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PROVIDING ELECTROMAGNETIC COMPATIBILITY OF THE SECONDARY ELECTRICAL CIRCUTS OF NUCLEAR POWER PLANTS

Problems of electromagnetic compatibility equipment for nuclear power industry is considered. The results of the impact of interference on the apparatus and equipment, methods of dealing with harmful effects, examples of the modernization of nuclear power plants and solutions for better noise immunity are presented.

Keywords: nuclear power plants, Instrumentation and Control systems (I&C), technical tools of automation (TTA), electrical and electromagnetic effects, quality power supply network, Electromagnetic compatibility (EMC).

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ОБЕСПЕЧЕНИЕ ЄЛЕКТРОМАГНИТНОЙ СОВМЕСТИМОСТИ ВТОРИЧНЫХ ЭЛЕКТРИЧЕСКИХ ЦЕПЕЙ АТОМНЫХ ЭЛЕКТРОСТАНЦИЙ

Рассматриваются проблемы электромагнитной совместимости оборудования для атомной энергетики. Представлены результаты воздействия помех на приборы и оборудование, методы борьбы с вредными эффектами, приведены примеры модернизации ядерных установок и решений для повышения помехоустойчивости.

Ключевые слова: АЭС, системы контроля и управления (СКУ), технические средства автоматизации (ТСА), электрические и электромагнитные факторы влияния, качество сети электропитания, электромагнитная совместимость (ЭМС).

1. Introduction

Electromagnetic external factors include electromagnetic processes caused by work and / or problems with other technical tools of automation (TTA), the plant processing equipment as well as natural phenomena and personnel actions that degrade or may degrade the performance of TTA (hereinafter – the noise). TTA immunity requirements set in the general case, with respect to the following types of interference in accordance with: static electricity on the housing, controls and screens external cables; microsecond pulse interferences in the supply circuits; nanosecond pulse interference from external sources for information circuits and the supply circuits; exposure to radio frequency interference; dynamic changes in power supply voltage; magnetic fields of industrial frequency; pulsed magnetic fields; short sinusoidal interference in protective circuits and signal ground; microsecond pulse interference in protective circuits and signal ground. Depending on the class of security TTA and the electromagnetic environment in the place to accommodate a group of TTA establish noise immunity.

Influence of electromagnetic compatibility TTA is considered in two aspects:

- on the one hand, this malfunction TTA under the influence of interference;
- on the other - that TTA may themselves serve as sources of interference to other products including other TTA.

Noise immunity in the theory of transmission of electrical signals called a communication channel withstand interference. Among all the possible types of interference exclusive place and is so-called fluctuating noise such as "white noise", which is composed of very short pulses (duration 10-12 sec) with varying amplitude. White noise is a stationary random process, power spectral density is constant at all frequencies. According to theorem Winner-Khinich [1], the correlation function of white noise is delta-function. White noise is an abstract mathematical model and physically can not exist. This is primarily due to its infinite variance (average power). The occurrence of white noise is due to the thermal motion of elementary particles. White noise is the main noise determines the sensitivity of the receiver. Therefore, in theory, the transfer of information to simplify the analysis considers the impact of white noise, where the studied system bandwidth substantially narrower effective width of the noise spectrum on which it acts.

Literature [2], [3] and immunity requirements set in the general case, with respect to the following types of noise:

- static electricity on the body, controls and external cable screens;
- microsecond pulse interferences in the supply circuits;
- nanosecond pulse interference from external sources for information circuits and the supply circuits;
- exposure to radio frequency interference;
- dynamic changes in power supply voltage;
- power frequency magnetic fields;
- pulsed magnetic fields;

- short circuits in the sinusoidal interference shielding and signal ground;
- microsecond pulse interference in protective circuits and signal ground.

