A STUDY ON POWER TRAIN AND CONTROL SIMULATION OF A SERIES HYBRID ELECTRIC VEHICLE CONTROL BASED ON THE LIGHT - DUTY TRUCK

NGHIÊN CỨU HỆ ĐỘNG LỰC VÀ MÔ PHỎNG ĐIỀU KHIỂN HEV NỐI TIẾP TRÊN CƠ SỞ XE TẢI NHẸ

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Abstract - This study presents the development and simulation of a rule-based control strategy for a series Hybrid Electric Vehicle (HEV) based on the Kia Frontier K200 platform. The powertrain consists of an internal combustion engine, generator, electric motor, and lithium-ion battery pack modeled in the MATLAB/Simulink environment and evaluated under the WLTP Class 3 driving cycle. Simulation results show that the vehicle accurately follows the reference cycle with a mean absolute speed error of 0.5754 m/s. The engine-generator set operates steadily near 2000 rpm within the high-efficiency region, while the electric motor delivers a peak traction power of 78.26 kW. The battery state of charge increases from 0.4 to 0.65, demonstrating effective energy management. The proposed HEV achieves a fuel consumption of 5.14 L/100 km, corresponding to a 39.5% reduction compared with the conventional vehicle, confirming the feasibility of series HEV technology for light-duty trucks.

Key words - Hybrid Electric Vehicle (HEV); WLTP; State of Charge (SOC); Powertrain; Control Strategy; Simulation.

Tóm tắt – Nghiên cứu này trình bày quá trình phát triển và mô phỏng chiến lược điều khiển cho hệ động lực xe Hybrid Electric Vehicle (HEV) kiểu nối tiếp trên nền tảng Kia Frontier K200. Hệ động lực xe bao gồm động cơ đốt trong, máy phát điện, động cơ điện kéo và bộ pin lithium-ion, được mô hình hóa trong môi trường MATLAB/Simulink và đánh giá theo chu trình lái WLTP Class 3. Kết quả mô phỏng cho thấy, vận tốc xe bám sát chu trình tham chiếu với sai số tuyệt đối trung bình đạt 0,5754 m/s. Cụm động cơ–máy phát vận hành ổn định quanh 2000 vòng/phút trong vùng hiệu suất cao, trong khi động cơ điện cung cấp công suất kéo cực đại 78,26 kW. Trạng thái sạc của pin tăng từ 0,4 lên 0,65, cho thấy hiệu quả của chiến lược quản lý năng lượng. Hệ HEV đề xuất đạt mức tiêu thụ nhiên liệu 5,14 L/100 km, tương ứng giảm khoảng 39,5% so với xe truyền thống, qua đó khẳng định tính khả thi của công nghệ HEV kiểu nối tiếp đối với xe tải nhẹ.

Từ khóa – Xe điện hybrid (HEV); WLTP; Trạng thái sạc pin (SOC); Hệ động lực; Chiến lược điều khiển; Mô phỏng.

1. Introduction

In recent years, challenges associated with climate change, environmental pollution, and the depletion of fossil fuel resources have imposed significant pressures on the global transportation sector. To mitigate emissions and reduce fuel consumption, many countries and automotive manufacturers have intensified efforts toward the research and development of clean-energy vehicles, among which Hybrid Electric Vehicles (HEVs) represent a promising solution due to their capability to integrate internal combustion engines (ICEs) and electric motors for optimal performance [1].

Among various HEV architectures, the series hybrid configuration offers distinct advantages, particularly the ability to maintain the ICE operation within its high-efficiency region, thereby improving fuel economy and lowering exhaust emissions. Moreover, the series configuration exhibits a simpler mechanical structure compared to parallel or power-split architectures. However, effective energy management in a series HEV requires coordinated control and optimization among key subsystems, including the engine, generator, battery pack, and electric motor [2].

Previous research has primarily focused on existing commercial hybrid vehicles, with domestic studies in Vietnam concentrating mainly on powertrain design for motorcycles and passenger cars, often emphasizing parallel or power-split hybrid architectures [3-7]. Research on series HEV powertrain systems for light commercial vehicles, particularly light-duty trucks, remains limited. This represents a research gap that needs to be addressed to support the development and localization of HEV technologies across different vehicle categories (e.g., buses, trucks, and specialized vehicles). Bridging this gap would provide a scientific foundation for both the design of new hybrid vehicle models and the conversion of conventional vehicles to hybrid operation.

The present study develops a simulation model of a series-hybrid powertrain system based on the KIA Frontier K200 light truck platform - a vehicle widely used for urban and suburban goods transportation in Vietnam. The integration of hybrid technology into this vehicle class is expected to yield significant improvements in fuel efficiency and reductions in environmental impact [3-4].

The main objectives of this study are to (1) develop a simulation model of the proposed series HEV powertrain,

(2) design a suitable energy management strategy, (3) evaluate the system performance under representative driving conditions and (4) in particular, evaluating the State of Charge (SOC) of the battery system, the battery charging and discharging phases, and comparing the fuel consumption between the baseline Kia Frontier K200 currently in operation and the K200 HEV under simulation based on the WLTP Class 3 driving cycle. The findings are anticipated to serve as a technical basis for future research and development of hybrid powertrain systems for small commercial vehicles in Vietnam.

2. HEV powertrain system

Based on the powertrain diagram of the Kia Frontier K200 model [8] and the serial HEV vehicle architecture [9-10], the Hybrid vehicle powertrain based on the Kia Frontier K200 (abbreviated as K200 HEV) is shown in Figure 1.

