POWER CONSUMPTION AND PERFORMANCE ANALYSIS OF A 72 V 2000 W ELECTRIC MOTORCYCLE CONVERSION USING VOTOL AND NANJING CONTROLLERS

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ABSTRACT
The increasing adoption of electric motorcycles, particularly conversion-based systems, has highlighted the importance of improving energy efficiency and optimizing motor controller performance. This study evaluates the power consumption and dynamic performance of a converted electric motorcycle equipped with a 72 V, 2000 W brushless DC (BLDC) motor using two programmable controllers, Votol and Nanjing. Performance was assessed through chassis dynamometer testing at constant speeds of 25, 30, 40, and 50 km/h to measure torque, power output, and energy consumption. A 30 km road test along the Gianyar–Tabanan route was also conducted to examine energy use under real-world riding conditions. The results showed clear differences between the two controllers. The Votol controller delivered higher low-speed torque (19.57 Nm), providing better acceleration and throttle response, which are advantageous for stop-and-go urban traffic. In contrast, the Nanjing controller demonstrated slightly higher energy efficiency at 50 km/h, consuming 14.24 Wh compared with 14.98 Wh for the Votol controller. During the road test, the Votol-equipped motorcycle achieved an average energy consumption of 0.029 kWh/km. These findings demonstrate that controller selection significantly influences both vehicle performance and energy efficiency, providing useful guidance for optimizing converted electric motorcycles for daily urban transportation.

Keywords: electric motorcycle conversion; energy consumption; energy efficiency; nanjing controller; votol controller

INTRODUCTION
The rapid advancement of science and technology has significantly increased global energy demand. Energy has become one of the fundamental drivers of technological development and economic growth. According to the International Energy Agency (IEA), global energy demand is projected to increase substantially due to continued industrialization and economic expansion, particularly in developing countries. Consequently, energy sustainability has emerged as a critical global issue with far-reaching environmental, economic, and social implications. To address these challenges, renewable and environmentally friendly energy sources have become increasingly important. Among various sustainable transportation technologies, electric vehicles (EVs) have attracted considerable attention because of their potential to reduce greenhouse gas emissions and dependence on fossil fuels. This transition includes both four-wheeled electric vehicles and electric motorcycles, the latter being particularly important in countries where motorcycles represent the dominant mode of personal transportation.

In Indonesia, the adoption of electric motorcycles has experienced remarkable growth in recent years. According to the Indonesian Ministry of Industry, the number of registered electric motorcycles increased from approximately 17,000 units in 2022 to more than 62,000 units in 2023. This growth has been further accelerated by government incentive programs that support both the purchase of new electric motorcycles and the conversion of conventional internal combustion engine motorcycles into electric-powered vehicles. The Directorate General of New, Renewable Energy, and Energy Conservation of the Ministry of Energy and Mineral Resources reported that 495 motorcycles were successfully converted into electric motorcycles during the 2023 fiscal year, including both government-assisted conversion programs and official government fleet vehicles. The number increased significantly in 2024, with more than 1,100 government-assisted motorcycle conversions completed nationwide. In addition, Corporate Social Responsibility (CSR) collaboration programs have supported hundreds of additional electric motorcycle conversion projects, particularly in the Greater Jakarta metropolitan area. These initiatives demonstrate the Indonesian government's commitment to accelerating electric vehicle adoption and reducing transportation-related carbon emissions.

The increasing number of converted electric motorcycles has consequently created a growing demand for skilled technicians capable of maintaining, diagnosing, and optimizing electric vehicle systems. Beyond routine maintenance, improving vehicle performance while maintaining high energy efficiency has become a major engineering challenge. Among the key components affecting electric motorcycle performance are the battery pack and the motor controller. While the battery primarily determines driving range, the motor controller governs torque delivery, acceleration characteristics, and overall power management. An inappropriate controller configuration may lead to excessive battery current, increased operating temperature, and reduced battery lifespan. Conversely, selecting and properly programming a suitable controller can significantly improve acceleration, ride quality, and overall energy efficiency. Therefore, understanding the influence of different controller technologies on vehicle performance is essential for both manufacturers and electric motorcycle conversion practitioners.

Based on these considerations, this study evaluates the power consumption characteristics of a converted electric motorcycle equipped with a 72 V, 2000 W BLDC motor by comparing two widely used programmable controllers: the Votol controller and the Nanjing controller. The investigation includes controller programming optimization, chassis dynamometer testing, and real-world road testing to determine the most suitable controller configuration for daily operation while maintaining high energy efficiency. In addition, motor operating temperature is considered as an important parameter influencing energy consumption and overall system performance.

