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IMPROVING THE RELIABILITY OF INFORMATION-CONTROL SYSTEMS AT POWER GENERATION FACILITIES BASED ON THE FRACTAL-CLUSTER THEORY

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Проведено дослідження процесів обробки інформаційного простору технологічного процесу енергоблоків електростанцій, підстанцій, електромереж. На основі застосування динамічної фрактальної кластерної моделі були виявленіпомилкові спрацьовування і відмови технологічного обладнання. Встановлено аварійні ознаки інформаційних сигналів в режимі реального часу. Отримані результати можна застосувати для підвищення надійності роботи інформаційних керуючих систем програмного технічного комплексу автоматизованих систем управління

Ключові слова: процес обробки інформації, фрактальна кластерна модель, аварійні ознаки, критерії надійності

Проведены исследования процессов обработки информационного пространства технологического процесса энергоблоков электростанций, подстанций, электросетей. На основе применения динамической фрактальной кластерной модели были выявлены ложные срабатывания и отказы технологического оборудования. Установлены аварийные признаки информационных сигналов в режиме реального времени. Полученные результаты можно применить для повышения надежности работы информационных управляющих систем программного технического комплекса автоматизированных систем управления

Ключевые слова: процесс обработки информации, фрактальная кластерная модель, аварийные признаки, критерии надежности

1. Introduction

One of the main directions to enhance the safety of nuclear and thermal power plants (NPP, TPP) in Ukraine is to improve information control systems (ICS), software technical complexes (STC) in automated process control systems (APCS) of power plants [1].

Analysis [2] of the applied ICS for STC in APCS at power plants revealed that they have some significant drawbacks when processing information, which lead to a large number of false triggering and failures in the operation of electric power equipment.

Modernization of ICS for STC in APCS of NPP (TPP) is performed in accordance with documents [3–5]: the standard of the International Atomic Energy Agency IAEA SSG-37 (2015); normative-legal acts of Ukraine DSTU 62138:2008, ChP 306.5.02/3,035-2000.

Papers [6, 7] demonstrate contemporary requirements to technical means and mathematical software for ICS for STC in APCS in terms of life cycle, reliability, safety, and failure-free operation considering the number of control points for technological parameters.

One of the main criteria to ensuring high reliability of ICS for STC in APCS is the criterion of realization of the set of assigned algorithms and programs to process information for reliability in a real-time mode.

Thus, to improve the reliability of operation of ICS for STC in APCS at a power plant under non-standard modes of work of electric power equipment, it is necessary to detect false information in the form of informational signals about false triggering and failures.

This can be done by determining a dependence of change in the electrophysical quantities on a change in energy, power, amplitude, frequency, the phase of informational random signals in the information space based on the application of apparatus of the fractal-cluster theory.

Thus, it is an important task to improve reliability of the operation of ICS for STC in APCS at power plants by detecting reliable information about failures and false triggering of electric power equipment in a real-time mode.

2. Literature review and problem statement

Authors of paper [8], when examining existing ICS for STC in APCS at power plants, typically employ the averaged, or root-mean-square, values for electrophysical characteristics of technological parameters (current, voltage). As a rule, they underlie the formation of informational signals about changes and deviations, registering only at specified time intervals with a delay (2 s), for the assigned setpoints interrogating every 0.5 s. Such an approach does not make it possible to timely detect the misinformation that leads to false triggering and failures [9].

Analysis of papers [10, 11] revealed that the following known methods of information processing and evaluation are applied in order to improve reliability of the operation of ICS for STC in APCS at a power plant:

– the information processing method makes it possible to establish only the defining parameters of electric power equipment technical condition and it does not determine the degree of implementation of the concept of transition to a repair due to technical condition [10];

– the method for the estimation of information in ICS makes it possible to take into consideration only the beginning of planned maintenance and it does not determine the degree of influence of equipment on safety and operational efficiency [11];

Analysis of disadvantages and benefits of the above methods for processing and assessing information aimed at improving the reliability of operation of ICS at data processing showed that their application does not make it possible to determine the reliability of information on technological parameters in real time.

Analysis of papers [12, 13] revealed that the processing of information in ICS for STC in APCS at a power plant involves the following dynamic models:

– a model of neutron-physical processes [12];

– a model of thermophysical processes in the reactor's active zone [12];

– models of thermophysical processes in the first and second circuit of a steam generator [13];

– a model of dynamic processes in the turbine [13].

Consider the features of application of typical models of dynamics in ICS for STC in APCS of electric power equipment at a power unit of the power plant and their influence on control functions.

Model of neutron-physical processes [12] makes it possible to account for and control the following parameters:

– neutron flux parameters;

– mean effective life cycle of neutrons in a reactor;

– parameters of the concentration of sources of delayed neutrons;

– parameters in the decay of sources of delayed neutrons;

– parameters of decay of the core-emitter;

– common particles of delayed neutrons relative to the total number of instantaneous neutrons;

– reactivity of the reactor;

– temperature coefficients of heat carrier and fuel reactivity;

– fuel temperature and mean temperature of a heat carrier;

– efficiency coefficient of regulating rods and their relative displacement.

