Experimental Research and Energy Consumption Analysis of a 350 watt Brushless Electric Motor with LiFePO4 Battery

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Abstract. Conversion of bicycles into electric bicycles is currently carried out by many people. in the conversion process, there are still many people who do not understand the working concept and analysis of determining the right specifications for the conversion carried out. This paper presents experimental research and energy consumption analysis of a 350 Watt brushless DC electric motor with LiFePO4 Battery. LiFePO4 Battery is one of one of lithium-ion battery that Environmentally friendly, which will not destroy the ecological environment, also have no memory effects. The battery parameters that analyzed in this study are voltage, current, temperature, and internal resistance.

Keywords: BLDC, LiFePO4 Battery, BMS

1 Introduction

Both leisure and sporting activities have received attention in the modern period. As a result, more and more individuals are thinking about using bicycles for both recreational and physical activity [1]. Additionally, bicycles have evolved into a more practical mode of transportation as a result of the rising cost of gasoline [2]. The necessity to lessen the physical strain exerted on a rider when riding a bicycle has led to an increase in the popularity of electric-powered assisted bicycles [3]. Electric-power assisted bicycles have become more popular due to the need to reduce the physical load placed upon a rider in riding a bicycle.

The main component of electric bike is electric motor to convert the electric power into torque, battery to produce the electrical energy, and controller to transfer the electric current from battery to the electric motor [4], [5]. In addition, there are also several additional accessories such as a monitor display, pedal assist sensor, and electric brakes.

A typical motor of an electric bike includes a wheel motor disposed on the front or rear wheel, or in some cases, a middle motor disposed on the crankshaft. Electric motors without brushes, often known as BLDC (Brushless Direct Current) Motors, are a common form of motor that are being utilized globally [6]. It is an important

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part of the wheeled electric vehicle. BLDC motor has the advantages of simple structure, reliable operation, high efficiency and good speed regulation performance [7].

Controller is an electronic device that is used to convert DC (Direct Current) voltage into AC (Alternating Current) voltage. The output voltage of an controller can be an AC voltage in the form of a sine wave, a square wave and a modified sine [8]. The controller circuit on the BLDC motor controller is in the form of a mosfet with alternating and structured ignition.

Recently, lithium-ion battery have been widely used in different application, such as portable electronics devices and electric vehicles [9], [10]. LiFePO4 is one of lithium-ion battery that Environmentally friendly, which will not destroy the ecological environment, also have no memory effects [11]–[13]. It have low internal resistance and high flat voltage characteristics during strong current discharge, which ensures a wider application field [14]. A battery's internal resistance is expressed as a number that indicates the amount of resistance within each component. This resistance impacts the battery's lifespan, state of charge, and level of heat it produces [15]. Provide long storage life with few limiting conditions. It offers problem-free charge after long storage, permitting to use in a wide range of applications.

Any lithium-ion battery system must have a battery management system that maintains the health and performance of the battery pack's cells [16], [17]. A BMS also keeps track of the battery cells and makes sure they all function correctly together. It also measures voltage, current, and temperature to check on the battery's safety and health. A BMS aids in preventing overcharging, overvoltage, overcurrent, overheating, cell imbalance, and a shorter life cycle for the battery [18]. Additionally, it enhances each charge/discharge process's capacity and overall battery performance. In a battery pack, especially when they are stacked in series, the batteries must all have the same voltage. A characteristic known as balance is required to keep this voltage constant. The proposed BMS is constructed to have three main features, including monitoring, protection, and balancing.

Rising the battery temperatures impact the chemical reactions that take place inside batteries. The chemical reactions inside the battery speed up as the battery's temperature rises [19]. More excellent performance and enhanced battery storage capacity are two consequences of higher temperatures on lithium-ion batteries.

A research study to demonstrate the operating parameters of some of the key components of electric vehicles is important in order to analyze the performance characteristics of BLDC and LiFePO4 battery packs.

2 Methods

Three main components that make up an electric vehicle are: the electric motor, controller, and battery. This study analyzes the working parameters of the electric motor in terms of its effect on the work of the battery pack.

