The Research of Theoretical Approaches to Increasing the Reliability of Automated Control Systems in the Energy Sector

Kyaw Zin Lin, Aung Kyaw Myo, Evgeni Mikalovic Portnov and Kyaw Zaw Ye

February 24, 2021

The research of theoretical approaches to increasing the reliability of automated control systems in the energy sector

Kyaw Zin Lin[a], Aung Kyaw Myo[b], Portnov Evgeni Mikalovic[c], Kyaw Zaw Ye[d]

[a, b, c] Department of Informatics and Computer Software System, National Research University of Electronic Technology, Bld.1, Shokin Square, Zelenograd, Moscow, 124498, RUSSIA
[d]Department of electronic, telecommunication system and Automatic control system, Pyinoolwin Research Center Pyin Oo Lwin, Republic of the Union of Myanmar

Abstract

At present the problem of increasing the reliability automated control systems in the energy sector which makes it necessary to create automated control systems operating the equipment power is very urgent. In the development and modernization of these systems one must take into account a number of specific energy requirements including: increasing the speed of information processing and transmitting, diagnostics mode operation of the equipment, automatic determination of the optimal time of continuous operation and prevention of emergency situations, information support with time stamps and etc.

Keywords: technical diagnostics system, undetectable distortion, information transmission

1. Introduction

In accordance with GOST 26.205-88, the reliability of the automated control systems in the energy sector is estimated in size of the probability of undetectable distortion of information with the channel interference. According to this definition, reliability is the degree of conformity between the received and transmitted signal, in this case the channel interference is a distorting factor causing the nonconformity.

So, in the technical documentation on control systems and technical diagnostics of various producers it is shown that a high level of reliability (probability of undetectable distortion is~$10^{-10}…10^{-16}$)of the received information is achieved through the use of powerful anti-interference codes oriented to the protection against the distortion of messages with the channel interference. At the same time, this indicator does not take into account the possibility of distortion of the information before its receipt in the encoder, therefore a high level of reliability is provided only at one of the sections of the information delivery route from the sensor to the receiver [1].

Hence, a fuzzy definition of the basic characteristic of control systems of the reliability of information has led to a lack of interconnection between the coding and decoding methods from the principles of construction of technical diagnostic systems and the architecture of functional modules.

In this interpretation of the reliability the malfunction of the equipment systems which do not lead to any failure of the command or signal transmission and to undetectable distortion control commands or status signals of the equipment are not taken into consideration although it is obvious, that failures to execute commands are incomparably less likely to lead to emergencies than direct executing a false command. It is necessary to emphasize that this nonconformity of responsibility is reflected in GOST 26.205-88 [2]. Especially, the standard levels of allowable failure probability from executing a false control command or receiving false equipment state signals with undetected distortions is by several orders of magnitude lower than the levels of probability of the distorted data. Therefore, it is obvious that to determine the level of reliability of information in the systems of technical diagnostics, for example, control commands is necessary in accordance with the probability of false execution of the command control without specifying the cause and location of the command distortion. It is obvious that the reliability of information and other channels of technical diagnostics systems should be evaluated in this way[2].

If we analyze the most popular control systems and technical diagnostics applying the proposed principle, it turns out that having a very low probability of undetectable distortion of commands, signals and measurements with the channel interference they have much lower real reliability of the received information due to the lack of interconnection between the principles of building coding and information transfer modules.

In order to correlate the probabilistic measure of technical diagnostics system which are determined by the methods of information transmission, coding methods and architecture of functional devices, we introduce the indicator of transformation of reliability of the received information determined by the probability ratio of the undetected distortion of commands, signals or measurements of the interference in the communication channel to the probability of a false command or receipt of false signals and measurements regardless of the cause and place of distortion[3].

The probability of undetectable distortion of information signals and control commands with the channel interference - P_{unde_SC} is determined by the power of the applied code. Knowing the average rate of the flow of information transfer μ_{avg}, the average expected time between failures - T_{fail} can be determine.

$$T_{fail} = \frac{P_{unde\_SC}}{\mu_{avg}}. \quad (1)$$

Taking the flow of non-detectable failures as poisson we will receive:

$$\mu_{avg} = \frac{P_{unde\_SC}}{T_{fail}} = \frac{P_{unde\_SC} n_{req}}{t_h} [hour^{-1}], \quad (2)$$

Where n_{claims} - the average number of claims per year,

t_h - the number of hours per year.

