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Design of Battery Charger System Using AC-DC Converters with Automatic Current Regulator

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Abstract: This paper focuses on the design of the power converter for Lithium-Ion battery charger system. The use of battery as power source become high demand that's lead for good battery charger. For this purpose, a battery charger system using power converter with battery management system is proposed. This system implements the CC-CV charging method for controlling the voltage and current phase during charging. PI controllers are involved in obtaining constant current be the close loop system and microcontroller being programmed using Arduino Uno. This project result observed the output voltage and current and being analyzed. The features of this battery charger system have a protection mechanism cell balancing of the battery pack to ensure the safe and reliable operation of the Lithium-Ion battery pack. This charger is suitable for a wide range of lithium-ion batteries and can be used in applications such as electric vehicles, portable electronics, and renewable energy systems. Overall, this charger provides a reliable, efficient, and safe way to charge lithium-ion batteries using a power converter.

Keywords: Battery Charger, CC-CV, Lithium-Ion, Power Converter

1. Introduction

The use of battery has become popular and getting more significant due to the growing battery utilization as most used for portable devices such as electronic devices and renewable energy sources. Battery becomes solution to reducing the air population and fossil fuel dependance [1]. Since the batteries become energy source, the battery charger is a big issue and plays an important role as functionally for battery management, performance, and lifetime. The battery charger needs to play role as operation to the battery such as convey charging to the battery for charging phase. The lithium-ion battery is being conveyed by charging scheme which requires a constant current constant voltage (CC-CV) scheme [2]. Based on the role of the charger that need to design battery charger with high quality power, efficiency, and power density which the challenge part for designing a high-quality charger [3].

The high-quality charger will be designed by the structured of power converter such buck converter and rectifier for power conversion. The structure created of battery charger is from the combination of

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power converter such as AC/DC converter and DC/DC converter. The transformer was employed by the first battery charger to step up and step down the DC voltage. Since transformers are employed in power electronics [4], this situation needs to be improved and investigated utilizing power converters.

In terms of Li-Ion battery efficiency output when connected in series will cause the unbalanced that leads to unequal individual voltages either one or more cells will reach the maximum level before the rest. The precautions' part when handling a Li-ion battery cells is the battery cannot be over-charged due to its chemistry limitations in battery pack [5]. The issue leads to solution purpose in this project that design and develop Li-Ion battery charger with AC-DC converter circuit configuration that able to implement a CC-CV charging method with protection mechanisms passive cell balancing.

1.1 Controller for The System

The designed battery charger system should be implemented controller to control the current and duty cycle in obtaining the desired value of output current as achieving objective for this project. Firstly, part of controller is Pulse Width Modulation (PWM). Its is functional used to control switch power supplies that generate a sawtooth ramp signal. Power across load control is a technique that is frequently employed. This approach is highly effective and quite simple to use [6]. A digital signal is quickly turned on and off to perform the function, and the duty cycle, or the percentage of time the signal is on, is what defines the average value of the analogue signal [7].

Controlling the current in close loop system by implement the PI control. There are two types of system control that are frequently utilized in power converter circuits: closed loop system control and open loop system control. In this study, open loop control is considered. If the closed loop system is used in this study, it is necessary to regulate the DC-DC buck converter's input current [8]. The output current is controlled by using the PI controller. The block contains the Proportional (P) and Integral (I), two significant parameters [9]. The function of PI Controller is to compare the feedback voltage with reference voltage. The error or the difference between measured voltage and the reference voltage will be determined and PI will make an adjustment and minimize the error produced.

2. Methodology

The section will present the methodology used to develop the proposed Li-Ion battery charger system. The first subsection presents the overall block diagram of the system and battery charging pack followed by the flow chart of constant current and constant voltage (CC-CV).

2.1 Parameter Description

The specification parameters for AC/DC converter and DC/DC buck converter are shown in Table 1. The AC voltage input for rms value is 240 V and peak value is 339 V referring to scope study universal AC source. The output voltage of rectifier at C1 recorded as it being the input voltage for DC/DC buck converter. In obtaining the desired 16 V output voltage DC/DC buck converter calculated eq 1 for duty cycle. The switching frequency for the MOSFET is 50 kHz in generate the Pulse Width Modulation (PWM) for DC/DC buck converter.

