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# Design of Wireless Real Time Monitoring Lithium Ion Battery Charger Using Constant Current Constant Voltage Method

***Abstract**. Li-Ion battery is the main power source for portable devices and electric vehicles because of their excellent characteristics. After being used to supply energy, Li-Ion batteries will reduce their energy capacity and need to be charged so that the battery returns to its maximum capacity. There are several methods for charging a battery, one of the methods is Constant Current Constant Voltage (CC-CV). This method provides a a constant current first and continuing with constant voltage under certain conditions. This method is suitable for Li-Ion battery because the age of Li-Ion battery is greatly affected by overcharging conditions so that using this method can extend battery life. In this research, Li-Ion battery charger will be designed using the Buck Boost converter topology with the CC-CV method. Real time monitoring system during the battery charging process will also be proposed. In the implementation, the Buck Boost converter has an average efficiency of 88.2% at 10% to 100% load condition. The CC-CV method has high reliability in maintaining constant charging voltage and current and can produce a constant current of 1.3 A and a constant voltage of 12.6 V. In the Li-Ion battery charging test, it was found that the entire charging process took 89 minutes with 56 minutes in Constant Current mode and 33 minutes in the Constant Voltage mode with a cut-off current of 180 mA. The parameters of the Li-Ion battery such as charging voltage and current, the voltage between cells and the State of Charge will be updated every second so that it is monitored in real time wireless.*

***Streszczenie.** Akumulatory litowo-jonowe są głównym źródłem zasilania urządzeń przenośnych i pojazdów elektrycznych ze względu na ich doskonałe właściwości. Akumulatory litowo-jonowe po wykorzystaniu do dostarczania energii zmniejszają swoją pojemność energetyczną i wymagają ładowania, aby akumulatory powróciły do swojej maksymalnej pojemności. Istnieje kilka metod ładowania akumulatora, jedną z nich jest stały prąd o stałym napięciu (CC-CV), mianowicie najpierw dostarczanie stałego prądu i kontynuowanie stałego napięcia w określonych warunkach. Ta metoda jest odpowiednia dla akumulatorów litowo-jonowych, ponieważ na wiek akumulatorów litowo-jonowych duży wpływ mają warunki przeładowania, co może wydłużyć żywotność baterii. W badaniach ładowarka akumulatorów Li-Ion zostanie zaprojektowana z wykorzystaniem topologii konwertera Buck Boost z metodą CC-CV. Zaproponowany zostanie również system monitorowania w czasie rzeczywistym podczas procesu ładowania baterii. W swojej realizacji konwerter Buck Boost ma średnią sprawność 88,2% przy obciążeniu od 10% do 100%. Metoda CC-CV zapewnia wysoką niezawodność w utrzymywaniu stałego napięcia i prądu ładowania i może wytwarzać stały prąd o wartości 1,3 A i stałe napięcie o wartości 12,6 V. W teście ładowania akumulatora Li-Ion stwierdzono, że cały proces ładowania trwał 89 minut z 56 minutami w trybie stałego prądu i 33 minuty w trybie stałego napięcia z prądem odcięcia 180 mA. Parametry akumulatora Li-Ion, takie jak napięcie i prąd ładowania, napięcie między ogniwami oraz stan naładowania będą aktualizowane co sekundę, dzięki czemu są monitorowane w czasie rzeczywistym bezprzewodowo. (**Projekt bezprzewodowego monitorowania w czasie rzeczywistym ładowarki do akumulatorów litowo-jonowych przy użyciu metody stałego prądu I stałego napięcia**).*

**Keywords:** Buck Boost; Lithium Ion; CC-CV; Real Time Monitoring.
**Słowa kluczowe:** Buck Boost; Litowo-jonowa; CC-CV; Monitorowanie na żywo

## Introduction

Nowadays, technological developments especially in the electronic fields are heading towards being completely portable at every aspect. Many electronic devices require batteries as their main energy source to stay alive for a period of time. The characteristic type of battery chosen for these electronic applications is a battery that has rechargeable properties. Rechargeable in this context means that the batteries can be recharged to its maximum capacity. One example of a rechargeable battery is a Lithium - Ion (Li-Ion) battery. This battery consists of several cells that are arranged in series and parallel to meet the rated load voltage supplied by the battery. Lithium-ion batteries are the main power source of many portable devices and electric vehicles due to their excellent characteristics, such as high specific power density, high cell voltage, low self-discharge rate, long cycle life, and no memory effect [1].

