A Study of Converting a Conventional Vehicle into an Electric Vehicle

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***Abstract*— Electric vehicles and hybrid electric vehicles are practical solutions to solve increasing global energy demand and environmental problems. The paper describes the design of an electric bus based on a conventional bus. According to the vehicle performance index, the parameters of the designed electric vehicle were calculated and configurated. The AVL CRUISE flatform was used to simulate and analyze the vehicle performance based on the New European Driving Cycle and Japan mode 1 Urban cycle. The simulation results reveal that the designed vehicle has good dynamic performance and economic performance.**

***Index Terms*— Electric Vehicle, Electric Motors, Parameters, Dynamic Performance, Simulation**

I. INTRODUCTION

In the development process, environmental pollution is always a challenge for countries. Therefore, governments have many policies to improve the environment. In particular, reducing emissions is one of the main goals. It is essential to reduce greenhouse gas emissions to less than 60% by 2050 to avoid future climate change and disasters. However, current sources of fossil fuels are meeting 85% of the world's energy needs [1]. The primary source of emissions is the means of transport, accounting for 39.2% of the total emissions [2]. Fully electric, hybrid, and fuel cell vehicles have been proposed to replace conventional ones to solve the environmental pollution problem [3]–[4]. For personal transportation, personal mobility vehicles have been proposed [5]–[8]. For public transportation, buses are a means of public transport that need to be developed to reduce the amount of traffic in the inner cities. Therefore, designing and developing a bus with high performance and low emissions is necessary.

In recent years, many scientists worldwide have conducted research on electric buses. Economically, Samuel Pelletier et al. have built an optimal economic model to convert a fleet of petrol buses to electric buses [9]. A similar study was also carried out by the author group Sanjaka G. Wirasingha [10] for the bus fleet in Chicago, USA. Energy management strategies on electric buses are also taken into account. Weiwei Xiong developed an energy management plan for hybrid-electric buses [11]. Hongwei Liu has investigated the control strategy of regenerative braking energy in [12]. Up to now, there has been no research on converting petrol buses into electric buses in Vietnam. The authors implemented a plan to renovate a conventional bus by replacing the internal combustion engine with an electric motor, power supply (battery), and other ancillary systems.

This paper presents the calculation and design of an electric vehicle based on the Thaco TB79CT Bus. The calculation and selection of an electric motor and power supply for the electric vehicle are implemented in detail. AVL CRUISE software was used to simulate and analyze the dynamics. The dynamic parameters of the electric vehicle are analyzed and compared with those of the original bus – Thaco TB79CT.

II. VEHICLE CONFIGURATION

The designed electric vehicle was configurated based on the Thaco TB79CT Bus, mainly used in large cities of Vietnam. Fig. 1 describes the overall dimension of the Thaco TB79CT Bus, and the vehicle specifications are shown in Table I.

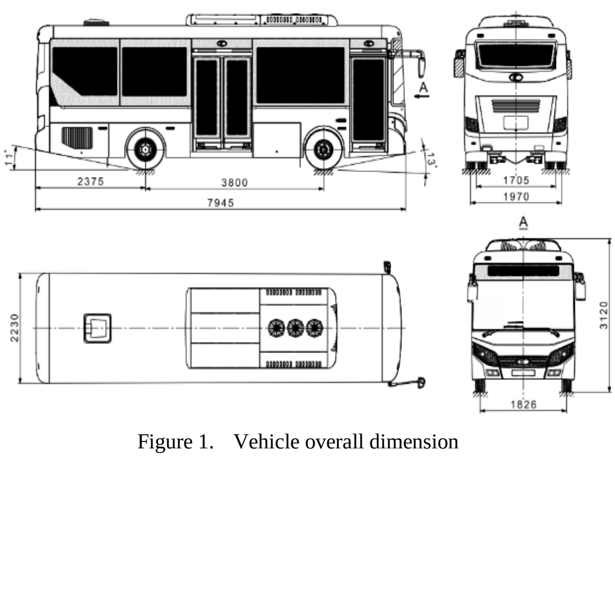

Figure 1. Vehicle overall dimension

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TABLE I. VEHICLE SPECIFICATIONS