A LiFePO4 battery pack system includes the battery and battery management system (BMS). When more than one cell is connected in series, one crucial requirement for LiFePO4 BMS is to monitor the voltage across each cell to ensure charge equalization and voltage balancing of the cells. To control cell voltage, a protective circuit is often included to the charger circuit. To ensure a safe functioning condition, LiFePO4 batteries have extremely important charging criteria that must be met while charging. Battery charging is significant in the BMS since it affects battery performance and life cycles significantly.

The three primary purposes of a battery charger are to charge the battery, optimize the charge rate, and to stop the charge process. Depending on the battery chemistry, the battery can receive the charge through a variety of charging techniques. Constant current-constant voltage (CC-CV) charging is a very popular and widely used method for charging LiFePO4 batteries due to its simplicity and ease of implementation. In order to prevent overcharging of the LiFePO4 battery, a battery charger with constant current-constant voltage (CC-CV) approach was adopted in this study.

The battery pack is discharged using a 350Watt BLDC motor with a variety of current settings. To accomplish this, the brake lever is pulled in order to load the motor and endure its spin. According to the BLDC motor's characteristics, the necessary current will increase when the electric motor encounters resistance during rotation. It will obtain various changes in discharge current using this technique. One ampere to ten amperes are the range for the discharge current. On a data logger connected to the system, all information will be collected.

To record battery parameters and compare the data read by the BMS, a data logger 1 was created using Arduino Uno, current sensors ACS 758, voltage devider as voltage sensors, and NTC temperature sensors. The data is recorded in real time and stored in the SD card. Moreover, the data logger 2 record the speed of electric motor. The experimental project are illustrated on figure 1.

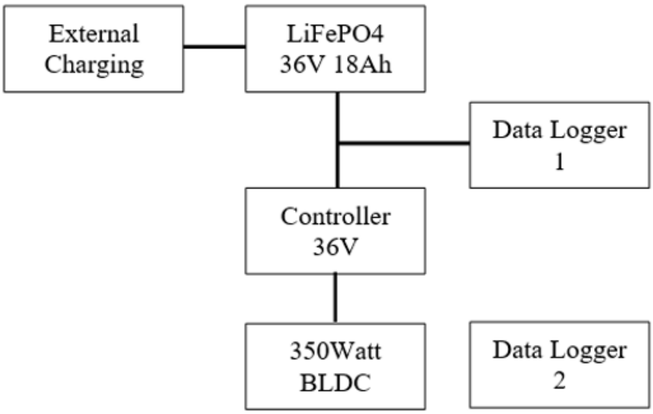

Fig. 1. Drivetrain BLDC Test Block Diagram

3 Results and Discussion

A Brushless DC motor is a type of permanent magnet synchronous motor supplied by a DC power source in its control and requires a three-phase AC power source to drive the motor rotor. A three-phase AC power source is needed because this permanent magnet synchronous motor has three coils on the stator. The connection between the coil and the trapezoidal stator winding will provide a trapezoidal electro motive back (trapezoidal electromotive force), namely the reverse voltage generated by the DC brushless motor winding, which will drive the rotor. The movement of the rotor is caused by the magnetic field in the stator, in which, at any time, only two phases are supplied while one other phase is not supplied. This phenomenon causes this motor to be like a DC motor because the current flowing in the stator coil is similar to a DC motor, even though three-phase current power this motor.

One of the most important parts of the battery feature study is the thorough real battery data. It is used to construct and validate the estimate of the battery parameters and the prediction of the battery status. Lithium-ion is named for its active materials, the words are either written in full or shortened by their chemical symbols. A series of letters and numbers strung together can be hard to remember and even harder to pronounce, and battery chemistries are also identified in abbreviated letters. Figure 2 ilustrate the comparation the type of lithium-ion battery. Lithium-ion battery compared is: Lithium Cobalt Oxide ($LiCoO_2$), Lithium Nickel Manganese Cobalt Oxide ($LiNiMnCoO_2$), Lithium Iron Phosphate ($LiFePO_4$), Lithium Nickel Cobalt Aluminum Oxide ($LiNiCoAlO_2$), Lithium Titanate (Li_2TiO_3). Furthermore, the battery parameters compared is: specific energy, specific power, safety, performance, life span, and cost.

