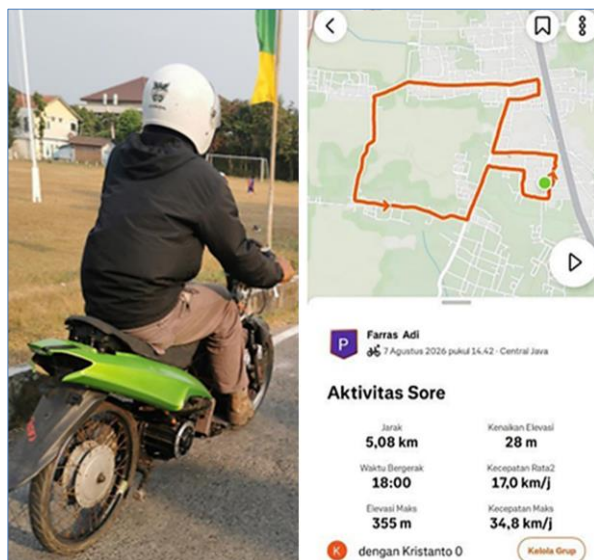




Performance and Energy Consumption Evaluation of a Yamaha 5TL Converted to BLDC Electric Propulsion

Farras Lutfi Adi¹, Listiyan Tri Kristanto¹,
Muji Setiyo^{1*}, Thirunavukkarasu Raja²,
Veermanikandan Murugan², Sathish Dhandapani³

¹ Department of Automotive Engineering, Universitas Muhammadiyah Magelang, Magelang 56172, Indonesia

² Department of Mechanical Engineering, SRM Institute of Science and Technology, Chennai – 600 089, India

³ Department of Mechanical Engineering, Dr.N.G.P. Institute of Technology, Tamil Nadu 641048, India

*Corresponding author: muji@unimma.ac.id



Copyright © The Author(s). This work is licensed under a [Creative Commons Attribution-NonCommercial 4.0 International License](https://creativecommons.org/licenses/by-nc/4.0/).
Published by AIS Indonesia

Article History: Received: 11 September 2026 | Revised: 11 October 2026 | Accepted: 13 October 2026 | Published online: 14 October 2026

Abstract

The growing interest in electric vehicles has encouraged the conversion of conventional internal-combustion motorcycles into battery-electric motorcycles as a way to extend the service life of existing vehicles while reducing dependence on fossil fuel. This study converts a Yamaha 5TL motorcycle, originally equipped with a continuously variable transmission (CVT) and a gasoline engine, into an electric motorcycle driven by a Brushless Direct Current (BLDC) motor. The objectives were to identify the components and mechanical adjustments required for the conversion, to characterize the performance of the converted vehicle, and to compare its energy consumption and operating cost with the original gasoline-powered configuration. The conversion involved the design and fabrication of a motor-mounting bracket, modification of the fan cover, roller housing, transmission bushings and rear pulley, and installation of an electrical system consisting of a lithium battery, a miniature circuit breaker (MCB), a Juken 10 controller, and a hand throttle. Performance was evaluated through no-load bench testing and on-road testing with a 69 kg rider load over a 5.08 km distance, while energy consumption was assessed by comparing battery-capacity depletion with fuel consumption under the same test conditions. The BLDC motor was successfully integrated with the Yamaha 5TL chassis and CVT drivetrain through the fabricated bracket and the modified transmission components. Under no-load conditions, the system reached a battery voltage of 64.6 V, 100% throttle position, a 95% duty cycle, an electrical power of 788.8 W, and a maximum motor speed of about 3,243 rpm (16,215 eRPM), with controller and motor temperatures of 32.4 °C and 34 °C, respectively. On the road, the converted motorcycle attained a maximum speed of approximately 35 km/h. Energy consumption tests indicated approximately 0.0272 kWh/km for the electric configuration and approximately 0.0394 L/km for the gasoline configuration. At an electricity tariff of IDR 1,393.70/kWh and a Pertalite price of IDR 10,000/L, the corresponding energy costs were about IDR 39.25/km and IDR 400/km, respectively, indicating that the electric configuration achieved an energy-cost saving of about 90.03% under the tested conditions.

Keywords: BLDC motor; CVT transmission; Electric motorcycle conversion; Energy consumption; Yamaha 5TL

1. Introduction

Electric vehicle (EV) technology has attracted increasing attention in recent years as a promising alternative to conventional transportation, offering opportunities to reduce environmental pollution, lower dependence on fossil fuels, and improve energy efficiency. This growing interest reflects a broader shift towards sustainable mobility, particularly in the transportation sector, where fossil-fuel-powered vehicles remain a major source of carbon emissions [1]. The transition to electric mobility is therefore becoming increasingly important, especially in countries where conventional motorised vehicles play a central role in everyday life.

This challenge is particularly relevant in Indonesia, where motorcycles account for nearly 70% of the national transport mode share and play an important role in everyday mobility. Their widespread use, combined with the continued dependence of road transportation on fossil fuels, makes the electrification of two-wheelers an important pathway towards more sustainable mobility. The urgency of this transition is further underscored by the scale of

Indonesia's transport emissions, which reached approximately 202 million tonnes of CO₂ in 2024 [2]. Replacing conventional gasoline-powered motorcycles with electric alternatives could therefore contribute to reducing fuel consumption and transport-related emissions while maintaining the accessibility and flexibility that make motorcycles essential to Indonesian society.

Recognising this need, the Indonesian government has introduced policies to accelerate the adoption of electric vehicles. Presidential Regulation No. 55 of 2019 on the Acceleration of the Battery Electric Vehicle Program for Road Transportation provides a framework for promoting research, technological development, innovation, and collaboration among government institutions, industry, universities, and research organisations. These policy measures create opportunities not only for the development of new electric vehicles but also for the conversion of existing gasoline-powered motorcycles into electric alternatives. Previous research has demonstrated the feasibility of converting conventional motorcycles to electric propulsion, including the use of brushless DC (BLDC) motors and direct-coupling conversion methods [1], [3]. Such approaches offer a potential route towards expanding electric motorcycle adoption by making use of existing vehicles and supporting the development of more accessible electrification solutions.

Beyond the development of new electric vehicles, converting existing gasoline-powered motorcycles into electric motorcycles offers a practical way to accelerate electrification while retaining vehicle components that remain serviceable. The feasibility of such conversions, however, depends partly on selecting a suitable traction motor. Brushless direct current (BLDC) motors are commonly considered for this application because electronic commutation eliminates brushes and a mechanical commutator, potentially reducing maintenance requirements and mechanical wear. Their other advantages include good efficiency, low-speed torque capability, and relatively quiet operation, while motor speed can be regulated through an electronic controller. Consequently, motor selection for electric vehicle applications generally involves balancing efficiency, power density, controllability, reliability, and cost [4].