We divide the system hardware into *n* groups according to the potential fault tolerance criterion. The intensity of undetected failure of the element in the equipment of the $i-th$ group is denoted as μ_i, and the probability of reception and transmission of the distorted information in the event of undetected failure - as P_i. Then the degree of transformation of the reliability of the received information can be defined as:

$$\Omega = \frac{\mu_{avg} + \sum_{i=1}^{n} P_i \mu_i}{\mu_{avg}}. \quad (3)$$

To illustrate the possible values of coefficient **Ω**, we substitute the numerical values of the parameters into the formula (3).

Let's take the probability of non-detectable distortion of information signals due to interference in the communication channel equaled to $P_{unde\_SC} = 10^{-12}$ (in accordance with GOST 26.205-83) and provided through the use of error-correcting code, the average number of requirements for switching the state of the object for a year $- T_{requ} = 10^3 year^{-1}$.

Suppose that, only one element is installed in the transmission of state signals by this object (the switch is in the input circuit), the failure of which is not detected by monitoring and diagnostic devices[4,5]. The standard failure intensity of this element is $\mu_i = 5 \cdot 10^{-7} hour^{-1}$ and the probability of the occurrence of the signal distortion state because of the fault in the given element will be taken as $P_j = 10^{-4}$. Consider that there are no other sources of distortion of information signals from formula (1), we obtain the following equation:

$$\mu_{avg} = \frac{10^3 \cdot 10^{-12}}{9 \cdot 10^3} = 1{,}1 \cdot 10^{-13} hour^{-1}.$$

Then the degree of transformation of reliability will be:

$$\Omega = \frac{1{,}1 \cdot 10^{-13} + 5 \cdot 10^{-7} \cdot 10^{-4}}{1{,}1 \cdot 10^{-13}} = 0{,}5 \cdot 10^3.$$

It is apparent that even in this assumption there are sufficient "soft" exposure conditions of influence on the system equipment, while real indicators of the reliability of equipment state signals are found to be several orders of magnitude worse than expected.

To find the ways to improve the reliability of technical diagnostics systems, consider the standard route of passing signals from equipment status sensors to the display elements which are shown in figure 1.

