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Simulation of DC Buck Converter for Battery Charger using MATLAB Simulink

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Abstract: This project is conducted to analyze the performance of a DC buck converter as well as other electronic components such as a rectifier used for a battery charger using MATLAB Simulink. The objective of the study was to determine the current output while optimizing the rate of charger and efficiency of the buck converter during the charger process. The simulation model was developed based on a block of electronic components as the foundation for the simulation development. It includes components such as a capacitor, inductor, diode and switch along with control signals for controlling the current and voltage output desired. The simulation scenarios included various charger conditions such as types of switches used, the value of an inductor, and additional components added in the simulation to be analyzed and compared in order to get the highest effectiveness. The results from the simulation demonstrate the effectiveness of the buck converter in aspects of getting a stable output voltage and regulating the charger current. The converter results in low current ripple and voltage ripple indicating a smooth charging procedure. The effectiveness of the buck converter was evaluated as well as the rectifier and highlighting the ability of the buck converter to convert input voltage (VAC) to charging output voltage (VDC) effectively. Overall, the simulation of the DC Buck converter as a battery charger using MATLAB Simulink shows a comprehensive analysis based on the performance of the converter as a battery charger. The findings from this project can contribute to the future design and implementation of efficient and reliable battery charger systems on a daily basis.

Keywords: DC Buck Converter, Current Ripple, Rectifier, Battery Charger, MATLAB Simulink.

1. Introduction

Nowadays, an increasing demand for reliable and efficient battery charger systems in various industries such as due to the importance of the energy storage field particularly for electric vehicles and electric scooters [1]. This project aims to evaluate and analyze the performance of a DC Buck converter in the application of a battery charger. In order to gain reliable and efficient battery charger systems,

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the understanding of improving the design of the buck converter is essential. The process of the simulation of buck converter for battery charger is being tested using a widely used simulation software which is MATLAB Simulink which provides a powerful platform modeling and simulating complex systems is important for making it an ideal tool for this project.

A battery charger consists of a rectifier circuit, power circuit, ripple monitoring, control circuit and fault detection circuit [2]. The simulation also will provide all the data involved in this simulation to show the reliable battery charger systems. By simulating the DC Buck Converter using MATLAB Simulink for the battery charger, the output simulation and performance parameters will be observed. The consistency of the output voltage, the existence of current ripple and the overall effectiveness of the converter under various operating scenarios are important factors of interest. The output current of the battery charger using a DC Buck converter in the simulation will be analyzed in order to optimize the output current by experimental changing the parameters in the circuit.

The design technique depends on several things, such as the value of the inductor and the type of switching tools, to achieve the desired results. The value of the input voltage is fixed according to Malaysia single phase supply which is rated at 240 Vac with 50 Hz.

2. Methodology

The project was broken up into three stages: calculating various components, Method to trigger MOSFET and analyzing the output of the converter. The project is implemented using MATLAB Simulink for the simulation and analysis parts. Figure 1 depicts the flowchart of the project methodology.

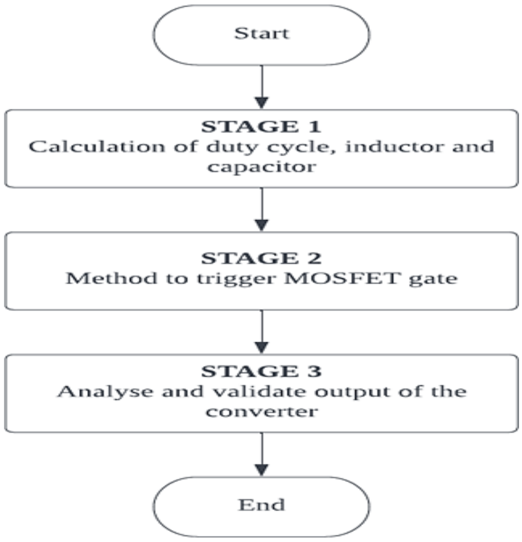


Figure 1: Flowchart of project methodology

2.1 Designing of DC Buck Converter as a Battery Charger

The workflow for this project will start from the schematic design before doing the simulation. MATLAB Simulink is the main software that is used for circuit and data analysis for the simulation. Next, the simulation design will continue with designing the DC/DC buck converter. The simulation design will be the first step to ensure the conversion of voltage from 240V into 24V. MOSFET switching will be used for the switching scheme for the converter. Figure 2 illustrates the process flow of the DC Buck Converter as a charger circuit.