Model of thermophysical processes in the reactor's active zone [12] makes it possible to take into consideration the following characteristics:

– temperature of a heat carrier at the outlet and inlet to the reactor's active zone and to a steam generator;

– time constants;

– a heat carrier flow rate through the reactor;

– mean temperature of a heat-carrier in the pipes of a steam generator;

– heat power isolated in fuel.

Model of thermophysical processes in the first circuit of steam generator [13] makes it possible to take into consideration time constants, deviations in steam pressure in a steam generator, flow rate of the heat carrier through a reactor, heat carrier temperature at the inlet and outlet of the steam generator and in the reactor's active zone.

Model of thermophysical processes in the second circuit of steam generator [13] makes it possible to take into consideration the following characteristics: flow rate of feed water, steam from a steam generator, steam for turbine; pressure in an evaporator; displacement of feed valves; pressure in a steam boiler; deviation in the steam pressure in a steam generator.

Model of dynamic processes in turbine [13] makes it possible to take into consideration and control the following parameters:

– pressure in the compartments of high and low pressure cylinder and separator-steam-heater;

– relative displacement of regulating flaps of valves for intermediate overheating;

– time constants of respective elements;

– coefficients that characterize part of the high-pressure and low-pressure cylinder in the power of turbine; consumption of steam for the turbine.

Analysis of the above models [12, 13] shows that they do not meet today's requirements to identify false information in real time.

It is noted in papers [10, 11] that only the timely detection of emergency signs, under non-standard operation modes of electric power equipment, can provide for the established degree of reliability.

Thus, the reliability of operation of ICS for STC in APCS at power plants under non-standard modes depends on the work of hardware and software when carrying out a continuous monitoring of informational signals at their random deviations from the established norm. In this case, it is necessary to solve the task on comparing the incoming current information about technological parameters with the data stored in the memory of microprocessor devices in ICS for STC in APCS at power plants.

3. The aim and objectives of the study

The aim of present study is to improve reliability of the functioning of ICS for STC in APCS at power plants units by reducing the number of failures and false triggering of electric power equipment, based on the detection of informational signals on emergency signs.

To accomplish the aim, the following tasks have been set:

– to develop a cluster model of the structure of informational space of technological process parameters for electric power equipment at the power units of thermal and nuclear power plants;

– to improve dynamic fractal cluster model of the volume of informational space of ICS for STC in APCS at power plants;

– to derive new analytical expressions for the criterion of reliability for the operation of ICS for STC in APCS at power plant – the flow of false triggering.

4. Dynamic fractal cluster models for processing the informational space of a technological process

To improve reliability of operation of ICS for STC in APCS at power plants under non-standard operation modes of electric power equipment by detecting information about failures and false triggering when identifying deviations in technological parameters, it is possible to apply an apparatus of the fractal-cluster theory. This makes it possible to determine dependences of change in the characteristics of electro-physical quantities (current, voltage) on changes in energy, power, amplitude, frequency, the phase of informational random signals in the volume of an informational space [15, 16].

To represent the volume of an informational space as a set of informational signals, it is proposed to employ a cluster model of the structure of an informational space based on the application of an apparatus of the fractal-cluster theory [17]. A graphical representation of cluster-cluster aggregations in the volume of an informational space is shown in Fig. 1.

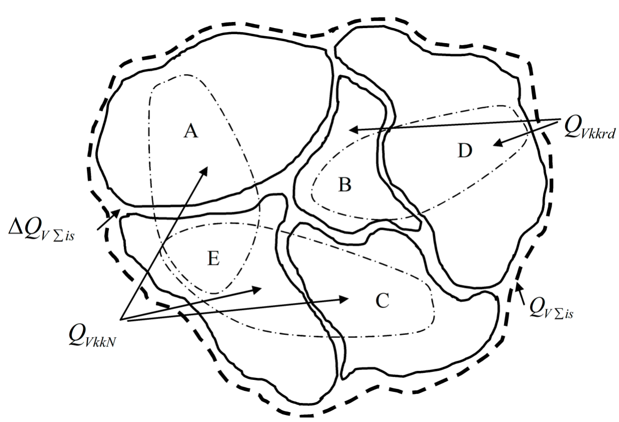


Fig. 1. Graphical representation of cluster-cluster aggregations in the volume of an informational space: $\Delta Q_{\sum is}$ is the gain in the amount of information; Q_{VkkN} is the volume of cluster-cluster aggregations with the normalized values of technological parameters; Q_{Vkkrd} is the volume of cluster-cluster aggregations with random values of technological parameters; $\Delta Q_{V\sum is}$ is the volume of an informational space

Fig. 1 shows that the clusters of separate informational signals on the parameters of a technological process form a certain volume of cluster-cluster aggregations with the normalized Q_{VkkN} and random Q_{Vkkrd} values of technological parameters.

