The architecture of adaptive neural network based on a fuzzy inference system for implementing intelligent control in photovoltaic systems

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Abstract. In this paper, we consider the architecture of the algorithm for extreme regulation in the photovoltaic system. An algorithm based on an adaptive neural network with fuzzy inference is proposed. The implementation of such an algorithm not only allows solving a number of problems in existing algorithms for extreme power regulation of photovoltaic systems, but also creates a reserve for the creation of a universal control system for a photovoltaic system.

1. Introduction
Photovoltaic systems have a relatively low efficiency. One way to increase their efficiency is to implement extreme power control. The MPPT (maximum power point tracking) algorithms allow minimizing the underproduction of power. It is known that the existing algorithms of extreme control have a number of disadvantages related to power fluctuations, losses when entering the work point, dependence on system configuration or external conditions. Eliminate these problems by adapting intelligent algorithms [1], for example algorithms based on fuzzy logic [2]. In this paper, we consider the architecture of an algorithm for extreme regulation in a photovoltaic system based on an adaptive neural network with fuzzy inference. The implementation of such an algorithm not only allows solving a number of these problems, but also creates a reserve for the creation of a universal control system for a photovoltaic system.

The urgency of solving these problems is related to a number of tasks, including the task of maximizing the time for the operation of autonomous objects, the task of minimizing battery charge time, the task of increasing the reliability of autonomous power supply systems, and the task of creating a universal system.

The purpose of this work is the development of an algorithm for extreme regulation in the photovoltaic system based on an adaptive neural network with fuzzy inference.

The tasks solved in the course of the development work include the design of the architecture of the adaptive neural network with fuzzy inference and its modeling.

2. The ANFIS architecture for the extreme regulation of photovoltaic systems
Adaptive neuro-fuzzy inference system, ANFIS is an artificial neural network based on the fuzzy Takagi-Sugeno output system. This method integrates the principles of neural networks with the principles of fuzzy logic, which allows to combine their advantages in one structure.
The introduction of ANFIS as a control device will solve the problems associated with the nonlinearity of functions describing processes in the photovoltaic system and eliminate the drawbacks of conventional algorithms for extreme control.

Figure 1 shows the structure of a photovoltaic system with an ANFIS controller.

![Figure 1. Structural diagram of the photovoltaic system with ANFIS controller.](image)

In the presented system, extreme power regulation is carried out by means of a pulse converter: when the voltage / current of the photoelectric module increases, the ANFIS controller increases the pulse frequency, which in turn leads to an increase in the output current. By increasing or decreasing the current / voltage in the system, the controller goes to the optimal pair providing the maximum power.

Figure 2 shows the algorithm for applying ANFIS in the system.

![Figure 2. ANFIS algorithm.](image)

As input variables, ANFIS uses the temperature and insolation of solar cells, because these two factors have the greatest impact on energy production. These variables undergo fuzzification procedure by membership functions. Then follows the processing of data on a set of fuzzy rules [3]. The output parameters are compared with the pre-loaded reference model. In the case of data
mismatch, the membership functions are reset. In the case of data reconciliation, the model becomes a learning model.

The structure of ANFIS is shown in Figure 3.

![Figure 3. Structure of ANFIS.](image)

ANFIS implements the Sugeno fuzzy inference system in the form of a five-layer neural network of direct signal transmission. The purpose of the layers is as follows:
- the first layer is the terms of the input variables;
- the second layer - antecedents (parcels) of fuzzy rules;
- the third layer - the normalization of the degree of implementation of the rules;
- the fourth layer - the conclusion of the rules;
- the fifth layer is the aggregation of the result obtained by different rules.

For the linguistic evaluation of input variables (temperature and insolation), three terms are used, connected by nine fuzzy rules. The output signal is formed taking into account the execution of all fuzzy rules.

3. Simulation model of the system
To create a simulation model, the MATLAB / Simulink environment was used. To assess the efficiency of ANFIS, a photovoltaic system has been developed. The model includes a solar battery, a charge controller, a battery and a load. The developed model is shown in Figure 4.

![Figure 4. Model of the photovoltaic installation.](image)

The simulation model of the solar battery is realized on the basis of the model of a single diode, with expansion to a specified number of solar cells in a solar battery. This model takes into account various factors of influence (temperature, illumination, angle of incidence of rays) [3].

Figure 5 shows the implementation of the model in the Simulink environment.
The controller model includes a pulse converter and a control device with ANFIS. The implementation of the model in the Simulink environment is shown in Figure 6.

4. Results/Investigation of the influence of ANFIS on the energy efficiency of the system
To create a simulation model, the MATLAB / Simulink environment was used.
To study the effect of ANFIS on the energy efficiency of the photovoltaic system, a comparative analysis of the performance of a conventional extreme algorithm, an algorithm of extreme regulation with fuzzy logic [4], and an ANFIS algorithm was carried out. The research was carried out on the basis of the developed simulation models. The results are shown in Figure 7.
Figure 7 shows the main advantages of using the ANFIS algorithm: reducing the search time of the operating point, neutralizing the power fluctuations.

5. Summary
The use of ANFIS significantly improves the characteristics of the MPPT algorithm: decreases the search time for the extreme point, decreases the amplitude of voltage fluctuations, reduces the underproduction of power.
- Reduces the search time of the extreme point by 42%.
- Power fluctuations decrease or are neutralized (depending on the number of epochs).
- The calculated efficiency values show an increase in the efficiency of the photovoltaic system by an additional 4–5% when using the MPPT controller with ANFIS.

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