Modelling and Simulation of Battery Charger Li-Ion using CC-CV PI Method

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Keywords: Battery Charger, Buck Converter, Charging, Constant Current, Constant Voltage, PI Controller, Voltage Threshold.

Abstract: Damage to the battery is caused by improper and correct charging methods. So it is necessary to have a system to maintain battery life time. The method is often used to charge batteries is constant voltage by providing a constant voltage from initial charging to full charge. Charging with constant voltage can provide a high charging current at the beginning of charging. High charging currents can be dangerous and reduce battery lifetime. In this seminar paper, charging Li-Ion batteries using Buck Converter with constant current constant voltage method, namely by providing a constant current before reaching the voltage threshold and continuing with a constant voltage to full (charging current 3-5% of the capacity of the battery). PI control is used in the Buck Converter which serves to maintain the stability of the current (constant current) and the voltage (constant voltage) by output buck converter. With this method the initial current when charging can be limited according to the ability of the battery, so that more current does not occur and the battery lifetime will be longer. The PI control on the buck converter can produce a constant current and a constant voltage at a battery load, with a current ripple of 12.5% and steady state 4A at a constant current and a voltage ripple of 0.95% and steady state 42V at a constant voltage.

1 INTRODUCTION

In this globalization era, many electrical devices use batteries as their energy source. The electrical devices in question are like laptops, unmanned aircraft (UAVs), even electric vehicles use batteries as their energy source. Means of transportation that are currently returning to the trend are bicycles, because it functions as a means of recreation, sports and short distance transportation. Seeing this, an electric bicycle was developed as a hybrid vehicle that uses human power and an electric motor. This vehicle has a number of advantages, including less energy than using human-powered vehicles, does not consume fuel, does not cause pollution, is not noisy, low maintenance costs, does not require special permission to drive and does not require a large parking area. A battery is a device that can store electricity. The types of batteries circulating in the community are as follows Lead Acid, Ni-CD, Li-Ion, and Li-Po. Overall the batteries mentioned above, the Li-Ion battery is one of the most widely used, because Li-Ion batteries have many advantages such as, large capacity with small physical size, no memory effect and can supply high currents up to 20 times its capacity (Thowil and Ayu, 2015). After the battery is used, it will cause the battery to decrease its capacity, to be able to return to its maximum capacity the battery must be charged first. There are several methods for charging a battery, one of the methods is Constant Current Constant Voltage (CC- CV), this method is suitable for Li-Ion batteries because the age of a Li-Ion battery is greatly influenced by overcharging conditions so that using this method can extend the battery's life (Vu and Tran, 2018).

To be able to process the battery charging in Constant Current Constant Voltage can use Buck Converter. It is because the buck converter has a voltage and current output with a small riple (Surya and Zuhri, 2017). So it is suitable for use in the battery charging process. PI controller is used in Buck Converter section which serves to maintain the stability of the output current (Constant Current) and the output voltage (Constant Voltage) of the Buck Converter. The stability of the current released until the battery voltage capacity reaches the voltage threshold. Furthermore, the stability of the issued voltage to full battery capacity with the current parameter is cut off.

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2 DESIGN OVERALL SYSTEM

2.1 Battery Charger System

The battery is an electric cell in which an electrochemical process takes place that can be reversed so that in the battery there are two processes namely the discharge process occurs when the conversion of chemical energy into electrical energy while the charging process occurs when the conversion of electrical energy into chemical energy. The charging process can occur by means of regeneration of the electrodes in it by providing an electric current in the opposite direction in the cell (Rashid, 2011) and (Ashari, 2017).

Constant Current Constant Voltage, which is to the battery voltage reaches its maximum voltage then it is continued with Constant Voltage until the current decreases according to the cut-off current. By using this method the battery charging will be in

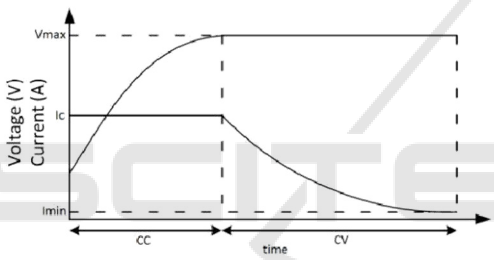

Figure 1: Charging of constant current constant voltage.

