Analysis of prospects for application of intellectual digital temperature sensors in data channels of on-line control means at nuclear power plants

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The article deals with some issues relating to the assessment of application of intellectual digital temperature sensors with one-line data transfer used in thermal monitoring systems of NPP. The comparative analysis of temperature measuring transducers has been undertaken considering information and energy aspects of the measurement theory.

Keywords — NPP, measure, 1-wire, temperature sensors, information.

Advancements in economic development of any country are closely linked to the level of its energy potential, and above all, to its capabilities of power generation. It makes many countries to focus on the development of nuclear engineering. Therefore, it should be taken into account that nuclear power plants (NPPs) having high safety demands and being objects of strategic importance require particular attention to ensuring its nuclear and radiation safety through minimizing the impact of possible risk factors [1].

Continuous improvements of control instrumentation incorporated in automatic process control systems, instrumental modernization as well as the use of new algorithms in system management related to nuclear power facilities contribute to maintaining an adequate level of safety at NPP units. Further implementation of digital technologies seems to contribute to it.

Possible applications of different modern digital technologies in the field of automation systems are often restrained by the cost for research of new technologies. Hence, there is a lack of such kind of research. An obstacle to the widespread implementation of digital systems and technologies at NPPs is the foreign production of most of the latest technological advances in electronics, reference manuals being incomplete and insufficient for the comprehensive assessment of their feasibility under particular operating conditions of objects involving risk. Nevertheless, this fact doesn't rule out the usefulness of new advanced developments and products of world's leading manufacturers, but requires additional analysis of the functional reliability in a variety of NPP automation applications.

The function of the modern NPP automatic process control system is related to measuring, collecting, transmitting, processing of technological data, the diagnostic analysis of processes and equipment, control signal generation and formation of control actions. The role of primary measuring transducers involved into NPP automatic process control system can scarcely be overestimated, the reliability and safety of power units greatly depending on their functional reliability [2].

From many sources of published information, particularly [3-5], we may conclude that in future automation systems will be based on intellectual sensors. It inevitably results in the transition to digital channels and to the signal data transfer. On the one hand, the advantage of analog means of signal formation and transmission is the ease of implementation of technical means for information processing and high response time. On the other hand, the major shortcoming of the analog equipment is its high sensitivity to interference resulting in signal distortion which, in the end, will lead to the technological process failure. It is unacceptable in conditions of NPPs and may result in emergency situations. On the contrary, the digital signal is more interference-tolerant and allows more accurate data transfer, however, application of complex analog-digital transformations is required, thus, complicating the technical interface. Intellectual sensor application is a promising alternative, as it allows to convert analog signals into digital ones within one device, a primary measuring transducer, on the output the digital code being formed. Transmitting digital signals the latest bits are normally a cyclic redundancy check (CRC) used to verify the accuracy of the received signal transmitted from the sensor. Therefore, the transition to the digital signal should result in improving reliability of control systems and automatics and, consequently, into proper technological procedure.

The study is aimed at analyzing arguments concerning the transition possibility of NPP automatic process control system equipment during the modernization to intellectual sensors and especially to temperature ones, temperature measurements at NPP being the most popular.

For analyzing the faults of information measurement channels applied at Ukrainian NPPs currently, we will consider one of channels used to measure temperature of the block bearing babbit of the turbine unit. All measurement channels being identical, it's enough to consider one of them. We will take as an example a temperature sensor located at the technological position SB11T01. In the given information measurement channel TSP 0690 (ТСП 0690) thermistor is used as a primary measuring transducer. According to the methodology [6], we have made the accuracy calculation of this channel and got the confidence interval with ultimate lower $\delta_{ИИКн}$ and upper $\delta_{ИИКв}$ bounds within which measuring channel temperature accuracy $\delta_{ИИКн(в)}$ equal to ± 1.6 % lies with the set probability P = 0.95. The parameter value for temperature information measurement channel isn't to exceed the value ± 1.5 %. The data indicate that a great number of elements comprising the information measurement channel reduces the informative reliability of the channel and of the system as a whole requiring the application of complex analog-digital transformations and complicating its technical interface. However, realizing that system reliability and its complexity are contradictory, we believe a certain complication is necessary for apparent merits.

