Control Steam Turbine Combined Cycle Power Plant Based on Soft Computing

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Abstract: In this paper for the first time has been presented a nonlinear controller for controlling the steam turbine combined cycle unit without the re-heater based on soft computing techniques.

This controller is provided based on the modified linear and nonlinear models using fuzzy membership functions and simultaneously control valve technique. A comparison between the proposed controller with existing example in power plant and also Comparison of the accuracy and error of the controllers can confirm the proposed controller.

Key-Words: Steam turbine, Fuzzy Control, Actual data, Neural networks

1 Introduction

In most modern power plant control systems, turbine control system must be able to response quickly to changes. This operation needs a control system for controlling the load and if necessary, adjusts the frequency of the network that has the ability to prevent instability of system in transient conditions. Modeling and providing a suitable control system can help to simulation of the turbine and can be investigated its performance in Situations that there is not possible applying on Actual model and also can analyze system in emergency conditions. After initial fluctuations in a power system, due to a disturbance, such as requesting additional load, the system must be balanced in suitable and sufficient time without disturbance and effective changes in the frequency in the new work-based.

In this paper, the control system using two control valves based on fuzzy control method and also how to open and close valves or in other words other its programming uses a smart method, as it can to improve behavior, increase flexibility and speed of its response.

2 Control

Power system stability is a feature of power system that Enables the system remain in normal conditions and in equilibrium and if the disturbance influences system, Again to obtain an acceptable mode. [1]. For increase the Ability turbine response to frequency and load changes and also prevent system instability in transient conditions, using two valves for control sets of turbine have suitable performance. How to connection two control valves is series, and the operation time of intermediate control valves (ICV) has delay is measured relative to the valve main control valves (MCV).

Determine the amount of time delay is very effective in controlling the turbine. The best performance is investigation and determining the opening and closing of the control valves independently.

In most cases, does not need to operation low-pressure valve and its continued operation will cause energy loss.

One of the solutions commonly, use LP control valve when the power drops. In this system the low pressure valve is open or closed when the signal of HP control valve passes a certain amount.
Boleka and his colleagues compared the performance of the turbine with two control valves in two conditions: 1- using a linear controller (with a mechanism similar to what was said) and 2-a non-linear controller (linear feedback system) [2] which results shows increase efficiency and speed of turbine response, in the coordinated operation of the two control valves.

3 Fuzzy controller algorithm

The proposed control structure generally is shown in Figure following.

![Fig. 1 The proposed control structure](image1)

Using the results of the turbine model, the Power and frequency values produced after feedback and compared to the Set point apply to inputs.

And then the error values and error changes rate enter a fuzzy controller.

![Fig. 2 - Self-tuning fuzzy controller](image2)

K1=0.031 , K2=0.105 , K3=0.3 , Saturation=0.2/1.07

Controller output membership functions to be considered fixed type due to will cause established a slight difference between the system output and its desirable value (fuzzy zero). Figure (4) is shown the Page fuzzy for fuzzy modifier controller.

![Fig. 3 control inputs and outputs](image3)

![Figure 4 - Page fuzzy for fuzzy modifier controller](image4)

![Figure 5](image5)

In a control system with a wide range of operating conditions, outputs of operators and actuators have limitations.
In these conditions, when the operator is in the saturation status (values are outside the range specified), a signal is applied to the system output and this output effects on the inputs, then feedback loops will be broken.

And the integral term in the controller diverges to large quantities and occurs "Wind up".

To avoid "Wind up", should be ensure the integral value remains in certain range when operator is in the saturation condition, and upon change in control error, the controller is ready to return to its operational status.

A form suitable is use of linear feedback as "Anti Wind up".

![Figure 5 - Anti-Wind up controller](image)

K1=0.9591, K2=1.082, Zero order hold=2

"Simulink Response Optimization" in MATLAB is used for the optimization of the all Ki coefficients. Operator is introduced as a restrictive signal, the difference between input and output operation is given feedback to the integration.

Upon the signal reaches the ultimate limit, Output signal be opposite of zero, and prevent from failure of integration.

K3 ratio is used as a ratio for adjusting the Wind-up value.

Output after passing through the Limiter of changes rate, goes to main valve (MCV).

This signal should be sent to intermediate pressure valve (ICV), to determine the opening and closing ICV valve commensurate with the main valve position.

In this regard there are important points:

In new methods, the intermediate pressure control valve (ICV) should be active when need to act and after that the system reaching steady state conditions remains completely open.

Intermediate control valve (ICV) should not be closed before closing MCV, or more than that, this can cause severe damage to the high pressure turbine. It is natural that the opening ICV before or more than MCV is permitted,[3] Although ICV in steady state is completely open but there is probably that MCV has be opened before ICV due to the delay when sudden changing. In these conditions considering a mechanism to prevent such cases is essential.

According to the above, pay to describing operation of other parts of the turbine control system. Control signal first enters a delay module. The time delay been considered to the size of a quarter of the time constant of high pressure turbine that prevents from change the state of ICV before MCV (item 2).

The valve position signal is compared with the fully open position and after crossing back Transfer function adds itself.

Time constant represents the time of transfer function for return valve position to fully opens (item 1).

