DESIGN AND IMPLEMENTATION OF A FRONT-WHEEL HYBRID DRIVE SYSTEM FOR MOTORCYCLES USING AN ELECTRIC MOTOR

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ABSTRACT:

This study presents the design, fabrication, and integration of an electric motor mounted on the front wheel of a SYM Attila motorcycle, followed by successful road testing. The modified vehicle demonstrated stable operation and enhanced acceleration relative to the original model, attributable to electric motor assistance under increased load conditions, particularly in urban traffic environments. The results indicate a high level of technical feasibility, with fuel consumption reduced by 13.2% per 100 km compared to conventional gasoline operation. At the same time, the hybrid configuration preserves extended driving range through the combined use of dual energy sources.

Keywords: SYM Attila, hybrid drive, hybrid motorcycle, environmental pollution.

1. Introduction

The global motorcycle industry is shifting strongly toward clean technology solutions that are energy-efficient and environmentally friendly. In Vietnam, motorcycles still account for a large proportion of total vehicles, playing an essential role in daily life and the economy. However, most current motorcycles primarily use internal combustion engines (ICE), which consume significant fuel and emit harmful exhaust gases affecting human health. Currently, there are almost no widely commercialized hybrid scooter models in the Vietnamese market. Researching and developing an integrated drive system between a traditional ICE and an electric motor not only reduces fuel consumption but also significantly cuts emissions, contributing to solving global challenges regarding air pollution and climate change. Therefore, researching a hybrid drive solution installed on the front wheel of a SYM Attila motorcycle using an electric motor is a practical solution for fuel economy and environmental protection.

2. Research overview

Motorcycles are a popular means of transport suitable for Vietnam's infrastructure, with one of the highest usage rates in the world. As of September 2024, Vietnam had 77 million registered motorcycles. Consequently, this research is not only topical but also holds scientific value for technological innovation, aiming for an efficient, flexible control system adaptable to real operating conditions at a cost suitable for the domestic market.

Tran Van Dang et al. (2022) conducted a study titled "Research, design, and fabrication of a power distribution control unit for hybrid vehicles". The control unit was developed based on power distribution between different motor types and speed-range-based control strategies. The research successfully fabricated a control unit that operates stably under both dual-source and individual-source modes. Experimental results indicated that the emissions of the hybrid vehicle were significantly reduced compared to conventional internal combustion engine vehicles.

In studies Ha et al. (2021) and Banh & Tai (2023), the authors focused on "Integrating hybrid drive systems for motorcycles with an electric motor at the rear wheel," specifically developing a hybrid Wave Alpha model. Similarly, the "Solution for converting a SYM Attila motorcycle into a gasoline-electric hybrid" proposed a retrofit method by installing a rear-wheel electric drive system and designing a dedicated control circuit. The finalized product maintains an external appearance similar to the original vehicle, operates reliably, and reduces operational costs.

Vu Quang et al. (2022) researched and developed a power combination system for vehicles using a Continuously Variable Transmission (CVT). The study detailed control strategies for various operating conditions, integrated with simulations based on experimental parameters using AVL-Cruise software and the UDC cycle. The results showed a 74.9% reduction in fuel consumption for the hybrid vehicle compared to conventional models.

Asaei et al. (2013) designed a simplified model simulated with ADVISOR2002 and fabricated a physical prototype using a Brushless DC (BLDC) motor mounted on the front wheel and a conventional internal combustion engine driving the rear wheel. The system was managed by a Hybrid Electric Motorcycle (HEM) controller consisting of two independent control levels. Simulation results demonstrated improved performance, such as a 46% improvement in 0-60 km/h acceleration, and a reduction in hydrocarbon, carbon monoxide, and nitrogen oxide emissions by 22%, 22%, and 7%, respectively.

Kumar et al. (2023) focused on developing a mathematical model for a parallel hybrid electric bicycle. The system is supported by an Android-based platform, enabling users to intuitively monitor and manage vehicle usage cycles. The mathematical model of the drivetrain was developed and simulated using MATLAB/Simulink, allowing for detailed analysis of dynamic parameters such as torque, velocity, resistance, and power distribution between the two energy sources. In this study, a Proportional–Integral–Derivative (PID) controller was selected as the primary feedback control algorithm. Laboratory and real-world testing yielded positive results regarding required power, cycle speed, and travel distance based on gradient, proving suitable for mountainous terrain.