Figure 4 above shows the process of charging a battery using the Constant Current Constant Voltage method. Charging starts with Constant Current and continues with Constant Voltage until the battery capacity is fully charged.

Lithium-Ion batteries used in this paper have a total of 10 series and 3 parallel cells. The battery charging process is done simultaneously. The capacity of the Li-Ion battery used is 10.5 Ah. As for the design of the Li-Ion battery charger can be seen in table 2. Where for constant current is set at 4 A current and for constant voltage is set at 42V.

Table 1: Specification of battery charger.

Parameters	Value
Constant Current	4 A
Constant Voltage	42 V
Total Cells	10S 3P

a) Block Diagram System

Block diagram system of battery charger is shown in Figure 2.

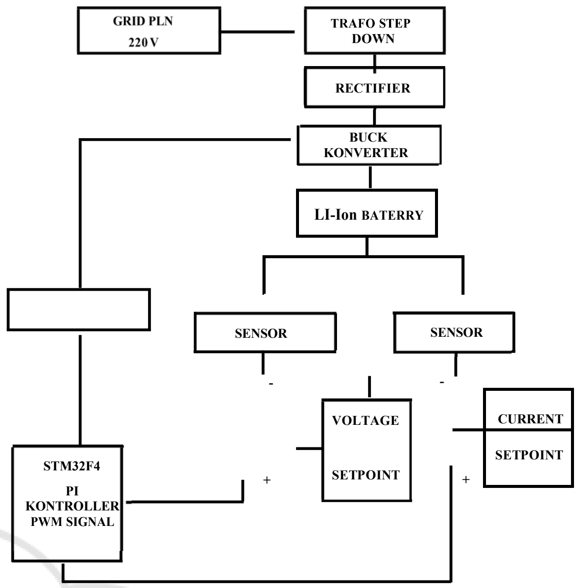

Figure 2: Block diagram system of battery charger.

Figure 5 explains that the source for this battery charger uses 220 VAC / 50 Hz PLN electricity, which will be reduced using a step-down transformer of 220VAC to 48 VAC. Next will be rectified into a DC voltage (Direct Current) using the Fullwave Uncontrolled Rectifier to 67.8 VDC. The output voltage of the rectifier will be varied using Buck Converter. The voltage sensor and current sensor are used to read the voltage and current from the battery which will then be compared to the value of the setpoint. The result will be an error signal which will then be processed by Arduino and produce a PWM control signal. Then the PWM signal will be strengthened in the mosfet driver so that the mosfet can switch.

B) The Flowchart of Constant Current Constant Voltage (CC-CV)

The flowchart battery charger system of constant current constant voltage shown in Fig. 3.

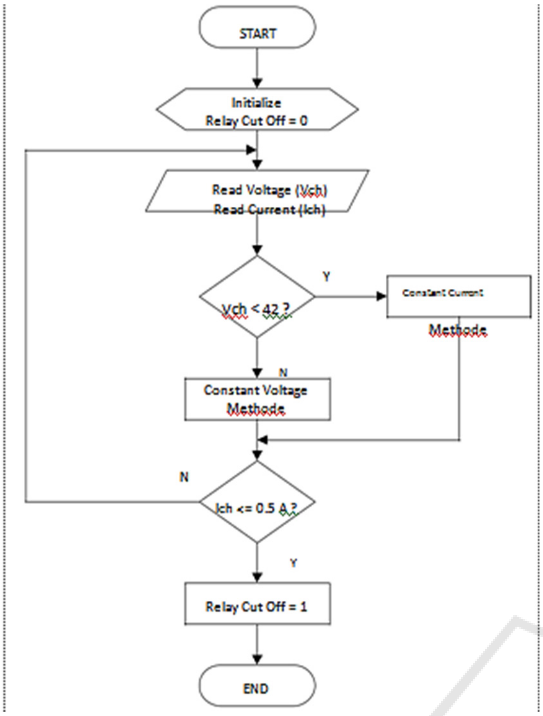

Figure 3: Flowchart system CC-CV.