Rechargeable batteries have the ability to store and restore their energy if they are properly used and well maintenance. One of the main parameters for extending the life of the battery is by properly charge and discharge based their characteristics specified by manufacturers [2]. To promote the benefit of the electric vehicle application, usually a shortest charging time of the battery may efficiently increase many people to use such kind of this electric vehicle. In addition, another feature that the user wants of charging battery is the display to monitor in a real time condition for the battery parameters such as voltage, charging current and its remaining capacity.

Actually, there are several methods to charge the battery. However, the most famous methods are Constant Current Constant Voltage (CC-CV). This method is also suitable for Li-Ion battery due to its life is greatly affected by charging conditions [3]. Furthermore, the CC-CV method is also can be used in today's commercial fast charger applications [4]. In CC Mode, the battery will be charged with a constant current first until the battery voltage rises to the constant voltage limit. After CC charging mode, the charging process enters CV mode to prevent overcharging. In CV mode, the charging current decreases gradually based on the condition of the battery, such as an increase in impedance or an increase in electromotive force (EMF) [5].

In this paper, to charge the battery in a Constant Current Constant Voltage, we use a buck boost converter because this converter topology it has a voltage and current output with a small ripple so it is suitable for battery charging process [6]. Besides that, buck boost converter able to maintain a constant output despite the input voltage is lower or higher than the output voltage level. In the hybrid Unmanned Aerial application (UAV) this battery is utilized for the main source to drive the brushless dc (BLDC) motor when main engine fails to drive the propeller. In addition, during flight time using engine, BLDC motor is operated as a generator to charge the battery. Therefore, it is very important to display the parameters of the Lithium - Ion battery such as the voltage conditions of each cell, the charging voltage and current and the energy stored during the charging process, it is necessary to monitor the entire charging process of the battery in real time using radio telemetry.

## Material and Method

### 1. Lithium – Ion Battery

Li-Ion uses two electrodes as a cathode (positive electrode) and anode (negative electrode) and an electrolyte as a conductor. The positive electrode is metal oxide and the negative electrode contains porous carbon. The lithium ion battery has several advantages, such as: high energy, high load capability, long cycle, maintenance free, high capacity, low internal resistance, simple and fast charging, low self-discharge compared to NiMH and NiCd batteries [7]. Standard Li - Ion cells have a nominal voltage of 3.7V which must be charged to 4.2V to become fully charged. As the battery voltage reaches its nominal charge value (4.2V), the current decreases and the voltage must be constant. Therefore, it is very important to consider for designing the battery charger control loop [8]. The charge and discharge limits for lithium ion battery cells must be strictly controlled to prevent deadly cell inside the battery. Overcharging will cause oxidation and electrolyte decomposition, while excessive discharge results in structural changes to the cathode. Under these circumstances the control of individual cells becomes a challenge in designing of the battery charger to keep both voltage control and cell balancing [9].

### 2. Buck Boost Converter

Buck Boost Converter is a DC-DC converter circuit that can produce an output voltage lower or higher than the input voltage. The output voltage on the Buck Boost Converter is always negative or inverse to the input voltage. This converter consists of input voltages, semiconductor switches, inductors, diodes, capacitors and loads [10]. This topology has the advantage of low voltage ripple on the input and output sides, so the Buck Boost Converter is the right topology to use in battery charger applications. In the Buck Boost converter there are two modes of flowing current, there are Continuous Current Mode (CCM) and Discontinuous Current Mode (DCM) [11]. This discussion below applies when the converter is in continuous current mode (CCM). The buck boost converter circuit is shown in Figure 1.

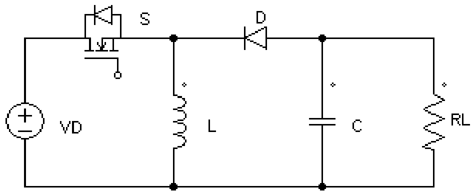


Fig. 1 Buck Boost Converter Circuit

*Close State Switch Analysis:* When the switch *S* is closed, this causes the diode to work in reverse biased so that the current will flow to the inductor *L*. With the current flowing into the inductor, the inductor will be charged so that the inductor current ($I_L$) increases.

