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Modeling of an Integrated Traction Motor Protection System

Purpose. The article is devoted to the creation of traction motor protection by modern methods and means based on a programmable logic controller (PLC). **Methodology.** To simulate motor fault monitoring in laboratory conditions, magnetic field and temperature sensors were installed on a small powerful induction motor, and then the data obtained from the sensors in normal and overloaded motor modes were analyzed. Based on the research, protection methods were developed. **Findings.** Previously used simple motor protection systems based on components such as timers, contactors, electromagnetic switches, voltage and current transformers were slow and inaccurate, and had low sensitivity. However, the production of PLCs and their application in this industry has eliminated these problems. The intensive operation of motors as the main executive equipment requires the creation of modern automated protection systems to ensure their reliable and stable operation. **Originality.** The paper improves the method of protection of traction motors based on the use of programmable logic controllers. In addition to the voltage and current parameters, the proposed method involves monitoring the magnetic field. It also provides for the possibility of adjusting the protection response time. As a result, in the event of overload, short circuit, and other non-standard situations, the improved method provides the system with the ability to make more accurate and reliable decisions. **Practical value.** The TIA Portal software package has modeled a traction motor protection system by temperature and current and considered its practical application. To make such systems more effective, in the future, comprehensive protection systems based on the diagnostic state of the traction motor can be developed. In addition, an effective system can be created by providing SCADA control of the engines of several vehicles simultaneously.

Keywords: traction motor; programmable logic controller (PLC); overload; magnetic field control; temperature control; overload; Hall sensor

Introduction

Electric motors are electromechanical machines used in industry and other fields to convert electrical energy into mechanical power. Electric motors are widely used in vehicles, machine tools, presses, cranes, escalators and elevators. Traction asynchronous motors used in transport are particularly distinguished from other traction electric motors by their high reliability, low maintenance requirements and high efficiency. Motor failure is mainly due to mechanical and electrical stress. Overloading, sudden and sharp load changes in motors cause mechanical stresses resulting in increased temperature, vibration and noise. Electric voltage can cause short circuit, temperature rise, phase loss etc. due to some other faults. Failure to prevent malfunctions and defects in time leads to motor failure. This is unacceptable in important production areas, as well as in transport. Real-time automatic protection and control of motors is required for timely detection of abnormal conditions to reduce the number of breakdowns that lead to long downtimes and high motor overhaul costs. The main difficulty in creating such a protection system is its complex organization. The variation of the main parameters to be protected in a wide range depending on the motor load and operating mode directly affects the accuracy of the protection [4, 11, 12].

Traction electric motor (TEM) stopping due to any malfunction during operation creates great difficulties in traction. To avoid such problems, it is possible to predict failures in TEM. Based on the diagnosis of the technical condition of traction electric motors, a list of malfunctions should be

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drawn up, and by determining the normal and threshold values of the main information parameters involved in the occurrence of these malfunctions, more reliable complex protection systems can be established in the future. With the application of such systems, it will be possible to monitor the changes occurring in the motors and draw conclusions about these changes by organizing regular diagnostic control of the motor parameters.

Currently, several methods are used to protect electric motors. The application of traditional protection systems in the protection of motors has some disadvantages. To overcome these shortcomings, modern protection systems should be developed according to the diagnostic status of motors. To overcome the problems of traditional protection systems, PLC (Programmable Logic Control) based protection systems can be applied to motor fault detection and protection.

Nowadays, system control in energy systems and several large enterprises is carried out based on SCADA. The main element of the SCADA system is the PLC. Considering the scope of use of PLCs, their application in motor protection is prospective. Below is a block diagram (see figure 1) for the protection of an electric motor based on PLC [1, 2, 4,15].

As shown in the block diagram, CT (current transformer), and PT (potential transformer) sensors are used to measure current and voltage, and LM35 sensors are used to measure temperature. The output of these sensors is fed to the PLC. In this protection method, online monitoring of the electric motor is carried out and all informative parameters – voltage, current and temperature are monitored. If all parameters are within the normal operating range, the PLC will continuously allow a three phase power supply to the motor.

