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SOME ISSUES OF INFORMATIONAL SUPPORT FOR MULTILEVEL DIAGNOSTIC SYSTEMS OF ELECTROTECHNICAL EQUIPMENT

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Abstract. Algorithmic software for the operation of informational measuring diagnostic systems according to the Smart Grid technology and with the conditional division of the electrotechnical equipment into hierarchical levels is proposed.

Key words. Electrotechnical equipment, diagnostic system, Smart Grid concept, teaching complex.

1. Introduction

As it was shown in works [1, … , 5, 7, … , 11, 12], modern electric-power industry, starting the use of intelligent networks developed on the basis of a Smart Grid concept, requires forming a holistic multilevel control system which provides the high level of automatization and reliability of the whole system and covers the producers of electricity, transferring and distributing networks, consumers etc. In this case, obtaining actual information about the current state of each power object (PO) and the exchange of this information among all participants of the electricity market is very important, because it provides the increase in the reliability of the work of electrical system as a whole.

So, in works [1, 2, 3, 6, 8, 9, 11, 12, 13] the main questions devoted to the processes of creating diagnostic signals in the electrotechnical equipment (EE) units, developing and investigating the mathematical models of such signals and models associated with the representation forms and methods of forming the teaching complexes relevant to certain technical states of PO units being investigated have been considered.

2. Aim of the work

The aim of the research is creating methods and facilities of informational support for informational and measuring systems (IMS) of the diagnostics of the EE units functioning according to the Smart Grid technology. For its fulfillment the following issues have been defined and solved in the work:

– according to the investigation of proposed mathematical models [1, 3, 6, 11, 12, 13, 14] of some physical processes which accompany the work of certain units of electrotechnical equipment, the presence of certain diagnostic features allowing the determination of technical state of EE units being investigated, taking into account different modes of EE operation, has been proved;

– algorithmic software taking into account substantiated diagnostic features and conditional hierarchical levels (into which the EE of power plants can be subdivided) was proposed which allows functioning the multilevel diagnostic system for the electrotechnical equipment via the Smart Grid technology;

One of the main components of informational support for IMS diagnostics is the result of the investigation of mathematical models describing physical processes which occur in working units of EE. During functioning of these units, physical processes are the carriers of diagnostic signals which contain the information of technical state of the EE units. The mathematical models of such signals can be represented as determinate or stochastic forms. The latter is more often used as a model of diagnostic signals, since the major physical processes occurring in different EE units are sporadic by their nature [1, 3, 6, 11, … , 15].

In works [1, 6, 13] the results of using the elements of the theory of linear random processes (LRP) for developing the mathematical models of physical processes occurring during the operation of certain EE units are given. It is the use of an LRP class that allowed obtaining the diagnostic features from the results of the analysis of the mathematical models of these processes in the terms of complete probabilistic characteristics (distribution functions or densities of probability distribution) of diagnostic signals being investigated. This, in turn, made it possible to use the higher-order moments of probability distribution of such signals as the diagnostic features and provided the increase in accuracy and reliability of EE diagnostics. As an example, the mathematical model of vibrations which occur in EE units is considered. The investigations of the vibrations are the source of data used for proving the diagnostic features for determining the technical state of certain EE units. Moreover, it should be noted that in accordance with above mentioned activities and with the use of substantiated diagnostic features in practical IMS diagnostics the operational modes of EE being examined must be taken into account. These mathematical models of different in physical nature diagnostic features developed with the use of the LRP theory allow choosing the diagnostic features which enable the determination of technical state of EE considering its operation mode (temperature, electrical, speed performance etc.).

3. Diagnostic features used for determining the technical state of EE.

By the results of investigation of mathematical models of different diagnostic signals [1, 2, 6, 11, 12, 14], the diagnostic features suitable for determining the technical state of EE units taking into account different operation modes were justified. Such features may be the following:

- at spectral correlation analysis: decay coefficients β_{ji}, frequency parameters ψ_{ji}, $j=\overline{1,n}$, $i=\overline{1,m}$;
- at autoregressive analysis: autoregression coefficients $a_1,...,a_p$ and an autoregression order p.
- at the analysis of probability distribution: pattern of density of probability distribution function; values of initial and central moments, among which the most informative are asymmetry coefficients k and coefficients of kurtosis γ.