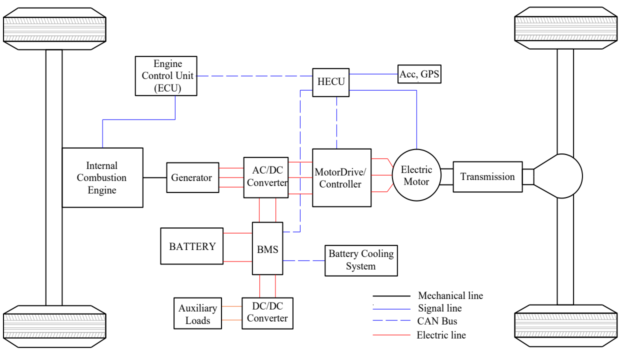

Figure 1. *Overview diagram of HEV series*

The K200 HEV powertrain has four main operating modes:

- *Battery-powered start-up and run mode*: energy from the battery supplies the electric motor to drive the rear axle of the vehicle; the ICE does not operate.

- *Long-distance running mode combined with battery charging:* the battery energy level is low below SOCmin, the ICE operates part of the energy to rotate the generator to charge the battery, and part of the energy to rotate the electric motor.

- *Regeneration mode:* the vehicle decelerates, the electric motor changes its function to a generator (converting mechanical energy from the vehicle's inertial force into electrical energy) to charge the battery.

- *Charging mode at stop position:* the electric motor stops working, the ICE works to rotate the generator and charge the battery.

3. Theoretical Background of the Control Strategy and Algorithm

3.1. Main Component Models

3.1.1. Vehicle dynamics model

The general kinematic diagram of the light-duty truck is presented in Figure 2.

According to Newton's second law:

$$\Sigma F_x = m.a = m.\frac{dV}{dt} \quad (1)$$

Longitudinal dynamic equation of the vehicle body:

$$P_k - (P_f + P_w + P_i) = m\frac{dV}{dt} \quad (2)$$

- The rolling resistance force:

$$P_f = f_v.G$$

where: f_v is the rolling resistance coefficient.

G is the gross vehicle weight.

- The aerodynamic drag force is calculated as follows:

$$P_w = K.S.V^2$$

where: K is the aerodynamic drag coefficient.

S is the frontal area of the vehicle.

V is vehicle speed.

- The grade resistance force is calculated as follows:

$$P_i = G.\sin\alpha$$

where: α is the road slope angle.

Applying Newton's second law to the combined wheel and vehicle body system, the vehicle dynamic equation can be expressed as follows:

$$\begin{cases} J\frac{d\Omega}{dt} = T_w - r_{bx}.P_k \\ m\frac{dV}{dt} = P_k - (P_f + P_w + P_i) \end{cases} \quad (3)$$

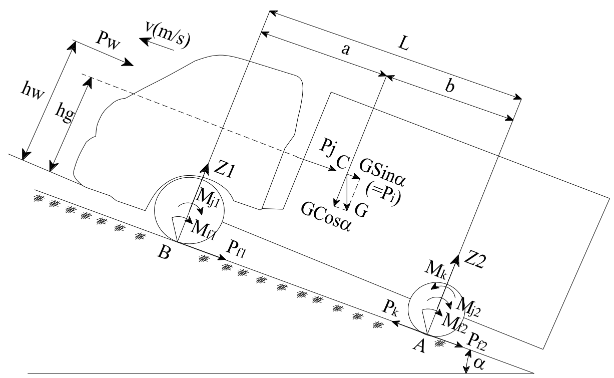

Figure 2. *Vehicle model on an inclined plane [11]*

3.1.2. Electric motor and transmission system model

The electric motor transmits torque to the drive wheels through a two-speed gearbox and a rear differential, generating the tractive force at the tire–road interface.

$$P_K = \frac{9550.P_m.i_T.i_{dif}.\mu_T.\mu_{dif}}{n_m.r_w} = \frac{T_m.i_T.i_{dif}.\mu_T.\mu_{dif}}{r_w} \quad (4)$$

$$P_m = \frac{n_m.T_m}{9550} \quad (5)$$

where: P_m is the power of the electric motor (kW);

T_m is the torque of the electric motor (N.m);

i_T is the ratio of transmission.

i_{dif} is the ratio of differential.

μ_T is gearbox efficiency;

μ_{dif} is differential efficiency;

n_m is the electric motor rotational speed (rpm);

r_w is the wheel radius (m).

Torque at the wheels:

$$T_w = T_m.i_t.i_{dif}.\mu_T.\mu_{dif} \quad (6)$$

Torque of the electric motor:

$$T_m = \frac{9550.P_m}{n_m} = \frac{T_w}{i_t.i_{dif}.\mu_T.\mu_{dif}} \quad (7)$$

3.1.3. ICE and Generator model

$$T_{e/g} = \frac{9550.P_{e/g}}{n_{e/g}} \quad (8)$$

where: $T_{e/g}$ is the torque of the engine/generator (N.m);

$P_{e/g}$ is the power of the engine/generator (kW);

$n_{e/g}$ is the electric motor rotational speed (rpm).

3.1.4. Battery model

During the simulation of hybrid vehicle dynamics, it is necessary to develop a battery model to evaluate the output voltage as a function of the battery state of charge (SOC) [12].