Most previous studies have focused on rear-wheel electric motor installations, simulations, and the development of mathematical models for hybrid vehicles. This paper focuses on a hybrid drive solution installed on the front wheel of a SYM Attila motorcycle using an electric motor. This approach offers practical significance, fuel efficiency, and a meaningful contribution to environmental protection.

3. Research methodology

3.1. Technical specifications of SYM Attila *(Table 1)*

Table 1. Motorcycle specifications SYM Attila

Content	Technical specifications
Engine Type	Gasoline, 4-stroke, 1-cylinder, air-cooled
Cylinder Capacity	124.6 cc
Maximum Power	6.5 kW at 7500 rpm
Maximum Torque	8.6 Nm at 6000 rpm
Transmission System	Continuously Variable Transmission (CVT), belt drive
Fuel Tank Capacity	5 liters
Wheel Size	Front: 90/90 – 10, Rear: 100/90 - 10
Dimensions (L x W x H)	1815 x 690 x 1080 mm
Curb Weight	115 kg
Battery	12V – 6Ah

3.2. Power transmission diagram

The hybrid solution involves independent power transmission: the front wheel is driven by an electric motor powered by an accumulator (Accu), while the rear wheel is driven by the original ICE. Both can operate simultaneously when dual power assistance is needed at low speeds or under heavy loads.

3.3. Electrical system circuit diagram *(Fig 2)*

3.3.1. Battery system (Accu)

The power supply system consists of four 6-DZF-12 (SUPER-15) 12V - 12Ah batteries connected in series to generate a total voltage of 48V - 12Ah. This power source is supplied to the BLDC controller to produce a three-phase current for driving the electric motor at the front wheel. Simultaneously, the power is passed through a step-down circuit (48V to 5V/12V) which is regulated to provide a 12V output to power the Arduino Mega 2560.

3.3.2. Three-phase brushless motor control unit and digital potentiometer

The brushless three-phase motor control unit and the X9C103S digital potentiometer serve as an interface between the central processing unit and the electric motor. Their primary function is to convert control signals from the Arduino Mega microcontroller into a three-phase current to drive and regulate the motor's operation. (Fig 3)

3.3.3. Central controller

The vehicle's central controller, with a power rating of 1000 W and a voltage range of 48-60 V, acts as the "brain" of the control system. It manages and coordinates the operation of the electric motor, battery (accumulator), and throttle. The central controller is typically designed to be compact and is housed in a heat-dissipating metal casing to protect it from environmental impacts and ensure durability during use.

When the throttle is applied, based on the rotational speed of the rear wheel captured by the