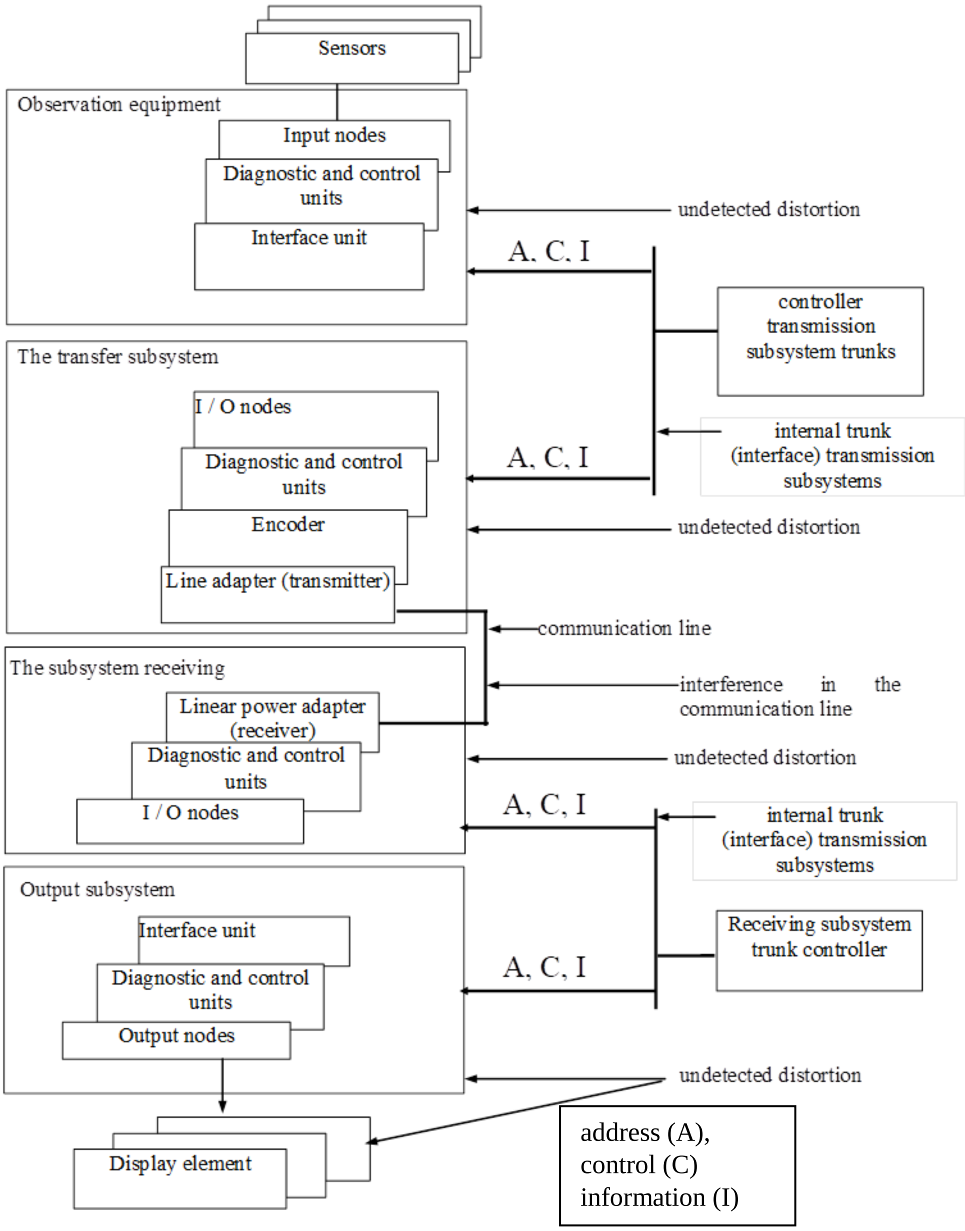

Fig. 1. The model of the part of technical diagnostics system

The data from the input subsystem hardware status signal source with the permission from the controller of the internal trunk of the subsystem passes through the interface on which the signals of address (A), control (C) and information (I) are sent to the data transmission subsystem in the communication channel.

The factors determining the level of reliability of the information transmitted on the internal highway are:

- failures and malfunctions of hardware and software of subsystems of input and information transfer,
- interference received in the input / output circuit of interface signals.

The information from sensors in the area from data input to the transmission subsystem encoder is exposed to interfering factors - interference ("tips" on the communication circuits of the module with sensors), faults and failures. These "disturbing" factors can lead to detectable and undetectable distortions.

With the help of “powerful” anti-interference codes one can detect almost all possible channel interference.

However, the encoder-decoder pair shown in figure 1 cannot ensure the data reliability, in case of receipt of information in the encoder with previously undetected distortions. Thus, the "standard" principles of building of the devices (with emphasis on information protection only against distortion with the channel interference) do not guarantee the reliable reception of data from sensors. Moreover, to the mentioned above possible reasons for entering false information the following should be added:

- undetectable distortion of data in the internal trunk of the receiving subsystem;
- undetectable distortions due to interference, equipment failures and malfunctions in the data output area of the source module.

It should be emphasized, that the impact of" interfering " factors outside the communication line of the control station in modern devices are increased for a number of reasons:

- the transition to the use of microprocessor elements in which the sensitivity to external action is incomparably higher than that of relay or semiconductor elements,
- Increase in the speed of information input from the sensors and reduction of the energy ratio of operating signals and interference,
- the transition to digital communication channels in which the impact of interference is lower than that of traditional analog, for example, high frequency communication channels.

It is obvious that taking into account the above factors to improve the actual reliability it is necessary to take additional measures.

