



Techno-Economic Analysis of CVT Configuration on Converted Electric Motorcycle Performance

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Abstract. This research investigates the performance and economic viability of electric motorcycles converted from conventional internal combustion engine (ICE) motorcycles in Indonesia. The study focuses on optimizing the continuously variable transmission (CVT) system, a crucial component in these conversions. Through dynamometer testing and performance analysis, the optimal CVT configuration for maximum acceleration and speed was determined to be a roller mass of 12 grams and a returning spring of 1000 RPM. However, the research also highlights significant power transmission inefficiencies, primarily due to slipping in the CVT and centrifugal clutch. This results in lower overall tractive performance than expected. Despite these limitations, the converted electric motorcycles still offer economic benefits compared to ICE motorcycles, especially for longer travel distances and with lower electricity tariffs. Breakeven point (BEP) analysis indicates that the converted motorcycles become more cost-effective than ICE motorcycles for travel distances exceeding 73,410 km with a 450 W electricity tariff. The findings of this study provide valuable insights for consumers and policymakers in Indonesia considering the transition to electric motorcycles. The research recommends further improvements in CVT technology to enhance the performance and efficiency of converted electric motorcycles, ultimately contributing to a more sustainable transportation landscape.

Keywords: Electric Motorcycle Conversion, Continuously Variable Transmission (CVT), Performance Optimization, Economic Feasibility, Techno-Economic Analysis.

1 INTRODUCTION

Motorcycles have become an integral part of Indonesian society, with over 130 million units in use. This makes motorcycles one of the primary modes of transportation in the country. However, the widespread use of conventional motorcycles has contributed to increased greenhouse gas emissions and dependence on fossil fuels [1] as well as the traffic noise [2].

To address environmental and energy concerns, the Indonesian government has introduced various incentives to promote the adoption of electric vehicles, including

electric motorcycles. Subsidies for both new electric motorcycles and conversions from internal combustion engine (ICE) motorcycles are among the government's support initiatives [3]. Teo et al. demonstrates that such conversion program is promising as an alternative to produce the new electric motorcycle [4]. Nevertheless, consumers' decisions to switch to electric motorcycles are not solely driven by environmental concerns and government policies [5], but also by considerations of performance and cost [6].

Converting ICE motorcycles to electric ones is typically done by replacing the internal combustion engine with an electric motor, while retaining the continuously variable transmission (CVT) system integrated with the chassis. This approach is preferred as it is considered easier, faster, and more cost-effective due to minimal component replacement. However, it is important to note that CVTs are specifically designed for the characteristics of ICE engines, which differ from electric motors. Therefore, this research aims to Analyze the performance of converted motorcycles with CVT systems and identify the optimal tuning parameters of the CVT, such as roller weights and return springs, to achieve the best performance. Then to compare the performance of converted motorcycles with CVT systems to pure electric motorcycles and conventional ICE motorcycles. The other goal to calculate the break-even point (BEP) of converted motorcycles and compare it to ICE motorcycles and new electric motorcycles.

There are some studies regarding the tuning parameter of CVT in motorcycle. Jusnita and Ayu Lestari proposed an optimum combination of roller mass and returning spring to maximize the tractive power of ICE motorcycle [7]. Safar et al. increased the weight of centrifugal clutch drum to improve the power transmission [8]. The economic analysis also has been studied to compare the economic value of different type battery system for motorcycle [9]. Those researches indicate the importance of techno-economic analysis of the electric motorcycle. However, there is a research gap in such analysis to that of converted electric motorcycle. The ultimate goal of this research is to provide recommendations for the optimal CVT configuration in converted electric motorcycles and to provide useful information for consumers in choosing the right type of motorcycle to suit their needs and preferences. By doing so, this research is expected to contribute to the development of electric vehicle technology in Indonesia and accelerate the transition to more sustainable transportation.