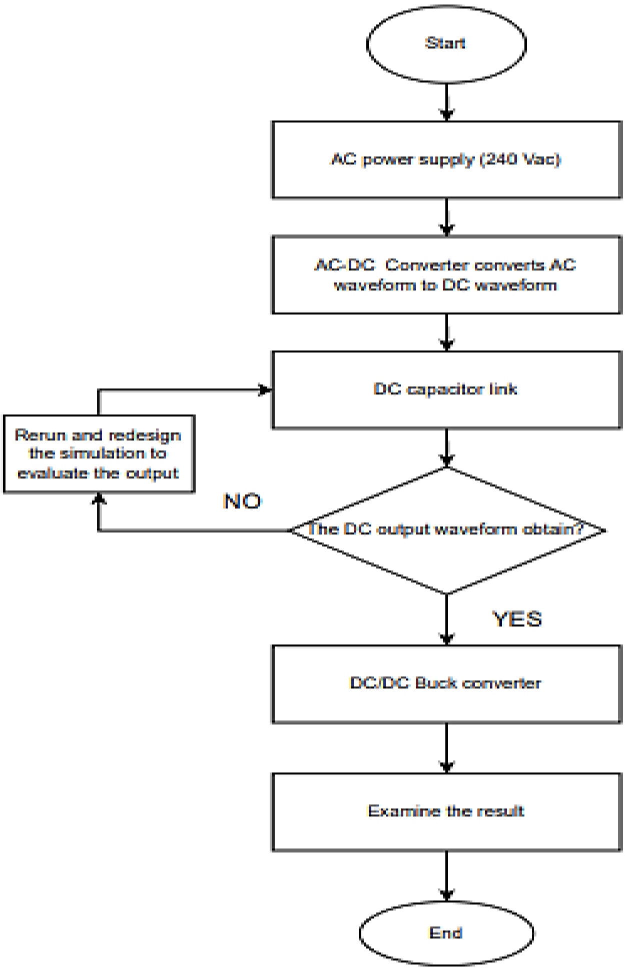


Figure 2: Flowchart of system design

2.2 Design of Main Circuit DC/DC Buck Converter.

The Full-wave bridge rectifier will be used for the conversion of the AC to DC process, which involves the design of the four diodes and DC link capacitor that connects the AC/DC converter to the DC/DC converter. The design has been optimized and will be used in MATLAB Simulink simulation and run processes to examine the voltage output and output current. During this simulation process, the value of capacitors, and inductors are maintained. The circuit connections are shown in Figure 3 (a) and (b).

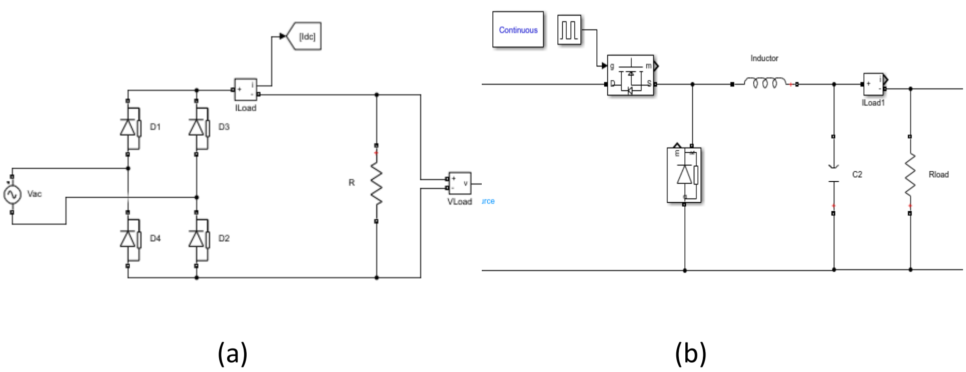


Figure 3: The design structure of a battery charger (a) Full-wave Bridge Diode Rectifier with capacitor link (b) DC/DC Buck Converter

2.3 Method to increase the output current for DC Buck Converter

The purpose of this method is to increase the current output of the DC Buck converter to achieve a faster rate of the DC Buck Converter charger. There are two types of methods that are used to achieve the objective of this simulation are tabulated in Table 1.

