Analysis of battery charging in the development of BMS for solar UAV application

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Abstract. Solar UAV is an alternative technology for UAV to upgrade endurance and energy management of the UAV. PUSTEK Bang as an aeronautics institution in Indonesia also develops a project related to it. Providing research in Solar UAV field, there are some sub systems development to attain its applications, one of the most important elements is energy management system. Specific experiments were carried out in order to improve the research development for switching process on parallel batteries. Further analysis will be conducted based of these tests related to Battery Management System (BMS) and Energy Management System (EMS). This paper presents the analysis of charging characteristics from two kinds of battery’s capacity (3000mAh and 8000mAh) that have been conducted with variation of voltage inputs and two values of current inputs (2A and 1A). The result shows that when the battery is charged in 2A, time consuming for both types of batteries will increase 2 times in a row with the increasing of voltage input. Then, when the battery is charged in 1A, time consuming for both types of batteries is a little bit longer which is about 2.5 times in a row with the increasing of voltage input.

1. Introduction
Now, the development of UAV has created many innovations and modifications based on human needs. Recently, one of the advanced UAV technologies is Solar UAV [1]. Solar UAV is an UAV that uses solar cell as an energy source to supply UAV’s endurance in long operation [2]. PUSTEK Bang as an institution which is responsible as an aeronautics institution in Indonesia has developed few projects related to UAV, called LAPAN Surveillance UAV (LSU). One of the research groups in PUSTEK Bang, SOLAR UAV Research Group has a focus of research on the development of energy management system on LSU-03 using solar panel. Furthermore, this aircraft will be implemented to monitor illegal fishing in maritime territory of Indonesia [3]. Therefore, it needs a high cruising range dan a validated stable system. These requirements became the background of this paper, in which the charging characteristic of battery is analyzed.

Solar photovoltaic cells, which are the element used to obtain electrical energy, are generally made of a semiconductor material, usually silicon, which releases electrons after receiving the radiation from the sun. Electrons can move through the material creating a potential difference in it [4]. As a consequence, cells behave like a small unlimited battery when a load between the terminals is applied. Hence, BMS is needed to maintain the battery from overcharging or overdischarging [5].

The power crop from solar panel has to be integrated with the batteries on the UAV. Indeed, it takes important role to assure energy availability during operation [6]. When implemented into an aircraft design environment, the energy density of the batteries, or other energy storage systems, becomes one of the primary indicators of technology level, and represents a major determinant of aircraft weight [7]. Hence, one of the important aspect in the development of solar UAV system is...
Battery Management System (BMS). BMS analysis is necessary to control charging and discharging battery in guaranteeing reliability and safety of the battery [8].

In [9], characteristics of cell cycled at 10°C which had been observed on lithium-ion battery showed lower capacity, due to decrease in ionic conductivity of electrolyte at low temperature and also due to the sluggish kinetics for Li-ion diffusion into electrodes.

Also, an evaluation of charging methods had been conducted in [10], resulting FLC or MPC shown better performances than CC-CV. Their main benefits are charging time, improved charging efficiency, mitigation of the temperature rises, and keeping the battery SOC within secure limits. Latest reviews about charging techniques of Li-ion battery in [11] shows that boostcharging method is found as the most suitable charging technique that can recharge a fully discharged battery Li-ion within 5 min to one third if its rated capacity without damaging it. Meanwhile, four charging techniques are CC-CV, five-step charging pattern, pulse charging, and boostcharging method. At first research, this paper will start to evaluate charging battery using CC-CV method as basic procedure on Solar UAV.

As initial research about Solar UAV, this paper presents the analysis of battery charging with different capacity. A battery with high capacity will be used in system with high power needs. Meanwhile, the battery with low capacity will be used in system which needs low and reliable power. Moreover, this research is to select appropriate battery for supplying UAV system operation that is charged using solar as energy resource. The comparison of two charging tests are presented with MPPT 2 channels. First channel is for input from voltage generator and the second channel is output to Lithium Battery (LIPO) 3S battery. Variances of current and voltage are put on to find out the duration of charging battery.

2. Methodology
The method for analyzing the battery charging was using Maximum Power Point Tracker (MPPT) and recording current and voltage using sensor and microprosessor. The design of the MPPT (Maximum power point tracking) circuit consisting of resistors, rectifiers and microprocessor capable of turning excess power into additional charge current and solar charge controller to prevent battery from overcharging [12].