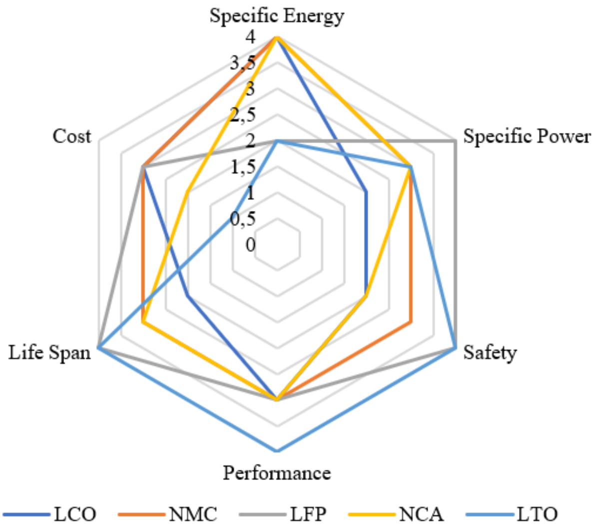

Fig. 2. Comparation type of Lithium-Battery

Based on figure 2, Lithium Iron Phosphate ($LiFePO_4$) battery has offers good electrochemical performance with low resistance, besides high specific power, safest, and long cycle life. These batteries have a wide temperature range and can operate between +60 ◦C to −30 ◦C and are much less likely to suffer from a thermal runaway. With the efficient power-to-weight ratios, high safety features and the chemistry's resistance to thermal runaway, LiFePO4 batteries are achieving popularity for use in energy storage system, electric motorcycle, and electric car.

Lithium Iron Phosphate (LiFePO4) 32650 battery is a cylindrical cell battery featuring physical dimensions 32mm of diameter and 65mm of height. It has 3,2 Volt nominal voltage, and 6000mAh of a nominal capacity. The capacity test of LiFePO4 32650 battery cell shows on figure 3. The constant discharge current used in testing the capacity of this 32650 LiFePO4 battery is 900mA. Then the lower cut-off limit of the lower voltage used is 2.2Volt. The graph shows that the time required for the discharge process is 7 hours. This discharge time can represent the actual capacity of the battery used, which is close to 6000mAh.

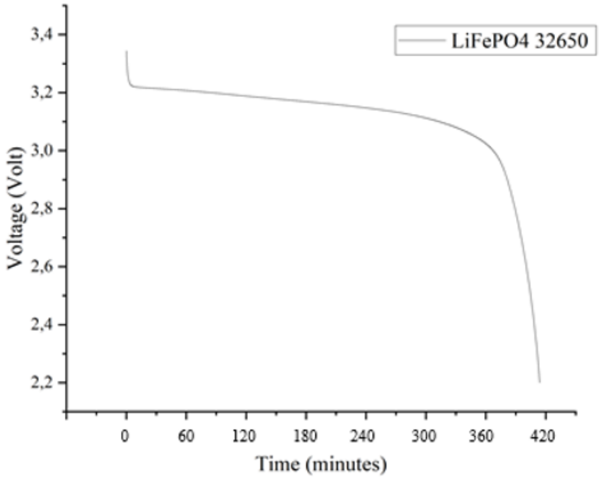

Fig. 3. Capacity Test of LiFePO4 32650

To operate the electric motor which requires high power demand and energy the LiFePO4 battery cell required to be connected in series in order to increase the voltage, and parallel connected to increase the capacity. In this study, the battery is set up in 12 series and 3 parallel configurations, resulting in a 36V battery voltage and an 18Ah battery capacity. The datasheet of battery pack shows on table 1.

Table 1. The Specification of Battery Pack.