Selecting an appropriate motor is only one part of the conversion process. The motor must also be securely mounted to the motorcycle frame and integrated with the existing drivetrain, while the electrical system must accommodate a battery, motor controller, throttle, and appropriate protection devices. These requirements become particularly important for motorcycles equipped with a continuously variable transmission (CVT), in which the motor position, shaft coupling, pulley arrangement, and other transmission components must be adapted to ensure effective power transfer. Retaining the original CVT may simplify the use of existing drivetrain components, but its compatibility with the torque and speed characteristics of the electric motor must be considered.

Previous studies have demonstrated several approaches to motorcycle electrification, including conversions that retain or modify the original transmission. Permana *et al.* [3] designed a motor mount and a coupling shaft that connect a BLDC motor to the original CVT of a 110 cc motorcycle, allowing the existing transmission to be retained. Yohanes *et al.* [5] coupled the motor to the CVT drive-pulley shaft and tuned the roller mass and return spring for electric operation, an arrangement whose efficiency penalty relative to other drivetrain layouts has also been quantified [6]. Similarly, Vyshakh *et al.* [1] discussed the conversion of an internal-combustion motorcycle to BLDC-powered propulsion, involving modifications to accommodate the motor, controller, and throttle. Collectively, these studies illustrate that successful conversion requires more than replacing the original engine; the motor installation and drivetrain configuration must also be adapted to the characteristics of the selected vehicle and propulsion system.

Further studies have examined the effects of motor configuration and transmission design on the performance of converted motorcycles. Firmansyah *et al.* [7] converted a motorcycle with an automatic transmission using a 2 kW, 72 V mid-drive BLDC motor and reported improved performance alongside substantially lower electricity costs than gasoline costs. Prasetya *et al.* [8] investigated the influence of gear ratio on a 2 kW mid-drive BLDC conversion, highlighting the importance of reduction-ratio selection for achieving the desired speed and torque. Related studies have explored the retention and adaptation of belt-and-pulley CVT systems, including the effects of pulley, roller, and clutch configurations on drivetrain compatibility [9], [10], [11]. Other investigations have examined how CVT slip and clamping-force behaviour affect transmission efficiency [12], [13]. In addition to drivetrain integration, the motor-mounting bracket must withstand operational loads and vibration; finite-element analysis has therefore been applied to evaluate bracket design in electrified two-wheelers [14]. More recent Indonesian studies have provided further evidence from converted motorcycles. Aji *et al.* [15] combined

dynamometer and road testing of an underbone motorcycle equipped with a 2 kW, 72 V BLDC motor and a 72 V, 20 Ah battery, reporting energy consumption of 26–33 Wh/km. Rusli *et al.* [6], meanwhile, compared hub-motor, CVT, and single-gear-ratio configurations on a converted Honda Vario 125 and reported the weakest performance for the CVT configuration among the three alternatives examined. These findings indicate that the resulting performance depends not only on the motor itself but also on how the motor is integrated with the vehicle drivetrain.

The implications of motorcycle electrification extend beyond technical performance to operating costs, emissions, and sustainability. Techno-economic assessments suggest that converted electric motorcycles may become cost-competitive with gasoline-powered alternatives as annual or cumulative travel distance increases [16], [17]. At the policy level, national-scale analyses indicate that existing subsidies and incentives may be insufficient to achieve Indonesia's electric motorcycle adoption targets without stronger interventions [18], [19], [20]. Comparative studies of electric and gasoline motorcycles have also reported lower energy costs and CO₂ emissions for electric configurations under the conditions examined [21], [22]. From a broader sustainability perspective, Habibie *et al.* [23] identified conversion as the most sustainable option among the alternatives they evaluated for replacing internal-combustion-engine motorcycles, while Santoso *et al.* [24] assessed Indonesia's conversion programme as fairly sustainable and identified institutional support as its weakest dimension. Together, these findings establish the potential benefits of motorcycle conversion while indicating that its technical feasibility and practical advantages need to be assessed for specific vehicle configurations.

Despite these advances, the findings of previous studies cannot automatically be generalised to every motorcycle model or conversion arrangement. The selection of motor mounting, drivetrain adaptation, and transmission configuration may influence the resulting vehicle performance and energy consumption. Accordingly, this study investigates the conversion of a Yamaha 5TL motorcycle from gasoline-powered propulsion to electric propulsion using a BLDC motor. Specifically, it aims to (1) identify the components and modifications required for the conversion, (2) characterise the performance of the converted motorcycle, and (3) compare its energy consumption with that of the same motorcycle operating with its original gasoline-powered system. By examining both configurations of the same vehicle, the study provides a practical basis for evaluating the technical outcomes and energy-use implications of the conversion.

2. Materials and Methods

The conversion, assembly, component adjustment, and preliminary testing were carried out between March and August 2026 at the Automotive Workshop of Universitas Muhammadiyah Magelang. The object of the study was a Yamaha 5TL motorcycle converted from a gasoline-fuelled propulsion system into an electric propulsion system using a BLDC motor of the permanent-magnet inner-rotor type with a Hall sensor. While the original chassis and CVT transmission were retained, several components were modified, including the fabrication of a BLDC motor bracket, modification of the fan cover and roller housing, fabrication of a replacement bushing, adjustment of the roller-housing bushing, and modification of the rear pulley, so that the rotation of the BLDC motor could be transmitted through the CVT to the rear wheel.

2.1. BLDC motor specification

The electric motor used was a QS Motor permanent-magnet inner-rotor BLDC motor with a Hall sensor (model TF113BH), designed for single-axle applications such as scooters and motorcycles. The manufacturer's data sheet specifies a continuous power of 2,000 W, a nominal voltage of 72 V, a magnet height of 70 mm with 40 magnets arranged as 5 pole pairs, and a stator diameter of 120 mm. The no-load speed is approximately 2,900 rpm without flux weakening and up to about 4,500 rpm with flux weakening. At the default reduction ratio of 1:4.7, the listed maximum torque is 187.9 N·m, and the maximum efficiency is 89.2% [25]. This efficiency level is consistent with permanent-magnet motor designs reported for other light electric two-wheelers, where optimised rotor geometries have been shown to reach efficiencies in a similar range [26]. The complete specification is summarised in Table 1.