Formula for calculating the SOC [13]:

$$SOC(t) = SOC_0 - \frac{1}{Q_{nom}} \mu \int_0^t I(t)dt \quad (9)$$

where: SOC(t) is the state of charge of the battery at time t;

SOC_0 is the initial state of charge of the battery at $t = 0$;

Q_{nom} is the nominal battery capacity (Ah);

I(t) is the battery current at time τ;

μ is the Coulombic efficiency of the battery.

The energy changes in the PPS can be expressed as [13]:

$$\Delta E = \int_0^T P_{pps} dt \quad (10)$$

where: Ppps is the power of the PPS (kW);

The whole energy capacity of the peaking power source can be calculated using the following equation [13-14]:

$$E_{Cap} = \frac{\Delta E_{max}}{SOC_{top} - SOC_{bott}} \quad (11)$$

The battery charge at time t is calculated as follows:

$$Q_{ch}(t) = Q_{ch}(0) - \int_0^t I(t)dt \quad (12)$$

where: $Q_{ch}(t)$ is the remaining battery charge at time t;

$Q_{ch}(0)$ is the initial battery charge at t = 0;

I(t) is the battery current at time t.

- Static battery model [12]:

Using the charge and discharge characteristic curves provided by the manufacturer and the values at different temperatures, the static equation of the battery is described as follows:

$$V_{batt}(SOC, t_{batt}) = V_{0c}(SOC, t_{batt}) - R_{batt}(SOC, t_{batt}).i_{batt}$$

- Dynamic battery model [12]:

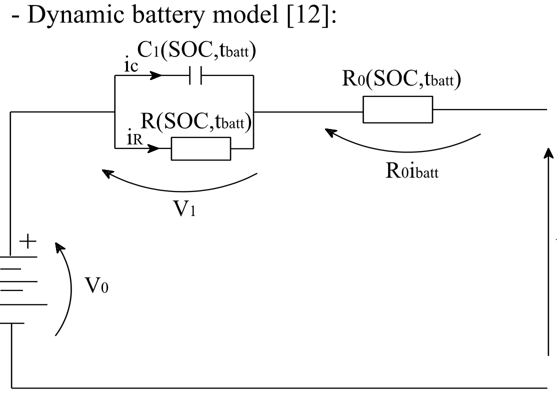

***Figure 3.** Dynamic Battery Model*

During operation, the battery experiences variations in the battery current ibat. The static battery model is not sufficient to investigate all operating conditions. The schematic of the dynamic battery model is shown in Figure 3.

Applying Kirchhoff's voltage law to the circuit:

$$V_{batt} = V_{oc}(SOC) - V_1 - R_0 i_{batt}$$

3.2. Control strategy

The control strategy is defined as a set of predefined control rules embedded in the vehicle control unit to manage the operation of individual components. The vehicle controller receives driver commands and feedback signals from the powertrain and associated subsystems, processes these inputs, and subsequently determines the appropriate operating mode.

In practice, several control strategies can be applied to the vehicle powertrain to meet different requirements and objectives. In this study, two typical control strategies are introduced: (1) the Maximum State of Charge of the Peak Power Source (Max. SOC of PPS) and (2) the engine on–off strategy [13-16].

3.2.1. Max. SOC-of-PPS Control Strategy

The target of this control strategy is to meet the power demand commanded by the driver and, at the same time, maintain the SOC of the PPS at its high level. This control strategy is considered to be the proper design for vehicles for which the performance relies heavily on the peak power source. This includes vehicles with frequent stop–and–go driving patterns, and military vehicles for which carrying out their mission is the most important. A high SOC level will guarantee the high performance of the vehicles at any time [13].

The Max. SOC-of-PPS control strategy is depicted in Figure 4, in which points A, B, C, and D represent the power demands that the driver commands in either traction mode or braking mode. Point D represents the commanded braking power that is less than the maximum braking power that the motor can produce. In this case, only regenerative braking is used [13].

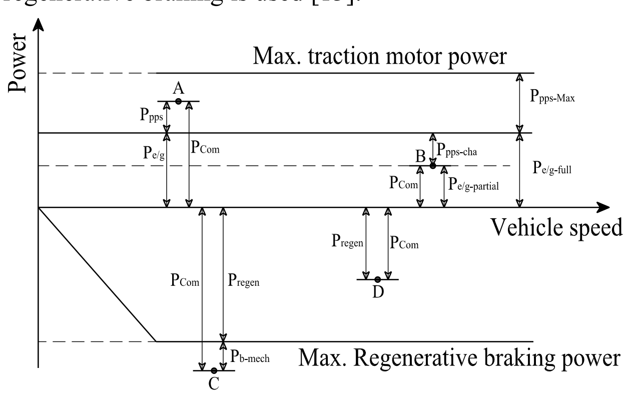

***Figure 4.** The Max. SOC-of-PPS control strategy*

P_{com}: Commanded power; P_{pps}: Power of the peaking power source; $P_{e/g}$: Power of engine/ generator; $P_{pps\text{-}cha}$: PPS charging power; P_{regen}: Regenerative braking power; $P_{b\text{-}mech}$: Mechanical braking power

A - Hybrid traction mode

$$P_{com} = P_{ppg} + P_{e/g}$$

B - Engine/generator-alone traction mode or PPS charging mode

$P_{com} = P_{e/g}$

C - Hybrid braking mode

$P_{com} = P_{regen} + P_{b\text{-}mech}$

D - Regenerative braking mode

$P_{com} = P_{regen}$

3.2.2. Thermostat Control Strategy (Engine-On–Off).

The operation of the engine/generator is completely controlled by the SOC of the PPS. When the SOC of the PPS reaches its preset top line, the engine/generator is turned off, and the vehicle is propelled only by the PPS. On the other hand, when the SOC of the PPS reaches its bottom line, the engine/generator is turned on. The PPS gets its power from the engine/generator. In this way, the engine can always be operated within its optimal deficiency region. This control strategy is illustrated in Figure [13-16].

