Calculation of Capacity and Usage Time of Lithium-Ion Batteries on Electric Bikes with 350 W BLDC Motors

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ABSTRACT
Batteries are one of the most important components in electric vehicles. Batteries are used as an energy source for the entire electrical system and as a place to store electrical energy during the charging process. The battery functions to supply electric current in order to operate the electric machine. The lithium-ion battery is a type of secondary battery (rechargeable battery) that can be recharged and is an environmentally friendly battery. This battery has excellent energy storage stability and higher energy density compared to other types of secondary batteries, making this type of battery increasingly attractive for use in electric vehicles. This study aims to design the size of an electric bicycle battery according to its specifications. In addition, an analysis of the calculation of the capacity of the battery to be used and the time for the recharging process is also carried out.

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1. INTRODUCTION
With increasing carbon emissions from vehicles that employ the Internal Combustion Engine (ICE) concept, alternate sources of vehicle fuel are required. Electric automobiles and hybrid electric vehicles are the ideal answer for reducing environmental impact [1]. Electric bicycles (e-bikes) for commuting in urban areas are a viable solution to the major problems of pollution, traffic, and road congestion due to their advantageous properties such as low cost, convenience of use, and tiny footprint [2]. The battery is the most suited energy storage and power supply component for use in high-power EV applications. Developed battery technologies have numerous advantages, such as high energy density, low environmental contamination, and long cycle life[3].

Batteries are used as an energy source for the entire electrical system and as a place to store electrical energy during the charging process. In addition, the battery is used to supply electric current to run the drive, lights and other electrical components [4]. With the advantages offered by li-ion batteries, more and more people are switching to this type of battery where previously the use of electric bicycles generally still used VRLA type batteries which have a lower energy density.
Due to the increasing use of li-ion batteries as energy storage, it is necessary to further calculate the capacity of the batteries that will be used to drive electric bicycles, store energy and recharge them so that electric vehicles can be used sustainably with high energy reliability.

2. METHOD

2.1. Electric Bike With BLDC Motor

An electric bicycle is a two-wheeled vehicle that runs on electricity and has an electric motor as its main drive. The electric bicycle in this study is powered by a 48V brushless DC motor with a 350W output. A brushless direct current (DC) motor is one that does not have a brush. Because the brush and commutator pieces have been removed, this motor has greater efficiency, less noise emitted when rotating, lower maintenance, and can revolve at high speeds due to reduced friction with the brush. The disadvantage of this motorbike are that it is more difficult to control and more expensive [5]–[7].

![BLDC Motor Hub Drive and Controller](image)

Figure 1. BLDC Motor Hub Drive and Controller

This electric bike has a 48V BLDC motor with a hub-drive type. The motor gears on an electric bike are directly attached to the wheels. The motor rotation speed will then be regulated by the controller device. The controller on a brushless DC motor plays a critical function and is the primary support for the motor's operation. Brushless DC motors require a pulse trigger that enters the electromagnetic part (stator) of a brushless DC motor to provide regulation of the amount of current flowing so that the rotation of the motor can be adjusted accurately. Table 1 displays the technical specifications for BLDC motors.

<table>
<thead>
<tr>
<th>BLDC Motor Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>48 V</td>
</tr>
<tr>
<td>Power Watt</td>
<td>350 W</td>
</tr>
<tr>
<td>Commutation Angle</td>
<td>120°</td>
</tr>
<tr>
<td>Current</td>
<td>4 – 7.2A</td>
</tr>
<tr>
<td>Over Current Max</td>
<td>17 A</td>
</tr>
<tr>
<td>Torque</td>
<td>18 Nm</td>
</tr>
</tbody>
</table>

2.2. Lithium-Ion Battery

The lithium-ion battery is a secondary (rechargeable) battery. Rechargeable battery that is safe for the environment because it does not include dangerous elements like Ni-MH and Ni-Cd batteries. This battery has an advantage over other types of secondary batteries in that it
has great energy storage stability (lasting up to 10 years or more), high energy density, no memory effect, and is relatively less weight. As a result, lithium batteries produce twice the energy of other types of batteries for the same weight [8].

The battery used in this study is a li-ion battery 18650 with a voltage of 3.7 V per cell. This cannot meet the power requirements of an electric motor which requires a battery voltage of 48 V. This results in the battery having to be connected in series and parallel to fit with need. The specifications of the battery used include capacity, nominal voltage, maximum charging voltage, maximum charging current, and maximum discharging current respectively are 3 Ah, 3.7V, 4.2V, 6.5 A, and 20A.

2.3. Battery Management System

Battery management system is a type of electronic system used to manage rechargeable batteries. The BMS regulates the charging or discharging path of the battery, the battery is protected from overcharging, and the battery voltage is balanced. BMS can also increase a battery's life cycle, and in general, BMS is only used on lithium batteries due to their complex conditions [9].
3. RESULTS AND DISCUSSION

3.1. Battery Size

This electric bike has a BLDC motor drive with a voltage of 48 V and a power of 350 W, thus we need a battery with sufficient capacity to provide the necessary voltage. The following equation can be used to calculate the number of battery series required to match the operational voltage:

\[
\text{Battery series} = \frac{\text{Motor Voltage}}{\text{Battery Voltage}} = \frac{48 \text{ V}}{3.7 \text{ V}} = 13 \text{ series}
\]

The minimum battery capacity in this electric vehicle system is [7]:

\[
\text{Battery capacity} = \frac{\text{Daily Energy}}{\text{Battery Voltage}} = \frac{350 \text{ wh}}{48 \text{ V}} = 7.3 \text{ Ah}
\]

