National Research University of Electronic Technology
«MIET»

Portnov E.M., Gagarina L. G., Kyaw Zaw Ye,
Kyaw Zin Lin

“Method for increasing reliability for signal transmission state of power equipment energy”

Kyaw Zaw Ye
Department of Informatics and Computer Software System
National Research University of Electronic Technology
Zelenograd, Moscow, Russia
Email: kyawzawye85@gmail.com

IEC 60870-5

IEC 60870 part 5 is one of the IEC 60870 set of standards which define systems used for telecontrol (supervisory control and data acquisition) in electrical engineering and power system automation applications. Part 5 provides a communication profile for sending basic telecontrol messages between two systems, which uses permanent directly connected data circuits between the systems. The IEC Technical Committee 57 (Working Group 03) have developed a protocol standard for telecontrol, teleprotection, and associated telecommunications for electric power systems. The result of this work is IEC 60870-5. Five documents specify the base IEC 60870-5:

IEC 60870-5-1 Transmission Frame Formats

IEC 60870-5-2 Data Link Transmission Services

IEC 60870-5-3 General Structure of Application Data

IEC 60870-5-4 Definition and Coding of Information Elements

IEC 60870-5-5 Basic Application Functions

IEC 60870-5-6 Guidelines for conformance testing for the IEC 60870-5 companion standards

The IEC Technical Committee 57 has also generated companion standards:

IEC 60870-5-101 Transmission Protocols, companion standards especially for basic telecontrol tasks

IEC 60870-5-102 Companion standard for the transmission of integrated totals in electric power systems (this standard is not widely used)

IEC 60870-5-103 Transmission Protocols, Companion standard for the informative interface of protection equipment

IEC 60870-5-104 Transmission Protocols, Network access for IEC 60870-5-101 using standard transport profiles

IEC 60870-5-101/102/103/104 are companion standards generated for basic telecontrol tasks, transmission of integrated totals, data exchange from protection equipment & network access of IEC101 respectively.

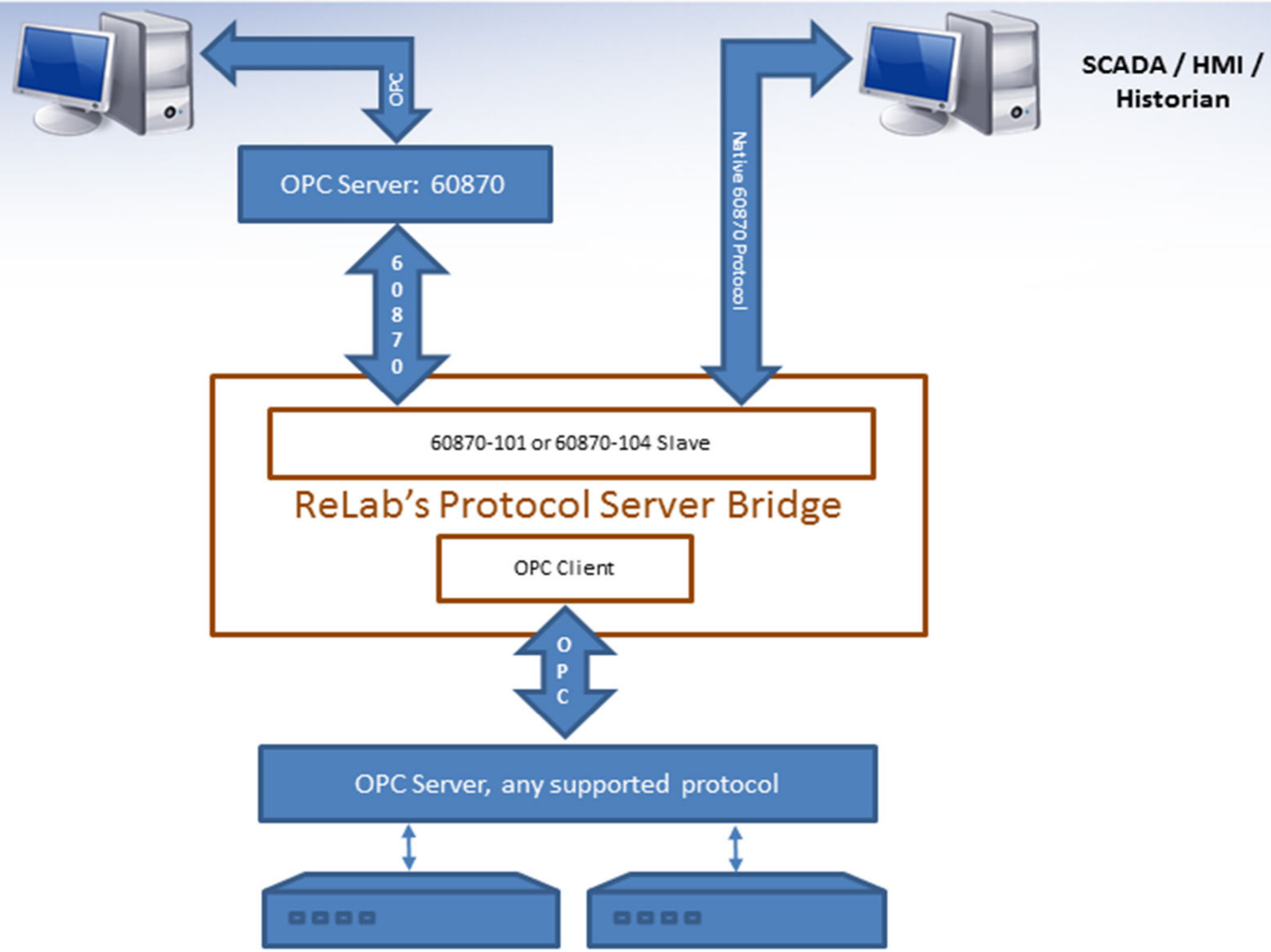
IEC 60870-5-104

- IEC 60870-5-104 (IEC 104) protocol is an extension of IEC 101 protocol with the changes in transport, network, link & physical layer services to suit the complete network access. The standard uses an open TCP/IP interface to network to have connectivity to the LAN (Local Area Network) and routers with different facility (ISDN, X.25, Frame relay etc.) can be used to connect to the WAN (Wide Area Network). Application layer of IEC 104 is preserved same as that of IEC 101 with some of the data types and facilities not used. There are two separate link layers defined in the standard, which is suitable for data transfer over Ethernet & serial line (PPP - Point-to-Point Protocol). The control field data of IEC104 contains various types of mechanisms for effective handling of network data synchronization.
- The security of IEC 104, by design has been proven to be problematic, as many of the other SCADA protocols developed around the same time. Though the IEC technical committee (TC) 57 have published a security standard IEC 62351, which implements end-to-end encryption which would prevent such attacks as replay, man-in-the-middle and packet injection. Unfortunately due to the increase in complexity vendors are reluctant to roll this out on their networks.

GOST 26.205-88

Russian standard : Telemechanics complexes and devices.
General specifications:
This standard applies to systems and devices of remote control (then- products), including program-controlled for performing the following functions: telemeasurement current (DC) and (or) the integral (TI) parameters; remote signaling (TS) discrete state facilities; remote control (TC) object; teleregulation (TP); sending teams of instructions (CI); transmission of data (PD) through the channels (lines) telemechanical communication network; relaying information (RT). This standard can perform several functions (in any combination) or all functions.

Protocol Server Bridge for IEC-60870



The main directions of current research

- Improving the efficiency of information exchange
- Improving the efficiency of detection and failure detection
- Increasing the reliability of the information

Purpose of current research

- The purpose of the current work is development of the theory and principles of building automated systems for the management, control and technical diagnostics for increasing reliability for signal transmission state of power equipment energy.

The objectives of current research

- ➢theoretical research to study the possibility of creating automated systems to improve the credibility and reliability of the control;
- ➢offer mathematical models of software and hardware platform on criteria of economic efficiency;
- ➢develop techniques and algorithms to improve the detection of failures and troubleshooting;
- ➢-develop methods and principles for improving the effectiveness of information exchanges;
- ➢-develop methods of forming control commands, timing information signals;
- ➢-develop techniques to increase reliability of the information;
- ➢experimental research to study the effectiveness of the proposed technical solutions.

Challenges in the implementation of system for increasing reliability for signal transmission state of power equipment energy

- Need to requires new ways of process for the increment of information flow of data exchange.

- Requires increase reliability of data signals and control commands, because of reducing operating reliability of power system equipment, the strategic importance and the potential danger of power equipment system.

- The need to integrate systems of different manufacturers on the same power facility causing difficulties in the use of as a baseline protocol IEC 60870-5-104.