Table 1: Selected Value of Inductor and Capacitor being tested

Value of Inductor	Value of Capacitor
5mH	$2.8\mu F$
10mH	$1.4\mu F$
20mH	$0.7\mu F$
50mH	$0.2\mu F$

The first method is by changing the value in the value of the inductor somehow related to the size of the current ripple and the current output in the DC Buck converter. Table 1 shows the parameter that is being tested to increase the current output in the simulation. A higher inductance value yields a smaller ripple current and the peak inductor current cannot be greater than the peak internal switch current [3]. The use of a greater inductance value permits the output current to be slightly higher since the peak current is equal to the average load current plus half the ripple current. The value of the capacitor also is adjusted, following the formula of the DC Buck converter [4]. Figure 4 shows the flow of adjusting the inductor value.

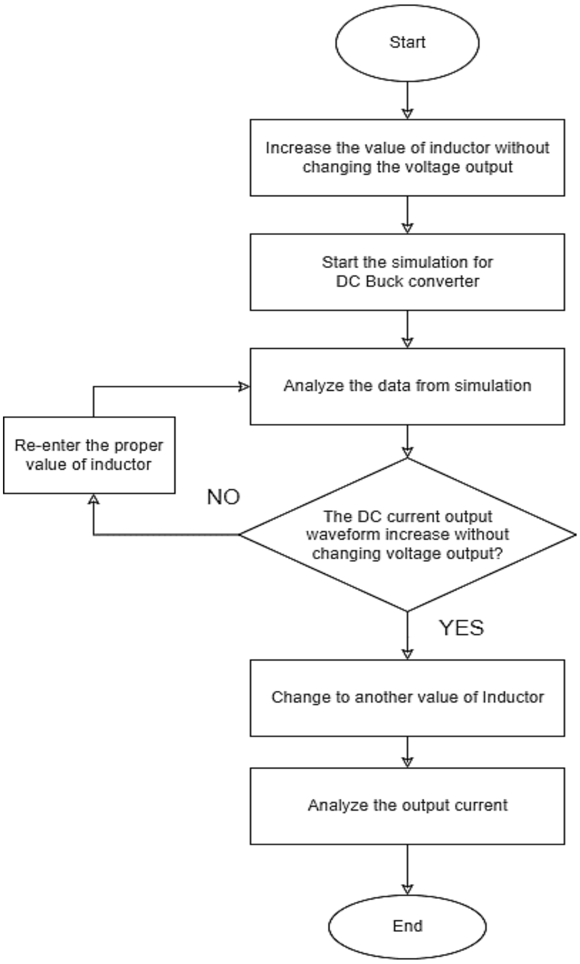


Figure 4: Flowchart of Buck Converter Simulation

The second method to increase the current output is by using the PID controller that controls the voltage output through voltage control mode so that the voltage output not exceed the value of 24V output. The value of inductor and capacitor are changed in order to increase the current output while tuning the voltage output using PID controller. The Figure 4 show the process of the repeating the tuning of PID controller after changing the value of components. The process will continue until the PID controller cannot longer adjust the voltage output. Figure 5 shows circuit of DC Buck Converter as a charger with PID controller.

