JOURNAL OF ENERGY, MATERIALS, AND INSTRUMENTATION TECHNOLOGY

Journal Webpage https://jemit.fmipa.unila.ac.id/

Performance Analysis of Electric Motorcycles as Logistics Vehicles

Rifki Dwi Putranto, Julia Putri Maharani, Darul Panji Khakiki, Ryan Nur Saputro, and Afredo Oktaviano

Electrical Engineering Study Program, Telkom University, Surabaya Campus, Jl. Ketintang No.156, Surabaya 60231, East Java, Indonesia

Article Information

Article history:
Received April 23, 2026
Received in revised form May 20, 2026
Accepted May 25, 2026

Keywords: *BLDC motorcycles, energy efficiency, energy consumption, electric motorcycles, speed variation, load variation*

Abstract

This study analyzes the performance of a 3000 W Brushless Direct Current (BLDC) motor implemented in the E-Ninja Tel-U Surabaya electric motorcycle, which was converted from a conventional motorcycle for logistics applications. The research focuses on evaluating energy consumption, motor efficiency, and vehicle performance under different operational conditions. Testing was conducted using a 72 V 24 Ah lithium-ion battery system with variations in speed ranging from 30–60 km/h and payloads of 100 kg and 150 kg. The analysis includes charging–discharging characteristics, traction force calculations, rolling resistance, aerodynamic drag, climbing force, and acceleration force. Electrical parameters such as voltage, current, power, and energy consumption were measured using a PZEM Energy Meter, while speed and travel distance were monitored through a GPS Speedometer application. The results show that higher vehicle speed and heavier payload significantly increase power consumption due to greater aerodynamic drag, rolling resistance, and motor workload. The most efficient operating condition was achieved at speeds of 30–40 km/h with the lowest energy consumption of 29.27 Wh/km. Increasing the load from 100 kg to 150 kg caused proportional growth in energy consumption because the motor required higher torque to maintain constant speed. In addition, the 72 V battery charging system with a 5 A charger demonstrated stable and efficient three-stage charging performance within approximately five hours. The findings indicate that BLDC-based electric motorcycle conversion is a feasible and sustainable transportation solution for logistics operations, supporting energy efficiency and the achievement of Sustainable Development Goals (SDGs) related to clean energy and carbon emission reduction.

Informasi Artikel

Proses artikel:
Diterima 23 April 2026
Diterima dan direvisi dari 20 Mei 2026
Accepted 25 Mei 2026

Kata kunci: *Motor BLDC, efisiensi energi, konsumsi energi, motor listrik, variasi kecepatan, variasi beban*

Abstrak

Penelitian ini bertujuan untuk menganalisis kinerja motor Brushless Direct Current (BLDC) 3000 W yang diterapkan pada sepeda motor listrik E-Ninja Tel-U Surabaya, yang dikonversi dari sepeda motor konvensional untuk aplikasi logistik. Penelitian ini berfokus pada evaluasi konsumsi energi, efisiensi motor, dan kinerja kendaraan dalam berbagai kondisi operasional. Pengujian dilakukan menggunakan sistem baterai lithium-ion 72 V 24 Ah dengan variasi kecepatan mulai dari 30–60 km/jam dan muatan 100 kg dan 150 kg. Analisis meliputi karakteristik pengisian-pengosongan, perhitungan gaya traksi, hambatan gelinding, hambatan aerodinamis, gaya pendakian, dan gaya akselerasi. Parameter listrik seperti tegangan, arus, daya, dan konsumsi energi diukur menggunakan PZEM Energy Meter, sedangkan kecepatan dan jarak tempuh dipantau melalui aplikasi GPS Speedometer. Hasil menunjukkan bahwa kecepatan kendaraan yang lebih tinggi dan muatan yang lebih berat secara signifikan meningkatkan konsumsi daya karena hambatan aerodinamis, hambatan gelinding, dan beban kerja motor yang lebih besar. Kondisi operasi paling efisien dicapai pada kecepatan 30–40 km/jam dengan konsumsi energi terendah sebesar 29,27 Wh/km. Peningkatan beban dari 100 kg menjadi 150 kg menyebabkan peningkatan konsumsi energi secara proporsional karena motor membutuhkan torsi yang lebih tinggi untuk mempertahankan kecepatan konstan. Selain itu, sistem pengisian baterai 72 V dengan pengisi daya 5 A menunjukkan kinerja pengisian tiga tahap yang stabil dan efisien dalam waktu

---

* Corresponding author.
E-mail address: rifkidwi@telkomuniversity.ac.id

sekitar lima jam. Temuan ini menunjukkan bahwa konversi sepeda motor listrik berbasis BLDC merupakan solusi transportasi yang layak dan berkelanjutan untuk operasi logistik, mendukung efisiensi energi dan pencapaian Tujuan Pembangunan Berkelanjutan (SDGs) yang terkait dengan energi bersih dan pengurangan emisi karbon.