The first step in the design of energy management system is to identify the power demand and the maximum power that can be generated with the available surface area. The energy management system has to be incorporated into UAV, as shown in figure 1.

![Diagram of Energy Management System](image)

**Figure 1. Diagram of Energy Management System.**

To provide detailed data for Battery Managenet System (BMS), such as charging and discharging characteristics, we created charging battery test. This test used varying input voltages from 14V until 20V by 2V of increment. Its numerous values are based on the result data from solar panel test with Condor aircraft type. The input current was also varied between 1 A and 2 A, with assumption of 2A in sunny day and 1A in cloudy weather. The variances of input current and input voltage were conducted by voltage generator. Meanwhile, the measured current and voltage from MPPT would be monitored by microprocesser and validated by clampmeter. Flowchart of the test is shown in figure 2.

If the measured data shown from the monitor was different with the measured data from clampmeter, checking the integration of devices, cables connection, and line of the program were necessary to be analyzed. After that, the program was observed once again to prevent malfunction and to gain valid result. The experiments were divided into two main type. Firstly, experiment of charging battery using 3000mAh. Secondly, charging battery test using 8000mAh battery capacity. These differences are important to decide suitable battery type for LSU 03. In addition, charging would start
if only battery was empty and would be charged until full (99%). During this period, current, voltage, and time duration were recorded every 10 seconds.

![Flowchart of charging battery test using MPPT](image)

**Figure 2.** Flowchart of charging battery test using MPPT.

Figure 3 shows the integration of the experiment. Voltage generator acted as power supply that substituted solar panel function. Then, the current flowed through MPPT, voltage sensor, current sensor, and then charged the battery. The recorded data were processed by microprocessor and showed on the monitor in realtime.
3. Result and analysis

The experiments were conducted in two times with two different battery capacities, i.e., 3000mAh and 8000mAh, while the test and results of charging 8000mAh battery had been done before. Figure 4–7 illustrates the voltage and current measurements with different voltage inputs and constant current inputs in 2A and 1A. During charging, the battery cells were applied with constant current–constant voltage (CC-CV). The voltage would rise across the terminals of the battery from the “empty” level (typically around 3.3 V) up to the “full” level (typically around 4.2 V) as illustrated for a lithium-ion battery with a nominal charge capacity of 3000 mAh. During the constant current phase, the primary task of battery management was to confine the current of the maximum permissible battery current. While the charging current was maintained within the defined thresholds, the battery voltage increased as the battery was charged. The constant current phase ended when the cell voltage of the battery reached the set point specified. In the constant voltage phase, the battery voltage was controlled at a constant value. As a result, the battery current decreased continuously, as can be seen in figure 5 and figure 7.

From figure 4 and figure 5 below, it also can be observed that input currents take important role in charging process. As higher current flows, the faster charging process for a battery occurs. Similarly, the battery which is charged in 20V is quicker to reach full charged condition than battery which is charged in 14V (both have input current of 2A). During fast charging it is possible to pump electrical energy into the battery faster than the chemical process can react to it, with damaging results. The chemical action cannot take place instantaneously and there will be a reaction gradient in the bulk of the electrolyte between the electrodes with the electrolyte nearest to the electrodes being converted or “charged” before the electrolyte further away. This is particularly noticeable in high capacity cells which contain a large volume of electrolyte.
Figure 4. Voltage vs time when charging 3000mAh battery and 8000 mAh battery in 2A.

Figure 5. Current vs time when charging 3000mAh battery and 8000 mAh battery in 2A.

The differences between figure 4 and figure 5 with and figure 6 and figure 7 is about their input current. Figure 4 and figure 5 has input current of 2A and figure 6 and figure 7 shows the results of output voltage and current from input current of 1A. The duration of charging the 8000mAh battery is longer than the 3000mAh battery.

First, the results of charging method when input current is 2A is shown in figure 4 and figure 5. In 3000mAh, charging period is about 30 minutes until it reaches full charged condition, for 20V input voltage. Meanwhile, with same input voltage and current, it takes 2 hours for 8000mAh battery to be charged from empty to full. Afterwards, it takes 4 hours for 8000mAh battery to fulfill its capacity if it is charged in 14V, 2A. Similarly, if being charged in 14V, 2A, it also takes longer duration, which is about 1 hours for 3000mAh. To summarize, in constant current input condition (2A), both 3000mAh
and 8000mAh batteries increase two times of their time charging along with the increase of voltage input.