The total volume of informational space $Q_{V\sum is}$ can be represented as the sum of volumes $Q_{V\sum kk}$ of cluster-cluster aggregations with the normalized values of parameters Q_{VkkN} and the volumes of cluster-cluster aggregations with random values of parameters Q_{Vkkrd}. Thus, the random chaotic signals account for a part of the free informational space $\Delta Q_{V\sum is}$.

According to the fractal-cluster theory, the informational fractal dimensionality d_{fi} is proposed to be used as a quantitative physical quantity, which characterizes the degree of filling up the total volume of informational space $Q_{V\sum is}$ with relevant informational signals on the parameters of a technological process (Fig. 2).

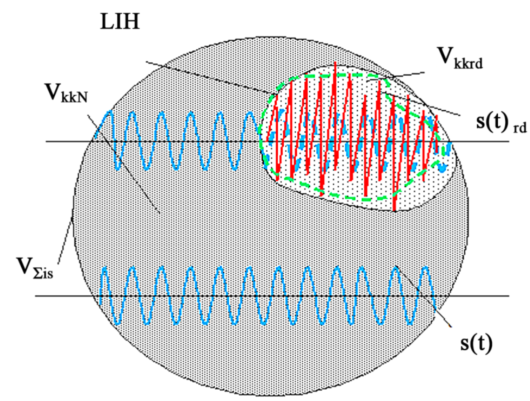


Fig. 2. The process showing the passage of an informational random signal throughout the volume of an informational space: V_{kkN} – volume of the informational space with the normalized values of technological parameters; V_{kkrd} – volume of the informational space with random values of technological parameters; $V_{\sum is}$ – total volume of the informational space; $s(t)$ – informational signal about the norm of technological parameters; $s(t)_{rd}$ – random deterministic chaotic signal; $s_f(t)$ – informational fractal signal

Therefore, the volume $Q_{V\sum is}$ of the informational space of ICS for STC in APCS at power units of thermal and nuclear power plants with the amount of information $Q_{\sum is}$ can be represented by expression (1):

$$Q_{V\Sigma s} = (Q_{VA} + Q_{VB} + Q_{VC} + Q_{VD} + Q_{VE})^{d_{fi}}, \quad (1)$$

where Q_{VA}, Q_{VE}, Q_{VC} is the amount of information on the normalized values of technological parameters; Q_{VB}, Q_{VD} is the amount of information on the random values of technological parameters; d_{fi} is the informational fractal dimensionality.

Thus, it follows from expression (1) that the volume $Q_{V\sum is}$ of the informational space of ICS for STC in APCS at power units of thermal and nuclear power plants is in a power-law dependence on the informational fractal dimensionality d_{fi}, which means that the structure of the volume $Q_{V\sum is}$ of informational space possesses fractal properties.

According to the theory of signal transmission, we assumed that the amount of information $Q_{\sum is}$ in the volume of an informational space with fractal properties $Q_{V\sum is}$ is equivalent to a change in energy ΔE and power ΔP of the signals that pass through the structure of a given volume, that is, $\Delta Q_{V\sum is}$~ΔE~ΔP~ΔQ.

Energy and power ΔE, ΔP of informational signals depend on changes in the amount of information $\Delta Q_{\sum is}$ in volume of the informational space of ICS for STC in APCS at power units of thermal and nuclear power plants. Therefore, it was concluded that the changes in energy and power of a random signal ΔE, ΔP that passes through the structure of the volume of informational space $Q_{V\sum is}$ with fractal properties are also associated with a change in the quantitative magnitude – informational fractal dimensionality d_{fi}.

The informational fractal dimensionality d_{fi} of an informational space depends on a gain in the amount of information $\Delta Q_{\sum is}$ in the informational signal, as well as on the time τ of returning to the normalized values, and on the time increment of cycle ΔT, as shown by expression (2):

$$d_{fi} \cong d_{0fi} \cdot 2^{(\ln 2)\left|\Delta \overline{Q_{\Sigma is}}\right|(\tau_f - \Delta t)}, \quad (2)$$

where d_{0fi} is the initial value of the informational fractal dimensionality at the normalized values of technological parameters.

Formula (2) shows that a change in the informational fractal dimensionality Δd_{fi} is related to a change in the amount of information $\Delta Q_{\sum is}$ in the volume of informational space $Q_{V\sum is}$. Given this, in order to find a change in the amount of information $\Delta Q_{\sum is}$ in the volume of informational space $Q_{V\sum is}$ depending on a change in the informational fractal dimensionality, the following expression can be applied

$$\left|\Delta \overline{Q_{\Sigma is}}\right| \cong \frac{\ln \dfrac{d_{fi}}{d_{0fi}}}{(\ln^2 2)(\tau_f - \Delta t_c)}. \quad (3)$$

