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Diagnostics of electric drive Electric vehicle with Valve Motor

***Abstract**. The reliability, safety and economy of the electric vehicle depend on the operation of the electric drive. Diagnosing malfunctions at startup avoid an accident by turning off the system power. Idle testing prevents an accident that may occur while driving. Monitoring the technical states of the electric power supply during the transport process provides an emergency operation mode by redistributing power between its elements. This model presents the results of testing the method of spectral analysis of electrical processes occurring in the power circuit of the electric power supply simulation model. The information content of spectrograms, as a characteristic of the diagnostic parameter, is determined by the options for setting up the FFT analyzer. These options are configured to a maximum frequency switching converter. And other is the sampling period of the spectral characteristic, and the fundamental frequency is selected as multiples of the rotation speed of the electric motor and the switching frequency of the inverter, taking into account the number of phases of the machine. This paper deals with faulty states of electric drive. It is associated with the failure of a functional element, the circuit (breakage or closure) or the deviation of the element parameters from the nominal values. In the first case, the structural identification problem, the system's state, is considered the second - parametric.*

***Streszczenie.** Od działania napędu elektrycznego zależy niezawodność, bezpieczeństwo i ekonomia pojazdu elektrycznego. Diagnozowanie usterek podczas uruchamiania pozwala uniknąć wypadku, wyłączając zasilanie systemu. Testy na biegu jałowym zapobiegają wypadkom, które mogą wystąpić podczas jazdy. Monitorowanie stanów technicznych zasilania elektrycznego podczas procesu transportu zapewnia awaryjny tryb pracy poprzez redystrybucję mocy pomiędzy jej elementy. Model ten przedstawia wyniki badań metody analizy spektralnej procesów elektrycznych zachodzących w obwodzie mocy modelu symulacyjnego zasilania elektrycznego. Zawartość informacyjna spektrogramów, jako cecha parametru diagnostycznego, jest określona przez opcje konfiguracji analizatora FFT. Opcje te są skonfigurowane do maksymalnej przetwornicy częstotliwości przełączania. Drugim jest okres próbkowania charakterystyki spektralnej, a częstotliwość podstawowa jest wybierana jako wielokrotność prędkości obrotowej silnika elektrycznego i częstotliwości przełączania falownika z uwzględnieniem liczby faz maszyny. Artykuł dotyczy stanów wadliwych napędu elektrycznego. Jest to związane z uszkodzeniem elementu funkcjonalnego, obwodu (przerwanie lub zamknięcie) lub odchyleniem parametrów elementu od wartości nominalnych. W pierwszym przypadku problem identyfikacji strukturalnej, stan systemu, jest uważany za drugi - parametryczny. (**Diagnostyka napędu elektrycznego Pojazd elektryczny z silnikiem zaworowym**)*

Keywords: electric car; electric drive; valve motor, high-voltage battery; diagnostics; simulation model; data analysis.
Słowa kluczowe: samochód elektryczny; napęd elektryczny; silnik zaworu, akumulator wysokonapięciowy; diagnostyka; model symulacyjny; analiza danych.

Introduction

Renewable energy and environmental issues attract much public attention worldwide, along with the technological development of production systems to reduce global warming [1]. In this regard, world leaders have decided to phase out fossil fuel vehicles, as evidenced by the Paris Climate Agreement adopted by 196 Parties in 2015 [2]. The road transport emissions from total pollution in some large cities reach 90% [3]. Many countries have announced the abandonment of cars with internal combustion engines and the stimulation of electric vehicles and facing challenges to do it. [4,24,26]. The development of electric cars has become a national strategy of some countries, for example, China and Japan.

One of the main elements of an electric vehicle is electric drive traction (ED) [5]. The entire vehicle's safety, efficiency and reliability depend on its quality [6,7]. Consequently, maintaining and diagnosing these drives' states is of great concern and becoming increasingly important [8].

The ED of an electric vehicle consists of electrical, electronic and mechanical parts. ED is a complex diagnostic system. The causes of malfunctions in the ED can be the following [9]:

- destruction of elements of electrical circuits;
- breakdown of electronic components;
- wear of mechanical parts.