METHOD

Research Design

This study employed an experimental research design to evaluate the influence of two programmable motor controllers on the performance and energy consumption of a converted electric motorcycle. The experimental procedure was conducted systematically, beginning with a comprehensive literature review, followed by component installation, controller programming, laboratory testing, and real-world road testing. The experimental vehicle consisted of a converted electric motorcycle utilizing a Yamaha NMAX chassis equipped with a 72 V, 2000 W brushless direct current (BLDC) hub motor. The propulsion system was powered by a 64 Ah lithium-ion battery pack with a maximum operating voltage of 87 V. Two programmable motor controllers, namely the Votoland Nanjing controllers, were evaluated under identical operating conditions to ensure a fair comparison of their performance characteristics. To monitor the electrical parameters during testing, a Smart ANT Battery Management System (BMS) was installed to record battery voltage and current in real time. In addition, a chassis dynamometer was used to evaluate torque, power output, and energy consumption under controlled laboratory conditions.

Controller Installation and Programming

The experimental procedure began with the installation of both programmable controllers on the motorcycle. Since the study compared two different controller models, a customized mounting bracket was fabricated to facilitate rapid controller replacement while maintaining identical electrical and mechanical configurations throughout the experiments. The Votol controller was configured manually using the manufacturer's programming software. Several operational parameters were optimized according to the characteristics of the 72 V BLDC motor, including: Undervoltage protection, Busbar current limit, Phase current limit, Throttle response, Torque rise rate, Torque decay rate, and Flux-weakening parameters for high-speed operation. These parameters were adjusted to maximize vehicle performance while maintaining safe operating conditions and acceptable energy efficiency. In contrast, the Nanjing controller utilizes an Auto-Learn feature that automatically identifies critical motor characteristics, including phase sequence, Hall sensor angle, and motor pole pairs. After the automatic identification process was completed and the motor rotation direction was verified, additional manual adjustments were performed to configure operational limits such as maximum vehicle speed, maximum phase current, and riding mode. These settings were optimized to ensure stable operation and reliable controller performance throughout the testing procedure.

Experimental Procedures

The experimental evaluation consisted of two complementary testing scenarios.

Chassis Dynamometer Test

The first stage involved laboratory testing using a chassis dynamometer to evaluate electrical performance under steady-state operating conditions. Measurements were conducted at four constant vehicle speeds: 25 km/h, 30 km/h, 40 km/h and 50 km/h. Each test was performed for **one minute**, and repeated **three times** to improve measurement reliability. During each test, the following parameters were continuously recorded: Battery voltage (V), Battery current (A), Electrical power (W), Motor torque (Nm), Motor rotational speed (rpm) and Output power (hp). Average energy consumption at each speed was then calculated and compared between the two controllers.

Road Test

Following the laboratory evaluation, real-world testing was conducted to assess energy consumption under actual operating conditions. The road test employed a full-to-full battery measurement method, in which the battery pack was fully charged before and after each test cycle. This approach enabled direct measurement of the electrical energy required during vehicle operation. The selected test route extended approximately 30 km, connecting Poltrada Bali Gianyar Campus and Poltrada Bali Tabanan Campus. The route included a variety of traffic and road conditions representative of daily commuting in Bali, passing through: Batuyang Road-Batubulan Main Road-Jagapati Road-Angantaka Road-Denpasar–Gilimanuk Highway. During the road test, the Smart ANT BMS continuously recorded battery voltage and current to evaluate energy consumption under acceleration, constant-speed cruising, regenerative braking, and deceleration. The total electrical energy consumed during each trip was subsequently calculated in kilowatt-hours (kWh).

Data Analysis

The collected experimental data were analyzed descriptively by comparing the performance characteristics of the Votol and Nanjing controllers. Performance indicators included: Maximum power output (hp), Maximum torque (Nm), Maximum acceleration (kph/s), Maximum battery current (A), Maximum BLDC motor current (A) and Maximum motor power (kW). Energy efficiency was evaluated using the measured electrical energy consumed during both laboratory and road tests. Specific energy consumption was calculated as:

$$\text{Specific Energy Consumption} = \frac{\text{Energy Consumed (kWh)}}{\text{Distance Traveled (km)}}$$

The comparison between controllers focused on identifying the configuration that provided the most suitable balance between acceleration performance and energy efficiency for daily urban commuting.

