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Increasing Electric Bicycle Performance using Lithium Ferro Phosphate Batteries with a Battery Management System

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ABSTRACT: The depletion of fossil fuel sources and the increasing environmental pollution caused by the burning of motor vehicle fuels are major problems worldwide that need to be solved. One of the promising solutions to overcome energy security and environmental pollution is the use of electric vehicles. E-bikes are one of the most popular electric vehicles because of their many benefits. A valve-regulated lead acid battery (VRLA) is now the most common energy source for electric vehicles. It is heavy and unsafe for the user due to its poor energy density. Lithium-ion batteries may be a feasible solution. One type of Li-ion battery that is environmentally friendly is lithium ferro phosphate (LFP). The potential that exists encourages researchers to conduct research and compare the performance of VRLA batteries with LFP batteries. The data retrieval method is carried out using the Arduino data logger application and is equipped with a microcontroller to read current and voltage. The test results prove that the LFP battery has good voltage stability. The distance that can be traveled is quite long, which is up to 50.16 km, because it is supported by a large capacity. On the other hand, VRLA can only travel 37.83 kilometers. Furthermore, the energy density of LFP batteries is great. The VRLA battery has a low energy density of 38.7 Wh/kg, whereas the LFP battery has a higher energy density of 117 Wh/kg, making it lighter and safer for users.

Keywords: batteries, e-bike, electric vehicles, lithium-ion, LFP battery

1. Introduction

Air pollution is increasing from year to year. This is due to the increasing number of industrial factories and motorized vehicles. Motor vehicles that use traditional fuels such as gasoline and diesel can cause environmental pollution problems because they produce exhaust emissions such as hydrocarbon (HC), nitrogen oxides (NOx), carbon monoxide (CO), and particulates (PM), which are predicted to increase significantly [1]. Several countries in the world, including the UK, China, France, Germany, Ireland, and Norway, have plans to ban the use of fossil fuel vehicles (gasoline and diesel) by 2040 [2].

Air pollution is one of the main factors that causes global warming. This has now been realized by environmental experts, who have begun to look for several ways to reduce the increasing impact of global warming. To reduce the impact of global warming, it is recommended that we reduce the use of motorized vehicles by walking or cycling so that the pollution that causes global warming is reduced [3].

Electric vehicles are one of the alternative choices that can be used to reduce the impact of increasingly high pollution [4,5,6]. The use of electric bicycles is more recommended than the use of other electric vehicles because it has many benefits [7]. Electric bicycles are usually small and can traverse various terrains such as hilly, steep, and flat, making them more flexible [8]. Electric bicycles are usually cheaper, have low maintenance costs, and can improve the health of the rider [9,10,11], where on the electric bicycle there is a pedal that can be used like a bicycle so that the driver can carry out sports activities. The electric bicycle itself is driven by a machine that has a power source from a battery or lead acid, which can store electrical energy to drive the engine, so it does not cause exhaust emissions, which will cause pollution.

Several types of batteries that can be used as energy storage in electric bicycles include lead acid batteries, nickel cadmium batteries, nickel metal hydride batteries, and lithium-ion batteries. For now, the most common type of battery used in electric bicycles is the valve-regulated lead acid (VRLA) type. VRLAs are easy to recycle and offer relatively low prices [12]. In terms of safety, VRLAs are safer because they are tolerant of overcharging [13] and VRLA has a low internal impedance. VRLAs are known to produce very high currents and are widely available around the world because they are commonly used. On the other hand, VRLA has a low energy density. This causes VRLA to weigh much more than other types of batteries, making them dangerous to drop and heavy when lifted. In addition, VRLA contains lead, which is not environmentally friendly [14]. Li-ion batteries are a solution to overcome the weaknesses in VRLA batteries. The energy source arranged in electric vehicles such as the E-Bike consists of a number of Li-ion batteries arranged in series and parallel to obtain high voltage and capacity [15]. Li-ion batteries have a large energy density and capacity. So it tends to be lighter than other rechargeable batteries. However, there are disadvantages of Li-ion batteries, namely the relatively expensive price. The high price is comparable to the lifetime of Li-ion batteries, which can last about 9 years when compared to lead-acid batteries, which only last up to 2 or 3 years [13]. In addition, from a safety point of view, Li-ion batteries can be dangerous in the event of overcharging.