2 METHODOLOGY

This study aims to convert a 110cc automatic scooter into an electric vehicle by replacing the internal combustion engine (ICE) with a brushless DC (BLDC) motor. The conversion process involves disassembling the ICE and other related components and installing a BLDC motor, Li-ion battery, and controller. The BLDC motor is mounted on the existing engine mount, while the motor output shaft is connected to the CVT input driver pulley shaft using a flexible coupling to accommodate shaft misalignment. The power flow from engine to the driving wheel is shown in Figure 1. The existing CVT transmission is retained with adjustments made to the roller weights and return spring tension to optimize performance. The technical specification of the motorcycle is shown in Table 1. To evaluate the performance of the converted scooter,

dynamometer tests were conducted as shown in Figure 2. The tests measured torque and rotational speed at the driven wheel. Tractive power was calculated based on the torque and speed of the roller, while rolling resistance and aerodynamic drag were considered in the calculation of total resistance. Acceleration is determined based on the gap between the tractive power and the road load power while maximum speed is determined based on the balance between tractive power and the power of total resistance.

Table 1. Technical specification of motorcycle.

Specifications	Value
Gross vehicle weight, m	200 kg
Wheel radius, r_w	0.258 m
Overall trans. Ratio, n	12 ~ 45
ICE	9.2 N.m
Max. torque, T_{max} @ speed	6000 RPM 6.5 kW
Max. power, P_{max} @ speed	7500 RPM
BLDC motor	24.12 N.m
Rated Torque, TEM	5 kW
Rated Power, PEM	

To obtain more accurate data on rolling resistance and aerodynamic drag, a coast down test was performed. The scooter was accelerated to a speed of 70 km/h, and then the power supply to the electric motor was cut off. The change in speed and distance during the deceleration process was recorded using a GPS application that had been validated against a wheel speed sensor. The test distance was 300 meters. The obtained speed data was then analysed to calculate the total resistance. The overall road load resistance obtained from this test is $F_R = 22.07 + 0.126v^2$.

Performance testing was conducted by varying the roller weights and return spring tension of the CVT system. Variations were limited to commercially available options to simplify the conversion process and ensure parts availability. The available roller weight is 7, 11, and 12 grams while the available returning spring are for 1000, 1500, and 2000 RPM actuating speed. The combination of roller weights and return spring tension that resulted in the best acceleration and energy efficiency was selected as the optimal configuration. The test data was analysed using spreadsheet to obtain torque speed curves and calculate other performance parameters.

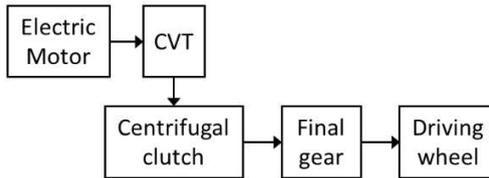


Fig. 1. The powertrain layout of the converted electric motorcycle.



Fig. 2. The powertrain layout of the converted electric motorcycle.

In addition to performance evaluation, this study assesses the economic feasibility of converting motorcycles to electric power through break-even point (BEP) analysis. By comparing the total cost of ownership (TCO), encompassing initial investment, operational and maintenance costs, and revenue (assumed to be equivalent to the operational costs of gasoline motorcycles), this research aims to determine the mileage at which the investment in both converted and new electric motorcycles becomes profitable. This paper calculates TCO based on formula proposed by Halidah et al. [10] with some simplifications as shown in Equation (1). Here, the new electric motorcycle is represented by GESITS as it uses 5 kW electric motor driver.

$$TCO = CC - OC \tag{1}$$

$$OC = C_M + C_E \tag{2}$$

This paper assumes the capital cost (CC) as on the road (OTR) price for both converted and new electric motorcycle as it includes the government incentive. Cost of charging equipment and power installation are excluded as electric motorcycle does not require such equipment. While, resale values are equal for both motorcycles. Operational cost (OC) covers regular maintenance (CM) and energy (CE) costs while

neglected factors of inflation, tax, and battery price as well as the time value of money. Table 2 resumes both CC and OC. Electricity tariff used to calculate energy cost is presented in Table 3.

Table 2. Resume of CC and OC.

Motorcycle	Capital Cost (CC)	Operational Cost (OC)
ICE (as it is)	Rp -	Rp 563
ICE (new)	Rp 17.905.000	Rp 563
Electric (retrofit)	Rp 12.600.000	Rp 301
Electric (new)	Rp 28.700.000	Rp 309

Table 3. Tariff of electricity (as October 2024)

Category	Power Capacity (VA)	Tarif (IDR/kWh)
Subsidized	900	605
Non- Subsidized	900	1352
	1300-2200	1444.70
	3500 ≤	1699.53

The contribution margin, defined as the difference between revenue and variable costs, is crucial in the BEP calculation. This analysis facilitates the identification of conditions under which converted electric motorcycles offer a more economical solution compared to conventional gasoline motorcycles.