2.2 Buck Converter

Functions to reduce voltage. The working principle of the Buck Converter is to use a switch that works continuously (ON-OFF). As for the so-called PWM (Pulse Width Modulation) and Duty Cycle in controlling the speed (frequency) work of the switch. The choice of buck converter is based on high efficiency in changing input power to output power (Pulungan and Sukardi, 2018) and (Wahyu and Supriono, 2018).

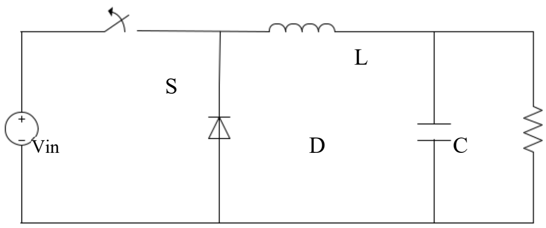

Figure 4: Equivalent of buck converter circuit.

The rating of inductors and capacitors can be found by following equation (Hart, 2011):

$$\frac{Vo\ \chi\ (1-D)}{\Delta\ iL\ \chi f} \quad (1)$$

$$\Delta V = Vo\ 0.1\% \quad (2)$$

$$1 - D\ 8Lrf\ 2 \quad (3)$$

Then the switch is in the ON position, diode reverse bias. Here the inductor starts to absorb some of the power from the power supply (Hart, 2011).

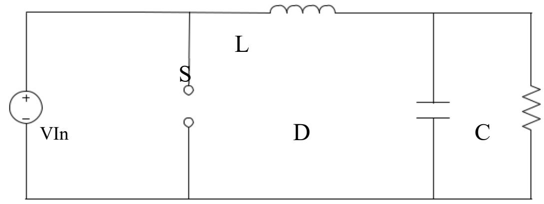

Figure 5: Buck converter is ON condition.

When the switch is at the OFF point. Although not connected to the source, at this position the power is supplied from the inductor which has absorbed power as long as the circuit is connected to the source (switch position ON).

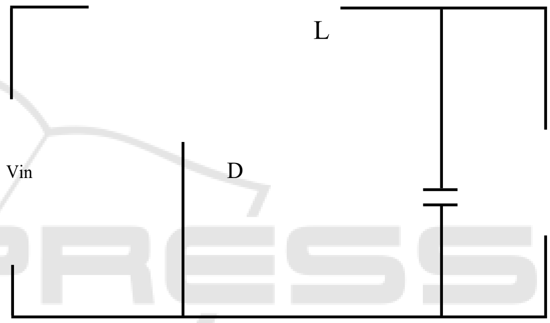

Figure 6: Buck converter is OFF condition.

Table 2: buck converter parameters.

Parameters	Value
Input Voltage (Vs)	65 V
Output Voltage (Vo)	42 V
Output Current (Io)	4 A
Switching Frekuensi (fs)	100 kHz
Ripple Current(ΔiL)	20%
Ripple Voltage (r)	0.1%

2.3 PI Controller

Proportional control functions to strengthen the error signal of the driver (error signal), so that it will speed up the system output to the reference point. Integral Control in principle aims to eliminate the error of steady state (offset) which is usually generated by proportional control (Suryatini). However, the use of P controller alone cannot eliminate the steady state error, therefore a PI controller is needed to eliminate the steady state error. The use of this PI controller can also reduce rise time and settling time. Just like the P controller, increasing the Ki value to a certain value will also increase the overshoot value (Temel).

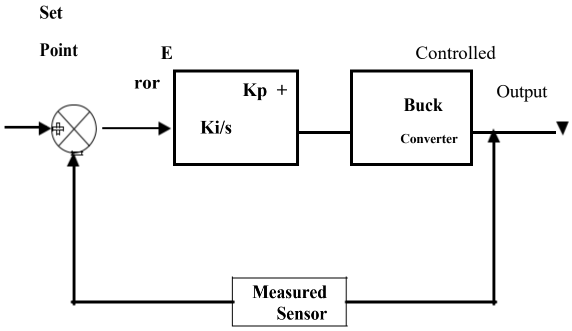

Figure 7: Block diagram of PI controller system.

Table 3: Characteristic of pid controller.