1. Introduction

The electric vehicle industry has grown rapidly over the past decade. Production, battery and motor technology, and sales of electric vehicles have all experienced significant growth. Driven by government incentives and environmental awareness, electric vehicles are predicted to continue to grow across various transportation sectors. This is evident in the increasing global market share and the increasing number of new electric vehicle models each year [1].

In Indonesia, the potential for electric vehicle adoption is significant, given that 84% of vehicles are motorcycles, which are a major contributor to CO2 emissions. Converting to electric vehicles can reduce carbon emissions and improve air quality. Indonesia is developing the Converted Electric Motorcycle (CEM) concept, which allows motorcycle owners to convert conventional vehicles to electric using a conversion kit. The government is supporting this program by providing incentives of up to millions of rupiah to encourage electric vehicle conversion [2].

Not only limited to motorcycles, electric vehicle technology has penetrated various types of vehicles, including ATVs for rough terrain. Research by Donjaroennon et al. shows the importance of the CAN BUS protocol to improve communication between sub-systems to improve the performance and safety of electric ATVs. The emergence of electric ATVs proves the increasing interest in electric vehicles for off-road vehicles, but control systems and infrastructure still need to be improved to face the challenges of extreme terrain [3].

The development of electric vehicles for this specific terrain is highly relevant considering that electric vehicles are a transportation solution for remote and mountainous areas due to fuel logistics issues. The development of electric vehicles in the mountainous transportation industry requires dedicated charging infrastructure for rugged terrain. In regions like Papua where access to fossil fuels is difficult, electric vehicles can utilize the growing electricity grid and reduce dependence on fuel distribution. Electric vehicles are considered a sustainable mobility solution for 3T (frontier, outermost, and disadvantaged) regions like Papua [4].

Technically, converted electric vehicles are more efficient than gasoline engines. BLDC motors have an efficiency of around 80%, AC induction motors reach 85%, and motor controllers around 75.6%. The average power consumption of electric vehicles is 29.27 Wh/km or around 0.029 kWh to travel 1 km. Although not 100% efficient, converted electric vehicles are still more energy efficient and environmentally friendly than conventional combustion engines. This supports the Sustainable Development Goals (SDGs), especially those related to clean energy environments, efforts to address climate change, and Indonesia's commitment to reducing CO2 emissions [5].

2. Research Methods

2.1 BLDC Motor Topology

BLDC motors are known for their high efficiency, good durability, and low maintenance requirements. These motors operate without brushes, thus reducing friction and increasing mechanical efficiency [6]. BLDC motors operate on the principle of attraction or repulsion between two magnets with different poles. Conversely, since the stator consists of windings, the stator magnetic poles can change according to the polarity of the stator winding current [7]. A 3000 W BLDC hub motor was analyzed based on torque, speed, and efficiency parameters. The specifications of the 3000 W BLDC hub motor show a peak torque of approximately 191 Nm with a peak efficiency reaching 90% [8].

2.2 Traction Analysis

Various forces acting while the vehicle is moving, especially when climbing, affect the performance of electric vehicles. These types of forces include [9]:

$$F_r = \mu R\, m\, g \tag{1}$$

where F_r is the rolling resistance force, μR is the rolling coefficient, m is the mass of the vehicle plus passengers (kg), and g is the acceleration due to gravity (9.8 m/s^2). Aerodynamic Resistance (F_{ad}): Aerodynamic resistance occurs due to the movement of the vehicle through the air and is formulated as follows:

$$F_{ad} = 0.5\, \rho\, A\, CD\, V^2 \tag{2}$$

where ρ is the air density, A is the front cross-sectional area of the vehicle, CD is the drag coefficient, and V is the motor speed. Climbing Force (F_h): The climbing force appears when the motor moves on a certain slope, with the formula:

$$F_h = m\, g \sin\theta \tag{3}$$

where F_h is the climbing force, m is the mass of the vehicle and passengers (kg), g is the acceleration due to gravity (9.8 m/s^2), and θ is the gradient of the slope. Acceleration Force (F_{ac}): The acceleration force determines the acceleration of the vehicle and can be formulated as [10]:

$$F_{ac} = m\, a \tag{4}$$

where F_{ac} is the acceleration force, m is the mass of the vehicle + passengers (kg), and a is the acceleration of the vehicle (m/s²). Total Traction Force Requirement (FT): The total traction force requirement required to move the vehicle is formulated as [10]:

$$FT = F_r + F_{ad} + F_h + F_{ac} \tag{5}$$

where FT is the total traction force requirement (Newton).

2.3 Charge dan Discharge

Battery cycle testing measures cycle life characteristics through repeated charging and discharging processes. One cycle is defined as the release of energy to a certain depth of discharge (DOD) and then recharging to full capacity [11]. The basic formula for calculating battery power and energy includes:

$$P = V \times I \tag{6}$$

where P is power in watts, V is voltage in volts, and I is current in amperes.

$$E = P \times t \tag{7}$$

where E is energy in watt hours, P is power in watts, and t is the power usage time in hours (h).

2.4 Characteristics of Lithium-Ion Batteries

Lithium-ion batteries are a type of rechargeable, environmentally friendly secondary battery. The advantages of lithium-ion batteries include high energy density, no memory effect, a lifespan of up to 10 years, and light weight [12].

2.5 BLDC Motor Control System

BLDC motors require a special controller that functions as an inverter to convert the battery's DC voltage into three-phase AC current according to the motor's needs. This controller is crucial for regulating the motor's torque and speed and optimizing power efficiency. In this test, a Votol Controller was used. The Votol Controller is a sinusoidal PWM-based BLDC motor drive circuit often used in electric vehicles [13]. The Votol Controller also has splash protection, namely IP67 [14].

2.6 Power Consumption and Efficiency Calculations

The electrical power consumed by a vehicle is calculated using the equation:

$$P = V \times I \tag{8}$$

where P is power in watts, V is voltage in volts, and I is current in amperes. System efficiency is calculated using the formula [15]:

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% \tag{9}$$

where P_{out} is the maximum output power in watts, P_{in} is the input power, η is the efficiency expressed in percent.

$$T = \frac{P_{out}}{\omega} \tag{10}$$

where T is torque in newton meters, P_{out} is output power, and ω is angular velocity.

$$\omega = \frac{2\pi N}{60} \tag{11}$$

where ω is the angular velocity, π has a value of $22/7$, and N is the rotational speed.

$$P_{out} = F_{total} \times v \tag{12}$$

where P_{out} is the output power, F_{total} is the total force required by the vehicle, and v is the speed (m/s).

2.7 Speed Measurement and Battery Consumption

The Power Zenergy Energy Meter (PZEM) monitors electrical parameters such as battery voltage, current, power, and energy consumption during testing [16]. PZEMs are often used in DC source monitoring systems (solar panels or batteries). The PZEM is connected to the battery so that its internal shunt can measure current and voltage, and the results are then displayed on an LCD or monitor screen [17].

An additional application used is a GPS Speedometer. This GPS Speedometer is an application that collects data on vehicle speed, distance traveled, and driving time. A scale is also used to measure the mass of the load. This is done to determine its effect on traction force.

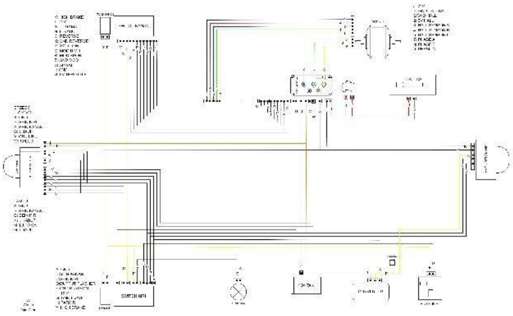

Figure 1. PZEM schematic [16]

2.8 Tel-U Surabaya E-Ninja Electric Motorcycle Concept

The E-Ninja is a conventional vehicle converted into an electric vehicle. Powered by a 3000W BLDC motor, the vehicle is designed to meet logistics needs in rugged terrain. The goal of converting the E-Ninja from a conventional vehicle to an electric vehicle is to create an environmentally friendly transportation solution with superior performance.

