Structure and distribution of function between the stages of the information and measurement system for diagnostics of traction substations and contact network installations

Mirdjalil Yakubov[1*], *Islom* Karimov[1], and *D.* Abdullaev[2]

[1]Tashkent State Transport University, pass. 1st Temiryulchilar, 1, 100167 Tashkent, Uzbekistan
[2]Tashkent State Pedagogical University, Bunyodkor avenue, 27, 100070 Tashkent, Uzbekistan

Abstract. The article presents the results of the study of the multistage information-measuring system (IMS) of the diagnostic of traction power supply objects combined with the operational-dispatch control allowing to ensure reliability, attributing to unit value of the IMS. Taking into account the introduction of functional redundancy in the structure of duplicate channels of diagnostics of each stage. he upper level of the complex should maintain processing of information received more frequently from previous devices and issue of certain tasks to the operating personnel for the work of maintenance according to the actual condition of the diagnosed facility. Based on mathematical models of reliability of primary converters and information processing devices on probabilistic indicators. The functional block-circuits of the multi-stage IMS for obtaining and converting information on the example of power transformer diagnostics and contact network devices are disclosed. It has been shown that, given the vulnerability of communication channels, it is advisable to transmit information in large flows, for example, related to spectral analysis, to process at the lower stages of the IMS, and through communication channels to transmit their integral indicators.

1 Introduction

The technical and economic criteria for the optimum information and measurement system (IMS) for the functional diagnostics of traction power units integrated with the existing operational control system can be evaluated in several ways [1-3] For example, the economic measure of IMS efficiency is the best value for money measure with maximum reliability [4, 5].

* Corresponding author: nauka.islom@gmail.com

2 Materials and methods

In IMS, by obtaining and processing a large amount of measurement information, the cost of maintenance to improve the reliability of its components is less than the cost of accident response, which can be described as:

$$E_i = E - E_r, \quad (1)$$

where E_i– efficiency indicator is the efficiency of the use of the IMS, E_r- is the real efficiency.

The full cost of the IMS is defined by:

$$C = (E - E_r) + \sum_{i=1}^{\mathrm{p}} (E - E_i)\,\mathrm{P}_i + \mathrm{C}_a + \mathrm{C}_{\text{к}} \quad (2)$$

where $(E - E_r)$ - loss of efficiency of the hierarchical IMS system due to lack of reliability of sensors and interface devices and pre-processing equipment with probability of uninterrupted operation, $\mathrm{P}_i, \mathrm{C}_e$ - cost of IMS equipment, C_e - cost of communication channel.

To optimize the structure of the IMS according to the criterion (2) of difficult because of the complexity of expressing the components of useful costs. More convenient is the performance of the IMS structure, defined as [6-10]:

$$E_i = \frac{\mathrm{P}}{\mathrm{C}_i}, \quad (3)$$

where P - the probability of the IMS functioning correctly, C_i - the cost of the IMS. In order to simplify mathematical expressions, the analysis of the effectiveness of IMS will be carried out in parts.

The efficiency of the introduction of intermediate processing facilities as compared to the centralized system is assessed by the relative indicator:

$$\delta_0 = \frac{E_p}{E_{ri}}, \quad (4)$$

where E_{ri} - Processing efficiency in a centralized system structure; E_p - efficiency of information processing in a multi-level hierarchical system.

At the same time

$$E_{ri} = \frac{\mathrm{P}_{ce}}{\mathrm{C}_{ce}};\ E_p = \frac{\mathrm{P}_{ce} + \sum_{i=1}^{n_{ie}} \mathrm{P}_{iei}}{\mathrm{C}_{ce} + \sum_{i=1}^{n_{ie}} C_{cei}}, \quad (5)$$

where P_{ce} - the probability that the central processing egnipment will not work properly; C_{ce} - the cost of central information processing equipment, including service costs; P_{io}- the probability that the intermediate processing facilities will not function properly; C_{ie} -cost of intermediate processing facilities, including maintenance costs; n_{ie}- number of intermediate information processing facilities;C_{ce}, C_{cei} - the probability of a faultless operation and the cost of a central processing facility in a hierarchically structured system.