It should be noted that the control valves to open more than 7 percent is not possible.

As in figure(6) is seen, Limiter of Intermediate valve position signal is the dynamic type that its upper limit is 100 and the lower limit is the main control valve position.

According to The lower limit that is considered, the intermediate valve never let to be closed more than the main valve.

And also if the sudden opening of the main valve (when intermediate valve is closed), its position will be moved to the position of the main valve (item 2 and 3).

![Figure 6 – (MCV-ICV)](image)

It may an unexpected disturbance and severe load to be imposed on network (due to exit a power plant of the circuit) so that Network can't give an appropriate response. In this case, is applied significant electrical torque to the turbine.

In these conditions, protection systems, Separates generators from the circuit and thus due to removing electrical torque, the turbine speed increases.

Should be noted that Turbine can reached in less than 1 second to 109% of the nominal speed, Therefore reaction rate to against it must be significant.

In such conditions Two protection mechanisms is been considered.
In the first mechanism to achieve the turbine speed to 109%, MCV and ICV valves start to closing. 100% reduction in the flow rate and pressure regulating valve in the middle of the entrance to the LP turbine.

If a sudden change in the adjustment of speed changer does not create, speed will stops in 100%.

The second mechanism is the emergency condition of speed that protection system when Excessive increase of turbine speed will be announced, trip of turbine and with closing stop valves prevents run up turbine excessive speed.

This speed will be considered between 110 to 120 percent of speed, via the manufacturers [4]. In these conditions, the control system should puts valves position in a suitable and to keep the turbines in stand-by position, provide Ability return the unit to the network.

To limit the frequency change range of network due to changing load is used control of the load-frequency system.

In The load-frequency control system is made a control signal that via the governor system of power plant is applied to the units.

Governor control system for controlling the frequencies are divided into two types of Isochronous and Droop.

The two systems show the following forms.

![Figure 7 - Load-frequency control system – Isochronous](image1)

![Figure 8 - Load-frequency control system Droop](image2)

In the Isochronous mode, frequency imports to a pure integrator.

According to the theory of linear control systems, Closed-loop when reaches steady and calm state that the error between the desired output and actual output (the input signal integrator) is zero. Otherwise the integrator output is small or large and system doesn't reaches steady state.

Although the zero frequency error is ideal, But if the total units of a network be in isochronous mode, all units will trying to Produce zero frequency error with reduce or increase Produced power And As a result of the intervention together, Network will be unstable.

Each network selects a few units for this work and others adjust in Droop mode.

Of course due to limitations that that are in production, the few units partially can cope with frequency error.

In Units that load - frequency control system is droop mode, a feedback loop with the gain R is placed on integrator. The R-value will be adjusted by the operator of the plant.

If this value is selected zero, the state of governor is Isochronous and the participation rate of unit is maximum in decrease the frequency error to zero.

Otherwise, the unit accepts a small error.

Whatever larger R is selected, Unit indicated less sensitive than frequency error.

![Figure 9 - Frequency Control](image3)

To obtain transfer function of power to frequency is used the ANFIS (Adaptive Neuro Fuzzy Inference Systems).

Fuzzy transfer function is trained using neural network and actual data from the steam turbine combined cycle power plant of "Neka".

For producing FIS (Fuzzy Interface System ) ,type and number of membership functions of input and output is determined as below:

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

Table1 - Specifications of membership Functions

in learning this model has been used hybrid combined method that consists of two methods Gradient Descent and least square error (LSE).
Also value of allowable error is considered zero, 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>50</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 - Training parameters

The simulation was repeated 50 times in order to reach the lowest possible error. The average error for training data is 0.1782 and for the test data is 0.18982.

4 Simulation and results

Now it is necessary assessing the ability of control system in changing load. In the beginning, evaluates system conditions in increasing load and the obtained results are compared with the conventional method of connecting two valve (with controller PI) and Fast closing (= 170 ms).

In Figure (10) is shown the system response when the load change of 72 to 156 MW.

As can be seen system response with the proposed controller is much faster and the settling time is reached of 50 minutes to about 25 minutes.

As can be seen both valves be used when load are increased and preventing of disturbances that occurs when increasing load. In addition to show an optimal performance, which makes faster the load increasing of turbine.

As can be seen Fuzzy controller use from all capacity of intermediate valve when increasing load for increasing speed and reducing time, that system reach to equilibrium.

Also, in figure (11) Position of control valves during change load is shown.

Figure 10 - Changing load of 71 to 156 MW

Figure 11 - Status of control valves in change load of 71 to 156 MW

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In Figure (13) observes, that changes in frequency and load when the disturbance is 2 MW.
5 Conclusion
In this article for increase the ability turbine response to frequency and load changes and also prevent system instability in transient conditions, using two valves for control of turbine set has been proposed. It also proposed that the intermediate control valve acts while load changing and returns to open condition after reaching system to steady-state. Rapid response and eliminate disturbance of electrical is advantage of this proposed control systems in compared with conventional systems. Feasibility and effectiveness of proposed controller has been investigated using various simulation tests in operation range.

The results show that the proposed control system can considerably increase the set performance in terms of structure and used algorithms. These methods can also modify and replace the control structure of the power plants that are working.

6 References