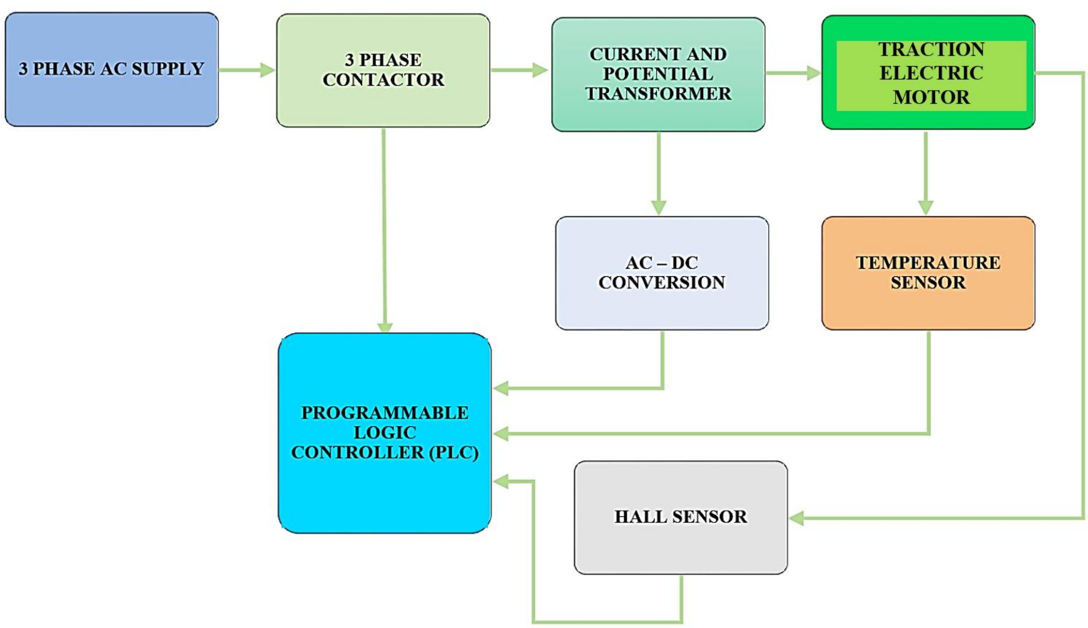

Fig. 1. Block diagram for protection of electric motor based on PLC

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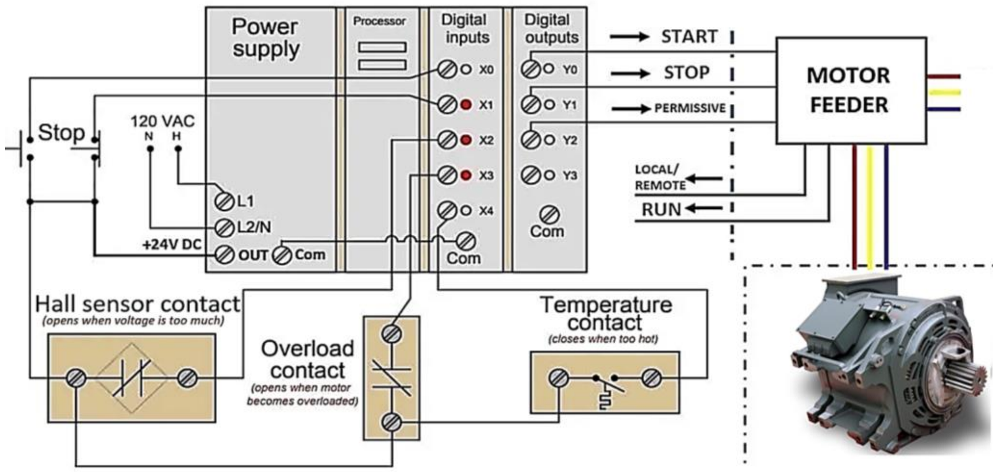

Fig. 2. Motor protection circuit based on PLC

However, if any abnormal mode is detected, the PLC will stop the induction motor by giving an opening signal to the magnetic contactor and relay according to the programmed conditions [2, 4, 13, 15].

Today, PLCs are continuously evolving and striving to be the best choice for various industrial automation applications. Since the PLC-based protection system is a reliable, fast, high-precision system, modern protection systems of traction electric motors based on PLC are studied in the article [3, 5, 8, 9].