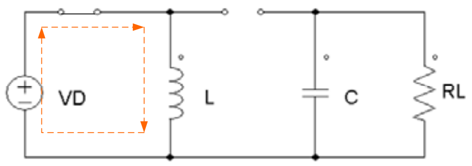


Fig. 2 Buck Boost Converter Circuit When Switch *S* is Closed

Figure 2 is the converter equivalent circuit when the switch *S* is closed. By using Kirchhoff Voltage Law analysis, the equations that can be derived from the above circuit are:

$$V_L = V_D \quad (1)$$

$$V_D = L\frac{dI_L}{dt} \quad (2)$$

$$V_D = L\frac{\Delta I_L}{t_{on}} \quad (3)$$

If the Duty Cycle (*D*) is the ratio between the switch *S* active time interval and the length of the system period, then:

$$t_{on} = DT \quad (4)$$

$$t_{off} = (1-D)T \quad (5)$$

By substituting equations (3) and (4), the $V_d$ equation changes as follow:

$$V_D = L\frac{\Delta I_L}{DT}$$

$$V_D D = L\frac{\Delta I_L}{T} \quad (6)$$

*Open State Switch Analysis:* When the switch *S* is open, the diode will work in forward bias and the current stored in the inductor will be discharged and flow to the load, the current flowing in the same direction as the charging current. The energy stored in the inductor is discharged.

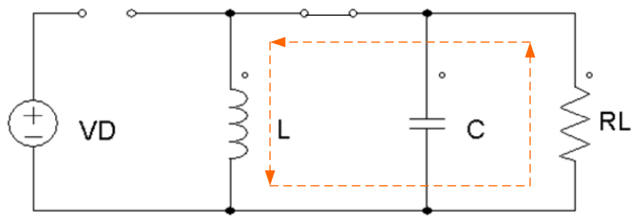


Fig. 3 Buck Boost Converter Circuit When Switch *S* is Opened

Figure 3 is the converter equivalent circuit when the *S* switch is open. By using Kirchhoff Voltage Law analysis, the equations that can be derived from the above circuit are:

$$V_L = -V_O$$

$$-V_O = L\frac{dI_L}{dt}$$

$$-V_O = L\frac{\Delta I_L}{t_{off}}$$

$$-V_O = L\frac{\Delta I_L}{(1-D)T}$$

$$-V_O(1-D) = L\frac{\Delta I_L}{T} \quad (7)$$

By using the second balance voltage on *L* in equations (6) and (7), so we can get an equation:

$$-V_O(1-D) = V_D D$$

$$V_O = -V_D\frac{D}{(1-D)} \quad (8)$$

Equation 8 is the equation for the output voltage value of the buck boost converter. If the PWM duty cycle as an trigger switch is more than 50%, the output voltage will be higher than the input voltage. And if the PWM duty cycle is less than 50%, the output voltage will be lower than the input voltage [12].

## 3. Radio Telemetry 915 MHz

Telemetry is a wireless telecommunications technology that work in long range distance and reports information from the air station to the ground station or system operator. Telemetry is often used for Unmanned Aerial Vehicle (UAV) applications as a telecommunications device between remote control and UAV. This telemetry can communicate over long distances, which is about one mile. This telemetry system uses full-duplex communication with open source firmware. This device interface uses standard 5V serial TTL or serial USB FTDI. Configuration can also be done with 3DR Radio Configurator or AT Command [13].

Figure 4 is a radio frequency telemetry system modelling. The 915 MHz telemetry communication system uses a serial communication base between devices with a baud rate of 57600. Basically, the telemetry transmitter sends data bits that have been processed by the microcontroller one by one. The telemetry receiver will receive the data and will be displayed on the user's computer by using the software.

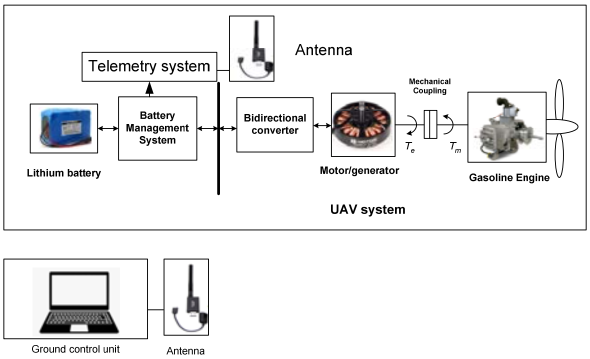


Fig. 4 Radio Frequency Telemetry in UAV system

## 4. Constant Current Constant Voltage Method

Batteries are often to degrade prematurely and it will lead to the battery replacement costs increase. One way to increase battery life is by optimizing the charging process.