Value of EMC compliance can not be overestimated. Any object electricity (including nuclear power), has system of control and power, as well as instrumentation. The use of information technology, problem solving to increase nuclear capacity expansion of power supply systems leads to the increase in the influence of noise immunity apparatus and equipment of nuclear power. Due to the rapid development and use of microprocessor technology threshold level of electromagnetic interference, disrupt the normal functioning of the power equipment fell sharply. For example, the response time of electromechanical relays the old model and electronic equipment developed in 1950-1980, was about 20 ms, while the response time of modern digital equipment - about 0.2 ms (100 000 times less). Reducing the operating voltage relays from 110 to 5 Volt increased the susceptibility of modern digital equipment to high-frequency electromagnetic interference switching character, to magnetic and electric fields, microsecond pulse interferences of high energy. Additionally, the number of failures of electrical NPP is one of the largest in comparison to other systems, resulting in impaired or stop operation units.

The reasons for these failures are often non-compliance for immunity. This is not always correctly determined by the commission to investigate the causes of failure and can lead to repeated similar failures and accidents.

The purpose of this article - to provide information that may be useful operator personnel to consider the effect of noise in the secondary circuits, leading to false positives.

2. Fundamentals of signal noise immunity of equipment

2.1 General consideration

Consider the most characteristic effects of interference, resulting in false positives appartury. As an example, the effect of noise on the storage device and information processing (DSP) neutron flux monitoring system for the control room. When you receive on the input DSP from the detection units or pulsed current signal with interference is possible positives false alarm emergency and preventive protection.

It is well known [3] that the input reception device or the receiver (in this case – DSP) of any communication system is usually a mixture of the transmitted signal arrives *S (t)* and noise *n (t)* as:

$$x(t) = S(t) + n(t)\,. \tag{1}$$

Wherein the signal S (t) is as a rule, complex oscillation comprising, aparts from the time t, a plurality of parameters: amplitude a, phase b, frequency c and etc.:

$$S(t) = f(a,b,c,...t)\,. \tag{2}$$

One or a group of these parameters is used for transmitting information, and the task of the receiver is to determine (measure) parameters in these conditions interference of the interfering action. If this problem is solved well compared to other receivers, receiver called an optimum realizing optimum noise immunity ("ideal" receiver). Outstanding soviet scientist V. A. Kotelnikov [4] developed the theory of potential noise immunity, allowing to define the quality of any communication channels. Moreover, the potential noise immunity was first defined in terms of Gaussian noise. According to this theory, any data transmission system with a given ensemble of signals in specific noise immunity is of the utmost value, which can not be improved by improving the receiver (***potential immunity***).

Depending on the purpose of the communication system of the receiver task will be classified as follows:

2.2. Problem of signal detection.

The receiver determines whether its input signal (with noise), or only one interference and the signal is known in advance Fig. 1, Space within a given space (coordinate system - *Z, τ*) shows the vector signal *S*, which is superimposed on the noise vectors with different phases and amplitudes (at any given time is added to the vector signal is one of the vectors of interference). In Figure 1 are several interference vectors to show that the vector can be of any interference phase and value. If the signal *S* is absent at the receiver input, interference vectors originate from the origin (point 0).

To address the question of the presence or absence of signal at the receiver input all the space is divided into two subspaces: subspace and signal subspace interference. Depending on in which subspace enters the end of vector, the receiver performs decision on the presence or absence of a signal. Border subspaces will depend on the reliability of the test used in the reception. If under the influence of interference end summary vector enters the subspace interference occurs pass signal; if the end of the vector without the interference of the signal enters the signal subspace there is a false alarm.

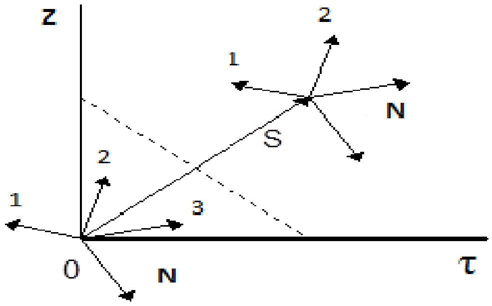

Fig 1. Detection signal interference.