Purpose

The article is dedicated to the organization of PLC (programmable logic controller)-based protection of the traction electric motor with modern methods and instruments. In order to simulate the control of a series of faults in the motor, magnetic field and temperature transmitters were installed on a small powerful asynchronous motor in laboratory conditions, the data received from the transmitters in the normal and overload modes of the motor were studied and protection was established.

Methodology

In the practical part of the research, a model of a modern protection system was created in laboratory conditions based on a small powerful motor. Temperature, magnetic field (overload), current and voltage are taken as informative parameters for motor protection.

One of the most modern and promising methods chosen for constant control of the technical condition of the TEM during operation is magnetic field measurement and spectral analysis. In the laboratory, an experimental stand based on a small powerful motor was developed to simulate possible malfunctions of the TEM and control changes in the main parameters [6, 10, 13, 14]. The results of the analysis show that defects and malfunctions in the electric motor significantly affect the spectrum of the electromagnetic field generated outside it. By analyzing the spectrum of the external magnetic field, an idea can be made about the failure of the TEM. Research has prioritized the use of a Hall sensor as a sensor that allows non-contact diagnostics without interfering with the motor design. Thus, this sensor can be considered one of the most informative sensors that allows you to evaluate the condition of the motor by monitoring the electromagnetic spectrum. A traditional connection diagram for this type of sensor is shown in figure 3.

During the experimental studies, the use of KY-024 Hall sensor, distinguished by its performance, was preferred. The oscillograms of the magnetic field change in different modes of the motor studied using the KY-024 Hall sensor is shown in figure 4.

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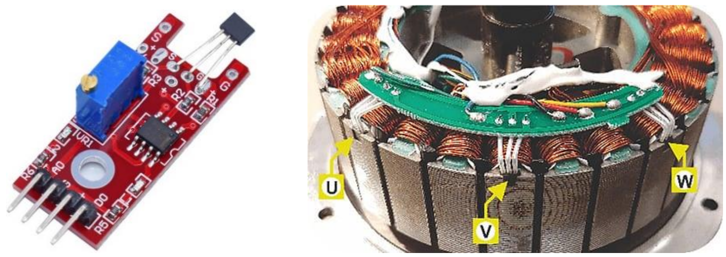

Fig. 3. Connection and constructive description of Hall sensor with motor

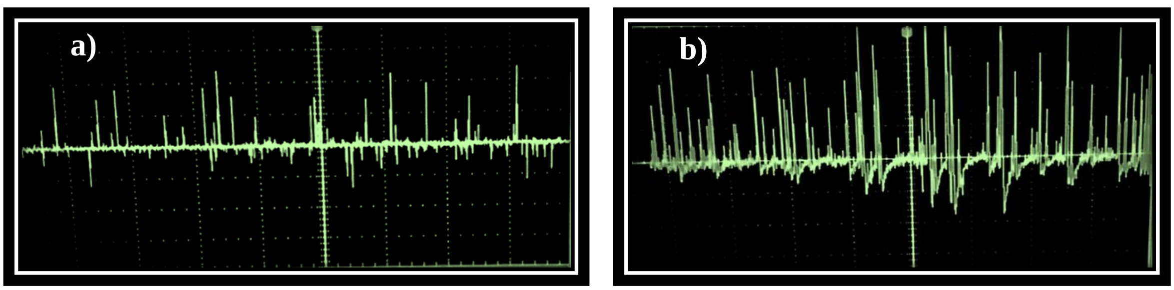

Fig. 4. Recorded oscillograms of magnetic field changes:
a – during normal operation; *b* – in case of overload

The oscillograms were recorded and analyzed using a oscilloscope.

As can be seen from the analysis of oscillograms, magnetic field control can be selected as one of the most important parameters for modern protection system of the motor.

Temperature control is one of the main diagnostic parameters of the TEM under study. The increase in temperature may depend on several parameters: failures in the bearing, overload, cessation of ventilation, etc. Several methods are used to measure temperature. These include fiber-optic temperature sensors, electrical resistance thermometers, thermography, thermocouple-based temperature sensors, and more [7, 10 ,14].

When the operating temperature of the motor windings exceeds the heating limit of 100^{o}C for any period of time, the service life of the stator and rotor windings is reduced by half. Temperature diagram for different insulation classes and schematic diagram of the temperature protection of traction motor studies are given in figure 5.