2.2. Tools and materials

The conversion used three groups of items: the propulsion components, the parts made or modified to fit the motor to the CVT, and the instruments used during testing. The propulsion system comprises the TF113BH BLDC

motor, a Juken 10 controller, and a 60 V, 23 Ah lithium-ion battery with its own battery management system (BMS). A BMS of this kind monitors cell voltages and temperature, estimates the state of charge, and protects the pack against abnormal charging and discharging, functions that are central to the safe operation of lithium-ion batteries in electric vehicles [27], [28]. A 10 A MCB and the original ignition switch provide circuit protection and isolation, while the custom bracket, the modified bushings, and the modified rear pulley form the mechanical interface between the motor and the transmission. During testing, the Juken 10 monitoring software recorded the electrical and thermal parameters of the motor and controller, the front-wheel speedometer and the Strava application recorded speed and distance, and a graduated cylinder was used to measure the fuel consumed by the gasoline configuration. All items, together with their specifications and functions, are listed in Table 2.

Table 1. Specifications of the BLDC motor used in this study

Parameter	Specification
Motor type	Permanent-magnet inner-rotor BLDC motor with Hall sensor
Brand	QS Motor
Motor design	Single axle
Matched wheel	12-inch wheel (default)
Magnet configuration	70 mm height, 40 magnets, 5 pole pairs
Stator diameter	120 mm
Rated power	2,000 W (peak power pending)
Rated voltage	72 V (default)
No-load speed	70 km/h with 12-inch wheel
Maximum torque	187.9 N·m (reduction ratio 1:4.7)
Reduction ratio	1:4.7 (default)
Maximum efficiency	89.2%
Continuous / peak battery current	35 A / 60 A at 72 V
Suggested peak phase current	250 A
Hall-sensor phasing angle	120°
Waterproof rating	IP54
Net / gross weight	7.8 kg / 9.1 kg

Table 2. Tools and materials used in the conversion process

No.	Item	Specification	Function
1	Yamaha 5TL motorcycle	Converted vehicle	Research object
2	BLDC electric motor	TF113BH, permanent-magnet inner rotor with Hall sensor	Main propulsion source
3	Controller / ECU	Juken 10	Regulates power supply and BLDC motor operation
4	Lithium-ion battery	60 V nominal, 23 Ah (≈ 1.38 kWh), Viar BMS	Electrical energy source
5	Hand throttle / TPS	Electronic throttle	Sends control signal to the controller
6	BLDC motor bracket	Custom-designed and fabricated	Mount and link between motor and transmission
7	DC-to-DC converter	Supporting electrical component	Adjusts voltage for the electrical system
8	MCB	10:00 AM	Protection against excess current
9	Ignition switch	Vehicle switch system	Connects / disconnects the electrical system
10	Bushings	Modified	Adjusts position and dimension of transmission components
11	Rear pulley	Modified	Transfers rotation through the transmission
12	Juken 10 monitoring device	Real-time monitoring	Measures voltage, current, speed, duty cycle, power, and temperature
13	Speedometer	Connected to the front wheel	Measures vehicle speed
14	Strava application	Trip-logging application	Cross-checks speed and distance data
15	Fuel-volume measuring device	Graduated cylinder	Measures Pertalite consumption of the gasoline motorcycle

2.3. Conversion stages

The study followed the sequence shown in Figure 1. After the vehicle and components had been prepared, the motorcycle was converted mechanically and the electric propulsion system was installed. The converted vehicle was then checked for correct operation; any fault found at this stage was corrected and the check repeated before testing began. Testing comprised a no-load test of the motor and controller, a road test, and energy-consumption tests on the converted vehicle and on the same motorcycle in its original gasoline configuration, followed by a comparison of energy costs and analysis of the data.

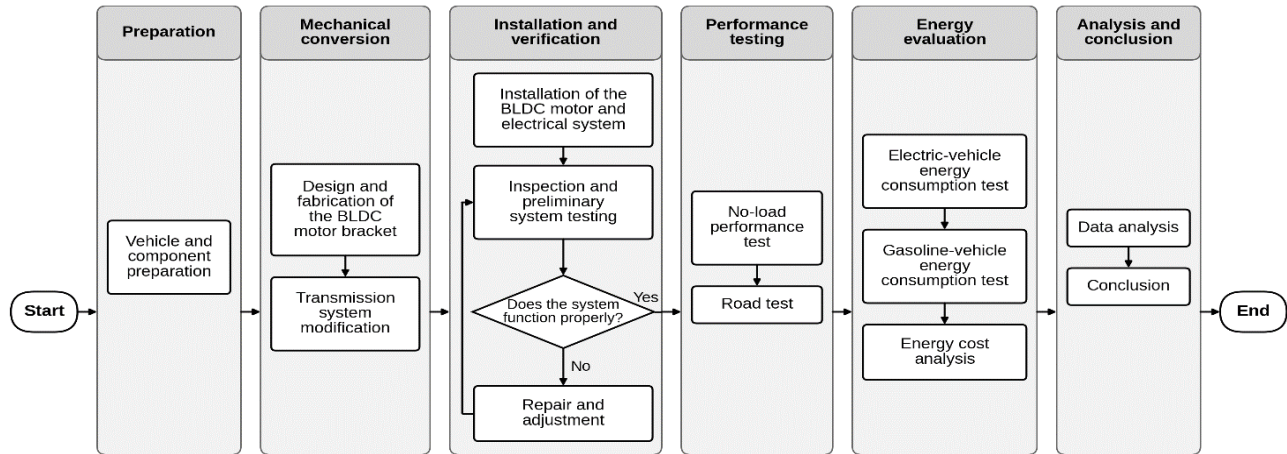


Figure 1. Research flow diagram

2.4. Mechanical conversion

The conversion retained the original Yamaha 5TL frame and CVT and replaced only the power source, so that the BLDC motor drives the rear wheel through the existing belt-and-pulley transmission. Components of the gasoline system that were no longer required were first removed, and the frame, transmission, wheels, and remaining parts were inspected before any new component was fitted. The mounting pattern of the BLDC motor differs from that of the original engine, so the motor could not be attached to the standard engine mount. A dedicated bracket was therefore designed to support the motor and connect it to the transmission housing (Figure 2). The governing requirement was shaft alignment: the motor shaft had to be in line with the CVT drive pulley, while the bracket also had to fit the transmission housing and hold the motor in a suitable position on the frame. The bracket was fabricated once the design had been finalised and was then fitted to the vehicle.

