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Voltage drop comparison in Lead-acid and Lithium-ion batteries on electric scooters

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Abstract: This article compares the voltage drop on Lead-acid and Lithium-ion batteries used as an energy source for electric scooters. An experiment was conducted with five electric scooter users weighing 60.25 Kg, 70.60 Kg, 83.20 Kg, 95.40 Kg, and 103.75 kg to obtain data on voltage drop. Each user of this electric scooter carried out three experiments by circling about 1.07 Km at the Politeknik Negeri Bali area. This study proves that the voltage drop on the Lead-acid and Lithium-Ion batteries has a linear relationship to the weight of an electric scooter user with a 36V 400-watt BLDC motor load. The linear equation has an intercept value of -1.36766 and a slope value of 0.04791 for the Lead-acid battery. In contrast, the linear equation has an intercept value of -2.47064 and a slope value of 0.05417 for Lithium ion batteries. The average voltage drop across lead acid is 25% higher than that across Lithium-ion.

Keywords: voltage drop, lead-acid, lithium-ion, electric scooter History Article: Submitted 19 May 2024 | Revised 22 May 2024 | Accepted 28 May 2024 How to Cite: A. A. N. G. Sapteka, A. A. N. M. Narottama, and K. A. Widyatmika, “Voltage drop comparison in Leadacid and Lithium-ion batteries on electric scooters”, Matrix: Jurnal Manajemen Teknologi Dan Informatika, vol. 14, no. 1, pp. 43-49, 2024.

Introduction Townsend and Gouws studied the comparative review of Lead-acid, Lithium-ion, and ultracapacitor technologies and their degradation mechanisms [1]. Other researchers, Keshan et al., said the comparison shows Li-Ion to have higher efficiency and 5-10 times the life cycle of Leadacid. On charging and discharging, Li-Ion outperforms Lead-Acid with wide margins [2]. Lopez et al. reported for OPzS Lead-Acid batteries, an advanced weighted Ah-throughput model is necessary to correctly estimate its lifetime, obtaining a battery life of roughly 12 years at the Pyrenees and around five years at

Tindouf. For Li-Ion batteries, the cycle and calendar aging must be considered, obtaining more than 20 years of battery life estimation at Pyrenees and 13 years at Tindouf. In the cases studied, the lifetime of LiFePO4 batteries is around two times the OPzS lifetime [3]. Kebede et al. said the techno-economic simulation output provided that the system with a Li-Ion battery resulted in a Levelized Cost of Energy (LCOE) of 0.32 €/kWh compared to the system with a Lead-acid battery with LCOE of 0.34 €/kWh. Besides, the Net Present Cost (NPC) of the system with Li-Ion batteries is found to be €14399 compared to the system with the Leadacid battery resulting in an NPC of €15106. According to the result, Li-Ion batteries are technoeconomically more viable than lead-acid batteries under the considered specifications and application profile [4]. Krieger et al. compared battery degradation rates and mechanisms in Leadacid, LCO (Lithium Cobalt Oxide), LCO-NMC (LCO-Lithium Nickel Manganese Cobalt Oxide Composite), and LFP (Lithium Iron Phosphate) cells charged with wind-based charging protocols. Excellent power performance and consistent voltage and power behavior during cycling suggest that LFP batteries are well-suited to withstand the stresses associated with off-grid renewable energy storage and have the potential to reduce system lifetime costs [5]. Yudhistira et al. showed that Lithium-ion batteries have fewer environmental impacts than lead-acid batteries for the

observed environmental impact categories. The study can be used as a reference to decide how to substitute Lead-acid batteries with Lithium-ion batteries for grid energy storage applications [6]. Carroquino et al. reported the economic performance of Li-Ion batteries, compared to Leadacid ones, is relatively better in hybrid systems than in PV. Greater solar irradiation favors Li-Ion batteries in PV systems but harms them in hybrid systems. In these, it would be favored by lower inflation in fuel prices. Finally, a 21% reduction in the price of Li-Ion batteries would make them the economically optimal option in all hybrid cases and if 36% is reached in all PV cases studied [7]. Muslimin et al. compared some types of batteries that are used in

