Grading of Lithium Ion Battery Module for Public street lighting

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Abstract. A module of lithium ion battery has been constructed to replace ion battery for public street lighting. The module was designed to deliver a power of minimum~120 Wh for running 10 Watt solar street lighting, with a solar panel of 80 Wp. The module consisted of 40 cylinder cells 18650 of LiFePO4. Before designing the module, all the cells have to be formatted, graded and sorted out, to obtain an optimum results. The charge-discharge testing and internal resistance were measured to every single cell using a battery analyzer. The cells grading, sorting and grouping were consecutively done to obtain an optimum LIB module. The results showed each cylinder cell delivering discharge capacity, voltage and internal resistance of ~1.2-1.4 Ah, ~ 3.2-3.3 V, and 50-70 Ω, respectively. The cells were arranged into 4 serial and 10 parallel, to produce LIB module with the power of ~130-140 Wh, which is higher than expected. The LIB module made in Indonesia, with high local content can run the public street lighting and replace the conventional Lead Acid battery.

Keywords: grading, module battery, lithium ion battery, solar panel, public street lighting

1. Introduction

The Indonesian government has targeted the use of 30 % mixed energy in 2030 that mostly from the renewable energy resources, such as geothermal, wind, solar, hydro, biomass and nuclear power plant [1]. In order to store the energy from the renewable sources, the energy storages are required and very important aspects [2,3]. The combination of a pollution-free, battery energy storage system and a ‘clean’ photovoltaic energy supply results in an efficient peak-power supply without harmful environmental effects. At the same tune, the economics are greatly unproved as the expensive solar energy is used to supply electricity at peak-power rates. In certain cases, a primary battery, e.g. aluminum/a-, may be used as an emergency power supply. Reliability and flexibility are intrinsic characteristics of electrochemical energy storage. The electrical features of a solar generator have to be taken into account when charging the battery. The particular requirements for both the charge and the operation of the lead/acid battery must be considered in order to obtain the most efficient, i.e, the
The most economic use of solar energy [4]. The great interest in load-levelling systems, using lead/acid batteries for energy storage, has already resulted in several very large storage units in storing energy to meet the peak-power requirements. Solar energy is certainly very attractive for load-levelling applications. However, the use of conventional lead acid batteries are limited due to short life cycles, non-rechargeable, and not friendly to the environment, due to toxic lead materials. Therefore, the replacement of lead acid with the lithium ion battery is important and one of the scientific breakthroughs. The use of LIB module will have more advantageous in comparison with the conventional lead acid battery [5]. The LIB module is much lighter, smaller size, long life cycles, and higher energy density. Thus requires an extensive investigation for each application [1,2,6,7].

Solar energy has to be consumed locally in order to avoid conversion and distribution losses. The same advantages are present in small, stand-alone installations. The use of battery storage enables the use of smaller photovoltaic generators as the consumption peaks are levelled out by the battery. The larger the batteries, the less generators will have to be operated [8,9]. The installation of the solar systems feeding into the street lights is one of the most interest, due to the large applications in isolated area, housing or along the highway. It is also simple and no electrical power supply needed. The solar energy itself can be run unlimited and of course renewable. Thus the research on application of solar panel for the public street lights and household has becoming a significant issue.

The aim of this study is to design a module of lithium ion batteries to turn on the public street lighting. The LIB module will be designed and constructed from the LIB cells that previously investigated [1,10]. The process of grading of lithium ion cells will be discussed in order to optimise the system configuration that will present the closest match between generator, storage, and user. Finally performance of the module will be characterized using a charge discharge instruments.

2. Experimental Detail

There are several steps on obtaining the module of lithium ion battery (LIB), namely grading, sorting, grouping, welding and battery module testing. These series of experimental procedures have to be conducted to obtain an optimum module for Lithium Ion Battery. The size and capacity of the LIB module was first determined from the targeted output, such as the minimum power to run the solar street lamp. Design of the modules is decided by arranging numbers of cylinder cells 18650. The detail of cylindrical battery 18650 for this research has been described previously [1,10,11]. The cell consists of LiFePO$_4$, polymer, LiPF$_6$ and C, as cathode, separator, electrolyte and anode materials, respectively. The cathode was coated on the Al-foil as positive current collector, while the anode was coated on the Cu-foil as the negative current collector. The electrolyte was pour into the cylindrical cell in the glove-box. Detail of cylindrical cell assembly has been described elsewhere [10]. The cell formation was done for each cell using a battery analyzer, in order to obtain the discharge capacity, voltage, and internal resistance. The process is called grading of cells. All experiments were done at Integrated Battery Laboratory – BATAN Indonesia. The measurement of internal resistance, capacity, and voltage were done by using NEWARE battery testing system-5V6A.
2 Grading