Several CVT components were then adapted to the new drive arrangement. The fan cover and roller housing were modified around the motor shaft to provide clearance and allow the motor to drive the pulley. Because the new arrangement changed the axial position of the transmission components, two bushings were shortened on a lathe. A replacement starter-gear bushing was made 8 mm shorter than the original (Figure 3), and the roller-housing bushing was shortened by the same amount. The final modification concerned the centrifugal clutch of the rear pulley. The clutch was disabled by welding the clutch housing to the clutch bell, so that the rear pulley remains permanently engaged with the final drive (Figure 4). In the original engine, this clutch disconnects the wheel at idle and engages as engine speed rises. A BLDC motor has no idle speed and develops torque from standstill, so the clutch was no longer required.

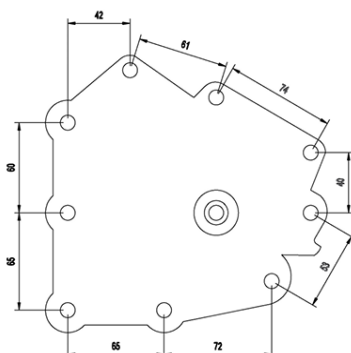


Figure 2. Bracket connecting the BLDC motor to the transmission housing



Figure 3. Replacement bushing for the starter gear



Figure 4. Modified rear pulley

2.5. Electrical system

The electrical propulsion system consisted of the battery, a miniature circuit breaker (MCB), the Juken 10 controller, the BLDC motor, a hand throttle with a throttle position sensor (TPS), an ignition switch, and the associated wiring. The wiring diagram is presented in [Figure 5](#) and the configuration of the electric propulsion system and mechanical drive train is presented in [Figure 6](#). Power flows from the battery through the MCB to the controller, which supplies the BLDC motor according to the throttle signal. The MCB is placed on the battery supply line to protect the circuit against overcurrent and short circuits, and the ignition switch is used to energise or isolate the system. After installation, all connections were inspected and the system was function-tested before the performance and road tests were carried out.

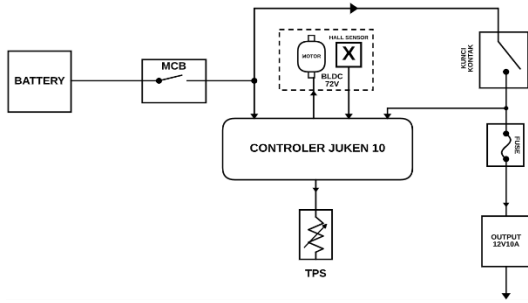


Figure 5. Wiring diagram of the converted electric propulsion system

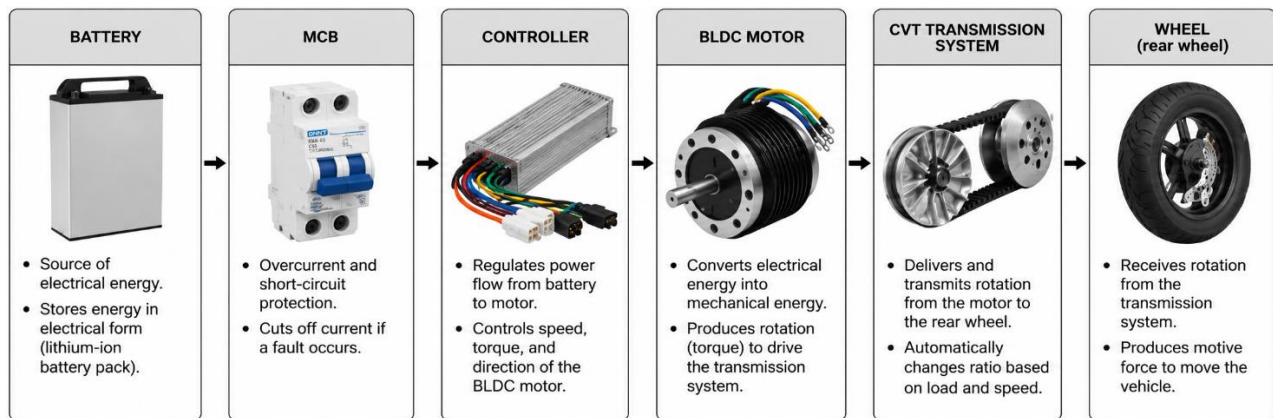


Figure 6. Configuration of the electric propulsion system and mechanical drive train

2.6. No-load performance testing

After the mechanical and electrical systems had been installed and checked, no-load testing was performed with the motorcycle stationary and without a rider load. The Juken 10 controller monitoring software was used to record the operating parameters in real time, including battery voltage, battery current, motor current, motor speed (rpm), electrical speed (eRPM), throttle position (TPS), duty cycle, electrical power, controller temperature, and motor temperature. During the test, the throttle was progressively opened to its maximum position while the motor response and recorded parameters were monitored. Data collection continued until the observed operating conditions stabilised.

2.7. Road testing

Following successful functional and stationary checks, road testing was conducted to evaluate the converted motorcycle under operating conditions with a rider weighing 69 kg. Vehicle speed and travel distance were recorded using the motorcycle's speedometer, which was driven by the front wheel. The recorded trip data were cross-checked against the Strava trip-logging application to provide a secondary reference for the measured speed and distance. These measurements were subsequently used to characterise the motorcycle's on-road performance.

2.8. Energy-consumption testing and analysis

Energy consumption of the electric configuration was determined from the reduction in battery state of charge after a fixed test distance of 5.08 km with a 69 kg rider load, following a full charge; this capacity-depletion approach is a common practical proxy for state-of-charge-based range and consumption estimation in battery electric vehicles [29]. Because this approach relies on the state-of-charge reading, its accuracy is bounded by the estimation method used in the battery management system [30]. Under the same load and distance, the fuel consumption of the same motorcycle running on its original gasoline system was measured using a graduated cylinder. Energy consumption per kilometre, estimated travel range, and energy cost were then calculated using Eqs. (1)–(5).

$$R = \frac{C_{full}}{C_{test}} \times d_{test} \quad (1)$$

$$e_{elec} = \frac{E_{elec}}{d_{test}} \quad (2)$$

$$f_{fuel} = \frac{V_{fuel}}{d_{test}} \quad (3)$$

$$c_{energy} = e_{energy} \times p_{energy} \quad (4)$$

$$S_{cost} = \frac{c_{fuel} - c_{elec}}{c_{fuel}} \times 100\% \quad (5)$$

where R is the estimated driving range (km), C_{full} is the battery capacity at full charge (Ah or kWh), C_{test} is the battery capacity consumed during the test (Ah or kWh), and d_{test} is the test distance (km). E_{elec} denotes the electrical energy consumed (kWh), and e_{elec} represents the specific electrical energy consumption (kWh/km). V_{fuel} is the volume of fuel consumed (L), while f_{fuel} denotes the specific fuel consumption (L/km). Furthermore, c_{energy} represents the energy cost per kilometer (currency/km), e_{energy} is the energy consumption per kilometer (energy unit/km), and p_{energy} is the unit price of energy (currency/energy unit). The symbols c_{fuel} and c_{elec} denote the fuel cost and electricity cost per kilometer, respectively (currency/km), while S_{cost} represents the cost savings (%).