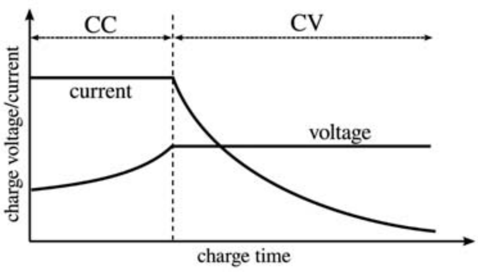


Fig. 5 CC-CV Charging Process

The charging process must work with an electrochemical process to optimize chemical reactions by minimizing the internal heat generated. Many charging techniques are widely used to charge Li-ion batteries [14]. Among these techniques, the one used in this research is Constant Current Constant Voltage (CC-CV).

CC-CV is a charging method that will charge the battery with constant current first, after the battery voltage reaches its maximum voltage, then will be continued with constant voltage until the current flows decreases according to the cut-off current. By using this method, the battery charging process will lead to its full capacity [15]. Figure 5 shows the process of charging a battery with the CC-CV method. Charging process starts with constant current and continues with constant voltage until the battery capacity is fully charged.

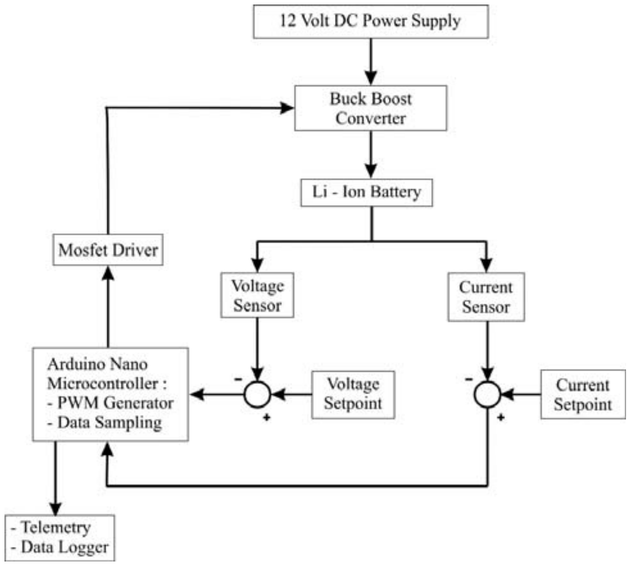


Fig. 6 Battery Charger System Block Diagram

In Figure 6 it can be seen that the battery charger system circuit uses a close loop control system. The DC voltage of 12 V will be the input of the buck boost converter. The output of the buck boost converter will be used to charge the battery. The parameters of the Li - Ion battery, namely the voltage and current will be sensed by the voltage sensor and current sensor which will then be compared with the setpoint value. The result will be an error signal which will then be processed by Arduino and produce a control signal in the form of PWM. Furthermore, the PWM signal will be amplified on the mosfet driver so that the mosfet can perform switching.

## 5. Battery Charging Simulation

The working mechanism of the system starts by reading the voltage from the battery, if the voltage is less than 4.2 V, the system will enter constant current mode, if it is more than or equal to 4.2 V, it will enter constant voltage mode. In constant current mode, the first step is to adjust the current set point value, which in this research is 1.3 A. Furthermore, the current set point value will be compared with the output current feedback value of the buck boost converter. The difference of these two values results in an error signal which will be processed by the controller and will produce a control signal. After that, the control signal in the form of a PWM signal with a certain duty cycle value will regulate the switching of the converter mosfet. This constant current process will continue until the battery voltage slowly rises to a voltage of 4.2 V. If the battery voltage has reached 4.2 V, then the mode will switch to constant voltage. The process works the same as constant current, but the difference is that the constant voltage process will stop if the current flowing is less than its cut-off value. The following flowchart for charging Lithium - Ion batteries can be seen in Figure 7.

