Abstract: In this article for the first time, a nonlinear model of steam turbine without re-heater (160 MW) that is used in many power plants based on soft computing techniques and using real, has been modeled data. The Modeling includes: low-pressure turbine (LP), high pressure turbine (HP) and control valves. For the more accurate the results, model is divided into two sub model: 1- above 85 MW 2- under 85 MW. This model has been prepared based on modification of existing linear and nonlinear models and Using fuzzy rules. Fuzzy transfer functions have been trained using real data and neural networks techniques. Eventually, the comparison between the response of the proposed Fuzzy-neural model outputs and actual model and a widely used linear model outputs can be confirmed accuracy.

Key-Words: steam turbine, Fuzzy modeling, actual data, neural networks

1 Introduction
Large class of mathematical models to analyze and study the dynamics of power plant turbines have been
In many cases, these models are so simple that only a mapping between the input and output variables, intermediate variables in many of them have been removed [1]. Lack of care in the simplified models can cause problems in the evaluation of control strategies. In this regard, the models used in designing control systems should always have an acceptable degree of accuracy.
Finding an appropriate method for modeling a steam turbine Combined Cycle Power Plant should be so that having more accurate and close to the real system, the design of control systems is also useful. Existing models for power plant systems are usually a combination of theoretical and experimental models and have Mainly a linear structure with few parameters are adjustable.

Despite the simplicity, the use of these models, dramatic changes in the design of control systems were developed. [2,3,4] Power systems modeling techniques in addition to providing analytical models based on thermodynamic laws and the physical, model-based methods for data input - output is always of interest to researchers. The application of neural networks, genetic algorithms, fuzzy systems, or a combination of these theories for the modeling of industrial processes such as power plants have been used widely in recent years. With having a good set of data input and output systems that are operating in a wide range of data, method, fuzzy – neural networks can be very useful for modeling nonlinear systems. Nowadays, using soft computing methods in systems that modeling them help to physical and thermodynamic relations are complex and difficult, is common. (When the availability of experimental data) [5, 6, 7]
In this paper, for the first time one nonlinear model based on actual data for a 160-megawatt steam turbine in Neka power plant, without re-heater, is provided. Modeling is include: the low-pressure, high pressure and control valves. For more accurate results, the original model is divided into two sub models, which have similar structure but are different in the training fuzzy transfer functions: One for the powers above 85 MW and the other for powers less than 85 MW. These models have been prepared based on modification of existing linear and nonlinear models and Using fuzzy rules. The new algorithm for determining the parameters of the turbine transfer functions by using a method based on fuzzy – Neural networks presented. Fuzzy transfer functions have been trained using real data and neural networks techniques. Finally, the comparison between the response of the proposed Fuzzy-neural model outputs and actual model and a widely used linear model outputs can be confirmed accuracy.

2 steam turbine power plant

In this article has been investigated Steam turbine combined cycle, Salimi (Neka) power plant. This combined cycle power plant consisting of 2 Gas turbines and 1 steam turbine Created by Siemens company. Nominal capacity is 435 MW and Containing 2 units of gas with 137.6 MW and one unit of steam with 160 MW. Combined cycle unit consists of two heat-recovery units, HRSG, which have responsible of supplying steam to the steam turbine. Steam turbine consists of High-pressure HP and low pressure LP. Feeding steam of HP units supply by two HP drums in heat-recovery units and The LP steam to be provided by two LP drums in heat-recovery units. (Figure 1)

3 Modeling

In Power systems modeling in addition to analytical models based on thermodynamic and physical laws, Modeling methods based on data inputs - outputs has always been considered by researchers. Recently, application of neural networks, genetic algorithms, fuzzy systems, or a combination of these theories for the modeling of industrial processes such as power plants have been used widely. With having a good set of data input and output systems that are operating in a wide range of data, method, fuzzy – neural networks can be very useful for modeling nonlinear systems. Although increasing the number of membership functions of fuzzy adaptive systems to increase the accuracy of models produced there, But often increase the number of membership functions and fuzzy rules followed by the number of problems in calculating the parameters of the fuzzy rules. To avoid errors, and optimum response should be careful in selection of the Generate FIS type and number of Trainings and parameters. When modeling Conditions caused that cannot select the membership function only with looking at the data. So instead of choosing the parameters for an arbitrary membership function, one can for calculate the changes in values, was selected parameters for organizing membership function According to the data inputs / outputs. This is what called the neural adaptation training technique and used in construction anfis. ANFIS (adaptive network-based fuzzy inference system) is an adaptive and Ability to learn network that is quite similar in terms of performance to fuzzy inference system. In proposed fuzzy - Neural model, steam turbine is simulated based on control valves (MCV and HCV ) opening and the input temperature.
In here the Input and output of each of the models are considered based on inputs that influence the dynamics of real systems. 

