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МОДЕЛИРОВАНИЕ СИЛОВОЙ УСТАНОВКИ ПОЛНОПРИВОДНОГО ЭЛЕКТРОМОБИЛЯ

THE POWERTRAIN MODELLING OF ALL-WHEEL DRIVE ELECTRIC VEHICLE

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Возрастающая популярность электромобилей (EVs) требует разработки сложных моделей симуляции для анализа их производительности и оптимизации их конструкции. В данной статье представлено моделирование силовой установки полноприводного (AWD) электромобиля, что позволяет проводить комплексные исследования работы электродвигателя, тяговой батареи и транспортного средства в целом. Предложенная модель может использоваться для анализа продольной динамики транспортного средства и потребляемой автомобилем энергии. Были представлены результаты моделирования процесса разгона автомобиля, на основе которых были даны рекомендации по использованию электромобилей с точки зрения энергоэффективности.

The increasing prevalence of electric vehicles (EVs) necessitates the development of sophisticated simulation models to analyze their performance and optimize their design. This paper presents the powertrain modeling of the All-Wheel Drive (AWD) EV, enabling comprehensive investigations of electric motors, traction battery operations, and vehicle motion in total. The proposed model can be used for analyzing vehicle longitudinal dynamic quantity and energy consumption. The simulation results on the acceleration process were shown, and based on it the rec-

ommendations about using electric vehicles in order of energy efficiency were given.

Ключевые слова: *электромобили, моделирование силовой установки, электродвигатель, модель батареи, потребление энергии.*

Keywords: *electric vehicles, powertrain modeling, electric motor, battery model, energy consumption.*

INTRODUCTION

Over the years, a plethora of scientific articles have addressed electric vehicle modeling, encompassing motor models, battery models, regenerative braking models, and vehicle dynamic models [1–3]. Konstantinos N. Genikomsakis and co-authors [1] propose a computationally efficient simulation model including the above models for EV energy consumption. It combines a physics-based vehicle model with EV component specifications to estimate battery power requirements from traction power. The model dynamically calculates energy recuperation and simulates motor overload under demanding driving conditions. Compared to FASTSim on a test EV, the model is lightweight and accurate. The corresponding percentage errors of the estimated final energy consumption for the driving cycles UDDS, HWFET, SFTP, and NEDC are 6,80 %, 0,98 %, 7,00 %, and 3,27 % respectively [2]. Further simulations with varied road gradients and driving cycles demonstrate the model's ability to capture real-world EV operation dynamics. This approach allows for fast computation of EV consumption factors suitable for route planning and integration with mobile routing applications for trip consumption assessment and energy-efficient route suggestion using real-time speed data. With the explosive growth of the electric vehicle revolution in the modern era, the research and development of propulsion engines for electric vehicles cannot be inevitable.

In this paper, the computer environment was created to construct a comprehensive powertrain model of the all-wheel drive EV, encompassing vehicle dynamics, traction battery, and electric motor models. Beyond these submodels for evaluating dynamic performance, a vital model for assessing EV energy optimization during operation is the battery. The acceleration process was chosen for the simulation scenario.

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The simplify powertrain model as in the fig. 1 was used in this study. This model included the gas pedal model, electric motor model, battery model and simplify vehicle model. The gas pedal model presented by the signal from -1 to 1, according to full brake and full acceleration.

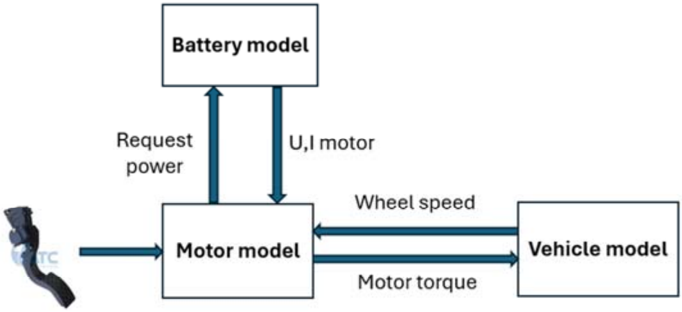

Figure 1 – EVs powertrain model

1. Electric Motor Model.

The electric motor of the electric vehicle is referred to as a «Permanent Magnet Synchronous Motor». The motor relates to the energy storage device and reversibly converts the supplied electrical power into torque and speeds at the output interfaces.

The motor used in the Vinfast VF8 reference electric vehicle has specifications [4] as shown in the table below.

Table 1 – Motors Specification of Vinfast VF8 ECO

Parameters of VF8 ECO Motors	Value	Unit
Motor Mass	2 x 90.6	Kg
Peak Power	2 x 130	kW
Peak Torque	2 x 250	Nm
Motor Max Speed	16000	Rpm
Peak Efficiency	97	%

The external characteristics curve of the electric motor is illustrated in the figure below:

The maximum torque (T_{max}) of the electric motor is a simple function of angular velocity. In most cases, when the angular velocity is small, the torque is maximum and remains constant. As the motor's angular velocity reaches a sufficiently large value (ω_c), the torque decreases. The torque decreases linearly as the speed increases, and the power remains nearly constant.