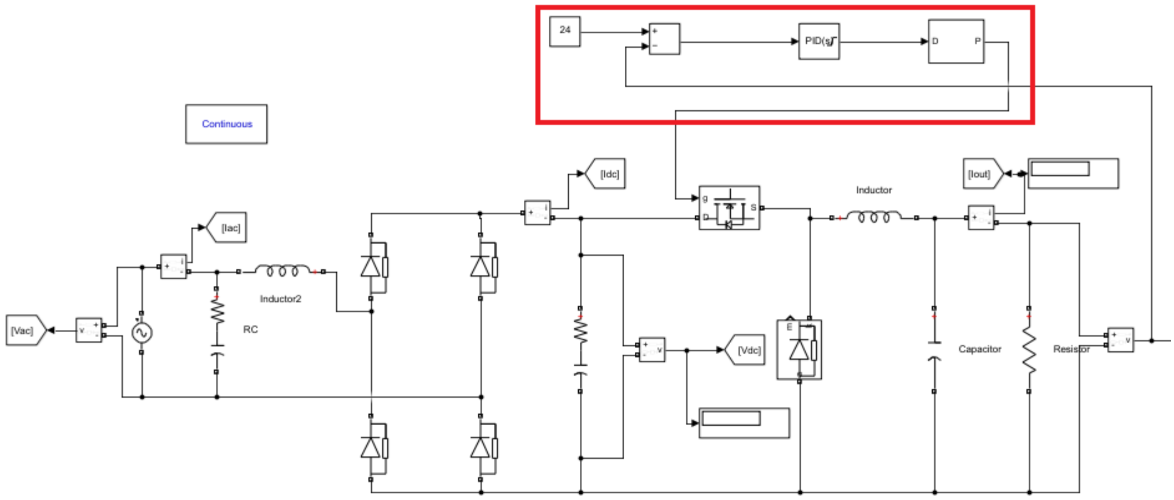
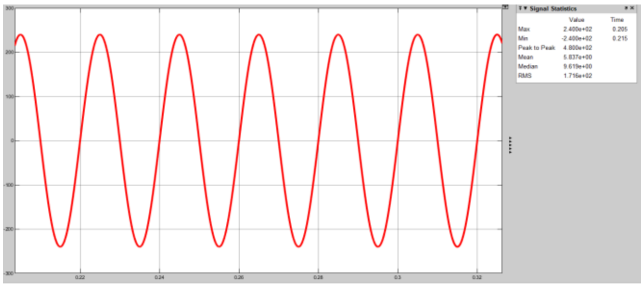
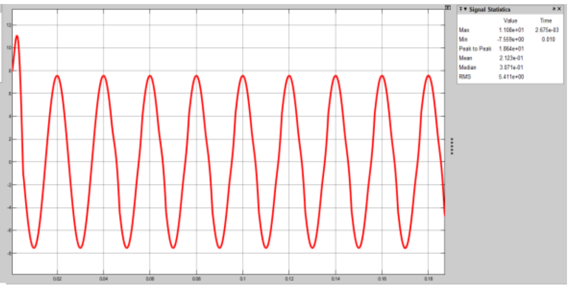


Figure 5: Connection of DC Buck converter with PID Controller

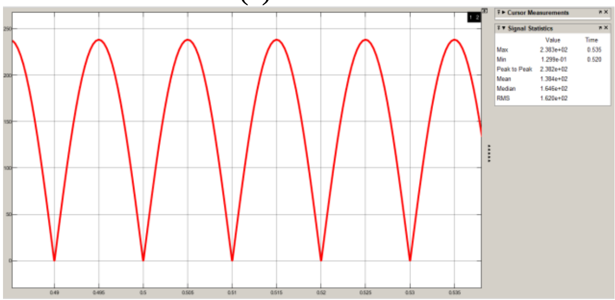
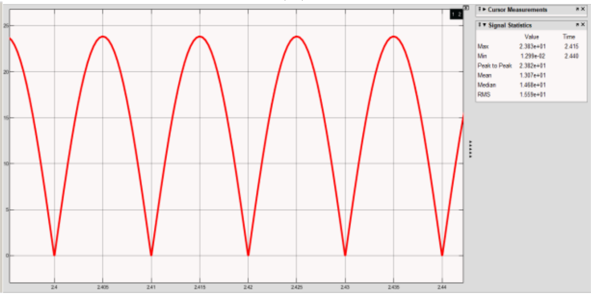
3. Results and Discussion

This section will be the output findings from the simulation result. The outcome from the simulation will be compared with the hardware result. Three cases will be tested with the simulation using MATLAB Simulink. Therefore, the changes value of components and the tuning of PID control will be shown.

The first case for testing the simulation is to make sure the shape of the waveform is accurate. The data from the waveform will be collected to be analyzed. The accuracy of the waveform is determined by the design and calculation method for this simulation. Figure 6(a) shows the sine wave of the Voltage AC supply The AC waveform with 240V peak to peak, a frequency of 50 Hz and a phase of zero degrees. The waveform is practically accurate with the theoretical. Figure 6(b) shows the waveform of the AC current supply. The AC current waveform reaches 7.6 A for its maximum amplitude. The rms value for the AC current supply is 5.343 A. The frequency of the AC current amplitude is 50 Hz with a phase of 0 degrees. Figure 6(c) shows the changes in pattern voltage waveform after the rectification through a Full-wave Bridge Diode rectifier from AC to DC. The value of rectified voltage is 238 V which is equivalent to 240V supply. Figure 6(d) shows the graph of DC current after the rectification through a Full-wave Bridge Diode rectifier from AC to DC. The value of the rectified rms current is 1.68 A.