Fig 1. Power transmission diagram when an electric motor is installed

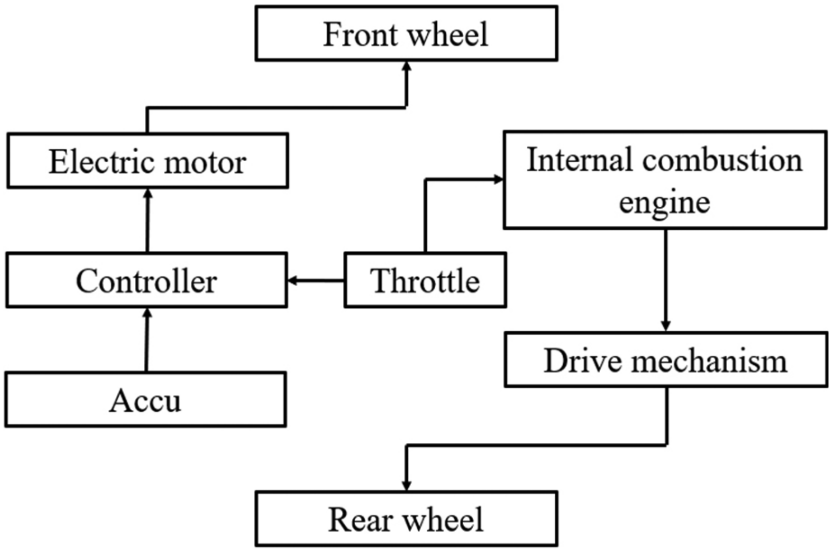


Fig 2. Electrical system circuit diagram

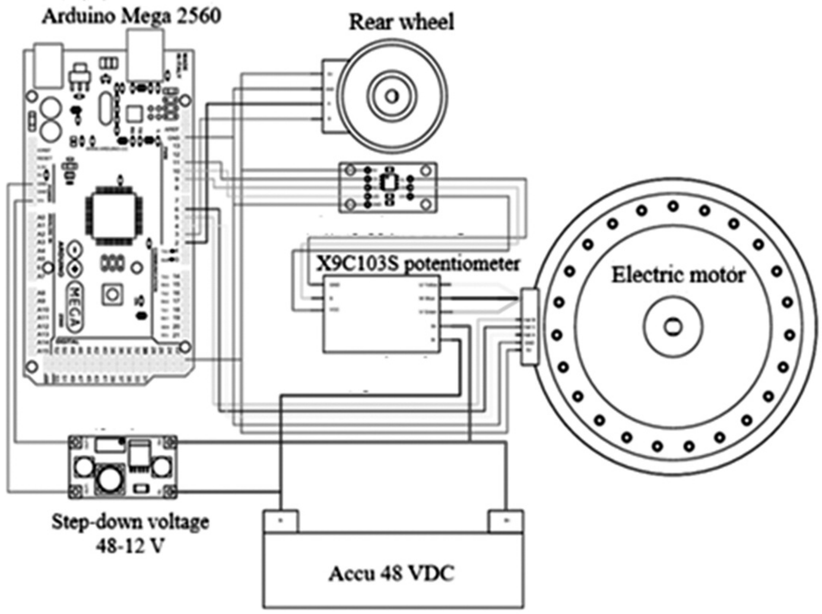
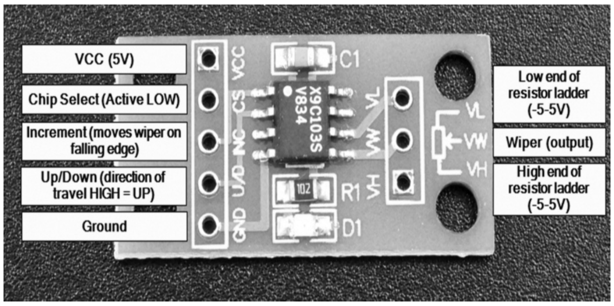


Fig 3. X9C103S potentiometer



Source: Magdy (2018)

encoder, the Arduino outputs pulse signals to the digital potentiometer. The resulting voltage signal from the digital potentiometer is then transmitted to the central controller. The central microprocessor processes this value and subsequently sends control commands to the power circuit to regulate the current supplied to the motor.

3.3.4. Front-wheel electric motor

The electric drive system is equipped with a 1000W hub motor integrated directly into the wheel. This configuration ensures smooth, quiet operation and higher energy efficiency compared to conventional brushless motors. (Table 2, Fig 4).

3.3.5. Installation of the signal unit (Encoder) at the rear wheel

The encoder is attached to the vehicle frame via a 4 mm thick steel connecting bar with pre-drilled bolt holes. The encoder mount is fabricated using 3D printing with PETG plastic to ensure mechanical durability and heat resistance. Additionally, it is designed with holes for bolting it securely to the connecting bar on the vehicle frame, as shown in Figure 5.

3.3.6. Retrofitting and Installation of the Control Box

The motor control circuit, power switches, and related components, as shown in Figure 6, are arranged within the front trunk of the vehicle. When the trunk is closed, the vehicle's original appearance remains unchanged.

3.3.7. Arduino IDE software installation

Download and install the Arduino IDE software → Write the control program → Select the Arduino Mega 2560 microcontroller board → Upload the program to the control circuit.

