УДК 629.03

РАСЧЕТ ЭНЕРГИИ РЕКУПЕРАТИВНОГО ТОРМОЖЕНИЯ ПРИ ДВИЖЕНИИ ЭЛЕКТРОМОБИЛЯ ПО ЕЗДОВЫМ ЦИКЛАМ С ИСПОЛЬЗОВАНИЕМ FASTSIM НА ПРИМЕРЕ Г. ХАНОЙ

CALCULATION OF REGENERATIVE BRAKING ENERGY DURING EV'S DRIVING CYCLES BY USING FASTSIM IN A CASE OF HANOI CITY

Ле Нуе Тай Минь, **Ле Ван Нгиа**, **Нгуен Тхань Тунг**,
Дам Хоанг Фук,
Группа «Автомобили», Институт Механики,
Университет Ханоя Техники и Науки, г. Ханой, Вьетнам
Le Hue Tai Minh, Le Van Nghia, Nguyen Thanh Tung,
Dam Hoang Phuc1,
Automotive Engineering Group, School of Mechanical Engineering, Hanoi University of Science and Technology, Hanoi, Vietnam

В данной статье рассчитывается энергия рекуперативного торможения при движении электрического автомобиля в ездовых циклах Ханоя с использованием программного обеспечения FASTSim. Дается оценка об эффективности рекуперативного торможения в снижении потребления энергии (EC) в различных ездовых циклах (DC), таких как городские и шоссейные DC. Приведенны результаты расчета рекуперативной энернии при торможении и их влияния на снижение общей потреблямой автомобилем энергии EC, особенно в условиях движения с частыми остановками. В исследовании также подчеркивается важность поведения водителя и дорожных условий для определения эффективности системы рекуперативного торможения (RBS). Анализируется потенциал RBS для повышения энергоэффективности электрических автомобилей, что может способствовать сокращению выбросов парниковых газов и улучшению качества воздуха.

This paper calculates the amount of regenerative braking energy when the vehicle is traveling in Hanoi's driving cycles by using the FASTSim software. The study aims to evaluate the effectiveness of regenerative braking in reducing energy consumption (EC) in different *driving cycles (DCs), such as urban and highway DCs. The results demonstrate that regenerative braking can significantly reduce EC, especially in traffic conditions with frequent stops. The study also highlights the importance of driver behavior and road conditions in determining the effectiveness of regenerative braking system (RBS). Overall, the analysis provides valuable insights into the potential of RBS to improve the energy efficiency of vehicles, which can contribute to reducing greenhouse gas emissions and improving air quality.*

Ключевые слова: *управление движением автомобиля, динамика рулевой системы, алгоритмы управления управляемыми колесами.*

Keywords: *regenerative braking, FASTSim, city and highway driving.*

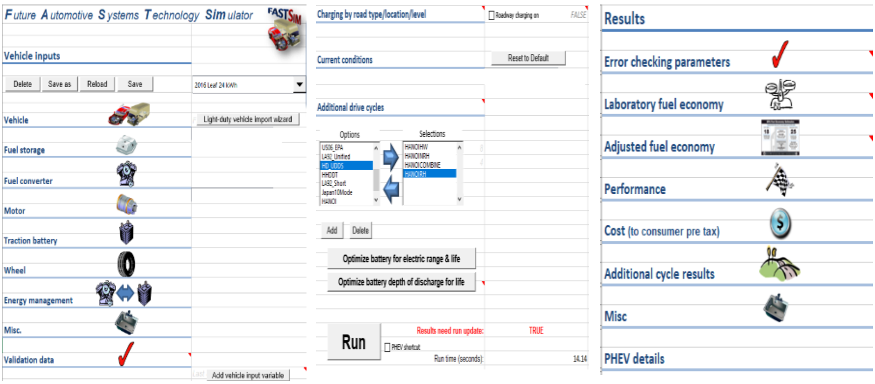
INTRODUCTION

EVs are cleaner and kinder to the environment than their fossil fuel-powered counterparts since no exhaust fumes are produced, meaning there are fewer dangerous greenhouse gases such as carbon dioxide being expelled from the vehicles into the atmosphere. Promoting the development of BEVs is considered one of the promising solutions for treating severe air pollution in metropolises [1]. Moreover, the drivetrains of EVs can operate at over 80 % efficiency, which shows they have great potential to reduce the transportation energy demand [2]. Many countries worldwide offer a series of incentive schemes (such as subsidies and tax credits) to promote the adoption and use of EVs, lowering the cost to the consumer due to those benefits mentioned above [3]. However, the low driving range, generally, is the main reason that halts the widespread use of EVs.

