1735	$173.50	$173.50
C1608JB2A102K080A/	445-11305-1-ND	1000	0.0121	$12.10	$12.10
C1005X5R0J225K050E	445-6847-1-ND	1000	0.04225	$42.25	$42.25
12063C204KAT4A	478-12814-1-ND	2000	0.11453	$229.06	$229.06
SBR3U60P5-7	SBR3U60P5-7DICT-ND	1000	0.24278	$242.78	$242.78
293D155X9050C2TE3	718-1811-2-ND	1000	0.34291	$342.91	$342.91
ES3B	ES3BFSCT-ND	1000	0.1428	$142.80	$142.80
1715721	277-1263-ND	1000	0.9435	$943.50	$943.50
1729131	277-1248-ND	1000	1.173	$1,173.00	$1,173.00
PCB				$1,013.00	$1,013.00
Total from digikey				$15,013.58	$14,115.84
From mouser 1000 pieces prices				1,984.00 €	$1,984.00
Total				$17,414.22	$15,128.84
Per unit price				$17.41	$15.13

For PCB there is $273 shipping cost which is inserted in the analysis.