Yuriy BORODENKO[1], Leonids RIBICKIS[2], Anatolijs ZABASTA[3], Shchasiana ARHUN[4], Nadezhda KUNICINA[5], Anastasia ZHIRAVETSKA[6], Hanna HNATOVA[7], Andrii HNATOV[8], Antons PATLINS[9], Konstantins KUNICINS[10]

Kharkiv National Automobile and Highway University (1), Riga Technical University (2), Riga Technical University (3), Kharkiv National Automobile and Highway University (4), Riga Technical University (5), Riga Technical University (6), Kharkiv National Automobile and Highway University (7), Kharkiv National Automobile and Highway University (8), Riga Technical University (9), Riga Technical University (10)

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Using the Method of the Spectral Analysis in Diagnostics of Electrical Process of Propulsion Systems Power Supply in Electric Car

***Abstract**. In this paper is presented a simulation model of the electric drive (ED) system for the diagnosis of an electric vehicle. Model is built by the method of spectral analysis of the electrical process of propulsion systems power supply. Moreover, the efficiency of ED is a key challenge for the research team. The developed model adequately imitates the electrical processes that occur in the power circuits of the ED system with an AC converter-fed motor. The developed model can be used for virtual studies of dynamic ED modes and studies, and optimization tasks.*

Streszczenie.** Przedstawiono model symulacyjny napędu elektrycznego umożliwiający diagnostykę pojazdów elektrycznych. Model bazuje na analizie widmowej ciągu. Analizowana jest też efektywność napędu. Model mopże także służyć do wirtualnej analizy dynamiki. **Diagnostyka systemu napędowego z wykorzystaniem analizy spektralnej.

Keywords: electric car, electric drive, diagnostics, transport model.
Słowa kluczowe: pojazd elektryczny, napęd, analiza widmowa.

Introduction

Currently, various types of diagnostic systems are being used increasingly on modern vehicles. For electric vehicles, one of the most important elements is the electric drive (ED), therefore, it should be diagnosed with the greatest attention. Timely detection of ED faults will reduce costs during its operation, maintenance and repair. In this paper, a simulation model of the ED system for the electric vehicle diagnosis by means of the spectral analysis method for the electrical process of propulsion systems power supply is built. Moreover, the efficiency of ED is a key challenge for the research team. The developed model adequately imitates the electrical processes that occur in the power circuits of the ED system with an AC converter-fed motor. The spectral characteristics of the high-voltage battery discharge current function allow a qualitative and quantitative assessment of the starting and power modes of ED, as well as evaluate the efficiency of the solution in general. The composition of the dominant harmonics in the spectrograms depends on the design parameters of the electric motor and the circuit design of the voltage inverter. To increase the informational content of spectrograms, it is advisable to use various FFT analysis formats. The developed model can be used for virtual studies of dynamic ED modes and studies, and optimization tasks related to the identification of structural and parametric faults arising in its circuits.

Environmental issues and the depletion of natural resources have become the main engine for the development of energy-efficient technologies worldwide. This is especially true for the transport industry. The use of alternative sources of electric energy in transport and infrastructure solves these problems partially [1] – [3]. A more tangible result is given the replacement of vehicles with internal combustion engines to cars using electric traction.

The analysis of different transport network exploitation conditions, integration of electric transport in transport network, as well as future development of new power supply solutions within the frame of smart city context are being discussed. [4,5] The developed approach [6] will allow the usage high-performance (HPC) capabilities, which are considered to be the main technology of the next generation of computing. In addition, the development focuses on the graphic processing unit (GPU), where the consumption of energy is several times lower than the classic architecture of computing elements. The proposed data transmission method has been tested on the basis of Interactive Technology, proposed in [7].

The use of electric traction in road transport allows us to solve problems associated with the improvement of its environmental performance and fuel efficiency. Today, two main areas of concept development are considered - the use of hybrid power plants that use an auxiliary electric motor, and the use of all-electric traction from battery power sources [8,9].