Table 1: Description of AC/DC and Buck Converter

Parameters	Value
RMS input voltage, V_{AC}	240 V
Peak input Voltage, V_P	339 V
Input Voltage, V_C	267.035 V
Duty cycle, D	0.05991

Switching frequency, f_s	50 kHz
Inductor, L_1	100 mH
Capacitor, C_1	470 µF
Inductor, L_2	36.3 µH
Capacitor, C_2	500 µF
Output resistor, R_1	1.6 Ω

2.2 Block Diagram and Flowchart

Based on the Figure 1 shows that the block diagram of designed structure battery charger system. For this project using power converter starting from the AC source convert to DC through rectifier smoothing by LC filter that will be step down to 16 V as desired voltage using buck converter. The battery controller applied the CC-CV and controlled PWM duty cycle.

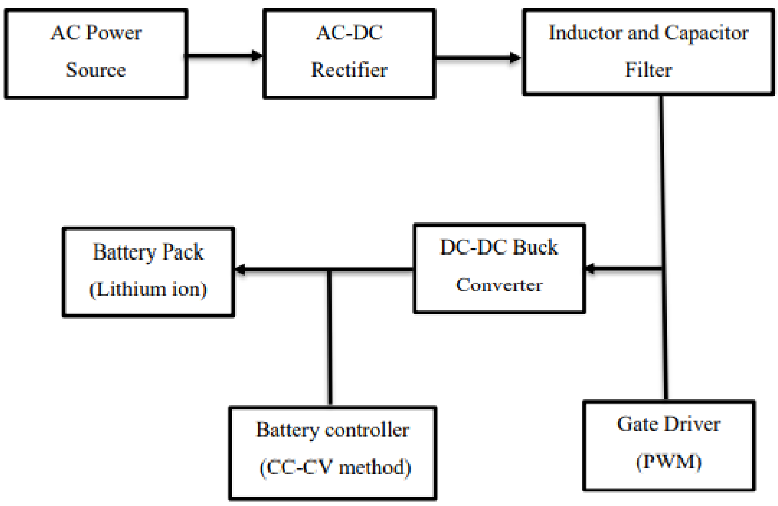

Figure 1: Block Diagram Designed Structure of Battery Charger System

The process of constant current and constant voltage explained by flowchart shown in Figure 2. The output current and output voltage will be compared to desired value that been set and the comparison is to ensure the duty cycle either need to increase or decrease. The controlling value of duty cycle as a close loop system that any error occur betwwen actual and desired will be eliminated and the expected output current and voltage will be achieve.

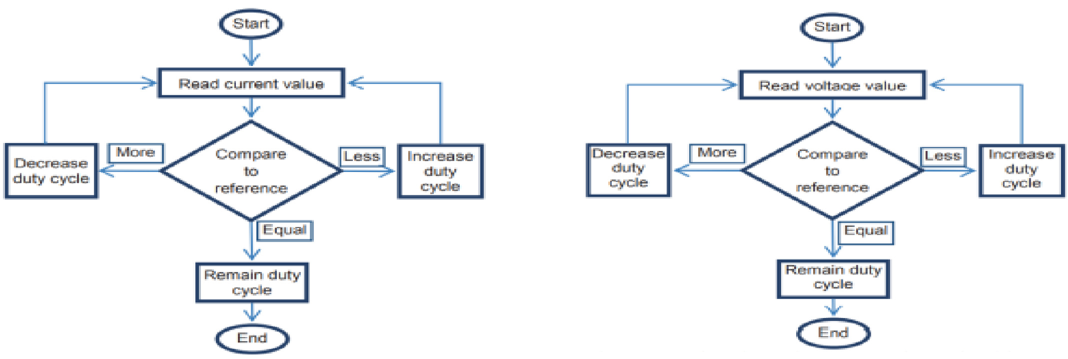

Figure 2: Flowchart of Constant Current and Constant Voltage (CC-CV)

2.3 Equations

The conventional buck converter is used to step down the DC output voltage from rectifier to desired 16 V. This converter has one switching device, an inductor, and capacitor. Duty cycle varies to fix load voltage despite of changing in load current or input voltage. In order to design a buck converter, a suitable value for each parameter must use an appropriate formula to get the proper value. The consideration selection of the component can be calculated using the equation:

$$Duty\ Cycle = \frac{V_o}{V_s} \qquad Eq.1$$

$$Inductor, L = \frac{(1-D)V_o}{\Delta IL \times f} \qquad Eq.2$$

$$Capacitor, C = \frac{(1-D)}{8L\left(\Delta V_o/V_o\right)f^2} \qquad Eq.3$$

2.4 Block Diagram Battery Pack

Based on Figure 3 shows the block diagram to charge a battery pack. The design is divided into 4 battery modules that are connected in series by adding each battery cells 3.7 V to 14.8 V in total of 4 battery cells. In battery pack design must include the switching control to select a battery module that can be charged and the cell balancing circuit required to monitor the charging and discharging process in balance voltage and current as battery status.