It follows from expression (3) that, when the volume of informational space $Q_{V\sum is}$ is passed by a random informational signal, there occurs a gain in the amount of information $\Delta Q_{\sum is}$ and a local informational heterogeneity is created in the form of an attractor (Fig. 2). The existing and applied informational dynamic models of the structure of the informational space of ICS for STC in APCS at a power plant constitute a system of mathematical equations with lumped parameters that characterize the state of the informational space. An informational random signal, according to the fractal-cluster theory, was considered to be a signal that possesses fractal properties. We have introduced the notion of an informational fractal signal $s_f(t)$, which constitutes a system or the sum of signals of the informational signal $s(t)$ on the norm of a technological process parameters. In addition, we have isolated a random deterministic chaotic signal $s(t)_{rd}$ about a deviation consisting of self-similar reference oscillations, which are in a certain sense similar to the entire signal, that is, we observe a scale invariance.

When generating a fractal signal, we used as a reference signal the reference harmonic oscillations with a certain amplitude U_0, frequency ω_0, and phase φ_0. Applying the theory of signal transmission, we obtained expression for the total fractal informational signal $s(t)_\sum$ (4):

$$s(t)_\Sigma = \left[U_0 \cos(\omega_0 t + \varphi_0)\right] + \left[U_{rd} \cos(\omega_{rd} t + \varphi_{rd})\right]. \quad (4)$$

Paper [18] also demonstrated that the presence of a signal with the signs of emergency when a technological process parameters deviate can be determined by difference $\Delta s(t)$ between a total $s(t)_\sum$ and useful $s(t)_0$ informational signals. This, in turn, relates to a change in energy ΔE, power ΔP, amount of information $\Delta Q_{\sum is}$, fractal return time τ_f, fractal dimensionality of time t_f: $\Delta s(t)$~ΔE~ΔP~$\Delta Q_{\sum is}$~$\Delta\tau_f$~t_f.

It is known that the amount of information $Q_{use\sum is}$ when transmitting one value of the normally distributed signal excluding an interference is derived from expression:

$$Q_{use\Sigma} = \frac{1}{2}\ln(1 + P_0),$$

where

$$P_0 = \frac{1}{T}\int_{t_0}^{t_0+\Delta T} \left[U_0 \cos(\omega_0 t + \varphi_0)\right]^2 \mathrm{d}t$$

is the average power of informational signal with the normalized attributes. Therefore, the amount of information $Q_{\sum is}$ when transmitting one value of the normally distributed signal taking into consideration an interference and the fractality of informational signal is determined from expression (5):

$$Q_{\Sigma is} = \frac{1}{2}\ln\left(1 + \frac{P_0}{P_f - P_0}\right), \quad (5)$$

where

$$P_f = \frac{1}{T}\int_{t_0}^{t_0+\Delta T} \left[U_f \cos(\omega_f t + \varphi_f)\right]^2 \mathrm{d}t$$

is the power of the informational fractal signal; U_f, ω_f, φ_f are the amplitude, frequency and phase of the informational fractal signal, which are derived from formulae (6)–(8):

$$U_f = \sqrt{\left[\frac{2}{t_c}\int_0^{t_c} s(t)_{rd} \cos\left(\frac{2\pi kt}{\tau_f^{t_f}}\right)\mathrm{d}t\right]^2 + \left[\frac{2}{t_c}\int_0^{t_c} s(t)_{rd} \sin\left(\frac{2\pi kt}{\tau_f^{t_f}}\right)\mathrm{d}t\right]^2}, \quad (6)$$

$$\omega_f = \frac{2\pi}{\tau_f^{t_f}}, \quad (7)$$

$$\varphi_f = \operatorname{arctg}\frac{\dfrac{2}{t_c}\displaystyle\int_0^{t_{rd}} s(t)_{rd} \sin\left(\frac{2\pi kt}{\tau_f^{t_f}}\right)\mathrm{d}t}{\dfrac{2}{t_c}\displaystyle\int_0^{t_{rd}} s(t)_{rd} \cos\left(\frac{2\pi kt}{\tau_f^{t_f}}\right)\mathrm{d}t}. \quad (8)$$

Therefore, an increment in the amount of information $\Delta Q_{\sum is}$ in the volume of informational space $Q_{V\sum is}$ during transmission of a random informational signal $s(t)_{rd}$, according to the theory of information and the theory of signal transmission, is observed in the case of large-scale invariance (a self-similarity property). We accepted as a change in the amount of information $\Delta Q_{\sum is}$ the amount of information ΔQ_{rd} on the random informational signal, that is ΔQ_{rd}=$\Delta Q_{\sum is}$.

