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

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IEC 60870-5

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IEC 60870-5-1 Transmission Frame Formats
IEC 60870-5-2 Data Link Transmission Services
IEC 60870-5-3 General Structure of Application Data
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IEC 60870-5-101 Transmission Protocols, companion standards especially for basic telecontrol tasks
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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.

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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.
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

**The Grid: How Electricity Is Distributed and Regulated**

**1. Generation.** Electricity is generated at power plants by utility companies and power producers. It is directed to substations that control the voltage.

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LS-lowering substation
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control systems in the energy sector

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- 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: \(D = \frac{N_{\text{Right}}}{N_{\text{False}}}\)

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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:

\[ S = \lg \frac{1}{P_{\text{dis}}} \]

where \( P_{\text{dis}} \) - the probability of undetected distortion. In case of analog signals the veracity measure is an increasing function of probability:

\[ P = P(\epsilon \leq \epsilon_0) \]

i.e. the probability that deviation of the received signal from the transmitted one \( \epsilon \) will not exceed some predetermined value \( \epsilon_0 \).
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 \( \lambda_i \):

\[ \lambda_i = \frac{1}{t_y} \frac{n_{ob} P_i}{t_y} \]

where \( n_{ob} \) - statistically average number of applications of i-type year, \( t_y \) - number of hours per year.

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

\[ D_i = \frac{10^{-15} + 5 \cdot 10^{-7} \cdot 10^{-6}}{10^{-15}} = 0.5 \cdot 10^3 \]
Probabilistic mathematical model states conditional (control systems in the energy sector)

\[ x_1(p_1,t) \quad \mu_m \quad \lambda_m \quad x_2(p_2,t) \]

\[ x_3(p_3,t) \quad \lambda_1 \quad \mu_n \quad \lambda_2 \quad x_4(p_4,t) \]

\[ x_5(p_5,t) \quad \lambda_m \quad \lambda \]

A mathematical model of complex derivatives:

\[
\begin{align*}
\dot{p}_1(t) &= (-\lambda_2 + \lambda)p_1(t) + \mu_x p_2(t) + \mu_n p_3(t) \\
\dot{p}_2(t) &= (-\mu_n + \lambda)p_2(t) + \lambda x_1(t) \\
\dot{p}_3(t) &= (-\mu_n + \lambda_1)p_3(t) + \lambda x_2(t) \\
\dot{p}_4(t) &= -\lambda_2 p_4(t) + \lambda x_1(t) \\
\dot{p}_5(t) &= \lambda_x p_5(t) + \lambda_x p_4(t) + \lambda p_2(t)
\end{align*}
\]

\[
\begin{vmatrix}
0 & x + \lambda + \mu_m & -\lambda & 0 & 0 & 0 \\
1 & -\mu_m & x + \lambda + \lambda_m & -\mu_n & 0 & 0 \\
0 & 0 & -\lambda_1 & x + \mu_n + \lambda_m & 0 & 0 \\
0 & 0 & -\lambda_2 & 0 & x + \lambda_m & 0 \\
0 & -\lambda & 0 & -\lambda_m & -\lambda_m & x
\end{vmatrix}
\times
\begin{vmatrix}
a_2 \\
a_1 \\
a_3 \\
a_4 \\
a_5
\end{vmatrix}
\]
Analysis of mathematical model states (control systems in the energy sector)

The average residence time of the complex is able to inoperability ($x_3$)

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

<table>
<thead>
<tr>
<th>№ graphic</th>
<th>$\lambda_m$ (1/hour)</th>
<th>$\lambda$ (1/hour)</th>
<th>$\mu_m$ (1/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$10^{-1}$</td>
<td>$10^{-3}$</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>$10^{-1}$</td>
<td>$10^{-3}$</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>$10^{-1}$</td>
<td>$10^{-3}$</td>
<td>$3 \cdot 10^{-1}$</td>
</tr>
<tr>
<td>4</td>
<td>$10^{-1}$</td>
<td>$10^{-3}$</td>
<td>$10^{-1}$</td>
</tr>
</tbody>
</table>

$T_{\text{average}}$ ($mc$)

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

- Input subsystem
  - Input nodes
  - Diagnostics and control nodes
  - Interface block

- Transmission subsystem
  - Input-Output nodes
  - Diagnostics and control nodes
  - Encoder
  - Line adapter

- Receiving subsystem
  - Line adapter
  - Diagnostics and control nodes
  - Input-Output nodes

- Output subsystem
  - Address bus
  - Data bus
  - Management bus

- Address bus
- Data bus
- Management bus

- Interference on the communication link
- Undetected distortion
- Transmission line controller unit
- Backplane transmission device
- Undetected distortion
- Backplane receiving device
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 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-Output telesignalization

\[ P_{ДС} = P_{\text{дам}} + P_{\text{кс}} + P_{\text{кд}} + P_{\text{дкд}} \]