RESULT

Controller Installation

The experimental work commenced with the preparation and installation of the primary electrical components, including the programmable motor controllers, battery monitoring system, and electrical protection devices. The electrical system incorporated two programmable controllers (Votol and Nanjing), a 100 A circuit breaker, and a Smart ANT Battery Management System (BMS) for real-time monitoring of battery voltage, current, and battery status through a mobile application. To accommodate both controller types within the same motorcycle chassis, a customized controller mounting bracket was fabricated. This design enabled rapid replacement of controllers while maintaining identical mechanical positioning and electrical connections throughout the experiments. Consequently, differences observed during testing could be attributed primarily to controller characteristics rather than installation variations.

Controller Programming

The programming procedures differed considerably between the two controller models. The Votol controller was configured manually using proprietary programming software. Parameters including undervoltage protection, battery current limit, phase current limit, throttle response, acceleration rate, deceleration rate, and flux-weakening were adjusted according to the specifications of the 72 V, 2000 W BLDC motor. In contrast, the Nanjing controller employed an automatic learning (Auto-Learn) function capable of identifying essential motor characteristics such as phase sequence, Hall sensor angle, and motor pole configuration. Following automatic calibration, additional manual adjustments were performed to configure maximum vehicle speed, phase current limits, and riding modes to ensure safe and efficient operation. These programming strategies allowed both controllers to operate under optimized conditions prior to performance evaluation.

Dynamometer Performance Evaluation

The chassis dynamometer test revealed substantial differences in the performance characteristics of the two programmable controllers. The Votol controller (Programming Mode 2) generated a maximum torque of 19.57 Nm at 1,960 rpm, producing a maximum output power of 6.58 hp. This high torque at relatively low motor speed resulted in rapid acceleration and improved throttle responsiveness, characteristics that are particularly advantageous in urban stop-and-go traffic conditions. Conversely, the Nanjing controller (Programming Mode 1) achieved a considerably higher maximum power output of 10.05 hp at 5,360 rpm. However, the corresponding maximum torque was lower at **16.09 Nm**, indicating that higher motor rotational speed was required to achieve peak performance. These results demonstrate that the Votol controller prioritizes low-speed torque and acceleration, whereas the Nanjing controller is optimized for higher-speed operation and maximum power output. The Votol controller required higher battery and motor currents than the Nanjing controller. Nevertheless, it produced greater motor torque and slightly higher BLDC motor power, indicating superior low-speed driving capability. In contrast, the Nanjing controller achieved higher peak power while operating with lower current demand, suggesting a design better suited to sustained high-speed performance.

Table 1.
Performance comparison between the Votol and Nanjing controllers

Parameter	Votol (Mode 2)	Nanjing (Mode 1)
Maximum Power (hp)	6.58 @ 3,480 rpm	10.05 @ 5,360 rpm
Maximum Torque (Nm)	19.57 @ 1,960 rpm	16.09 @ 1,700 rpm
Maximum Acceleration (kph/s)	17.58	16.23
Maximum Battery Current (A)	70.78	66.32
Maximum BLDC Motor Current (A)	135.66	99.04
Maximum Motor Power (kW)	6.23	5.70

Energy Consumption During Dynamometer Testing

Energy consumption was evaluated at constant vehicle speeds of 25, 30, 40, and 50 km/h. Each measurement was repeated three times, and average values were calculated. The results indicated that both controllers exhibited nearly identical energy consumption under low- and medium-speed operating conditions. At 25 km/h, the Votol controller consumed an average of 7.870 Wh, whereas the Nanjing controller consumed 7.874 Wh. At 30 km/h, both controllers recorded an identical average consumption of 9.448 Wh, while consumption increased equally to 12.606 Wh at 40 km/h. A noticeable difference emerged at 50 km/h, where the Nanjing controller demonstrated superior energy efficiency by consuming 14.240 Wh, compared with 14.983 Wh for the Votol controller. These findings indicate that controller selection has minimal influence on energy consumption at moderate speeds but becomes increasingly important under higher-speed operating conditions.