In accordance with the stated aim, the development and further practical application of the informational support is not possible without choosing or creating the proper algorithmic software. Key attributes at this process are above mentioned justified diagnostic features, as well as physical processes (informational diagnostic signals) having been justified by the investigation of the appropriate mathematical models. Obtaining numerical evaluation of chosen diagnostic features, in turn, is first of all necessary for forming teaching complexes and, further, for conducting the diagnostics itself according to the formed teaching complexes. But before considering this facility, it is necessary to determine the structure of the multilevel IMS diagnostics of EE. For this the generalized structure of such an IMS can be used, which is mentioned in works [4, 7]. This structure is directly connected with conditional hierarchy of EE of a traditional power plant (TPP, NPP, HPP). In Fig.1 the conditional levels of EE of a typical power plant are shown.

At the first and the lowest level, the elements of the main units of the EE structure of the power station are located. For making the content of this paper more illustrative, an electrical machine (EM) has been chosen as the object of investigation. It is just this level, which determines what defects are possible in the object being considered. The thorough study of elements located at the first hierarchy level gives all necessary information about kinds, causes of occurring and manifesting of defects. As a result of such an analysis, diagnostic models are built and diagnostic signals and parameters are chosen.

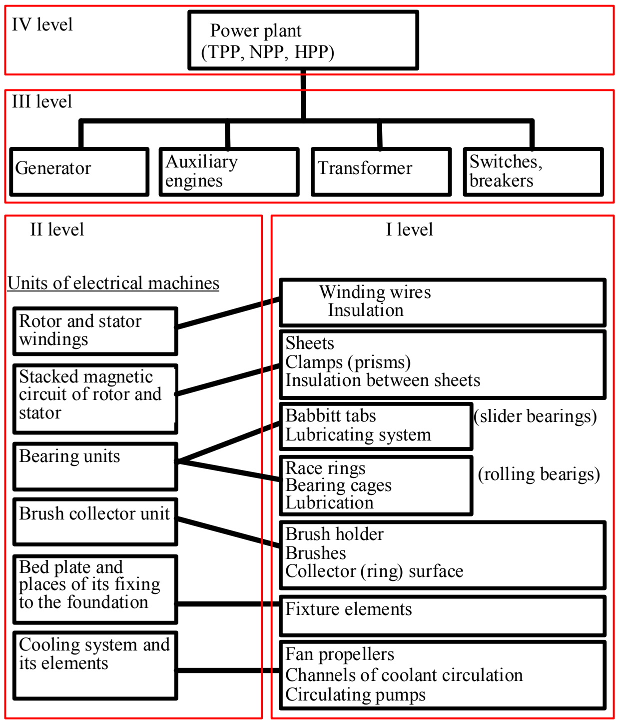

Fig. 1. Conditional levels of EE of a power plant.

The second level is represented by units of equipment themselves, which are the constructive whole. Here we can mention windings of rotor and stator of rotating machines, magnetic circuits, bearing units, housing, bed plate, foundation, cooling system.

The third level represents EE of the power plant: generators, auxiliary engines, transformers, switches, breakers, insulators, pumps etc.

The forth hierarchical level is the level of the power plant as a whole.

Moreover, it is possible to consider some higher hierarchical levels like power association, power system etc.

It is evident, that any diagnostic system must reveal killing defects, since they completely cease the operation of the object being examined. At the same time, some nonfatal or partial failures can be left beyond the consideration. Such an approach to the development of the system provides the opportunity to simplify its structure, reduce the volume of information being processed in the system and transferred between its hierarchical levels. This can make the system cheaper, and existing computing resources can be redistributed for carrying out more urgent functions.

Let us first consider the peculiarities of constructing the multilevel diagnostic systems for power industry objects [4, 7].

At the top hierarchical level, a central diagnostic system (CDS) is located. It is the main unit of the power station diagnostic system whose block diagram is shown in Fig.2. The main purpose of the central diagnostic system is gathering and generalizing the data which comes from all local EE diagnostic systems. When it is necessary, CDS can transfer the received data to a higher level of hierarchy.