EVs, such as Lithium-ion (Li-Ion), Lead-acid, Nickel Cadmium (NiCd) and Nickel-Metal Hydride (NiMH), etc. Li-Ion battery has become the most popular power supply implemented for EVs [8]. Rajanna and Kumar analyzed a comparison of two types of batteries. Results show that the Lithium-ion battery has better discharging voltage and current than the Lead-Acid storage battery at various percentages of state of charge. It is also observed that while maintaining constant load voltage, the Lithiumion battery delivers more power to the utility grid. Lead-acid battery consumes more power when charged to 100% state of charge. Lead-acid storage battery is 2.79 times costlier than Lithiumion battery. So, for a solar photovoltaic system with high power demand, a Lithium-ion battery is more suitable both performance-wise and cost-wise [9]. Iclodean et al. said nowadays, Li-Ion batteries have the biggest market segment in equipping electric vehicles. Moderate energy consumption (14.7 kWh/100 km), the continuous decline of the cost price, advanced manufacturing technology, increased cycle life, low weight, and high energy storage potential make Li-Ion batteries an optimal choice in this field. Their disadvantage is represented by high functioning temperatures, which may negatively affect their energetic performances and lifecycle. All of these represent risks regarding the safe exploitation of the vehicle [10]. This article compares the voltage drop on Lead-acid and Lithium-ion batteries used as an energy source for electric scooters. To our knowledge, this has not been studied by other researchers. Methodology This study on the voltage drop on Lead-acid and Lithium-ion batteries was carried out using a brushless DC (BLDC) 36V 400-watt electric scooter, as shown in Figure 1. An experiment was conducted with five electric scooter users weighing 60.25 Kg, 70.60 Kg, 83.20 Kg, 95.40 Kg, and 103.75 kg to obtain data on the voltage drop. Each user of this electric scooter carried out three experiments by circling the 1.07 Km located at the Politeknik Negeri Bali area according to the map in Figure 2. We used an electric scooter using a 36V Lithium-ion battery with a capacity of 12 Ah and a Lead-acid of 12V×3 with a capacity of 12 Ah. The experimental results calculate the average voltage drop of each battery and each user with a different weight difference. Next is to determine the mathematical model that relates the value of the voltage drop to the user's weight. Figure 1 shows the electric scooter with a 36V 40-watt BLDC and Figure 2 shows the area experiment using an electric scooter. Figure 1. Electric scooter with a 36V 40-watt BLDC

Figure 2. Area experiment using an electric scooter The experimental results calculate the average voltage drop of each battery and each user with a different weight difference. Next is to determine the mathematical model that relates the value of the voltage drop to the user's weight. Results and Discussions This research is a descriptive statistical research that processes data on user weight, and voltage drop before and after using an electric scooter with a 36V 40-watt BLDC at a distance of 1.07 km at the research location. Results Research shows the performance of Lead-acid batteries as shown in Table 1 and the performance of Lithium-ion batteries in Table 2. In addition, the tables show the weight of electric scooter users, battery voltage before and after use for a round with a distance of 1.07 Km, and the voltage drop. Table 1. Lead-acid data Weight (Kg) Before (V) After (V) Voltage Drop (V) 60.25 41.0 39.6 1.4 60.25 40.9 39.6 1.3 60.25 40.8 39.4 1.4 70.60 40.7 38.4 2.3 70.60 40.6 38.4 2.2 70.60 40.4 38.2 2.2 83.20 40.3 37.7 2.6 83.20 40.2 37.6 2.6 83.20 40.6 37.9 2.7 95.40 40.7 37.6 3.1 95.40 40.4 37.3 3.1 95.40 40.8 37.7 3.1 103.75 40.8 37.1 3.7 103.75 40.7 37.1 3.6 103.75 40.9 37.3 3.6

Table 2. Lithium-ion data Weight (Kg) Before (V) After (V) Voltage Drop (V) 60.25 40.0 39.2 0.9 60.25 40.2 39.3 0.9 60.25 40.1 39.2 0.9 70.60 40.1 38.7 1.4 70.60 40.3 38.9 1.4 70.60 40.0 38.7 1.3 83.20 40.0 38.2 1.8 83.20 40.2 38.6 1.6 83.20 40.1 38.3 1.8 95.40 40.0 37.2 2.8 95.40 40.1 37.3 2.8 95.40 40.0 37.1 2.9 103.75 40.2 37.0 3.2 103.75 40.2 37.0 3.2 103.75 40.2 37.0 3.2 The test results in Tables 1 and 2 show the average voltage drop value on each user's weight. Then we 12 determine the value of the appropriate intercept and slope for the linear equation. Discussions Figure 3 shows the user weight vs. voltage drop data along with the

linear fit of the data for an electric scooter using a Lead-acid battery. Figure 4 shows the user's weight data against voltage drops along with the linear fit of the data for an electric scooter using a Lithium-ion battery. Figure 3. Weight vs. voltage drop data for electric scooter using Lead-acid battery