2.3. Problem of distinguishing two signals (or n signals).

The receiver determines which of the signals (S_1 or S_2) has its input. Fig. 2 shows two vector signals together with interference. All interference signals and the space is divided into subspaces by the number of signals (in this case into two subspaces); receiver decides in favor of the signal in the subspace which is the end of the vector sum of the signal and noise. If under the influence of interference summary vector fall into someone else's subspace then error will occur.

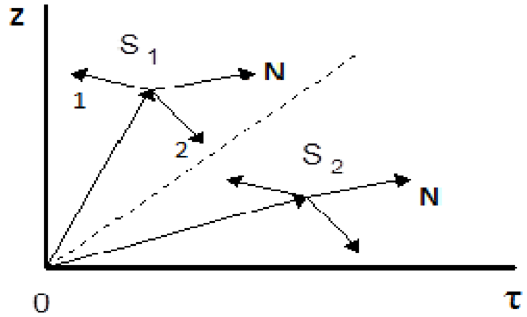

Fig 2.Differences between the two signals in noise

It should be borne in mind that in a receiver for receiving digital signals (detection signals, discrimination of signals), the shape of the output signals, usually does not coincide with the shape of the signals at its input. For example, if the receiver discriminates the signals S_1 *(t)* = $A{\cdot}cos\omega_1 t$ *and* S_2 *(t)* = $A{\cdot}cos\omega_2 t$ (discrete frequency modulation), when receiving a signal S_1 *(t)* at the receiver output will be positive polarity voltage pulse and when receiving the signal S_2 *(t)* - a pulse of negative polarity (or zero, depending on the specific implementation of the receiver circuitry).

2.4. Parameter of the estimation signal

Carried out if the rate of change of the measured parameter signal is much less speed measurement (parameter value is not changed during the measurement).

2.5. Recovery of the transmitted signal

Carried out when receiving analog signals (filtering) and differs from the parameter estimation that the measured value is constantly changing during the measurement. From the foregoing, it is clear that the receiver is major unit (PY) (Fig. 3), which, in accordance with some rule *Φ (x)* (***rule-solution***) find information parameter value (decides the output value *y (t)*, using the input signal *x (t)*).

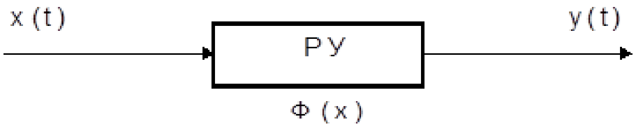

Fig. 3. Diagram of solver.

3. Statistical tests of optimal reception of digital signals.
3.1 Quality criterion

Quantitatively Immunity will determine some measure of conformity of the received message (signal). This measure (the measure of the quality of the decision) always determined by statistical and consumer communication (degree of sensitivity of the consumer to those or other distortions).

Optimum receiver (optimal decision rule) will provide the best quality solutions (minimum distortion of the sent message in accordance with the measure of the quality specified by the customer). The optimal value of quality measures, which is achieved by the receiver in the optimization process will be called ***optimality criterion reception*** (or just ***quality criterion***).

Consider some of the most used methods of evaluating the noise immunity during transmission equipment of two signals S_1 *(t)* and S_2 *(t)*, as communication technology such problem frequently occurs. Note that when discriminating the error signal is required to occur at any of the signal power and interference because may be significant interference value. Fig. 4 shows transition graph in communication system when transmitting signals S_1 *(t)* and S_2 *(t)*. If the transmitted signal S_1 and adopted y_1 - means that the first signal is received correctly. If transmitted signal S_1, and adopted y_2, when receiving the first signal is received instead of the second signal, an error has occurred.

Conditional probabilities $P\ (y_1\ /\ S_1)$ and $P\ (y_2\ /\ S_2)$ are the probability of correct reception of these signals.

There is no generally accepted criteria of noise immunity, so consider a few criteria for noise immunity in distinguishing signals. These criteria are actually different decision rule *F (x)*, based on specific customer requirements to the quality of reception for different purposes [5], [6].