Hence, it follows that the amount of information ΔQ_{rd} about a random informational signal can be represented as the difference between the amount of information $Q_{f\sum is}$ in the fractal informational signal and the amount of information $Q_{use\sum is}$ on the normalized values for a parameter, as shown in expression (9):

$$\Delta Q_{rd}=\frac{1}{2}\ln\left(1+\frac{\frac{1}{t_c}\int\limits_{t_0}^{t_0+\Delta t_c}\left[U_0\cos\left(\omega_0 t+\varphi_0\right)\right]^2 \mathrm{d}t}{\frac{1}{t_c}\int\limits_{t_0}^{t_0+\Delta t_c}\left[U_f\cos\left(\omega_f t+\varphi_f\right)\right]^2 \mathrm{d}t-\frac{1}{t_c}\int\limits_{t_0}^{t_0+\Delta t_c}\left[U_0\cos\left(\omega_0 t+\varphi_0\right)\right]^2 \mathrm{d}t}\right)-$$
$$-\frac{1}{2}\ln\left(1+\frac{1}{t_c}\int\limits_{t_0}^{t_0+\Delta t_c}\left[U_0\cos\left(\omega_0 t+\varphi_0\right)\right]^2 \mathrm{d}t\right). \quad (9)$$

Expression (9), taking into consideration expressions (6)–(8), shows that the amount of information ΔQ_{rd} depends on changes in the amplitude U_f, frequency ω_f and phase φ_f with respect to the fractal return time τ_f and fractal dimensionality of time t_f.

We have chosen, as a characteristic of operational reliability of ICS for STC in APCS at a power plant, the main criterion – an indicator that characterizes the reliability of devices – "flow of false triggering", determined by analogy to the estimation of a failure rate. It should be noted that the failure rate $W(t)$ depends directly on the degree of determining the reliability of information on the characteristics of a technological process parameters at a power plant unit. In this case, a record is kept depending on $R(t_2)$, the number of false triggering by time t_2; $R(t_1)$, the number of false triggering by time t_1.

Therefore, to estimate a flow rate $W(t)$, we took into account the time of cycle T_c, gain in the amount information $\Delta Q_{\sum is}$, a change in the informational fractal dimensionality Δd_{fi}, as shown by expression (10):

$$W(t)=\frac{R\left(T_c+\Delta T\right)-R\left[T_c-\left(\frac{\ln\Delta d_{fi}}{\left(\ln^2 2\right)\left|\Delta Q_{\Sigma is}\right|}-\Delta T\right)\right]}{\left(T_c+\Delta T\right)-\left[T_c-\left(\frac{\ln\Delta d_{fi}}{\left(\ln^2 2\right)\left|\Delta Q_{\Sigma is}\right|}-\Delta T\right)\right]}. \quad (10)$$

Thus, expression (10) takes account of unreliable information about changes in technological parameters and, consequently, helps reduce the flow of false triggering and failures.

An increase in the degree of detection of false information about deviations in the magnitudes of technological parameters improves the reliability of operation of ICS for STC in APCS at power plants units by 33 %.

5. Experimental study into informational signals on technological parameters in order to detect the signs of emergency

To confirm the results of theoretical study and a possibility to estimate the process of change in the parameters of the informational space of a technological process depending on the electrophysical quantities, we designed a composition of equipment for the experimental setup (Fig. 3), which includes:

– low-frequency signal generator, GZ3-124 – for a set of standard frequencies;

– chaos generator (a dual electric circuit, which includes a variable resistor and two operating amplifiers, type TL-082CD) – to generate random noise;

– digital oscilloscope, type 54622d, and information-measuring equipment – to measure characteristics of electro-physical parameters of a signal;

– a personal computer, hardware and software, a printer at the workplace of operator-researcher.

We measured and investigated technological parameters of the primary circuit of the reactor VVER-1000 at NPP unit (Fig. 4): temperature T_{1k} and pressure P_{1k}, whose values are represented by electro-physical magnitudes – current signals I_{T1k}, I_{P1k}. To monitor a change in the fractal properties of the volume of informational space $Q_{V\sum is}$, in the present work we applied a scheme of chaotic random informational signals $s_{f(t)}$. Generation of random noise was simulated by using a dual electric circuit with positive resistance.