Item	Specification
Configuration	12 Series 3 Parallel
Nominal voltage	36 Volt
Max voltage	39,96 Volt
Min voltage	30 Volt
Charging Voltage	42 Volt
Nominal capacity	18 Ah
Charging Current	9 Ampere
Max Continous Discharging Current	54 Ampere

The BMS has function to estimate State of Charge (SOC), State of Health (SOH), voltage, power, temperature and to provide a thermal management capability. Figure 4 Shows the realtime data monitoring from BMS android app. the green curve is the current charge&discharge. Then, the blue curve is the voltage of the battery pack 36V 18Ah. All of the data displayed is realtime battery power usage.

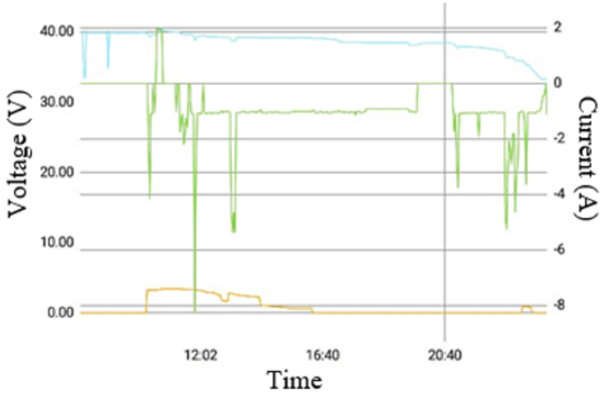

Fig. 4. Monitoring Data From BMS Android App

The 36V battery pack is set up in 12 series and 3 parallel connections. All battery voltages in series have been read and calibrated with a different range of below 1% when calibrated with data loggers & measuring equipment based on the results of reading the BMS data logger. The voltage range of the battery cells from the first cell battery to the 12th cell has been accurately read, and it is 3.35V to 3.37V. There is just a 0.016V voltage variation between the results of this voltage measurement. The battery pack has an operating temperature of 29.6°C and a total voltage of 40.4V. The capacity that enters the battery is close to 18Ah, based on the results of charging using a 36V 2A charger, according to the remaining capacity indicated on the android display application. The Android display of the battery pack fully charge is shown in figure 5.

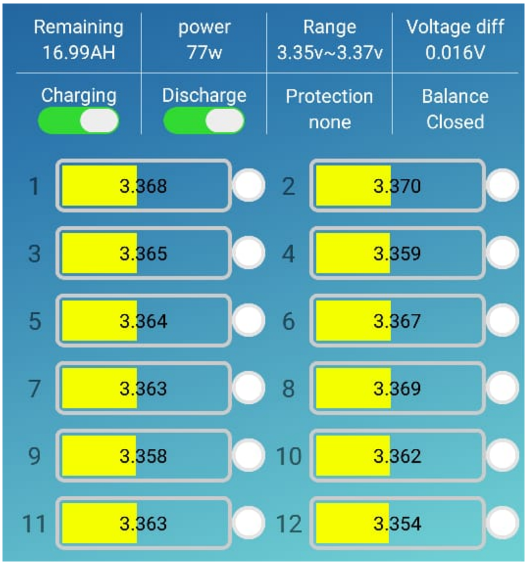

Fig. 5. Android app display of battery pack fully charged

For the battery life, as well as the performance and longevity of the vehicle, battery temperature management is also essential. Battery temperature affects the energy and charge acceptance during energy recovery from regenerative braking as well as the availability of discharge power (for start-up and acceleration) [20]. Driving comfort and fuel efficiency are impacted by these factors. In order to maximize performance and life, batteries should preferably operate in a temperature range. This range varies depending on battery chemistry and is typically substantially smaller than the vehicle's declared operating range.

Table 6 compares constant current discharge (CDC) with the energy efficiency of the battery. It shows the average of the testing process' multiple cycles. Once the temperature is steady, the final cycle is performed. The continuous discharge current from the BLDC motor is 1 Ampere until 10 Ampere. The test findings demonstrate a relationship between the battery's efficiency and the size of the continuous discharge current. The battery's efficiency will decline as continuous discharge current increases. The efficiency can reach 99% when the continuous discharge current is 1 Ampere. The efficiency value falls to 97,8% when the continuous discharge current is 10 Ampere.

