Investigation of the Protection System According to the Main Working Parameters of Electric Motors

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***Abstract*—The research work is devoted to the creation of a protection system for electric motors used in industry and transport, based on modern and traditional sensors. In the course of operation, the malfunctions of electric motors were investigated and it was found that the emergency modes occur mainly as a result of exceeding the permissible values of the current, voltage and temperature parameters. Modern sensors of current, voltage, and temperature were compared and the most effective ones were selected for use in electric motors. On the basis of these sensors, a protection system for a low-power electric motor was built in the laboratory. Also in the Multisim application software package, a simulation of the operation of the protection system at different voltage and current values is performed, a circuit of the sensor control unit and the power source for powering the protection system is constructed. It is proposed to apply such a multi-parametric complex protection system for electric motors specially in transport.**

***Keywords*—electric motor, short circuit, overload, current sensors, relay control, protection system**

I. INTRODUCTION

In industry, transport and various fields of technique asynchronous, synchronous and collector alternating current machines are widely used. Currently, it is used more than asynchronous machines that work in motor mode.

In connection with the development of static converters, the capabilities of induction motors have significantly increased. In this regard, the possibilities of using these motor in electric transport are considered more effective. Modern vehicles mainly use a short-circuit rotor asynchronous motor as an electric motor.

As in all electrical machines, there is always a high probability of occurrence of abnormal and accidental regimes, injuries on induction motors. Therefore, the working process and operating parameters of induction motors especially in railway transport, operating in difficult working conditions should be constantly monitored.

One of the most important issues to increase the efficiency and durability of vehicles, power supply system is to provide reliable and accurate control of its electrical parameters, optimal protection against voltage, current and other parameters in case of emergency operation.

Thus, as a result of the research, it was determined that the application of modern electronic sensors to control the technical condition of electric motors can provide a more reliable mode of operation.

It is known that the increase in load for one reason or another during the use of electrical equipment leads to the failure of the device, and at best, to the damage to the elements of the electrical circuit of the device. Faults of electrical origin occur as a result of the effects of short-circuit currents, electric arcs and sparks, reduced insulation resistance and other causes. This shortcoming requires more funding and worker from operating companies.

In recent years, significant research has been conducted to develop new methods to monitor the technical condition of electric motors, to overcome the shortcomings of traditional methods. The incidence of motor failures or abnormal modes increases with the complexity of its operating mode, and therefore there is a need to create more sensitive and modern protection systems based on the results of additional failures and the results obtained.

Only the temperature parameter is used to conduct diagnostic monitoring of traction electric motors operating in railway transport, produced by a number of leading companies in the world. The results of the research show that the temperature parameter alone does not provide complete and perfect information about the technical condition of the motors and a number of parametrs need to be added to these parameters in row in order to obtain more accurate results. For this reason, complex diagnostic monitoring of electric motor and the creation of multi-parameter proection systems based on it is actual [1].

II. STATEMENT OF THE PROBLEM AND SELECTION SUBSTANTIATE OF SENSORS FOR MULTI-PARAMETER PROTECTION SYSTEM

The technical condition of electrical equipment is carried out primarily by checking the level of reliability and parameters. It is possible to create more reliable and sensitive protection systems due to the information obtained as a result of diagnostic monitoring of the technical condition.

In order to ensure more stable working conditions, it is necessary to take into account the characteristics of the effect of caution and reliability indicators in the motors on the uninterrupted operation of the power supply system associated with this unit.

Suppose two identical motors are used as a backup in a system. If one of them fails, the other motor will run at full system load. The breakdown intensities of the motors are the same and constant, $\lambda = \lambda_1 = \lambda_2 = 0{,}0005$ 1/s. In this case, it is necessary to determine the exponential law of the probability of proper operation of the motor at t = 400 hours.

Since the motors are of the same type, the probability of a malfunction is as follows:

$$P_{sis}(t) = 2e^{-\lambda_1 \cdot t} - e^{-2\cdot\lambda_2\cdot t} = 2\cdot e^{-0{,}0005\cdot 400} - e^{-0.0005\cdot 400} = 0{,}9671 \quad (1)$$

According to the data, the average operating time of the system is calculated as follows:

$$T_O = \frac{1}{\lambda}\left(1+\frac{1}{2}\right) = \frac{3}{2}\cdot\frac{1}{0{,}0005} = 3000 saat \quad (2)$$

In order to increase the probability of proper operation of the electric motor, it is necessary to ensure that it is switched on and off and that the operating modes are protected from leaps in transition process and possible accidents.