Parameter	Value
Drive	4x2R
Overall dimension (length x width x high) (mm)	7945x2230x3120
Wheelbase (mm)	3800
Curb weight (kg)	6270
Gross weight (kg)	9000
Engine	Weichai, WP4.1NQ170E40
Peak power/ speed (Kw/ v/ph)	125/2600
Peak torque/ speed (Nm/ v/ph)	600/1300 –1900
Transmission	6DF60T, 6 forwards, 1 reverse I= 6.67, II=4.01, III= 2.42, IV=1.52, V=1, VI=0.78, R=6.13

The powertrain system of an electric vehicle mainly includes the battery, drive motor, clutch, gearbox, driveshaft, axles, and differential. Among them, the drive motor and battery are the key components of the vehicle. They replace the internal combustion engine of conventional vehicles. The drive motor is an electric motor, and the battery is made up of multiple lithium-ion cells. The power system of the designed electric vehicle in this study contains an electric motor, battery, mechanical driving device, and control system. For increasing the transmission efficiency, we omit the clutch and gearbox from the power system. The structure diagram of the power system is shown in Fig. 2.

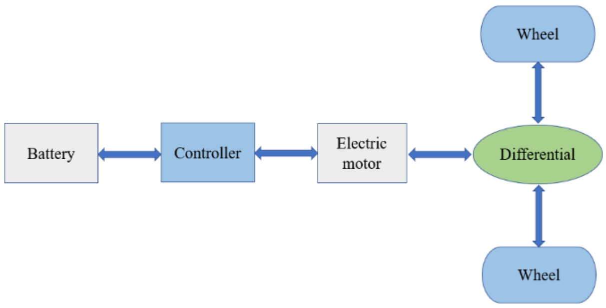

Figure 2. Electric vehicle configuration

Based on the operating conditions, the national technical regulation on safety and environmental protection for automobiles [13], the designed vehicle performance is required as in Table II.

TABLE II. REQUIRED VEHICLE PERFORMANCE

Parameter	Value
Maximum speed (km/h)	120
Maximum inclination (%)	≥ 20
Acceleration time (0 to 40 km/h) (s)	≤ 10
Acceleration time (0 to 200 m) (s)	≤ 23.6
Endurance mileage (km)	≥ 200

III. CALCULATION OF DRIVE MOTOR AND POWER SUPPLY FOR THE VEHICLE

A. Drive Motor

Selecting an electric motor with characteristics suitable for driving conditions helps the vehicle operate smoothly, save energy, and achieve high performance.

The characteristics of electric motors are shown in Fig. 3. At the low-speed area (less than the rated speed), the motor has a constant torque. In the high-speed area (higher than the rated speed), the motor has constant power. This characteristic is usually represented by a speed ratio x, defined as its maximum speed to its rated speed. In low-speed operations, the voltage supply to the motor increases with the increase of the speed through the electronic converter while the flux is kept constant. At the point of rated speed, the voltage reaches the source voltage. After the rated speed, the motor voltage is kept constant, and the flux is weakened, dropping hyperbolically with increasing speed. Therefore, its torque also drops hyperbolically with increasing speed [3]. Because the electric motors have high torque at the start, electric vehicles have high acceleration performance at low speeds, which is the advantage of electric motors compared to combustion engines. Therefore, an electric vehicle may not require a gearbox.

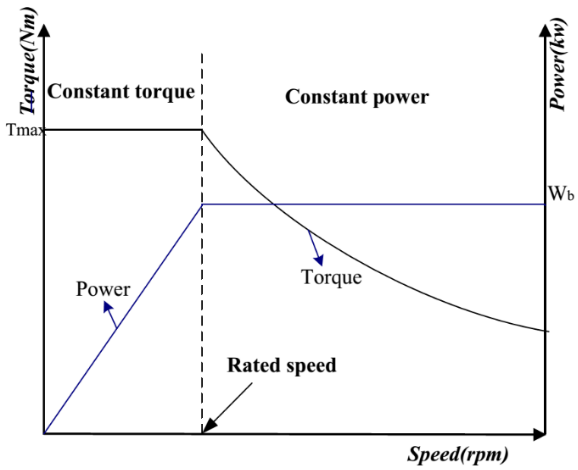

Figure 3. Electric motor characteristics

The selected electric motor must have power meeting the operating conditions of the vehicle. The peak power of the motor is generally determined by three driving conditions: maximum speed, acceleration from standstill to 40 km/h, and maximum gradient. Among those, the motor power is maximum when accelerating from standstill to 40 km/h and calculated as the following formulation:

$$\boldsymbol{P_{max}} = \frac{\delta m}{2 t_a \eta}\left(V_f^2 + V_b^2\right) + \frac{2}{3} mgV_f + \frac{1}{5}\rho C_d A V_f^3 \quad (1)$$

where:

δ: is rotating mass conversion coefficient (1.04 – 1.08), δ = 1,05.