Findings

The most suitable method for temperature regulation in high-power motors, as well as in the studied TEM, is the use of thermocouples. During the study, the operation of the traction electric motor protection system was modeled using PLC in the TIA Portal:

– simulation of motor overload;

– simulation of activation of motor temperature protection;

– simulation of an electric motor protection system based on the magnetic field of the air gap between the rotor and stator;

– simulation of operation of motor overcurrent protection with time delay;

– simulation of activation of motor overcurrent protection with a time delay of 5 seconds.

The schematic diagram and design description of the thermocouple used in the experimental studies are given in figure 6. In normal conditions, the motor is controlled by the «Start» and «Stop» buttons. The motor's current and temperature protection system is simulated in the program, also measurement and control magnetic flux based on

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hall sensor. If the value of the current reaches the maximum limit, the motor will be protected from the maximum current with a waiting period of 5 seconds. Also, if there is an overload in the motor due to the current, then the temperature is measured and, analogously, fan is automatically connected. After 10 seconds of fan operation, the temperature is measured again. If the measured temperature is equal to or greater than the previous value, the motor is protected. Otherwise, based on the diagnostic monitoring system, the warning system starts and makes a decision about the real condition of the motor. That is, the obtained informative parameter is compared with other parameters.

We use hall sensor for measurement magnetic flux in air gap. So, output signal of hall sensor give us 2,5–6,5 V voltage depend on flux. When output voltage above 5V, we protect motor from increasing voltage. As mentioned, the proposed modern protection system is implemented according to the diagnostic situation.

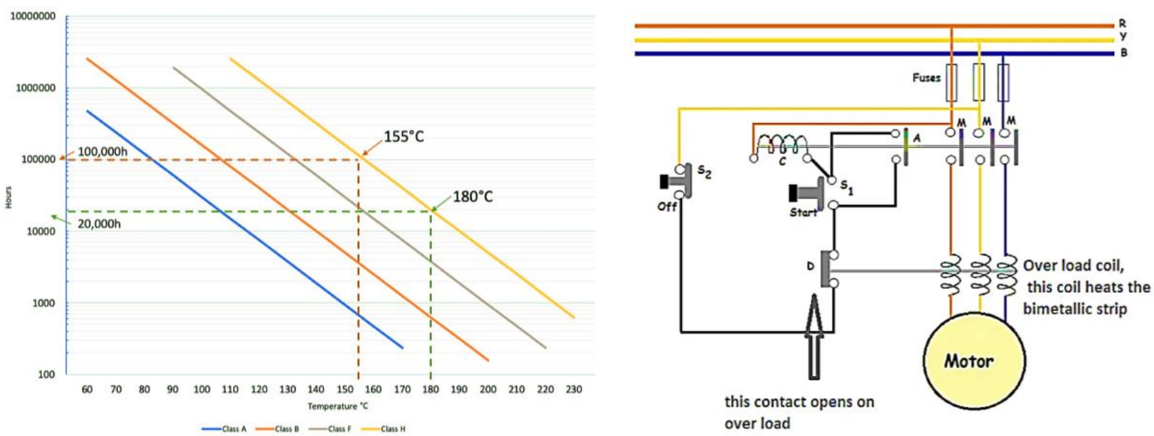

Fig. 5. Temperature diagram for different insulation classes and schematic diagram of the temperature protection of traction motor