Acute voltage fluctuations, current overloads, short circuits, temperature changes, etc. in such cases, the establishment and application of a multi-parameter protection system to prevent equipment, source and loads failures is of particular importance.

During operation of electric motors, non-standard and possible emergency cases can be divided into the following groups:

- Abnormal and accident modes occurring in the network (voltage above and below the nominal value, frequency change, etc.)

- Non-standard and accident situations related to the current (interphase short circuits in three-phase motors; breaks in the stator or rotor windings; overload or short-circuit currents etc. perforation of insulation due to temperature rise caused by)

Special protection devices are developed and applied to protect motors from damage in unacceptable and emergency modes. As it is known, a short-term decrease in voltage leads to a decrease in the torque of electric motors used in transport. After the voltage is restored, the motor restores its torque and returns to the nominal operating mode. In this case, the value of the current required by the motor increases sharply, which, in turn, can lead to the activation of the protection. The setting parameters of the protection installed in the electric motor should be selected so that the protection does not start and turn on the motor circuit when the short-term voltage drops. For this, special attention should be paid to the selectivity of the security system.

In addition to the current and voltage parameters, one of the other main parameters that must be protected is the operating temperature of the windings. It is unacceptable to increase the temperature in the windings. If the operating temperature of the motor windings exceeds the +10°C heat limit for any period of time, the insulation of the stator and rotor windings is reduced by half the service life.

It is known that, there are plenty of sensors based on various physical effects to control the values of current and voltage: resistive, inductive and capacitive sensors based on Ohm's law; transformer sensors based on Faraday's electromagnetic induction law; voltage and current sensors based on the Holl's effect, and traditional voltage and current sensors based on other effects [2-5].

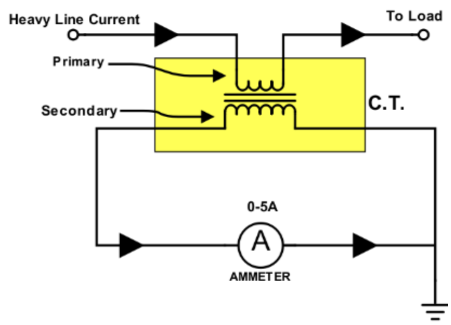
At the same time, there are modern sensors based on the application of Rogovsky winding, electro-optical and magnetic-optical effects for non-contact measurement of high voltages and currents.

Resistors, transformers and Holl-effect sensors are mainly used to measure the electrical parameters of modern locomotives used in railway transport.

Resistive sensors are simpl and economical, the principle of operation is based on the direct proportion of the voltage across the reference resistor connected in series with the load in the current circuit (Ohm's law), can be used to measure direct and alternating currents.

The external appearance and connection diagram of the widely used different types of current sensors are shown in Fig.1, and the constructive and principle diagram of the voltage sensors are shown in Fig. 2.

a) Hall sensors *b) Inductive sensors* *c) Rogowski winding*



d) Current transformer

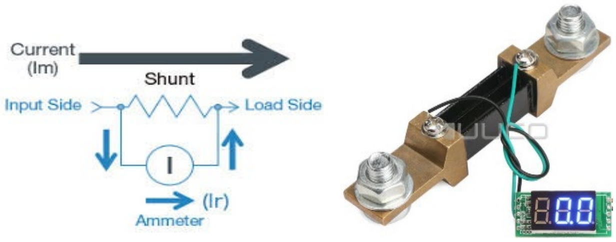
Fig. 1. Constructive and principle scheme of current sensors

In the laboratory, a current transformer was used to control the current value in protection system designed for a low-power asynchronous motor. In high-power motors, the introduction of the Ragowsky windings is considered to be more promising than the current sensors [6].

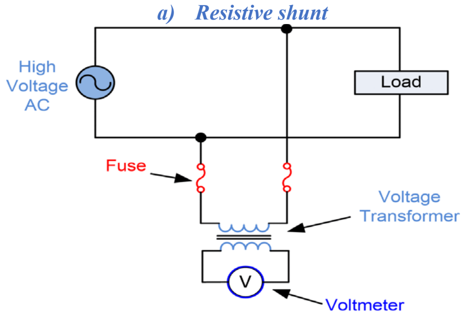
Voltage sensors based on electrical, electro-magnetic, electromechanical, electro-thermal, electro-optical and other similar physical effects are widely used in theoretical and practical researches.