How Electricity is Distributed and Regulated

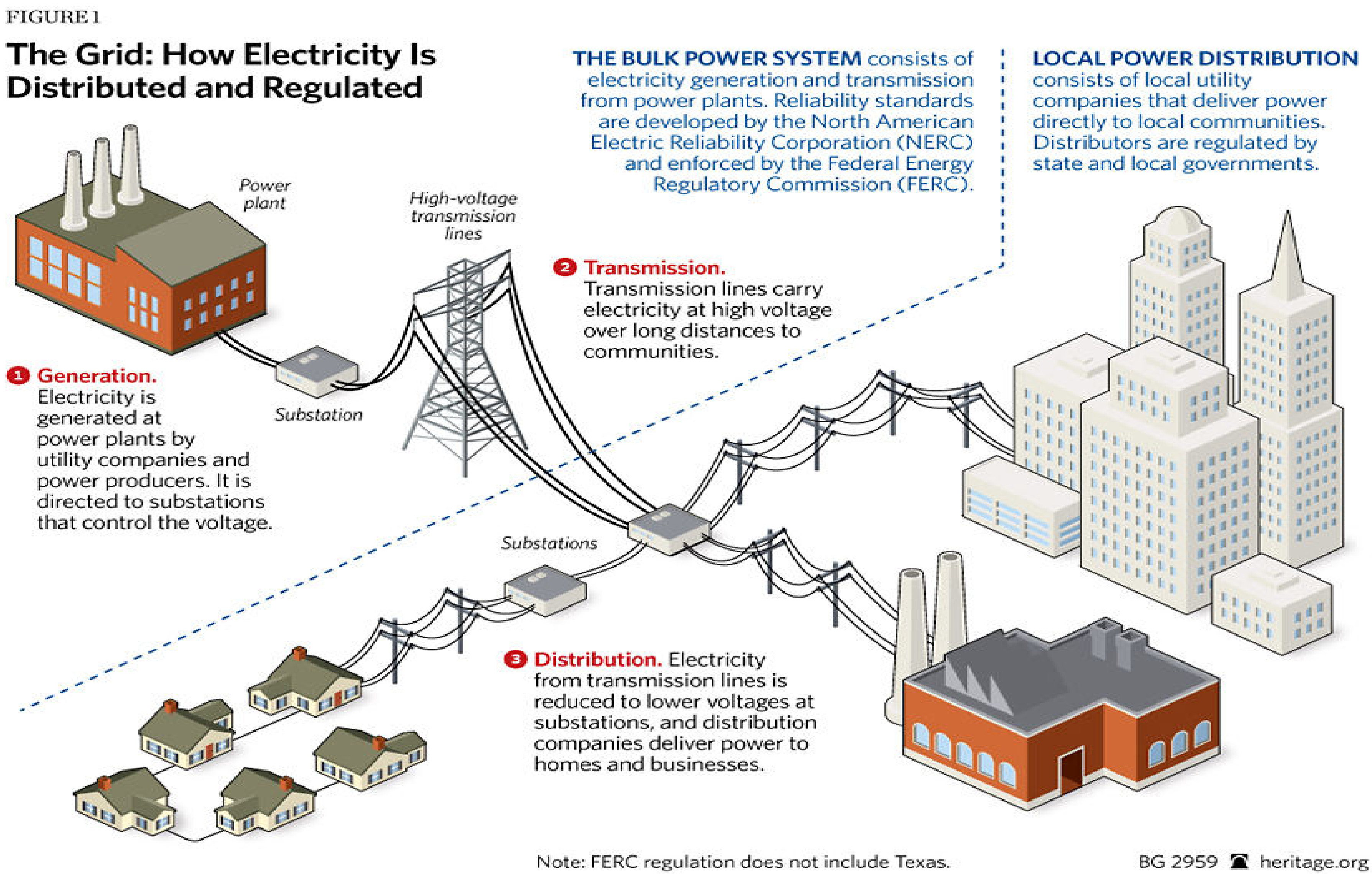
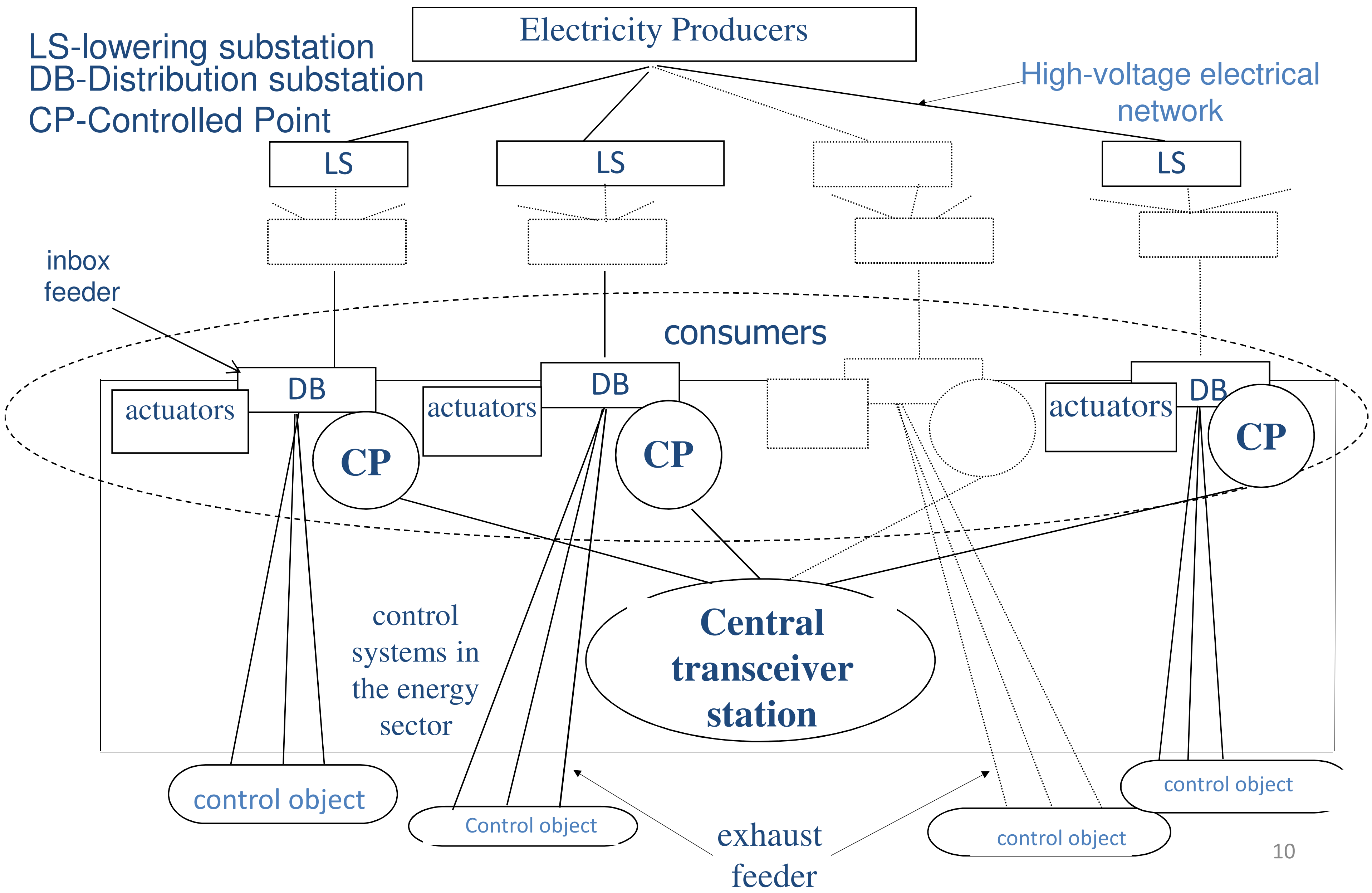


Diagram of the system of energy management



Problems implementing effective energy management systems increased reliability

•impossibility of combining information on entering bound "events" to the time stamps;
•the precise fixing sequence of "events", recorded by different modules and different programmable logic controllers (PLC);
•limited capacity of the diagnostic procedures and the formation of diagnostic messages;
•all systems based on PLC is not met the standards of the division execute commands on remote control and remote signaling steps and use pauses between stages to control (in chains feedback) lack of distortion.

As a result, the confidence level - the probability of satisfying distorted team will be at 10^{-14} - 10^{-16} degrees, and 10^{-6} - 10^{-8}, i.e would be six to eight orders of magnitude worse than the agreed standards

Requirements for energy management systems reliability

The reliability is the degree of conformity of received and transmitted information. Mathematically accuracy (D) can be expressed in a probability of correct reception: $D = N_{Right} / N_{False}$

Probabilistic Characteristics	Probability of the event, P		
	Classes reliability		
	I_1	I_2	I_3
Chance of transformation commands	10^{-14}	10^{-10}	10^{-7}
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Probability of false commands	10^{-12}	10^{-7}	10^{-4}

NOTION OF INFORMATION VERACITY IN TELEMECHANICS

In accordance with GOST 26.205.88 the accuracy is determined by the magnitude of the probability of undetectable distortion of commands, signals and measurements by noise in the communication line (channel) . In other words the veracity can be defined as a degree of received signal (message) compliance with transmitted one.

a quantitative measure of veracity is a decreasing function of distorted signal reception probability:

$$S = \lg \frac{1}{P_{dis}}$$

where P_{dis} - the probability of undetected distortion. In case of analog signals the veracity measure is an increasing function of probabilit

$P = P\{\varepsilon \leq \varepsilon_0\}$ i.e. the probability that deviation of the received signal from the transmitted one ε will not exceed some predetermined value ε0.

ANALYSIS OF THE REAL VERACITY OF INFORMATION PROVIDED BY MODERN TELEMECHANICS SYSTEMS

$$T_m = \frac{1}{w_m P_{dis}}$$

For elementary flow of undetectable failures its intensity λi : $\lambda_i = \frac{1}{T_m} \frac{n_{ob} P_1}{t_y}$

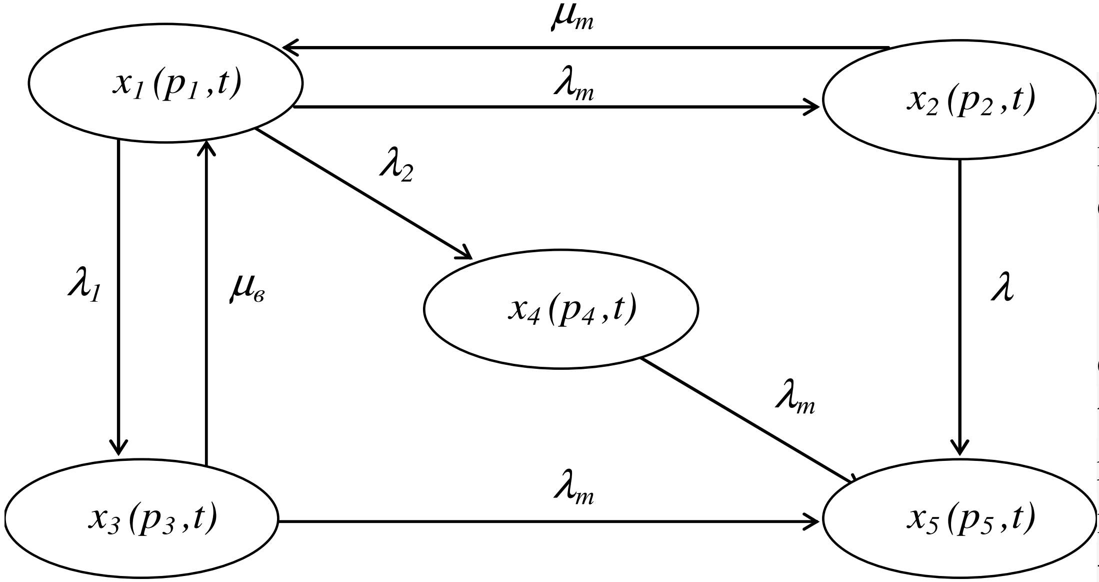
where n_{ob} - statistically average number of applications of i-type year , ty - number of hours per year.