Figure 2. E-Ninja Electric Motorcycle Tel-U Surabaya

2.9 Consumption of Lithium-Ion Batteries

Lithium-Ion Battery is a rechargeable battery widely used in electric vehicles due to its high energy density, long cycle life, and good efficiency. Battery consumption represents the amount of electrical energy used during vehicle operation.

The electrical power consumed by the battery can be calculated using:

$$P = V \times I \tag{13}$$

where P is power (W), V is voltage (V), and I is current (A). The energy consumption is calculated using:

$$E = P \times t \tag{14}$$

where E is energy (Wh), P is power (W), and t is operating time (h).

Battery consumption increases with higher vehicle speed and payload because the motor requires greater power and torque to overcome aerodynamic drag and rolling resistance.

2.10 Performance of Lithium-Ion Batteries

Lithium-Ion Battery performance in electric vehicles is evaluated based on battery capacity, charging time, discharge characteristics, efficiency, and stability during operation. Lithium-ion batteries are widely applied because they provide high energy density, lightweight construction, fast charging capability, and long service life compared to conventional batteries.

Battery capacity can be expressed as:

$$C = I \times t \tag{15}$$

where C is battery capacity (Ah), I is current (A), and t is discharge time (h). Battery efficiency can be calculated using:

$$\eta = \frac{E_{out}}{E_{in}} \times 100\% \tag{9}$$

where η is battery efficiency (%), E_{out} is output energy, and E_{in} is input energy.

The performance of lithium-ion batteries is affected by operating temperature, load conditions, charging cycles, and vehicle speed. Higher loads and speeds generally increase current demand, causing faster energy depletion and reduced battery efficiency.

3. Results and Discussions

3.1 Charger and Discharger Analysis

A three-phase charging process using a 72V 24A charger for 5 hours ensures efficiency and prevents overcharging. **Figure 3** shows the relationship between charging time and voltage. A 5-hour charging process with a 72V 5A charger demonstrates rapid charging in the initial phase (0-90 minutes), with the voltage rising from 65.8V to 73.6V. In the middle phase (90-210 minutes), the voltage reaches 79.9V. In the final phase (210-314 minutes), the voltage reaches 84.6V, and the charging time slows, reflecting an efficient charging system and preventing overcharging.

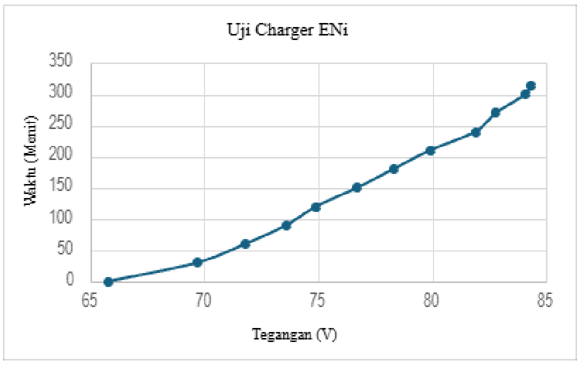

Figure 3. E-Ninja Motorcycle Charger Test

Figure 4 shows the discharge time in one of the experiments with varying total loads of 150kg.The figure demonstrates the relationship between distance traveled and power consumption, where power consumption increases proportionally with distance traveled.

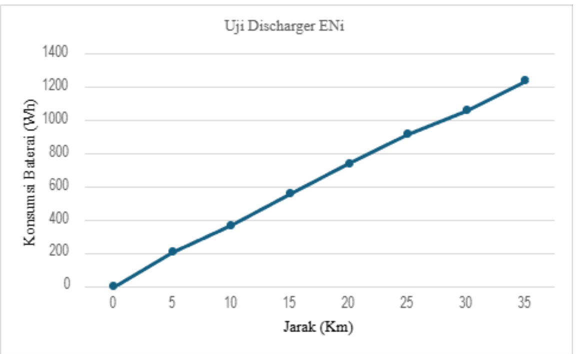

Figure 4. E-Ninja Motorcycle Discharger Test

3.2 Performance Analysis

The results of the performance graph test (Wh/km) show that increasing speed causes a linear increase in power consumption with distance traveled. The analysis is consistent with the theory that aerodynamic drag increases with speed, so most of the energy is used to overcome air resistance at high speeds (50-60 km/h). However, when a BLDC motor operates near its peak efficiency region, increasing speed can actually reduce consumption per km [18].