The battery in the current study is Lithium Ion (Li-Ion). In this study, we look at the battery depth of discharge to extend battery life. DOD is considered to be 80% for Li-Ion batteries. The following calculation shows that the minimum battery capacity used is:

\[
\text{Minimum Battery capacity} = \frac{7.3}{0.8} = 9.1 \text{ Ah}
\]

A battery with a minimum capacity of 9.1 Ah will be used in this study. We will utilize a battery with a voltage of 48 V and a capacity of 12 Ah to boost battery capacity and adapt the size of the battery accessible on the market. The following equation will calculate the number of batteries in parallel

\[
\text{Battery Parallel} = \frac{\text{Battery Capacity}}{\text{Cell Capacity}} = \frac{10 \text{ Ah}}{2 \text{ Ah}} = 4 \text{ Parallel}
\]

3.2. Discharging Time

The consumption of electric power in BLDC motors can be calculated using the current and working voltage parameters of the electric motor. On an electric motor with a voltage of 48 V and a working current of 7 A, the battery discharging time can be obtained as follows:

\[
\text{Discharging time} = \frac{\text{Battery Capacity}}{\text{Working Current}} = \frac{12 \text{ Ah}}{7 \text{ A}} = 1.72 \text{ h}
\]

With an 80% battery efficiency, the usage time will be:

\[
1.72 \times \frac{80}{100} = 1.37 \text{ h}
\]

As a result, the battery life is 1.37 hours.

Table 2. Discharging Time

<table>
<thead>
<tr>
<th>Current</th>
<th>Discharging Time (hours)</th>
<th>Discharging Time with Efficiency 80 % (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>0,8</td>
<td>0,6</td>
</tr>
<tr>
<td>14</td>
<td>0,9</td>
<td>0,7</td>
</tr>
<tr>
<td>12</td>
<td>1,0</td>
<td>0,8</td>
</tr>
<tr>
<td>10</td>
<td>1,2</td>
<td>1,0</td>
</tr>
<tr>
<td>8</td>
<td>1,5</td>
<td>1,2</td>
</tr>
<tr>
<td>6</td>
<td>2,0</td>
<td>1,6</td>
</tr>
<tr>
<td>4</td>
<td>3,0</td>
<td>2,4</td>
</tr>
<tr>
<td>2</td>
<td>6,0</td>
<td>4,8</td>
</tr>
</tbody>
</table>
Figure 4. Battery Discharging Time

The discharging time is depends on the battery usage current in this case is the motor current. Table 2 shows that discharging the battery takes a discharging current of 7 A and a discharging duration of 1.37 hours. In figure 4 shows that the higher the motor usage current will cause the li-ion battery capacity to be drained.

3.3. Charging Time

The time needed to charge the battery is determined by the amount of current in the battery and the charging method used. Furthermore, the voltage required to charge the battery must be greater than the battery voltage. The idea is to have a potential difference between the charging equipment and the battery to be charged so that an electric current can go from a high potential voltage to a low potential voltage when there is a potential difference [4]. Batteries with an operating voltage of 48 V can be charged with voltages ranging from 52.5 V to 54 V. Battery charging time depends on the charging current where the maximum charging current of the battery is 40% of its capacity [7]. Through this, we can use a current of 5 A to charge a battery with a capacity of 12 Ah. The charging time can be calculated by the following equation [5].

\[
\text{Charging Time (hour)} = \frac{\text{Battery Capacity}}{\text{Charging Current}} + (20\% \times \frac{\text{Battery Capacity}}{\text{Charging Current}})
\]

\[
= \frac{12}{5} + (0.2 \times \frac{12}{5})
\]

\[
= 2.4 + (0.2 \times 2.4) = 2.88 \text{ (3 hours)}
\]

Charging a battery with a capacity of 12 Ah takes 3 hours at a charging current of 5 A.

Table 3. Charging Time

<table>
<thead>
<tr>
<th>Current (Ampere)</th>
<th>Charging Time (hour)</th>
<th>Charging Time with efficiency 80% (hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>1.5</td>
<td>1.8</td>
</tr>
<tr>
<td>7</td>
<td>1.7</td>
<td>2.1</td>
</tr>
<tr>
<td>6</td>
<td>2.0</td>
<td>2.4</td>
</tr>
<tr>
<td>5</td>
<td>2.4</td>
<td>2.9</td>
</tr>
<tr>
<td>4</td>
<td>3.0</td>
<td>3.6</td>
</tr>
<tr>
<td>3</td>
<td>4.0</td>
<td>4.8</td>
</tr>
<tr>
<td>2</td>
<td>6.0</td>
<td>7.2</td>
</tr>
<tr>
<td>1</td>
<td>12.0</td>
<td>14.4</td>
</tr>
</tbody>
</table>
The charging time is determined by the amount of current used to charge the 12 Ah 48 V Li-Ion battery. Table 4 shows that charging the battery takes a charging current of 5 A and a charging duration of 3 hours. In figure 4 shows that the higher the battery charging current will cause the capacity of the li-ion battery to be filled faster.

4. CONCLUSION

The energy storage used in this electric bike is a Li-Ion battery with a voltage of 48 V and a capacity of 12 Ah. This battery pack is made from a 18650 lithium ion battery with a 13S4P configuration and consists of 13 pieces arranged in series and 4 in parallel.

This battery can power an electric motor for 1.37 hours at a current of 7 amps. The battery will be fully charged in three hours with a charging current of five amps. Li-Ion batteries are of higher quality and can deliver more electrical energy than a VRLA battery of the same capacity. This is associated with the Depth of discharge value and battery efficiency. The higher the discharging current of the motor will cause the capacity of the li-ion battery to be drained. on the other hand the higher the battery charging current will cause the li-ion battery capacity to be filled faster.

REFERENCES