When troubleshooting in the traction ED various methods are used:

- the imitation of intermediate signals; probabilistic-relevant analysis of principal components in terms of probability;
- feedback circuit opening method;
- a sequential checking from end to the beginning;
- The replacement and elimination of individual parts and vibrational elements [10–14].

The paper [15] proposes an intelligent method for diagnosing synchronous motors with permanent magnets. This method is supposed to be used in the electric drive of autonomous vehicles to detect critical stator malfunctions early.

The electrical parts in the ED allow you to investigate electrical processes in the power circuits of the ED and use them to diagnose malfunctions [13]. Improving the means and methods of diagnosing ED makes it possible to reduce the operational costs of vehicle maintenance. These tasks are solved at the design and development stages (adaptation of the plan) of ED systems and during the car's operation (monitoring technical conditions). At the same time, there is a need to create expert systems that operate with information based on knowledge and data [9,16,25,27,28].

The publication [17] proposed a new methodology for diagnosing asynchronous motor malfunctions based on SVM. In this study, vibration and current signals make it possible to detect electrical and mechanical malfunctions.

The article [18] analyses damage to the windings of electrical machines bay using the frequency method. This method allows you to detect an internal fault in the windings of the device.

The electrical circuits of the ED system will divide into a signal (sensors and actuators) and power (power sources and electrical machines). Regarding the first, integrated self-diagnostics tools are used to monitor the state of the control system elements. At the same time, it is impossible to monitor the technical condition of power elements that do not have galvanic connections with the electronic control unit without additional measuring channels.

The study [19] presents a machine learning method for diagnosing faults in ED with asynchronous motors. The work presents a simulation of the system. The authors argue that a structured neural network system, trained using the proposed approach, gives high accuracy in detecting a malfunction and allows you to determine the type of malfunctions in power electronics accurately.

The paper [20] method for detecting faults in the electric vehicle transmission consist of combination logic. The proposed method confirms by modelling in real-time. It allows you to identify more than 20 malfunctions that occur in different modes of operation of the ED, in various components of an electric car transmission - in the inverter, transmission and sensors.

The article [21] presents a method for diagnosing and predicting the state of power modules on bipolar transistors with an insulated gate for use in electric vehicles. A feature of this method is the possibility of accurate online testing to diagnose and predict the power module to determine the malfunction of the wire connections.

The article's authors developed [22] a method for identifying faults in traction ED control systems based on modelling system malfunction scenarios and created a platform for modelling various scenarios of failures in the ED traction control system. But this method, like the previous one, does not allow for identifying malfunctions associated with the wear of mechanical parts.

This article is a continuation of a series of works [9,16,23] which present the results of modelling the ED system in the Matlab Simulink application package, based on which the prerequisites for the harmonic analysis of electrical processes along the circuits of the ED system are determined. The results of these studies show that the requirements that impose on the diagnostic parameter in terms of information content, sensitivity and manufacturability of the measurement are most satisfied by the discharge current of the primary power source. In the first stage, a qualitative analysis of the processes in the valve motor system performed in stationary modes without a secondary power supply (high-voltage converter). The system model used a simplified model of a high-voltage battery in the form of an idealized EMF source with a particular internal resistance.

They were performing a quantitative assessment of the battery's temporal current function based on spectral analysis for the model of the ED system with an overvoltage converter [9,16] in the simulink. Chosen was the nickel-metal-hybrid battery model as the primary source of direct current. The type of spectrograms obtained from the simulation results justifies the research direction.

The purpose of this work is to form a database of an expert system for identifying the technical condition of the ED of an electric vehicle. To achieve a given goal, the resulting model of the system should simulate damage to its elements in operational modes and analyze the spectral composition of the current function in the power circuit.

Several self-diagnosis functions must be implemented in ED operation mode as the problem solution.

Registration of a malfunction at startup allows you to avoid severe consequences by cutting off the power system. Testing on idle mode prevents an emergency that may occur while the car is moving. Monitoring the technical condition of the power source during the transport process provides an emergency mode of operation by redistributing power between its elements

2. Materials and Methods

As an object of diagnostics, the power part of the electric drive of the car, consists of:

- three-phase synchronous electric motor;
- inverter and control circuits;
- rotation speed controller;
- high voltage converter.