Under these conditions, the application of intellectual sensors may solve this problem. However, the implementation of new elements requires a multifaceted evaluation of the possibilities for their application at NPP as well as a thorough selection of sensors from a wide range available nowadays. The undertaken review concerning the characteristics of intellectual temperature sensors has revealed the scarcity of information in that regard, it being insufficient to meet challenges related to the further updating. Therefore, there is a strong need for carrying out experiments to evaluate intellectual sensor behavior with different modulation effects based upon the NPP operation conditions. To carry out the research we had to choose types of digital sensors whose characteristics are similar to those of NPP equipment operation conditions, namely,

- digital output signal;
- temperature measuring range from -25 °C to 125 °C;
- supply voltage from 3 V to 5.5 V;
- resolution of information signal from 7 bits to 12 bits.

To compare an analog primary measuring transducer we have studied TSP 0690(ТСП 0690) that is commonly used in measuring instruments at Ukrainian NPPs. Table 1 shows data related to temperature sensors selected for the comparative analysis.

Table 1 – General characteristics of the selected temperature sensors

Sensor Type	**Measuring range, °C**	**Maximum measurement time, sec**	**Accuracy, °C**		**Interface**	**Resolution, bits**	**Supply Voltage, V**	**Maximum Current Consumption, μA**
			in the limited range	***in the working range***				
ADT-75	-55÷125	0.06	2	3	I^2C	12	3÷5.5	525
DS18B20	-55÷125	0.75	0.5	2	1-Wire	9÷12	2.7÷5.5	15
LM92	-55÷150	0.5	0.5	1.5	I^2C	12	2.7÷5.5	625
TMP 100	-55÷125	0.6	2	3	I^2C	9÷12	2.7÷5.5	75
TSP 0690 (ТСП 0690)	-50÷150	0.4	3		4 wires	-	÷5	100 mA

To carry out the comparative analysis we have used terms and apparatus of information theory adapted to the measuring equipment.

So, we have assumed that energy sensitivity threshold C, being a cumulative characteristic of precision, sensitivity, power consumption and response time of measuring instruments, may be expressed by the following relation:

$$C = \gamma^2 Pt \,, \tag{1}$$

where γ – measuring accuracy;
P – power expended during the measurement by the device, W;
t –measuring time, sec.

We consider energy sensitivity threshold C of measuring instruments to be rather general informative quality indicator unambiguously specifying such informative characteristics of these instruments as power efficiency $\eta_э$, precision loss χ and loss of information Δq.

$$\eta_э = \frac{W_ш}{C} = \frac{\pi e k \Theta}{C} \tag{2}$$

$$\chi = \sqrt{\frac{C}{W_ш}} \tag{3}$$

$$\Delta q = 0{,}5 lg \frac{C}{W_ш} \,, \tag{4}$$

where $W_ш$, J– sound energy value;
k –Boltzmann's constant, J/K;
Θ – absolute temperature, K.

It's recognized that data transmission from the measurement object to the measuring instrument may occur only through the energy interaction. Without energy interchange between the measurement object and the measuring instrument data transmission and, consequently, measurements are impossible. In this regard it should be noted that energy interchange increasing, more data may be received. It is expressed by the following equation [7]:

$$q_ш = 9{,}3 + 0{,}5\lg(Pt) \,, \tag{5}$$

where $q_ш$ is a maximum data amount being received during the measurement expressed in units of energy (J). Sometimes this ratio shows not clear connection between data and energy.

To evaluate data transmission efficiency of the measuring process it would be appropriate to use the notion of informative efficiency of the measuring process [7] expressed by the following equation:

$$\eta_и = \frac{9{,}3 + 0{,}5\lg W_ш + 0{,}5\lg \eta_э}{9{,}3 + 0{,}5\lg W_ш} \tag{6}$$

The strong point of this parameter is its suitability for comparison of different kinds (electrical, chemical, optical, etc.) of measurements regardless of operating principles applied in primary measuring transducers as well as in any other equipment used. This assessment approach fits well not only with the principles of computer sciences but also with those of nuclear engineering [8-10].

