Neural network architecture choice for modelling various configurations power system

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Abstract. Gas turbine power plants based on converted aircraft engines have been successfully produced in Perm city since 1991. Their power range is steadily expanding. Such gas turbine electro power stations have significant advantages. However, the need to make full use of these advantages requires power station control processes significant intellectualization. Intellectualization will provide an opportunity to improve the electricity quality, increase the power supply reliability and improve environmental friendliness. To achieve these goals, it is necessary to study the behavior of gas turbine power electro station in different operation modes and in various configurations power system. Such research can only be carried out on the basis of mathematical models. Moreover, these models should be high-speed, since the research of control algorithms requires a large number of various experiments in a limited time. One of the promising ways to obtain such mathematical models is to use the artificial neural networks apparatus. To construct a gas turbine power electro station mathematical model, it is necessary to choose such a neural network architecture that will allow obtaining a model for an acceptable period of time and will allow modeling the processes with the required accuracy. Therefore, the problem of choosing the neural network architecture is an urgent research priority. On the basis of the performed studies, the architecture of a neural network for modeling various configurations power system is proposed and substantiated.

1. Introduction

In the course of using artificial neural networks [1, 2] for modeling [3, 4] gas turbine electro power station (GTEPS) [5 - 8] a neural network architecture (NNA) was obtained, which we called basic NNA (Figure 1).
Figure 1. Basic neural network architecture for gas turbine electro power station modeling.

In Figure 1 $G_T$ is a gas turbine unit (GTU) fuel consumption (kgph), $U_F$ is a generator field voltage (volt), $P$ is a power system load power (Watt), $n_{TC}$ is a turbo compressor speed rotation (rpm), $n_{FT}$ is a free turbine speed rotation (rpm), $U$ is a generator linear voltage (volt), $I$ is a generator current (amp), $N_G$ is a generator power supply (Watt), $w_{abc}$ is a connection weight (where $a$ is a layer number, $b$ is a neuron number in the layer where the connection is coming from, $c$ is a neuron number in the layer where the connection is coming to), $n, m$ are the hidden layers neuron number.

The basic NNA (Figure 1) is as follows:

- Number of hidden layers is equal 2;
- Number of neurons in each hidden layer is equal 30;
- Number of modelling variables is equal 5;
- Number of feedback depth 2;
- Number of neurons in the input layer is equal 3 (excluding feedbacks);
- Activation function hyperbolic tangent.

2. Methods
2.1. Development of NNA for various power systems

The basic NNA was originally obtained for a GTEPS scheme that operates on a dedicated load (Figure 2) [5–8].
In Figure 2 GTU is a gas turbine unit, SG is a synchronous generator, Load is power system load, GTEPS is a gas turbine electro power station.

Figure 3 shows the change in the rotation speed of a gas turbine unit (GTU) free turbine when the power system load power changes from 1000 kW to 6000 kW.

Then the basic NNA was applied to another GTEPS scheme that operates on a dedicated load in parallel with an infinite power network. (Figure 4).

Figure 4 shows the change in the rotation speed of the GTU free turbine when the power system load power changes from 1000 kW to 2000 kW (scheme shown in Figure 4).
The next considered scheme was a scheme of two parallel-connected GTEPS operating on a load (Figure 6).

In the scheme presented in figure 6, in contrast to the previously considered schemes, two GTEPS are already involved, therefore, each of them requires its own experimental data for training. Based on this, the number of control and disturbing effects has doubled, as well as the number of modeled variables has doubled. Other basic NNA parameters remained unchanged. Figure 7 shows the GTU free turbine speed rotation change of the scheme shown in figure 6, when the power system load power changes from 2000 kW to 1000 kW.
Figure 7. GTU-1 free turbine speed rotation (red – experimental data, blue – model data).