Usually, in addition to the use of powerful anti-interference codes, feedback channels are used to improve the reliability of information transmission. Currently, the most common of these are the channels of information feedback (IF) and decision feedback (DF), the scheme of which is presented in Figures 2 and 3.

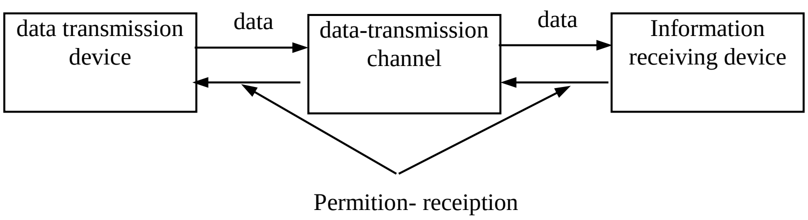

Fig. 2. System with decision feedback

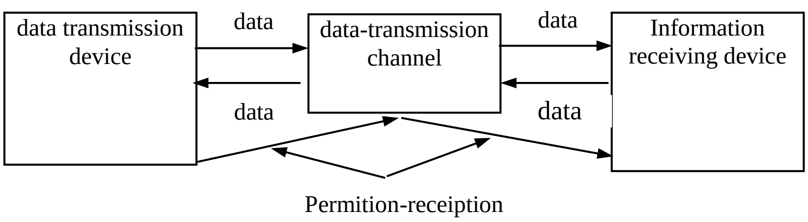

Fig. 3. Systems with information feedback

In systems with decisive feedback, the receiver makes a decision on the absence or presence of errors/distortions based on the analysis of the received data. In the first case, "receipt" is transmitted in the direction of the transmitter, confirming the undistorted reception of information. In systems with informational feedback, the receiver returns a received message to the transmitter. The decision on the absence of distortion is made by the transmitter, which transmits to the receiver a "receipt", according to which the receiver realizes the previously received information.

The probability of distortion of data in the channels with DF is higher, since the control is carried out only on the message received from the transmitter, and in the channel with IF the control is carried out both on "direct" and on "return" message. However, if a "direct" message is distorted, even a system with information feedback does not provide a blockage of distortions.

Therefore, traditionally used methods for constructing technical diagnostic systems with common encoder and decoder for all modules do not provide reliable data reception from sensors.

According to the results of the analysis the following conclusions can be drawn:

- to improve the reliability of the information, it is necessary to enter the diagnostic nodes that allow in a dynamic mode to detect distortions along the entire route of information delivery to the receiver,
- The time shift between failure detection and the display of it at the central control point of the system must be minimal,
- the diagnostic nodes should provide a dynamic control of the operability of all elements of the system, that is to detect faults equivalent to short circuits ("excess" signals "1") and breaks of connections (("excess" signals "0").

Thus, in order to ensure a high level of system reliability of equipment state signals in the process of technical diagnostics, it is necessary to combine the procedures for inputting information from sensors with coding, that is to include the signal coding device in the information input module. Dynamic performance monitoring can be successful if during the input of information combined with its coding, one can check the possibility of installing any module element in the state "1" and "0".

Similar to the traditional double-pulse signal coding Manchester code is used [7], in which each discrete signal is represented by two bits “10” or “01”, the second bit being formed by simply inverting the first. This code allows to detect the distortion of information message signals with the channel interference of the controlled point in which an encoder with a central control point (information decoder) is installed.

But the presented coding method based on the use of Manchester code does not allow to detect the distortions caused by a rupture or a short in the encoder's communication circuit with any sensor, that is it does not provide the required level of reliability.

To eliminate this disadvantage, a coding method, based on the coding procedure was developed for all sensors simultaneously in three time-separated stages-at the first stage for each sensor of the discrete signal, a signal “1” or “0” is formed for the closed and open state respectively, at the second stage determine the presence of a short in the circuit or breakage of the sensor communication circuits with the encoder is determine, and at the final third stage the serviceability of the output code generation elements is identified.

It should be noted that the three-stage coding procedure is carried out in such a way that the combination of the signals obtained at all three stages when coding the signal from the sensor is not repeated in the closed and open state of the sensor, the presence of a short in the circuit and a break in the sensor communication circuit with the encoder, and also at malfunction of the encoder and (or) the controller of data transfer to the communication channel.