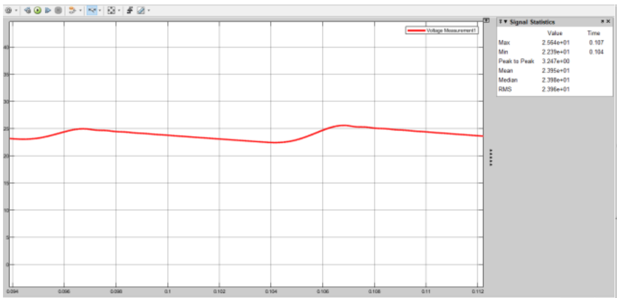
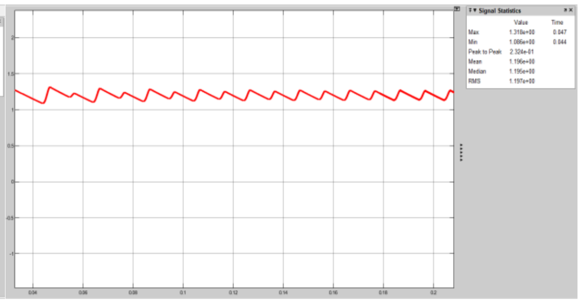
(a) (b)

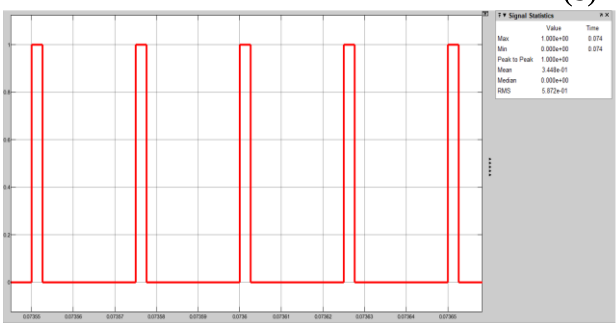
(c) (d)

Figure 6: The output waveform from the simulation AC (a) Voltage Input AC (b) Current Input Ac (c) Voltage rectifier output (d) Current rectifier output

Figure 7(a) shows the graph of DC current after the rectification through a Full-wave Bridge Diode rectifier from AC to DC. The value of rectified rms current is 1.68 A. Figure 7(b) shows the voltage output waveform initially from 240V to 24V DC. The 240V passes through a DC Buck converter that steps down the voltage, to get the desired voltage output which is 24V. Figure 7(c) shows the PWM signal that is generated into the DC-DC Buck converter with the amplitude set at 1. The repeating sequence gives a pulse for switching the ON and OFF timeline. The frequency of the PWM is 40000 Hz.

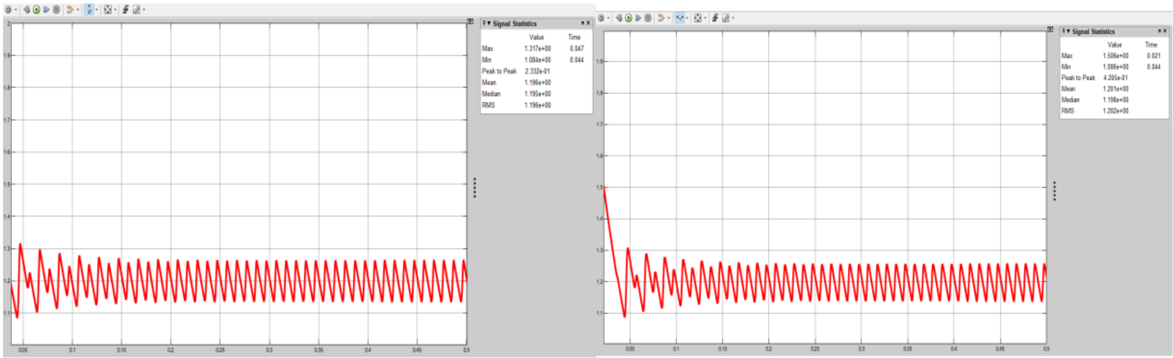
(a) (b)