V_b, V_f: rated speed and accelerating terminal velocity, V_b = 8.33 [m/s], V_f = 11.1 [m/s].

t_a: the accelerating time, t_a = 10 [s].

m: the vehicle mass, m = 9000 [kg].

ρ: the density of the air, $\rho = 1.125$ [kg/m³].
C_d: the drag coefficient, $C_d = 0.7$.
f: the coefficient of rolling resistance, f = 0.015.
A: the front area, A = 5.88 m².
η: the transmission efficiency, η = 0.9.
g: the gravity acceleration, g= 9.81 m/s²

Calculated P_{max} =113.59 N. The maximum power of the motor P_{max} must meet the condition $P_{emax} \geq \lambda P_{max} = 130.62$ N; where λ = 1.15 is the overload coefficient of the motor. The characteristics and specifications of the selected electric motor are shown in Fig. 4 and Table III.

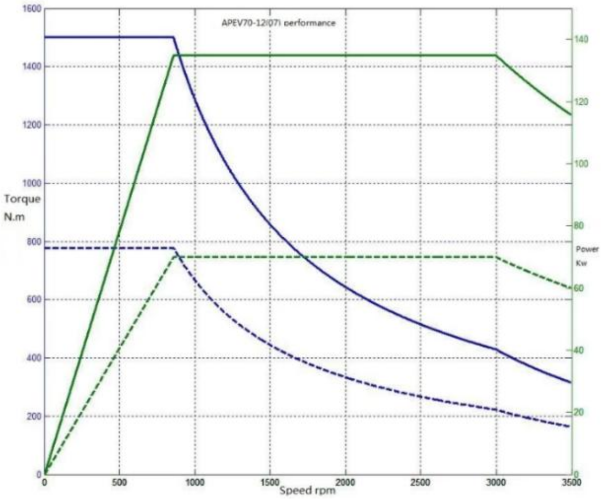

Figure 4. Drive motor characteristics of the electric vehicle

TABLE III. DRIVE MOTOR SPECIFICATIONS

Parameter	Symbol	Value
Type	-	PMSM
Rated voltage	U(V)	540
Rated current	I (A)	240
Peak current	I_{max}(A)	400
Rated power	P (KW)	70
Peak power	P_{max}(KW)	135
Rated speed	ω_b(rpm)	1200
Peak speed	ω_{max}(rpm)	3500
Rated torque	M_{max}(N.m)	780
Peak torque	M (N.m)	1500
Weight	m (kg)	160

B. Power Battery

The battery is one of the most important components of an electric vehicle. The selection of battery parameters must meet the demand of endurance mileage requirements and the maximum power of vehicle driving.

Lithium Iron Phosphate ($LiFePO_4$) is used in this research with nominal voltage U_c= 3.2 V, maximum continuous discharge current I_c= 15 A, and nominal capacity C_c = 5 Ah. A battery pack is made by connecting 176 cells in series. The supply voltage of the vehicle is U_{sup} = 563.2 V.

The electric vehicle is designed to drive in the inner cities with an endurance mileage of 200 km and an average speed of 27 km/h.

The required power of the electric motor:

$$P_{motor} = \frac{\left(\frac{1}{2}\rho A C_d v^2 + fmg\right).v}{\eta} = 12121 \text{ (W)} \tag{2}$$

The required capacity of power battery:

$$C = \left(\frac{P_{motor}}{\eta_1} + \frac{P_{load}}{\eta_2}\right)\frac{S}{U_{sup} V \xi_{soc}} \tag{3}$$

Where:
P_{load}: auxiliary system power, P_{load} = 5823 (W).
η_1, η_2: energy efficiency. $\eta_1 = 0.85$; $\eta_2 = 0.9$
ξ_{soc}: coefficient of state of charge. $\xi_{soc} = 0.8$
S: endurance mileage. S = 200 (km)
V: average speed. V= 27 (km/h)

The required battery capacity for the electric vehicle to drive in the above condition is 340.8 Ah.