Investigating is done to faulty states associated with the failure of a functional element of the circuit (breakage or closure) or the deviation of the element parameters from nominal values. In the first case, the problem of structural identification of the system's state is considered, and in the second - parametric.

Considering the test examples, it is the only option for structural fault identification of DC/DC voltage converter elements.

Further studies involve the system's structural (destruction, breakdowns) and para-metric (temperature destructurization of materials, corrosion, evaporation) deviations.

Signals of standard load monitoring sensors of electric drive power units (temperature, average voltage and current values) do not allow for identifying the cause of the deviation of the indicator parameter values (operational (mode) factors or malfunction). The proposed method registers abnormal variations in the spectral composition of current functions in the power circuits of the electric drive. To allow you to prevent emergencies during the transport process, localize the cause of the malfunction in advance, or use emergency redundancy algorithms in automatic mode.

The simulation model of the ED system is built in the Matlab Simulink application package, Figure 1. The power supply of the valve motor system is provided from the primary voltage source (Battery) with a nominal voltage of 250 V. In this article, attention is focused on the circuit of the converter of constant increased voltage 250/500 V.

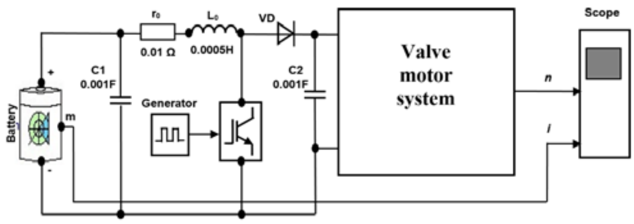


Fig 1. Diagram of a simulation model of a voltage converter.

The scheme of the system uses a Simulink-model synchronous machine with a nominal torque of Mn = 35 Nm and a nominal rotational speed of nn = 3000 rpm. The transistor of the VD converter is controlled by a rectangular pulse generator (Generator) in static mode (f = 20 kHz). The parameter values of the passive elements of the model correspond to the nominal values of the circuit elements of the voltage converter unit of the Lexus RX400h car.

To observe the instantaneous values of the Battery discharge current and the speed of rotation of the motor shaft is used the oscilloscope (Scope) with the spectrum analyzer function (FFT-Analysis).

Simulation of the system is in starting modes without load, in idle mode and under a given engine load M = 37 Nm, at which the shaft rotation speed is n = 850 rpm.

The load is applied to the electric motor after 0.3 seconds after it is turned on.

Imitation of structural damage to the power part of the ED system is performed by switching and breaking off its elements.

Within the framework of the article, we will analyze several faulty states of the high-voltage converter following the scheme above.

Identification of structural damage to the system is based on an analysis of the nature of systematic processes. The sequence of detection of structural damage to the system:

- provide a subjective assessment of the unsatisfactory performance of the system;
- make a diagnosis based on the symptoms (a change in the rotation shaft of the electric motor;
- Based on the results of spectral analysis of the temporal functions of the battery cur-rent by quantifying the diagnostic parameter, we will perform hardware diagnostics.

3. Research results

After activating the model, waveforms of these functions were obtained for a healthy and faulty state of the system (Figure 2), where iB is the current in the power supply circuit of the inverter (high-voltage battery); n is the rotor speed [9].

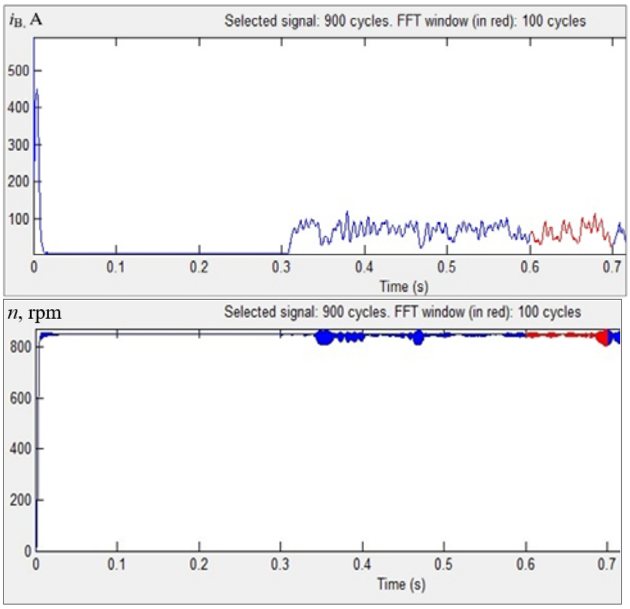
It should be noted that the analysis of mechanical processes considers individual modes (sections of diagrams).