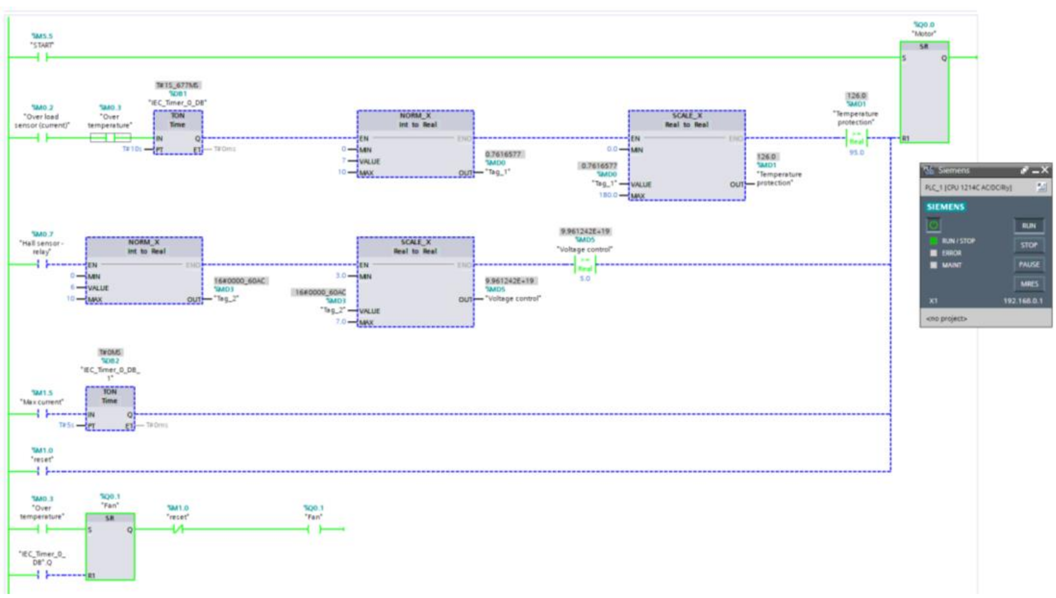

Fig. 6. Simulation of motor overload. When the motor is overloaded, using a signal from the temperature sensor, the fan turns on and tries to reduce the temperature to normal

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As can be seen from the simulation models shown in figures, when the START button is pressed, the motor starts, and the motor is stopped by pressing the STOP (reset) button. The given SR block indicates the priority of the motor STOP button. If the motor is stopped with the STOP button and the button is active, if the START button is pressed at the same time, the motor executes the command of the STOP button.

As shown in the figure 6 and 7, the motor is started by pressing the START button and the motor is already under load. At this time, the temperature in the stator winding of the motor increases due to the effect of overload current. As we know, the increase in temperature value and exceeding the permissible limit is undesirable for the motor.

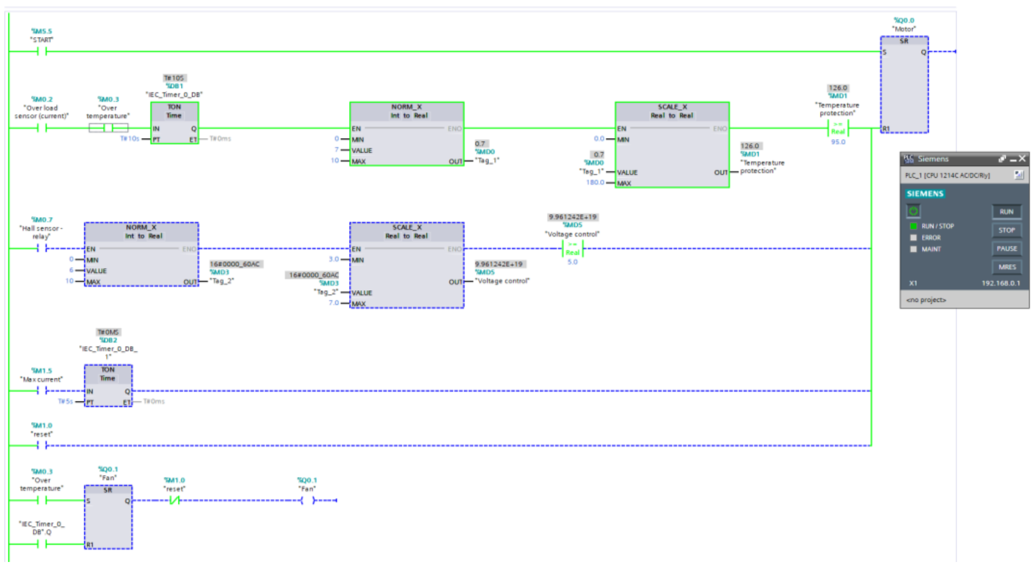

Fig. 7. Simulation of activation of motor temperature protection. After running the fan for 10 seconds, the motor temperature is measured again and compared with the normal value. If the temperature is still higher than normal, the motor temperature protection is activated

To prevent this, a temperature-based protection system is built. The maximum value for temperature is set at 95ºC. When the temperature increases, the fan connects to the circuit and tries to reduce the temperature value to the previous level. In the program, the operating time of the fan is set to 10 sec. After 10 sec, the temperature is measured again by stopping the fan. If the temperature value is equal to or greater than the previous value, then the motor is protected due to temperature.