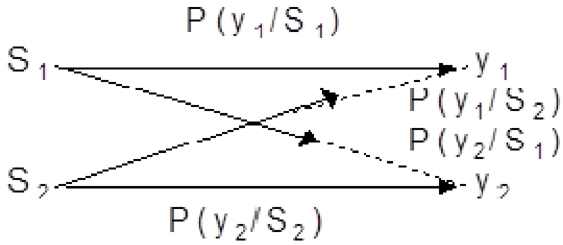

Fig. 4. Transition graph in a communication system.

3.2 Criterion of minimum average risk (criterion R_{ma}):

When receiving digital signals as noise immunity is usually used average risk R_{ma}; then the optimality criterion is min $\{R_{ma}\}$.

The average risk can be defined by the formula:

$$R_{ma} = \sum_{i=1}^{m}\sum_{j=1}^{m} \Pi_{ij} P(S_i, y_i), \tag{3}$$

where: $P\ (S_i, y_j)$— joint probability of transmission S_i and receive y_j;

Π_{ij}—loss function(consumer's risk) when receiving y_j, where the signal S_i; in this case $i = j$ corresponds to the correct reception (values $\Pi_{ij} = 0$), $i \neq j$ —error (value $\Pi_{ij} > 0$); m — number of transmitted signals.

According to formula (3), this criterion for the two signals will minimize the average risk in the form of:

$$R_{ma} = \{\Pi_{12} P(S_1, y_2) + \Pi_{21} P(S_2, y_1) = \Pi_{12} P(S_1) P(y_2 / S_1) + \Pi_{21} P(S_2) P(y_1 / S_2)\}. \tag{4}$$

Depending on the value of the loss function (in this case, the weighting coefficients Π_{12} and Π_{21}), this criterion can be used in communication systems for various purposes, taking into account the losses that result from the distortion of signals $S_1$and S_2.

3.3. Maximum likelihood criterion (criterion K_{ml}).

$_l K_m$ criterion is obtained from the criterion of minimum average risk, if we assume that $\Pi_{12} = 1/P\ (S_1)$, $\Pi_{21} = 1/P(S_2)$. When the receiver gets this optimum solution, so the value is minimized:

$$K_{ml} = P(y_2 / S_1) + P(y_1 / S_2). \tag{5}$$

Criterion K_{ml} will be called the criterion of minimum loss of information, since the optimal decision rule in this case establishes boundary subspace (Fig. 2) So, as to reduce the likelihood of distortion of the signal, which is less than the probability of transmission (hence the signal contains more information).

Maximum likelihood criterion used in communication systems and in those cases, where the prior probabilities $P\ (S_1)$ *и* $P\ (S_2)$ is unknown.

3.4 Criterion ideal observer (K_{io}).

If the weighting coefficients $\Pi_{12} = \Pi_{21} = 1$, then the criterion of minimum average risk minimize the average probability of error:

$$K_{io} = P(S_1) P(y_2 / S_1) + P(S_2) P(y_1 / S_2), \tag{6}$$

and will be called the ***ideal observer criterion***.

Criterion the ideal observer is widely used in communication systems when any signal distortion is equally undesirable.

3.5 Neyman-Pearson criterion (K_{opt}).

In some communication systems there needed fixing (tasks) one of the conditional probabilities – $P\ (y_1/S_2)$ or $P\ (y_2/S_1)$.Wherein the receiver decides an optimal manner to minimize the conditional probability, which is not specified. Optimality criterion, which is used in the receiver, called ***Neyman-Pearson criterion***.

For example, given the probability of missing signal S_1, $P\ (y_2/S_1) = \alpha$. Then Neyman-Pearson requires minimizing the conditional probability $P\ (y1\ /\ S2)$, providing a predetermined value α. Probability P (y_1 / S_2) is usually denoted by β, then (1-β) = $P\ (y_2\ /\ S_2)$ is called ***quality of solution***. Typically solutions the Neyman-Pearson provides min β or max (1 - β) at $\alpha = const.$

Receiver using criterion K_{opt} constructed so as to obtain sufficiently low probability of crossing signal (target) $P\ (y_2\ /\ S_1) = \alpha$, so that in this case despite the minimization $\beta = P\ (y_1\ /\ S_2)$ may be a lot of false signals, which have to put up. This is the essence of this criterion K_{opt}.

