Exploring the possibility of applying different neuronal activation functions to a single-circuit ACS

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Abstract. This work is devoted to the study of the influence of the neuron activation function in the neuroregulator on the quality of the automated control system. The description of the approach to solving the problem of automatic control of real technical objects using a controller, which is an artificial neural network, is given. The research results were summarized in tables and displayed on graphs.

1. Introduction
In modern power engineering, increasing the energy efficiency of technological facilities and systems is becoming an increasingly important topic. There are a huge number of factors that affect it. Increasing the quality of regulation has a direct impact on energy efficiency upwards. At the moment, the world is actively developing promising control technologies based on the use of artificial intelligence that imitates the activity of brain neurons. Artificial neural networks perform a wide range of tasks in various fields of human activity, such as forecasting, decision making, optimization, pattern recognition, data analysis. To solve applied problems, more and more attention is focused on the use of artificial neural networks (ANN) in the field of control of technological objects [1,2,3].

2. Theoretical foundations
A simulation model of an automatic control system with a neuroregulator was developed for the research. The structural scheme of the model of the automatic control system was based on [4]. This scheme is shown in figure 1 and represents a single-circuit automatic control system, which consists of: a control object consisting of two serial connected aperiodic links, ANN is used as a regulator, and a pulse-width modulator and an actuator with parameters identical to those of real equipment are included.

Figure 1. Structural scheme of ACS with neuroregulator.
The main work was to research the impact of the ANN neuron activation function on the quality of regulation using different neuroregulator structures. The following activation functions were studied:

- hyperbolic tangent;
- linear with saturation;
- logarithmic;
- aperiodic link.

However, a series of experiments with different object parameters, shown in table 1, were required for a comprehensive study.

| Object  | Object parameters |
|---------|-------------------|
|         | Ta 1 | Ta2 | Ka | Time delay |
| Object 1 | 60   | 15  | 0.65 | 5         |
| Object 2 | 130  | 15  | 0.65 | 5         |
| Object 3 | 200  | 15  | 0.65 | 5         |

The function of generating regulatory influences in the regulator algorithm is implemented by direct ANN of different execution structure with four or seven neurons (depending on the structure of the ANN). Structural diagrams of ANN to be researched are shown in figures 2 and 6. Optimum synaptic weights for each object, ANN structure and activation function are calculated by a separate program block relative to the ANN structure and object parameters [5]. External perturbations are also fed to the object input throughout the calculation [6]. Comparison of different control system configurations will be carried out on the basis of a modular integrated quality indicator [7].

3. Research of the first neuroregulator structure

Two structures of an artificial neural network were used as the basis for this research. Both structures are models of a direct distribution network. The difference lies in the structure itself: for the first set of studies, a structure with one input neuron, one hidden layer and an output neuron was taken, while for the second set of studies, another hidden layer was added and the number of neurons for the first set was increased. We first look at the data obtained for the first execution of the structural scheme shown in figure 2.

![Figure 2. First structural scheme of ANN.](image)

The research has considered four functions of activation of neuroregulator neurons. Studies were also carried out for different configurations of an object other than a real object. Cases for increased and decreased time constant of the aperiodic link included in the mathematical model of the object were considered. The results obtained with respect to each activation function were divided into three graphs concerning each object and are presented in figures 3-5.
Figure 3. Transition process of a low-inertia facility.

Figure 4. Transition process of a real object.

Figure 5. Transition process of a highly inertial object.

It can be seen that the inertia of a facility directly affects the quality of regulation. One can immediately notice the different nature of the regulation of the neuroregulator, the activation function of which is an aperiodic link, when adjusting the output parameter of objects of both increased and decreased inertia, and in the first case there is no pronounced dynamic deviation, and the object comes out on a uniform low frequency auto oscillation. The logarithmic neuron activation function and hyperbolic tangent behave similarly in a low-inertia object, while in a standard configuration object they are identical. This can be explained by the similarity of function charts at small values. Together with this, it can be seen that when the configuration of an object changes in relation to real parameters, the fluctuations of processes increase. This may be due to the fact that the parameters of the actuator are optimally matched to the standard object and need to be adjusted for use on objects with changed parameters.

By carrying out a general analysis of the transients for each control unit, it can be concluded that the aperiodic link has proved to be the best in all three cases. The positive qualities include the fact that the auto oscillations that occur at the output of the object are much less frequent than with the other activation functions that have been considered. And with the right parameters for the activation function and the object, there can be no pronounced dynamic deviation.

4. Research of the second neuroregulator structure
In this part of the research, it is necessary to consider the impact of the neuroregulator structure on the quality of regulation with the same activation functions. The question to be considered is identical to
that presented in the first part of the study. For the sake of objectivity of the study, the parameters of the technical equipment have remained unchanged and are presented in table 1.

![Second structural scheme of ANN](image)

**Figure 6.** Second structural scheme of ANN.

It is easy to see that this structure is slightly more complex than the previous one. This fact indicates that the number of optimised weights will be increased, which will undoubtedly affect the time taken to calculate them.