3 RESULT AND DISCUSSION

Figure 3 shows the available tractive power and the required power to overcome the resistive load at the driving wheel of the converted motorcycle. The tractive power and resistive power are in balance which demonstrates the possible maximum speed of motorcycle. Acceleration performance is indicated by the gap between the available power with the resistive power prior the maximum speed. Variation in roller mass results in the shifting up/down of the available tractive power. This shifting of available power changes the acceleration performance and the maximum speed of motorcycle. Figure 3.c clearly shows that CVT using roller mass of 12 grams delivers higher tractive power to the driving wheel compared to others. The power peak of 1.4 kW is delivered at speed of 25 km/h. This power generates maximum acceleration of 1.34 m/s².

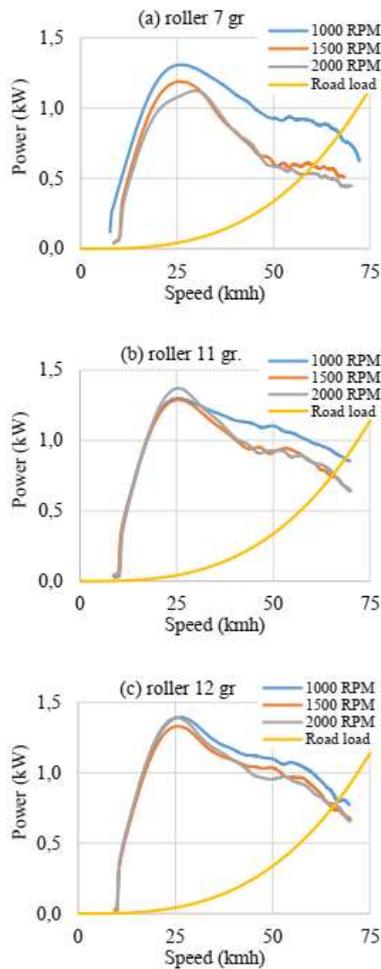


Fig. 3. Available tractive power and the required resistive power at the driving wheel.

Spring variation governs the degradation of tractive power after motorcycle reaching its peak power. Softer spring maintains the tractive power higher than that of stiffer one. It means that CVT using spring of 1000 RPM has better acceleration and achieves higher maximum speed of 70 km/h. However, the effect of spring on power is less pronounced when CVT uses higher roller mass.

Based on those analyses, the optimum performance in acceleration and maximum speed of motorcycle is obtained for CVT with roller mass of 12 gram and returning spring of 1000 RPM. The maximum acceleration is 1.34 m/s^2 and the maximum speed is 70 km/h. However, all CVT setups deliver much lower tractive performance than could be expected from a 5 kW BLDC motor. The power transmission efficiency is only

28% of the motor rated power. The possible source of such high-power loss is due to slipping in belt-pulley CVT transmission and centrifugal clutch. Therefore, knowing the characteristic of the engaging speed of centrifugal clutch can explain that condition.

Centrifugal clutch transmits power through friction between liner material at flyweight/shoe and the surface of drum casing. The developed frictional force grows with the input shaft speed as shown in Figure 4. The maximum torque is transmitted when the clutch is fully engaged. The clutch used in this motorcycle deliver torque of 10 N-m at shaft speed of 6000 RPM which is assume to be fully engaged. Therefore, the clutch is slipping below this speed and thus delivers less torque. Such behaviour is antithetical to the low-speed torque characteristics of an electric motor. Moreover, the electric motor of 4000 RPM in maximum speed never puts the clutch to be fully engaged.