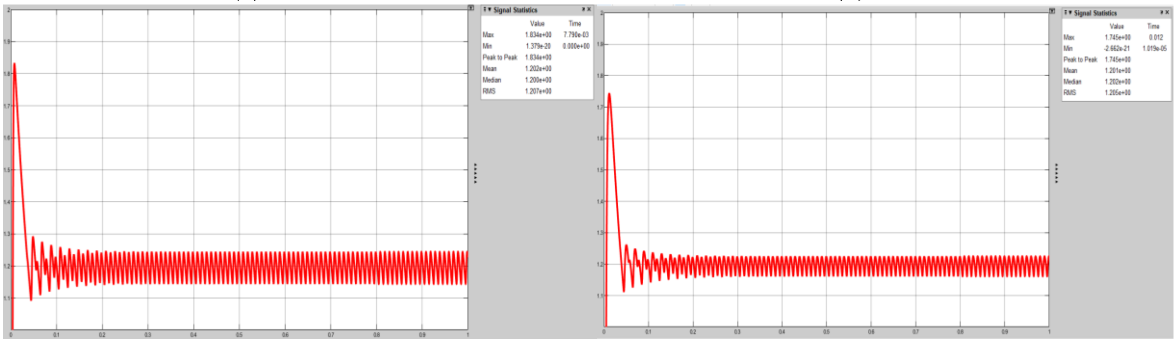
(c)

Figure 7: The output waveform from the simulation AC (a) Voltage Output DC (b) Current Output DC (c) PWM

The process of this method is by increasing the value of the inductor step by step in order to achieve a higher current output. A higher current output means a faster charger rate. Increasing the value of the inductor can produce a lower inductor ripple current It also increases the value of the current output. Figure 8(a) - Figure 8(d) show the difference of the current output waveform when the value of the inductor is changed to 5mH, 10mH, 20mH and 50mH respectively. Table 2 lists the readings for inductors and capacitors.



(a) (b)



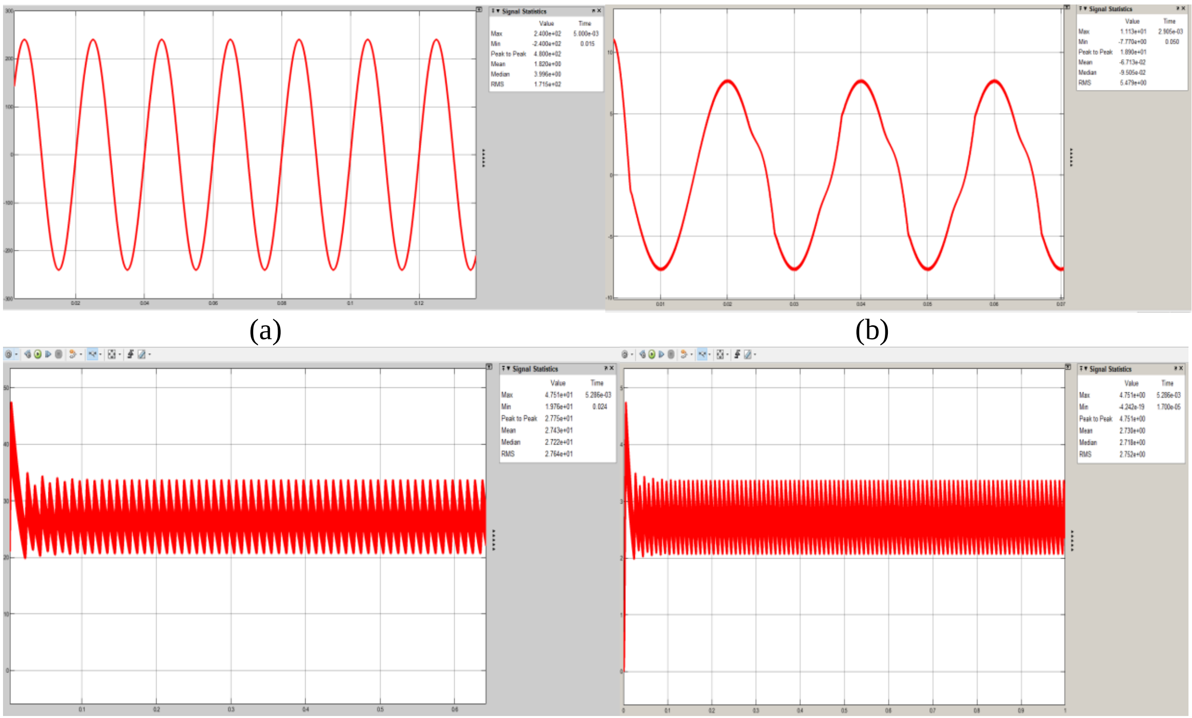
(c) (d)