Li-ion batteries have been widely developed in the world. There are various types of battery cathodes, including LFP, LCO, LMO, and NCA. Lithium Ferro Phosphate, or often called $LiFePO_4$ (LFP), is one of the most widely used battery cathode types. The LFP battery is the cheapest battery cathode among the other Li-ion battery cathodes and is thermally stable. The main material is non-toxic iron, so it is environmentally friendly [16]. Due to their safety and efficiency, LFP batteries are ideal for use in e-bikes. Therefore, replacing VRLA batteries with LFP

Figure 1. The Process Flow Diagram

batteries is expected to improve the performance of electric motors as well as expand electrical energy storage. In this study, the replacement of VRLA batteries with LFP batteries on commercial e-bike was carried out and the performance tested.

The battery pack of electric vehicles, such as the E-Bike, is made up of many Li-ion batteries connected in series and parallel to achieve high voltage and capacity [17]. For safety reasons and to achieve a long lifetime, every cell in a battery pack must be in the same energy state. The charging and discharging processes must be stopped immediately if there are cells with banned circumstances (overvoltage, undervoltage, overcurrent, or overheating) [15]. To overcome this problem, a balancing process is carried out on the battery using a battery management system. A BMS (Battery Management System) is a device that monitors the voltage and current of a battery and balances the battery pack to prevent it from harm [15]. A good BMS should protect the driver/operator by detecting unsafe operating situations, protecting the cells from harm in failure cases, extending the battery's life in normal operating settings, and informing the user about the battery's details and operational status [18].

2. Materials and Methods

2.1. Materials

The materials and tools used in this research were Selis e-bike type Mandalika, Valve regulated lead acid battery (VRLA) 36V 12Ah, Lithium-ion battery type LFP 18650 with 12 series, 10 parallel 36V 12Ah arrangement, Battery Management system (BMS), and testing application.

2.2. Methodology

The stages of the research process include the battery pack assembly process, battery installation, and testing. The process flow diagram is shown in Figure 1.

2.2.1. Battery Pack Assembly

The e-bike battery pack assembly process is adjusted to the working voltage of the electric motor, where the working voltage of the motor is 36V [13]. The LFP 18650 battery arrangement is matched to the dimensions of the VRLA battery. The assembly process of the LFP battery uses a spot welder with 12 series and 10 parallel arrangements as shown in Figure 2. The total battery assembled has 120 cells with a capacity per cell of 1800mAh and a voltage of 3.4V. The 120-cell LFP battery arrangement stores 734 Wh of electrical energy.

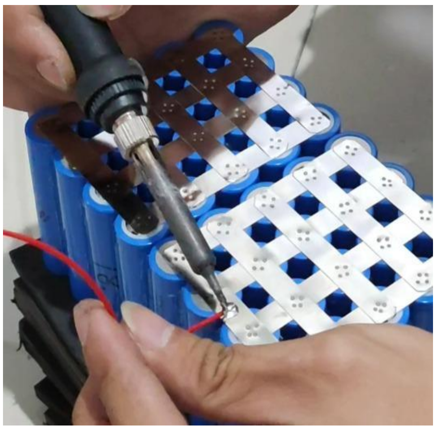

Figure 2. Battery Pack Assembly Process

2.2.2. Battery Installation

When the battery pack is ready, then proceed with installing the battery cell voltage monitoring cable and the battery power cable. After installing the power cable, BMS installation is needed as a safety and smart control system where the BMS will automatically cut-off if the battery is exhausted and also full, when a short circuit occurs, and when the battery cell voltage is unbalanced or damaged. After the battery has been assembled and the BMS has been programmed, the battery is covered with a casing to prevent direct exposure to dust and dirt. Figure 3. shows the finished battery pack and casing. In the BMS system, it is necessary to test charging and discharging to find program bugs or hardware problems until the BMS can be used. After everything is working normally, it will be continued with a road test using the Selis e-bike.

Figure 3. Battery Pack with BMS and Casing

2.2.3. Testing

The test of the Selis e-bike using the LFP battery was carried out together with the VRLA battery with the aim of providing comparison data on battery life, motor speed, and distance traveled. During testing, the Arduino-ide application was used to set up the BMS system; the Blynk application to display test data; and the Cycle meter cycling tracker application to display and track the distance traveled.

3. Result and Discussion

The electric bicycle test was carried out by comparing the performance of the bicycle with energy sources from lead acid and lithium-ion batteries. The LFP and VRLA battery tests were carried out on the same type of bicycle, namely the Mandalika selis bicycle, with a carrying capacity of 150 kg, a maximum speed of 30 km/h, a 350 watt dynamo, tire dimensions of 16 x 2.25, with a frame weight of 44.4 kg and dimensions of 160 x 160 x 108 cm. The parameters tested are maximum voltage, maximum current, internal resistance, distance traveled, energy density, and capacity. The data recap of the test results can be presented in Table 1.