By connecting 70 above packs in parallel, a power supply is made with a voltage of 563.2 V, a maximum continuous discharge current of 1050 A, and a capacity of 350 Ah.

IV. SIMULATION AND ANALYSIS OF VEHICLE PERFORMANCE

A. Modeling of Electric Vehicles

In this study, AVL CRUISE software is used to simulate and study vehicle performance. The powertrain of the electric vehicle includes the components retained from the original vehicle such as the differential, brakes, wheels, etc., and new components such as the electric motor, power battery, electrical loads. The model of the electric vehicle was built by creating modules connected by links, creating calculation tasks, and inputting required parameters. The calculation tasks include the driving cycle, full load acceleration, climbing performance. The model of the electric vehicle in AVL CRUISE is shown in Fig. 5.

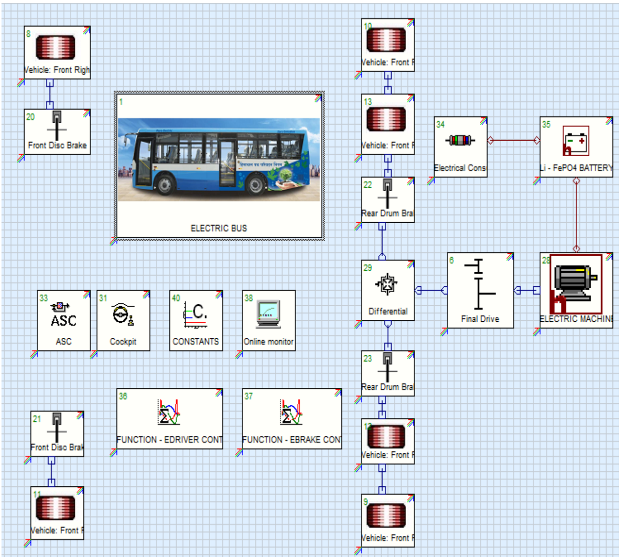

Figure 5. Model of electric vehicle in AVL CRUISE

B. Results and Discussion

1) Cycle run analysis

As electric vehicles are mainly driven on urban roads, NEDC (New European Driving Cycle) and the Japan mode 1 Urban cycle are used in this analysis, as shown in Fig. 6 and Fig. 7. The normal speed in NEDC is at 40-60 km/h, acceleration is at -1-1 m/s^2, the respective values of Japan mode 1 Urban cycle are 20-40 km/h and -0.5-0.5 m/s^2.