Let us divide components of modules used in transmitting and receiving i-type information into m groups. Let j denotes the Intensity of undetected failure in j group, and p_j – the probability of distorted information transmission as a result of undetected failure. Then the degree of received i-type information veracity reduction D_i is

$$D_i = \frac{\lambda_i + \sum_{j=1}^{m} \lambda_j p_j}{\lambda_i}$$

$$D_i = \frac{10^{-15} + 5 \cdot 10^{-7} \cdot 10^{-6}}{10^{-15}} = 0{,}5 \cdot 10^{3}$$

Probabilistic mathematical model states conditional (control systems in the energy sector)



$x_1$state serviceability complex require ments of its translation in a working condition are not available; x_2-state of serviceability, the complex is busy serving the received request; x_3-fault condition detected by means of con-trol and diagnostic complex translation requirements in working condition are not available; x_4-state is not detected fault, translation require-
ments in working condition are not available; x_5-fault condition during the receipt of the request transfer to a working condition possible misrepre-sentation.λ_m- flow rate requirements on the use of complex information; μ_mStream service requirements; λ- to-

A mathematical model of complex derivatives:

$$\begin{cases} p_1'(t) = (-\lambda_т + \lambda)p_1(t) + \mu_т p_2(t) + \mu_в p_3(t) \\ p_2'(t) = (-\mu_т + \lambda)p_2(t) + \lambda_т p_1(t) \\ p_3'(t) = (-\mu_в + \lambda_т)p_3(t) + \lambda_1 p_1(t) \\ p_4'(t) = -\lambda_т p_4(t) + \lambda_2 p_1(t) \\ p_5'(t) = \lambda_т p_3(t) + \lambda_т p_4(t) + \lambda p_2(t) \end{cases}$$

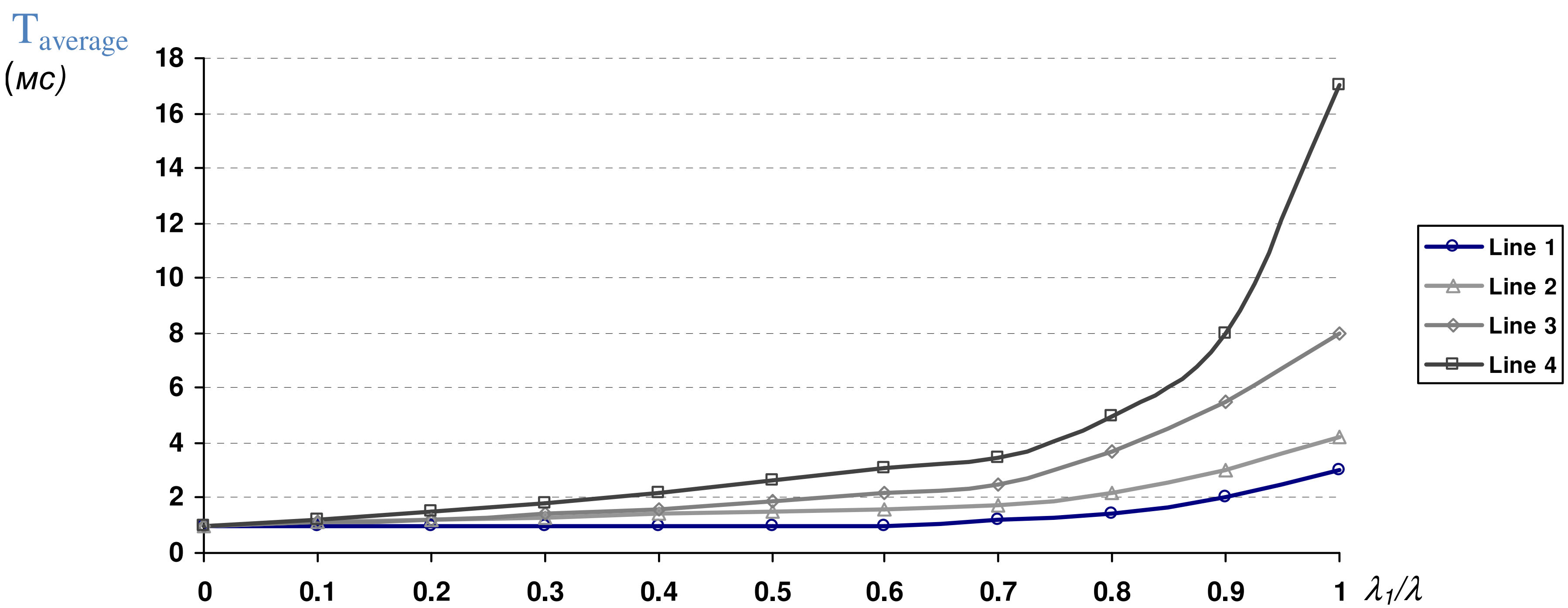
$$\begin{vmatrix} 0 \\ 1 \\ 0 \\ 0 \\ 0 \end{vmatrix} = \begin{vmatrix} x+\lambda+\mu_m & -\lambda_m & 0 & 0 & 0 \\ -\mu_m & x+\lambda+\lambda_m & -\mu_в & 0 & 0 \\ 0 & -\lambda_1 & x+\mu_в+\lambda_m & 0 & 0 \\ 0 & -\lambda_2 & 0 & x+\lambda_m & 0 \\ -\lambda & 0 & -\lambda_m & -\lambda_m & x \end{vmatrix} \times \begin{vmatrix} a_2 \\ a_1 \\ a_3 \\ a_4 \\ a_5 \end{vmatrix}.$$

Analysis of mathematical model states **(control systems in the energy sector)**

The average residence time of the complex is able to inoperability (x_5)

$$T_{average}=\frac{[\lambda_m\lambda_1\mu_m+\lambda_m\lambda(\mu_{\text{в}}+\lambda_m)][(\lambda_m+\mu_m)(\mu_{\text{в}}+\lambda_m)-\lambda_1\mu_{\text{в}}]}{\mu_m^2(\lambda_m\lambda+\lambda_2\mu_{\text{в}})^2}+\frac{\lambda_2(\lambda_m+\mu_m)(\mu_{\text{в}}+\lambda_m)^2}{\mu_m(\lambda_m\lambda+\lambda_2\mu_{\text{в}})^2}-\frac{\lambda_2[\lambda_m(\mu_{\text{в}}+\lambda_m)-\mu_m\mu_{\text{в}}]}{\lambda_m\mu_m(\lambda_m\lambda+\lambda_2\mu_{\text{в}})}.$$

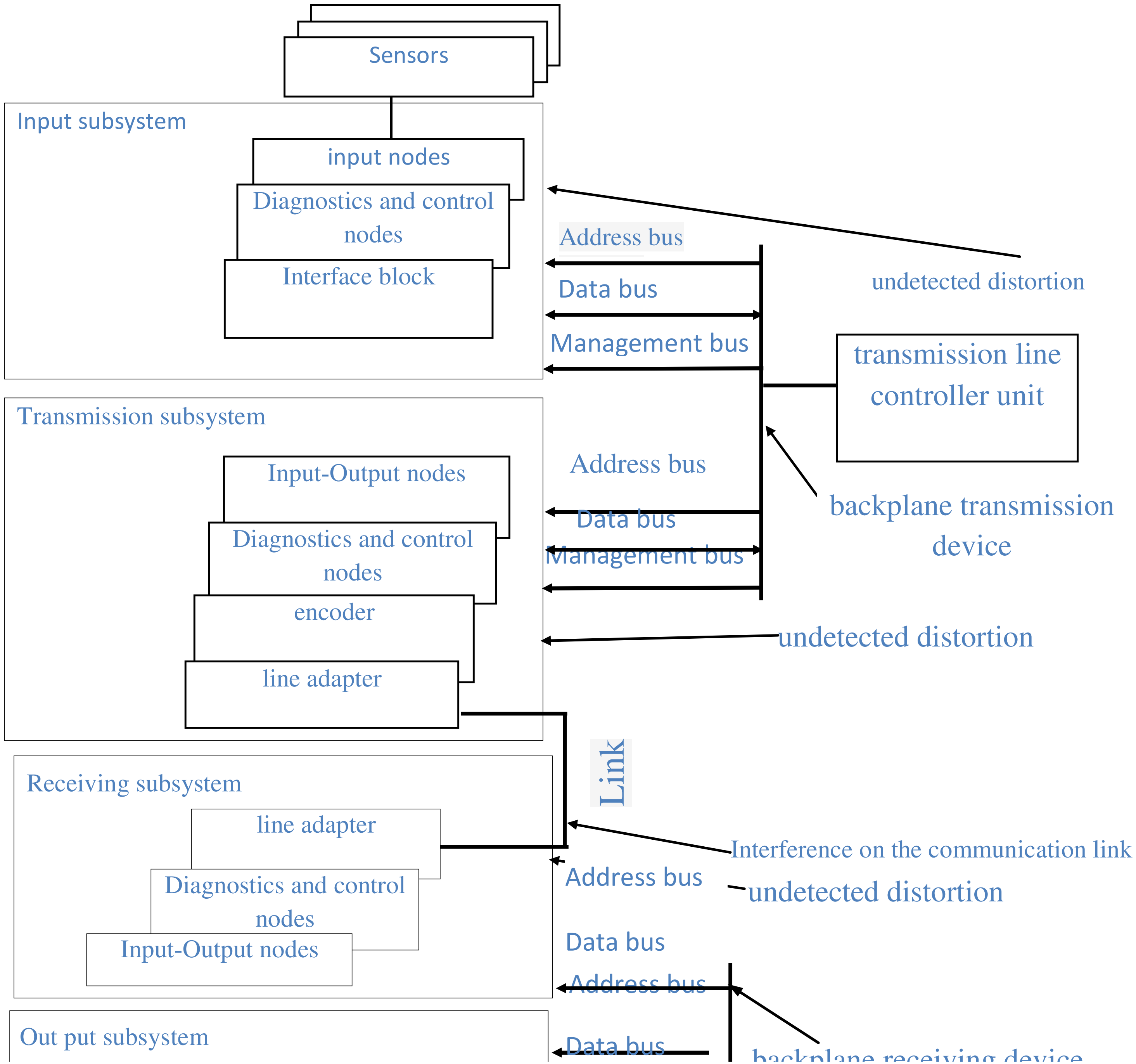
№ graphic	λ_m (1/hour)	λ (1/hour)	$\mu_{\text{в}}$ (1/hour)	μ_m (1/hour)
1	10^{-1}	10^{-3}	2	$5\cdot10^{-3}$
2	10^{-1}	10^{-3}	1	$5\cdot10^{-3}$
3	10^{-1}	10^{-3}	$3\cdot10^{-1}$	$5\cdot10^{-3}$
4	10^{-1}	10^{-3}	10^{-1}	$5\cdot10^{-3}$