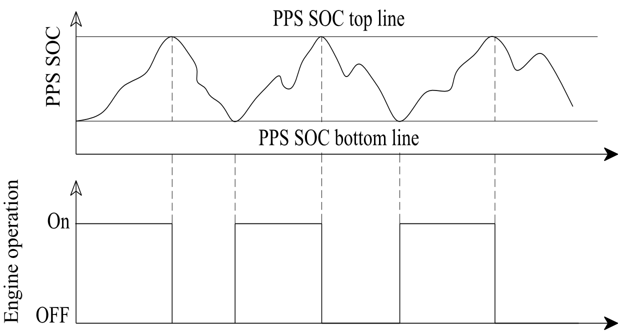

Figure 5. *Thermostat Control Strategy (Engine-On–Off)*

3.2.3. Rule-based power management strategy

The control strategy for a series HEV is straightforward, running the Engine/generator at its most fuel-efficient points or along the Optimal Operating Line (OOL) by controlling the throttle position and generator torque. The Engine/generator will be turned off when the predefined conditions are satisfied. In this work, two traditional rule-based control strategies are investigated [17].

a. Thermostat control strategy [17]

The Thermostat Control (TC) is a rule-based on/off strategy and runs the engine at its optimal operating point (OOP). The Engine/generator will be turned off ($S_{e/g}$=0) when the state of charge (SOC) reaches its upper threshold SOC_U, and turned on ($S_{e/g}$=1) when the SOC approaches its lower threshold SOC_L. The corresponding power distribution can be defined as:

$$P_{e/g}(t) = \begin{cases} 0 \text{ if } S_{e/g} = 0 \\ P_{OOP} \text{ if } S_{e/g} = 1 \end{cases}$$

$$P_B(t) = \begin{cases} 0 \text{ if } SOC(t) < SOC_L \\ P_{com}(t) - P_{e/g}(t) \text{ if } SOC_L \le SOC(t) \le SOC_U \\ P_{com}(t) \text{ if } SOC(t) > SOC_U \end{cases}$$

where, $P_{e/g}$, P_B, P_{OOP}, and P_{com} are the Engine/generator output power, the battery power, the Engine/generator power at the OOP, and the commanded power.

b. Power Follower Control Strategy [17]

For the Power Follower Control (PFC) strategy, the Engine/generator is designated as the primary power source to meet the power demand under almost all working conditions, in addition to the cases when the required power is low, and the SOC is greater than the upper SOC limit. The control logic of the Engine/generator is shown in Figure 6.

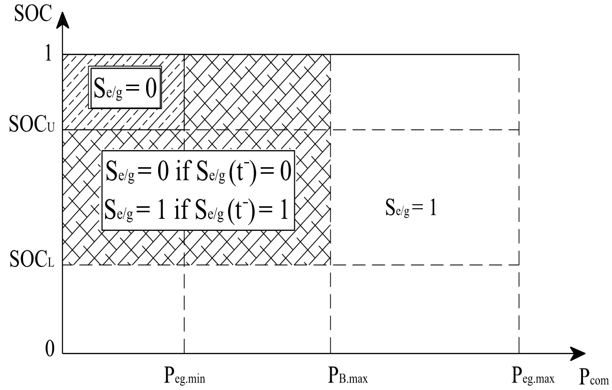

Figure 6. *Engine on/off map when using the PF strategy*

The output power is determined by the following:

$$P_{e/g}(t) = \begin{cases} P_{e/g.min} \text{ if } SOC(t) \ge SOC_U \\ P_m(t) \text{ if } SOC_L < SOC(t) < SOC_U \\ P_{e/g.max}(t) \text{ if } SOC(t) \le SOC_L \end{cases}$$

$$P_m(t) = P_{com}(t) + P_{ch}\left[\frac{SOC_U + SOC_L}{2} - SOC(t)\right]$$

$$P_B = \begin{cases} P_{com} \text{ if } S_{e/g} = 0 \\ P_{com} - P_{e/g} \text{ if } S_{e/g} = 1 \end{cases}$$

Where P_m – Target power of the ICE/generator in the normal SOC range; P_{ch} – Adjustment coefficient used to regulate the SOC toward its nominal (average) level.

Due to the reduction of battery usage, the PFC can extend the battery life and decrease the power losses during charging and discharging.

3.3. Control algorithm

After determining and selecting the main components of the hybrid powertrain system - namely the generator, electric motor, and battery pack - and establishing the overall control system architecture, the subsequent step involves the development of the control algorithm, as illustrated in Figure 7. This algorithmic framework constitutes the core of the system's coordination logic, governing the interaction among subsystems within the vehicle. It provides the foundation for implementing control strategies that ensure synchronized, stable, and energy-efficient operation of all components, thereby enhancing the overall performance and reliability of the hybrid powertrain system.