Testing the maximum voltage and current obtained during the charging process for LFP battery and VRLA batteries. Internal resistance testing is carried out by measuring the voltage of internal battery resistance using a voltmeter. Meanwhile, for testing the stability of the battery voltage at various currents, the Arduino-ide application is connected to the BMS system and the Blynk application to display test data. Variations are made to the resulting current to test the stability of the voltage. Based on the test results, the internal resistance value of LFP battery is higher than that of VRLA, which is 29 mOhm compared to VRLA, which is only 7 mOhm. Electricity energy of an electrical vehicle consumed to travel a distance of 1 kilometer, or watt hour per kilometer (Wh/km), was also evaluated. LFP battery has 12.92 Wh/km and VRLA only 11.42 Wh/km. However, it is found that the LFP battery has advantages. The maximum voltage for an LFP battery, which is 41V, is greater than the voltage produced by VRLA batteries, which is 39V. The maximum current that can be achieved by LFP battery is also greater, which is 45A, compared to VRLA, which is only capable of producing a maximum current of 24A. Based on the test results, it is also found that the voltage generated by the LFP battery remains stable even though it is carried by a high current. The results of this test are shown in Figure 4. From the graph, it can be seen that the LFP battery voltage is quite stable. This can lead to a shorter cycle life for-

Table 1. Test Results Comparison Between Lead Acid and Li-ion Battery

No	Parameters	LFP battery 36V 18Ah	VRLA 36V 12Ah
1	Max Voltage (V)	41	39
2	Max Current (A)	45	24
3	Internal Resistance (mOhm)	29	7
4	Distance (km)	50.16	37.83
5	Energy Density (Wh/g)	0.117	0.0387
6	Cell Design	12S10P	18S
7	Capacity (mAh)	18000	12000
8	Watts to distance (Wh/km)	12.92	11.42

VRLA batteries than LFP batteries. This is in accordance with the statement of Jonathan et. al. (2007), which states that the life time for VRLA is quite short, namely 2 to 3 years from the date of manufacture with a cycle life of 300, while for LFP batteries it can last for a long period of time around 9 years with a cycle life of 800 [13].

Testing the distance on the selis e-bike was carried out using a cyclemeter cycling tracker application and equipped with GPS. The total distance traveled by a Selis e-bike with an LFP battery is capable of reaching 50.16 km, while for a Selis e-bike with a VRLA battery it is only 37.83 km. The survey shows that the average e-bike user in three medium-to-large cities only travels 9.3 km/day. The farthest distance that an e-bike could cover on the market in 2006 was 70 km [19]. The LFP battery is able to maintain a constant speed of 30 km/h even though the battery condition is approaching low battery. In contrast to the VRLA battery, there is a power drop when approaching a low battery. The results of this distance test are shown in Figure 5.

Energy density is a measure of how much energy a battery contains in proportion to its weight. This measurement is usually expressed in watt-hours per kilogram (Wh/kg). A watt-hour is a measure of electrical energy equivalent to the consumption of one watt for one hour. VRLA batteries have a low energy density. Based on the measurements, the energy density of the LFP battery is 117 Wh/kg while the VRLA is only 38.7 Wh/kg. These results are in agreement with Anuphappharador et al. (2014), which states that the specific energy of LFP batteries is 110–175 Wh/kg while for VRLA it is 30–40 Wh/kg [20]. This causes VRLA batteries to be heavier than LFP batteries. The weight of the battery is limited

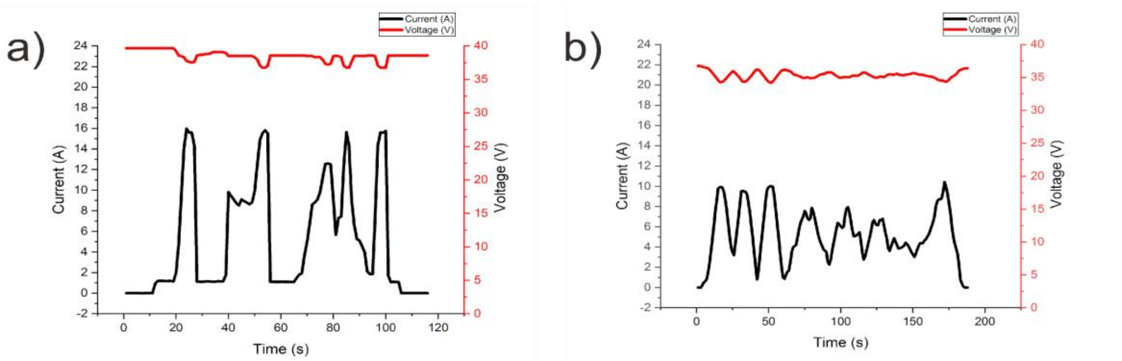

Figure 4. Test results of voltage and current on an e-bike with (a) LFP battery and (b) VRLA