In turbine Collection, the energy of fluid is converted into mechanical energy and then to electrical energy and thus the temperature and pressure drop it.

![Figure 2 - The neural–fuzzy model of steam turbines (below 85 MW)](image1)

Both models are identical in shape but data sets and types of training are different. fuzzy inference functions (FIS) have been trained using input and output data to determine the amount of power can be produced by steam turbines. Output values of the fuzzy inference, Given that the error variation can be very large, so consider Rate Limiter mechanism in the Output is necessary. As mentioned in the first part, the system consists of two HP and LP turbines which are modeled as follows:

![Figure 3 - The neural–fuzzy model of steam turbines (over 85 MW)](image2)

The inlet pressure of high pressure turbine (HP) calculates by fuzzy inference functions FIS which trained by neural network. Effective parameters in determining of fuzzy functions and training them are: the inlet pressure of HP turbine and opening main control valve (MCV). To get better results from the coefficient K, is used by MATLAB software (Simulink Response Optimization) And improved values of the coefficients are applied to inputs. The model parameters are determined so that can match the turbine power plant.

![Figure 4 - The fuzzy - neural model of HP](image3)

The inlet pressure of low pressure turbine (LP) calculates by fuzzy inference functions FIS which trained by neural network. Effective parameters in determining of fuzzy functions and training them are: the inlet temperature of LP turbine and opening intermediate control valve (ICV). Also The inlet flow of high pressure turbine (HP) calculates by fuzzy inference functions FIS which trained by neural network. Effective parameters in determining of fuzzy functions and training them are: the inlet pressure of LP turbine and opening intermediate control valve (ICV).

![Figure 5 - The fuzzy - neural model of LP](image4)

**4 Calculation of transfer functions**

Method of fuzzy inference functions and fuzzy inference system (FIS) are as detailed below: All calculations and presented diagrams are displayed in the range of 70 to 157 MW of power. To generate FIS (Fuzzy Interface System), type and number of membership functions of input and also output membership function type must be determined. In Education all transfer functions, is used Hybrid combination method that is including two methods: Gradient Descent method and least square error (LSE) method. Also the amount of allowable error is 0. Type of output membership functions are all considered as linear.
The average error for training data and test data have been met each other for each training.

Error as the difference between the response of proposed functions and actual values and as below parameters are defined:

The maximum error value: Max (| e |), minimum error value : Min (| e |), Mean Absolute Error : MAE (e), average absolute deviation - AAD (e) and correlation coefficient.

For example, the structure of transfer function of generated power is in the following:

dm1 is inlet flow the HP turbine, P1 is inlet pressure the HP turbine, dm2 is inlet flow the LP turbine and P23 is total inlet pressures LP turbine from ICV valve and HP turbine.

D is Output power that obtained using the input parameters.

In training this model is used Hybrid combination method that is including two methods: Gradient Descent method and least square error (LSE) method.

Also the amount of allowable error is 0. In this section we start the training system:

<table>
<thead>
<tr>
<th>Train FIS</th>
<th>Optim. Method</th>
<th>Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error Tolerance</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Epoches</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

The simulation was repeated 10 times in order to can calculate average and reached the lowest possible error.

the average error for the training data is 0.30723 and for the test data is 0.30723.

The error values are defined as above, we have:

<table>
<thead>
<tr>
<th>Error values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max (</td>
</tr>
<tr>
<td>Min (</td>
</tr>
<tr>
<td>MAE</td>
</tr>
<tr>
<td>AAD (e)</td>
</tr>
<tr>
<td>R² (e)</td>
</tr>
</tbody>
</table>

The following forms, outputs of actual model and a conventional linear model are compared with Proposed Model.

Figure 6 - increasing output power turbine from 70 to 157 MW.

To produce FIS (Fuzzy Inference System), type and number of membership functions of input and output to be determined:

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specifications of Membership Functions</td>
</tr>
</tbody>
</table>

```markdown
<table>
<thead>
<tr>
<th>INPUT</th>
<th>Number Of MFs</th>
<th>3 3 3 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>MF Type</td>
<td>gbellmf</td>
<td></td>
</tr>
<tr>
<td>OUTPUT</td>
<td>MF Type</td>
<td>Linear</td>
</tr>
</tbody>
</table>
```

In the following forms, outputs of actual model and a conventional linear model are compared with Proposed Model.
5 Conclusion

In this article, presented a modeling of steam turbine combined cycle by the proposed method using fuzzy- nervous techniques, And Outputs was obtained from fuzzy- neural model compared with linear model data and actual data.

This non-linear model due to training and accommodating with actual data has better performance and compatibility in Facing with major changes in the parameters affecting the turbine.

And also because of separation of model for loads below 85 MW and above 85 MW, has Less error in comparison with other non-linear models for different steam turbines.

REFERENCES