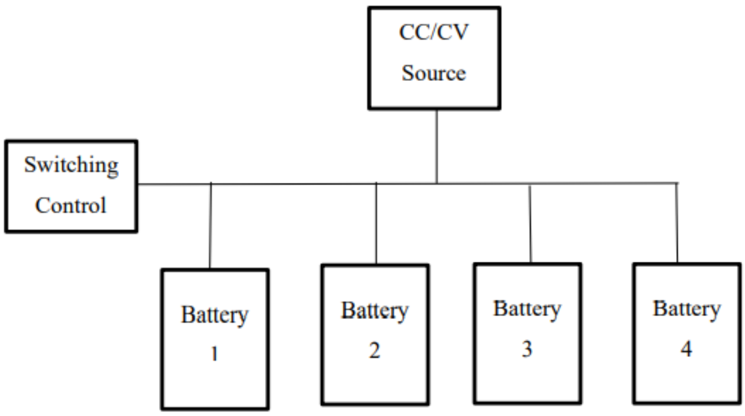

Figure 3: Block Diagram Battery Pack

2.5 PI Controller Block

This section is about designing a controller for constant current. The PI controller is used as the set point of the desired value will be compared with feedback to achieve constant. Based on Figure 4 shows that close loop method generates the PWM of duty cycle by connecting with switching in the circuit which is MOSFET. MOSFET plays a role in generating the PWM with the output duty cycle as set the output and input voltage where the system will automatically set the duty cycle in obtain the desired output current.

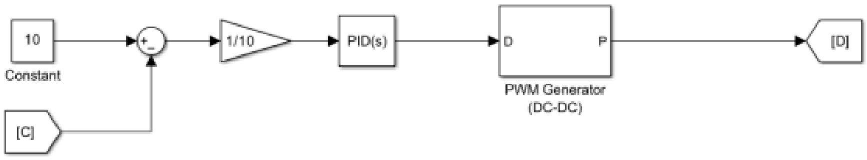

Figure 4: PI Controller Block for Constant Current

3. Results and Discussion

The results that have been obtained throughout this study are analyzed and discussed in this section. The battery charger system uses a conventional power converter which is combination rectifier and buck converter. The analysis was performed by using MATLAB SIMULINK software and hardware development with multi meter.

3.1 AC/DC Converter and DC/DC Buck Converter Analysis

Based on the data waveform in Figure 5 shows that the waveform signal is converted from the AC to DC signal. The result demonstrated indicated voltage value constant 240 V at a frequency 50 kHz. This indicated that the rectifier is functioning as expected and producing the desired output waveform.

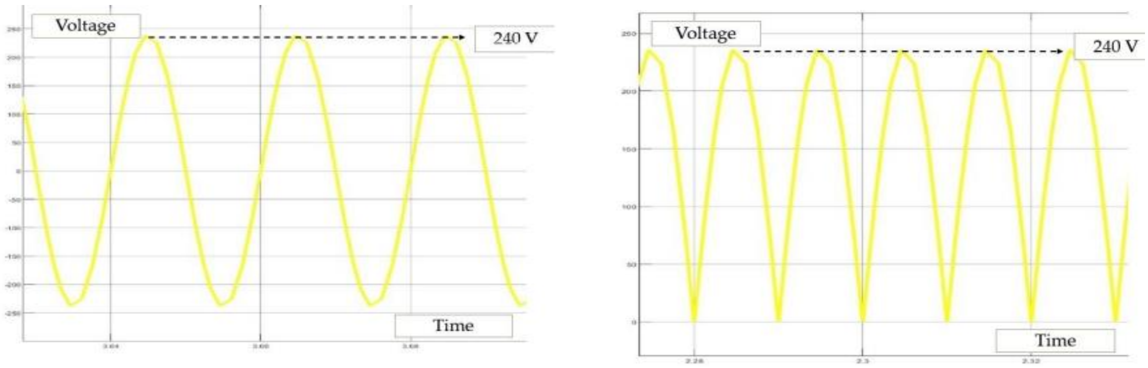

Figure 5: AC-DC Waveform

According to Table 2 the DC input voltage will be calculated in duty cycle formula to get value of duty cycle for output buck converter 16 V. From these data it proves that the buck converter functionally steps down the voltage when input voltage greater than output voltage.