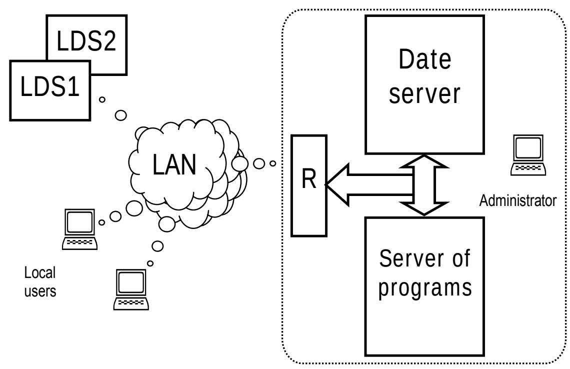

Fig. 2. The Structure of central diagnostics systems: LDSn – local diagnostics systems; LAN – local area network; R – router.

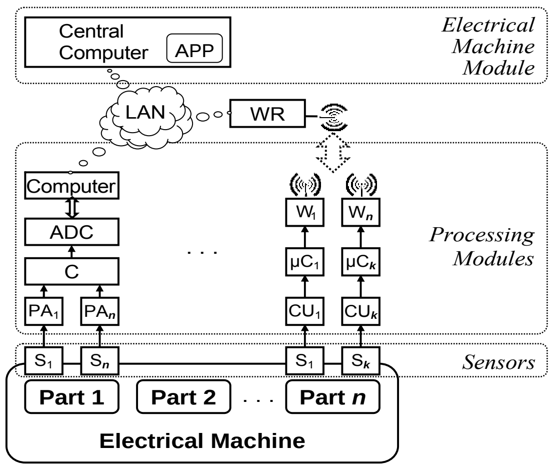

Fig. 3. Structure of a multilevel local system for technical diagnostics of electrical machines: S – sensor; PA – pre-amplifier; C – commutation device; ADC – analog-to-digital converter; CU – conversion unit; µC – microcontroller; W – wireless communication unit; WR – wireless router; APP –application package for data analysis, diagnostic decision making, assessment of residual life; LAN – local area network.

Typical structure of each local diagnostic system (LDS) according to [7] is provided in Fig. 3.

Equipment being the part of LDS can be logically subdivided into 3 hierarchical levels:

– level 1 is intended to the initial selection of diagnostic information (measurement of diagnostic signals, amplification, analog filtering, conversion to a digital form);

– level 2 is intended for the preliminary mathematical processing and making intermediate diagnostic decisions (simple algorithms whose realization does not require vast computing resources; dividing information according to the degree of defect criticality); warning signaling to the higher level in the case of defect presence; storage of limited (insignificant) amount of measurement information and its transfer to the higher level (on request);

– level 3 is for storage, adequate processing and thorough analysis of data, quick response to emergency signals from a lower level, making diagnostic decisions about the examined object as a whole, archiving the statistical data, predicting the reliability and evaluating the residual life of the equipment, planning the repairing work etc.

As it is shown in [4, 7, 11, 12], modern distributed multilevel systems of monitoring and examining the state of electrical power equipment are built on the basis of digital computing facilities. At the same time, certain power objects are equipped with standard measuring converters (especially, turbogenerators can be equipped with the sensors of temperature of a stator and a rotor) which can be used as the part of a monitoring system.

It should be also stated that at the development stage of LDS the quite complete list of possible defects, which are to be revealed by the diagnostic system, is given and the units and EM elements in which these defects can possibly occur are listed. Moreover, the operation modes (electrical, temperature, speed performance etc.) of the EM units which are to be examined are certainly taken into account. On these units the measuring equipment is mounted for obtaining the diagnostic signals.

At the level of construction units of the EM a separate computing module is mounted for further transferring and processing the measured diagnostic signals. This module provides converting the analog signals to digital ones and preliminary processing of such signals obtained from this unit. The above mentioned computing module can be a microcontroller or a small industrial computer working under the control of special software. The main task of this module is conducting the measurements of diagnostic signals and preliminary evaluation of the real technical state of each construction element belonging to its hierarchy (intermediate analysis). In most cases, the considerable deviations of real state from the normal one will not be revealed, so that it might not be necessary to transfer the information to the higher level. If considerable deviation from the normal state (highly critical (fatal) defect) is observed, the module of data measuring and preliminary processing should transfer the information to the higher level of system hierarchy for more detailed analysis.

In more general case, the algorithm of functioning of this module depending on the results of preliminary analysis should realize the following logic of data exchange with the higher hierarchical level of the diagnostic system:

– transfer no information if no deviation from a normal state is detected;

– emit a warning signal if minor deviations are detected;

– transfer measured data to the higher hierarchical level for conducting thorough analysis if the revealed deviations are considered to be significant;

– emit an emergency signal if detected deviation is fatal.