2.2. Use the base NNA for power system combined schemes

After basic NNA successful application for individual power system schemes, it was decided to train
an artificial neural network to simulate various power system schemes. As such schemes, the
schemes shown in figures 2 and 4 were chosen. The use of the basic NNA did not give acceptable
results, so it was decided to change the NNA to solve the current problem. To solve this problem, 5
experiments were conducted, where the hidden layers number and neurons number in hidden layers
changed:

- "Architecture 1": 2 hidden layers, 40 neurons in each hidden layer;
- "Architecture 2": 3 hidden layers, 30 neurons in each hidden layer;
- "Architecture 3": 3 hidden layers, 40 neurons in each hidden layer;
- "Architecture 4": 4 hidden layers, 30 neurons in each hidden layer;
- "Architecture 5": 4 hidden layers, 40 neurons in each hidden layer.

3. Results and Discussion

Experimental results analysis showed that with the "Architecture 2" help it was possible to obtain a
model with acceptable adequacy according to the Teil criterion (Table 1) [9], which allows modeling
the power systems shown in figures 2 and 4.

Table 1. Teil criterion adequacy

| Data type                      | Adequacy measure |
|--------------------------------|------------------|
| GTU free turbine speed rotation|                  |
| Learning data                  | 0.03212          |
| Test data                      | 0.02125          |
| Synchronous generator linear voltage |              |
| Learning data                  | 0.02389          |
| Test data                      | 0.02176          |

Figure 8 shows GTU free turbine rotation speed change when modeling the scheme shown in
figure 2, when power system load power changes from 6000 kW to 1000 kW.
Figure 8. GTU free turbine speed rotation (GTEPS operating on a load, red – experimental data, orange – model data).

Figure 9 shows GTU free turbine rotation speed change when modeling the scheme shown in figure 4, power system load power changes from 1000 kW to 2000 kW.

Figure 9. GTU free turbine speed rotation (GTEPS operating in parallel to the infinite power network, red – experimental data, orange – model data).

4. Conclusions
The use of the basic NNA makes it possible to significantly simplify the procedure for selecting such an architecture for various power system schemes, which was clearly shown by the experiments shown above. The basic NNA allows you to model the power system schemes, such as shown in figures 2 and 4, without any changes and, having modified the architecture of the basic NNA, the artificial neural network simulates the power system schemes shown in figures 4 and 6.

The obtained results allow us to assume that within the framework of a single neural network, we can model not only the power system operating modes majority [9], but also various power system schemes. In the future, this gives us a huge advantage, as it allows us to obtain a universal neural network mathematical model of the power system, which should significantly simplify the procedure for testing power system elements [10].
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References
[1] Haykin S 1999 Neural networks: A comprehensive foundation (Singapore: Person Education)
[2] Borisov V and Kruglov V 2001 Artificial neural networks. Theory and practice (Moscow: Hotline-Telecom)
[3] Asgari H, Chen X, Menhaj M and Sainudiin R 2013 Artificial Neural Network–Based System Identification for a Single-Shaft Gas Turbine J. of Engineering for Gas Turbines and Power. JEGTP135(2013)0902
[4] Asgari H, Chen X and Sainudiin R 2013 Modeling and simulation of gas turbines Int. J. of Modeling, Identification and Control IJMIC 20 (2013) 0310
[5] Kilin G, Kavalerov B and Masyagin E 2017 Choosing a neural network architecture for constructing a mathematical model of a gas turbine power plant Int. Conf. Actual problems of electromechanics and electrotechnologies (Yekaterinburg:Publishing house Educational Methodological Center Ural Polytechnic Institute) pp. 205-208
[6] Zhdanovsky E, Kavalerov B and Kilin G 2017 Development of a neural network model of a gas turbine power plant for tuning regulators of a gas turbine installation Fundamental researches 12 pp. 479-485
[7] Kilin G and Kavalerov B 2019 Neural network mathematical model for automation of tests of the automatic control system of gas turbine power plants of small and medium power Modern High Technologies 02
[8] Sobrovtsv E, Kolpakova M and Kilin G 2020 Neural network mathematical model of a gas turbine power plant taking into account the different modes of operation Perm National Research Polytechnic University Bulletin. Electrical Engineering, Information Technology, Control Systems 34
[9] Theil H 1971 Principles of Econometrics vol 1 (New York: Wiley)
[10] Kavalerov B and Romodin A 2011 Mini electric power stations on the base of converted aircraft engine autopilot system of gas turbine plant North-Eastern Federal University Bulletin 08