The measurement procedure, the selection of the appropriate type of sensors is determined by the type and level of voltage. It is important to amplify the signals in order to record low voltages in the measurement circuit, and to reduce the received signals to an acceptable level at high voltages [7-9].

Voltage dividers (resistive, capacitive and inductive), voltage transformers, electronic voltage sensors, etc. are more widely used as voltage sensors (Figure 2).



a) Resistive shunt



b) Voltage transformer

Fig. 2. Constructive and principle scheme of voltage sensors

The use of voltage transformers for measuring high voltages is considered more expedient.

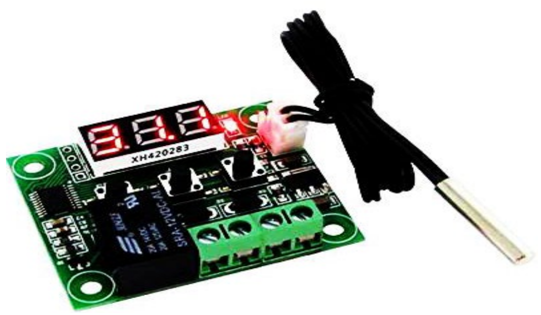
A resistive divider was used to control the voltage value in the protection system designed for the low-power electric motor. The resistive divider is considered simpler and technically more economical.

Voltage transformers are often used as voltage sensors in high power motors. Due to the large dimensions of voltage transformers, it is more expedient to use a resistive shunt and a resistive divider as a voltage sensors, where possible [10, 11].

Several methods are used to measure temperature. These include fiber-optic temperature sensors, electrical resistance thermometers, thermographic methods, thermocouple-based temperature sensors, etc. (Fig. 3).

As a contact temperature sensor for determining the temperature value in high-powered motors, the thermocouple is considered more suitable.

The main advantage of a thermocouple-based module sensor is the transmission of a signal with a direct relay output. Based on the signal received from the sensor, it is possible to both protect the motor and perform diagnostic analysis of the recorded data, as well as set up special alarm systems by displaying the data on special displays. Thanks to this, it is possible to ensure more reliable and stable operation of the motor.



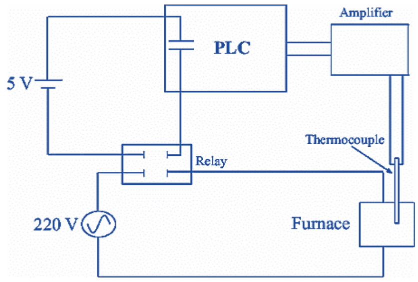


Fig. 3. Constructive and principle scheme of temperature sensors

Experiments were carried out on the electric motor according the three important parameters mentioned above and a protection system based on automatic control with relay output was installed. The operation of the relay is determined by the electrical signal received from the sensors. Based on the electrical signals, in any abnormal and emergency situation the relay motor which is controlled by the protection system is disconnected from the mains. MLE00137 of type relay was used to protect the motor (Fig. 4).

This type of relay is distinguished by its compactness, large process switching capabilities, start-up speed, etc. This relay is able to provide normal operation when the supply voltage of the working winding is in the range of 6-15V.

III. MAGNETIC FIELD MEASUREMENT AND OUTPUT SIGNAL ANALYSIS

In laboratory conditions, an experimental stand on the basis of a low powerful motor has been developed to simulate malfunctions that may occur in motors and control the changes that occur in electrical parameters.

One of the most modern and promising methods for diagnosing motor malfunctions and building a protection-warning system based on this, is the measurement and spectral analysis of the magnetic field.

The results of the analysis show that the defects and malfunctions in the electric motor have a significant effect on the spectrum of the electromagnetic field generated outside it. By continuously monitoring the magnetic aura of the motor in working condition, it is possible to determine the change of a number of parameters and create special protection and warning systems based on the results obtained. For example: overload, increase and decrease of voltage, change of current frequency, etc.