Figure 8 is a battery charging simulation performed using the MATLAB software. In this battery charging simulation, it uses two modes, namely constant current and constant voltage modes. Constant current mode works first, by providing constant current to charge the battery. After the voltage reaches its maximum value, the charging mode switches to constant voltage mode by providing a regulated constant voltage.

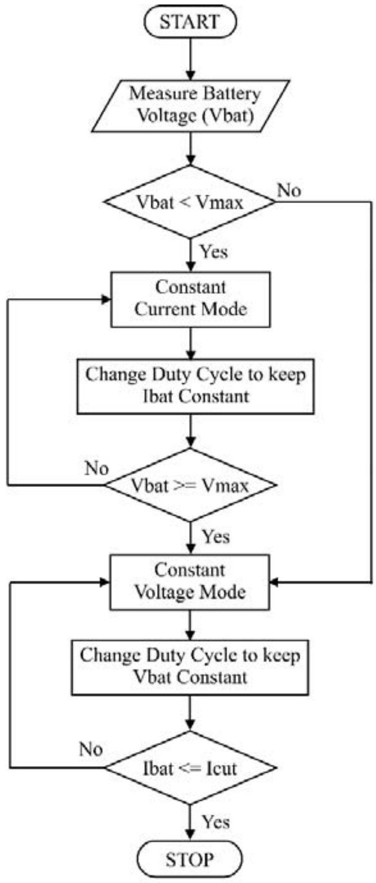


Fig. 7 Constant Current Constant Voltage Flowchart

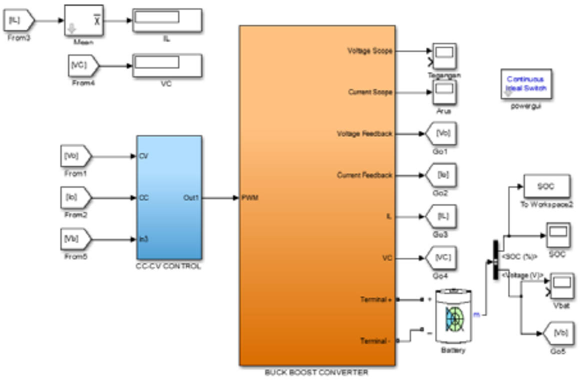

Fig. 8 Battery Charging Simulation Using Constant Current Constant Voltage Method

## Result and Discussion

### 1. Design of Lithium – Ion Battery Charger

Based on the specifications of the Lithium - Ion battery, the battery used in this research is the SAMSUNG ICR18650-26F with a series topology of three cells. The capacity of the Li - Ion battery used is 2600 mAh. With the specification data obtained, the buck boost converter design will be adjusted to the SAMSUNG ICR18650-26F battery specifications. The design of the Li - Ion battery charger can be seen in table 1. Where the constant current parameter is set at current value of 1.3 A and for constant voltage it is set at a voltage value of 12.6 V.

Table 1. Li - Ion Battery Charger Specifications

| No. | Parameter | Value |
|---|---|---|
| 1 | Constant Voltage of 1 Cell | 4.2 V |
| 2 | Constant Voltage of 3 Cell | 12.6 V |
| 3 | Constant Current Value | 1.3 A |
| 4 | Cut-off Current | 130 mA |

### 2. Design of Buck Boost Converter

In designing a buck boost converter, there are several things that must be determined. The initial process in designing a converter is to determine the initial parameters based on the load and source specifications to be used. The electrical parameters of the converter to be determined are the input voltage value ($V_{in}$), output voltage ($V_o$), switching frequency ($f_s$), output power ($P$), inductor current ripple ($\Delta I_L$), capacitor voltage ripple ($\Delta V_c$). The determination of the parameters is also adjusted to the existing equipment in the Energy Conversion Laboratory and components on the market. The determination of these values will be used as a reference in determining and designing the components to be used. The initial parameters of the buck boost converter circuit can be seen in table 2.

Table 2. Buck Boost Converter Specification

| No. | Parameter | Value |
|---|---|---|
| 1 | Output Power ($P$) | 24 W |
| 2 | Switching Frequency ($f_s$) | 20 KHz |
| 3 | Inductor Current Ripple ($\Delta I_L$) | 12.7 % |
| 4 | *Capacitor Voltage Ripple* ($\Delta V_c$) | 0.8 % |
| 5 | Input Voltage ($V_{in}$) | 12 V |
| 6 | Output Voltage ($V_o$) | 12.6 |

After designing and calculating the parameter values of each required component, the next step is to implement or manufacture the real time monitoring lithium - ion battery chargers. The parameter value of each component for the implementation is adjusted to the available components on the market. The component value in the implementation is a value that is greater than the value of the component that has been designed. It aims to anticipate the converter in a DCM state. Table 3 below is the components that will be used in implementing real time monitoring Li-ion battery chargers.