Such an approach to the system development enables the simplification of its structure, decrease in the information being processed in the system and transferred between its hierarchical levels. Due to this, the system can become cheaper, and existing computing facilities can be re distributed for carrying out more critical functions.

Let us consider algorithmic software for the EE multilevel diagnostic system which is one of the important components making up the informational support for given IMS along with the mathematical models of diagnostic signals and teaching complexes.

Software being the constituent of multilevel IMS diagnostics can be conditionally subdivided into 3 main components: operation control of the whole system; statistical processing of experimental data for obtaining numerical values of diagnostic features; developing solving rules for diagnostics and classification of possible defects in EE units. Let us briefly consider these 3 components.

Software for the control of multilevel diagnostic system.

In general, software is a complex of programs of the system of data processing for multilevel system of monitoring of state and technical diagnostics of electrical power plants can be conditionally subdivided into 3 classes:

- system software;
- embedded software;
- applied software.

System software is the operational system, as well as the set of utilities which in complex create operational environment and provide main services to applied software. It was not the task of this paper to develop the system software. However, ready-made operational systems will be used, namely, Microsoft Windows and Linux, as they are the most widely spread operational systems. Moreover, it should be mentioned that operational systems of Linux family do not need significant computational capability, they flexibly adapt to performing the planned functions and also are well protected from unauthorized invasion from outside which in the future will ease the development of measures to be taken to provide the cybersafety of diagnostic system.

Embedded software operates in microcontrollers on which the modules of the 1-st hierarchical level of the diagnostic system are constructed. The functions of such software are significantly limited by the low computational capability of hardware and mainly come to controlling the process of analog – digital conversion of the measured diagnostic processes and transferring data to the modules of the 2-nd level to which they are connected. The peculiarity of such software is that it operates without operational system, so it should independently realize input – output protocols necessary for communication with other modules. For most modern microprocesses there exist compilers for C language realized on personal computers which significantly eases the development of embedded software and in certain cases gives the possibility of using the existing programming code on the microcontroller and in other systems simultaneously.

Applied software performs functions specific for system being developed. Key tasks of applied part of software are collection, processing according to the set algorithms and storage of the measured information.

The peculiarity of the system being developed is that software should work on different kinds of computers:

– desktop computer systems and laptops (modules of the 3-rd level);

– low-capacity single-board computers (modules of the 2-nd level).

The block diagram describing functioning of the multilevel diagnostic system of electric machines under the control of created algorithmic software is shown in Fig. 4.

Assuming the fact that software should work on different software-hardware platforms, the following features of it should be taken into account during its development:

– interfaces for data exchanging should be unified and be realized in a simple way on any platform being a part of the system;

– standards of data storage should be common for different systems;

– software which can perform on any platform being a part of the system should be developed with the use of programming languages whose compilers are available simultaneously on all target platforms (taking into account the compatability requirements); such programs should depend only on the libraries available on all target platforms;

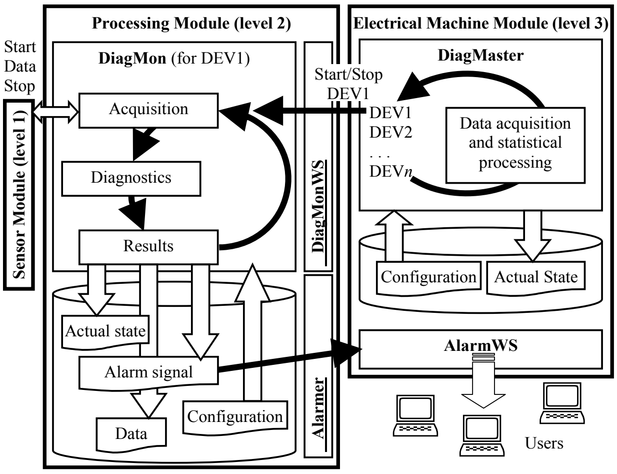

Fig. 4. Functional block-diagram of the modules software.

– programs which it is not reasonable to move on to the other platform and which do not realize the interfaces with other hardware-software modules can be developed in any programming language available in certain working environment.

In turn, applied software can be divided into 2 categories:

– controlling software for the realization of the diagnostic algorithms including collaboration between separate modules;

– diagnostic software for the statistical processing of measured data, making decisions, evaluating residual life, planning failures etc.