The algorithm can be divided into the following main parts: one loop for ICE mode, another loop for charging/discharging, and a third loop for energy regeneration. An ICE engine has two main operating modes: power mode, which is used when the power demand *P*req for the electric motors *P*em exceeds the power generated by the power supply combination between the ICE engine and the generator, and torque mode, which is used when the power generated exceeds the power demand, at which point the excess energy can be stored. In this mode, the optimal torque value T_0 is reached [18].

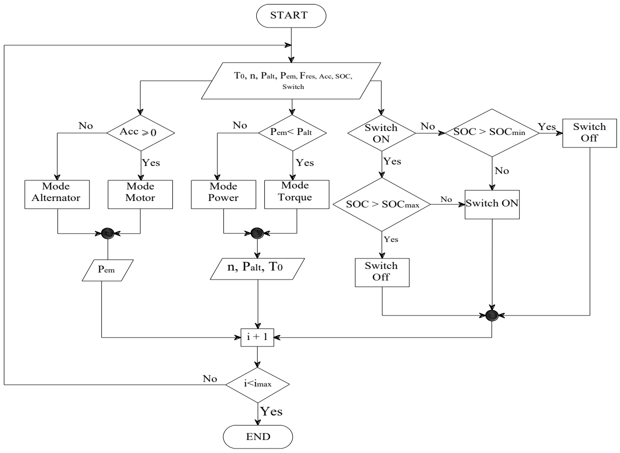

__Figure 7.__ Schematic diagram of the serial HEV vehicle control algorithm [18]

ACC – Acceleration; SOC- State of charge; T0: Optimal torque; n - Engine speed; Palt - Alternator power output; Pem - Motor power output; Fres - Traction

To maintain the system at its optimal point, the hybrid powertrain is managed based on the performance of the internal combustion engine. The power supply combination is controlled according to the state of charge (SOC) of the battery. When the charge level reaches 100%, the ICE engine switch is automatically turned off and is reactivated when the SOC drops below 30% [18].

Electric motors, like internal combustion engines (ICEs), have two modes: electric motor mode and generator mode. Typically, the electric motor operates as a propulsion until the braking phase, at which point it begins to recover braking energy. The charging mode can be used either with a main generator running or separately as a means of extending the vehicle's operation using electric power [18].

4. Simulation of HEV control system

4.1. Simulation model

The control system plays a particularly important role in hybrid vehicles, responsible for coordinating and commanding the vehicle components to operate synchronously and efficiently. Based on the calculation parameters, control diagrams, algorithm diagrams, and specific working conditions, the system model is built in the MATLAB Simulink environment. The simulation process follows the WLTP (Worldwide Harmonized Light Vehicle Test Procedure) type 3 standard cycle [19] for the K200 HEV truck model as shown in Figure 8.

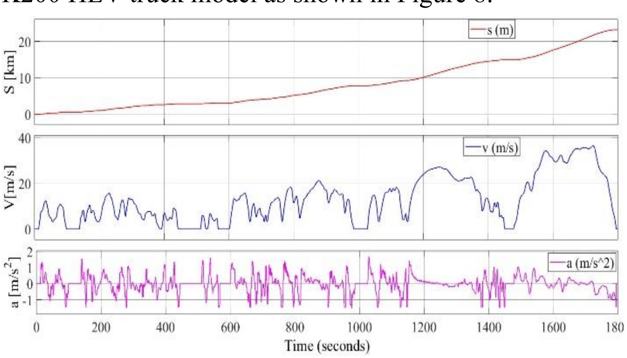

__Figure 8.__ WLTP simulation cycle – Type 3 [19]

In other words, the WLTP cycle effectively reproduces a wide range of vehicle operating conditions - from urban congestion to highway driving - providing a comprehensive basis for evaluating vehicle performance, energy consumption, and emission characteristics under representative driving scenarios.

4.2. Longitudinal Vehicle Dynamics Simulation

Based on the calculation results, the coefficients and parameters of the K200 HEV are presented in Table 1.

***Table 1.** Vehicle parameters*

Parameters and coefficients	Unit	Symbol	Value
Drag coefficient	Ns^2/m^4	K	0.6
Rolling resistance coefficient	-	fv	0.014
Frontal area	m^2	S	3.68
Air density	-	ρ	1.25
Transmission efficiency	-	μ_T	0.97
Differential efficiency	-	μ_{dif}	0.95
Acceleration due to gravity	m/s^2	g	9.81
Wheel radius	m	r_w	0.26
Ratio of transmission (High gear)	-	i_1	0.72
Ratio of transmission (Low gear)	-	i_2	4.54
Ratio of differential	-	i_{diff}	3.727
Vehicle mass	kg	m	4467
Wheelbase	m	L	2.615

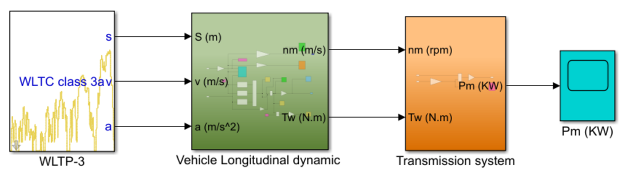

__Figure 9.__ Longitudinal Dynamics Simulation Model of the K200 HEV

MATLAB/Simulink is used to develop a simulation model of the longitudinal vehicle dynamics of the K200 HEV under the WLTP Class 3 driving cycle (as shown in Figures 10-15).