The results of the analysis show the following.

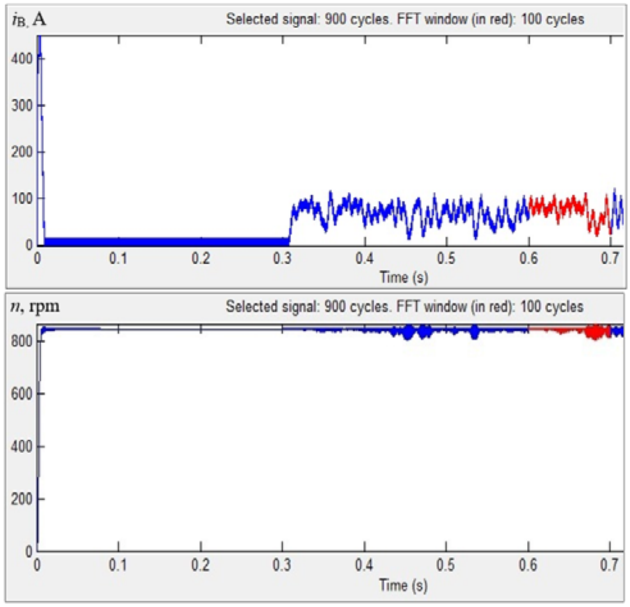
For a healthy system (Figure 2(a)) for the engine start period t <0.05 s, after turning on the power, a current surge occurs caused by the starting moment and charge of the C1 capacitance. The current amplitude values are limited, mainly by the battery's internal resistance. At the same time, the rotor rotation speed increases to a constant idle speed. Further, during the idle period (0.05 s< t<0.3 s), the average values of the current consumption units are amperes, and the speed of the rotor of the electric motor is at a given level (n = 850 rpm).

After the load applies to the motor shaft (t> 0.3 s.), the consumption current (Battery discharge) increases and periodically changes by the torque values. The angular velocity of the rotor shaft also has slight fluctuations with a frequency of change in instantaneous torque values. These effective values are determined by the moment of resistance (given load).

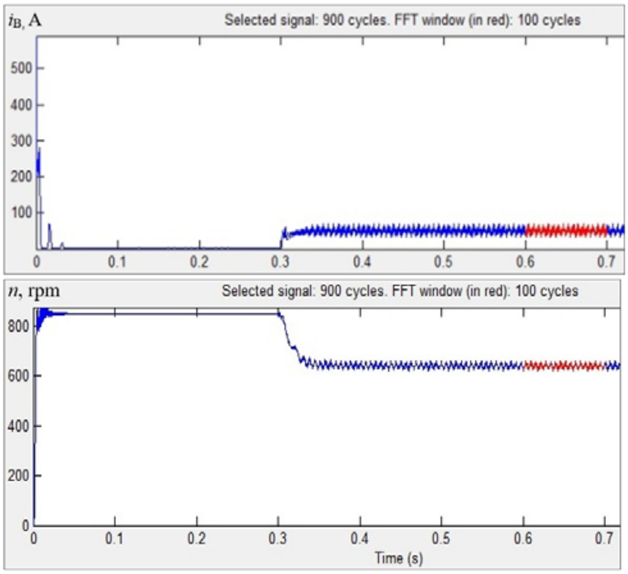
A break in the capacitor circuit (Figure 2(b)) practically does not lead to a change the speed of n, and therefore, the symptom of a malfunction does not record.