To characterize the relative efficiency of measuring instruments it is suitable to use a relative assessment, namely, logarithmic exponent of energy gap band of the measuring instrument (of a particular measuring instrument):

$$pC = \frac{lg C}{lg\, W_ш} \tag{7}$$

Using an “ideal” device for which $C = W_ш$, $\eta_э$ = 100 % and $\eta_и$ = 100 %, this exponent will be pC = 100 %. However, in practice all measuring devices have this exponent within cell boundary from 0 % to 100 %.

The analysis takes into account that during the observation no measuring process data could be received from the device, during the so-called “dead time” of the measuring instrument (the total indicator of the accuracy and response time of the measuring instrument).

$$\tau = \gamma^2 t \tag{8}$$

All calculations concerning the undertaken analysis were performed in Mathcad. Calculation results were put in table 2 and shown in figures 1-4.

Table 2 – Calculated values in comparison

Sensor Type	Energy Sensitivity Threshold, J	Exponent of energy gap band, %	Informative Efficiency, %	Dead time of measuring instrument, sec
ADT-75	4.8×10^{-8}	37.7	46.8	1.7×10^{-5}
DS18B20	7.6×10^{-9}	41.8	53.8	9.3×10^{-5}
LM-92	1.3×10^{-7}	35.6	37	3.7×10^{-5}
TMP100	6.9×10^{-8}	37	38.6	1.7×10^{-4}
ТСП 0690	4.5×10^{-5}	22.4	23	3.6