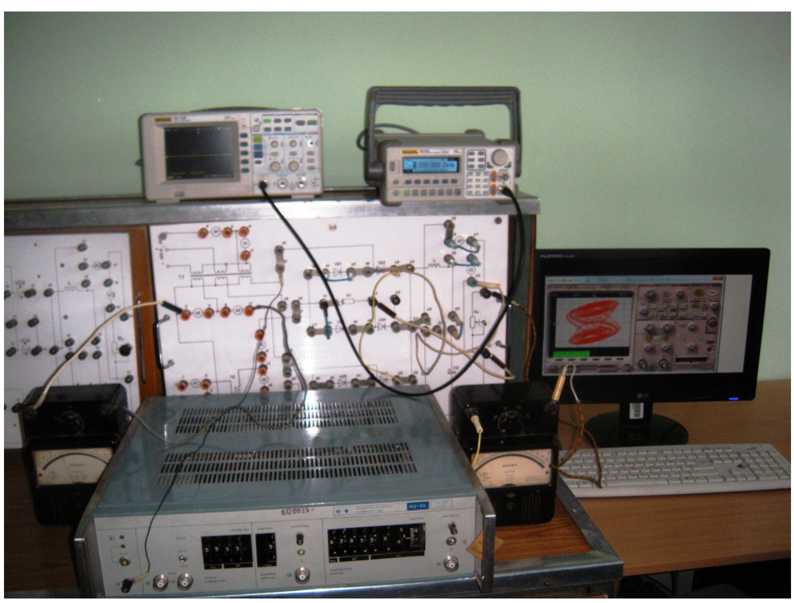


Fig. 3. Composition of equipment and layout of the experimental setup

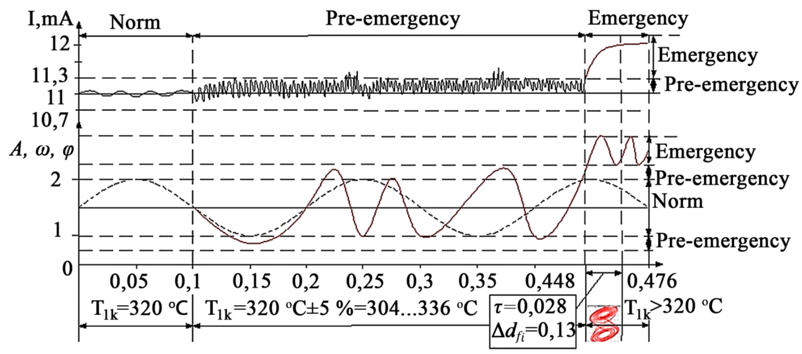
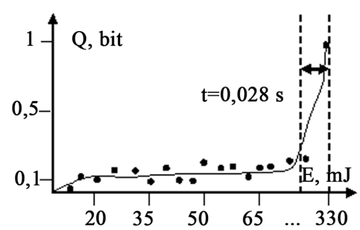


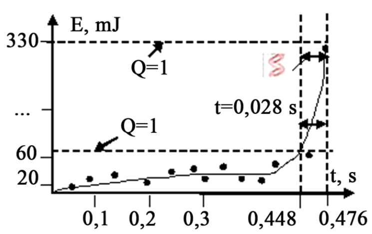
Fig. 4. Charts of current signal and its amplitude dependence on time

Chart in Fig. 4 shows that in the time interval from 0.112 s to 0.448 s the current signal values are in the range from 11 mA to 11.32 mA, which correspond to the temperature of a heat carrier in the first circuit of VVER-1000 reactor at NPP power unit T_{1k}=320 °C±5 %, that is, they are in a pre-emergency situation.

In addition, the chart in Fig. 4 shows a selected time interval from 0.448 s to 0.476 s, over which there occurs a jump-wise change in the values of current signal I_{T1k}. This time interval witnesses an increase in the temperature of a heat carrier in the first circuit of VVER-1000 reactor at NPP power unit, exceeding 336 °C, indicating an emergency. At the same time, the oscilloscope displays in the time interval from 0.448 s to 0.476 a phase portrait of the signal in the form of an attractor; in this case, the informational fractal dimensionality d_{fi} changes from 2.86 to 2.73, indicating the signs of emergency.



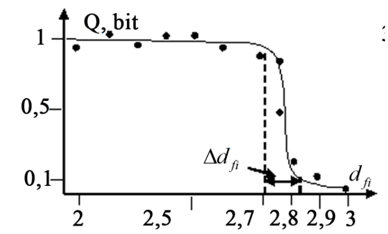
a



b

Fig. 5. Gain diagrams: *a* — amount of information at an increase in the energy of current signal; *b* — energy of current signal over time

Based on the results of numerical experiment, we derived dependences of change in the energy of current signals on the gain in the amount of information about parameters of the first circuit of VVER-1000 reactor at NPP power unit: temperature and pressure. Diagrams in Fig. 5 show that an increase in the amount of information of the informational fractal signal occurs at the increase in the energy of the signal.



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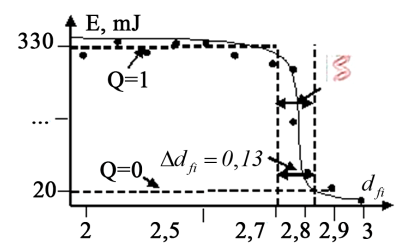

b

Fig. 6. Dependence charts of change in the informational fractal dimensionality on: *a* — amount of information; *b* — energy of current signal

The chart in Fig. 6 shows that a jump-wise increase in the energy of signal I_{fT1k} from 80.496 mJ to 335.248 mJ results in a gain of additional information about parameters of the first circuit of VVER-1000 reactor at NPP power unit, equal to one bit. This circumstance testifies to the presence of signs of emergency in a technological process, specifically the temperature of a heat carrier exceeded 336 °C.

Based on the results of numerical experiment, we acquired dependences of change in the amount of information $\Delta Q_{\sum is}$ about parameters of the first circuit of VVER-1000 reactor at NPP power unit on the change in informational fractal dimensionality d_{fi}, which are shown in Fig. 6. Fig. 6 shows that in the interval of change in the informational fractal dimensionality d_{fi} from 2.86 to 2.73 there is a gain in the additional information about technological parameters of NPP power unit, equal to one bit, which indicates the signs of emergency.