In researchs, the use of a Hall sensor as a sensor that allows non-contact diagnostics without interfering with motor design has been preferred. Thus, this sensor can be considered one of the most informative sensors that allows you to assess the condition of the motor by monitoring the electromagnetic spectrum.

In experimental research, the use of KY-024 Hall sensor, which is less sensitive to external influences, was preferred. The connection scheme and design structure of these types of sensors are given in Figure 4.

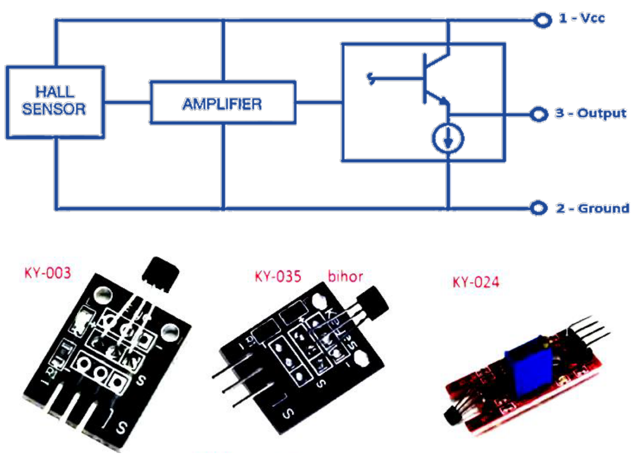


Fig. 4. Traditional connection scheme and constructive descriptions of Hall sensors

The recorded oscillograms of the magnetic field change in different modes of the electric motor studied using the KY-024 sensors are given in Figure 5.

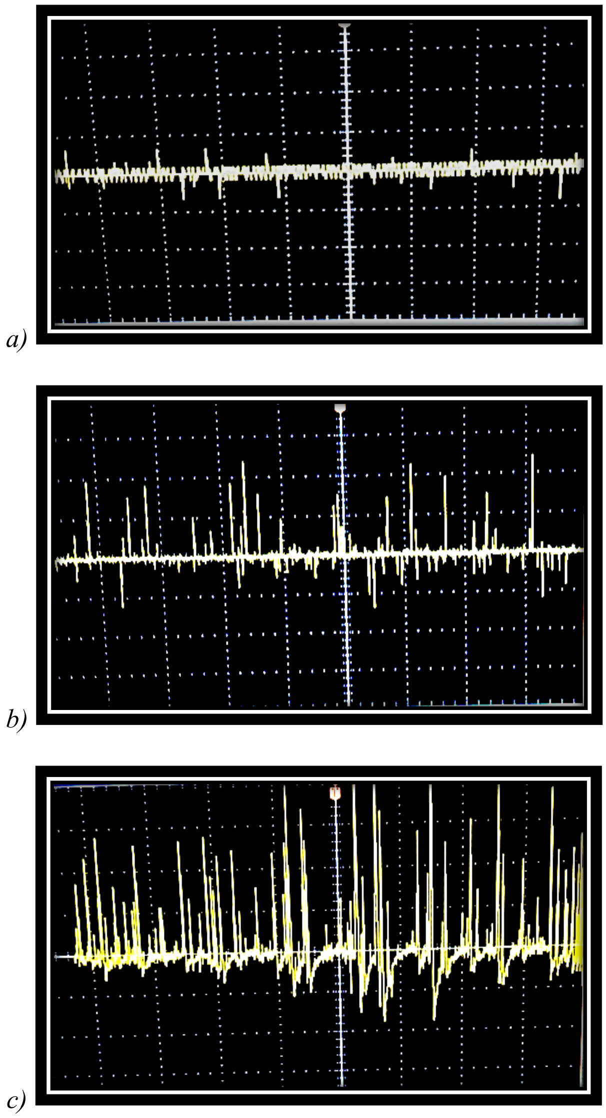


Fig. 5. Oscillograms of the motor magnetic field: a) at standstill; b) in normal operation; c) in overload

As can be seen from the analysis of oscillograms, in normal, failures or defects, overload and etc. conditions, the magnetic field around the electric motor changes with big difference. Thus, on the basis of the recorded data, it is possible to create a modern protection-warning system by diagnosing the motor and at the same time analyzing the signals at the output of the sensor [1].

