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Vehicle energy consumption as factor of combined power plant parameters' definition

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Abstract. The development and creation of innovative transport systems, environmentally friendly and energy-efficient vehicles must be considered as the strategic direction of the global transport industry. The equipment improving and its operation modes optimization allows efficient use of available traction drive resources. The implementation of innovative technologies using modern storage devices and non-traditional fuels provide high-efficiency electricity usage by the electrical complex. The hydrogen fuel usage is considered in this article as one of the common areas of electric vehicles development. Hydrogen is the first element of the Periodic Element System and the most common in the universe. On Earth, by the number of atoms in compounds (17%) Hydrogen is second only to oxygen (52%). Hydrogen is non-toxic - combustion products are water vapors, it has the highest combustion heat per unit of mass compared to other types of fuels. All these factors, coupled with the current trends of the widespread implementation of energy-saving technologies, are encouraging the world's car companies to move from the advancement of the traditional car to the design of new types of vehicles using Hydrogen as the primary source of energy.

1. Introduction

As known, transport spends about half of the world's oil, and in the U.S. - even 65%. Global consumption of petroleum products by transport at the beginning of the 21st century was estimated at 637 million tons of gasoline and 327 million tons of diesel fuel. The environmental consequences of burning fuel are more severe than from thermal power plants. Therefore, the problem of large-scale implementation of Hydrogen into transport systems is very relevant. This process is because the calorie contained 1 kg of Hydrogen is equivalent to almost 4.5 litres of gasoline. According to the Well-to-Wheel concept (which aims to reduce harmful emissions, improving energy efficiency and reducing financial costs in the transport sector), the rolling stock with fuel cells is in the leading positions in comparison with the other types of modern transport. Current researchers classify fuel cell vehicles as "hybrid" vehicles based on the electrochemical generator capabilities [1]. Similar to "hybrid" cars with internal combustion engines (ICE), fuel cell transport has the following advantages:

1. The operation of the vehicle at idle speeds is excluded because, during this period, a significant amount of energy can be consumed.



2. The energy of regenerative braking is stored in a battery. In traditional vehicles, the energy of braking dissipates in the form of heat in the braking system and is lost irretrievably.
3. The urban environment supposes an operating mode of frequent launches and stops, low speeds and low moment, which is inefficient for a traditional vehicle with ICE. In the case of a "hybrid" vehicle with fuel cells, the working conditions of the electrochemical generator and the battery are separated, depending on movement and the principles of the power plant operating mode.
4. As with traditional "hybrid" vehicles in the vehicle with ICE and battery and electric vehicles, a high torque (in comparison to ICE) can be achieved at low speeds through electric traction engines.

An additional advantage of fuel cell transport in comparison with electric cars is the increased battery lifespan [2]. According to this study, the current dynamics of the battery has a direct correlation with the level of discharge. A high discharge rate causes a rapid reduction in capacity and an increased internal resistance to the battery. The fuel cells usage allows the distribution of two power sources, contributing to the operation in the optimal load's range and prolonging the lifespan of both battery materials and electrochemical generator membranes.

Fuel Cell Electric Buses are considered as a promising technological solution for environmentally save future cities. European countries have already followed a firm policy of this transport type integration in cities car parks. The consequence of this policy is the program "Joint Initiative for hydrogen Vehicles across Europe 2" (JIVE 2) which is financed by the interstate fund "Fuel Cell and Hydrogen: Joint Undertaking" (FCH-JU). In accordance with this program, it is planned to purchase 152 FCEBs and their usage in European cities. According to the results of JIVE 1 program, which has been running a year earlier, for a period up to 2023 a delivery of almost 300 FCEBs and several petrol stations to 22 cities in Europe are expected.

2. Problem statement

Despite being environmentally friendly, energy-efficient and scalable [6], the use of fuel cells in transport applications is very constrained. The main reason is the low dynamics of the hydrogen conversion. Fuel cells show maximum efficiency in the stability of the external load, which mismatches with the traction drive of urban passenger transport. The typical fuel cell has a low dynamics and initial voltage in a relatively stable state. This state fuel cell reaches within a few seconds tens after launching. Therefore, the fuel cell is not able to power drives with dramatically variable load as the only source of power. In this regard, studies of fuel cell operation together with other power sources are necessary for further development of this transport industry area [3,4,5].