The results we obtained were realized and implemented as a module of ICS "Complex Titan-2" for STC in APCS based on cabinets TPTS-51 8 unit at power unit with a capacity of 325 MW at Zmiyev TPP (Ukraine). Structural-functional diagram of the microprocessor system of ICS for STC in APCS with the introduced module for detecting the signs of emergency is shown in Fig. 7.

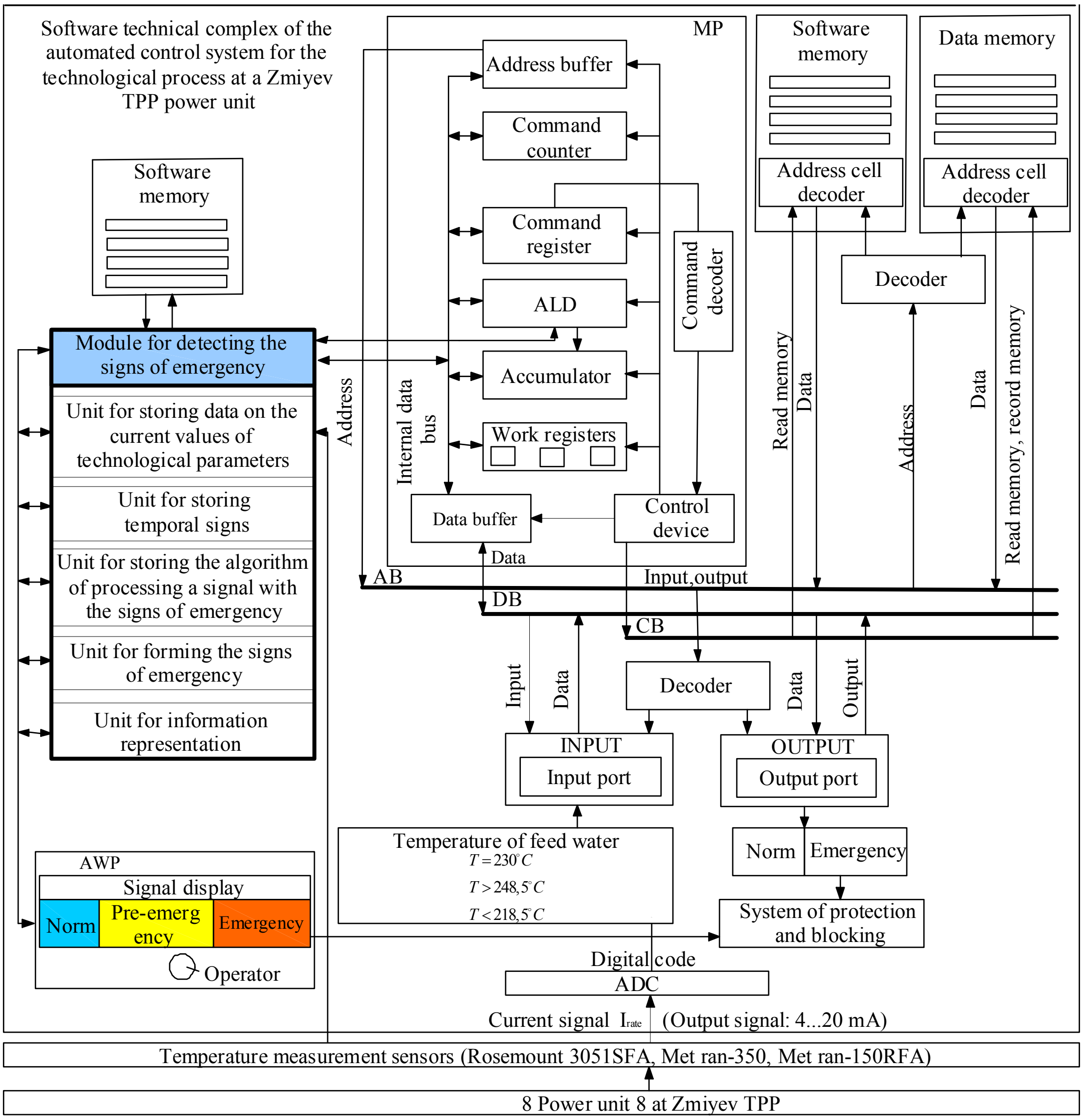

Fig. 7. Structural-functional diagram of the microprocessor system of STC of APCS with the introduction of the module for detecting the signs of emergency

6. Discussion of results of studying the processing of information in ICS for STC in APCS

When designing a cluster and a dynamic fractal cluster model of the structure of an informational space, in order to improve reliability criteria in the operation of ICS for STC in APCS at a power plant, we considered the appropriateness of applying an apparatus of the fractal-cluster theory.