Table 2: : Output Voltage and Output Current from Buck Converter

Parameter	Value
Output Voltage	16 V
Output Current	10 A

3.2 PI Controller Analysis

Based on Figure 6 and 7, shows that the output current in 2 value which is 10 A and 5 A. Those two values being set at constant value in PI block that the output connected to the gate of MOSFET to generate the exact PWM of duty cycle. This test was carried out to prove the PWM generator can operate correctly in gaining desired out current of the buck converter to get the constant current in charging a battery.

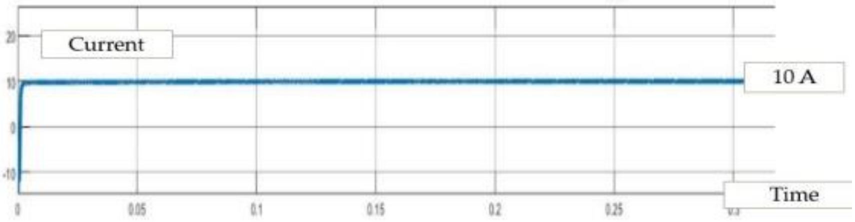

Figure 6: Waveform Output Current 10 A

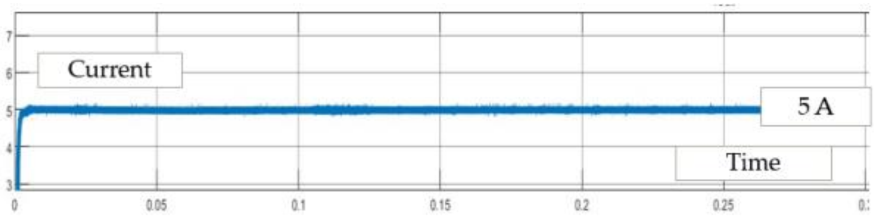

Figure 7: Waveform Output Current 5 A

3.3 Cell Balancing Analysis

Based on Figure 8, shows that the varies value of SOC will be rising from its initial state and approaching to achieve the balance state of charge. Once each battery cell is in balance, the state of charge will rise to 100 percent of state of charge. From that the cell balancing system work that observed from these simulations.

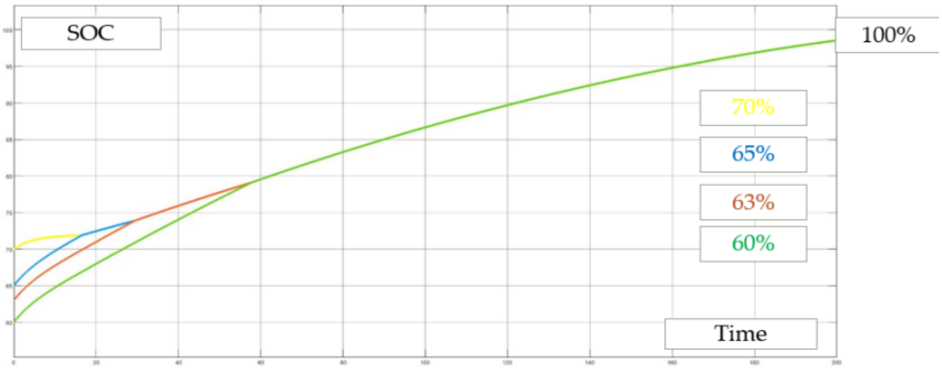

Figure 8: State of Charge Battery Pack

3.4 Prototype DC/DC Buck Converter Analysis

From the data that shows in Table 3 is obtained from the experiments conducted by varying the duty cycle, it is known how the response of PWM effective the output voltage at the buck converter as the given control is. From these data it proves controlling the value of duty cycle will gain desired value of output voltage that step down by buck converter working principle. In hardware development of buck converter is achieved to step down the output voltage as its comparison between input voltage and output voltage.

Table 3: Data Result of Voltage and Current

Duty Cycle	Input Voltage (V)	Input Current (A)	Output Voltage (V)	Output Current (A)
0	9	500 m	0	0
0.25	9	500 m	2.15	110 m
0.50	9	500 m	4.30	234 m
0.70	9	500 m	6.10	330 m
0.90	9	500 m	8.00	442 m

4. Conclusion

Overall conclusion for this project, the power converter designs the power conversion and steps down the voltage has been designed for Lithium-Ion battery charger. Based on the result analysis showed many constraints had to be considered and managed in charging a LI-ion battery that the sensitivity requires a proper battery charger. The proposed solution for a proper battery charger is for protection and monitoring system which is battery management system. The battery management system in balancing the battery pack is part of improvement in efficiency charging the battery. Therefore, further research of component specification played a role to ensure that each part of component able to handle current and voltage stress that for designed the potential battery charger to charge a battery.

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