In this data, the Wh/km value is lowest at low to medium speeds (30-40 km/h), while at high speeds (50- 60 km/h), the Wh/km value increases. This difference indicates that the optimal speed for energy efficiency lies in the low to medium speed range. moderate, before aerodynamic drag takes effect.

At any constant speed, a 150 kg load results in higher power consumption per kilometer compared to a 100 kg load. An additional 50 kg load increases tire friction and vehicle inertia, forcing the motor to generate more torque and current to maintain speed. Therefore, the additional weight significantly reduces the efficiency of an electric vehicle [19].

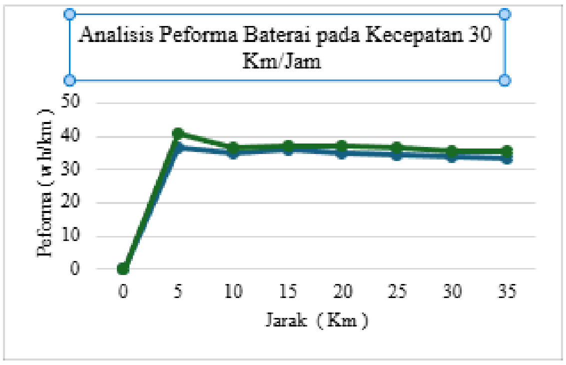

Figure 5. Battery Performance Test at 30 km/h

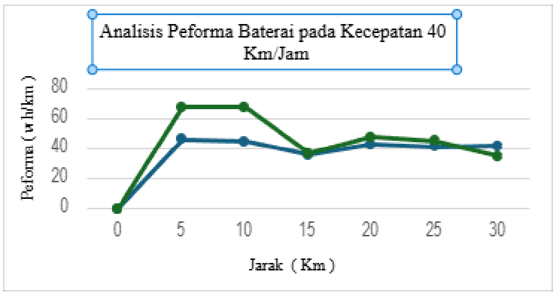

Figure 6. Battery Performance Test at 40 km/h

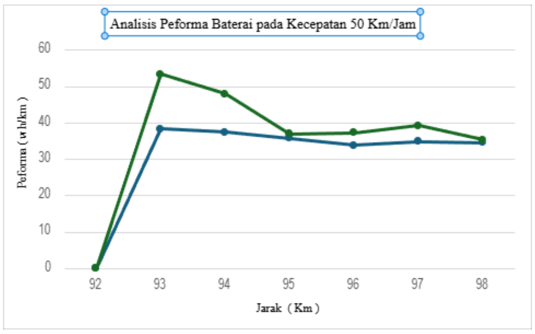

Figure 7. Battery Performance Test at 50 km/h

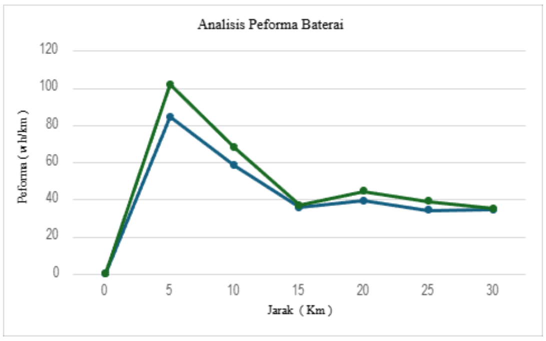

Figure 8. Battery Performance Test at 60 km/h

3.3 Consumption Analysis

For each constant speed, the graph of the relationship between battery power consumption (Wh) and distance traveled shows that power consumption increases linearly with distance traveled. The power consumption per kilometer is represented by the slope (gradient) of the graph at each speed. In general, a vehicle with a 150 kg load has a greater gradient at the same speed than a vehicle with a 100 kg load; this indicates that a heavier load requires more energy per distance traveled. This comparison, which is consistent at speeds of 30, 40, 50, and 60 km/h, indicates that the additional load makes the electric motor work harder [20].

For the four speed variations tested, the optimal speed is estimated to be at a medium speed. Based on the graph, the lowest Wh per kilometer consumption curve occurs at low to medium speeds (30-40 km/h). This indicates that low to medium speeds produce the most efficient torque and drag.