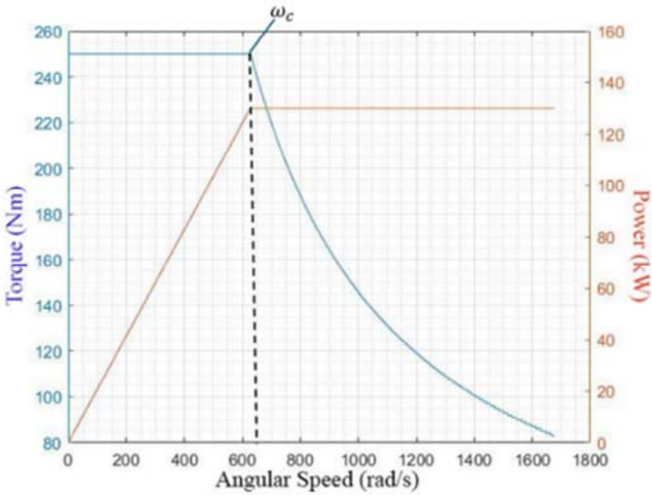

Figure 2 – Electric motor external characteristic curve

When the angular velocity of the motor rotor is smaller than the critical speed of conversion $\omega \leq \omega_c$ the motor torque reaches its maximum value.

When the angular velocity of the motor rotor is greater than the critical speed of conversion $\omega \geq \omega_c$, the motor torque is inversely proportional to the angular velocity of the rotor.

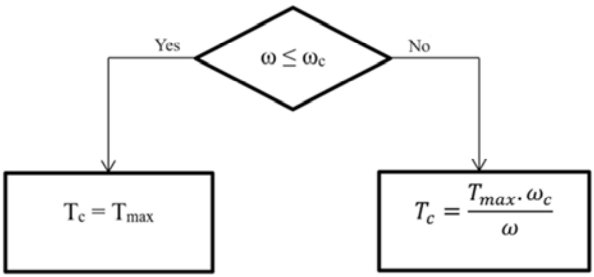

Figure 3 – Motor torque algorithm

2. Battery Model.

The computation model is based on power requirements to determine the output power of the battery over time. Modeling the internal chemical characteristics of the battery system will be conducted in the future. Based on the equivalent circuit model in fig. 4 and the technical parameters in tabl. 2, the equations for calculating the battery's output power as the sum of the power demand and the power loss due to internal resistance were created. Additionally, the battery model calculates the State of Charge (SOC), voltage, and current values to estimate energy consumption over time.

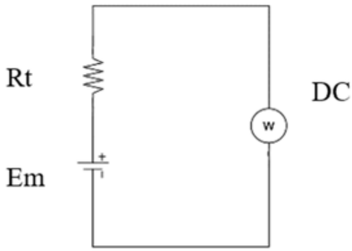

Figure 4 – Equivalent circuit diagram of the battery

Table 2 – Specifications of Vinfast VF8 Battery [4]

Parameters	Value
Type	Lithium Ion
Model	CATL Prismatic
Mass (kg)	540
Geometric parameter (mm)	2388 x 1511 x 135
Nominal battery capacity (kWh)	93,3
Effective battery capacity (kWh)	87,7
Rated voltage (VDC)	402,8
Capacity (Ah)	231,7

From the equivalent circuit model, the output power of the battery was given by formula (1):

$$P_a = P_{yc} + P_r \text{ ,} \qquad (1)$$

in which $P_a = U \cdot I$ is the power supplied by the batte at the output; U is the voltage between the two terminals of the battery; $P_r = R_t \cdot I^2$ is the power loss due to the internal resistance of the battery; R_t is the internal resistance of the battery; P_{yc} the power that the motor requires to be supplied.

Solving (1), the battery current is:

$$I_1 = \frac{1}{2} \cdot \left(\frac{U}{R_t} \pm \sqrt{\left(\frac{U}{R_t} \right)^2 - 4 \cdot \frac{P_{yc}}{R_t}} \right).$$

Another important parameter of a battery is the SOC. SOC is defined as the ratio of remaining capacity to fully charged capacity. The SOC of the battery can be expressed as

$$SOC_{(t)} = SOC_{(t_0)} - \frac{1}{C} \int_{t_0}^{t} I(t)\, dt \, ,$$

where: $SOC_{(t)}$ is the instantaneous SOC at time t; $SOC_{(t_0)}$ is the initial SOC of the battery; C is the battery capacity (Ah); *I(t)* is the instantaneous current intensity.

Based on the diagram, the voltage of the two terminals of the batter is calculated by the formula:

$$U - V_{in} = V_{out} \, ,$$

in which U is the voltage across the two terminals; V_{in} is the voltage drop across the internal resistance; V_{out} is the voltage drops across the motor.

The vehicle longitudinal dynamics in this study were used by the simplified model, which is described in the document [5].