	Rise Time	*Settling Time*	*Error Steady State*	*Overshoot*
p	Decrease	Small Change	Decrease	Increase
i	Decrease	Increase	Eliminate	Increase
d	Small Change	Decrease	Small Change	Decrease

The PI controller that is used in the system is obtained from the simulation response of the buck converter which uses the predetermined parameters (Marian, 2012). The open-loop transfer function (OLTF) of the system is shown in equation (4) and the response of the OLTF shown in Figure 8 and the closed-loop transfer function (CLTF) of the system is shown in equation (5) and the response of the CLTF shown in Figure 9.

$$F = OLT \frac{K}{ts+1} \quad \frac{0.985}{0.02\,S+1} \tag{4}$$

$$F = CLT \frac{K}{ts+1} \quad \frac{1}{0.004\,S+1} \tag{5}$$

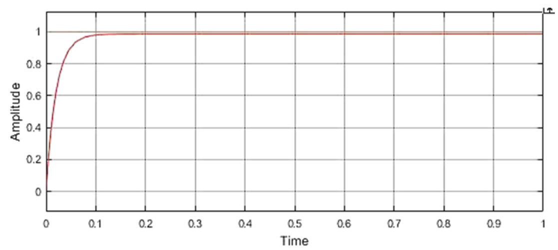

Figure 8: Step response of Open-Loop Transfer Function (OLTF).

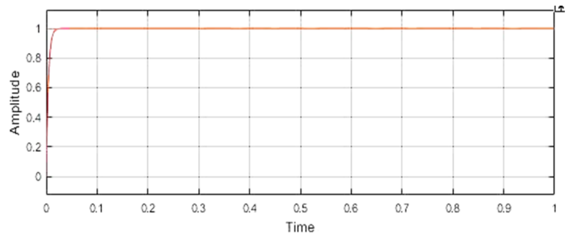

Figure 9: Step response of Close-Loop Transfer Function (CLTF).

3 SIMULATION RESULT

Battery charging simulation is done using two modes, namely constant current and constant voltage modes. The constant current mode works first by giving a constant current until the charging voltage reaches its maximum value. After the voltage reaches its maximum value, it is continued with a constant voltage mode, which is to provide a constant voltage until the current flowing in the battery reaches its cut-off value.

PI controller is used to optimize the output voltage and current to be stable in the setpoint. The simulation uses Matlab with certain patterns.

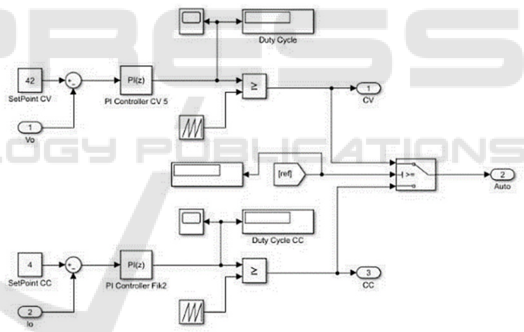

Figure 10: PI Controller and switch constant current to constant voltage.

The simulation results for the battery charging system using constant current constant voltage are shown in Figure 11.

4 CONCLUSION

The technical and economic analysis of tracker based solar power system for remoted islanded has been presented. The potential of the energy of the PV system can be generated 3,341 kWh/year. The test result using three different PV structure installations - fixed structures, single-axis tracking, and dual-axis tracking mechanisms, shows that the two-axis tracking system has more profitable in terms of PV electricity production 3,931 kWh in a year and had the lowest COE of 0,307 $/kWh. This system requires less PV module and battery storage, as well as lowest PV system, cost 2,579 $, and less space needed for system installation. The analysis of environmental influence needs to be considered for future research in order to reduce CO_2 emission.