3. Results and Discussion

3.1. Conversion result

The completed installation is presented in Figure 7. All components of the electric propulsion system could be accommodated on the standard Yamaha 5TL frame. The BLDC motor sits at the centre of the frame on the fabricated bracket, and the battery is placed in the central part of the frame. Apart from the bracket, the conversion required changes to only four CVT parts: the fan cover and roller housing, the two bushings, and the rear pulley. The preliminary function test confirmed that the controller responded to the throttle signal and drove the motor as intended, so the vehicle could proceed to performance testing.



Figure 7. Photographic view of the electric-motor installation on the Yamaha 5TL frame (1. Yamaha 5TL frame, 2. BLDC motor, 3. Bracket, 4. ECU, 5. Hand throttle, 6. Battery, 7. MCB, 8. Ignition switch)

3.2. No-load performance test results

Figure 8 shows the Juken 10 monitoring display recorded with the vehicle stationary and the rear wheel off the ground. Because the rear-pulley clutch had been locked, the motor drove the complete CVT and rear wheel during this test, so the measured power reflects the losses of the drivetrain rather than those of the motor alone. At full throttle (100%) the controller operated at a duty cycle of 95%, with a battery voltage of 64.6 V, close to the full-charge voltage of the 60 V nominal battery. Under steady-state conditions the battery current was 12.2 A and the

electrical power 788.8 W. The motor reached about 3,243 rpm, which the monitoring software reports as 16,215 eRPM for the configured five pole pairs. This speed is higher than the 2,900 rpm that the manufacturer specifies for no-load operation without flux weakening at 72 V, even though the test voltage was lower, which suggests that the controller was operating in the flux-weakening region.

During acceleration, the motor current rose to about 75 A before settling at about 56 A, whereas the battery current peaked at about 26 A and settled at about 12 A. The initial peak in both currents corresponds to the torque needed to accelerate the rotor and drivetrain. The large difference between the steady-state motor and battery currents at a 95% duty cycle cannot be explained by PWM averaging alone. It is consistent with flux-weakening operation, in which the controller supplies a substantial field-weakening current component that raises the phase current without a corresponding increase in power drawn from the battery. The speed trace rose quickly and then remained steady without significant fluctuation, indicating stable operation of the motor and controller. The controller and motor temperatures at the end of the test were 32.4 °C and 34 °C, well below the protection limits of 75 °C and 150 °C, although the short test duration means these values do not represent thermal behaviour under sustained road use.

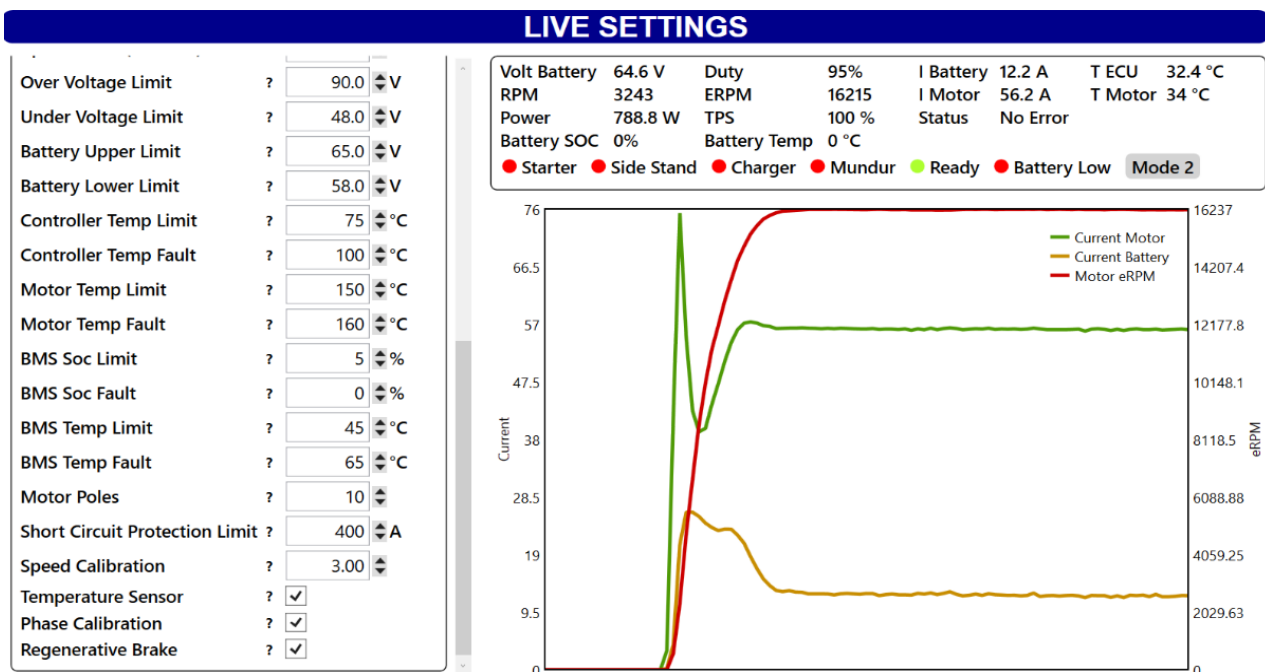


Figure 8. No-load performance test on the Juken 10 monitoring display

3.3. Road test results

Road testing was performed with the battery fully charged and a rider load of 69 kg, since no-load testing alone cannot represent the performance of the vehicle under an actual operating load; on the road, the motor must generate sufficient torque to move the vehicle, the rider, and to overcome rolling and aerodynamic resistance. Vehicle speed was measured with the front-wheel speedometer and cross-checked using the Strava application (Figure 9).

Under these conditions and over the 5.08 km test distance also used for the energy-consumption test, the converted motorcycle reached a maximum speed of approximately 35 km/h (Strava record: 5.08 km, maximum 34.8 km/h, average 17.0 km/h), showing that the electric propulsion system was able to drive the Yamaha 5TL under the tested conditions. To provide a benchmark, the same test conditions (load and distance) were repeated using the Yamaha 5TL in its original gasoline configuration, allowing a direct comparison of energy consumption and operating cost, as discussed in the following section.