Table 2.
Average energy consumption during chassis dynamometer testing

Vehicle Speed (km/h)	Votol (Wh)	Nanjing (Wh)
25	7.870	7.874
30	9.448	9.448
40	12.606	12.606
50	14.983	14.240

Road Test Results

Following the laboratory evaluation, real-world testing was conducted over a distance of approximately 30 km between Gianyar and Tabanan using the Votol controller, which was selected based on its superior low-speed torque characteristics. During acceleration, the battery current reached a peak value of 76.9 A, whereas regenerative braking generated a minimum current of approximately −14 A during deceleration. The first road test yielded a calculated energy consumption of 0.893 kWh, while the full-to-full charging method measured 0.891 kWh, indicating excellent agreement between the two measurement approaches.

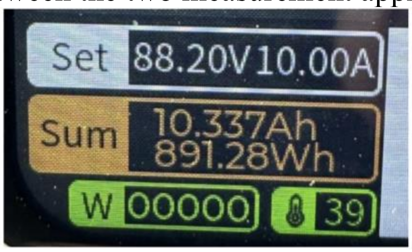

Figure 1. Energy Consumption During the Gianyar-Tabanan Road Test

The second road test produced a calculated energy consumption of 0.891 kWh, whereas the full-to-full charging method recorded 0.823 kWh. Despite minor variations resulting from charging efficiency and environmental factors, both methods produced comparable results.

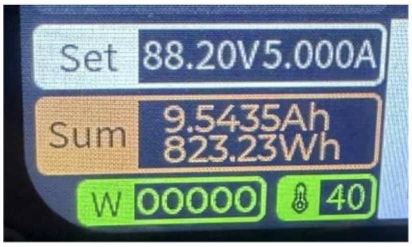

Figure 2. Energy Consumption During the Tabanan-Gianyar Road Test

The average electrical energy required to travel 30 km was approximately 0.866 kWh, corresponding to a specific energy consumption of 0.029 kWh/km. These findings demonstrate that the converted electric motorcycle provides relatively low daily energy consumption under actual road conditions, supporting its feasibility as an energy-efficient urban transportation solution.

Table 3.
Road test energy consumption

Parameter	Value
Test distance	30 km
Average energy consumption	0.866 kWh
Specific energy consumption	0.029 kWh/km
Maximum battery current	76.9 A
Minimum regenerative current	−14 A

DISCUSSION

Effect of Controller Programming on Vehicle Performance

The experimental results demonstrate that controller programming plays a crucial role in determining the dynamic performance of a converted electric motorcycle. Although the Nanjing controller achieved a higher maximum power output (10.05 hp), the Votol controller exhibited superior low-speed performance by producing a substantially higher maximum torque of 19.57 Nm. This characteristic enabled the motorcycle to accelerate more rapidly despite its lower peak power output. Peak power alone is therefore not a sufficient indicator of real-world vehicle performance. In urban traffic environments, where frequent acceleration and deceleration occur, torque availability at low motor speed has a greater influence on vehicle responsiveness and rideability than maximum horsepower. The Votol controller reached its maximum power at a considerably lower rotational speed (3,480 rpm) than the Nanjing controller (5,360 rpm), indicating that it delivers usable power earlier during acceleration.

The higher battery and motor currents recorded for the Votol controller also indicate a more aggressive torque control strategy. By supplying greater phase current to the BLDC motor, the controller generates stronger electromagnetic torque during vehicle launch. Consequently, riders experience smoother and more responsive acceleration, particularly in congested urban traffic where repeated stop-and-go operation is common. Conversely, the Nanjing controller appears to prioritize high-speed performance. Its ability to generate higher peak power suggests that the controller is better optimized for maintaining output at elevated motor speeds. However, this advantage is less significant for typical daily commuting, where motorcycles generally operate at relatively low to moderate speeds. Overall, these findings indicate that controller selection should be based on the intended operating conditions rather than solely on maximum power specifications. For urban transportation, greater low-speed torque and responsive acceleration are generally more beneficial than higher peak horsepower.

Energy Consumption During Chassis Dynamometer Testing

The chassis dynamometer tests revealed that both controllers exhibited remarkably similar energy consumption at constant speeds between 25 and 40 km/h. The differences observed were negligible, suggesting that under steady-state operating conditions the electrical efficiency of both controllers is comparable. A measurable difference emerged only at 50 km/h, where the Nanjing controller consumed approximately 5% less electrical energy than the Votol controller. This finding suggests that the Nanjing controller manages current delivery more efficiently at higher motor speeds, possibly through more effective switching strategies and optimized field-weakening operation. These results also indicate that vehicle speed has a stronger influence on energy consumption than controller selection within the tested operating range. As vehicle speed increases, aerodynamic drag and drivetrain losses become increasingly dominant, leading to higher electrical power demand regardless of controller type. From a practical perspective, the experimental data imply that riders who frequently travel at relatively high cruising speeds may obtain modest improvements in energy efficiency by using the Nanjing controller. However, the magnitude of this improvement remains relatively small under normal riding conditions.