2.1 Measurement of battery capacity and voltage.

Figure 1 shows process of testing battery from cylindrical cell. The charge discharge measurements were performed using NEWARE battery testing system-5V6A. As shows in Table 1, the charging process was performed with two steps, these are the constant current and constant voltage (CCCV_Chg) of 0.28 A, which is equal to 0.2 C-rate until reaching Vmax= 3.65 V. For discharge process, the battery was drained by current of 0.28 A until battery voltage drops to 2.6 V. The voltage measurement was done before and after cycling. For the batteries using LFP cathode, the voltage is around 3.2 volt. Using the charge-discharge battery analyzer the data is more accurate.

Table 1. Set of charge discharge for batteries grading.

| Step ID | Step Name     | Time (h:min:s.ms) | Voltage (V) | Current (A)     | End Current (A) |
|---------|---------------|-------------------|-------------|-----------------|-----------------|
| 1       | Rest          | 0:05:00.000       |             |                 |                 |
| 2       | CC_DChg       |                   | 2.6000      | 0.2800000       |                 |
| 3       | Rest          | 0:05:00.000       |             |                 |                 |
| 4       | CCCV_Chg      |                   | 3.6500      | 0.2800000       | 0.0280          |
| 5       | Cycle         | Start from step ID: 1 | Cycle Count: 5 |
| 6       | End           |                   |             |                 |                 |

2.1.2 Measurement of internal resistance.

Internal resistance (iR) is very important variable to be measured before arranging a module. Without testing, selecting and sorting this item, the module will not properly function. The iR was determined by discharging a battery in 1 second. Current and voltage limit are the same with the charge discharge process as explained above. The difference during 1 second discharge step, the current used was 1.4 A which was equal to 1 C-rate. The set of the process is shown in Table 2.
Table 2. Set of determination internal resistance (iR).

| Step ID | Step Name   | Time (h:min:s.ms) | Voltage (V) | Current (A) | End Current (A) |
|---------|-------------|-------------------|-------------|-------------|-----------------|
| 1       | Rest        | 0:02:10.000       |             |             |                 |
| 2       | CC_DChg     | 0:00:1.000        | 2.6000      | 0.2800000   |                 |
| 3       | CC_DChg     | 0:05:00.000       | 0.1400000   |             |                 |
| 4       | Rest        | 0:05:00.000       |             |             |                 |
| 5       | CCCV_Chg    | 0:00:01.000       | 3.6500      | 0.2800000   | 0.0280          |
| 6       | End         | 0:02:10.000       |             |             |                 |

iR can be calculated by equation (1):

\[
iR = \frac{\Delta V}{\Delta t} = \frac{V_t - V_0}{I_t - I_0}
\]  

(1)

where \( V_0 \) and \( V_t \) are start and end voltage when the battery was discharging at in a second. \( I_0 \) and \( I_t \) are start and end current (see Table 2).

2.2. Selection, Sorting and Grouping

The selection process was done by choosing batteries with internal resistance value of less than 100 mΩ and sorting them from the smallest values. The batteries should have capacity at least 1 Ah, and for the batteries with capacity less than 1 Ah, will be rejected. Similar to the batteries with the voltage are less than 3.2 Volt, will also be rejected. The battery module can be customized and used for energy storage on Public street lighting, electric vehicle, and electric bike, etc. Public street lighting need 12 volt battery. So that we need 4 seri connection to generate it.

3. Results and Discussions

3.1 Charge discharge Module battery

During formation, the batteries were charged and discharged for 5 cycles. Battery capacity data was taken from the fifth cycle is shown in Table 3. The result showed that the capacity of battery was 1.4797 Ah, at 5th cycle, identifying that the battery performance was good. The discharge capacity is depicted in Figure 2.