3.4. Energy-consumption analysis

Energy consumption was compared between the converted electric configuration and the original gasoline configuration under matched conditions of test distance (5.08 km) and rider load (69 kg). Electric configuration.

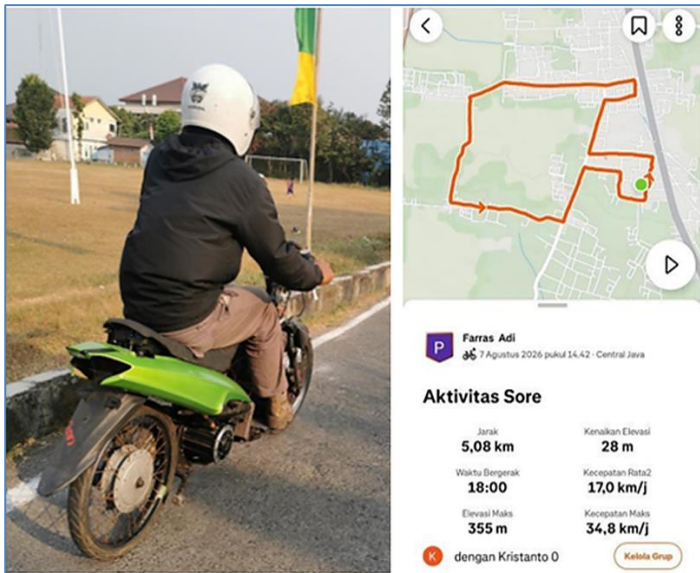


Figure 9. Road testing of the converted electric motorcycle (Strava monitoring interface in Indonesian)

electric motorcycles in the literature [31]. The resulting value of about 27.2 Wh/km lies within the 26–33 Wh/km reported by Aji *et al.* [15] for a converted underbone motorcycle and is comparable to the 37.0 km/kWh (about 27 Wh/km) obtained with the most efficient layout tested by Rusli *et al.* [6]. Gasoline configuration. The fuel tank of the Yamaha 5TL, still using its gasoline propulsion system, was filled to full capacity before the same 5.08 km test was repeated with the same 69 kg rider load and a comparable maximum speed of about 35 km/h. The measured fuel consumption was approximately 0.2 L (200 mL) over the 5.08 km distance, corresponding, by Eq. (3), to approximately 0.0394 L/km (39.4 mL/km).

3.5. Comparison of energy cost

Energy cost per kilometre was calculated using Eq. (4), based on a domestic electricity tariff of IDR 1,444.70/kWh and a Pertalite price of IDR 10,000/L (price at the time of data collection). For the electric configuration, an energy consumption of 0.0272 kWh/km gives an energy cost of approximately IDR 39.25/km. For the gasoline configuration, a consumption of 0.0394 L/km at IDR 10,000/L gives an energy cost of approximately IDR 393.70/km. Because the electrical energy was estimated from battery-side state-of-charge depletion, charger losses are not included; assuming a charger efficiency of 85–90% would raise the electricity cost to about IDR 44–46/km. Using Eq. (5), the percentage saving is $[(393.70 - 39.25)]/393.70 \times 100\% \approx 90.03\%$

These results are summarised in Table 3. Under the tested conditions, the energy cost of the converted motorcycle was about 90% lower than that of the gasoline configuration, or roughly one-tenth of the fuel cost per kilometre. This is close to the ninefold reduction reported by Firmansyah *et al.* [7] for a converted automatic motorcycle and comparable to the 82% cost saving reported by Yuwono *et al.* [22] for a battery electric motorcycle tested under UNECE Regulation No. 40. A similar picture emerges for energy use: taking the lower heating value of Pertalite as 44.26 MJ/kg and its density as 0.733 kg/L [32], the fuel contains about 9.0 kWh/L, so the gasoline configuration

Table 3. Comparison of energy consumption and energy cost between the electric and gasoline configurations

Parameter	Electric configuration	Gasoline configuration
Test distance	5.08 km	5.08 km
Rider load	69 kg	69 kg
Maximum speed	≈ 35 km/h	≈ 35 km/h
Energy source	1.38 kWh lithium-ion battery (60 V, 23 Ah)	Pertalite gasoline
Energy consumption	≈ 0.0272 kWh/km	≈ 0.0394 L/km
Estimated full-charge/full-tank range	≈ 51 km	—
Unit energy price	IDR 1,444.70/kWh	IDR 10,000/L
Energy cost per km	≈ IDR 39.25/km	≈ IDR 393.70/km
Cost saving of electric vs. gasoline	≈ 90.03%	—

consumed about 0.35 kWh/km and the electric configuration used roughly 92% less energy, in line with the 88% reduction reported by Yuwono *et al.* [22]. These figures compare energy costs only. They do not include battery degradation and replacement, the cost of the conversion itself, or the effect of subsidised fuel prices, all of which determine whether conversion is economically worthwhile over the vehicle's life [16], [17]. They are also based on a single 5.08 km test and a coarse state-of-charge reading, so they should be treated as indicative. The corresponding reduction in CO₂ emissions is less certain, because well-to-wheel analyses for Southeast Asian countries, including Indonesia, show that the climate benefit of electric motorcycles depends on how clean the electricity mix is [33].

4. Conclusion

The conversion of the Yamaha 5TL from a gasoline powered motorcycle to an electric motorcycle using a BLDC motor was successfully completed. The motor was integrated with the vehicle frame using a fabricated mounting bracket, and the electrical system, comprising a battery, an MCB, a Juken 10 controller, a hand throttle, and an ignition switch, functioned properly as an integrated propulsion system. Several transmission modifications were also required, including adjustments to the motor mounting bracket, fan cover, and roller housing, fabrication of a replacement bushing, adjustment of the roller housing bushing, and modification of the rear pulley. During no-load testing, the motor reached approximately 3,243 rpm (16,215 eRPM) at a battery voltage of 64.6 V and full throttle. The motor and controller temperatures were 34 °C and 32.4 °C, respectively. During road testing with a 69 kg rider, the converted motorcycle achieved a maximum speed of approximately 35 km/h. Energy consumption was compared between the electric and gasoline configurations over the same 5.08 km test distance with the same 69 kg rider. The electric configuration consumed approximately 0.0272 kWh/km, whereas the gasoline configuration consumed approximately 0.0394 L/km. Based on the nominal battery capacity of 1.38 kWh (60 V, 23 Ah), the estimated driving range was approximately 51 km per full charge, assuming the nominal battery energy was fully usable. Using an electricity tariff of IDR 1,444.70/kWh and a Pertalite price of IDR 10,000/L (price at the time of data collection), the estimated energy cost was IDR 39.25/km for the electric configuration and IDR 393.70/km for the gasoline configuration, representing an energy cost reduction of approximately 90.03% under the tested conditions. These results demonstrate the potential of the conversion to reduce operating energy costs, although the comparison does not include battery replacement, maintenance, or initial conversion costs.