You need:

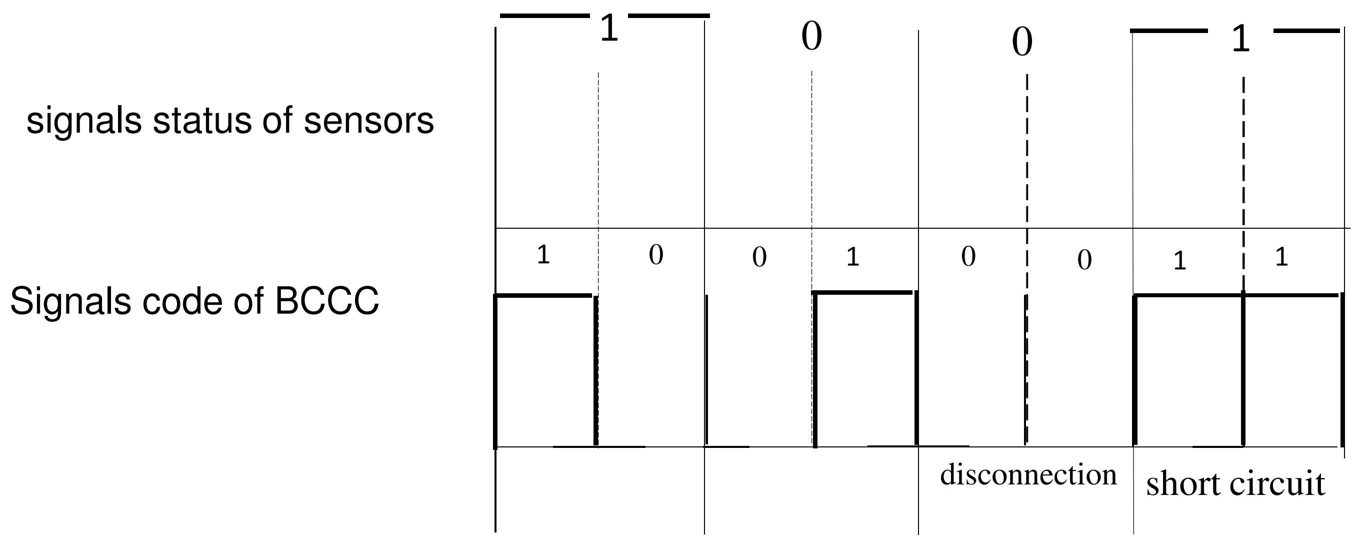
the introduction of the complexes continuously operating control devices and diagnostics

Scheme of the information in the signal flow path in the control systems in the energy sector

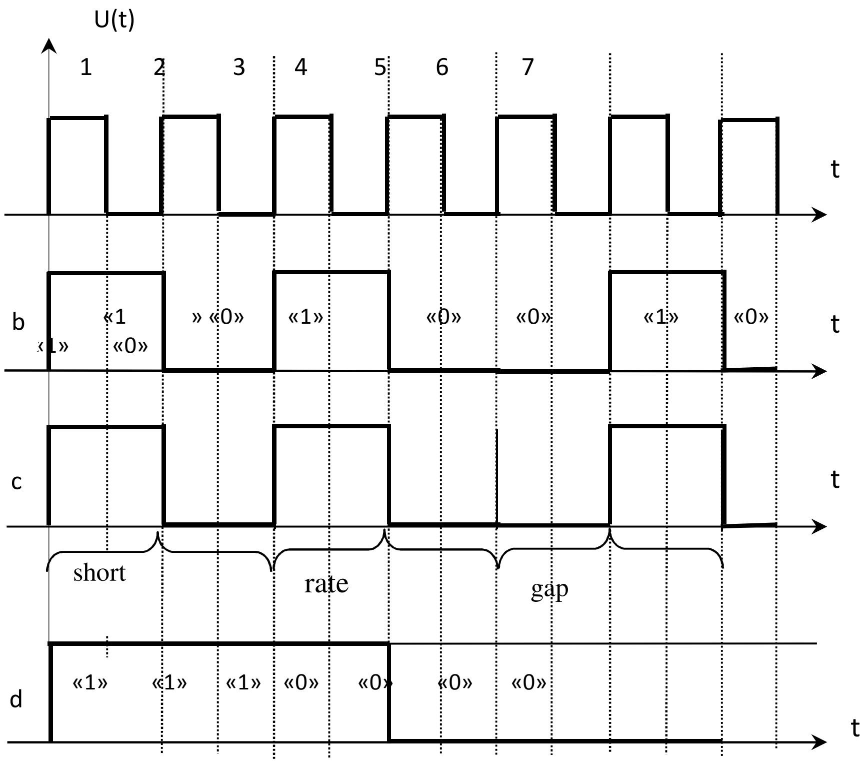


Biimpulse conditionally correlation code (BCCC)

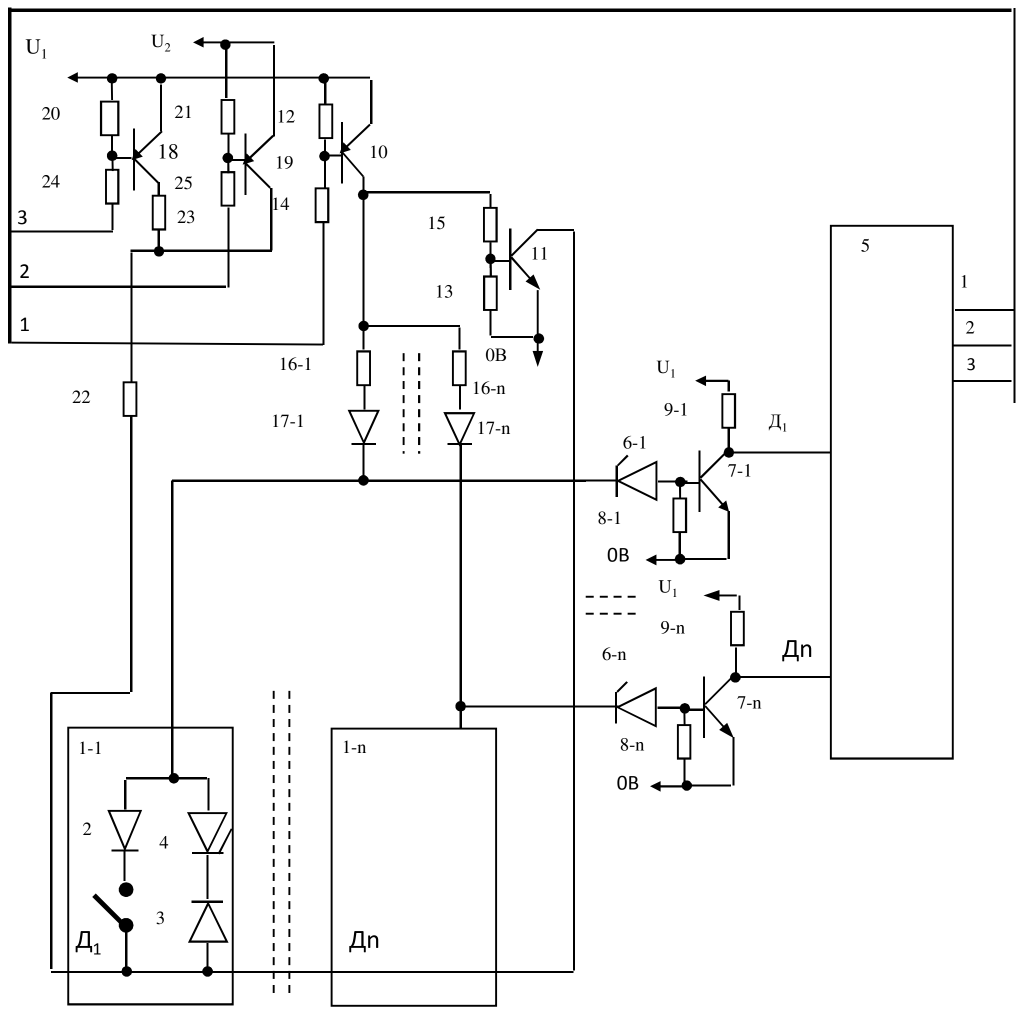
- The biimpulse conditionally correlation code (BCCC) was developed in which “conventional” inversion of second bit in the pair" depends on the outcome of diagnostics of communication chains. The signal of the sensor status is inverted only if dynamic control doesn’t n detect distortions. In this case biimpulse pair becomes «10» or «01». Upon detecting distortion the code becomes «11» (short) or «00» (break in the chain of communication with the sensors), making possible to detect distortion place and type through the use of two unresolved combinations.