Table 3. Converter Component Parameters

| No. | Parameter | Value |
|---|---|---|
| 1 | Supply Voltage | 12 V |
| 3 | MOSFET | IRFP4227 |
| 4 | MOSFET Driver | TLP250 |
| 6 | Diode | MUR1560 |
| 7 | Inductor | 620 µH |
| 8 | Inductor Core | Toroid Ferrite Core |
| 9 | Input Capacitor | 1000 µF 50 V |
| 10 | Output Capacitor | 1000 µF 50 V |
| 11 | Resistive load | 6,615 Ω |
| 12 | Li – Ion Battery | 2600mAh, 3 cells |
| 13 | Switching Frequency | 20 kHz |
| 14 | Output Voltage | 12.6 V |
| 15. | Voltage Sensor | Multiturn 100kΩ |
| 16 | Current Sensor | ACS 712, 10 A |
| 20 | Radio Telemetry | Telemetry 915 MHz |

From the design results in the table 3, before carrying out the implementation stage, a simulation is carried out using MATLAB software. After the simulation results match the design made, the converter implementation stage is carried out.

### 3. Battery Charger Simulation Result

Figure 9 shows the current response during constant current and constant voltage modes, when entering the constant current mode, the current flows at a constant rate of 1.3 A according to the setpoints. And when it switches to constant voltage mode, the current flows slowly decrease until the cut – off value. Figure 10 shows the voltage response during constant current and constant voltage modes, when entering the constant current mode, the voltage starts to increase towards the specified voltage, which is 4.2 V. And when it switches to constant voltage mode, the voltage is kept at constant value of 4.2 V.

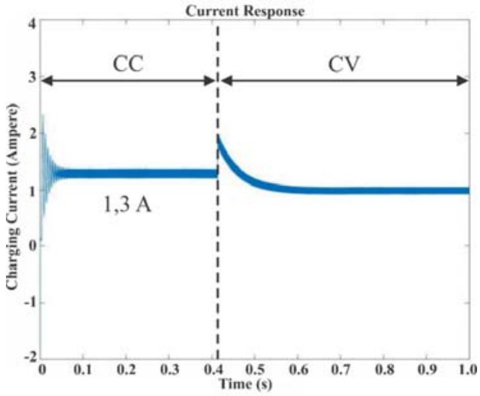


Fig. 9 Current Response in Battery Charging Simulation

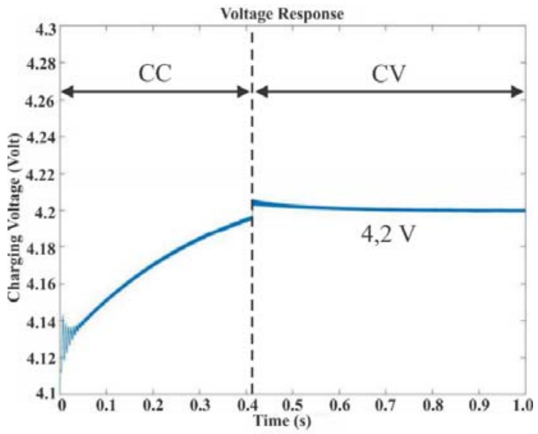


Fig. 10 Voltage Response on Battery Charging Simulation

## 4. Battery Charger Implementation

The results of the converter implementation can be seen in Figure 11. After implementing the converter, several tests were carried out to determine whether the converter was working properly or not. The converter tests include switching testing, inductor current signal, capacitor voltage signal, input-output voltage signal, current and voltage sensor test, and efficiency. From the converter test results, it can be concluded that the converter can work according to the design although several parameters such as current and voltage ripple having values above the calculation. This is because the components used in the implementation of the converter are not ideal, and it causing power losses. The converter can achieve a maximum efficiency of 90.2% at 40% loading and a minimum efficiency at 84.3% at full-load. From the efficiency test, the converter has an average efficiency of 88.2%.