Second, if solar UAV flies in cloudy condition, we assume it provides 1A as input current. So for the second experiment, we used various voltage inputs and constant current input which was 1A. In figure 6 and figure 7 we can investigate that charging 3000mAh needs almost 1.5 hours at 20V,1A input. Likewise, it needs about 4 hours with same inputs for 8000mAh to fulfill its capacity. Both current inputs, resulting same trends in the current and voltage measured. As long as measured voltage climbs, the measured current levels off as its condition is in charging process. Conversely, when the battery is nearly full, its measured current declines while the measured voltage starts to be stabilized as the battery is full and the charging process is ended.

![Figure 6](image1.png)

**Figure 6.** Voltage vs time when charging 3000mAh battery and 8000mAh battery in 1A.

![Figure 7](image2.png)

**Figure 7.** Current vs time when charging 3000mAh battery and 8000mAh battery in 1A.

The graphs in figure 4 and figure 5 show fluctuation values since there are some errors in the program. These errors can be reduced by applying some filters.
4. Conclusion
The tests for different charging capacity (3000mAh and 8000mAh) have been conducted with variation of voltage inputs and two values of current inputs (2A and 1A). The measurements deliver two main trends. First, when the battery was charged in 2A, time consuming for both types of batteries would increase 2 times in a row with the increase of voltage input. Second, when the battery was charged in 1A, time consuming for both types of batteries was a little bit longer which is about 2.5 times in a row with the increase of voltage input. In addition, considering the application of these batteries are for UAV, which concerns about its weight that plays important role in the system, the batteries with less capacity is more suitable, such as 3000mAh batteries, since it can be charged within only 30 minutes with the power of 20V, 2A, assuming the LSU Solar flies in a short time. Alternatively, the batteries with high capacity should be used if LSU Solar has to fly in a long operation. In conclusion, charging battery which has high or low capacity is a substantial part that has to be decided based on its charging characteristics and system’s requirements to provide reliable system during operation.

References

[1] Ma D-m, Shiau J-k, Su Y-j, Chen Y-h. Optimal level turn of solar-powered unmanned aerial vehicle flying in atmosphere. J Aircr 2010;33.
[2] Oettershagen, Philipp, et el. Perpetual flight with a small solar-powered UAV: Flight results, performance analysis and model validation. IEEE Aerospace Conference. 2016.
[3] Yono Putro, I.N., Chasanah, N. Analysis of Link Budget Design Using Free-Path-Loss Model for LSU02LD. Seminar Nasional IPTEK Penerbangan dan Antariksa XXI, pp 282-288. 2017.
[4] Wasfi, M., Solar Energy and Photovoltaic Systems. Journal of Selected Areas in Renewable and Sustainable Energy (JRSE). February 2011.
[5] Yinjiao Xing, Eden W.M.Ma, Kwok L. Tsui, Pecht, M., Battery Management Systems in Electric and Hybrid Vehicles. Energies, 4(11), 1840-1857. 2011.
[6] Noth A. “Design of solar powered airplanes for continuous flight, PhD”, Autonomous System Lab, ETH Zurich, Switzerland; 2008.
[7] Abbe G., Smith H., “Technological Development Trends in Solar-Powered Aircraft Systems,” Renewable and Sustainable Energy Reviews pp. 770-783. 2016.
[8] J. R. Lorch and A.J. Smith, “Software strategies for portable computer energy management,” IEEE Personal Communications., vol. 5, no. 3, pp. 60-73, Jun. 1998.
[9] Rahul Deb Pal and Alok K R Paul. Charge-Discharge Studies of Lithium-Ion Batteries. Proceedings of the COMSOL Conference. 2015
[10] Banguero, E, Correcher, A, Perez Navarro, A. A Review on Battery Charging and Discharging Control Strategies: Application to Renewable Energy Systems. MDPI Energies. 2018, 11, 1021.
[11] Ayoub E, Karami N. Review on The Charging Techniques o a Li-ion Battery. TAAECE. 2015.
[12] M. Jantsch, M. Real, H. Häberlin, C. Whitaker, K. Kurokawa, G. Blässer, P. Kremer, C.W.G. Verhoeve.” Measurement Of PV Maximum Power Point Tracking Performance”, Working Group 3: PV Systems, Technical Committee 82: Photovoltaics, International Electrotechnical Commission. Netherlands Energy Research Foundation ECN.”