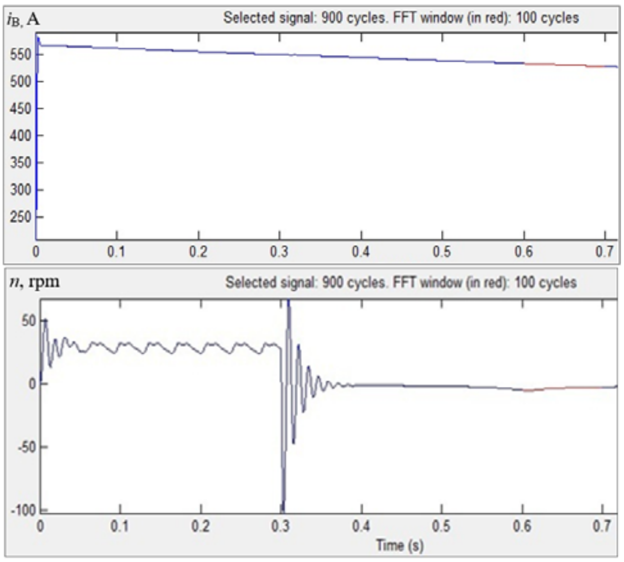
(a)



(b)



(c)



(d)

Fig 2. Temporary functions of motor shaft rotation speed and Battery discharge current in the technical states of the system: (a) In order; (b) With dangling capacitor C1; (c) When the voltage converters are not working; (d) With a punctured diode.

In the circuit breach event of the transistor wrench (Figure 2(c)), the supply voltage of the inverter is equal to the voltage of the battery. At the same time, the start and idle of the electric motor occur without symptoms, and the load of the shaft n speed drops to 610 rpm at idle, and there is some uneven rotation.

Diode breakdown (Figure 2(d)) causes the voltage converter to bypass the battery current is limited only by the resistive impedance of the power circuit. Insufficient idle torque slowly and unevenly rotates the motor rotor at an average speed of n = 30 rpm. In this case, the load of the electric motor stops. Thus, based on the symptoms, malfunctions have been identified that lead to a static state of the voltage converter.

It should be understood that malfunctions not identified by the symptoms of unsatisfactory operation of the ED lead to a decrease in the energy qualities of the power source (increased fuel consumption in hybrids, reduction of autonomous mileage in electric vehicles).

Therefore, to separate the faulty state of the system with a dangling capacitor (Figure 2 (b)) from the serviceable one, a spectral analysis of the battery current function should be carried out, the nature of the change of which has not only quantitative but also qualitative differences.

For spectral analysis by the method of "Fast Fourier transform" (FFT-analysis), specific parameters of the FFT analyzer are selected, which provide sufficient information content for each of the three modes:

- t0 – the moment of the start of the countdown;
- Δt – reference period;
- F is the fundamental frequency that determines the degree of sampling of the spectral characteristic;
- Fmax is the frequency of the upper harmony of the spectral characteristic.

Figure 3 shows the spectrograms obtained at the start of the electric motor. The field of the figure shows the amplitudes of the base harmonics IA(FF) and the harmonic coefficients THD of the current functions at the corresponding modes.

It is important to note that 20 kHz is the maximum frequency (range) of observations (spectral analysis) in the framework of research, which is by the boundary frequency of the DC/DC pulse converter (250/500 V). In each example of malfunctions (technical conditions) and in individual modes of operation of the electric drive, it is possible to distinguish a narrower range of dominant frequencies (spectrum up to 800 Hz), in which the indicator parameter (amplitude, phase) is the faulty state has maximum deviations relative to values in good condition, figure. 3

On the axes of the ordinate of spectral characteristics is a percentage of the amplitude of the base harmonic %FF.

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

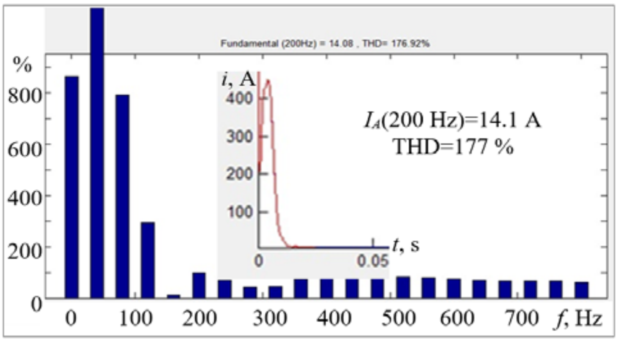
As parameters that allow distinguishing the states of the system, according to the results of the spectral analysis:

- spectral composition IA(fj);
- harmonic coefficient THD;
- a phase shift of harmonics.