Both controlling and diagnostic software works on modules from 2-nd to 3-rd hierarchical levels of the multilevel diagnostic system. Let us briefly consider these issues.

4. Algorithmic software for modules of the 2-nd hierarchical level of the multilevel system

The main functions of the modules of the 2-nd hierarchical level are:

- preliminary mathematical processing and making intermediate decisions about the real technical state of a separate electrotechnical device or its unit;
- signaling to the higher level when defects exist;
- storing non-significant volumes of measuring information and transferring it to higher level when appropriate request from higher level module comes.

For fulfilling these functions, the 2-nd level modules should realize simple algorithms of data processing (diagnostic software), as well as the diagnostic algorithms and data exchange between modules (Fig. 4).

The diagnostic algorithm in the case of the 2-nd level module consists in periodical polling of the 1-st level modules connected to it, analyzing this information and the proper reacting according to the results of analysis. This algorithm is implemented by the use of DiagMon (Diagnostic Monitor) program. Let us consider its operation at a normal cyclic mode.

Cooperation between the modules of the 1-st and 2-nd levels is organized according to the classical architecture "consumer – server", and the 1-st level modules operate as servers. Most of the time they stay at the waiting mode with reduced power consumption which can prolong their life span until their replacing or battery recharging. For polling the detached modules, DiagMon software working on the 2-nd level module initiates the beginning of the communication with the chosen module of the 1-st level, and after that the respective module should pass to the measuring mode and begin the data transfer with preset frequency. After the 2-nd module being given the necessary amount of values of measuring process, it breaks the connection with the respective module of the 1-st level which at once enters the waiting (standby) mode. The 2-nd level module starts existing diagnostic software for evaluating the real state of the unit being monitored and records the results into a file of a set format.

The situation can be considered to be optimum when the whole cycle of the DiagMon program has been finished without any failures and the analysis of the obtained data has not revealed the deviation of the real state of the examined unit from the norm.

In this case the program just enters the standby mode for the set time period.

Off-optimum situations processed by the DiagMon program are the following.

1) The 1-st level module does not answer to the request about the link startup.

This situation is possible, for example, when the battery of the 1-st module is discharged and cannot feed the module.

In this case the DiagMon program records the message of the set format about the failure of the measuring module into the result file and finishes the operation.

2) After the link startup with the 1-st level module and the transfer of the part of data the 1-st level module stops sending data.

The causes and the reaction are the same as in the previous case.

3) The results of the diagnostic software operation show that the state of the examined unit cannot be considered satisfactory, but it is not a complete failure.

The cause can be both the error of signal measuring or the mistake in the evaluation of the diagnostic parameters and the real degradation of technical state of the object. The DiagMon program records the message of the set format about the fatal failure of the object into the result file and continues the operation.

4) The results of diagnostic software performance indicate that the state of the examined unit can be considered to be in equipment-damaging condition.

Therefore, the most likely cause of this is the emergency condition.

The DiagMon program records the message of the set format about the failure of the object into the result file. Moreover, the program creates a special signal file and after that continues the operation.

For the implementation of the data exchange between modules of the 2-nd and 1-st level, an especial process- indicator (Alarmer) has been developed which periodically scans the given directory for the presence of a file-indicator. The frequency of this scanning is much higher than the frequency of performing the usual diagnostic cycle by the DiagMon program. If the Alarmer finds the file-signal, it creates a special request to the Web-service launched on the respective 3-rd level module, signaling about the presence of emergency state of the examined unit.

For providing the possibility for the 3-rd module to access the 2-nd level modules when it is necessary, a special Web-service DiagMonWS has been developed. Receiving a special request from the 3-rd level module, it forms and sends a message about the real state of the examined object and time of the last poll. Answering to the other request, DiagMonWS forms and sends a data packet having been recorded as a result of the last poll. Therefore, when it is necessary, the 3-rd level module can conduct more thorough data analysis with the use of complex algorithms, performing which on the 2-nd level modules would take too much time.

Another type of request which the 3-rd module can send to the Web-service DiagMonWS is the start of the monitoring process.

The 2-nd level modules can monitor several objects simultaneously. For this it is necessary that the appropriate number of 1-st level measuring modules should be connected to the 2-nd level module, as well as proper settings should be provided in a configuration file. Each measuring module is given some identificator, or a name of the device.