4.Concept of the likelihood ratio of discrete signal.

Distinguishing signals in the receiving device generally carried establishing certain "threshold" at the output of the receiver and the actual boundary of the subspaces signals S_1 and S_2.

Figure 5 shows some discrete signal $S\ (t)$ (direct current pulses), which is superimposed on the fluctuating noise, and held the line corresponding to the selected threshold S_n. If $S\ (t) < S_n$, the receiver outputs a signal S_1, if $S\ (t) > S_n$, the receiver outputs a signal S_2. As can be seen from the figure, the time interval t_1, t_2 under the influence of strong noise value $S > S_n$, in this case, the receiver may issue a signal S_2, although passed S_1.

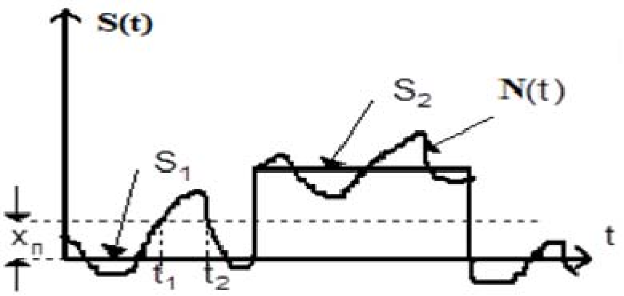

Fig.5 Change discrete signal depending on the interference.

Various criteria for reception of digital signals actually differ in the way of establishing the threshold. This problem is solved using the ***likelihood ratio.***

If at the receiver there were no interference, we would be dealing with a "clean" signals S_1 and S_2 and the task of signal separation would be very simple. In the presence of interference signals are distorted, and their descriptions have to use a probability space. Signals together with interference signals already described by a probability density function $w\ (x\ /\ S_1)$, and $w\ (x\ /\ S_2)$, which are present in Fig. 6 (these functions are multiplied by the weighting coefficients as $\Pi_{12} P\ (S_1)$ and $\Pi_{21} P\ (S_2)$ and also shows the threshold x_n.

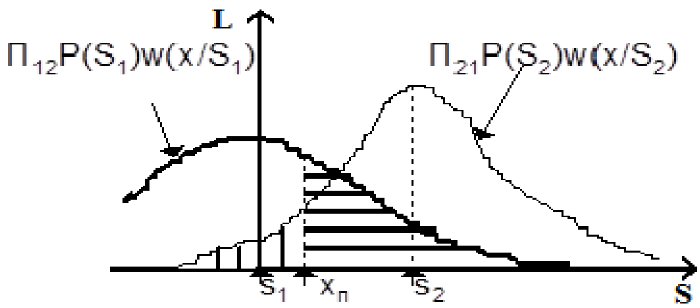

Figure 6. Probability density signal interference

Area of the shaded part of the figure to the left of x_n is equal to:

$$L = \int_{-\infty}^{x_n} \Pi_{21} P(S_2) w(x / S_2) dx, \tag{7}$$

and the shaded area to the right of the x_n:

$$L = \int_{x_n}^{+\infty} \Pi_{12} P(S_1) w(x / S_1) dx = \Pi_{12} P(S_1) P(x / S_1). \tag{8}$$

The sum of these values in accordance with the formula (3) is the average risk R_{ma}. Fig. 6 shows that R_{ma} will be minimal when the minimum total area under the curve, and this will be the case if x_n corresponds to the point of intersection. Therefore, the condition for obtaining min *{R_{ma}}*is threshold x_n, in where equality occurs ordinates of these curves:

$$\Pi_{12}P(S_1)P(x/S_1) = \Pi_{21}P(S_2)P(x/S_2), \tag{9}$$

which the following relations:

$$\lambda(x) = \frac{w(x/S_1)}{w(x/S_2)}. \tag{10}$$

Standing on the left in equation (10) will be called the ***credibility ratio.***

The function w *(x / S_i)*, which represents the probability density that the received signal x is formed in the transmission signal S_i, the function will be called the ***function of credibility*** (function of credibility is also a function of any monotone w (*x / S_i)*, for example, *log [w (x / S_i)])*.