One of the aspects of the development of automotive electric drives (ED) is the reduction of operating costs during their operation, maintenance and repair. Such problems are solved at the stages of ED development (adaptation of the design, integration of diagnostic systems) and during the transport process (use of monitoring systems for technical condition) [8, 9].

The information basis of these systems is knowledge and data base for expert analysis [10]–[14]. For this reason, the article discusses a method for the quantitative assessment of electrical processes occurring in the ED power supply circuit for the purpose of using the received information as a diagnostic one.

The ED electric structure consists of the information part (sensors and controllers of the control system) and the power electric part (voltage converters, electric machines).

Applied integrated self-diagnosis systems allow the monitoring of technical condition of the control system components directly connected to the electronic control unit, but do not allow the identification of malfunctions of actuation devices of the power part, which are remotely controlled [14] – [15]. Thus, [20] proposes the use of the built-in processor and bidirectional communication with an intelligent actuation device in the steering system. This enables self-diagnosis, which should lead to increased reliability.

Testing of the ED power electric [19] part traditionally begins with monitoring the voltage levels of all power sources at idle and under rated load in static modes. Next, the ED operation is checked in dynamic modes [21].

When using the AC converter-fed motor with a primary DC source and a voltage inverter, the information about the level (average value) of voltage or current is not enough to identify a malfunction.

In [15], a qualitative analysis of the processes in the AC converter-fed motor system at stationary modes without a secondary power source (overvoltage converter) was made. The system model used a simplified model of a high-voltage battery (HVB) in the form of an idealized EMF source with internal resistance.

The aim of the work is to build an electric drive system simulation model for diagnosis of an electric vehicle by the spectral analysis method for the electrical process of propulsion systems power supply.

Simulation model of an electric drive system

The power part of the car's electric drive system consists of an overvoltage converter, an inverter and a synchronous electric motor with rotor position sensors [15]. To increase the supply voltage in the converter circuit, a reactor (inductance) is used in which self-induction EMF pulses arise as a result of switching the current of the power circuit (Fig. 1) [15].

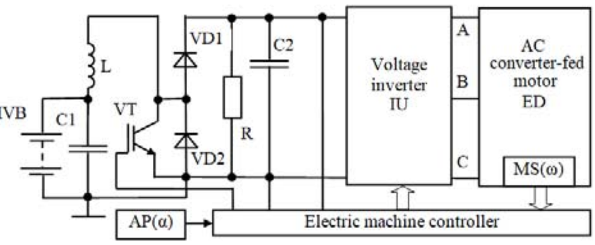

Fig.1. Electric drive circuit with AC converter-fed motor

The electric motor of the drive is a ED (AC converter-fed motor) with excitation from permanent magnets and perceives the position of the accelerator pedal AP (α) and the feedback signal of the angular position of the shaft of the machine MS (ω) for control actions. The controller of the electric machine generates the control pulses of the keys of the converter of increased DC voltage (L, VT, VD1, C2, R) and the inverter UI.

The period of the working cycle of electrical processes in the converter circuit is determined by the switching time of the current in the reactor L with a transistor switch VT. During the closed state of the key, the voltage of the nickel-cadmium HVB UB = 250 V is applied to the reactor under the action of which a current arises in the circuit, which increases with time to a steady state. During the opening of the key (switch), the reactor induces EMF pulses.

The amplitude of the pulses generated as a result of transient processes exceeds the level of HVB voltage supplied to the reactor. At the output of the converter circuit, an integrating capacitor C2 is included, which maintains a constant voltage at the level of amplitude values of 500 V. The diode VD1 eliminates the discharge of the capacitor C2 through a transistor switch, during its open state. The diode VD2 protects the transistor switch VT from surge impulses. Buffer capacitor C1 smooths out the surges in the supply circuit during transients.

To conduct virtual research, a simulation model of the ED system was built in the application package Matlab / Simulink. The model of an electric drive system consists of a primary voltage source Battery, a ED system of AC converter-fed motor [22] and an overvoltage converter (secondary power supply) (Fig. 2).