Simultaneous implementation of coding procedures for all sensors provides the increased efficiency and the use of three stages of coding allows to create the non-repeatable code combinations allowing to identify the presence and type of malfunction of the elements participating in coding, forming and transmitting of the generated message through the communication channel with the central control point.

Figure 4 show the code combinations of the three-pulse correlation code (TCC) formed at three time-separated stages when coding signals from sensors and when generating the message transmitted over a communication channel.

In the closed state of any sensor, code combination 110 is formed at three stages of coding and when the open state – code combination is 010. If the open circuit fault of sensor is fixed with the encoder device, at three coding stages, code combination 011 is formed for the corresponding sensor, and when detecting of short circuit in the circuit connection of the sensor with encoder - the code combination is 101. In case of failure type" false operation " of elements, that forming an information message for transmission over the communication channel code combination 111 is formed, and in the event of a failure type "failure" - the code combination is 000. Thus, a unique code combination is formed for each considered case, in the analysis of which by the presence and type of failure or absence of distortion in the information message received at the central control point is definitely determined.

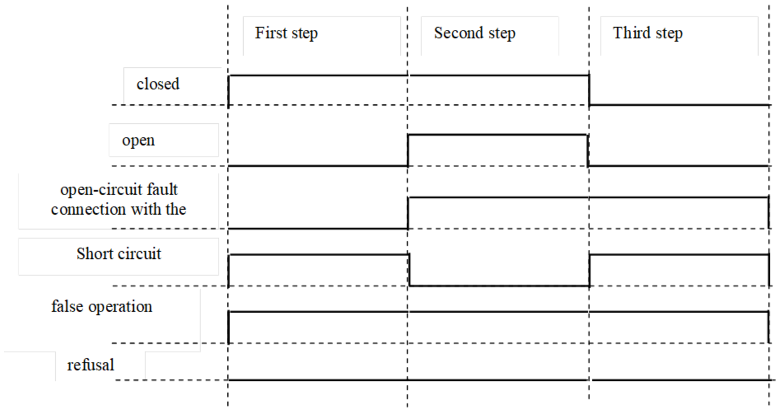

Fig. 4. The code combinations of three-pulse correlation code

In the figure 5 has shown the implementation of coding procedures in dividing each of the three stages into three clock period. The total number of clock period, in which three stages of coding are realized, is equal to nine (from zero to eight). The number of clock period in each stage is equal to three. On the first clock period of each stage of coding (1-1; 1-2; 1-3) the state of sensors is fixed, and the received information is written to the memory register. Simultaneously data is read from the random access memory (RAM) with writing data to the register, which is received on earlier procedures of coding of signals from sensors.

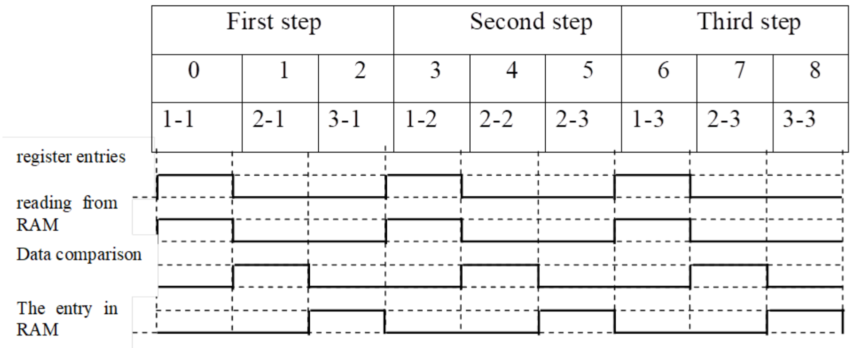

Fig. 5. The implementation of coding procedures

At the second clock period (2-1, 2-2, 2-3) of each coding step the data written to the register and corresponding to the current state of each sensor and its communication circuits are compared with the information read from the RAM. Nonconformity of the compared signals indicates about changing the status of any sensor or its circuits. At detection a nonconformity for any sensor, new information on the third clock period of the corresponding stage (3-1; 3-2; 3-3) is entered into RAM and also into the transfer controller. The controller generates the information message for transmission over the communication channel in the form of a cyclic code containing except the status codes of sensors, communication circuits with them and information about the performance of the equipment, additional components- the address of the controlled point, the code of the information type as well as the sequence of control code (SCC).