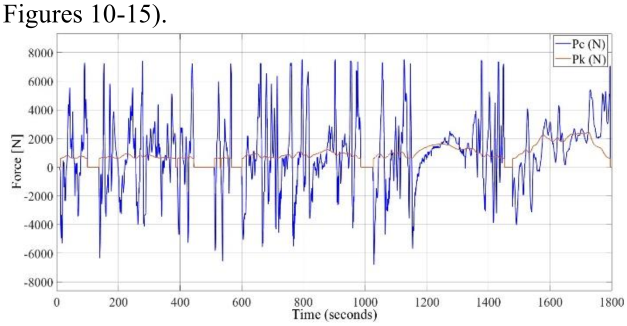

__Figure 10.__ Tractive force and resistance force graph of the vehicle

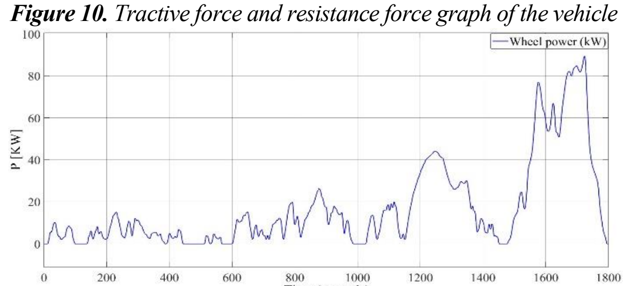

__Figure 11.__ Required power at the wheels diagram

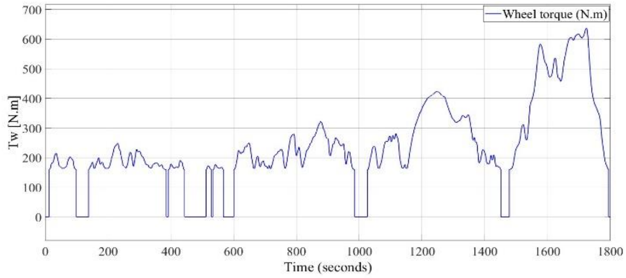

Figure 12. *Required torque at the wheels diagram*

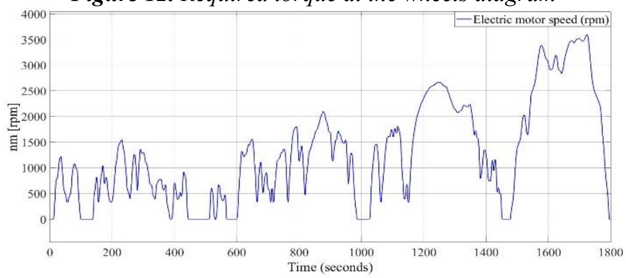

Figure 13. *Electric motor rotational speed diagram*

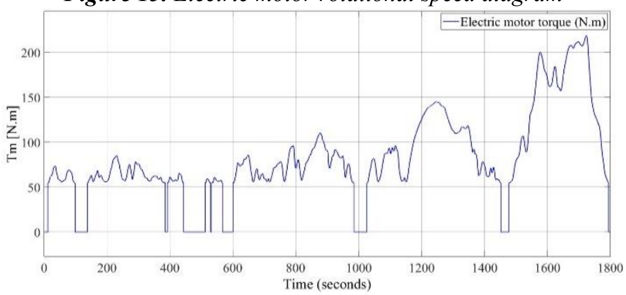

Figure 14. *Required electric motor torque diagram*

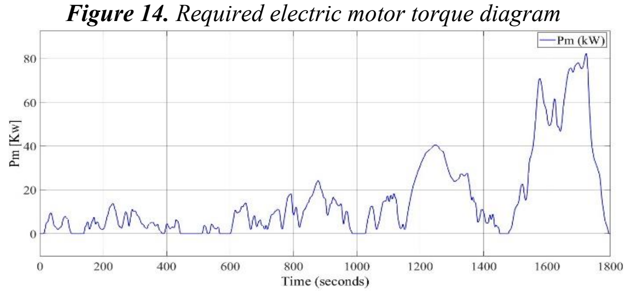

Figure 15. *Required electric motor power diagram*

Based on the simulation results, the following conclusions can be drawn:

- The simulation results indicate that the dynamic variables are consistent with the WLTP Class 3 driving cycle. The electric motor achieves a maximum power of 82.31 kW and a torque of 218.7 N.m at a vehicle speed of 131 km/h, while the maximum rotational speed of 3595 rpm remains within allowable limits. The maximum required power and torque at the wheels are 89.3 kW and 636.8 N.m, respectively, reflecting drivetrain losses.

- The tractive and resistive force analysis shows a maximum total resistance force of 7521 N and a maximum tractive force of 2449 N, following the acceleration and deceleration phases. Overall, the results confirm the validity of the proposed model and its applicability for further HEV control and energy efficiency studies.

4.3. Vehicle Powertrain Simulation

The current study used MATLAB Simulink software to build a simulation model for the K200 HEV vehicle transmission system in series, as shown in Figure 16.