Development of Biimpulsny ’s conditional correlation code



Biimpulsny ’s scheme conditionally correlative coding



Scheme fragment encoder input module coding telesignalization

METHOD OF CALCULATING THE RELIABILITY OF INTEGRATED INPUT-OUTPUT CHANNELS TELESIGNALIZATION

Chance undetectable distortion channel Input- Ouput telesignalization

$$P_{ДС} = P_{дат} + P_{кс} + P_{кд} + P_{дкд}$$

Chance undetectable distortion when entering information from sensors

$$P_{дат} = n_{TC}\ P_1^2\ P_{пмх}\ (\frac{T_{стр}}{T_{ц.опр}})^2\ .$$

Chance undetectable distortion code in the encoder (decoder)

$$P_{кд} = P_{дкд}\ 2\ n_д\ P_{нкд}^2\ P_{пмх}$$

Chance undetectable distortion in the communication channel

$$P_{кс1} = P_1^4\ C_{a_1+a_2+a_3}^2\ \ P_1^4\ C_{a_1+a_2+a_3+a_4}^6$$

$P_{пмх}$ – the conditional probability of the disturbance during the second input digital signal distortion, which is opposite effects in the primary distortion; $n_д$ – number of sensors DS; $T_{стр}$- the duration of the strobe signal; $T_{ц.опр.}$- between adjacent cycles survey sensor status; $P_{нкд}$ – probability of failure of the encoder (decoder); $C_{a_1+a_2+a_3}^2$ - The number of possible combinations of pairs of characters in the transmitted code correlation; a_1- digit code number of the sensor DS, a_2 – bit code for the first time stamp events binary signal, a_3 – bit code-state sensor ; $C_{a_1+a_2+a_3+a_4}^6$ - the number of combinations of the code containing ;$(a_1+a_2+a_3)$ - character code correlation и a_4 - characters cyclic code.

Substituting the averages for the control system in the energy values, например $P_1 = 10^{-3}$, $P_{нкд} = 10^{-6}$; $T_{стр} = 10^{-6}$с ; $T_{опр.} = 10^{-2}$ с; $n_д = 32$, $a_1 = 5$; $a_2 = 10$; $a_3 = 1$; $a_4 = 16$, we get

$$\boldsymbol{P_{ДС} \sim 10^{-13}},$$

which greatly exceeds the most stringent regulatory technical requirements set GOST.

Results of experimental studies of reliability channel telesignalization

Indicator	The index value
Normal operating conditions (signal to noise ratio 8/1)	
Probability of receiving a false DC	$8{,}7\cdot 10^{-13}$
Chance of refusing DS	$1{,}52 \cdot 10^{-12}$
Distortion to communication with sensors (signal to noise ratio 3/1 ... 7/1)	
Probability of receiving a false DC	$3{,}47\cdot 10^{-10}$
Chance of refusing DS	$5{,}1\cdot 10^{-10}$
Distortions in the communication channel (signal to noise ratio 3/1 ... 7/1)	
Probability of receiving a false DC	$3{,}09\cdot 10^{-10}$
Chance of refusing DS	$5{,}06\cdot 10^{-10}$

Conclusions

- ❖ The principles of the combined coding TMN combining first synthesized biimpulsny conditional correlation code BCCC cyclic code, providing a high level of reliability telesignalization, far surpassing the standards
- ❖ To implement the technique described in the IEC 61850 protocol services necessary to introduce the possibility of signal transmission state of the object and two bits describing the function of all four working vehicle combinations that display data from one object control ("ON" - "OFF" - "short circuit due to sensor" - "open circuit sensor communication“
- Experimental evaluation of information signals veracity showed that the probability of undetectable distortion of false signals transmission under normal operating conditions before disturbance is whereas after exposure and the probability of undetectable distortion of false signals transmission when exposing to noise is which (A) is significantly higher than the levels specified in GOST 26.205-88 (10^{-10} – 10^{-12}).
- Thus, the principles of combined coding, characterized by usage of biimpulse conditionally correlational code with cyclic BCCC code, providing a high level of veracity, considerably exceeding the standards requirements.

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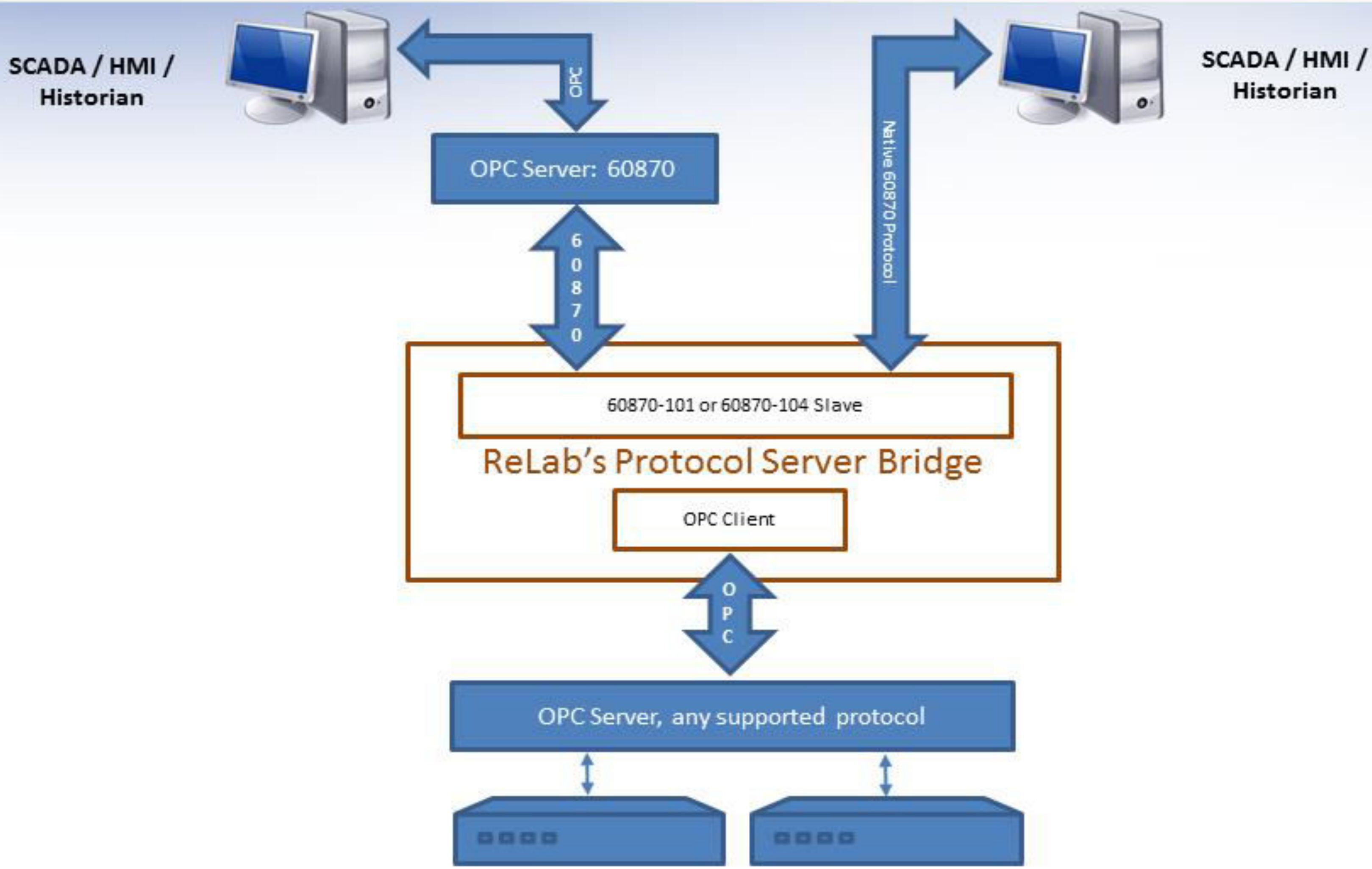

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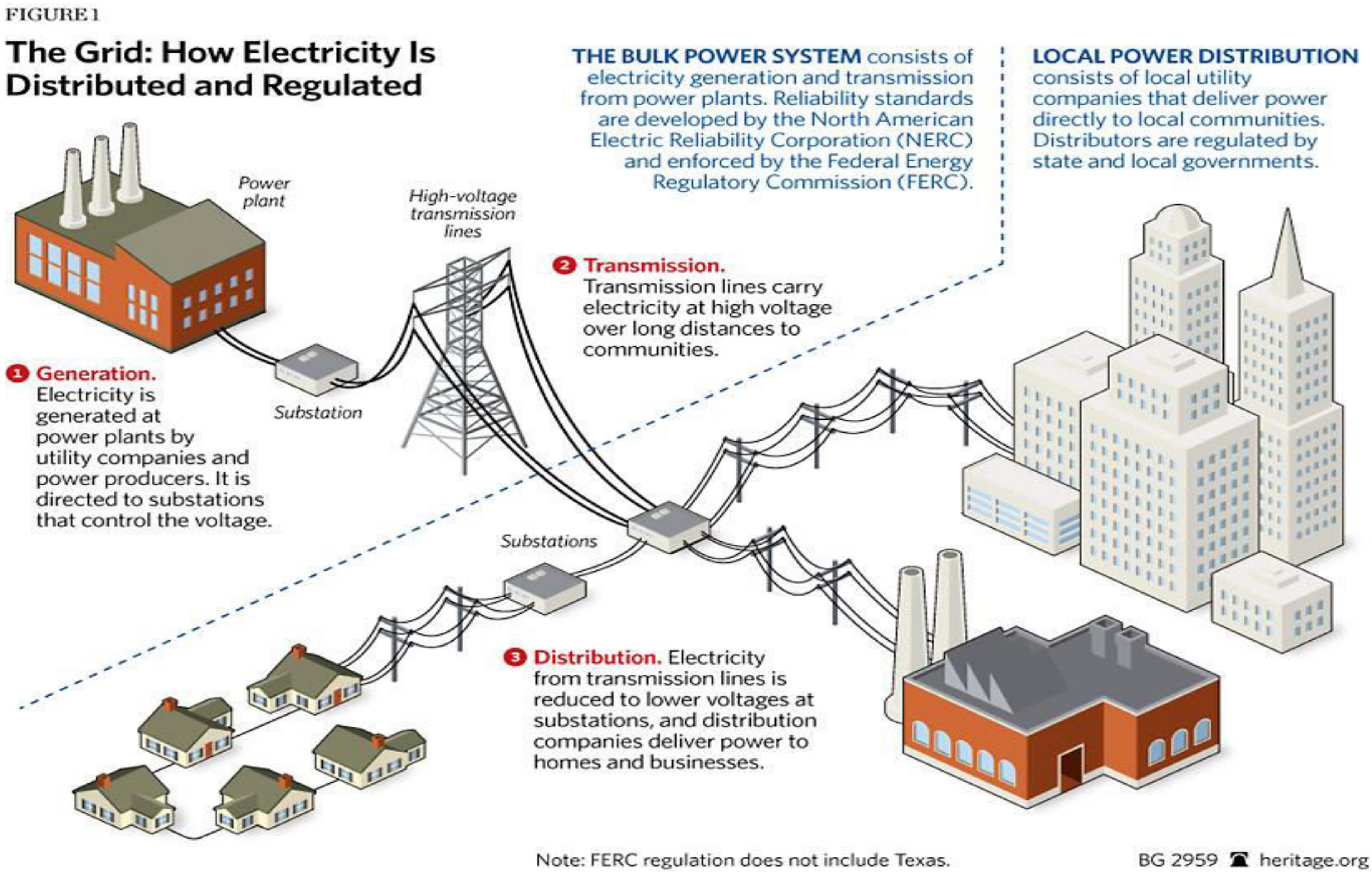