3. Theory

There are several approaches to assess the vehicle energy. The dependence of its speed on time, current characteristics, and levels of consumed and generated capacity can be obtained based on calculated motion curves, international standardized motion cycles used for determining of the cars' fuel efficiency [6,7] and experimentally obtained data [8]. In large cities, public transport movement is generally hampered and is characterized by both a large number of stops and the need to reduce the speed without complete stop. As a result, the frequency of accelerations and braking increases, and the vehicle speed decreases. Thus, the average energy generated during braking is significantly less than the maximum one, calculated in the conditions of braking on the descent with a full load, but also the energy assessed for the case of compliance with the calculation mode of movement. For this reason, the suspected assumption in traction calculations that the cycle of movement between stops consists of one-time acceleration, run-out and braking is inaccurate and cannot be used for determining motion modes and estimate vehicle energy consumption [9,10].

Riding test cycles are used for vehicle fuel consumption and emissions determination. These standards are generally used for cars with ICE. Still, according to the trends of reducing fuel consumption and emissions with waste gases, these cycles are applied for cars with combined energy installations.

The riding test cycle is a set of parameters and sequences, which are supposed to approximate the movement of the average vehicle in real conditions. Depending on the average traffic speed, the cycles are divided into urban and suburban.

There are several standard test cycles. Each of them is characterized by its acceleration values, average and maximum speeds, as well as sequences of vehicle modes. On the territorial basis, they can be divided into European, American and Japanese [7].

The unevenness of the average traction drive input power can have a significant impact on the parameters of the designed power plants. This unevenness can be caused by alternating cycles of traffic in congestion and on a free road. In this regard, to assess the dependence of the power consumed by the electric traction drive from the time and parameters of the calculated combined power plant, it is rational to use experimental data obtained during the vehicle movement in real operating conditions.

4. Conclusion

Experimental data obtained from the onboard registrar of the trolleybus ST-6217 operate on the route 5 in Novosibirsk is taken as the initial survey data for assessing the level of the vehicle energy consumption (trolleybus is equipped with DC traction drive with an impulse control system) (Figure 1) [11].

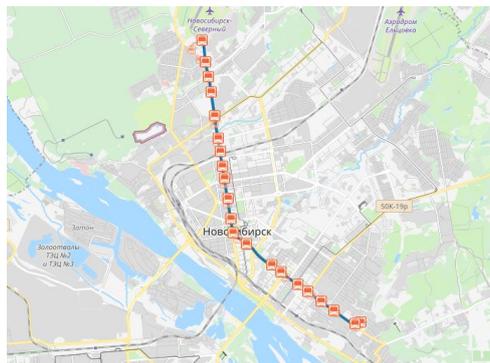


Figure 1. Trolleybus rout № 5.

The speed information came to the registrar in the form of signals from the speed sensor located on the shaft of the electric traction motor. The control system aggregated analogue data from the speed sensor and converted it into messages under the CAN protocol requirements, which is perceived by the onboard registrar. For securing message registration and make research data complete, a "2-point per second" setting value was chosen as the optimal recording speed [11].

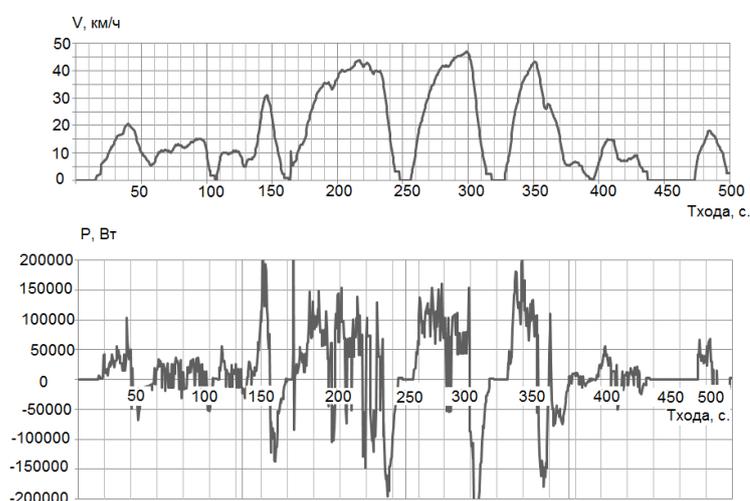
The study includes data of the trolleybus parameters, obtained during the day shift of the vehicle crew. During this time, 10 ridings were conducted with a total duration of about 7.5 hours and a distance of about 118km.