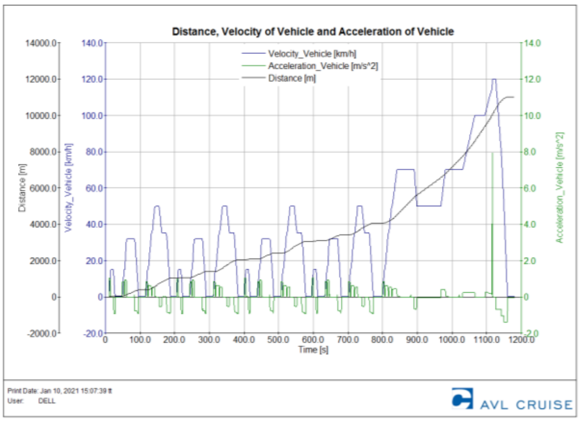

Figure 6. NEDC cycle

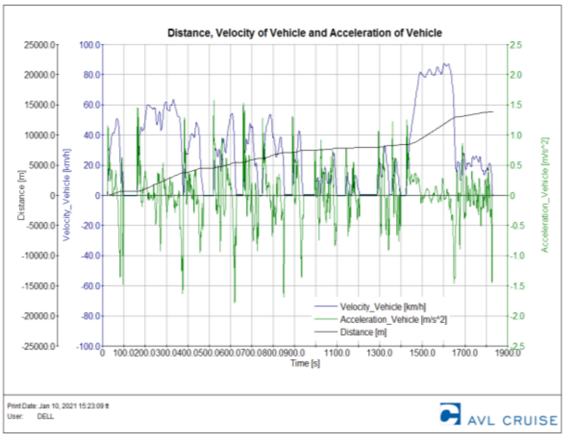

Figure 7. Japan mode 1 Urban cycle

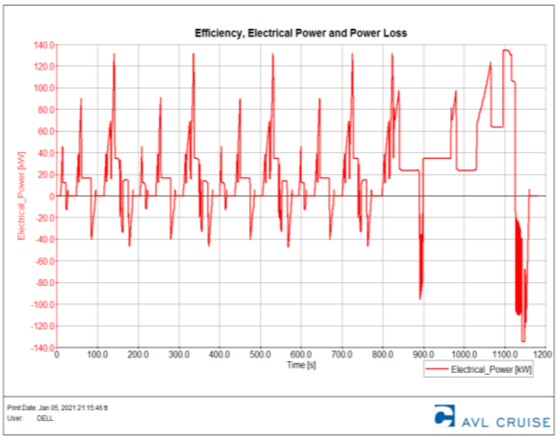

Figure 8. Electric power in NEDC cycle

The maximum output power of the electric motor in the NEDC cycle and Japan mode 1 Urban is 134.6 kW and 119.6 kW at 1096 s and 437 s, as shown in Fig. 8 and Fig. 9, respectively, no more than the peak power of the selected electric motor (135 kW). Therefore, the chosen electric motor ensures that the electric vehicle can operate in those cycles.

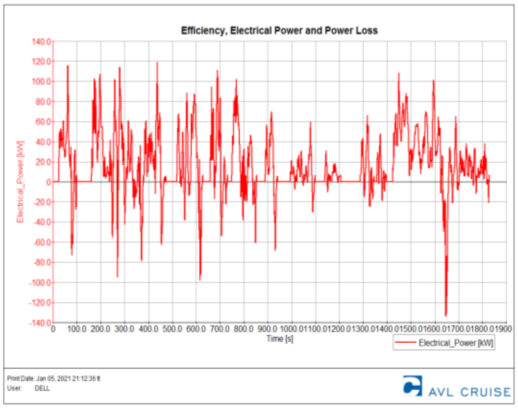

Figure 9. Electric power in Japan mode 1 Urban cycle

2) Acceleration and climbing performance analysis

Fig. 10 and Fig. 11 compare the maximum acceleration and climbing performance of the electric vehicle with the original vehicle in all gears.

At speeds from 4 km/h to 24 km/h, the acceleration and climbing performance of the original vehicle is greater than those of the electric vehicle in the 1st and 2nd gear due to the electric vehicle is not equipped with a gearbox. The maximum accelerations of the original and electric vehicle are 3.15 m/s^2 and 1.65 m/s^2, respectively; the climbing performance are 56 % and 21 %, respectively (greater than 20 %, meeting the requirement). Because the electric vehicle mainly operates in inner cities that do not require a great acceleration and climbing performance, the above acceleration and climbing performance of the electric vehicle are suitable for the operating conditions.

At speeds greater than 24 km/h, the electric vehicle has better acceleration and climbing performance than the original vehicle, which can help the electric vehicle has better driving performance than the conventional vehicle in 3rd to 6th gear.

Because the electric vehicle has no gearbox, the characteristic curves of the electric vehicle are very smooth, ensuring quiet operation, which is an advantage of the electric vehicle compared to the conventional vehicle.

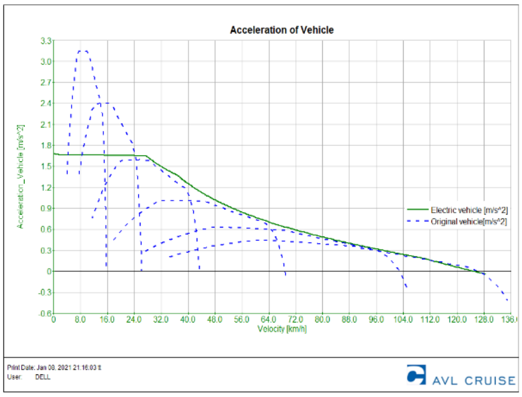

Figure 10. Vehicle acceleration curve.