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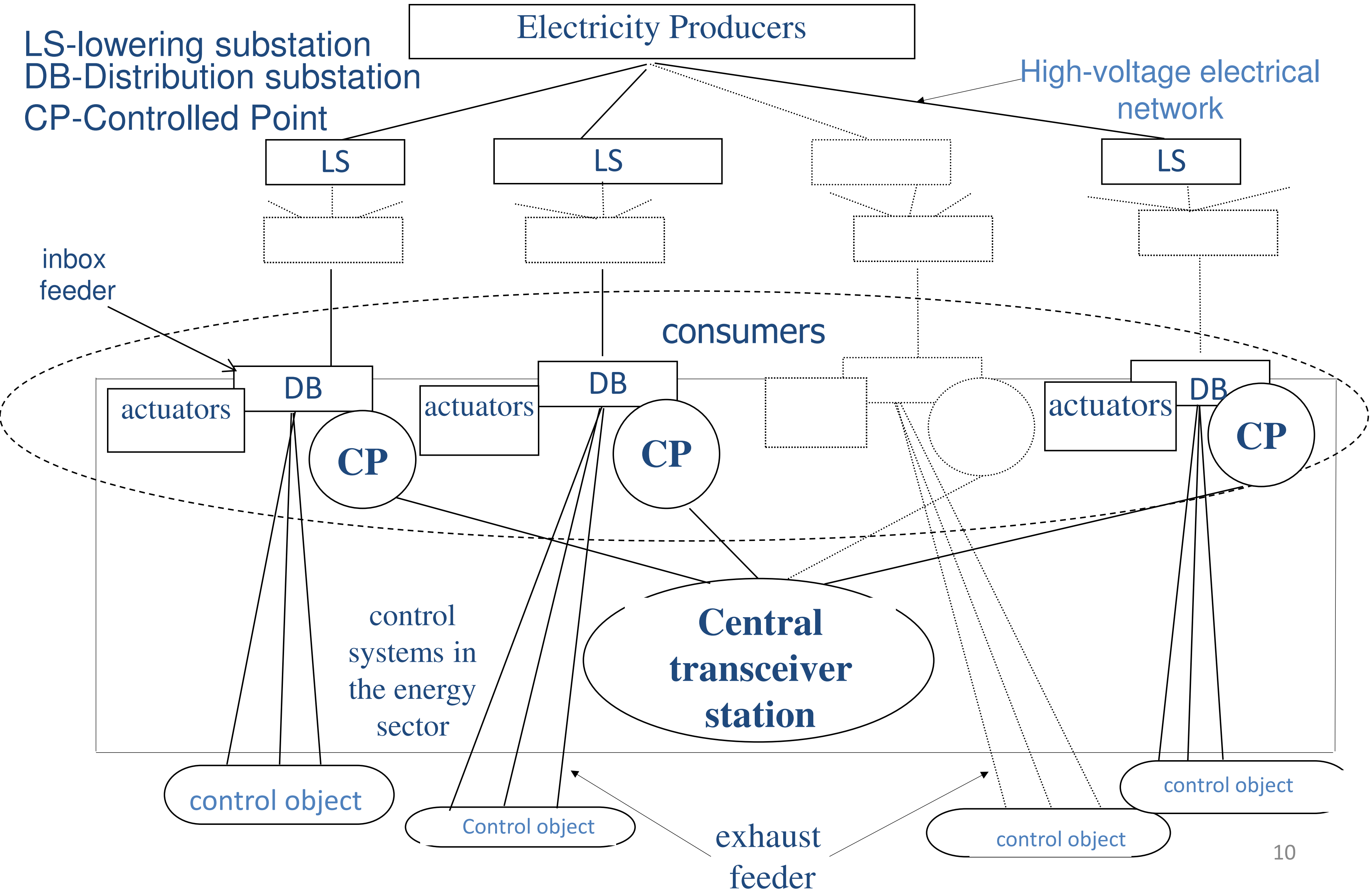

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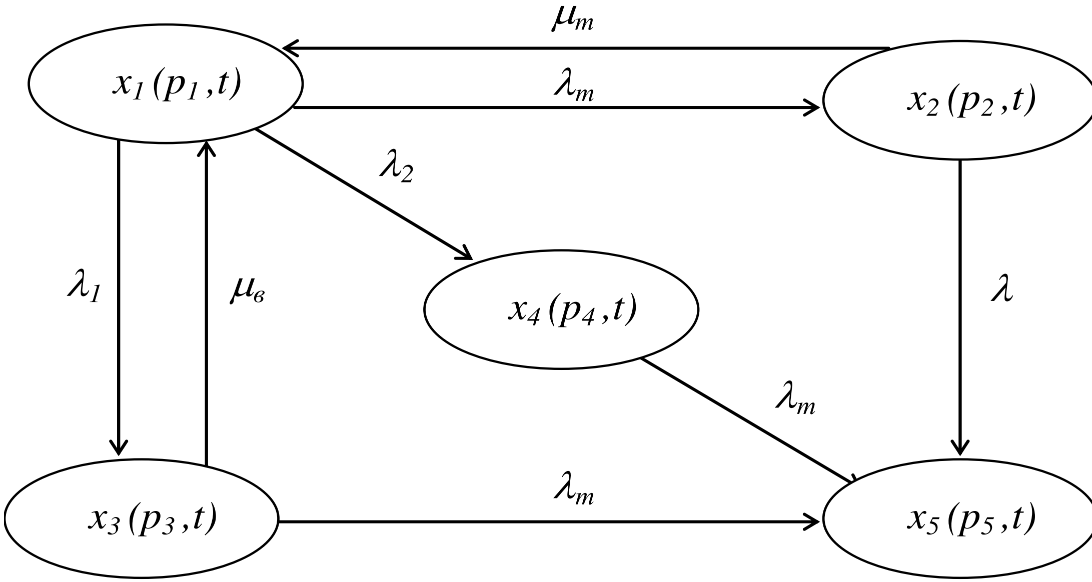

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A mathematical model of complex derivatives:

$$\begin{cases} p_1'(t) = (-\lambda_т + \lambda)p_1(t) + \mu_т p_2(t) + \mu_в p_3(t) \\ p_2'(t) = (-\mu_т + \lambda)p_2(t) + \lambda_т p_1(t) \\ p_3'(t) = (-\mu_в + \lambda_т)p_3(t) + \lambda_1 p_1(t) \\ p_4'(t) = -\lambda_т p_4(t) + \lambda_2 p_1(t) \\ p_5'(t) = \lambda_т p_3(t) + \lambda_т p_4(t) + \lambda p_2(t) \end{cases}$$