Further studies should evaluate the converted motorcycle under a wider range of operating conditions, including different rider loads, speeds, road grades, and travel distances, to establish more comprehensive performance and energy consumption characteristics. More precise instrumentation should be used to improve the accuracy of energy measurements. Reliability and safety assessments should also examine the mounting bracket, transmission, battery, controller, and electrical system, particularly their resistance to water and moisture and their protection against overcurrent and elevated temperatures. Finite element analysis of the mounting bracket under static and dynamic loads could provide further evidence of structural integrity, as demonstrated in studies of other electrified vehicle mounting brackets. Future investigations could also examine transmission ratio optimisation, acceleration, hill climbing performance, and the economic feasibility of the conversion, including battery service life and replacement costs, drawing on techno economic approaches used in other converted motorcycle studies.

Acknowledgements - Thank you to the laboratory staff for their valuable assistance in completing this research.

Conflict of Interest - The authors declare that there are no conflicts of interest.

CRedit Author Statement - **FLA**: conceptualization, methodology, investigation, data processing, data curation, and writing – original draft; **LTK**: conceptualization, methodology, investigation, data processing, data curation, and writing – original draft; **MS**: supervision, writing – review and editing; **TR**: data curation, writing – review and editing; **VM**: data curation, writing – review and editing, **SD**: writing – review and editing.

Funding - This work was independently funded by the authors and did not receive financial support from the university, government agencies, commercial organizations, or non-profit organizations.

Gen AI Statement - Claude was used solely for language editing, grammar correction, and improving manuscript readability. It did not generate any scientific content. All research ideas, methodology, data, analysis, interpretations, and conclusions are the original work of the authors, who take full responsibility for the manuscript.

References

- [1] M. R. Vyshakh, S. Jose, N. Ramesh, A. J. Philip, K. Praveen, and S. S. Raj, "Conventional IC Engine to BLDC Powered Electric Motorcycle Conversion E Motorcycle," *International Journal of Electrical Engineering and Technology*, vol. 11., no. 2, pp. 69–74, 2020.
- [2] F. A. Padhilah, I. R. F. Surya, J. C. Adiatma, R. P. Sari, R. H. Permono, and R. Pradityo, "Indonesia Sustainable Mobility Outlook 2025: Driving Transport Decarbonization: Multi-pathways to Sustainable Mobility in Indonesia," Institute for Essential Services Reform (IESR), Jakarta, Indonesia, 2025. [Online]. Available: <https://iesr.or.id/wp-content/uploads/2025/07/Indonesia-Sustainable-Mobility-Outlook-2025-IESR-2.pdf>
- [3] A. K. Permana et al., "Structural Design and Analysis of The Mount and The Shaft for ICE Motorcycle Conversion to Electric," *Evergreen*, vol. 11, no. 04, pp. 3450–3456, 2024, doi: 10.5109/7326981.
- [4] M. Zeraoulia, M. E. H. Benbouzid, and D. Diallo, "Electric motor drive selection issues for HEV propulsion systems: A comparative study," *IEEE Transactions on Vehicular Technology*, vol. 55, no. 6, pp. 1756–1764, 2006, doi: 10.1109/TVT.2006.878719.
- [5] Y. Yohanes, I. Sidharta, M. N. Yuniarto, and A. M. Fikri, "Techno-Economic Analysis of CVT Configuration on Converted Electric Motorcycle Performance BT - Proceedings of the 10th International Conference on Science and Technology (ICST 2024)," Atlantis Press, 2025, pp. 156–165. doi: 10.2991/978-94-6463-772-4_16.
- [6] M. R. Rusli et al., "Comparative Performance Evaluation of Electric Powertrains in ICE Motorcycle Conversion," *Advance Sustainable Science, Engineering and Technology*, vol. 8, no. 1, 2026, doi: 10.26877/asset.v8i1.2163.
- [7] A. I. Firmansyah, N. K. Supriatna, Y. Gunawan, G. T. Setiadanu, and Slamet, "Performance Testing of Electric Motorcycle Conversion," in *2022 7th International Conference on Electric Vehicular Technology (ICEVT)*, IEEE, Sep. 2022, pp. 165–168. doi: 10.1109/ICEVT55516.2022.9924921.
- [8] F. A. Prasetya, B. Basuki, B. T. P., A. Winarno, and D. J. Kristianto, "Pengaruh Gear Ratio pada Motor BLDC Mid Drive 2 kW terhadap Kinerja Sepeda Motor Listrik Konversi," *Jurnal Engine: Energi, Manufaktur, dan Material*, vol. 10, no. 1, pp. 17–25, 2026, doi: 10.30588/jeemm.v10i1.2605.
- [9] T.-A. Bui, H.-B. Nguyen, V.-H. Pham, and M.-T. Nguyen, "Design and Development of a Drive System Integrated a Continuously Variable Transmission (CVT) for an Electric Motorcycle," *International Journal on Advanced Science, Engineering and Information Technology*, vol. 10, no. 3, pp. 1184–1190, Jun. 2020, doi: 10.18517/ijaseit.10.3.11885.
- [10] V. La Battaglia, A. Giorgetti, S. Marini, G. Arcidiacono, and P. Citti, "Kinematic Analysis of V-Belt CVT for Efficient System Development in Motorcycle Applications," *Machines*, vol. 10, no. 1, p. 16, Dec. 2021, doi: 10.3390/machines10010016.
- [11] B. Supriyo, S. Ariyono, and S. Sihono, "Electronic system of rubber belt electro-mechanical continuously variable transmission for motorcycle applications," *IOP Conference Series: Materials Science and Engineering*, vol. 1108, no. 1, p. 012011, Mar. 2021, doi: 10.1088/1757-899X/1108/1/012011.
- [12] Y. Liu et al., "Study on the Design and Speed Ratio Control Strategy of Continuously Variable Transmission for Electric Vehicle," *IEEE Access*, vol. 11, pp. 107880–107891, 2023, doi: 10.1109/ACCESS.2023.3318323.
- [13] B. Fu, T. Zhu, J. Liu, and X. Hu, "Research on Clamping Force Control of CVT for Electric Vehicles Based on Slip Characteristics," *Sensors*, vol. 22, no. 6, p. 2131, Mar. 2022, doi: 10.3390/s22062131.
- [14] M. Y. Effendi, U. Ubaidillah, E. P. Budiana, and B. W. Lenggana, "Performance analysis on the structure of the bracket mounting for hybrid converter kit: Finite-element approach," *Curved and Layered Structures*, vol. 10, no. 1, Jul. 2023, doi: 10.1515/cls-2022-0206.
- [15] D. O. P. Aji, S. Suwanto, and Y. A. Rokhim, "Performance Analysis of a Converted Electric Underbone Motorcycle: A Combined Dynamometer and Road Test Approach," *Journal of Mechanical Engineering Science and Technology*, vol. 10, no. 1, pp. 22–34, 2026, doi: 10.17977/2580-0817.1180.
- [16] Y. Yohanes, I. Sidharta, M. N. Yuniarto, and A. M. Fikri, "Techno-Economic Analysis of CVT Configuration on Converted Electric Motorcycle Performance," 2025, pp. 156–165. doi: 10.2991/978-94-6463-772-4_16.
- [17] T. S. Rahmawati, W. Sutopo, and H. Wicaksono, "Investment Decision-Making to Select Converted Electric Motorcycle Tests in Indonesia," *World Electric Vehicle Journal*, vol. 15, no. 8, p. 334, Jul. 2024, doi: 10.3390/wevj15080334.
- [18] R. Z. Raung, W. Sutopo, M. Hisjam, and D. Hartono, "Scenario analysis of subsidy policies on electric motorcycle market in Indonesia using system dynamics simulation," *Transportation Research Interdisciplinary Perspectives*, vol. 32, p. 101487, Jul. 2025, doi: 10.1016/j.trip.2025.101487.
- [19] R. Agustina, Yuniaristanto, and W. Sutopo, "Factors Influencing Electric Motorcycle Adoption in Indonesia: Comprehensive Psychological, Situational, and Contextual Perspectives," 2025. doi: 10.3390/wevj16020106.