IV. MODELING OF MULTI-PARAMETER PROTECTION SYSTEM

In reality, the development and implementation of a working version of the system that can perform the above functions is accompanied by many technical problems. Therefore, since modern applications are more accessible for individual and complex simulation of functions, it is more expedient to develop an imitation model of the system through these programs. This, in turn, allows the creation of a working model based on an imitation model of the system in research and production facilities, which allows you to design a real prototype of the system. In our research, based on the Multisim program, an imitation model of the device was developed, which provides protection against short circuits, overloads, as well as drop of voltage and overvoltage in the phase of the motor powered by an electric power source.

Relay control is applied at both high and low voltage limits at specified values. In the Multisim program, the protection circuits are built and modeled according to the voltage limit. Schematics of protection activation at normal, high and low voltage values are shown in Figure 6, Figure 7 and Figure 8. When the green LED is turning on indicates that the voltage is within the normal range. In abnormal modes, red LED in turning on and indicates that the mains voltage has exceeded the allowable limit.

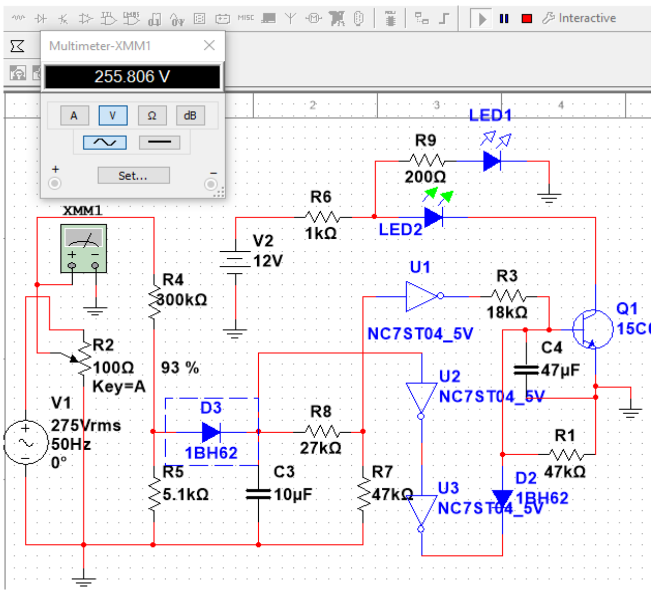


Fig. 6. Electrical circuit of the protection device at the range of normal operating voltages (168-260V)

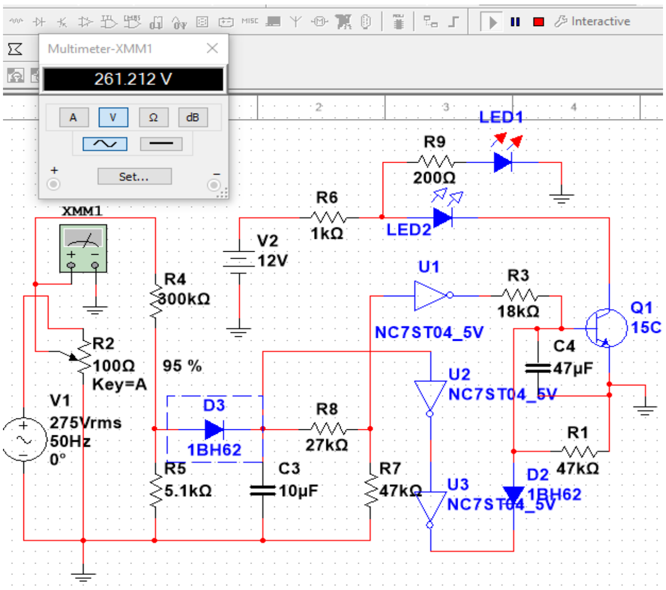


Fig. 7. Electrical circuit of the protection device at the value of the voltage above the nominal (U_{in} > 260V)