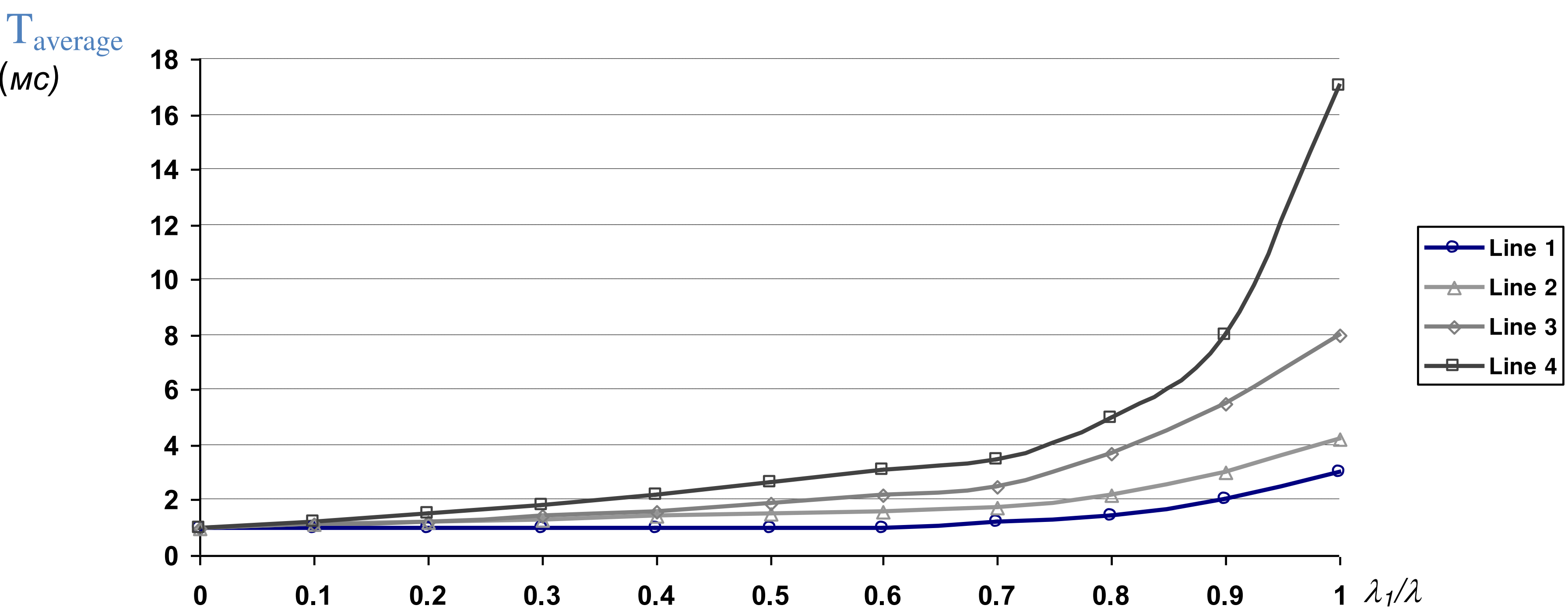
$$\begin{vmatrix} 0 \\ 1 \\ 0 \\ 0 \\ 0 \end{vmatrix} = \begin{vmatrix} x+\lambda+\mu_m & -\lambda_m & 0 & 0 & 0 \\ -\mu_m & x+\lambda+\lambda_m & -\mu_в & 0 & 0 \\ 0 & -\lambda_1 & x+\mu_в+\lambda_m & 0 & 0 \\ 0 & -\lambda_2 & 0 & x+\lambda_m & 0 \\ -\lambda & 0 & -\lambda_m & -\lambda_m & x \end{vmatrix} \times \begin{vmatrix} a_2 \\ a_1 \\ a_3 \\ a_4 \\ a_5 \end{vmatrix}.$$

Analysis of mathematical model states **(control systems in the energy sector)**

The average residence time of the complex is able to inoperability (x_5)

$$T_{average}=\frac{[\lambda_m\lambda_1\mu_m+\lambda_m\lambda(\mu_в+\lambda_m)][(\lambda_m+\mu_m)(\mu_в+\lambda_m)-\lambda_1\mu_в]}{\mu_m^2(\lambda_m\lambda+\lambda_2\mu_в)^2}+\frac{\lambda_2(\lambda_m+\mu_m)(\mu_в+\lambda_m)^2}{\mu_m(\lambda_m\lambda+\lambda_2\mu_в)^2}-\frac{\lambda_2[\lambda_m(\mu_в+\lambda_m)-\mu_m\mu_в]}{\lambda_m\mu_m(\lambda_m\lambda+\lambda_2\mu_в)}.$$

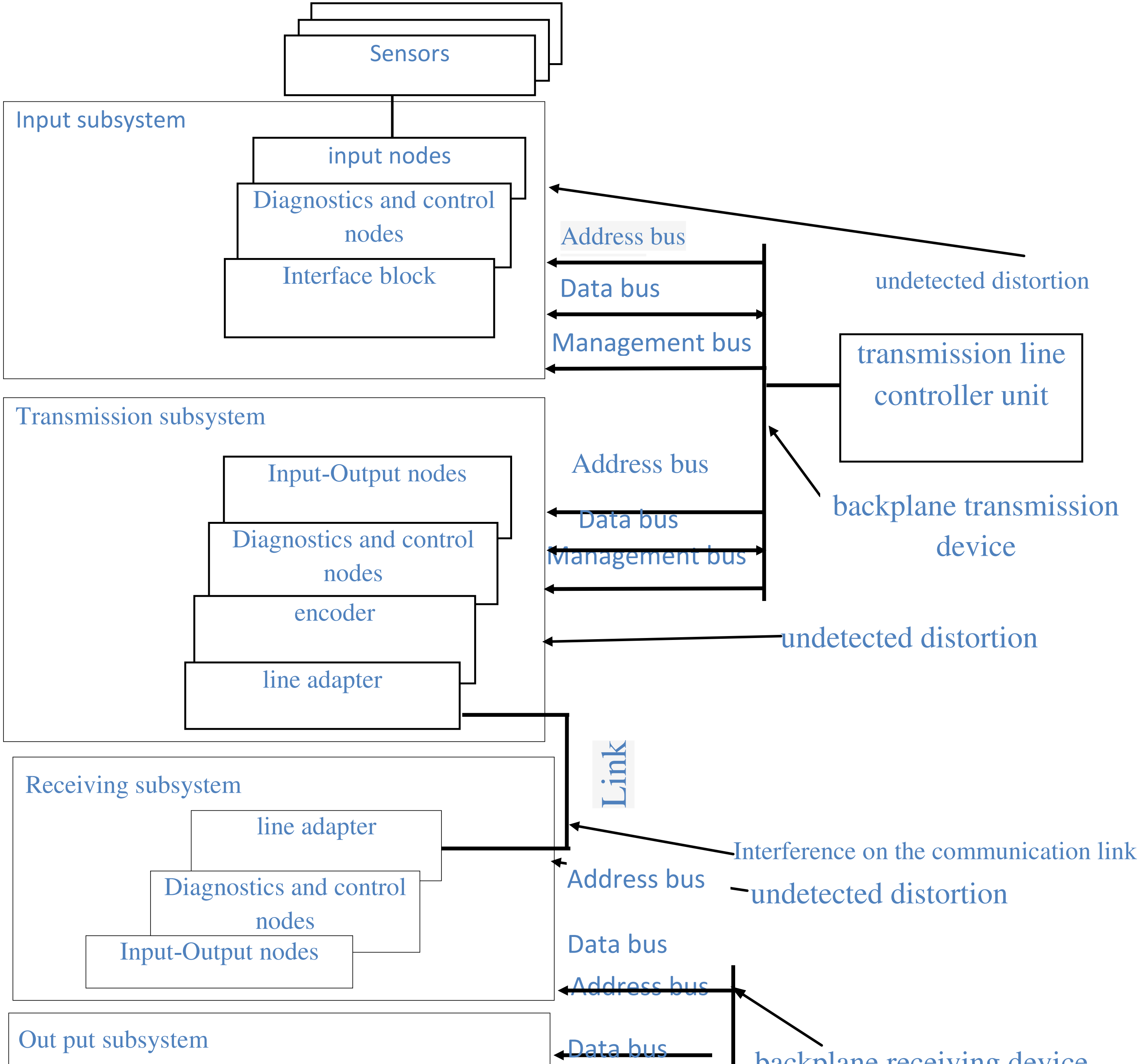
№ graphic	λ_m (1/hour)	λ (1/hour)	$\mu_в$ (1/hour)	μ_m (1/hour)
1	10^{-1}	10^{-3}	2	$5\cdot10^{-3}$
2	10^{-1}	10^{-3}	1	$5\cdot10^{-3}$
3	10^{-1}	10^{-3}	$3\cdot10^{-1}$	$5\cdot10^{-3}$
4	10^{-1}	10^{-3}	10^{-1}	$5\cdot10^{-3}$



You need:

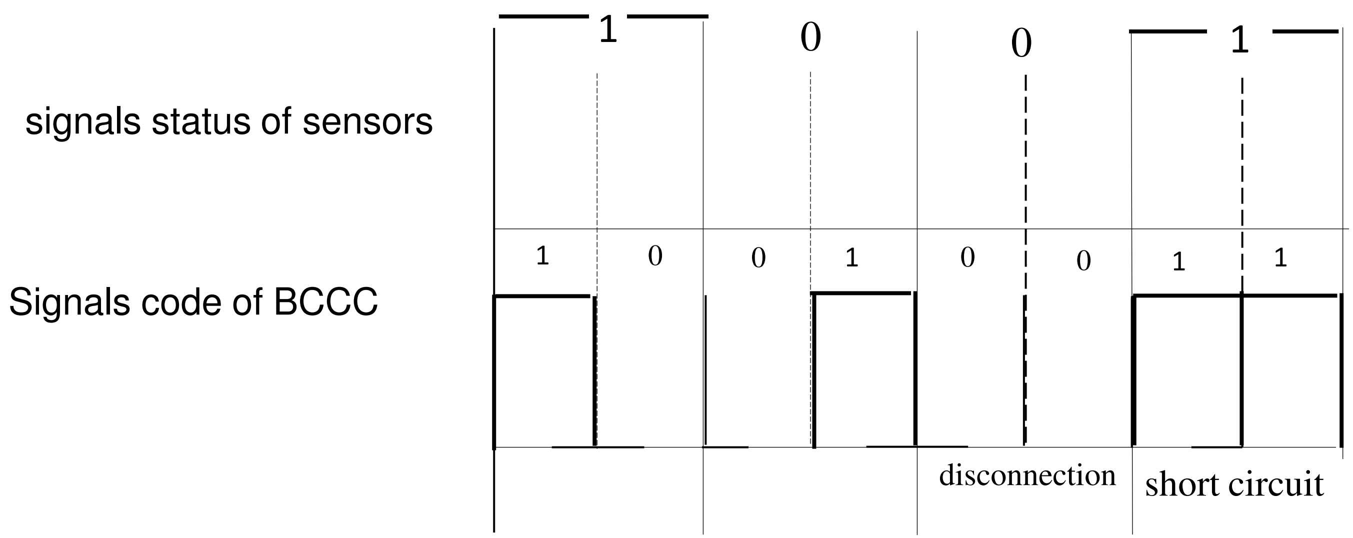
the introduction of the complexes continuously operating control devices and diagnostics

Scheme of the information in the signal flow path in the control systems in the energy sector