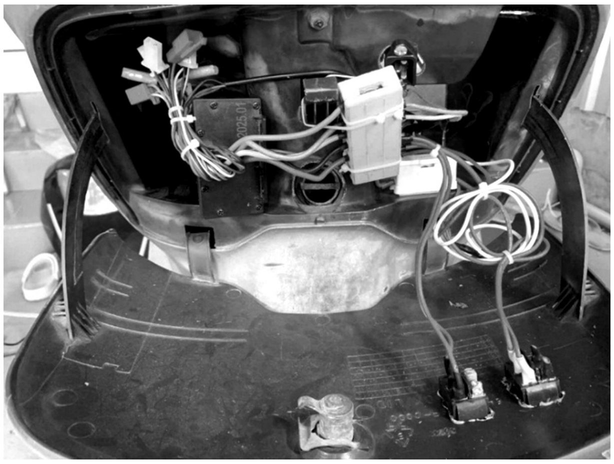
Table 2. Technical specifications of MZHL60-72V1000W30H

Item	Technical Specifications
Motor Type	Brushless Hub Motor (BLDC)
Rated Power	1000 W
Transmission Efficiency	85 – 90%
Design Speed	45 – 50 Km/h
Suitable Rim Size	10 – 12 inch
Operating Voltage	60 – 72 VDC

Fig 4. Electric motor installation location

Fig 5. Encoder installation location

Fig 6. Motor control circuit installation in the front trunk of the vehicle

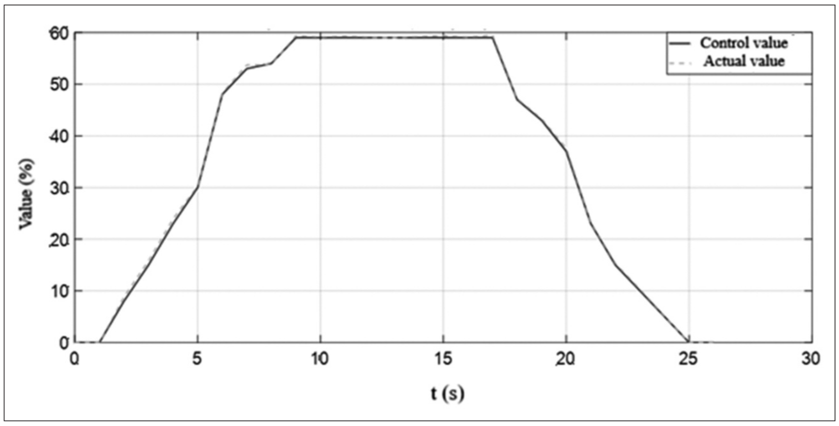


4. Results and discussion

4.1. Verification of digital potentiometer control signals

Figure 7 illustrates the correlation between the digital potentiometer's control input and the actual output value delivered to the motor control circuit. Prior to and following acceleration, when the encoder speed is zero, both the control and actual values of the digital potentiometer remain at zero, indicating a stable system free from signal interference or noise. During the acceleration phase, both values increase progressively and simultaneously. The maximum deviation observed between the control signal and the actual output is 0.5. These signal characteristics demonstrate that the controller operates stably with low error margins and high responsiveness.

Fig 7. Graph of control values versus actual values of the digital potentiometer



4.2. Road test in pure electric mode on flat terrain with a 65 kg load

The test results with the driver's payload on flat terrain showed high stability. The acceleration was steady and effective during the initial phase, with no jerking, which indicates that the drivetrain system functions well. With a travel distance of nearly 33 km on a single battery charge, the capacity is proven to be suitable for urban commuting and basic testing conditions. There were no signs of voltage drops or performance degradation, demonstrating that the battery operates stably under light load conditions. (Table 3).

4.3. Road test in pure electric mode on flat terrain with a 150 kg load

The test results under increased payload indicate that while the drivetrain is significantly affected, the vehicle operates stably throughout the journey with a consistent speed, making it suitable for practical urban commuting conditions. Completing a distance of 21.05 km in nearly 50 minutes demonstrates the efficiency of the drive system. Although the average and maximum speeds were lower than in the previous test due to the increased load, the vehicle maintained good overall performance. The battery provided a stable power supply without any voltage drops or interruptions, meeting the requirements for traveling under heavy load conditions. (Table 4).

4.4. Testing of Combined Electric Motor and Internal Combustion Engine (Hybrid Mode)

4.4.1. Single rider test on flat terrain

The vehicle was tested on a flat road with a single rider, resulting in a total gross weight of 196 kg (curb weight: 115 kg, rider: 65 kg, battery: 16 kg). The test results indicated that the vehicle operated stably; the electric motor could be heard rotating to provide assistive torque alongside the gasoline engine. At a constant speed of approximately 40 km/h, the vehicle remained highly stable, and its acceleration performance was significantly enhanced compared to the pure gasoline mode.