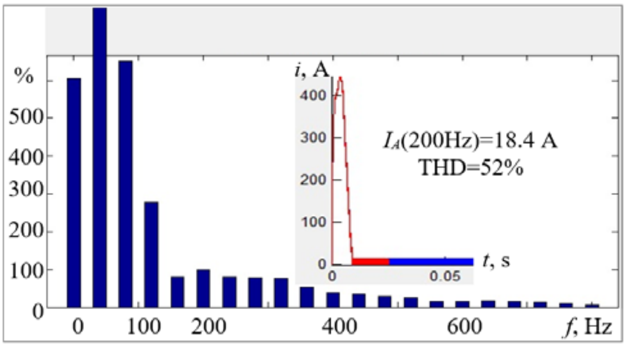
Analysis of the obtained spectrograms allows us to draw the following conclusions.

Spectrograms of the inrush current surge functions for all the technical states under consideration differ in amplitudes and make it possible to distinguish all the considered technical conditions of the system.

In idle mode, the state with a dangling capacitor is separated from the serviceable condition by the levels of the constant component and the harmonic f = 20 kHz (Figure 4 (a), 4 (b)).



(a)



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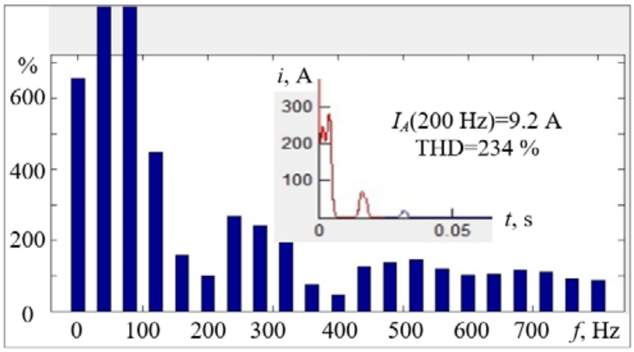

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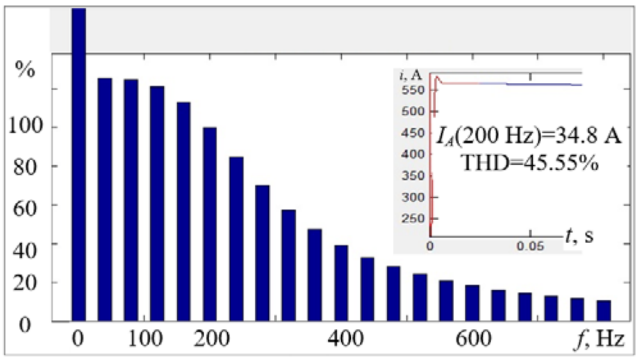


(d)

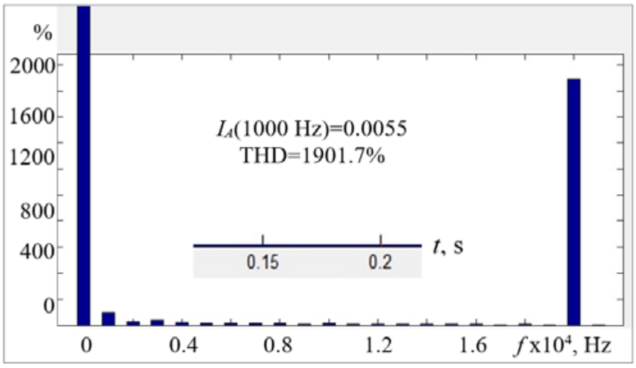
Fig 3. Spectral composition of current temporary functions in the power circuit when starting the electric motor in the technical state of the system: (a) Serviceable; (b) With dangling capacitor C1; (c) When the voltage converter is not working; (d) With a punctured diode.

Analysis of the obtained spectrograms allows us to draw the following conclusions.