Another protection and control system is the measurement and control of the magnetic field in the air gap between the rotor and stator parts of the motor as shown in figure 8. A Hall sensor with a relay output is used in the practical part of the work to measure the magnetic field, and during normal and abnormal conditions, the output of the sensor is evaluated diagnostically or the signal is processed for motor protection. In modeling, the maximum value of the output voltage of the sensor is set to 5 V. At voltage values equal to and greater than 5 V, the output signal of the sensor is used for motor protection.

As shown in figure 9 and 10, another parameter used for protection of the motor is the overcurrent protection with endurance time. When the value of the current reaches the maximum limit, the time relay protects the motor from the maximum current by counting the set time of 5 sec. As a result of the conducted experimental studies, the selected methods and tools will increase the effectiveness of the protection of traction motors, and more reliable working conditions of the motors will be provided.

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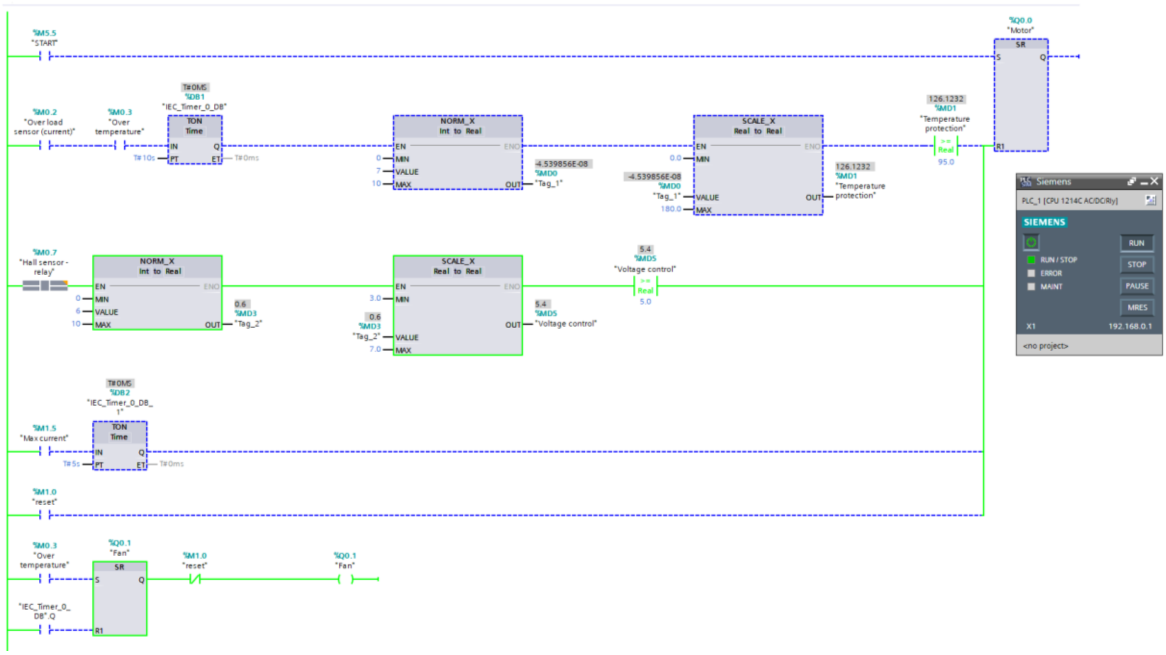

Fig. 8. Simulation of an electric motor protection system based on the magnetic field of the air gap between the rotor and stator (using Hall sensors)