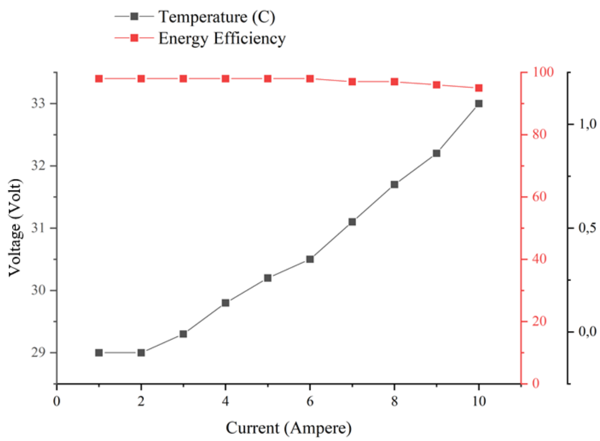

Fig. 6. The comparison between constant current consumption with energy efficiency of battery pack

A sequence of connected batteries will always have cell imbalance, which causes the degradation of individual cells. Additionally, the battery life will be reduced and its capacity will decline quickly. For operational and safety reasons, LiFePO4 battery monitoring requires a battery management system (BMS). It prevents undercharging and overcharging from damaging the cells, keeps the voltage balance between the battery cells, protects each cell from hazardous operating circumstances, and keeps track of the battery temperature.

In this study, the sell imbalance is caused by differences in the internal resistance values for each battery module. The internal resistance refers to a measurement of the resistance contained within a battery component. This resistance has an impact on the State of Health (SoH), State of Charge (SoC), and lifetime until the battery generates the heat. The voltage difference is visible when the battery is discharged until it runs out. Based on the comparison graph of internal resistance with voltage drop in Figure

7, it can be seen that cell two and the cell eight battery module have a smaller internal resistance.

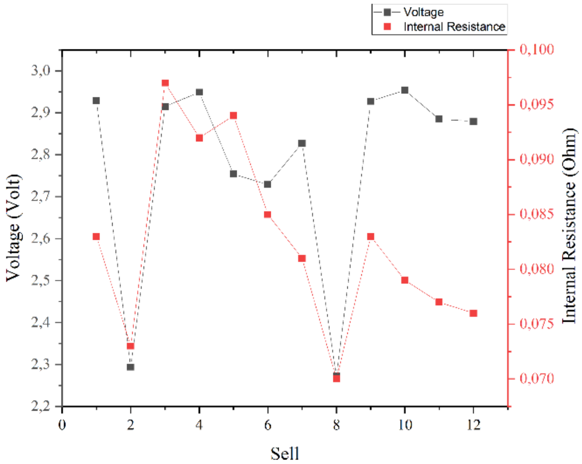

Fig. 7. The comparison between internal resistance and drop of voltage

The imbalance of each battery cell is enhanced when the battery string is being charged or drained. Additionally, the internal resistance and capacity of each cell will change as the charging-discharging cycle from the battery string grows, reducing the lifespan of battery strings. The balancing technique for each battery cell can be divided into active and passive balancing topologies.

A voltage balancer for each cell can be achieved during the process with tiny balancing circuits. However, the main elements affecting balancing performance, accuracy, and cell lifetime will be power losses and temperature problems. Using storage components and switch networks, active balancing topologies can transfer energy from a higher voltage cell to a lower one. These active balancing techniques aid in boosting productivity and performance while balancing. The process of moving the energy from the high voltage cell to the low voltage cell took longer.

4 Conclusion

This research is a reference for those who want to convert a bicycle into an electric bicycle. The analysis and experimental research of BLDC electric motor with LiFePO4 battery has been presented. The Performance of battery pack 36V 18Ah for the BLDC 350watt was examined with the drivetrain test. Based on the results obtained, the continous discharge current (CDC) can lead to reduced battery efficiency.

One of the battery parameters that might be impacted by the variation in internal resistance is voltage drop. However, this can be avoided by either standing alone outside the BMS or using a balancing component inside the BMS. The capacity of the battery will be balanced during the charge and discharge operation by this balancer component. As a result, the battery pack's condition will be better maintained, and its lifespan will be extended.

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