Energy Consumption Under Real-World Operating Conditions

The road test provided valuable insight into the actual energy requirements of a converted electric motorcycle operating under everyday traffic conditions. Unlike laboratory testing, real-world operation involves continuous acceleration, deceleration, road gradients, traffic congestion, and regenerative braking, all of which significantly influence electrical energy consumption. The average energy consumption of 0.029 kWh/km demonstrates that the converted motorcycle requires only a modest amount of electrical energy for daily commuting. This value is comparable to the energy consumption reported for many commercially available low-power electric motorcycles, indicating that properly engineered conversion motorcycles can achieve practical levels of energy efficiency. Furthermore, the close agreement between the calculated energy consumption and the full-to-full charging measurements confirms the reliability of the experimental methodology. The small discrepancy observed between the two methods is expected because charging losses, battery balancing processes, and environmental conditions inevitably affect charging efficiency. Another noteworthy observation is the occurrence of negative battery current during deceleration. The recorded regenerative current of approximately −14 A confirms that the controller successfully recovered part of the vehicle's kinetic energy during braking. Although the recovered energy represents only a fraction of the total energy consumed, regenerative braking contributes to improved overall system efficiency, particularly in urban environments characterized by frequent stop-and-go driving.

Practical Implications for Electric Motorcycle Conversion

The findings of this study provide several practical implications for electric motorcycle conversion projects. First, controller selection should consider the intended operating environment rather than relying exclusively on manufacturer power ratings. While the Nanjing controller offers higher maximum power, the Votol controller provides superior low-speed torque and acceleration, characteristics that are generally more desirable for urban transportation. Second, appropriate controller programming is equally important as hardware selection. Careful adjustment of current limits, throttle response, torque control, and field-weakening parameters can substantially improve vehicle performance without requiring modifications to the motor or battery system. This highlights the importance of software calibration in optimizing electric vehicle performance.

Finally, the relatively low average energy consumption measured during road testing demonstrates that converted electric motorcycles represent a practical and energy-efficient transportation alternative. In regions such as Bali, where motorcycles are the dominant mode of personal transportation and daily commuting distances are relatively short, electric motorcycle conversion offers significant potential for reducing fossil fuel consumption and greenhouse gas emissions while maintaining acceptable vehicle performance. Overall, this study demonstrates that optimizing controller selection and programming can improve both driving performance and energy efficiency, thereby supporting broader adoption of electric motorcycle conversion technology.

CONCLUSION

This study demonstrates significant differences in the performance characteristics of Votol and Nanjing programmable motor controllers when applied to a 72 V, 2000 W converted electric motorcycle. The performance evaluation revealed that the Votol controller, configured with Programming Mode 2, delivered superior low-speed performance by generating a maximum torque of 19.57 Nm, resulting in a maximum acceleration of 17.58 kph/s. This characteristic provides faster throttle response and makes the controller particularly suitable for urban stop-and-go traffic conditions. In contrast, although the Nanjing controller achieved a higher peak power output of 10.05 hp, it required substantially higher motor speed and current to attain this performance. Therefore, the selection of an appropriate motor controller should be based on the intended operating conditions, with low-speed torque and driving efficiency being more critical for daily commuting than peak power alone.

From an energy efficiency perspective, the chassis dynamometer tests demonstrated comparable energy consumption between the two controllers at moderate vehicle speeds, whereas the Nanjing controller exhibited slightly better efficiency at higher speeds. However, considering the operating characteristics of urban traffic, the superior low-speed torque and acceleration provided by the Votol controller offer a practical advantage for everyday use. Furthermore, the road test conducted over the 30 km Gianyar–Tabanan route confirmed consistent energy consumption results using both the calculated method and the full-to-full charging method. The converted electric motorcycle equipped with the Votol controller required an average of 0.866 kWh to complete the route, corresponding to a specific energy consumption of 0.029 kWh/km. These findings indicate that appropriate controller selection and parameter optimization can significantly improve vehicle performance while maintaining high energy efficiency, thereby supporting the practical implementation of converted electric motorcycles as a sustainable solution for daily urban transportation.

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