Unlike previous studies [16, 17] of the model, a circuit with an increased DC voltage converter is considered and a HVB model is used, taking into account its energy and conditional Faraday capacities. A NiMH-type HVB model (Battery) with a rated voltage of UB = 220 V and a rated capacity of SB = 5 A / h was selected as the primary voltage source. The reactor L is parameterized with an inductance L = 0.5 mH and an active resistance of the winding r = 0.01 Ohms. The Generator block (rectangular pulse generator) imitates the IGBT key control signal, which in a real system comes from the controller of an electric machine. An increased voltage of 500 V from the converter is supplied to the IGBT Inverter in which the phase currents of the "Ventil Dvig" AC converter-fed motor are switched. Maintaining a given speed of rotation of the electric motor under load (block 850) is carried out through a comparison circuit "Speed Ref" of the current speed of rotation of the motor shaft with its given value.

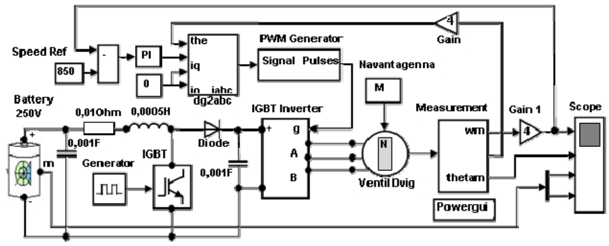

Fig.2. Scheme of a simulation model of an electric drive system with a AC converter-fed motor

In the model diagram, model No. 12 of a AC converter-fed motor is used, which develops a rated torque MN = 35 Nm at a rated rotation speed of nN = 3000 min-1. The circuit model of the electric drive system is investigated in a stationary mode. The signal of the generator (Generator) is: frequency 20 kHz, amplitude 3 V, duty cycle 50%. The motor load is 37 Nm, the shaft rotation speed n = 850 min-1 is supported. The load on the motor occurs after 0.3 s. after its inclusion (the function is implemented by the "Navantagenna" unit). The data of the passive elements of the voltage converter model correspond to the values of the parameters of the circuit elements of the Lexus RX400h vehicle voltage converter block.

Electrical processes simulation results

According to preliminary studies, the harmonic composition of the current function in the IB power supply circuit is the best diagnostic parameter from the point of view of information content, sensitivity and manufacturability. The results of the study of the model are shown in Fig. 3 [15].

When starting the engine after turning on the power 0 <t <0.05 s, the torque M, which overcomes the friction forces, and the inertia of the rotor mass and current iB, have maximum values. A noticeable surge in current consumption is caused by a charge on the capacitor C1. The maximum value of this current IB = 450 A is limited only by the internal resistance of the power source r0, and the duration of the surge is limited by the value of the capacitor C1.

Further, over a period of 0.05 <t <0.1 s, the torque gradually decreases as the engine rotor accelerates. The rotor speed n, in this case, increases to constant idle speed. The temporal functions of these mechanical quantities have a similar oscillatory character, damping in time. With a fixed electric motor power, these periodic functions are phase shifted by half a period, and the product of their instantaneous values is equal to the mechanical power on the shaft.

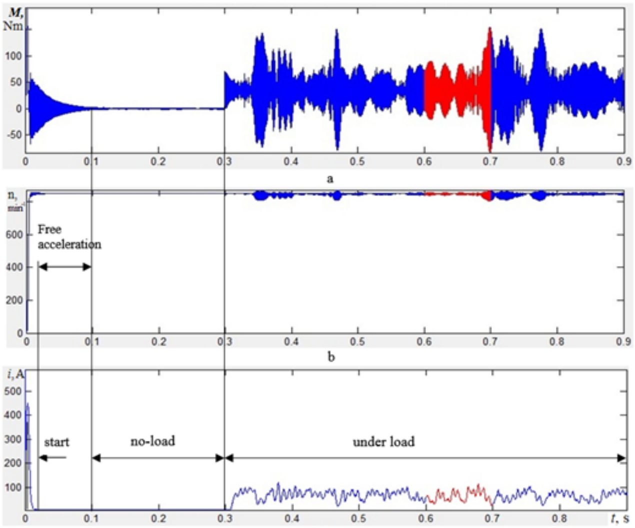

Fig.3. Functions of the output characteristics of the electric drive: a - torque on the motor shaft; b - rotor speed; c - current in the HVB circuit

After starting and accelerating an unloaded engine, during a period of 0.1 <t <0.3 s, in idle mode, the torque M is almost zero, the rotor speed is kept constant at a given level (n = 850 min-1), and the battery discharge current IB has minimum values of the order of units of amperes.