For the start of the monitoring of some object, the 3-rd level module must send the request to the Web-service DiagMonWS for the monitoring startup with a parameter identifying a given device. Answering the request, DiagMonWS launches the DiagMon process with the proper parameter. At the start, DiagMon checks whether the record of a set format exists in the configuration file for a given identificator. If such a record has been found, the DiagMon checks whether the monitoring for this device has not been started yet. The device identification whose monitoring has already been started is performed with the help of a certain file-marker.

If this file has been found for a respective identificator, the DiagMon stops the operation. If the file is not found, DiagMon reads the monitoring parameters from the configuration file (such as parameters of access to the measuring module corresponding to a given identificator, poll frequency, diagnostic algorithm of processing, criteria for determining the critical and failure states) and, after that, launches a normal cyclic mode described above.

The last type of request which can be sent by the 3-rd level module is a request for the stop of monitoring of the chosen object.

The DiagMon program is written in C language, since it is convenient for the processing of data arrays. The programs Alarmer and DiagMonWS are written in Java language which is appropriate for the realization of Web-services. The design of Web-services is provided with the help of the packet of public codes Apache Tomcat Version 7.

Taking into account the degree of the object state (normal, critical, failure) in the 2-nd level module enables reduction of data volume transferred between the hierarchical levels of the system. Due to this the number of the diagnostic parameters measured by the system can be increased without significant increase in computing capacity of its components.

5. Algorithmic software for modules of the 3-rd hierarchical level of a multilevel system

With the help of the 3-rd level modules the diagnostic functions of a separate power device are provided. The main software part of such modules is the diagnostic software.

The main software component performed in a cyclic mode is the main diagnostic monitor DiagMaster. It realizes a periodical poll of all connected devices: 2-nd level modules and multilevel ADC. In the case of the 2-nd level modules, DiagMaster first requests the information about the time of the last diagnostic operation on the particular device and the results obtained. If the 2-nd level module passes back to the normal state, the DiagMaster process moves to the next device or module. If the 2-nd level module informs about the critical state, the DiagMaster can implement the thorough analysis of the diagnostic information from the object. For making such a decision a special algorithm should be developed which will become the part of the diagnostic software. In the case of the poll of ADC channels, DiagMaster performs the measurement of the process realization of given length, and then the chosen algorithm of information processing is used.

After finishing each cycle of the DiagMaster program, the system receives renewed data slice about the real state of all monitored objects. This slice is recorded for the long-term storage and statistical analysis if it is necessary.

The other program component, which should work continuously, is an emergency alert guard AlarmWS created in the Web-service form. It receives the emergency signals from Alarmer processes which are performed at the attached 2-nd level modules.

The program DiagMaster is written in C programming language. The program Web-service AlarmWS is written in Java programming language. Web-service performance is provided with the help of packet of public codes Apache Tomcat Version 7.

As it was mentioned above, algorithmic software contains the diagnostic software intended for statistical processing of diagnostic signals, making diagnostic decisions, evaluating residual life, planning failures etc. In details this kind of software is considered in some other works, for example, in [1, 6]. It is exactly this type of software which is used for obtaining the numerical values of the diagnostic features which is the basis of further solving the tasks of determining the technical state of the EE, predicting its residual life etc.

6. Conclusions

1. According to the proposed hierarchical structure and with taking into account the conditional representation of the electrotechnical equipment with 4 levels, the algorithmic software has been developed which enables the functioning of the multilevel diagnostic system of the electrotechnical equipment by the Smart Grid technology.

2. With the use of the experimental data obtained on the laboratory investigating electro machine installations, the ways of practical implementation of the developed informational support in the multilevel IMS of the EE diagnostics are determined.

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ДЕЯКІ ПИТАННЯ ІНФОРМАЦІЙНОГО ЗАБЕЗПЕЧЕННЯ БАГАТОРІВНЕВИХ СИСТЕМ ДІАГНОСТУВАННЯ ЕЛЕКТРОТЕХНІЧНОГО ОБЛАДНАННЯ

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В даній статті з урахуванням умовного поділення електротехнічного обладнання на ієрархічні рівні, запропоновано алгоритмічно-програмне забезпечення для функціонування інформаційно-вимірювальних систем діагностики за технологією Smart Grid.

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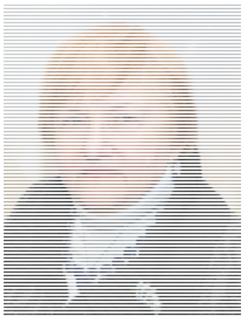

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