Table 3. Pure electric test results with a 65 kg load

Content	Results
Maximum speed	39 km/h
Travel distance (per full charge)	32.95 km
Acceleration	Smooth, no jerking

Table 4. 150 kg Load Test Parameters

Content	Technical Specifications
Distance	21.5 km
Payload	150 kg
Maximum speed	32 km/h
Travel time	49 minutes 37 seconds
Average speed	26 km/h
Time to reach 30 km/h	12 seconds

4.4.2. Two-rider test on flat terrain

When the payload was increased to two people, with a total gross weight of 261 kg (curb weight: 115 kg, two riders: 130 kg, battery: 16 kg), the vehicle maintained good stability on flat terrain. The sound of the assistive electric motor was more noticeable than in the single-rider case, indicating that the electrical system was working more intensively to compensate for the added load. At 40 km/h, the vehicle continued to run steadily, although the 0-40 km/h acceleration time was longer than with one person. Nevertheless, the acceleration capability still outperformed that of the pure gasoline version under identical load conditions.

Through testing under various load conditions on flat roads, the front-wheel assistive gasoline-electric hybrid system demonstrated several advantages over conventional gasoline motorcycles. The results show that the vehicle operates stably and maintains speeds between 25-40 km/h effectively. The acceleration is superior to pure gasoline vehicles thanks to the instantaneous torque support from the electric motor at low speeds and during load variations. Although fuel consumption gradually increases with payload and changing terrain, the hybrid vehicle consumed significantly less fuel than traditional gasoline motorcycles in all scenarios under the same operating conditions. Consequently, the power-assist hybrid technology has proven its technical and economic superiority, serving as a feasible solution for modern mobility needs that require both fuel economy and high operational performance.

5. Conclusion

The hybrid drive solution with a front-wheel electric motor does not alter the vehicle's fundamental structure. Installing the electric motor at the front wheel is straightforward, meets technical requirements, ensures stable operation, reduces fuel consumption, and contributes to environmental protection. This paper has presented the design, fabrication, and installation of the electric motor, battery integration, and control programming for the central unit, all of which were successfully road-tested. The vehicle exhibits stable performance and superior acceleration compared to the original model, particularly in urban environments, due to the electric motor's assistance during increased loads. These research results aim to enhance motorcycle efficiency, reducing fuel consumption by 13.2% per 100 km compared to pure gasoline operation, while maintaining long-distance range by combining two energy sources. This is a highly feasible solution for motorcycle drive systems as environmental regulations become stricter and traditional fuel sources deplete. However, further research, evaluations, and trials regarding different motor positions and optimized control programs are necessary to provide a more comprehensive assessment of hybrid drive solutions ■

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THIẾT KẾ, CHẾ TẠO VÀ TÍCH HỢP ĐỘNG CƠ ĐIỆN GẮN TRÊN BÁNH TRƯỚC CỦA XE MÁY XĂNG

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TÓM TẮT:

Nghiên cứu này được thực hiện nhằm thiết kế, chế tạo và tích hợp động cơ điện gắn trên bánh trước của xe máy thương hiệu SYM Attila. Các thử nghiệm có liên quan đến nghiên cứu này đã được vận hành, triển khai thành công trên thực tế. Phương tiện sau khi cải tiến cho thấy khả năng vận hành ổn định và gia tốc được cải thiện so với mẫu xe nguyên bản, nhờ sự hỗ trợ của động cơ điện trong các điều kiện tải tăng cao, đặc biệt trong môi trường giao thông đô thị. Kết quả nghiên cứu cho thấy tính khả thi kỹ thuật cao, với mức tiêu hao nhiên liệu giảm 13,2% trên mỗi 100 km so với vận hành thuần xăng. Đồng thời, cấu hình lai (hybrid) này giúp phương tiện có thể di chuyển xa hơn nhờ kết hợp hai nguồn năng lượng.

Từ khóa: SYM Attila, hệ thống truyền động hybrid, xe máy lai điện (hybrid), ô nhiễm môi trường.