Table 1. The study parameters of the trolleybus ST-6217 movement on route №5 in Novosibirsk.

Route length, km	Stops number, pcs.	Riding number for experiment, pcs.	Total running time, sec.	Total experiment route length, km
11,78	22	10	26053	117,8

According to the data, the shaft motor velocity of the trolleybus's traction was investigated with a frequency of two measurements per second. The data was subsequently processed and converted into a real-speed vehicle format.

Taking into account that the trolleybus control system does not provide the ability to capture the traction electric drive power in braking mode, the values of instant power were obtained by calculation using $V(t)$ relation in the sequence determined by the methodology [12]. Graphic of speed $V(t)$ and power $P(t)$ relations on time are shown below in Figure 2. Negative power values correspond to its generation in braking mode, and decisive – its consumption in traction mode.

**Figure 2.** Relations of the trolleybus route speed and traction electric drive power from time.

5. Results

The obtained data allow making analysis of the trolleybus movement energy. For example, it has been established that for one riding a trolleybus performs about 250-300 acts of braking and 34 stops (according to the road traffic). The more complete analysis results are shown in Table 2.

Table 2. The results of the interpretation analysis.

Measurable parameter	Unit	Value
Average riding time per day	min	43,5
Riding distance	km	12
Average traffic time between stops	sec	67
Average speed between stops	Km/h	17,9
Average braking between stops	pcs	9
Average braking per 1 minute	pcs	6
Average energy consumed between stops	MJ	2,2
Average braking energy between stops	MJ	1,6

Estimated data show that the instant maximum braking capacity during the riding varies from a few tens to hundreds of kilowatts. For example, as shown in Figure 3, braking power in some cases at its

peak value was more than 300kW. The average braking power maximum for the entire period from the first to the last stop is about 55kW.

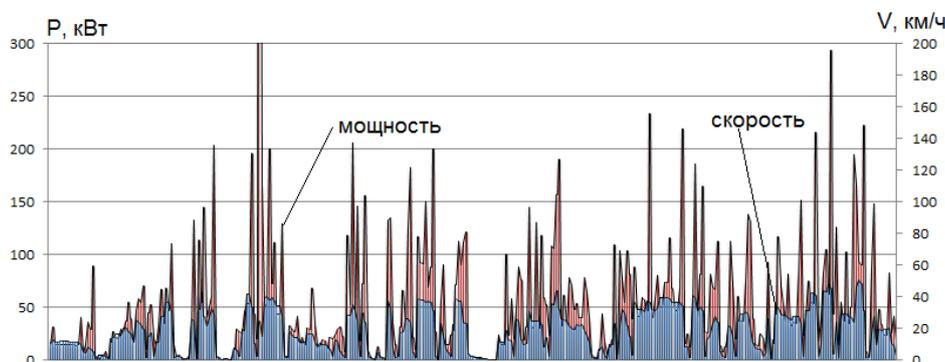


Figure 3. The range of in maximum braking power and start braking.

6. Discussion

Statistical analysis shows that with a probability of 98.5% braking power does not exceed 210kW. This aspect should be taken into account calculating the buffered energy storage characteristics so that its potential capacity is sufficient to absorb regenerative braking energy in a quantity that meets the requirements for efficient energy consumption.

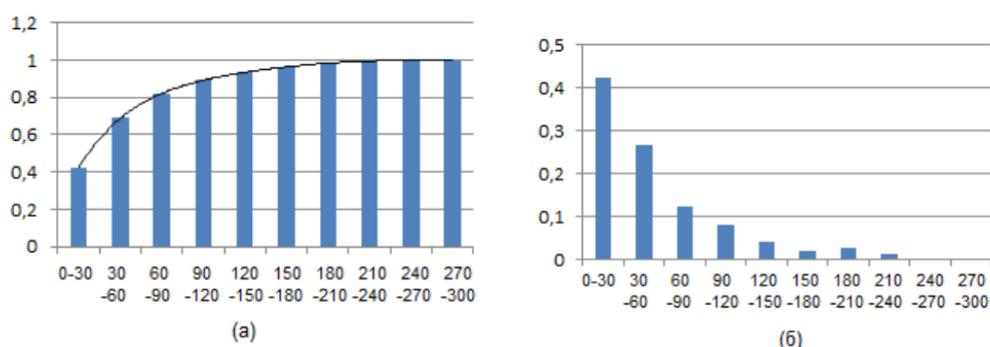


Figure 4. Statistical processing of maximum braking power: (a) integral distribution, (b) probability density.