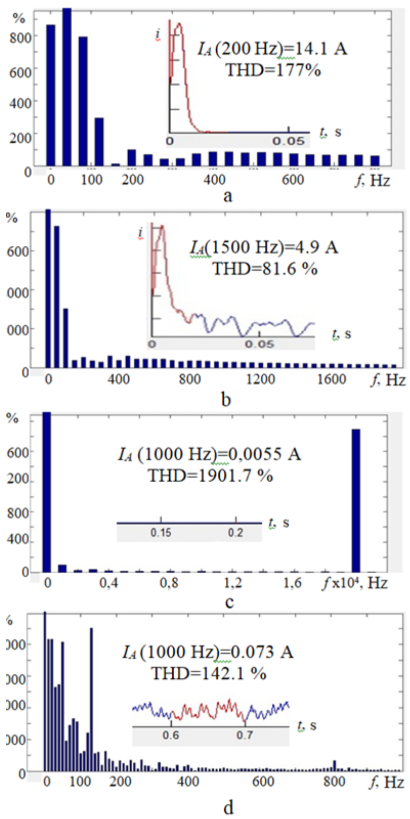

Fig.4. Spectral characteristics of the current functions in the HVB circuit in the AC converter-fed motor modes: a - start without load; b - start-up under load; c - idling; d - stationary load

After the load is applied to the motor shaft at t> 0.3 s, the angular velocity of the rotor shaft has a slight fluctuation with the frequency of change of instantaneous torque values, the actual value of which is determined by the resistance moment (given load). In the steady state under load, periodic processes occur due to the switching of the transistor switches of the inverter (with a frequency of multiple rotational speeds of the rotor of the electric motor) and the voltage converter (with a generator frequency of 20 kHz).

The analysis of spectrograms

Spectral FFT analysis (fast Fourier transform method) was carried out for certain modes of electric drive [18] (sections of the function IB). In this case, the sensitivity of the diagnostic parameter is determined by the discrepancy between the amplitudes and phase shifts of the individual harmonics of the spectrum for a given mode of the drive system, and the information content is determined by the discrepancy of the spectrograms of the selected mode for various technical conditions (operational and faulty).

The results of previous studies, on this occasion, show that for each mode of operation and the technical condition of the electric drive, certain spectrogram formats should be selected. To do this, select the “FFT Analysis” mode in the “Powergui” instrument menu and configure the spectrum analyzer options (maximum observation frequency “Max Freqency” and the base frequency of the relative harmonic amplitude reference (Fundamental Frequency FF). The results of the expansion of the functions in Fourier series are shown in Fig. 4 [22].

The figures show the amplitudes of the fundamental harmonics IA (FF) and harmonic coefficients THD of the current functions in the corresponding modes. On the ordinates of the spectral characteristics, the percentage of the amplitude of the base harmonic% FF is plotted.

So, the absolute discrete values of the amplitude of each j-th harmonic of the stream function are proportional to their ordinates IA (fj) =% FF (fj) • FF / 100 A.

The results of the analysis of spectral characteristics show the following. The characteristic (informative) harmonics for the start modes (Fig. 4, a, b) are components of 40 Hz and 80 Hz. According to the above formula, the amplitudes of these harmonics are respectively equal to IA (f40) = 169.2 A; IA (f80) = 110 A. Deviation of these amplitudes or frequencies from normalized values indirectly indicates a change in the values of the electrical parameters of the power supply circuit (malfunction of HVB elements, C1, L). The constant component, in this case, is IP.0 = 120 A.

At idle (Fig. 4 c), a harmonic of 20 kHz dominates, with an amplitude of IA (f20000) = 0.1 A, caused by switching the voltage converter key. The constant component, in this case, is IX.0 = 0.137 A.