- [20] C. Balijepalli, S. Shepherd, R. Crastes Dit Sourd, M. Farda, T. Praesha, and H. A.-R. Lubis, "Preferences for electric motorcycle adoption in Bandung, Indonesia," *Urban, Planning and Transport Research*, vol. 11, no. 1, Dec. 2023, doi: 10.1080/21650020.2023.2238033.
- [21] T. Koossalapeerom, T. Satiennam, W. Satiennam, W. Leelapatra, A. Seedam, and T. Rakpukdee, "Comparative study of real-world driving cycles, energy consumption, and CO2 emissions of electric and gasoline motorcycles driving in a congested urban corridor," *Sustainable Cities and Society*, vol. 45, pp. 619–627, Feb. 2019, doi: 10.1016/j.scs.2018.12.031.
- [22] T. Yuwono et al., "Energy consumption, CO2, and cost analysis of hybrid and battery electric motorcycle," *Journal of Mechatronics, Electrical Power, and Vehicular Technology*, vol. 15, no. 2, pp. 126–137, Dec. 2024, doi: 10.55981/j.mev.2024.989.
- [23] A. Habibie, M. Hisjam, W. Sutopo, and M. Nizam, "Sustainability Evaluation of Internal Combustion Engine Motorcycle to Electric Motorcycle Conversion," *Evergreen*, vol. 8, no. 2, pp. 469–476, 2021, doi: 10.5109/4480731.
- [24] A. D. Santoso et al., "Conversion of motorcycles to electric vehicles towards sustainable mobility," *Global Journal of Environmental Science and Management*, vol. 10, pp. 181–200, 2024, doi: 10.22034/GJESM.2024.SI.12.
- [25] Q. S. Motor, "2000W Mid Drive Motor Assembly for Electric Scooter, Motorcycle," Oct. 11, 2026, *QS Motor*. [Online]. Available: <https://www.qsmotor.com/product/mid-drive-motor/>
- [26] H. Gör and A. Dalcı, "Design and optimization of a high-performance multi-barrier IPMS motor for an electric scooter and bicycle," *Royal Society Open Science*, vol. 11, no. 3, Mar. 2024, doi: 10.1098/rsos.231650.
- [27] L. Lu, X. Han, J. Li, J. Hua, and M. Ouyang, "A review on the key issues for lithium-ion battery management in electric vehicles," *Journal of Power Sources*, vol. 226, pp. 272–288, 2013, doi: 10.1016/j.jpowsour.2012.10.060.
- [28] A. K. M. A. Habib, M. K. Hasan, G. F. Issa, D. Singh, S. Islam, and T. M. Ghazal, "Lithium-Ion Battery Management System for Electric Vehicles: Constraints, Challenges, and Recommendations," *Batteries*, vol. 9, no. 3, p. 152, 2023, doi: 10.3390/batteries9030152.
- [29] O. Demirci, S. Taskin, E. Schaltz, and B. Acar Demirci, "Review of battery state estimation methods for electric vehicles - Part I: SOC estimation," *Journal of Energy Storage*, vol. 87, p. 111435, May 2024, doi: 10.1016/j.est.2024.111435.
- [30] M. A. Hannan, M. S. H. Lipu, A. Hussain, and A. Mohamed, "A review of lithium-ion battery state of charge estimation and management system in electric vehicle applications: Challenges and recommendations," *Renewable and Sustainable Energy Reviews*, vol. 78, pp. 834–854, 2017, doi: 10.1016/j.rser.2017.05.001.
- [31] T. M. N. Bui, M. A. B. Subari, and T. Q. Dinh, "Real-Time Prediction of Remaining Driving Range for Electric Motorcycle Applications," *IEEE Transactions on Intelligent Transportation Systems*, vol. 25, no. 11, pp. 18171–18184, Nov. 2024, doi: 10.1109/TITS.2024.3445161.
- [32] A. Mallombasang, Z. Djafar, and W. H. Piarah, "Utilization of Gasoline Fuel as an Alternative Fuel for LPG Substitution," *EPI International Journal of Engineering*, vol. 3, no. 2, pp. 138–142, 2020, doi: 10.25042/epi-ije.082020.08.
- [33] P. Charoen-amornkitt, K. Nantasaksiri, K. Ruangjirakit, and Y. Laoonual, "Energy consumption and carbon emission assessment of battery swapping systems for electric motorcycle," *Heliyon*, vol. 9, no. 12, p. e22887, 2023, doi: 10.1016/j.heliyon.2023.e22887.