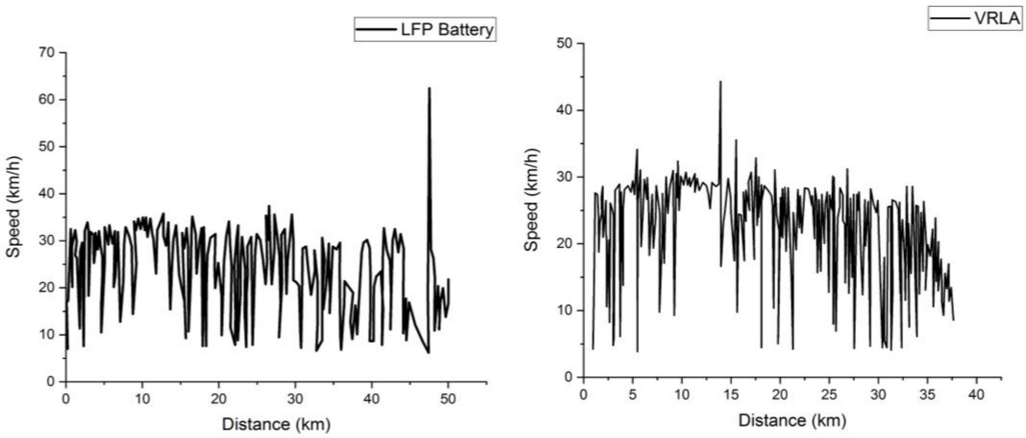

Figure 5. Electric bicycle distance tracking with an LFP battery pack (left) and VRLA (right)

by the physical strength of the user, as some users have to remove the battery from the bicycle to recharge it in their apartment or house. With the same casing dimensions of 17 x 10 x 33 cm, the LFP battery weighs up to 6.3 kg, while the VRLA battery weighs up to 12.1 kg. Since the mass of Li-ion batteries is approximately half the mass of lead-acid batteries of the same capacity [14], manufacturers have been able to develop e-bikes that weigh less than 20 kg [21].

The overall weight of an electric bike will depend primarily on where you decide to ride. When riding on a smooth, paved surface with a slight incline while traveling, the performance difference between a heavy and light e-bike will be almost the same. But if you're trying to ride uphill, the weight of an e-bike is important. The steeper the hill, the more significant the difference in overall bike feel and performance between a lighter and heavier bicycle will be. Heavy bicycles make the movement of the wheels slower because the friction between the wheels and the road becomes large. This can lead to high current use and increased energy requirements.

In order to be used to operate the alternating e-bike at a voltage of 36V, the LFP batteries are arranged in 12 series and 10 in parallel, and the VRLA batteries are arranged in 18 series. Under these conditions, the LFP battery capacity is 18.000mAh and the VRLA battery is 12.000mAh. This is consistent with Weinert's (2007), which states that a VRLA battery pack with a total voltage of 36V or 48V consists of three to four 12V modules producing a capacity of 12, 14 or 20 Ah. Meanwhile, LFP battery packs for e-bike range from 24V-37V with a capacity of 5-60 Ah [13]. The use of LFP batteries as an energy source for alternating electric bicycles gives more advantages because at the same voltage and dimension, the resulting capacity is greater and lasts longer. And also, the weight of the LFP battery is lighter than VRLA.

The use of electric vehicles is one solution to overcome the high air pollution in the world. One type of electric vehicle that is widely used is the electric bicycle, most of which use VRLA as an energy source. Based on their efficiency and safety, Li-ion batteries with LFP cathode can be used instead of VRLA as an energy source in e-bikes. LFP has good voltage stability. The distance that can be traversed is long, which is up to 50.16 km because it is supported by a large capacity in the same dimension with lower weight. In addition, the LFP battery has a high energy density, reaching 117 Wh/kg, which makes it lighter than VRLA, thus making it safer for users.

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CONFLICT OF INTEREST

State no conflicts of interest between authors.

AUTHOR CONTRIBUTIONS

Salman Al Farisi and Gilang Satria Ajie carried out the experiment. Windhu Griyasti Suci wrote the manuscript with support from Rosana Budi Setyawati, Khikmah Nur Rikhy Stulasti and Yazid Rijal Azinuddin. Salman Al Farisi fabricated the sample. Rike Aqila Nurfi, Sugeng Sulistiyawan and Dian Ahmad Pratama Bunayah Sudian helped supervise the project. Harry Kasuma (Kiwi) Aliwarga conceived the original idea. Windhu Griyasti Suci supervised the project. The final report was committed by all contributors.

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