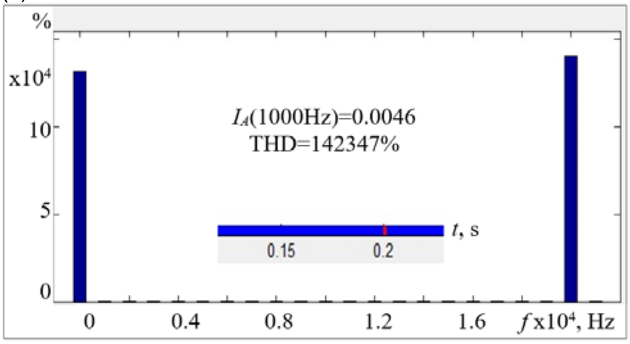
Spectrograms of the inrush current surge functions for all the technical states under consideration differ in amplitudes and make it possible to distinguish all the considered technical state of the system.

In idle mode, the dangling capacitor state is separated from the serviceable state by the levels of the constant component and the harmonic f = 20 kHz (Figure 4(a), 4(b)).

The last two states are distinguished quantitatively – by amplitude values and harmonic coefficients (Figure 4 (c), 4 (d)).



(a)



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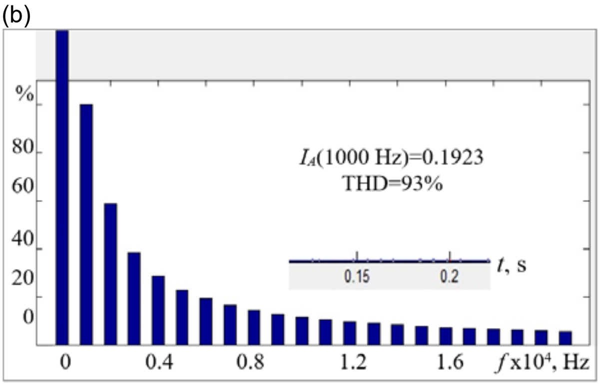

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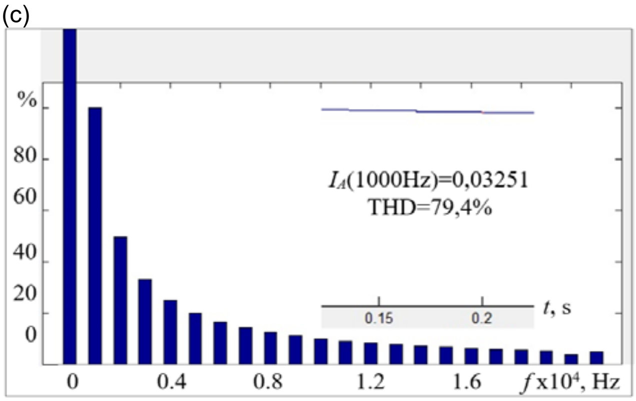
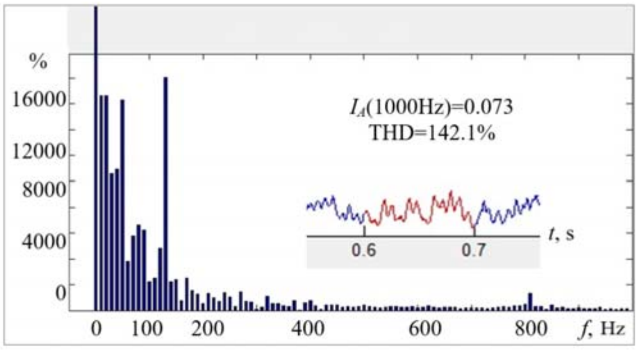


(d)

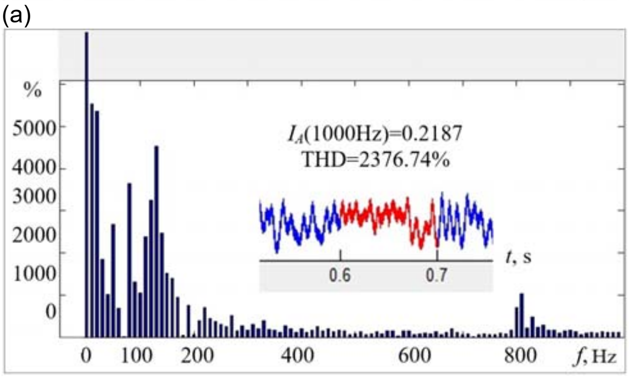
Fig 4. Spectral composition of the temporal functions of the current in the power circuit in the idle mode of the electric motor in the technical states of the system: (a) Reference; (b) With dangling capacitor C1; (c) When the voltage converters are not working; (d) With a punctured diode.