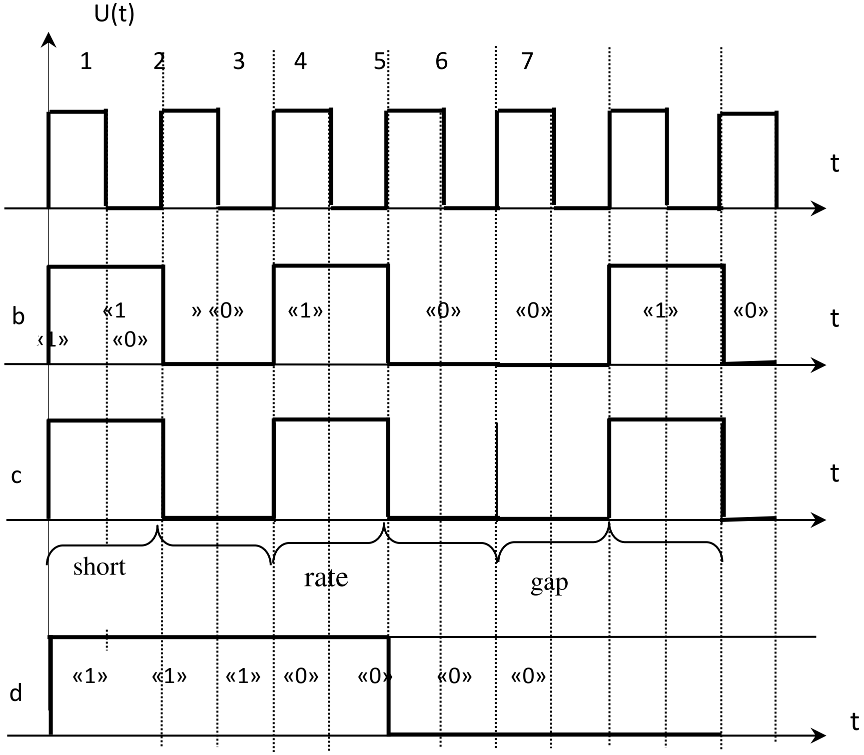


Biimpulse conditionally correlation code (BCCC)

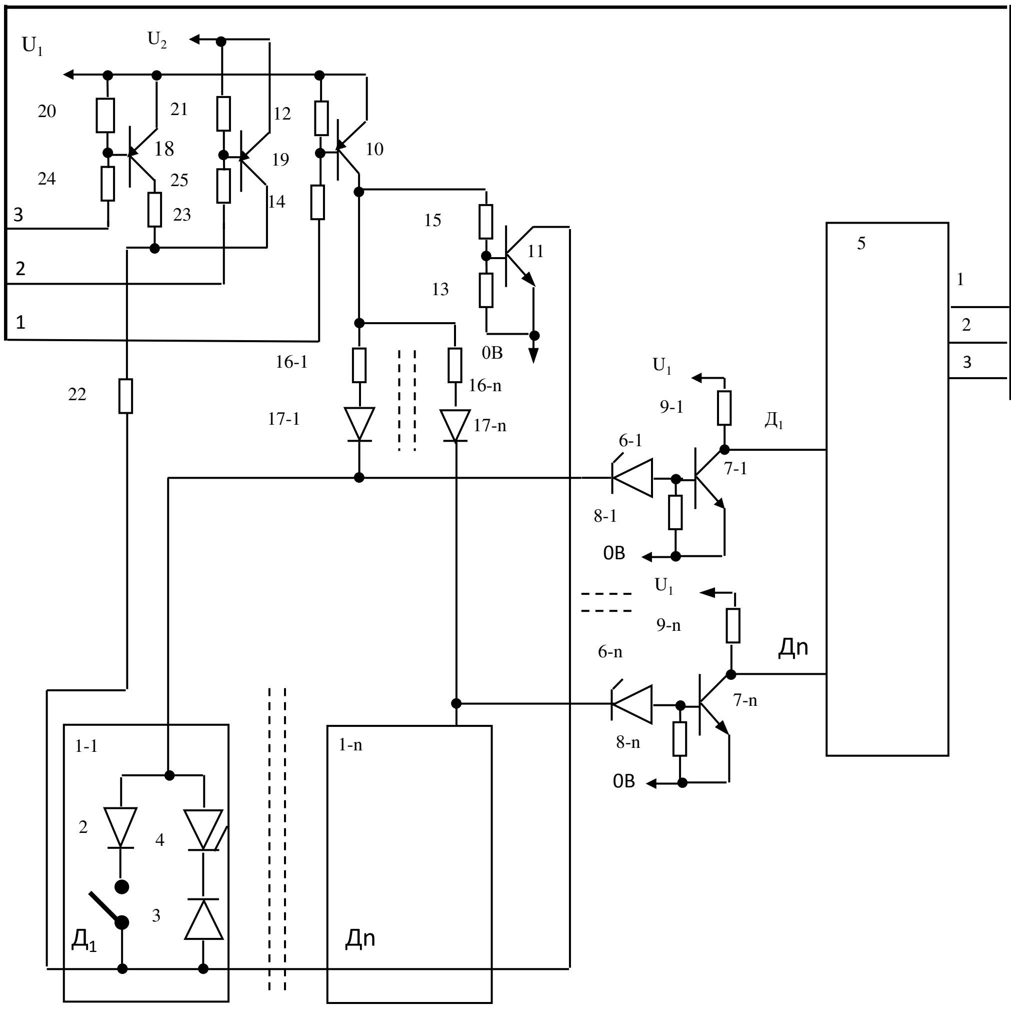
➢The biimpulse conditionally correlation code (BCCC) was developed in which “conventional” inversion of second bit in the pair" depends on the outcome of diagnostics of communication chains. The signal of the sensor status is inverted only if dynamic control doesn’t n detect distortions. In this case biimpulse pair becomes «10» or «01». Upon detecting distortion the code becomes «11» (short) or «00» (break in the chain of communication with the sensors), making possible to detect distortion place and type through the use of two unresolved combinations.



Development of Biimpulsny 's conditional correlation code



Biimpulsny 's scheme conditionally correlative coding



Scheme fragment encoder input module coding telesignalization

METHOD OF CALCULATING THE RELIABILITY OF INTEGRATED INPUT-OUTPUT CHANNELS TELESIGNALIZATION

Chance undetectable distortion channel Input- Ouput telesignalization

$$P_{ДС} = P_{дат} + P_{кс} + P_{кд} + P_{дкд}$$

Chance undetectable distortion when entering information from sensors

$$P_{дат} = n_{TC}\ P_1^2\ P_{пмх} \left(\frac{T_{стр}}{T_{ц.опр}}\right)^2 .$$

Chance undetectable distortion code in the encoder (decoder)

$$P_{кд} = P_{дкд}\ 2\ n_{д}\ P^2_{нкд}\ P_{пмх}$$

Chance undetectable distortion in the communication channel

$$P_{кс1} = P_1^4\ C^2_{a_1+a_2+a_3}\ \ P_1^4\ C^6_{a_1+a_2+a_3+a_4}$$

$P_{пмх}$ – the conditional probability of the disturbance during the second input digital signal distortion, which is opposite effects in the primary distortion; $n_{д}$ – number of sensors DS; $T_{стр}$- the duration of the strobe signal; $T_{ц.опр.}$- between adjacent cycles survey sensor status; $P_{нкд}$ – probability of failure of the encoder (decoder); $C^2_{a_1+a_2+a_3}$ - The number of possible combinations of pairs of characters in the transmitted code correlation; a_1- digit code number of the sensor DS, a_2 – bit code for the first time stamp events binary signal, a_3 – bit code-state sensor ;$C^6_{a_1+a_2+a_3+a_4}$ - the number of combinations of the code containing ;$(a_1+a_2+a_3)$ - character code correlation и a_4 - characters cyclic code.

Substituting the averages for the control system in the energy values, например $P_1 = 10^{-3}$, $P_{нкд} = 10^{-6}$; $T_{стр} = 10^{-6}$с ; $T_{опр.} = 10^{-2}$ с; $n_{д} = 32$, $a_1 = 5$; $a_2 = 10$; $a_3 = 1$; $a_4 = 16$, we get

$$\mathbf{P_{ДС} \sim 10^{-13}},$$

which greatly exceeds the most stringent regulatory technical requirements set GOST.

Results of experimental studies of reliability channel telesignalization

Indicator	The index value
Normal operating conditions (signal to noise ratio 8/1)	
Probability of receiving a false DC	$8{,}7 \cdot 10^{-13}$
Chance of refusing DS	$1{,}52 \cdot 10^{-12}$
Distortion to communication with sensors (signal to noise ratio 3/1 ... 7/1)	
Probability of receiving a false DC	$3{,}47 \cdot 10^{-10}$
Chance of refusing DS	$5{,}1 \cdot 10^{-10}$
Distortions in the communication channel (signal to noise ratio 3/1 ... 7/1)	
Probability of receiving a false DC	$3{,}09 \cdot 10^{-10}$
Chance of refusing DS	$5{,}06 \cdot 10^{-10}$

Conclusions

- ❖ The principles of the combined coding TMN combining first synthesized biimpulsny conditional correlation code BCCC cyclic code, providing a high level of reliability telesignalization, far surpassing the standards
- ❖ To implement the technique described in the IEC 61850 protocol services necessary to introduce the possibility of signal transmission state of the object and two bits describing the function of all four working vehicle combinations that display data from one object control ("ON" - "OFF" - "short circuit due to sensor" - "open circuit sensor communication“
- Experimental evaluation of information signals veracity showed that the probability of undetectable distortion of false signals transmission under normal operating conditions before disturbance is whereas after exposure and the probability of undetectable distortion of false signals transmission when exposing to noise is which (A) is significantly higher than the levels specified in GOST 26.205-88 (10^{-10} – 10^{-12}).
- Thus, the principles of combined coding, characterized by usage of biimpulse conditionally correlational code with cyclic BCCC code, providing a high level of veracity, considerably exceeding the standards requirements.