If the mathematical model of the hierarchical structure is a geometric progression [3]:

$$n = \text{к}^{\mathrm{p}-1}, \quad (6)$$

where n - the number of first-degree control objects, κ - the number of branching, p- the number of steps, the number of intermediate information processing objects is defined by:

$$n_{io} = \frac{\kappa^{p-1} - \kappa}{\kappa - 1}, \quad (7)$$

Applying that intermediate objects have equal reliability and cost taking into account (4) and (5) we get:

$$\delta = \frac{P'_{ce} + \frac{\kappa^{p-1} - \kappa}{\kappa - 1} \cdot P_{ie}}{P_{ie}} \cdot \frac{C_{ce}}{C'_{ce} + \frac{\kappa^{p-1} - \kappa}{\kappa - 1} \cdot C_{ie}}, \quad (8)$$

The graph of the dependency of the relative efficiency of $\delta_i$on the number of steps p of IMS is given (figure 1).

When a hierarchical structure is established, part of the function of the central information processing unit is transferred to intermediate facilities, which increases the reliability of the central authority and reduces its cost

$$P'_{ce} > P_{ce}, \qquad C'_{ce} < C_{ce}$$

The effectiveness of a hierarchical link to a centralized system is measured by the relative value of:

$$\delta_l = \frac{E_{cl}}{E_{il}}, \quad (9)$$

where E_{cl} - efficiency of the communication line in a centralized system; E_{il} - the efficiency of the communication line in a multi-level hierarchical system, respectively equal to [5]:

$$E_{il} = \frac{\sum_{i=1}^{n_{il}} P_{ili}}{\sum_{i=1}^{n_{il}} C_{ili}}, \quad E_{cl} = \frac{\sum_{i=1}^{n_{cl}} P_{cli}}{\sum_{i=1}^{n_{cl}} C_{cli}}, \quad (10)$$

where P_{il} - the probability of faultless operation of lines in a centralized system; C_{il} - the cost of the connection to the central system;n_{il} -number of connections in the centralized system;P_{cl}, C_{cl} - respectively the probability of a faultless operation and the cost of a communication line in the hierarchical system; n_{cl}-the number of communication lines in the hierarchical system.

It is known that the structure of IMS is determined by the interaction of its individual subsystems. The differences between the structure levels depend on the distribution of the function and the reliability of the system.

The distinguishing structure of the IMS of electrical installations is the need for joint integrated diagnostics of traction substation facilities as well as contact network installations with the existing operational Dispatch Control systemas the methods and technical means of diagnostics and energy efficient management principles.

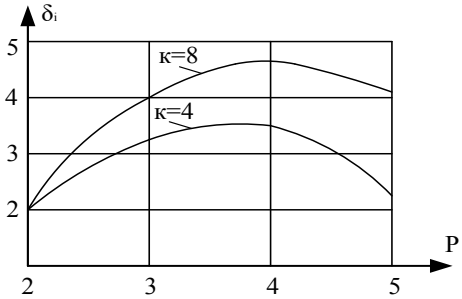

Fig. 1. Relationship of the relative performance indicator to the number of steps of the IMS structure δ_i.

The first stage of the IMS comprises primary measuring transducers (MT) (sensors), first processing units of measuring information (FPUM) and communication lines connecting primary transducers.

The converters of all traction substation equipment, the main elements of which are FPUMbased on microprocessor modules, are controlled by computers.

The measuring information from the voltage sensors of the contact wires, the traction cable, the prey arrows and other sensors mounted on the anchor section is processed along the line of the FPUMcontact network. Measuring information on the equipment of traction substations, for example, a group of diagnostic features from power transformers in the form of current, voltage and their harmonic components, air temperature and top oil layers, etc.