7. Conclusion

Research of the optimal interaction point between the battery and the fuel cell battery can be implemented in a variety of ways. Thus, the study [2] uses two different approaches to the determination of the power plant parameters. In the first approach, the power of an electrochemical generator is accepted as a permanent value, and the power of the battery is selected by experiment. Thus, the power of the traction drive in all study options under varies. In the second approach, as the raw data is taken traction electric drive power, and the results of the experiment select the power of individual components. At the same time, the study distinguished the results for urban traffic and traffic outside the city.

In another study [13], dynamic programming is used for determining the parameters of the power plant, esteeming different configurations of electric car traction drive with fuel cells and power plant collaboration modes.

In the article [14], the choice of the optimum in the power sources parameters ratio is implemented on the analysis of the energy consumption of the vehicle using intelligent algorithms of neural networks.

In any case, designing a fuel cell-based power plant, it should be taken into account that about 20% of its output is used for its balancing needs, which are fuel recycling, air recycling, refrigerant and temperature management, safety function and dc/dc converter operation.

References

- [1] Hayes J G and Goodzari G A *Electric Powertrain: Energy Systems, Power Electronics and Drivers for Hybrid, Electric and Fuel Cell Vehicles* (John Wiley & Sons Ltd) pp. 111-155
- [2] Herb F, Akula P R, Trivedi K, Jandhuyala L, Narayanna A, Wohr M Theoretical Analysis of Energy Management Strategies for Fuel Cell Electric Vehicle with respect to fuel cell and battery aging *World Electric Vehicle Symposium and Exhibition (EVS27)*
- [3] Kulikov K I, Schurov N I, Langeman E G Structural analysis of vehicle's hybrid power system based on fuel cell *EDM 2018*
- [4] Kulikov K I, Schurov N I, Yaroslavtsev M V, Langeman E G Vehicle Combined Power Plant by type "Fuel Cell-Battery", *EDM 2019*
- [5] Ciancetta F, Ometto A, Rotondale A, Rotondale N, D'Ovidio G, Masciovecchio C Analysis of flywheel-fuel cell system for mini electrical bus during an urban route *Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM)*
- [6] Blokhin A N, Bektakov V V, Zezyulin D V, Energy consumption of an electric vehicle driving in urban environments *Engineering* 21-25
- [7] Antipov S I and Dement'ev Y V, Modern test cycles and their relevance creating an algorithm for the car's control system with CPP *Volgograd State Technical University News* **10(13)** 8-11
- [8] Shtang A A and Yaroslavtsev M V Determining the main characteristics of a combined power plant for urban rail-free transport *Reports of the academy of sciences of the higher school of the Russian Federation* **4 (33)** 111-120
- [9] Schurov N V Methods and means of saving and increasing energy efficiency in the urban electric transport system *NSTU* **385**
- [10] Shtang A A, Improving the efficiency of electric transport systems based on the use of energy storage, *NSTU* **233**
- [11] Yaroslavcev M V, Energy-efficient traction drive of urban rail-free transport *NSTU* **157**
- [12] Yaroslavcev M V, Schurov N I, Anosov V N, Energy-efficient traction drive of urban rail-free transport *NSTU* **136**
- [13] Wei Z, Lin Y, Yishan C and Tianxing Y, Dynamic programming for new energy vehicles based on their work modes. Part II: Fuel cell electric vehicles *Journal of Power Source* 92-104
- [14] Tao Z, Zhan C, Hu M, Chen Y, Yuan C, Chen J, Zhou A, Modelling and predicting energy consumption of a range extender fuel cell hybrid vehicle *Energy* 187-197