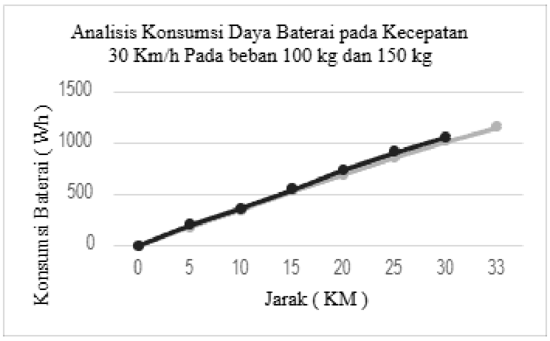

Figure 9. Battery Consumption Test at 30 km/h

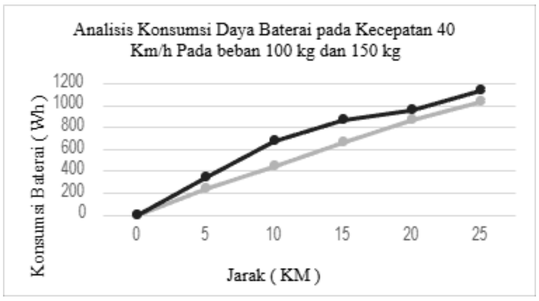

Figure 10. Battery Consumption Test at 40 km/h

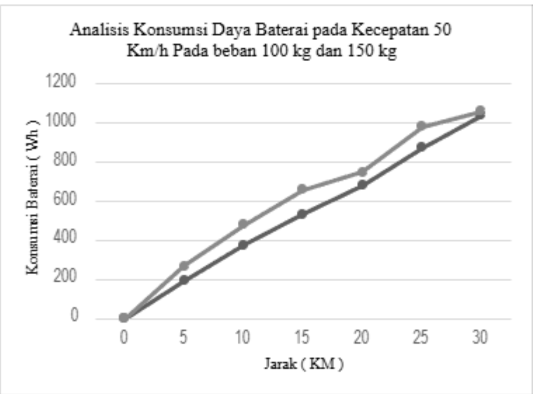

Figure 11. Battery Consumption Test at 50 km/h

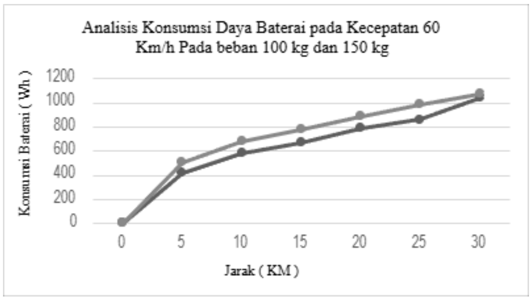

Figure 12. Battery Consumption Test at 60 km/h

4. Conclusions

This study analyzes the performance of a 3000 W BLDC motor in the E-Ninja Tel-U Surabaya electric vehicle, focusing on energy efficiency through variations in load and speed. Test results at speeds of 30-60 km/h show that increasing speed and load are inversely proportional to the distance traveled. A larger load increases power consumption and decreases vehicle efficiency. The optimal speed for the highest energy efficiency is 30-40 km/h with the lowest power consumption of 29.27 Wh/km. At speeds of 50-60 km/h, power consumption increases drastically due to aerodynamic drag. Increasing the load from 100 kg to 150 kg increases the power consumption per kilometer proportionally. The 72 V lithium-ion battery charging system with a 5 A charger demonstrates good efficiency through a five-hour three-phase process that prevents overcharging. Converting conventional vehicles to electric vehicles has proven to be an effective sustainable transportation solution for logistics needs, especially in areas with limited access to fossil fuels. This is in line with Indonesia's commitment to achieving the Sustainable Development Goals (SDGs) in reducing power consumption.

5. Bibliography

Akbar, D., & Riyadi, S. (2018). Pengaturan kecepatan pada motor brushless DC (BLDC) menggunakan PWM (pulse width modulation). *Seminar Nasional Instrumentasi*, 1.

Anggadewi, L., & Sunantra, I. N. (2020). Perancangan dan analisis sistem power dan drivetrain pada sepeda motor bertenaga hybrid dengan kapasitas 110 cc. *Jurnal Teknik ITS*, 9(2), 253–255.

Anwar, S., Artono, T., N. D., & Fadli, A. (2019). Pengukuran energi listrik berbasis PZEM-004T. *Proceeding Seminar Nasional Politeknik Negeri Lhokseumawe*, 3(1), Article 1A274.