RBS is an excellent solution for enhancing the driving range of EVs. Various studies have been conducted to calculate the recovered energy by RBS. However, there are a few studies conducted in the Vietnam traffic scenarios and on EVs manufactured in Vietnam. Thus, this paper focuses on calculating the regenerative energy generated by RBS using FASTSim (The Future Automotive Systems Technology Simulator). Vinfast VF e34 specification and dynamics are the input parameters of the simulation. Four real-time driving cycles are chosen to assess the recovered energy on VF e34. These driving cycles represent different driving conditions, including the rush-hour and pre-peak hour urban road, urban road during both peak and off-peak hour, and the highway.

METHODOLOGY

FASTSim (Future Automotive Systems Technology Simulator) is a high-level advanced vehicle powertrain systems analysis tool supported by the U.S. Department of Energy's Vehicle Technologies Office. FASTSim has been validated for hundreds of vehicles and most existing powertrain options [4]. The input data for most light-duty vehicles can be automatically imported. Those inputs can be modified to represent variations of the vehicle or powertrain. The vehicle and its components are then simulated through speed-versus-time DCs. At each time step, FASTSim accounts for drag, acceleration, ascent, rolling resistance, each powertrain component's efficiency and power limits, and regenerative braking.



Input Simulation Result

Figure 1 – FASTSim interface

Vinfast VF e34 specification and vehicle models are imported into the input data of FASTSim. Those parameters are presented in Table 1.

Table 1 – Vinfast VF e34 specs

Parameter	**Value**	**Unit**	**Parameter**	**Value**	**Unit**
Curb weight	1490	kg	Wheel friction of coefficient	0.7	
Wheelbase	2.611	m	Rolling resistance coefficient	0.008	
Mass centre height	0.58	m	Frontal area	2.424	m^2
Tire radius	0.32535	m	Motor power	110	kW

End of the table 1

Wheel's rotational inertia	0.815	kg.m^2	Motor efficiency	95	%
Transmission efficiency	95	%	Battery energy	44.5	kWh
Charger efficiency	86	%	Battery efficiency	95	%

The vehicle and its components are then simulated through four real-time DCs. The simulated DCs can be shown in Fig. 2.

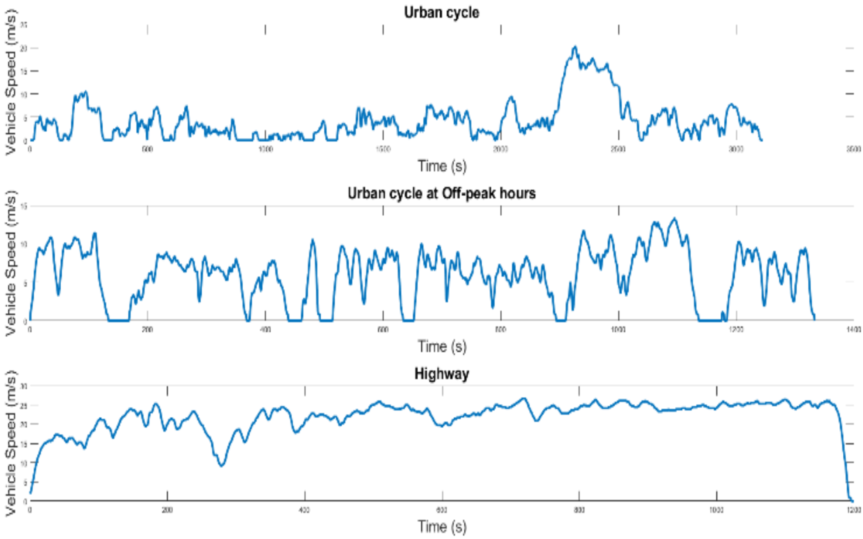


Figure 2 – Hanoi DCs speed profile

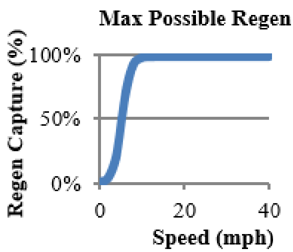


Figure 3 – Speed-dependent regeneration factor

For electric vehicles, it is possible to recover some kinetic energy during braking using the motor as a generator. The amount of regenerative power, P_{regen} is defined as (1), where η_{regen} = regenerative braking efficiency:

$$P_{regen} = P_{trac} \cdot \eta_{regen} = F_{trac} \cdot v \cdot \eta_{regen} \tag{1}$$

In which the F_{trac} is the traction force (W), v is vehicle speed (m/s), and η_{regen} is the regenerative energy coefficient. The components and the vehicle's speed limit the regenerative braking energy achievable. The battery power, usable SOC range, and motor provide the ultimate regenerative braking power limits. The regenerative braking energy that can be captured is defined as a function of vehicle speed, as seen in Fig. 3. The value of η_{regen} in FASTSim is calculated using equation (2):

$$\eta_{regen} = \frac{\%regen_{max}}{1 + RA \cdot \mathrm{e}^{-RB \cdot \left(v \cdot \left(\frac{mile}{h} \right) + 1 \right)}},\ RA = 500,\ RB = 0{,}99 \tag{2}$$

In which: $\%regen_{max}$ is the percentage of maximum attainable regenerative energy, v is the vehicle velocity (measured in mile/h), *RA* and *RB* are experimentally determined constants.