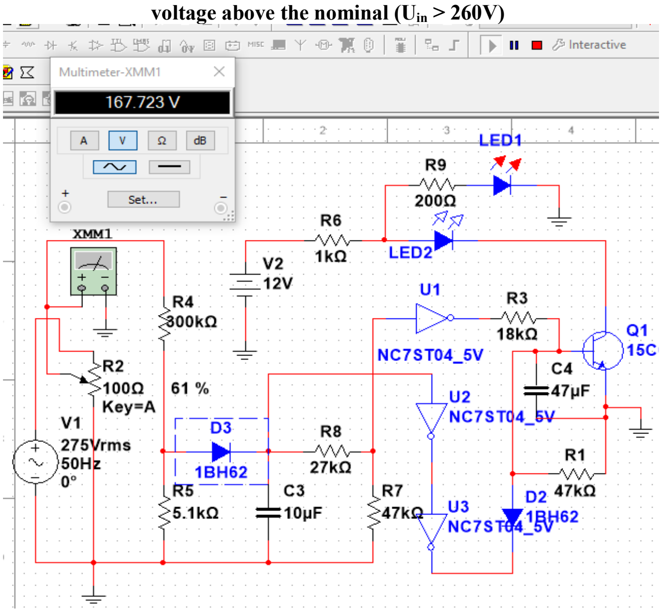


Fig. 8. Electrical circuit of the protection device at a voltage low the nominal value (U_{in}<168V)

The current protection ensures the opening of the motor from the food source by activating the relay at the limits of the current above the specified values. To simulate the current protection in Multisim, a resistive shunt-based protection scheme was used and the change of the current in the intended range was immobilized, giving an adjustable voltage to the input of the scheme.The simulation results for the current performed in Multisim are given in Fig 9 and Fig 10.

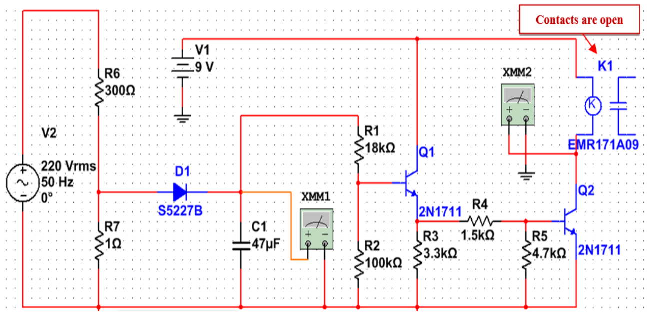


Fig. 9. Electrical circuit of the protection device at the nominal value of current

The rated motor current is 0.55A at 220V. In our case, the critical value of overloading, the minimum value of the current required for the protection of operation, is 0.9A.

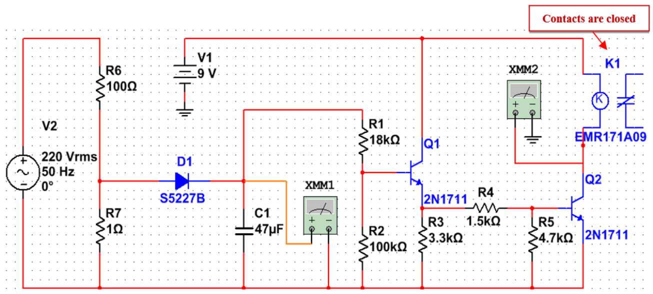


Fig. 10. Electrical circuit of the protection device during emergency operation (short circuit or allowable price overload)

Built on the logic elements of the protection system, a second transformless unit was developed to provide the nominal 5V and 9V supply voltages required to power the electronic control unit for voltage limits, transistor control unit for current limits, temperature protection unit and output relay unit.

An autotransformer was used to obtain a controlled voltage value in laboratory conditions.

As mentioned, the second power supply of the unit is for power supply of voltage and current, as well as the control unit of temperature control sensors and the protection system according to these parameters. On the basis of the transformerless power supply circuit for power supply of the protection system, the input voltage is 170 - 275V, the output voltage is 5.1V, the relay circuit is 7.5 - 12V, the total current required by the parametric stabilized power supply is 40-65mA. Since there is no autotransformer in the MultiSim software base, the regulated voltage is supplied to the circuit via a potentiometer.

For sufficient load capacity of the power supply, it is possible to use a transistor in the output circuit of the stabilizer as an amplifier. Since the base-emitter junction of the transistor has a voltage drop of 0.7 - 0.8V, a stabilitron with a stabilization voltage of 5.6 - 5.7V should be selected to provide 5V at the output. For the selected stabilitron to operate in stabilization mode, its current in the range Ist = 3 - 50mA, as well as the current of the base circuit and stabilitron together can be selected 10 - 15 mA, taking into account that the rated voltage of the transistor is higher than 50 and the current at the output of the transistor is less than 100 - 200mA.