Based on the developed cluster model of the structure of volume of the informational space as a set of cluster-cluster aggregations, it was established that the passing of random informational signals through informational space changes the degree of filling up its volume. This occurs depending on a change in the energy and power of fractal informational signals.

It was found that it is the most appropriate to use, among the dimensionalities (correlation, capacitive, point) that characterize the degree of filling up volume of an informational space, the informational fractal dimensionality. In doing so, the informational fractal dimensionality is accepted in the form of fractional magnitude and shows the way a shape or a time series fills up the space. Furthermore, it is directly related to a change in the amount of information in the volume of memory of ICS for STC in APCS at a power plant.

The results obtained allow us to state that when a random informational signal passes through the volume of informational space of ICS for STC in APCS at a power plant there occurs a gain in the amount of information. In this case, there forms a local informational heterogeneity in the form of a strange attractor, which may indicate the signs of emergency in random informational signals that pass through the volume of the informational space. The informational fractal dimensionality becomes different from its initial value.

Accounting for this fact opens up the possibility for an informational fractal dimensionality of a random informational signal to be matched with known parameters of the useful informational signal. By using a comparison method, it is possible to estimate the informational fractal dimensionality, and, therefore, the amount of information of an unknown random signal according to the parameters of the known one.

From a theoretical point of view, study into a cluster model makes it possible to obtain new analytical dependences for existing dynamic spatial-temporal models. Such an approach makes it possible to associate the amount of information on emergency signs, in the case of deviation of the magnitudes of technological parameters from the norm, with a change in energy, power, amplitude, frequency, and phase of the random informational fractal signal.

The results obtained are practical and relevant since they allow timely, in real time, detection of false information. This suggests the possibility of a timely response to emergency signs or a decrease in the number of false triggering and failures, thereby improving the reliability criteria in the operation of ICS for STC in APCS at a power plant.

It should be noted that in the process of developing a dynamic fractal cluster model of the structure of the informational space of ICS for STC in APCS at a power plant we accepted certain assumptions and limitations. The examined technological process in an informational space is presented as a dynamic system, which is a random, chaotic, unstable, nonlinear autonomous system with 3-dimensional phase space. We apply as the values of dynamic variables spatial coordinates and time, characterizing the moment of return of declined (altered) characteristics of their parameters to the normalized values over the period of course of a technological cycle.

7. Conclusions

1. We have developed a cluster model for the structure of an informational space as a combination of informational signals that carry information about emergency signs at a deviation of a technological process parameters at electric power facilities, based on the application of an apparatus of the fractal-cluster theory. The interrelation is established between a change in power and energy of a random informational signal and the degree of filling up the volume of an informational space, which is characterized by a quantitative magnitude, the informational fractal dimensionality, in an interval from 2.86 to 2.73. Passing of a random signal decreases the informational fractal dimensionality by the magnitude of 0.13, while increasing the amount of information, starting with one bit. We have derived a dynamic fractal cluster model of the structure of the informational space of ICS for STC in APCS at a power plant, which makes it possible to obtain new functional dependences of the dynamics in change (deviation) of electro-physical quantities (by 0 to 5 %) of technological parameters on the fractal informational dimensionalities. It is shown that the detection of random informational signals about deviation in the characteristics of technological parameters from the normalized values results in a change in the values of magnitudes for characteristics of energy, power, amplitude, frequency, and phase.

It was established that at a jump-wise increase in the signal energy, from 80.496 mJ to 335.248 mJ there occurs a gain in the additional information about the parameters of a technological process at a power plant unit, equal to one bit. Accounting for specific fractal cluster properties of the structure of volume of the phase informational space makes it possible to detect emergency signs under non-standard operation modes of electric power equipment at thermal and nuclear power plants units in a time less than 2 s.

2. We have derived analytical expressions for the estimation of reliability criteria of the operation of ICS for STC in APCS at power plants, which, in contrast to known expressions for detecting false triggering and failures, take into consideration new parameters: a gain in the amount of information, fractal time, informational fractal dimensionality. When processing information for authenticity, the probability of detection of false information in software and hardware of ICS for STC in APCS increased from 0.58 to 0.83.

3. We have designed and proposed a module for detecting emergency signs of deviation in the characteristics of electro-physical parameters of technological parameters. This module makes it possible to compare current deviations in electrophysical parameters of a technological process at a power plant with the data stored in memory of the microprocessor system. In addition, the module makes it possible to analyze emergency signs in a real-time mode, which improves reliability criterion by 10 % to 33 % by reducing the parameter of the flow of false triggering from 0.0011 per year (normal) to 0.0005 per year. This approach allows establishing new requirements to the reliability criterion of functioning of ICS "Complex Titan-2" for STC in APCS based on cabinets TPTS-51 at a power plant unit 8 with a power capacity of 325 MW at Zmiyev TPP. At the same time, the temporal characteristics of the speed of change in the magnitudes of characteristics of technological parameters over a period from 0.05 s to 0.5 s are taken into consideration.

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