RESULT AND DISCUSSION

The acceleration process was chosen for the simulation scenario: the gas pedal signal was created from 0 to 1 in various time stamps 1 s and 2 s for vehicle acceleration. The simulation results are shown in fig. 5–6, and table 3 below.

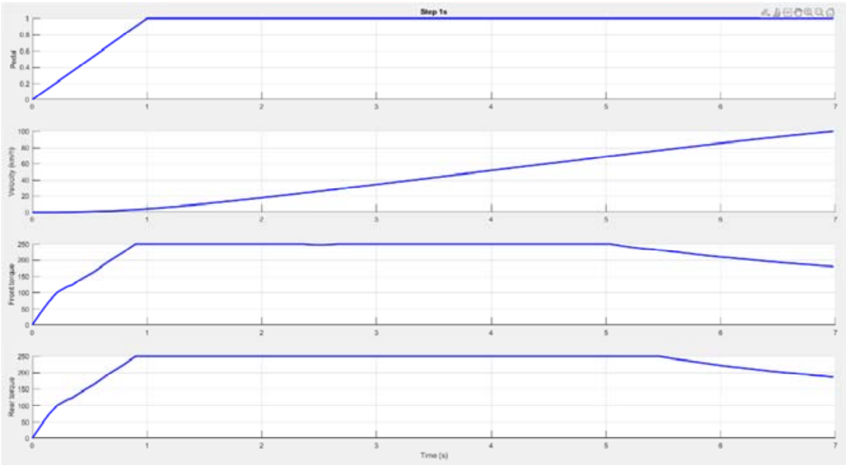

Figure 5 – Vehicle acceleration process when pressing the gas pedal by ramp 1 s

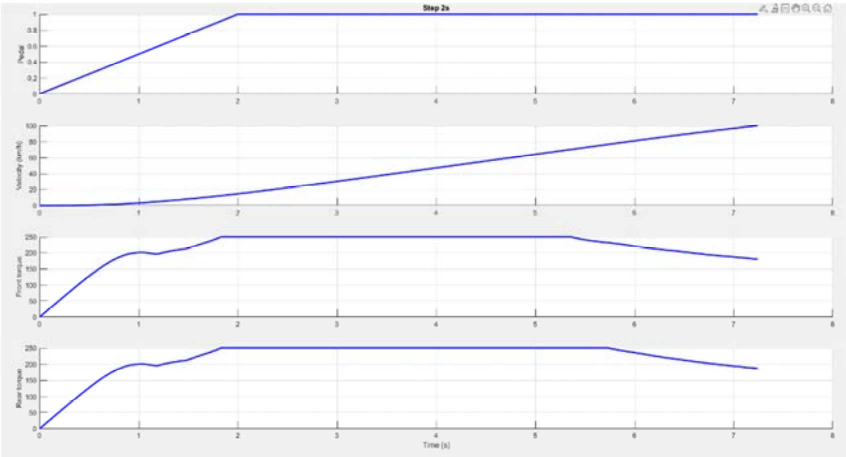

Figure 6 – Vehicle acceleration process when pressing the gas pedal by ramp 1 s

The simulation results show that the control gas pedal by ramp 1 s is better than ramp 2 s in vehicle acceleration characteristics (according to acceleration times 6,98 s and 7,24 s). These results follow the physical laws and show the accuracy of the proposed model. The control method by ramp 2 s, 3 s, 4 s are the same on energy consumption rate (according to energy consumption rate around 4,7 kWh/km). Based on simulation results, the fast control of the gas pedal is better to increase vehicle energy efficiency. This recommendation of using electric vehicles can help the driver get a better moving distance, but it was the opposite of the behavior of using traditional cars with combustion engines.

Table 3 – Simulation results of the Vehicle acceleration process

The gas pedal control method	Acceleration time (s)	Energy consumption rate (Wh/km)
Step 1 s	6,98	5660,32
Step 2 s	7,24	4724,62
Step 3 s	7,20	4717,69
Step 4 s	8,22	4670,27

CONCLUSION

The project presents a process and methodology for building a simulation model of EV powertrain, from gas pedal model to vehicle body models. The aim is to realize a pure electric vehicle powertrain model based on simulation software and obtain more accurate data results, which can be effectively used for the development and research of electric vehicles. A powertrain model of the VinFast VF8 car was successfully built. The simulation results on the acceleration process by ramp control method of gas pedal were given. Based on simulation results, the recommendation for fast gas pedal control of the acceleration process for the EV driver was presented in order to increase vehicle energy efficiency.

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ВЛИЯНИЕ ИЗМЕНЕНИЯ ДЛИНЫ ЗАДНЕГО КРЫЛА НА ДИНАМИКУ АВТОМОБИЛЯ

EFFECTS OF CHANGING REAR WING LENGTH
TO THE VEHICLE DYNAMICS

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В скоростных транспортных средствах аэродинамическая форма, передние и задние спойлеры, а также крыло создают дополнительные силы прижима для максимального увеличения тягового усилия. В данной статье представлены эффекты изменения длины заднего крыла на динамику автомобиля. Модель, использо-