Let's calculate the system reliability of electrical equipment status signals for the proposed method of coding.

The calculation will be carried out under the following initial conditions which determine the structure of the information package:

d_1 -identification code of the controlled point address (two bytes);

d_2-ode identifying the type of information messages (two bytes);

d_3 – information field (0 to 64 bytes);

d_4 - the field of protection, control sequence code (two bytes).

Provided that the distortion of each component of the information message is an independent event determine the probability of undetectable distortion of the entire message as the sum of the probabilities of all its components:

$$P_{unde} = P_{input} + P_{cpa} + P_{type} + P_{prote} \tag{4}$$

Where P_{input} – undetectable distortion when entering and encoding simultaneously for the formation of a three-pulse correlation code;

P_{cpa} –probability of undetectable distortion of the identification code of the controlled point address;

P_{type}–probability of undetectable distortion of message type identification code;

P_{prote} – the probability of undetectable distortion of the code control sequence.

The probability of undetectable distortion of information when entering information and forming a three-pulse correlation code is:

$$P_{input} = nP_0 P_{gat}^2 (1 - P_{gat})^{n-2} \tag{5}$$

Where P_0 - the probability of such interference impact in the case of the repeated distortion of the input signal of the state of equipment which is opposite to the effect of the primary distortion;

n - bit code combination equal to the number of sensors ,

$$P_{gat}^2 = \left(P_{dis} \frac{T_{gat}}{T_{cycle}} \right)^2 , \tag{6}$$

Where P_{dist} - the probability of a single signal distortion due to interference;

T_{gat} - signal duration gating signal from the sensor;

T_{cycl} - the period between adjacent cycles of survey of the sensor status

In the equation (5), the factor n is used, but not the number of triple combinations of distortions, so as to three-shots of the correlation code pairs of the control signals is carried out separately.

At $(1 - P_{gat})^{n-2} \rightarrow 1$ will get;

$$P_{input} = nP_0 \left(P_{dis} \frac{T_{gat}}{T_{cycle}} \right)^2 \tag{7}$$

Using the check sequence cyclic code provides the receipt of a code distance $d \geq 4$.

Therefore, when applying the control sequence to the input P_{input} , we obtain

$$P_{input} = \left(nP_0 \left(P_{dis} \frac{T_{gat}}{T_{cycle}} \right)^2 \right)^4 C_n^4 \ . \tag{8}$$

Taking into account the length of the identification codes of the KP address, the type of information message and the control sequence of the cyclic code, we obtain an indicator

$$P_{cpa} + P_{type} + P_{prote} = P_{dis}^4 \left(C_{d_3}^{2d_1} + C_{d_3}^{2d_2} + C_{d_3}^{2d_4} \right) , \tag{9}$$

Here d_3 is determined based on the bit width of the information for each sensor – 6 bits (3 bits of forward and inverse code) and the total number of sensors equal to $n = 32$

Then

$d_3 = 6n/8 = 24 byte$

Consequently:

$$P_{unde} = \left(nP_0 \left(P_{dis} \frac{T_{gat}}{T_{cycle}} \right)^2 \right)^4 C_n^4 + P_{dis}^4 \left(C_{d_3}^{2d_1} + C_{d_3}^{2d_2} + C_{d_3}^{2d_4} \right) \tag{10}$$

Substituting the numerical values: $P_{dis} = 10^{-4}$, $n = 32$, $T_{gat} = 10^{-7} c$, $T_{cycle} = 10^{-2} c$, $P_0 = 1/8$, $d_1 = d_2 = d_2 = 2$ will obtain $P_{unde} \approx 1{,}1 \cdot 10^{-12}$.

The resulting value satisfies the most stringent requirements of the standard and it is almost completely determined by the probability of distortion of additional components of the information message which makes it more relevant to use more secure identification codes of the controlled point address and message type.