Chance undetectable distortion when entering information from sensors

\[ P_{\text{дам}} = n_{TC} P_{1}^{2} P_{\text{пмх}} \left( \frac{T_{\text{cmp}}}{T_{\text{стр}}} \right)^{2} \]

Chance undetectable distortion code in the encoder (decoder)

\[ P_{\text{кд}} = P_{\text{дкд}} 2 n_{д} P_{\text{нкд}}^{2} P_{\text{пмх}} \]

Chance undetectable distortion in the communication channel

\[ P_{\text{kcl}} = P_{1}^{4} C_{a_{1}+a_{2}+a_{3}}^{2} P_{1}^{4} C_{a_{1}+a_{2}+a_{3}+a_{4}}^{6} \]

\[ P_{\text{пмх}} \] - 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; \( T_{\text{cmp}} \) - the duration of the strobe signal; \( T_{\text{стр}} \)- between adjacent cycles survey sensor status; \( P_{\text{нкд}} \) - 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 \( P_{1} = 10^{-3} \), \( P_{\text{нкд}} = 10^{-6} \); \( T_{\text{cmp}} = 10^{6} \) с; \( T_{\text{стр}} = 10^{2} \) с; \( n_{д} = 32 \), \( a_{1} = 5 \); \( a_{2} = 10 \); \( a_{3} = 1 \); \( a_{4} = 16 \), we get

\[ P_{ДС} \sim 10^{-13} \]

which greatly exceeds the most stringent regulatory technical requirements set GOST.
# Results of experimental studies of reliability channel telesignalization

<table>
<thead>
<tr>
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<th>The index value</th>
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</thead>
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<tr>
<td><strong>Normal operating conditions (signal to noise ratio 8/1)</strong></td>
<td></td>
</tr>
<tr>
<td>Probability of receiving a false DC</td>
<td>$8,7 \cdot 10^{-13}$</td>
</tr>
<tr>
<td>Chance of refusing DS</td>
<td>$1,52 \cdot 10^{-12}$</td>
</tr>
<tr>
<td><strong>Distortion to communication with sensors (signal to noise ratio 3/1 ... 7/1)</strong></td>
<td></td>
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<tr>
<td>Probability of receiving a false DC</td>
<td>$3,47 \cdot 10^{-10}$</td>
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<td>Chance of refusing DS</td>
<td>$5,1 \cdot 10^{-10}$</td>
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<td></td>
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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.
National Research University of Electronic Technology «MIET»

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

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\begin{align*}
    p_1'(t) &= (-\lambda_r + \lambda)p_1(t) + \mu_m p_2(t) + \mu_n p_3(t) \\
    p_2'(t) &= (-\mu_r + \lambda)p_2(t) + \lambda_r p_1(t) \\
    p_3'(t) &= (-\mu_n + \lambda_r)p_3(t) + \lambda_1 p_1(t) \\
    p_4'(t) &= -\lambda_r p_4(t) + \lambda_2 p_1(t) \\
    p_5'(t) &= \lambda_r p_3(t) + \lambda_4 p_4(t) + \lambda p_2(t)
\end{align*}
\]

\[
\begin{bmatrix}
    0 \\
    -\mu_m \\
    0 \\
    0 \\
    -\lambda \\
\end{bmatrix}
\begin{bmatrix}
    x + \lambda + \mu_m \\
    -\lambda_m \\
    x + \lambda + \lambda_m \\
    -\mu_6 \\
    -\lambda_1 \\
\end{bmatrix}
\begin{bmatrix}
    0 \\
    0 \\
    -\mu_6 \\
    0 \\
    0 \\
\end{bmatrix}
\begin{bmatrix}
    x + \lambda_m \\
    0 \\
    0 \\
\end{bmatrix}
\begin{bmatrix}
    0 \\
    -\lambda_2 \\
    0 \\
\end{bmatrix}
\begin{bmatrix}
    x + \lambda_m \\
    0 \\
\end{bmatrix}
\begin{bmatrix}
    0 \\
    0 \\
\end{bmatrix}
\begin{bmatrix}
    -\lambda_m \\
\end{bmatrix}
\begin{bmatrix}
    -\lambda_m \\
    -\lambda_m \\
\end{bmatrix}
\begin{bmatrix}
    0 \\
\end{bmatrix}
\begin{bmatrix}
    x \\
\end{bmatrix}
\begin{bmatrix}
    a_2 \\
    a_1 \\
    a_3 \\
    a_4 \\
    a_5 \\
\end{bmatrix}
\end{align*}
\]
Analysis of mathematical model states (control systems in the energy sector)