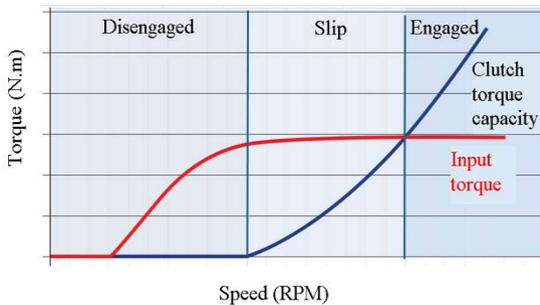


Fig. 4. Engaged speed characteristic of centrifugal clutch.

This paper uses BEP analysis to provide economical insight to continue using their ICE motorcycle as it is, to convert it to electric motorcycle or invest to new ICE motorcycle or new electric motorcycle. The BEP analysis is based on the simplified TOC as mentioned in the methodology.

Figure 5 demonstrates the BEP of the electric motorcycles using ICE motorcycles as a benchmark. The converted electric motorcycle reaches BEP after milage of 53,872 km in regard of ICE motorcycle (as it is), as represented by point A. While, the new electric motorcycle achieves BEP in a longer milage of 127,408 km, as indicated by point B. In regard of new ICE motorcycle, the investment of new electric motorcycle obtains BEP after milage of 47,922 km (point C). This analysis uses electricity tariff for 900 VA nonsubsidized and the gasoline price of Rp. 12,500/litre (non-subsidized). The gap between point A and B is due to lower investment and maintenance costs of the converted electric motorcycle compared to that of new one.

We varied electricity tariff to measure its sensitivity to BEP. Figure 6 shows the sensitivity of BEP due to electricity tariff. It is clear if lower electricity tariff results in sorter traveling distance to reach BEP, e.g., the subsidized tariff (900 VA*) achieves BEP at milage of 49,162 km. It means that the incentive in electricity tariff has significant impact in the economic consideration of the user to replace their ICE motorcycle with the electric one.

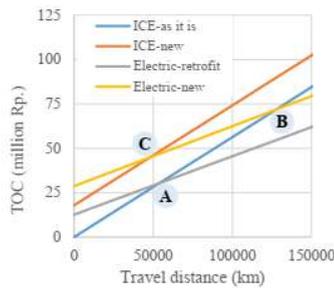


Fig. 5. BEP analysis of electric motorcycles using ICE motorcycle as a reference at electricity tariff of 900VA non-subsidized.

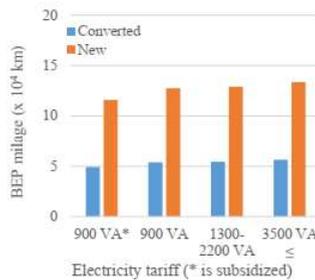


Fig. 6. Sensitivity of BEP due to electricity tariff.

In case we have an improved power transmission for the converted motorcycle, a lower rated power of electric motor, e.g., electric motor of 2 kW, may be used and the energy cost (*CE*) is reduced. This may lead to a faster BEP and more beneficial to users, especially to that of ride-hailing who have an average daily trip of 87 km or 32,000 km/year [11]. In that case, the BEP is reached in 1.5 year of trip. Minimizing the slippage and tuning the CVT should be addressed to improve the efficiency of the transmission.

4 CONCLUSION

Based on the analysis of the converted electric motorcycle, the optimal performance in terms of acceleration and maximum speed is achieved with a CVT (Continuously Variable Transmission) configuration using a roller mass of 12 grams and a returning spring of 1000 RPM. This combination yields a maximum acceleration of 1.34 m/s² and a maximum speed of 70 km/h. However, the overall tractive performance of the converted motorcycle is significantly lower than expected due to power losses in the transmission system, primarily attributed to slipping in the belt-pulley CVT and the centrifugal clutch. The centrifugal clutch, in particular, operates inefficiently at low

speeds, which is counterproductive to the high-torque characteristics of an electric motor.

Despite these limitations, the converted electric motorcycle still offers economic benefits compared to a conventional ICE (Internal Combustion Engine) motorcycle, especially for longer travel distances. The breakeven point (BEP) is reached sooner for the converted motorcycle due to lower maintenance costs. Furthermore, a reduction in electricity tariffs can further accelerate the economic viability of the converted motorcycle.

In conclusion, while the converted electric motorcycle demonstrates potential for improved performance and environmental benefits, addressing the power transmission inefficiencies is crucial for optimizing its overall efficiency and competitiveness.

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