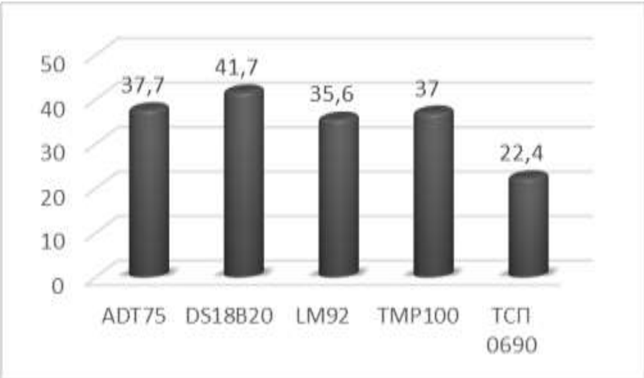

Fig.1 – Comparative diagrams of the energy sensitivity threshold indicator

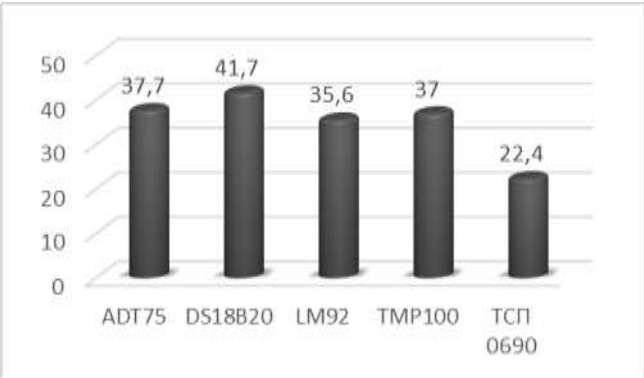

Fig.2 – Comparative diagrams of the energy gap band exponent

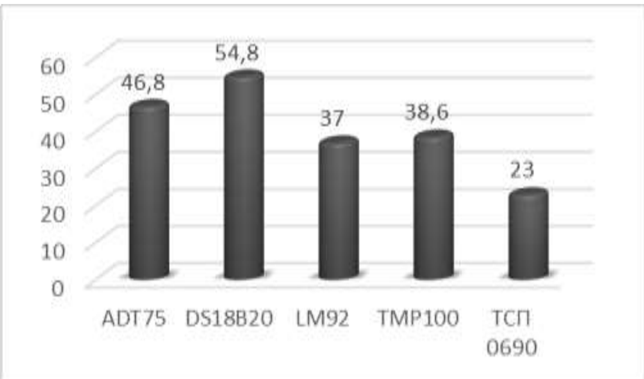

Fig.3 – Comparative diagrams of the informative efficiency indicator

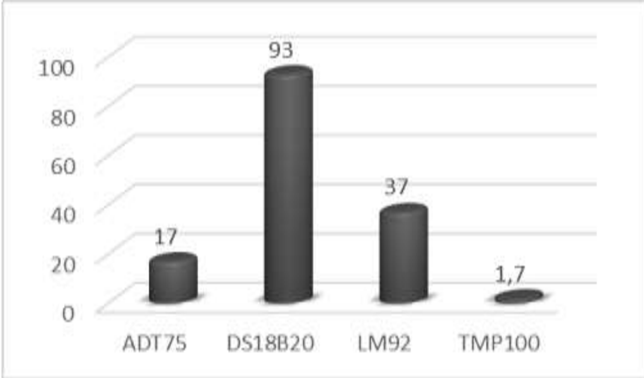

Fig.4 – Comparative diagrams of the measuring instrument dead time indicator

The comparative analysis has shown that all digital sensors have better characteristics than the standard TSP0690 (ТСП 0690) measuring transducer applied at NPP. It's worth mentioning that of the 5 examined types of temperature sensing transducers, DS18B20 temperature transmitter has the best characteristics. It's important to note that before a transition to any digital sensor while improving NPP instrumentation of monitoring and control system it's essential to review sensor algorithms to except measurement errors under processing conditions.

Thus, as a result of the undertaken analysis following conclusions were made

-digital temperature sensors have better metrological and informative characteristics, and are promising for application at NPPs comparing with the standard analog measuring transducer during the modernization of control instrumentation;

-application of intellectual digital sensors should result in the error reduction during both measuring process and data signal transmission for its future use;

-the use of digital signals in online data transfer channels should result in the equipment unification and simplify the integration process of new measurement and control instrumentation of different manufacturers that will lead to the increased competition among manufacturers and will benefit the constant improvement of the produced and supplied NPP equipment;

-the transition from the analog systems of signal transfer and processing to the digital ones will contribute to the increased informational reliability of control systems, and will provide the enhanced risk information management system and NPP equipment safety;

-the results of the undertaken research may be the basis for recommendations proposed for design of modern information-measuring systems for NPP units after the examined measuring tools being tested in field conditions of power enterprises.

References

[1] A. Pogosov, O. Derevyanko "Risk factors and possibilities of ensuring the safety of nuclear power plants", Odessa: Science and Technology, 2018.- 252 p.

[2] A. Pogosov, O. Derevyanko "Physical protection of NPP and information security as necessary conditions for reducing the risks of nuclear and radiation accidents", Nuclear and radiation safety 3 (75) 2017, pp. 50-55

[3] «Intelligent Measurement http://plasma.karelia.ru/~ekostq/PUBLIC/IntSrIzm/index.html.

[4] Y. Nechaev "Intellectualization of measurement information" http://skif.pereslavl.ru/~csa/kurs_5/5intinf.htm.

[5] G. Mintchell "It's time for smart sensors" http://www.asutp.ru/?p=600389 (25.06.2009).

[6] “Methodology for determining the generalized metrological characteristics of measuring channels of the IMS and the automated process control system by the metrological characteristics of aggregate measuring instruments” MT 34-70-038-87. Soyuztekhenergo, 1987.

[7] P. Novitsky “Fundamentals of the information theory of measuring devices” Energy, 1968.

[8] A. Pogosov, S. Polozhaenko, Y. Grigorenko “Modeling of physical processes and technological informatization in the oil industry and energy” Monograph: Odessa, Science and Technology, 2013, - p. 656

[9] V. Dubkovsky, H. Naffaa "The rationale for the choice of circuit design and geometric parameters of the SPOT GO VVER-1000" Nuclear and radiation safety 3 (63), 2014, pp.19-24

[10] Y. Komarov “Development of risk-oriented approaches for introducing the concept of repairing the technical condition of equipment of nuclear power plants”, Nuclear and Radiation Safety (included in the SCOPUS citation database). № 3 (59), 2013, pp. 21-26.