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

$$T_{\text{average}} = \frac{\lambda_m \lambda_1 \mu_m + \lambda_m \lambda (\mu_6 + \lambda_m) [\mu_m + \lambda_m] (\mu_6 + \lambda_m) - \lambda_1 \mu_6}{\mu_m^2 (\mu_m + \lambda_2 \mu_6)^2} + \frac{\lambda_2 (\lambda_m + \mu_m) (\mu_6 + \lambda_m)^2}{\mu_m (\lambda_m + \lambda_2 \mu_6)^2} - \frac{\lambda_2 [\lambda_m (\mu_6 + \lambda_m) - \mu_m \mu_6]}{\lambda_m \mu_m (\lambda_m + \lambda_2 \mu_6)}.$$ 

<table>
<thead>
<tr>
<th>№ graphic</th>
<th>$\lambda_m$ (1/hour)</th>
<th>$\lambda$ (1/hour)</th>
<th>$\mu_6$ (1/hour)</th>
<th>$\mu_m$ (1/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$10^{-1}$</td>
<td>$10^{-3}$</td>
<td>$2$</td>
<td>$5 \cdot 10^{-3}$</td>
</tr>
<tr>
<td>2</td>
<td>$10^{-1}$</td>
<td>$10^{-3}$</td>
<td>$1$</td>
<td>$5 \cdot 10^{-3}$</td>
</tr>
<tr>
<td>3</td>
<td>$10^{-1}$</td>
<td>$10^{-3}$</td>
<td>$3 \cdot 10^{-1}$</td>
<td>$5 \cdot 10^{-3}$</td>
</tr>
<tr>
<td>4</td>
<td>$10^{-1}$</td>
<td>$10^{-3}$</td>
<td>$10^{-1}$</td>
<td>$5 \cdot 10^{-3}$</td>
</tr>
</tbody>
</table>
Scheme of the information in the signal flow path in the control systems in the energy sector

- **Input subsystem**
  - Input nodes
  - Diagnostics and control nodes
  - Interface block

- **Transmission subsystem**
  - Input-Output nodes
  - Diagnostics and control nodes
  - Encoder
  - Line adapter

- **Receiving subsystem**
  - Line adapter
  - Diagnostics and control nodes
  - Input-Output nodes

- **Output subsystem**
  - Address bus
  - Data bus
  - Management bus

- **Interference on the communication link**
  - Interference on the transmission line

- **Backplane**
  - Transmission line controller unit
  - Backplane transmission device

- **Link**
  - Interference on the communication link
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 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.

<table>
<thead>
<tr>
<th>Signals status of sensors</th>
<th>Signals code of BCCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

disconnection  short circuit
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

\[ P_{\text{DC}} = P_{\text{dam}} + P_{\text{kd}} + P_{\text{kod}} + P_{\text{kdk}} \]

Chance undetectable distortion when entering information from sensors

\[ P_{\text{dam}} = n_{TC} P_1^2 P_{\text{nx}} \left( \frac{T_{\text{cmp}}}{T_{\text{u, onp}}} \right)^2. \]

Chance undetectable distortion code in the encoder (decoder)

\[ P_{\text{kod}} = P_{\text{kd}} 2 n_{\delta} P_{\text{nkdo}}^2 P_{\text{nx}} \]

Chance undetectable distortion in the communication channel

\[ P_{\text{kcl}} = P_1^4 C_{a_1+a_2+a_3}^2 P_1^4 C_{a_1+a_2+a_3+a_4}^6 \]

\[ P_{\text{nx}} \] – the conditional probability of the disturbance during the second input digital signal distortion, which is opposite effects in the primary distortion; \( n_{\delta} \) – number of sensors DS; \( T_{\text{cmp}} \) – the duration of the strobe signal; \( T_{\text{u, onp}} \) - between adjacent cycles survey sensor status; \( P_{\text{nkdo}} \) – 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 \((a_1+a_2+a_3+a_4)\) - character code correlation и \( a_4 \) - characters cyclic code.

Substituting the averages for the control system in the energy values, namely \( P_1 = 10^{-3} \), \( P_{\text{nkdo}} = 10^{-6} \); \( T_{\text{cmp}} = 10^{-6} \) c ; \( T_{\text{onp}} = 10^{-2} \) c; \( n_{\delta} = 32 \), \( a_1 = 5 \); \( a_2 = 10 \); \( a_3 = 1 \); \( a_4 = 16 \), we get

\[ P_{\text{DC}} \sim 10^{-13} \]

which greatly exceeds the most stringent regulatory technical requirements set GOST.
Results of experimental studies of reliability channel telesignalization

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