During operation of the drive under load (Fig. 4 d), a harmonic of 130 Hz with an amplitude of IA (f130) = 13.1 A (constant component IN.0 = 18.25 A) is noticeably separated. The spectral composition of the current function in this case is determined by the design parameters of the electric machine, the circuit design of the inverter, the operating parameters (M, n) and depends on the technical condition of the elements (electrical circuits) of the inverter and the AC converter-fed motor.

It should be noted that the variables and constant components of these spectrograms have the same sequence of absolute current values, which speaks in favour of the sensitivity of the chosen diagnostic parameter.

Conclusions

The built model adequately emulates the electrical processes that take place in the power circuits of an electric drive system with an AC converter-fed motor.

The spectral characteristics analysis of the function of discharge current for HVB allows a qualitative and quantitative evaluation of the starting and power modes of the electric drive.

The spectral composition of the supply current function is characterized by harmonics, caused by switching power elements of the inverter and the voltage converter, which are determined by the operating parameters of the electric drive.

The dominant harmonics structure in the spectrograms depends on the design parameters of the electric motor and the circuit design of the voltage inverter.

To increase the informational content of spectrograms, it is advisable to use various FFT analysis formats.

In the future, a developed model can be used for virtual studies of dynamic modes of the electric drive and studies associated with the identification of structural and parametric faults that arising in its circuits.

***Authors**: assoc. prof., Ph.D.,Yuriy Borodenko, Automobile Faculty, Vehicle Electronics Department, Kharkiv National Automobile and Highway University, Yaroslav Mudry str. - 25, Kharkiv, Ukraine, 61002. E-mail: docentmaster@gmail.com*

Prof., Dr Habil.,Sc, Ing., Leonids Ribickis, Faculty of Electrical and Environmental Engineering, Institute of Industrial Electronics and Electrical Engineering, Riga Technical University, Kalku str. - 1, Riga, Latvia, LV-1658. E-mail: Leonids.Ribickis@rtu.lv

Leading Researcher, Dr.sc.ing., Anatolijs Zabasta, Faculty of Electrical and Environmental Engineering, Institute of Industrial Electronics and Electrical Engineering, Riga Technical University, Kalku str. - 1, Riga, Latvia, LV-1658. E-mail: Anatolijs.Zabasta@rtu.lv

assoc. prof., Ph.D., Shchasiana Arhun, Automobile Faculty, Vehicle Electronics Department, Kharkiv National Automobile and Highway University, Yaroslav Mudry str. - 25, Kharkiv, Ukraine, 61002. E-mail: shasyana@gmail.com

Prof., Dr.,Sc, Ing., Nadezhda Kunicina, Faculty of Electrical and Environmental Engineering, Institute of Industrial Electronics and Electrical Engineering, Riga Technical University, Kalku str. - 1, Riga, Latvia, LV-1658. E-mail: Nadezda.Kunicina@rtu.lv

Student, Hanna Hnatova, Automobile Faculty, Vehicle Electronics Department, Kharkiv National Automobile and Highway University, Yaroslav Mudry str. - 25, Kharkiv, Ukraine, 61002. E-mail: annagnatova22@gmail.com

Prof., Dr. Sc., Andrii Hnatov, Automobile Faculty, Vehicle Electronics Department, Kharkiv National Automobile and Highway University, Yaroslav Mudry str. - 25, Kharkiv, Ukraine, 61002. E-mail: kalifus76@gmail.com

Leading Researcher, Dr.sc.ing., Antons Patlins, Faculty of Electrical and Environmental Engineering, Institute of Industrial Electronics and Electrical Engineering, Riga Technical University, Kalku str. - 1, Riga, Latvia, LV-1658. E-mail: Antons.Patlins@rtu.lv

Reasearchers assistant, Konstantins Kunicins, Faculty of Electrical and Environmental Engineering, Institute of Industrial Electronics and Electrical Engineering, Riga Technical University, Kalku str. - 1, Riga, Latvia, LV-1658. E-mail: Konstantins.Kunicins@rtu.lv

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