Jurnal Manajemen Teknologi dan Informatika 47 Figure 4. Weight vs. voltage drop data for electric scooter using Lithium-ion battery The test results in Tables 3 and 4 show the average value of the voltage drop on each user's weight, then we determine the value of the appropriate intercept and slope for the linear equation. Table 3. Lead-acid summary Intercept Slope Adjusted R-Square Value Standard Error Value Standard Error -1.36766 0.38776 0.04791 0.00461 0.964 Table 4. Lithium-Ion summary Intercept Slope Adjusted R-Square Value Standard Error Value Standard Error -2.47064 0.4862 0.05417 0.00578 0.956 Furthermore, Equation (1) shows 8 the relationship between the voltage drop and the user's weight on an electric scooter using a Lead-acid battery. In comparison, Equation (2) shows the relationship between the voltage drop and the user's weight on an electric scooter using a Lithium-ion battery. $Voltage\ Drop$ = 0.04791 × $Weight$ − 1.36766 (1) $Voltage\ Drop$ = 0.05417 × $Weight$ − 2.47064 (2)

Jurnal Manajemen Teknologi dan Informatika 48 Based on the data in Table 5, the average difference in the percentage of the voltage drop between Lead-Acid and Lithium-ion is 25%. In this case, the average voltage drop across Leadacid is 25% higher than that across Lithium-ion. Table 5. The average voltage drop of Lead-acid and Lithium-ion data Weight (Kg) Lead-acid (V) Lithium-ion (V) Difference (%) 60.25 1.37 0.90 34.1 70.60 2.23 1.37 38.8 83.20 2.63 1.73 34.2 95.40 3.10 2.83 8.6 103.75 3.63 3.20 11.9 This difference can be caused by load and terrain conditions. As stated by S. Dhawan et al., experiments 1 for different load conditions and varying terrains show a rise in discharge with increasing load, low discharge for concrete, and the largest discharge for rocky terrain

[11]. Imbalanced internal resistance should be avoided when using the Lithium battery. It causes on drop in voltage of the LiFePO4 battery system connected in parallel [12]. In the battery management system equipment installed on the scooter, it is necessary to apply adaptive control technology to be able to estimate the state of the battery, such as its state of health (SOH), state of power (SOP) and state of charge (SOC) [13, 14]. Rest time affects both types of batteries. For the Lead-acid battery, the relationships are mostly monotonic. For the Li-Ion battery, the relationships are more complex and demonstrate some oscillations before reaching a steady state [15]. Conclusion This study proves that the voltage drop on the Lead-acid and Lithium-ion batteries has a linear relationship to the weight of an electric scooter user at a distance of 1.07 km with a 36V 400watt BLDC motor load. The linear equation has an intercept value of -1.36766 and a slope value of 0.04791 for the Lead-acid battery, while the linear equation has an intercept value of -2.47064 and a slope value of 0.05417 for the Lithium-ion battery. The average voltage drop across Leadacid is 25% higher than that across Lithium-ion. Acknowledgments The research was funded based on a letter of agreement on the implementation of research on DIPA funds at the Politeknik Negeri Bali number: 1149/PL8/PG/2022. For this reason, the authors would like to thank the Center for Research and Community Service, Politeknik Negeri Bali References [1] A. Townsend, and R. Gouws, “A comparative review of Lead-acid, Lithium-Ion and UltraCapacitor technologies and their degradation mechanisms,” Energies, vol. 15, no. 13, 2022. [2] H. Keshan, J. Thornburg, and T.S. Ustun, “Comparison of Lead-acid and Lithium Ion batteries for stationary storage in off-grid energy systems,” in 4th IET Clean Energy and Technology Conference (CEAT 2016), 2016. [3] R. Dufo-López, T. Cortés-Arcos, J.S. Artal-Sevil, and J.L. Bernal-Agustín, “Comparison of Lead-acid and Li-Ion batteries lifetime prediction models in stand-alone photovoltaic systems,” Applied Sciences, vol. 11, no. 3, pp. 1–16, 2021. [4] A.A. Kebede, T. Coosemans, M. Messagie, T. Jemal, H.A. Behabtu, J. van Mierlo, and M. Berecibar, “Techno-economic analysis of Lithium-Ion and Lead-acid batteries in stationary energy storage application,” Journal Energy Storage, vol. 40, 2021. [5] E.M. Krieger, J. Cannarella, and C.B. Arnold, “A

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