The second stage of multi-stage IMS diagnostics of objects and modern operational control relates, firstly, to the remote control of the control operator, the main element of which is the personal computer. These computers receive measurement information pre-processed in FPUMunits. The second step will also include tele-measurement systems (TMS) that transmit measurement information via communication channels and mobile measurement systems (MMS) that are used on the basis of economic or reliable criteria.

The third tier of the multi-tier IMS includes the computer hardware of the traction power system. The management, engineering and operational personnel of the contact network use the processed measurement information for setting up the traction substation facilities and the contact network by the serviced personnel.

When dividing the functions performed between the stages of a multi-stage IMS, we choose as a basis the criteria of the reliability of the functioning of the IMS, on which the reliability of the main power equipment of the substation and the contact network depends as well.

As can be seen from the above distribution of the function of the multi-stage IMS, the power supply between its stages is monitored and diagnosed at all stages, which increases the reliability of theIMS operation. Diagnostic tasks are performed at the second and third stages. An increase in reliability is achieved by functional redundancy. As a result of the failure of the monitoring and diagnostic devices at any stage of the IMS, the diagnostics of technological facilities will continue, but with less efficiency. Therefore, special requirements are imposed on the reliability of the operation of primary measuring converters (sensors) as sources of measuring information. In order to increase the reliability of obtaining information trustworthiness, there is a functional duplication of first-stage elements.

Each technological power supply is different in terms of technology and design, so diagnostic methods for these facilities are different [7].

The first stage of IMS uses functional duplication to improve reliability and provides for three types of control.

The group of sensors is intended for producing measuring signals which enter the automatic control system (ACS) and the voltage of the power transformer. Here, the parameter control unit works with the setting of installations (CU 1).

The sensor group is designed to produce vibration acoustic signals, which it analyzes with the aid of the (CU 2) and Monitoring Information Processing Units (MIP).

Analysis by Control Unit (CU3) and primary processing by MIP2 units. In the first stage of the IMS, diagnostic information is presented in the form of signals a, b and c.

Introduction of CPU devices, including in its first stage, into the IR multi-stage power supply, allow to abandon the hardware implementation of a series of measurement transformations. These transformations (units ACS, CU 1, CU2, CU3, MIP1, MIP2– Fig.2) can be implemented through microprocessor-based applications.

The processed measurement information is transmitted via the CCh 1 channels to the second stage of the IMS, where it is analysed by means of the integrated indicators unit CU4 and further processing unit MIP3. The functionally separated blocks of CU4 and MIP3 are physically PC operating on the basis of specified programs. Here the parameters of diagnostic models of technological objects are calculated and the state of objects is evaluated according to these models. Diagnostic information of the second stage of the IMS of the presentation of signals d and e.

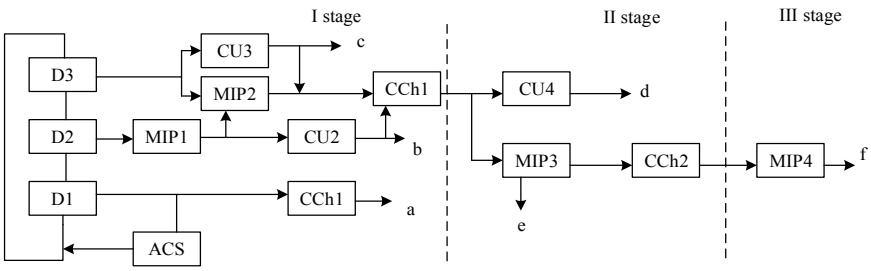

Fig. 2. Information acquisition and conversion scheme for power facility diagnostics.

The processed information is received via the CCh2 communication channels to the third stage of the IMS, where the technical and economic performance of the diagnostic system of the electrical facilities is determined with the help of the MIP4 information processing units, which, in some cases, is used as diagnostic information for the entire power supply system.