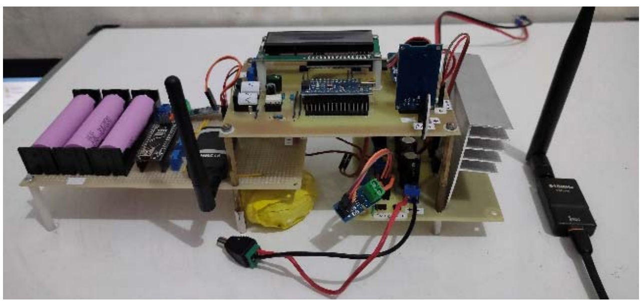

Fig. 11 Lithium Ion Battery Charger Implementation

## 5. Constant Current Constant Voltage Test Result

The constant current constant voltage control test is carried out in order to find out whether the Buck Boost converter can maintain constant current and voltage according to the design and simulation. The test is carried out using a variable resistive load or commonly called a rheostat with a specification of 25 Ω 5 Ampere. In order to produce a constant current and constant voltage, the Buck Boost converter must be in a closed loop control using a microcontroller.

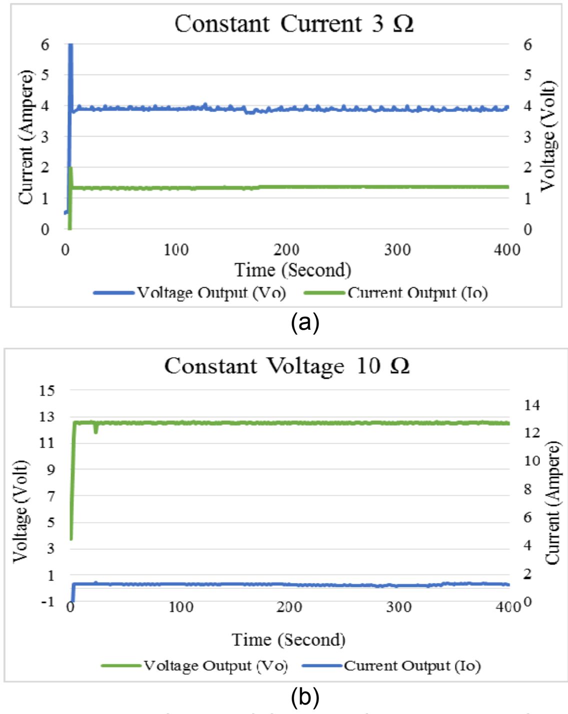


Fig. 12 (a) Testing Curves of Constant Current and (b) Constant Voltage

Figure 12 (a) is the curve of the Constant Current control test results on the Buck Boost converter with a load of 3 Ω. In the Constant Current control, it can be seen that the converter is able to maintain an output current of 1.3 A according to the set point. The response to the output voltage that arises at a 3 Ω load is 3.9 V.

Figure 12 (b) is the curve of the Constant Voltage control test results on the Buck Boost converter with a load of 10 Ω. In the Constant Voltage control, it can be seen that the converter is able to maintain an output voltage of 12.6 V in accordance with the predetermined setpoints. The response to the output current that occurs at a load of 10 Ω is 1.26 A.

## 6. Lithium – Ion Battery Charging Test Result

Figure 13 is a results graph of the Lithium Ion battery charging process. At the beginning of the test, the voltage between battery cells was measured before the charging process was carried out and it was found that all cells were in a balanced state with a voltage of 3.6 V. Then the Lithium - Ion battery is connected to the output of the Buck Boost converter. At the beginning of the charging process, the voltage at the converter output jumps to 11.07 V. This is the initial response of the battery occur because in order to let the current flows to the battery, there must be a voltage difference between the converter and the battery. After the current flows into the battery, the current is kept constant at the 1.3 Ampere level with a Constant Current control. The Lithium Ion battery voltage gradually increases until the threshold voltage is reached and switch to the Constant Voltage control. Constant Current charging mode lasts for 56 minutes. After that, switch to Constant Voltage mode and the voltage is kept constant at the 12.6 V level. The response of charging current when switching to Constant Voltage mode is a surge with a value of 2.17 A. The current value will decrease gradually until the battery cut-off current limit is reached, which is 180 mA in the 89th minute. So that the Constant Voltage mode lasts for 33 minutes.