Table 3. Charge-discharge Capacity of cylinder cell 18650 at 5th cycle.

| Cycle ID | Step       | Time (h:min:s.ms) | Cap_Chg(Ah) |
|----------|------------|-------------------|-------------|
| 5        | CCCV_Chg   | 5:22:44.700       | 1.4797      |
|          | Rest       | 0:05:00.000       | 0.0000      |
|          | CC_DChg    | 5:17:19.800       | 1.4750      |
|          | Rest       | 0:05:00.000       | 0.0000      |
Figure 2. Charge Discharge curve one of cylindrical battery 18650 at 5th cycle.

All the cells were charged and discharge for 5 cycles, then were selected that fulfill the requirements. Furthermore, the internal resistance were measured and calculated for each cell with the measurement data as listed in Table 4. By calculating the data of start and end voltage, the iR was determined using equation (1). In this case, for example, hence $I_0$ and $I_t$ are 0.28 A and 1.4 A, respectively, so $\Delta I$ is 1.12 A. The voltage different is marked in Table 4, and resulted $\Delta V \sim 0.0543$ V [12]. By using equation (1) the internal resistance for all the battery can be calculated, and some of the results are shown in Table 5.

Table 4. Measurement data iR of battery.

| Step ID | Step Name | Time (h:min:s.ms) | Start Voltage (V) | End Voltage (V) |
|---------|-----------|------------------|------------------|-----------------|
| 1       | Rest      | 0:05:00.000      | 3.3293           | 3.3293          |
| 2       | CC_DChg   | 4:56:20.700      | 3.3175           | 2.5998          |
| 3       | Rest      | 0:02:02.900      | 2.6140           | 2.7625          |
| 4       | CC_DChg   | 0:00:01.000      | 2.6866           | 2.6323          |
| 5       | Rest      | 0:05:00.000      | 2.6931           | 2.8134          |
| 6       | CCCV_Chg  | 5:36:21.900      | 2.8270           | 3.6495          |

Table 5. Grading data of the batteries.

| Cell | iR a (mΩ) | Voltage a (V) | DCHG Cap (Ah) | RCHG Cap (Ah) | Voltage t (V) | iR t (mΩ) |
|------|-----------|---------------|----------------|----------------|---------------|------------|
| 1    | 21.6      | 3.33          | 1.5632         | 1.5725         | 3.34          | 21.7       |
| 2    | 22.6      | 3.33          | 1.3665         | 1.3981         | 3.34          | 23.3       |
| 3    | 22.1      | 3.33          | 1.5122         | 1.5613         | 3.33          | 24.4       |
| 4    | 23.0      | 3.28          | 1.3842         | 1.4602         | 3.29          | 24.8       |
| 5    | 25.0      | 3.32          | 1.4571         | 1.4728         | 3.32          | 25.7       |
Table 5 shown how the cells have been selected, sorted and grouped into a parallel or serial. The ten parallel and four serial connection has been chosen. The battery module design is shown in Figure 5. Batteries are arranged in parallel in order of iR values, as well the serial connection listed in Table 5. All the four serial are grouped into four parallel to increase the capacity. From the calculation the expected module output 14.48 Ah and 13.33 V. The monitoring system will be designed and constructed in parallel in order to evaluate and analyze the results during the operation. An integrated system will be made to support this, and called as a smart public solar lighting [12].

![Figure 3. Battery module arrangement and design of welding in top view.](image)

4. Conclusion
This study has focused on developing the module of lithium ion battery (LIB) for public solar street lighting. The interest of using LIB module is due to more advantageous in comparison with the conventional lead acid battery. The “battery module” is usually only used associated with high-power batteries, consisting of an assembly of cell packages, including safety features, as well as a battery management system (BMS), and a base plate or housing. The cells are connected in parallel or in series, depending on the capacity or voltage needs for an application. Parallel configuration adds capacity, leaving the voltage constant, serial configuration adds voltage, leaving the capacity constant, respectively.

It has been shown here, that the battery grading are very important process before designing a module. Through grading will determine the discharge capacity, the voltage and the internal resistance of each cell. Then the sorting of those only cells that fulfill the requirements another important aspect before combining into parallel and serial. The module of LIB that consists of 40 cells parallel and serial has been successfully constructed, and exhibited the power of 140 Wh, with good ability and efficiency. This result has fulfilled the requirement to turn on the public solar street light, and open the challenge of replacing the lead acid battery overall. Finally, it is concluded that the Indonesia national battery consortium has successfully proven to produce a module lithium ion battery with high local content and made by Indonesian researchers.

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