Figure 8: Output waveform by adjusting the value of inductor AC (a) Current Ripple of 5mH Inductor (b) Current Ripple of 10mH Inductor (c) Current Ripple of 20mH Inductor (d) Current Ripple of 50mH Inductor

Table 2: Readings for inductors and capacitors

Inductor	Capacitor	I out	V out
5mH	2.8 μF	1.208 A	24.16 V
10mH	1.4 μF	1.213 A	24.25 V
20mH	0.7 μF	1.219 A	24.39 V
50mH	0.2 μF	1.224 A	24.35 V

The basic operation of voltage control mode is showed, including DC and AC characteristic of modulator gain. The voltage output is being compared with the desired output voltage and will be tuned in the PID controller. Then the signal will be converted in the form of PWM to trigger the gate of MOSFET. Figure 9(a) shows the voltage input 240V AC that supply the DC Buck converter as a charger. The VAC supply in sine wave before through the rectification process AC to DC converter. The PID controller gives signal to the MOSFET through gate. Figure 9(b) shows the current input 240V AC that supply the DC Buck converter as a charger. The VAC supply in sine wave before through the rectification process AC to DC converter. The PID controller gives signal to the MOSFET through gate. Figure 9(c) shows the hardware result for DC-DC Buck Converter final output when the circuit is complete with PID controller. The output is 23.72V after a step-down from 240V DC through DC Buck converter If the pulse from PID controller disconnected from gate MOSFET, the MOSFET will not able to control the simulation. The output current is 2.373 A as showed at Figure 9(d). A slightly increase the value of output current with PID controller.



(a) (b) (c) (d)

Figure 9: Output waveform by using PID Controller (a) Voltage Input AC (b) Current Input AC Inductor (c) Voltage Output DC (d) Current Output DC

To analyze the DC Buck converter as a battery charger, one simulation has been performed. The battery charger system of this simulation will be created using the application of a diode as a rectifier that turns AC to a DC source and the application of a DC Buck Converter to decrease the output voltage desired which is 24 volts. The output voltage will be maintained while trying to modify the parameters of the component in order to increase the current output that is related to a faster changing rate. The MATLAB Simulink will be used and analyze the data based on the battery charger circuit simulation. MATLAB is for the analysis and design of systems and products, mostly used by engineers and scientists. Users can use it to analyze data, design algorithms, model data, and develop applications. MATLAB is used by millions of engineers and scientists around the world for a variety of purposes [5]. Then, two methods are used to increase the current output and the result of the simulation will be compared.

The first method is being conducted by adjusting the value of the inductor with increments of the inductor value The size of the current ripple and the current output in the DC Buck converter are both affected by changes in the inductor's value in some way. The peak inductor current cannot be more than the peak internal switch current, and a higher inductance value results in a reduced ripple current. The second method was conducted through a voltage control mode by using a PID controller. The voltage control mode of the PID controller, which does not exceed the value of the voltage output 24V, aids in controlling the voltage output. to increase the current output while utilizing a PID controller to adjust the voltage output, the values of the inductor and capacitor are slightly altered.

4. Conclusion

In conclusion, the simulation of the DC Buck converter for a battery charger using MATLAB Simulink was successful and effective in accurately modeling the behavior of the converter. The simulation results showed that the Full-wave bridge diode rectifier able to convert AC waveform to DC waveform. The DC Buck converter was also able to step down the input voltage to the desired output voltage with good efficiency. The simulation also showed that the converter was able to regulate the output voltage even under varying load conditions. The change of the value inductor in the DC Buck Converter did not really have a huge impact on the current output. Only slightly increase the output current. Even so, the impact is minimal and not really recommended the method in the future. The results of the simulation showing the theoretical of increasing the value of the inductor causes the size of I ripple to decrease leading to a higher current output was successfully obtained from the simulation. Next, the second objective is achieved through the voltage control mode using the PID controller. The PID controller was able to give an accurate signal to the MOSFET gate and control the voltage output of the simulation. A better method to increase the current output. The output waveform indeed was not successfully achieved due to the pattern of the waveform. The output waveform showed a slight increase in the size of the ripple for the DC output. It is mainly due to the maximum point of getting the higher current output and parameter variation for both inductor and capacitor adjusted by the PID controller in order to get an increment current output while maintaining the 24V desired output [6]. The results from the simulation showed that the tuning of the PID controller method was able to increase the current output from 1.204A to 2.373A while the output voltage remained at 24V.

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