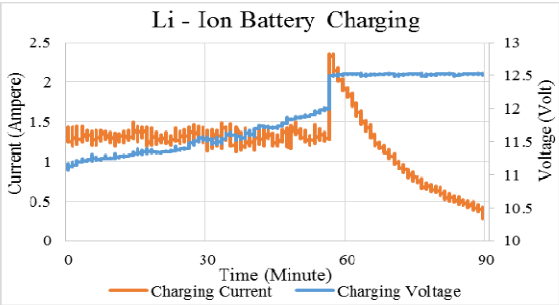


Fig. 13 Lithium Ion Battery Charging Test Curve

Based on the chart above, the Constant Current mode has a fairly large current ripple value. This ripple occurs because the ACS712 component or the current sensor of this converter is unstable if it is used for a long time. It can be seen on the curve when the condition is Constant Current, there are many current spikes caused by the unstable ACS712. The current reading value is shifted automatically even though the calibration has been carried out at the beginning of use. This causes an error of reading the feedback current by the microcontroller and causes a lot of current spike during the Constant Current process. This problem is not found at the Constant Voltage mode and it proven by a good voltage ripple curve. So, it can be concluded that the system is stable if we change the current sensor instrument with another type of sensors.

## 7. Real Time Monitoring Test Result

When testing the Lithium Ion battery charging and it was found that the DC-DC Buck Boost Converter can work as expected, the Real Time Monitoring system testing phase is also carried out simultaneously. Real Time Monitoring system testing is carried out in order to find out whether this system can display the parameters of the Lithium Ion battery while it is being charged. Figure 14 is an overall view of the Real Time Monitoring System.

On the display of the voltage curve between Lithium Ion battery cells during the charging process, it can be seen that the three batteries start with a voltage of 3.6 V and gradually go up to a voltage of 4.2. The three batteries undergo a similar process, first with Constant Current then followed by Constant Voltage when they reach the threshold voltage. The voltage curve between battery cells will be updated every second and can be monitored in real time. The curve above is the overall curve after the charging process is complete.

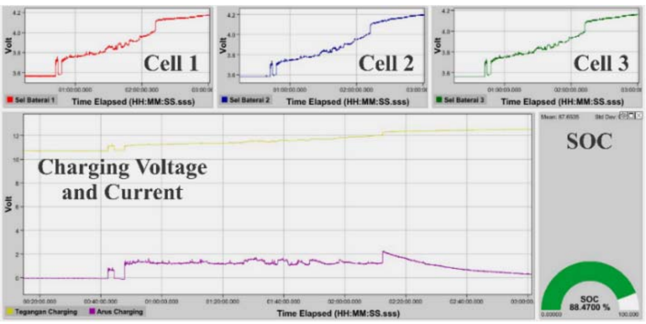


Fig. 14 Real Time Monitoring System Display

On the Lithium ion battery charging curve display, this curve display contains the voltage and current parameters of the Lithium Ion battery charging process. This curve will be updated every second so that users can monitor it in real time. The curve above is the overall curve after the charging process is complete.

State of Charge is the level of energy stored in a battery relative to its capacity. Units of State of Charge are percentage points (0% = empty; 100% = full). The state of charge from the battery will continue to increase along with the longer the charging process from the battery.

## Conclusions

Based on the results from simulation, implementation and testing of Real Time Monitoring Lithium Ion battery chargers using the Constant Current Constant Voltage method, the following conclusions can be drawn: In the Buck Boost converter test, there is a difference in the value of the component signal parameters between the simulation results and the implementation results with an average error of 4.67%, this is due to the use of components that are not ideal in the implementation process. Implementation of DC - DC Buck Boost Converter in this research can work according to the design with an average load efficiency of 10% to 100% is 88.2%. CC-CV control to regulate the duty cycle can produce a constant charging current and voltage, with the current parameter is 1.3 A and the voltage parameter is 12.6 V. In the Lithium Ion battery charging test, it was found that the whole charging process takes 89 minutes with a detailed 56 minutes in Constant Current mode and 33 minutes in Constant Voltage mode with a cut-off current of 180 mA. The Real Time Monitoring System can display the parameters of the Lithium Ion battery such as charging voltage and current, the voltage between cells and the State of Charge while it is being charged and will be updated every second so that users can monitor it in real time.


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