The spectrograms of the technical states under consideration during the ED under load operation differ in qualitative and quantitative indicators, Figure 5 [9].

Identifying states by spectral composition, and confirming the registration of mal-functions by symptoms, is not superfluous since the examples given do not consider all possible technical states of the system where this information is helpful.



(a)



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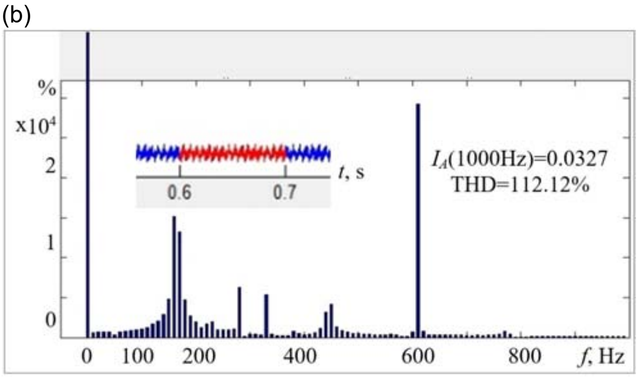

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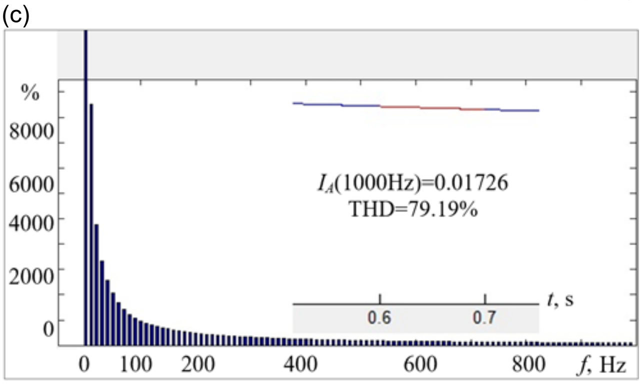

(d)

Fig 5. Spectral composition of the temporal functions of the current in the power circuit when the robot of the electric motor is under load in the technical states of the system: (a) Reference; (b) With dangling capacitor C1; (c) When the voltage converters are not working; (d) With a punctured diode.

But according to the studies, it can be argued that to localize a malfunction in the power circuits, it is advisable to conduct a spectral research of the temporary functions of the supply current at various system operation modes.

The information content of spectrograms, as a characteristic of the diagnostic parameter, is determined by the options for configuring the FFT analyzer. These options are assigned based on the following recommendations:

- Should be selected the upper limit of the frequency of the Fmax spectrum per the maximum frequency of switching the current of the converter (on this generator model - 20 kHz)
- The period of sampling of the spectral characteristic and fundamental frequency F – multiples of the rotational speed of the electric motor and the frequency of switching of the inverter, taking into account the number of phases of the machine.

The results of these studies will find further applications to improve the proposed method for diagnosing the electric drive of an electric vehicle with a valve motor.

Conclusions

It is advisable to conduct a spectral analysis of the temporary power functions in various system operation modes to localize the malfunction in the power circuits of the electric drive, along with the study, the symptom of their manifestation.

The information content of spectrograms as a characteristic of the diagnostic parameter is determined by the options for configuring the FFT analyzer. These options are assigned based on the following guidelines: The upper limit of the frequency of the Fmax spectrum should select by the maximum frequency of switching the current of the converter (on this generator model - 20 kHz), and the period of sampling of the spectral characteristic and, accordingly, the fundamental frequency F - multiples of the speed of rotation of the electric motor and, consequently, the frequency of switching the keys of the inverter, taking into account the number of phases of the machine.

Often systems have faulty states associated with the failure of the functional elements of the circuit (breakage or closure) or the deviation of the element parameters from the nominal values. In the first case, the problem is structural identification of the system's state, and secondly, parametric.

The test examples have only options for structural fault identification of DC/DC voltage converter elements.

Further studies involve the system's structural (destruction, breakdowns) and para-metric (temperature destructurization of materials, corrosion, evaporation) deviations.

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