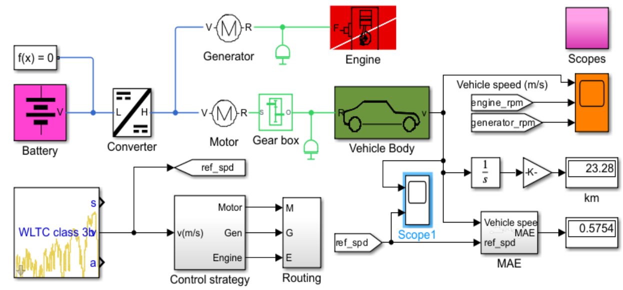

Figure 16. *Matlab model simulating K200 HEV series*

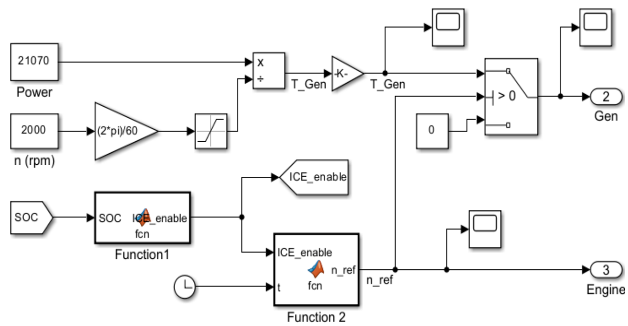

Figure 17. *Control strategy of the ICE and generator in the series K200 HEV model*

Based on the technical specifications of the Kia Frontier K200 base vehicle and the calculation and design results for converting the base vehicle into a series HEV, the parameters are presented in Table 2.

Table 2. *Parameters of the research vehicle and parameters of the power system*

Engine Hyundai D4CB-CRDi	
Specification	**Details**
Type	D4CB, 4-stroke Diesel, inline-4 (I4) engine
Maximum Power	96 kW/3800 rpm (130 Ps/ 3.800 rpm)
Engine displacement	2.497 cc
Maximum torque	255 N.m/ 1500~3500 rpm
Generator	
Maximum Power	50kW
Output voltage	220V ~ 400V
Rotational speed	2000 rpm
Electric motor	
Rated power / Peak power	55/80 kW
Rated torque / Peak torque	120/240 N.m
Rated current / Peak current	152/334 A
Voltage range	350-750 V
Battery system	
Battery type	Lithium-ion
Battery system capacity	49Ah
Battery system voltage	569.8 V
Maximum battery discharge current	147A
Efficiency	92%
Internal Resistance	0.05 Ohm
Optimal operating range of SOC	0.4-0.8

The parameters in Table 1 are applied to the simulation model, with the initial state of charge set to SOC_0 = 0.4 (In this operating mode, the ICE remains continuously on until the battery is fully charged; therefore, the fuel consumption is the highest among the operating modes of the series HEV. This condition serves as a reference for comparing the fuel consumption between the series HEV and the conventional Kia Frontier K200 vehicle, as well as for comparing the fuel consumption results obtained from simulation and experimental testing of the series HEV, and the initial generator power is selected to be equal to the average load power, calculated as 21.07 kW.

❖ **Results and discussion**

After entering the data and running the simulation according to the WLTP type 3 cycle with a simulation time of 1800 seconds, we obtained the following simulation results.