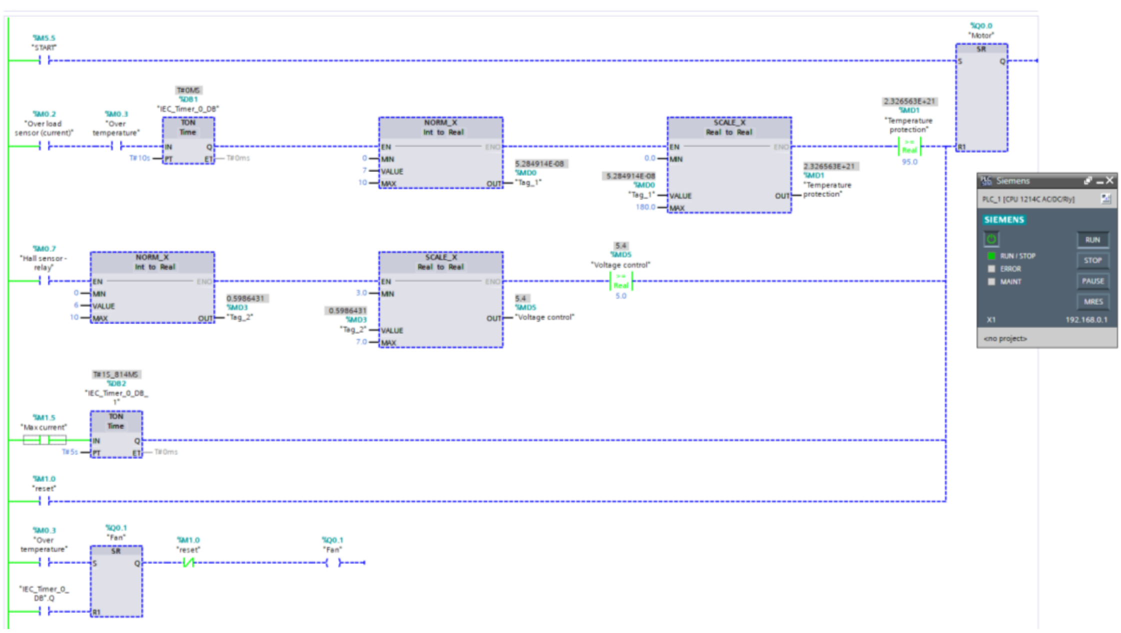

Fig. 9. Simulation of operation of motor overcurrent protection with time delay

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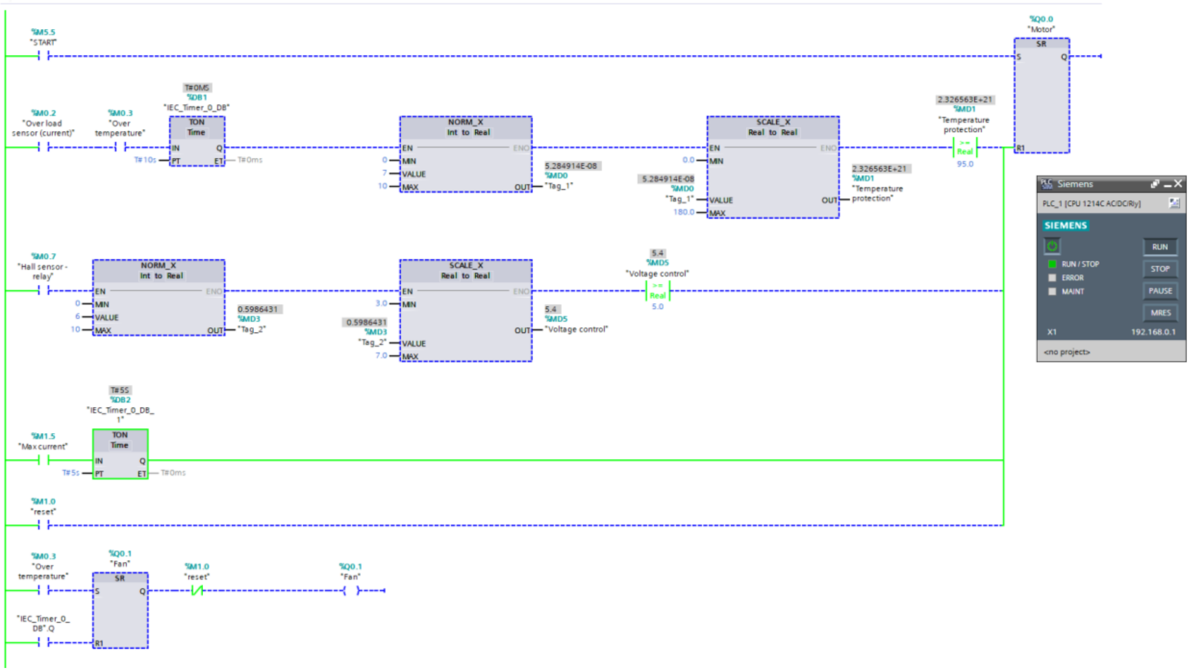