The greater the value of *w (x / S_i)*, more likely that x contains signal S_i (it is evident from Fig. 6). Standing right in (10), the expression will be called ***threshold credibility***:

$$\lambda_0 = \frac{n_{21}m(S_2)}{n_{12}m(S_1)}. \tag{11}$$

It should be noted that the receiver using the credibility ratio, will work as follows:

- first, we analyze the incoming signal at its input and determine the likelihood ratio λ (x) (formula 10);
- from the known values of a priori probability *P (S_1)* and *P (S_2)*, and the specified weighting coefficients Π_{21} *и* Π_{12}, the threshold is determined by the credibility.
- value of λ *(x)* compared with λ_0.When:if λ *(x)* > λ_0, the receiver outputs a signal S_1, otherwise - the signal S_2.

5.Electromagnetic compatibility of equipment.

Consideration of the effects of all kinds of interference in the secondary electrical circuits of equipment in one article is hardly. Theoretical presentation of the phenomenon of false operation discussed above as the most frequent case disturbance on instrumentation. However, it should be noted that the interference effects can lead to more serious consequences. Electromagnetic compatibility described by the laws of probability, and hence when certain events may be subject to strong interference, simultaneous exposure to different kinds of obstacles on several electronic devices that have different meanings in the structure of the plant. Interference, under certain conditions, can not only reduce the quality of reception of information, but also to disable such items such as generators, electric motors, power transformers.

Directive of the European Parliament and the Council 2004/108 / EC provides that in the design and manufacture of equipment and instrumentation systems important for NPP safety and must be guaranteed to comply with the following requirements:- generated by electromagnetic interference should not exceed the level where the equipment can not be used for other purposes;- own immunity to electromagnetic interference should be sufficient to interference.

The requirements of Directive 2004/108 / EC states that the establishment of fixed installations must be applied techniques of good engineering practice and subject to such conditions, which ensure that after the commissioning the equipment will meet the requirements of electromagnetic compatibility. Such conditions should be formulated by component manufacturers in the accompanying documentation. For example, in September 2012 passed the acceptance tests of power supply manufacturer «BENNING GmbH & Co KG» (Germany), intended for delivery to the Khmelnitskay NPP. Representatives of the NAEC "Energoatom", the operating organization, State Nuclear Regulatory Committee was provided with detailed set of reports «Measurements regarding to IEC 61000", which contains data on the compliance of the manufactured equipment with international standards series 61000 EMC. The values of the parameters characterizing the influence of EMC in the report are presented in tabular and graphical form, and impact test, simulating interference, chosen with the most reserve of the possible (for the applied voltage, the number of entry points, ect.). This reserve is not required in terms of the normative document, but apparently made in view of the importance of understanding the impact of these effects on the equipment.

Note, the Ukrainian regulations [7-14] EMC after replacing GOST (General standarts of Ukraine), given in accordancethe series of standards IEC 61000. Description EMC- test methods are also contained in [6], methods of protection against interference and examples of modernization of equipment NPP - [15].

Singly consider EMC- test on site electrical products. The most common faults of the electrical products are short-circuit, insulation breakdown, deterioration of insulating properties, overheating of the contact group. Often incorrectly specify the reasons for these faults: moisture, reduction of resource, overvoltage fault of electricity supply company, violation of installation, the negligence of staff. As a result, in case of simple replacement of components (products), this defect may recur in the near future. Therefore, in cases where the exact cause of the problem is the establishment of difficulty or failure repeats, although the above-mentioned reasons are eliminated, should be re-tested for immunity. The reasons for conducting such tests may be different: the exploitation of technical means, which are not set requirements for electromagnetic compatibility; low noise immunity and physical aging; designers and suppliers outside of Ukraine and others. As an example, almost complete replacement developed by the Moscow Institute "AEP" specifically for use in nuclear power plants and mass-produced in the USSR in Tbilisi plant "Elva" and Penza "Electromechanics" universal blocks of the technical means by production RPC "Radiy" (Kirovograd) and PJSC "SRPA "Impulse" (Severodonetsk) [16].