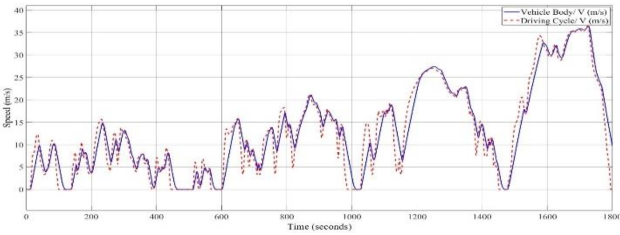

Figure 18. *Vehicle speed compared with the WLTP cycle speed*

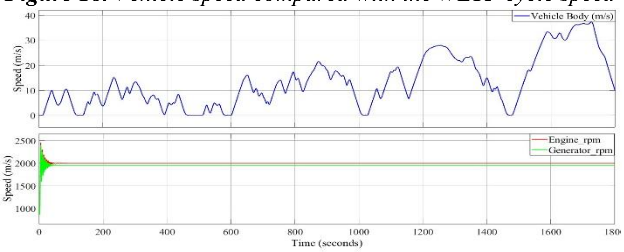

Figure 19. *Vehicle speed and ICE/ Generator, and vehicle body speed graph*

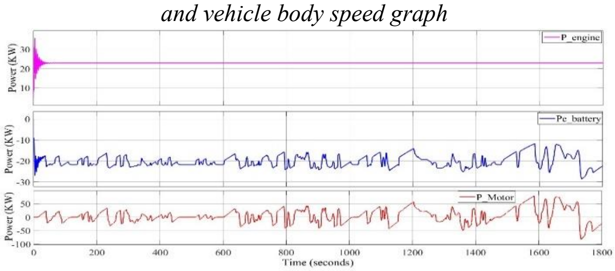

Figure 20. *Power of ICE, battery, and Motor charts*

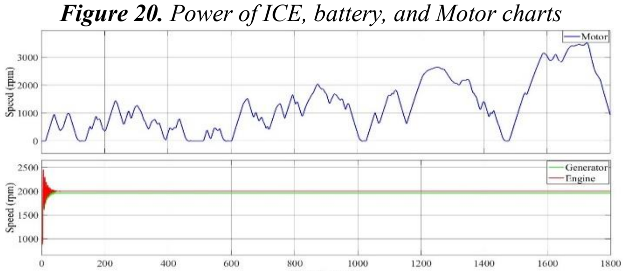

Figure 21. *Speed of electric motor, ICE/ Generator charts*

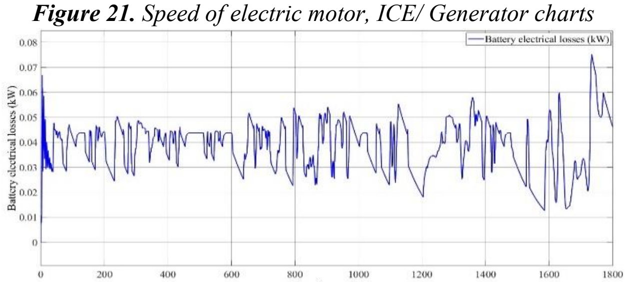

Figure 22. *Battery power loss graph (Power loss)*

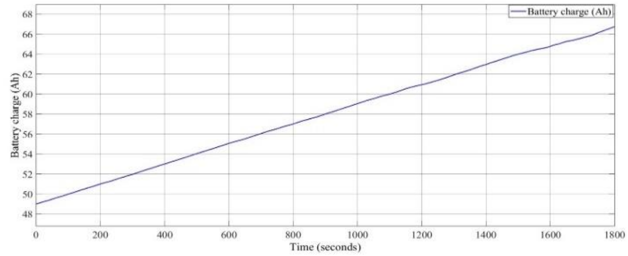

Figure 23. *Battery capacity chart*

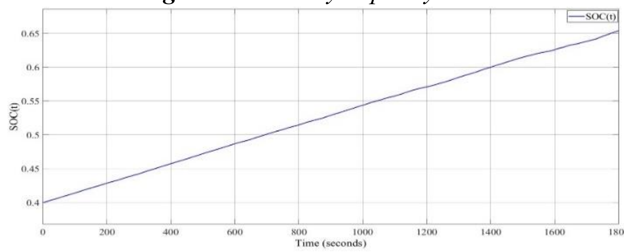

Figure 24. *State of Charge (SOC) profile*

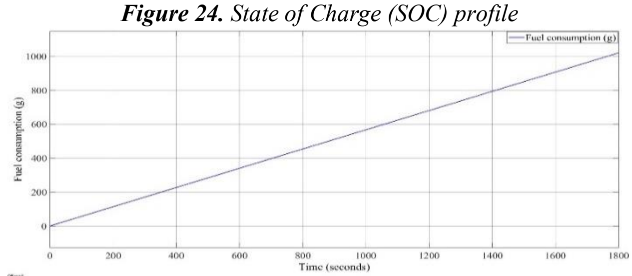

Figure 25. *Fuel consumption chart of ICE*

Based on the simulation results, several key observations can be made as follows:

The simulation results of the series hybrid powertrain based on the Kia Frontier K200 light truck, with an initial battery state of charge of SOC = 0.4, indicate that the model operates stably and follows the operating principles of a series hybrid system. Under the WLTP driving cycle with a simulation duration of 1800 s, the vehicle travels 23.28 km, and the simulated vehicle speed closely tracks the reference speed with an average error of MAE = 0.5754 m/s, confirming the reliability of the developed dynamic model.

The internal combustion engine (ICE) and generator rapidly reach steady-state operation and maintain a speed of approximately 2000 rpm, while the electric motor provides traction power with a maximum output of 78.26 kW. The ICE power is maintained around 22–23 kW, which is close to its optimal efficiency region and contributes to improved energy conversion efficiency. During operation, the battery balances the power demand, with the SOC increasing from 40% to about 65%, while the associated energy losses remain relatively small.

The results also indicate that the vehicle consumes approximately 1.23 L of diesel fuel over the 23.28 km driving cycle, corresponding to an average fuel consumption of about 5.14 L/100 km. Compared with the conventional Kia Frontier K200, which has a fuel consumption of approximately 8.5 L/100 km, the proposed series hybrid configuration reduces fuel consumption by about 39.5%. These results demonstrate the significant potential of hybridization for improving energy efficiency and reducing fuel consumption in light-duty trucks.

5. Conclusion

This study developed and evaluated a simulation model of a series Hybrid Electric Vehicle (HEV) powertrain based on the Kia Frontier K200 light-duty truck platform. The vehicle dynamic model, main component models (engine, generator, electric motor, and battery), and rule-based energy management strategies were implemented in the MATLAB/Simulink environment and tested under the WLTP Class 3 driving cycle.

The simulation results demonstrate that the developed model accurately reproduces vehicle operating behavior. The simulated vehicle speed closely follows the WLTP reference cycle with a mean absolute error of approximately 0.5754 m/s, indicating good dynamic performance and model reliability. During operation, the internal combustion engine and generator operate steadily around 2000 rpm within a relatively efficient operating region, while the electric motor provides the main traction power with a peak output of approximately 78 kW. The battery plays an important role in balancing power demand, with the state of charge increasing from 0.4 to about 0.65 during the driving cycle.

The results also show that the vehicle consumes approximately 1.23 L of diesel fuel over a distance of 23.28 km, corresponding to an average fuel consumption of about 5.14 L/100 km. Compared with the conventional Kia Frontier K200 vehicle (approximately 8.5 L/100 km), the proposed series HEV configuration can reduce fuel consumption by approximately 39.5%.

Overall, the simulation confirms the feasibility and effectiveness of applying series hybrid technology to light-duty trucks. The developed model and results can serve as a technical basis for further optimization of energy management strategies and future development of hybrid commercial vehicles in Vietnam.

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