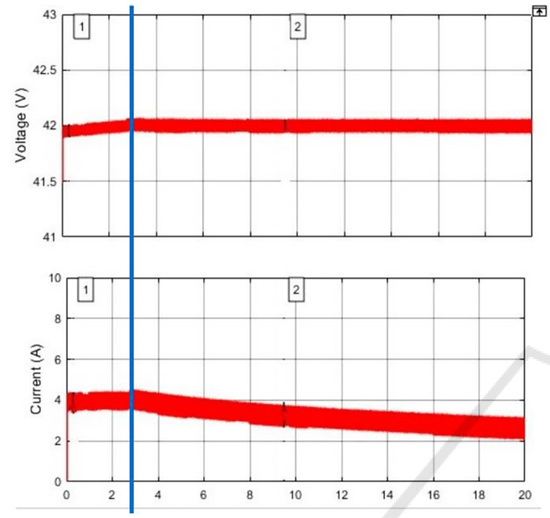

Figure 11: Simulation result of constant current (CC) constant voltage (CV) from: (a) output voltage response, (b) output current response.

The controller adjusts the duty cycle value assigned to the buck converter to match the setpoint. PI controller can reach the setpoint value with a time of 0.004s and maintain the charging current according to the setpoint. The constant current setpoint is 4A and the constant voltage setpoint is 42V.

From Table 4, the simulation results of battery charging using the constant current constant voltage method, the percentage of charging current error at CC is obtained by 0.5%. The constant current (CC) charging process takes place up to 99% battery SOC. After that, the charging process switches to CV mode until SOC is 100%. The simulation is performed with a discrete signal (sample times is 1e-6) and starting at the 99% SOC battery condition with a matlab time of 20.

Table 4: Simulation results.

SO C (%)	Vb Open (V)	Vch (V)	ch (A)	(Ω)
30	36.915	37.3 76	3. 95	0.11 67
35	36.930	37.3 98	4. 00	0.11 67
40	36.943	37.4 12	4. 02	0.11 67
45	36.953	37.4 20	4. 00	0.11 67
50	36.962	37.4 28	4. 00	0.11 67
55	36.971	37.4 38	4. 00	0.11 67
60	36.982	37.4 50	4. 02	0.11 67
65	36.999	37.4 64	3. 99	0.11 67
70	37.030	37.4 97	3. 99	0.11 67
75	37.092	37.5 60	4. 00	0.11 67
80	37.224	37.6 93	4. 02	0.11 67
85	37.505	37.9 72	4. 00	0.11 67
90	38.109	38.5 77	4. 01	0.11 67
95	39.415	39.8 83	3. 99	0.11 67
96	39.820	40.2 87	3. 99	0.11 67
97	40.292	40.7 60	4. 00	0.11 67
98	40.844	41.3 11	4. 00	0.11 67
99	41.487	41.9 55	4. 00	0.11 67
99.235	41.532	42.0 00	3. 00	0.11 67
99.5	41.768	42.00	1.97	0.1167
99.6	41.94	42	0.5	0.1167

Table 5: Switching results.

SOC Start at	Switch CC to CV	Setpoint		Output Mean	Oscillation
99 %	at SOC 99.1438 %	Current	4 A	4.022 A	12.5 %
		Voltage	42 V	42.014 V	0.95 %

Table 5 shows the process of switching from constant current (CC) to constant voltage (CV). The displacement occurs when the SOC of the battery is 99.14% with a charging voltage (Vch) of 42 V and a charging current (Ich) of 0.5 A. The allowed charging voltage of the battery is 42 V (according to the datasheet). With a CC current of 4 A, it lasts until the charging voltage is 42 V. So that's when the CC switches to CV. The oscillations that occur against the current setpoint are 12.5% and the oscillations that occur against the voltage setpoint are ± 0.95%. Oscillation can be affected by the buck voltage source (rectifier), PI control value and switching frequency.

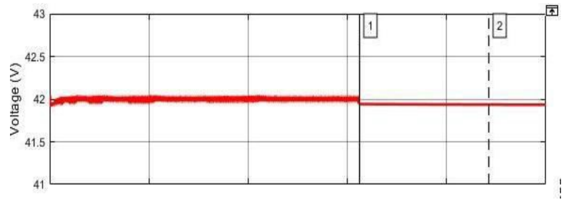

Figure 12: The simulation results of a full battery cut off.

Fig. 12, shows the charging process is complete (full). The battery will be considered full when the charging voltage is 42 V and the charging current drops to <= 0.5 A. The cut off process occurs when the SOC of the battery in the simulation is 99.6%. Battery voltage when open circuit after charging process is 41.94 V.

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