When assessing the reliability index, it should be taken into account that all modules of the information delivery route from the source module to the receiver are practically simple re-transmitters and do not affect to the format of the information message.

Acknowledgments

Thus, the system reliability of the information P_{syst} can be represented by the sum P_{unde} and the sum of the probabilities of undetectable faults of all modules of the information delivery route from the source module to the receiver P_{fault} :

$$P_{syst} = P_{unde} + P_{fault} = \left(nP_0 \left(P_{dis} \frac{T_{gat}}{T_{cycle}} \right)^2 \right)^4 C_n^4 + P_{dis}^4 \left(C_{d_3}^{2d_1} + C_{d_3}^{2d_2} + C_{d_3}^{2d_4} \right) + \sum_1^m (P_i)^4 \cdot C_{q_i}^4 \qquad (11)$$

Where P_i -the probability of occurrence of a single fault element of the $i = th$ module,

$C_{q_i}^4$ - the number of combinations of four elements of the $i = th$ module,

q_i – the number of elements in the $i = th$ module.

Indicator "4" takes into account the minimum code distance of the information message to be generated.

By accepting $P_i = 10^{-6}, q_i = 0.5 \cdot 10^3, i = 5$ obtain

$$P_{syst} = P_{unde} + P_{fault} = 1{,}103 \cdot 10^{-12} \qquad (12)$$

Thus, the proposed coding principle provides a high level of system reliability of information.

References

[1]. Ye, K.Z., Portnov, E.M., Gagarina, L.G., Lin, K.Z. Method for increasing reliability for transmission state of power equipment energy//2015 IEEE Global Conference on Signal and Information Processing, 14-16 Dec. 2015 – Orlando, FL, 2016. Pp. 433-437

[2]. Evgeni M. Portnov, Kyaw Zin Lin, Vitaliy V. Kolkin, Aung Kyaw Myo. Method for Detection of Failures in Complex Process Control Systems// 2017 IVth International Conference on Engineering and Telecommunication (EnT) (IEEE), 29-30 Nov. 2017, Moscow, Russia.

[3]. Kyaw Zin Lin, Portnov E.M. Development of methods for increasing the efficiency of information exchange in control systems of power energy// ISER – 83rd International Conference on Science, Technology, Engineering and Management (ICSTEM) Sydney, Australia, December 5th -6th 2016

[4]. Black Yu Computer networks: protocols, standards, interfeysy.-M .: Mir, 1990.-506 c.

[5]. A. R. Di Fazio • T. Erseghe • E. Ghiani •M. Murroni • P. Siano • F. Silvestro// Integration of renewable energy sources, energy storage systems, and electrical vehicles with smart power distribution networks, Received: 25 January 2013 / Accepted: 9 April 2013 / Published online: 8 May 2013_ Springer-Verlag Berlin Heidelberg 2013.

[6]. Candy, R Changing the telecontrol protocol to support substation based intelligent alarm processing and direct control staff interaction with the substation RTU / gateway / / IEEE PES Powe-rAfrica 2007 Conference and Exposition, PowerAfrica; Johannesburg; South Africa; 16 July 2007 through 20 July 2007

[7]. Carré, O., Englert, H., Ostermeier, A., Lange, J., Lhuillier, P. Substation to control centre communication based on IEC 61850: Requirements, concepts and practical experiences / / 44th In-ternational Conference on Large High Voltage Electric Systems 2012; Paris; France; 26 August 2012 through 31 August 2012

[8]. Han, G., Xu, B. IEC 61850-based open communication system of advanced distribution automation Dianwang Jishu / Power System Technology Volume 35, Issue 4, April 2011, Pages 183-186

[9]. Li, L., Miao, P., Wang, J. Analyze and implementation of substation automation system base on IEC 61850 standard (2006) Power System Technology, 30 (S1), pp. 321-324.

[10]. Xu, B., Li, T. Investigations to some distribution automation issues (2010) Dianli Xitong Zi-donghua/Automation of Electric Power Systems, 34 (9), pp. 81-86.