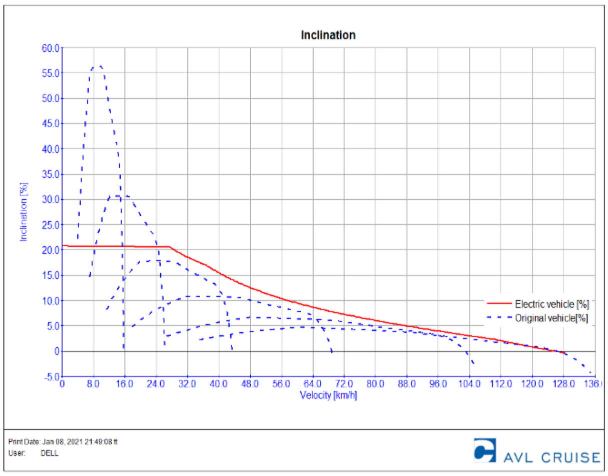

Figure 11. Vehicle climbing performance

3) Driving performance analysis

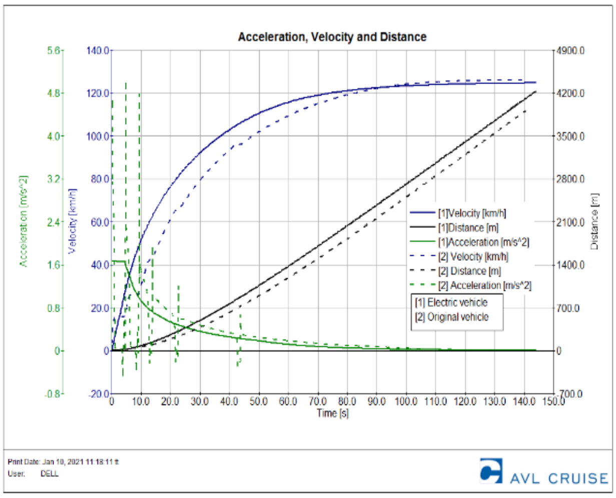

Figure 12. Driving performance from standstill to maximum velocity

The driving performance of the electric vehicle is better than the original vehicle in the speed range of 15–122 km/h. The acceleration time of the electric vehicle and the original vehicle from standstill to 100 km/h is 37.5 s and 48 s, respectively. The acceleration time of the electric vehicle and the original vehicle from 0 to 200 m is 20.7 s and 17.1 s, respectively, no more than 23.6, which meets the requirement.

4) Energy consumption analysis:

Because there is no estimate for endurance mileage in the simulation of AVL CRUISE software, the following method is used, including establishing driving cycle in AVL CRUISE with the vehicle constant velocity of 27 km/h and driving distance of 200 km, ignoring the impact of external factors and environment.

As shown in Fig. 13, battery SOC decreased with increasing mileage, the energy consumption is 106.9 kwh, and the remaining SOC is 23.7% (> 20%) in the driving cycle. Therefore, the electric vehicle meets the requirements for energy consumption.

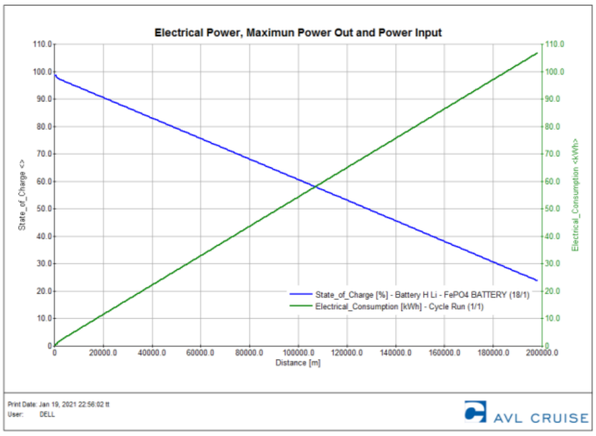

Figure 13. Consumption energy curve

V. Conclusion

The paper shows the study on the power system of electric vehicles and compares vehicle performance between electric and conventional vehicles by calculation and simulation using AVL CRUISE software. The designed electric vehicle has good dynamic performance and economic performance. The simulation results met the requirements with high precision. The result shows that the energy consumption in 200 kilometers is 106.9 kWh, and the remaining SOC is 23.7% when driving with an average speed of 27 km/h. The findings provide methods and references for manufacturers to develop the automobile power system. Further work will continue to research the regeneration system and charging station to improve energy consumption.

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Conflict of Interest

No potential conflict of interest was reported by the authors.

Author Contributions

Vo Trong Nam, Van Cong Tai, Huynh Duc Tri were in charge of conceptual generation, software, formal analysis, writing original draft preparation, and editing of the manuscript. Pham Quoc Thai is the corresponding author of this research work. He was in charge of the overall research direction and planning, validation, formal analysis, and the final editing of the manuscript.

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