Fig. 10. Simulation of activation of motor overcurrent protection with a time delay of 5 seconds

Originality and practical value

The scientific novelty of the work consists in the fact that it improves the method of protection of traction motors based on the use of programmable logic controllers. In addition to the voltage and current parameters, the proposed method provides for monitoring the magnetic field. It also assumes the possibility of regulating the response time of the protection. As a result, in case of overload, short circuit and other non-standard situations, the improved method provides the system with the opportunity to make more accurate and reliable decisions.

The protection system of traction electric motors based on temperature and current was simulated in the TIA Portal software package, and its practical application was considered. In order for such systems to be more effective, complex protection systems can be developed based on the diagnostic status of the traction electric motor in the future. Also, an effective system can be established by providing SCADA control over the motors of several drag vehicles at the same time.

Conclusions

Thus, the modern protection system of traction electric motor is practically built on a small powerful motor based on PLC, and simulated in TIA Portal program. In addition to voltage, current and temperature parameters, as well as magnetic field monitoring as a diagnostic parameter, the PLC can also provide protection based on other parameters.

PLCs can be integrated into a SCADA system using communication modules to provide simultaneous control of several traction motors. One of the key features of SCADA is the ability to monitor the entire system in real time. The main purposes of using this system are to collect data, display them on the monitor screen in the control room, store the relevant data on the hard disk of the master computer, and provide the ability to control field devices (remote or local). SCADA systems are equipped to make instant adjustments to the operating system, which increases equipment life, reduces the need for costly repairs, and reduces downtime. Thus, it is possible to control various

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parameters of the motor in real time from the SCADA system and, if necessary, monitor the technical condition of the motor from the computer screen. As mentioned, in order to organize deeper protection of electric motors and increase accuracy, new hybrid complex protection systems should be built according to the diagnostic situation.

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Моделювання комплексної системи захисту тягових двигунів

Мета. Стаття присвячена створенню захисту тягового електродвигуна сучасними методами та засобами на основі програмованого логічного контролера (ПЛК). **Методика.** Для моделювання контролю за несправностями двигуна в лабораторних умовах на невеликому потужному асинхронному двигуні було встановлено датчики магнітного поля і температури, потім проаналізовано дані, отримані від датчиків у нормальному і перевантаженому режимах двигуна. На підставі досліджень були розроблені методи захисту. **Результати.** Використовувані раніше прості системи захисту електродвигунів на основі таких компонентів, як таймери, контактори, електромагнітні перемикачі, трансформатори напруги та струму, були повільними та неточними, а також мали низьку чутливість. Проте виробництво ПЛК та їх застосування в цій галузі усунули вказані проблеми. Інтенсивна експлуатація двигунів як основного виконавчого обладнання вимагає створення сучасних автоматизованих систем захисту для забезпечення їх надійної і стабільної роботи. **Наукова новизна.** У роботі вдосконалено метод захисту тягових електродвигунів на основі використання програмованих логічних контролерів. На додаток до параметрів напруги та сили струму запропонований метод передбачає моніторинг магнітного поля. Також він передбачає можливість регулювання часу спрацьовування захисту. У результаті в разі перевантаження, короткого замикання та інших нестандартних ситуацій удосконалений метод забезпечує системі можливість приймати більш точні та надійні рішення. **Практична значимість.** У програмному комплексі TIA Portal змодельовано систему захисту тягових електродвигунів за температурою та струмом та розглянуто її практичне застосування. Щоб такі системи були більш ефективними, у майбутньому можуть бути розроблені комплексні системи захисту на основі діагностичного стану тягового електродвигуна. Крім того, ефективну систему можна створити, забезпечивши керування SCADA двигунами кількох транспортних засобів одночасно.

Ключові слова: тяговий електродвигун; програмований логічний контролер (ПЛК); перевантаження; контроль магнітного поля; контроль температури; перевантаження; датчик Холла

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