The regenerative braking power can also be calculated by using these equations:

$$P_{regen} = \mathrm{Max}\left(\mathrm{Min}\left(P_{motor_{in}} \cdot \eta_{trans}, P_{Wheel\,\mathrm{Re}q} \cdot \eta_{regen} \right), 0 \right) \tag{3}$$

$$P_{motor_{in}} = if\,(P_{Wheel\,\mathrm{Re}q} > 0, \frac{P_{Wheel\,\mathrm{Re}q}}{\eta_{trans} \cdot \eta_{bat}}, \frac{P_{WheelReq} + P_{FricBrake}}{\eta_{trans} \cdot \eta_{bat}}) \tag{4}$$

$$P_{Wheel\,\mathrm{Re}q} = P_{Roll} + P_{InertiaWheel} + P_{drag} + P_{slope} + P_{accel} \tag{5}$$

$$\mathrm{P_{FricBrake}} = -\min\left(P_{Wheel\,\mathrm{Re}q} + P_{regen}, 0 \right) \tag{6}$$

where: $P_{motor_{in}}$ is the input power of the electric motor (W), $P_{Wheel\,\mathrm{Re}q}$ is the wheel required power (W), P_{Roll} is the rolling resistance power (W),

$P_{InertiaWheel}$ is the inertia system power (W), P_{drag} is the aerodynamic power (W), P_{slope} is the road gradient power (W), P_{accel} is the acceleration power (W), η_{trans} is the transmission efficiency, η_{bat} is the battery efficiency.

RESULTS AND DISCUSSION

Simulation results are presented in Table 2.

Table 2 – EV component's EC and regenerative energy percentage

Parameter	Driving cycle		
	Urban cycle	Urban cycle at Off-Peak hours	Highway
Input power (Wh)	4170.15	7478,5	11795,56
Regenerative power (Wh)	1225.7	1409,21	1808,12
Regenerative energy percentage (%)	29.93%	18,84 %	15,33 %

The results indicate that the energy efficiency of a vehicle can vary significantly depending on the DC. The highest EC was observed in the Highway DC, while the two Urban cycle DCs had low EC. This can be explained by the fact that vehicles must produce high energy to meet the demand for high-speed travel on the highway. However, in the urban cycle, the traffic volume is high, and vehicles frequently stop and start at low speeds; hence there is no need for high energy generation.

RBS was found to collect and store less energy in the battery when driving on highways, as indicated by the lower percentage of regenerated energy. Meanwhile, the Urban cycle requires harsher acceleration and deceleration, making RBS more effective in this case, as demonstrated by the higher percentage of regenerated energy observed in these cycles.

Overall, these results highlight the importance of understanding vehicles' energy consumption and recovery models in different driving scenarios and the role that RBS can play in improving their energy efficiency. In order to improve the energy efficiency in EVs, optimizing the strategies and algorithms to control the electric motor in the braking process is essential to achieve high recovered energy [1].

CONCLUSION

This study introduces the EC calculation for a widely used EV in Hanoi by using FASTSim. RBS recuperates more energy in urban cycles than on the highway. This research provides potential insights into EV energy use. It should be expanded to include many different EV models and driving conditions to indicate the feasibility of EV in Vietnam traffic conditions.

REFERENCE

1. Research of Regenerative Braking Strategy for Electric Vehicles / V. N. Le [et. al.] // ENERGETIKA. Proceedings of CIS higher education institutions and power engineering associations, vol. 66(2), 2023. – PP. 105–123.

2. Modeling the driving behavior of electric vehicles using smartphones and neural networks / A. D. Alvarez [et al.] // IEEE Intelligent Transportation Systems Magazine, vol. 6, 2014. – Pp. 44–53.

3. Sweeting, W. Factors affecting electric vehicle energy consumption / W. Sweeting, A. Hutchinson, S. Savage / International Journal of Sustainable Engineering, vol. 4, 2011. – PP. 1–10.

4. Optimal Driving Range for Battery Electric Vehicles Based on Modeling Users' Driving and Charging Behavior / Zh. Lu [et. al.] // Journal of Advanced Transportation, 2020. – PP. 1–10.

5. FASTSim: A Model to Estimate Vehicle Efficiency, Cost and Performance / Aaron Brooker [et al.] // SAE Technical Paper , 2015. – P. 12.

Представлено 10.08.2023