Arif, M. (2022). *Analisis aerodinamika dalam penghematan energi mobil listrik di area Green Campus Universitas Teuku Umar* [Skripsi]. Universitas Teuku Umar.

Bima, R., & Mara, I. M. (2025). Pengaruh variasi rasio gear dan berat kendaraan terhadap efisiensi energi pada kendaraan prototipe listrik Fakultas Teknik Universitas Mataram. *ROTASI*, 27(1), 23–28.

Donjaroennon, N., Nambunlue, W., Nuchkum, S., & Leeton, U. (2024). Development of an improved communication control system for ATV electric vehicles using MRS Developers Studio. *World Electric Vehicle Journal*, 15(7), 2–10.

Hafizhah, Z. N. (2024). *Monitoring perangkat pengisian baterai mobil listrik dengan sumber sel surya menggunakan website berbasis GPS* [Skripsi].

Imaduddin, I., Ramadhan, D. F., & Noor, R. A. M. (2021). Effect of voltage, current, and power on revolutions per minute in the brushless direct current 3000-watt motor on E-gokart. *ASEAN Journal of Science and Engineering*, 1(3), 221–228.

Jondra, W. W., Sunaya, I. G. A. M., Arka, I. G. P., Parti, I. K., Sudiartha, I. W., & Widharma, I. G. S. (2020). The performance of electric vehicles converted from combustion motorcycles. *IOP Conference Series: Materials Science and Engineering*, 451–457.

Khwee, J. K. H., & Hiendro, A. (2016). Migrasi baterai lithium dari mode otomotif ke mode penyimpanan energi untuk sistem pembangkit listrik tenaga surya. *Elkha*, 8(2), 41–47.

Ma’arif, E. S., Dermawan, B. E., & Chamdareno, P. G. (2022). Studi perencanaan pengaturan kecepatan motor BLDC pada gerobak listrik. *RESISTOR (Elektronika Kendali Telekomunikasi Tenaga Listrik Komputer)*, 5(2), 140–146.

Mahendra, S., Fatra, F., & Tamamudin, M. (2021). Analisis performa pada sepeda motor listrik menggunakan motor BLDC 500 W. *Jurnal Rekayasa Mesin*, 19(3), 340–345.

Mara, I. M., I. G. A. K. C. A. W. A., Nuarsa, I. M., & Sutanto, R. (2023). The effect of vehicle speed on energy consumption of electric vehicle Faculty of Engineering University of Mataram. *Research Inventy: International Journal of Engineering and Science*, 13(12), 12–17.

Perdana, F. A. (2020). Baterai lithium. *Jurnal Pendidikan IPA*, 9(2), 103–109.

Putranto, R. D., & Sukino, R. F. H. (2025). Rancang bangun motor BLDC 2 kW untuk kendaraan listrik e-scooter sesuai standar konversi sepeda listrik Indonesia. *Journal Geuthee of Engineering and Energy (JOGE)*, 4(1), 1–10.

Rizal, F. A., & Imammuddin, A. M. (2024). Analisis pengaruh jarak dan beban terhadap konsumsi daya motor BLDC 2000 watt pada prototipe sepeda listrik E-Bomber. *Venus: Jurnal Publikasi Rumpun Ilmu Teknik*, 2(4), 342–354.

Sanguesa, J. A., Torres-Sanz, V., Garrido, P., Martinez, F. J., & Marquez-Barja, J. M. (2021). A review on electric vehicles: Technologies and challenges. *Smart Cities*, 4(1), 372–404. https://doi.org/10.3390/smartcities4010022

Sudjoko, C. (2021). Strategi pemanfaatan kendaraan listrik berkelanjutan sebagai solusi untuk mengurangi emisi karbon. *Jurnal Multidisipliner Mahasiswa Pascasarjana Indonesia*, 2(2), 54–55.

Syaifullah, S. A., & Azis, H. (2025). Design and development of a NodeMCU-based lamp power control and monitoring device using the PZEM-004T module. *Indonesian Journal of Networking and Internet of Things (IJONIT)*, 1(1), 1–12.

Teshome, M. B., Rasool, F., & Orzes, G. (2024). Mountain logistics: A systematic literature review and future research directions. *Logistics*, 8(4), 7–20.