The method of functional redundancy, which makes it possible to increase the operational reliability of IMS, is based on the consideration of the hierarchical structure of the multi-stage IMS.

Since the communication channels between the IMS stages are the most unreliable, the maximum functional redundancy which is introduced at the first stage, and at the subsequent stages this redundancy is reduced [6].

From (Fig.2), it can be seen that the first stage of the IMS uses three diagnostic channels. Let's evaluate the reliability of first-stage diagnostic channels:

First signal: $P_{c1} = P_{D1} \cdot P_{cu1}$;

Second signal: $P_{c2} = P_{D2} \cdot P_{ipu1} \cdot P_{cu2}$;

Third signal: $P_{c3} = P_{D3} \cdot P_{cu1}$;

where P_D - Reliability of operation of sensors; P_c The reliability of control units; P_{ipu}- reliability of information processing units.

Reliability of first-stage IMS diagnostic system in general:

$$P_1 = 1 - (1 - P_{D1} \cdot P_{cu1})(1 - P_{D2} \cdot P_{ipu1} \cdot P_{cu2})(1 - P_{D3} \cdot P_{cu1})$$

If there is no functional redundancy, we get:

$$P_1' = P_{D1} \cdot P_{cu1},$$

We have: $P_D = 0{,}96;\ P_{cu} = 0{,}98;\ P_{ipu} = 0{,}99$
$P_1 = 0{,}999;\ P_1' = 0{,}941.$

Consequently, when a three-channel control system and a functional redundancy system are introduced, the reliability of the first-stage diagnostic system of the IMS is significantly increased:

$$P_2 = P_{cch1}[(1 - (1 - P_{cu4}))(1 - P_{ipu3})].$$

When we get $P_{cch} = 0{,}93;\ P_2 = 0{,}929.$

In the absence of a third-stage diagnostic transformation:

$$P_3 = P_{cu2} \cdot P_{ipu4};\quad P_3 = 0{,}92.$$

Thus, six diagnostic signals (a, b, c, d, e, and f) are produced in the three-stage IMS that characterize the state of technological objects.

Assess the reliability of each of these signals:

$$P_a = P_D \cdot P_{cu};$$
$$P_b = P_D \cdot P_{ipu} \cdot P_{cu};$$
$$P_c = P_D \cdot P_{cu};$$

$$P_d = [1 - (1 - P_D)(1 - P_D \cdot P_{ipu})] \cdot P_{ipu} \cdot P_{cch} \cdot P_{cch};$$
$$P_e = [1 - (1 - P_D)(1 - P_D \cdot P_{ipu}) \cdot P_{ipu}^2 \cdot P_{cch};$$
$$P_f = [1 - (1 - P_D)(1 - P_D \cdot P_{ipu}) \cdot P_{ipu}^3 \cdot P_{cch}^2.$$

With the original reliability of the elements given above, we get:

$$P_a = 0{,}94;\ P_b = 0{,}93;\ P_c = 0{,}94;\ P_d = 0{,}90;\ P_e = 0{,}90;\ P_f = 0{,}84$$

Diagnostic information on the state of technological facilities is provided simultaneously at each stage of the IMS. The probability of the absence of at least one diagnostic signal due to a defect in the IMS elements can be found by the formula:

$$P_0 = (1 - P_a)(1 - P_b)(1 - P_c)(1 - P_d)(1 - P_e)(1 - P_f) = 0{,}0000004. \quad (11)$$

The calculated data show that the diagnostic IMS and the operational control system combined with it have a high reliability.

3 Conclusion

The most cost-effective structure of a multi-stage IMS, corresponding to the reliability per unit of its cost, is achieved with a three- to four-step structure.

When developing a multi-stage diagnostic IMS, it is recommended to combine its structure with the structure of the operational control. At the same time, functional

redundancy, by means of duplication of channels, will be compensated by increasing the reliability of diagnostics at each stage of the IMS.

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