The type of relay, designed to replace the power chains of the selected relays and powerful analog motors, can normally operate at wide voltages (in this case 7 - 15V), the stabilization is not required for the relay power circuit. If necessary, the same stabilization scheme can be applied.

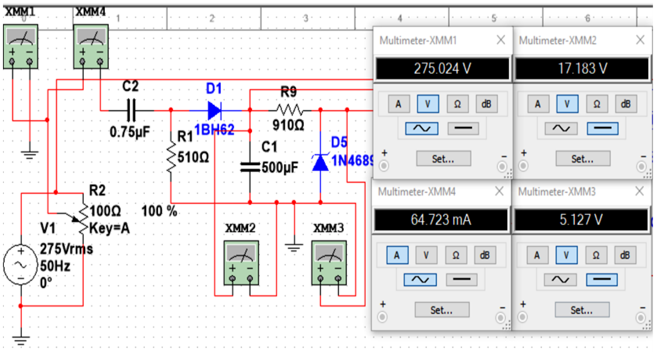


Fig. 11. Electrical circuit of the second power supply of the protection device

A protection system based on relay control was installed and experiments were performed on the motor to control the temperature parameter. The normal temperature of the motor windings is determined by the insulation class. Traction electric motors operated in the most modern locomotives used in railway transport are equipped with C-class insulation (200°C and above).

$$T_{open} \geq +38{,}5°C\ ;$$
$$T_{norm} = 0 \div 38.4°C;$$
$$T_{rec.t} = 35.7°C \qquad (1)$$

- T_{open} – operating temperature of the protection system;
- T_{norm} – normal motor operating temperature;
- $T_{rec.t}$ – reconnection temperature;

In order to connect the protection system (opening the motor) in motor, which is the object of study, the temperature of the windings should reach T_{open}. These temperature values were conditionally taken for the experiments. To restore the operation mode of the motor started by means of protection, the temperature of the windings must be conditionally lowered to the reconnection temperature value $T_{rec.t}$. When the winding temperature cools down to normal operating temperature (that is, reconnection temperature), the relay restarts the motor.

A modular thermocouple based on a was used to determine the temperature of the motor windings. The input of the module is supplied with a constant supply voltage of 9V. The output terminals are similarly connected to the motor and relay. The thermocouple transmits the signal to the module, where it compares the opening temperature with the normal temperature and sends a pulse to the relay. The relay turns on the motor according to the received impulse or restarts the motor with protection.

A model of the complex protection system for voltage, current and temperature, developed in laboratory conditions, is shown in Fig. 12.

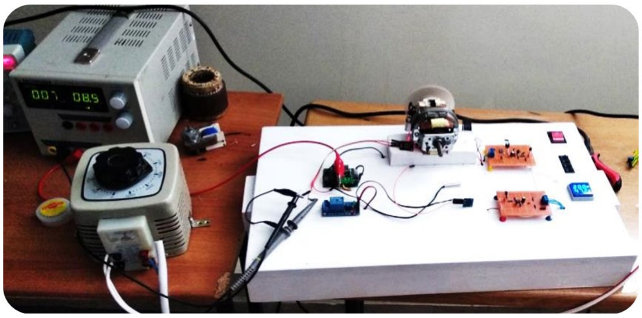


Fig. 12. Multi-parameter protection device developed in the laboratory

V. CONCLUSION

Thus, in the research, the faults of the electric motor were investigated and it was determined that the emergency modes occur mainly as a result of exceeding the permissible values of current, voltage and temperature parameters. Also, modern current, voltage, temperature sensors were compared and those with the best performance for use in electric motors were selected. According to the mentioned main parameters, the main control and power supply blocks of the protection system were analyzed in the Multisim application program and a model of the system providing complex protection in the laboratory was practically established.

At the same time, the use of LEDs as a signaling element, as well as limit elements in the control circuits of the lower and upper current limits, or as a component of the logic "OR" element in the proposed device has been found to have different advantages over other such devices.

Thus, based on theoretical and practical research, it can be said that it is possible to show the warning signals on the appropriate display by protecting the temperature, voltage and current of electric motors used in transportation and industry and transmitting also the results send to the relay control circuit and the central control station.

Using the modern sensors we offer, it is possible to ensure a stable operating mode of electric motors with the help of a complete multi-parameter protection system.

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