Noise immunity performance group, and hence the immunity test conditions, is determined according to the intended placement automation hardware. This involves monitoring of qualitative features (various grades) electromagnetic environment on a placement of TTA [2], as with the passage of time the integrity of the system grounding can disturb , shielding properties of the room can change, failure of the interference suppression devices is possible. Testing for immunity in the case of failure to eliminate the causes of deterioration of qualitative characteristics of electromagnetic environment, conducted in accordance with the really grade.

Electromagnetic environment at electric power facilities is a complex and difficult calculations, due to many cases it is determined experimentally. This includes developing special techniques and devices.

Directly in practice permissible levels of interference can be controlled by various technical measures. In summary, such activities include operating mode selection (for example, limiting short-circuit currents, voltage regulation, etc.), providing lightning protection, grounding, shielding, using protective devices that limit the overvoltage (for example, fuses, surge arresters, varistors, suppressor diodes, combined devices), filters, use of building structures as screens, rational location, ect.In order to eliminate deficits safety equipment including non-compliance with the regulations on noise immunity being modernized NPP. Examples include the modernization of the following I&C: control and protection system of the reactor (Unit 4 Rivne NNP, all power units South Ukraine NPP; 1-st and 2-nd power units Khmelnitskay NPP, 3- rd, 4 -th and 5 –th Zaporizhzhya NPP Units; control density and rate of change of the neutron flux at the 1-st, 2-nd, 3-rd, 4-th Unit Rivne NPP, 3-rd Unit South Ukraine NPP, 1-st, 2-nd Unit Khmelnitskay NPP; providing the security settings on the 3-rd power unit Rivne, South Ukraine NPP Units, the 1-st power unit Khmelnitskay NPP, all power units Zaporizhzhya NPP; control of the machine overload on Unit 4 of Rivne NPP, the 1-st, 2-nd South Ukraine NPP Units, 2-nd Unit Khmelnitskay NPP, 2-nd Unit Zaporizhzhya NPP).

Blocks harmonized set of technical means (UKTS) development and production of the 80-s have insufficient reliability, noise immunity, have hidden faults, under-diagnosed and also after prolonged storage came in partial or complete disrepair. Therefore, they are replaced with upgraded units UKTS, with sufficient depth self-test each unit. Separately, note that increasing application is use of fiber-optic lines as the method of dealing with electromagnetic interference.

Prerequisite to improve noise immunity is to use the element base of leading foreign companies - Motorola, Philips, Atmel and others. Ukrainian developers use highly reliable integrated circuits, capacitors, diodes, connectors, resistors, varistors. For example, in the devices of the power drive control logical part is made on the basis of microcontrollers from company Analog Devices, power on thyristor modules Eupec, diodes and transistors SEMIKRON. Widely used and high quality finished products - I&C components: servers and network switches Siemens Hewlett-Packard Co, monitors Samsung, uninterruptible power supplies - GE Digital Energy.

Conlusions

Due to the introduction of information and control systems important to safety of nuclear facilities, increasing the influence of external electric and electromagnetic exposure factors. These factors can lead to serious accidents in the electrical equipment. Also notice, in the repair and replacement of the failed devices or their components are not always properly established, that the cause of failure can be precisely the impact of these factors. It leads to similar or more serious damage. Along with the calculation methods of improvement noise immunity apply proven universal practical solutions, introduced modern leading manufacturers.

Basic knowledge of the theory of noise immunity will allow operation personnel better understand the origin of the various types of interference, their impact on the useful signal, to calculate the maximum values of noise and, therefore, more correctly solve the problem of electromagnetic compatibility at the NPP. Normative documents on EMC in Ukraine are constantly being improved according to international standards. In cases low noise immunity of the equipment, its physical aging and failure to establish the exact cause malfunction, EMC-testing should be carried out not only in the factory and in specialized testing laboratories, but also on site installation of electrical equipment on the NPP.

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