![Transition process of a low-inertia facility](image)

**Figure 7.** Transition process of a low-inertia facility.

![Transition process of a real object](image)

**Figure 8.** Transition process of a real object.

![Transition process of a highly inertial object](image)

**Figure 9.** Transition process of a highly inertial object.

Having analyzed the graphs, we can say that in two cases where the object parameters have been changed from real to real and to a greater or lesser extent, there has been a significant deterioration in the quality of regulation when using hyperbolic tangent, logarithmic and linear with saturation as an activation function. When research is conducted on a low-inertia facility, the frequency of auto oscillations has increased significantly, and the executive mechanism is in constant motion, which significantly reduces its operating life. Also, if the inertia of the object is increased and the second structure of the artificial neural network is used, a significant dynamic deviation at the beginning of regulation can be observed, which is unacceptable in most automatic regulation systems. However, in this study, as in the previous one, the aperiodic link as an activation function performs well. There is no
dynamic deviation at all on a low-inertia object, and on the rest it is almost comparable to the amplitude of auto-vibrations of other activation functions. The fact that the logarithmic function and hyperbolic tangent have identical transients when used on a standard site remains unchanged.

Thus, the expansion of the neuroregulator structure did not lead to an improvement in the quality of regulation and in some cases led to a deterioration. Transition processes using standard equipment have undergone the least change. This can be due to the fact that the parameters of each element of the real automated control system are well optimised relative to each other.

5. Conclusions
This article discussed the influence of the function of activation of neuroregulator neurons on the quality of regulation. A comprehensive study was carried out using objects of different inertia as well as different structure of the neuroregulator itself. The transients were derived in figures 3-5 and 7-9, and the results of calculating the modular quality indicator for each of the activation structures and functions are shown in table 2.

| Activation function      | Modular integral quality indicator | First structure of neural network | Second structure of neural network |
|--------------------------|-----------------------------------|----------------------------------|-----------------------------------|
|                          |                                   | Ta = 60  | Ta = 130  | Ta = 200  | Ta = 60  | Ta = 130  | Ta = 200  |
| Aperiodic link           |                                   | 2162     | 3253     | 3112     | 2152     | 3260     | 3186     |
| Hyperbolic tangent       |                                   | 2029     | 2790     | 3159     | 3577     | 3500     | 5969     |
| Linear with saturation   |                                   | 2469     | 3054     | 3462     | 2665     | 2845     | 4042     |
| Logarithmic              |                                   | 2207     | 2802     | 3452     | 2299     | 2522     | 4495     |

In conclusion, the best transition process is the structure of the neuroregulator using the aperiodic link as a function of neuronal activation. A characteristic feature is the low frequency of auto oscillations in relation to the transients of other activation functions to be investigated. It is also possible to see a kind of 'pad' where the actuator remains inactive at the exit, this allows for less AM load, which will increase the lifetime of the actuator, rather than in a situation where the output parameter is in constant dynamics and there is a constant change of direction of the actuator from 'more' to 'less' and vice versa. The switching schedule of the actuator is shown in figure 10.

![Figure 10. Transition process (AM output).](image)

It is this quality that makes it possible to call the aperiodic link more suitable for use as an activation function, even though it does not have the best modular quality indicator value.
However, this research does not give a complete picture, and the findings are only relevant for a single-circuit automatic control system using specific automation techniques.

Since such an area as artificial neural networks is new, there is a need for a greater basis for developing a common methodology for building the structure of the INN for systems of different complexity [8].

In order to form a complete picture, it is necessary to carry out a lot of research for various control objects, ways of organising the executive mechanism, as well as for various structures for building an automatic control system, such as:

- ADS with compensation for external disturbances;
- Multi-connected automatic control system;
- Cascade automated control system.

References

[1] Shecherbatov I A, Dementev D A and Maximova E D 2020 Applying of modeling tools pack SimInTech in the engineering personnel preparation for the energy sector. 5th International Conference on Information Technologies in Engineering Education, Inforino 9111787

[2] Mezin S V, Dementev D A and Maximova E D 2020 Development and implementation of regulators based on artificial neural networks in the process of training specialists in automated control systems. 5th International Conference on Information Technologies in Engineering Education, Inforino 9111650

[3] Rogalev N D, Arakelyan E K, Andryushin A V, Mezin S V and Dudolin A A 2017 Application of modern information technologies in the educational process and scientific research. MPEI Bulletin 6 9-19

[4] Arakelyan E K, Andryushin A V, Sabanin V R, Mezin S V and Pashchenko F F 2017 Use of modern information technologies to improve energy efficiency of thermal power plant operation Journal of Physics: Conference Series 891 012286

[5] Sabanin V R, Dementev D A, Kazmiruk I Y, Arhipov A B and Kirienok D S 2018 Using the method of error backward propagation for the parametric adaptation of the stepper neuroregulator Young scientist 13 1-11

[6] Sabanin V R, Mezin S V, Dementev D A and Kazmiruk I Y 2018 Research on the use of neural networks as an adaptive regulator. Theses of reports of XXIV international scientific and technical conference "Radio electronics, electrical engineering and power engineering" Moscow, Russia 15-16 March p 904

[7] Sabanin V R, Dementev D A and Kazmiruk I Y 2017 Some results of the use of artificial neural networks as an automatic control system regulator Collection of Proceedings of the 26th International Scientific and Technical Conference "Modern Technologies in the Problems of Management, Automation and Information Processing" Alushta, Crimea, Russia 14-20 September pp 60-1

[8] Sabanin V R, Dementev D A and Kazmiruk I Y 2019 Application of neural networks as a regulator in two-circuit automatic control systems Young scientist 4 91-6