A New Method For Controlling Boiler of Thermal Power Plant Using Fuzzy Logic

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Abstract: - This work presents a new method for controlling fuel and air fed boiler of thermal power plant using Fuzzy logic. The control strategy is based on supervisor level using Fuzzy logic that is required to determine automatically the optimal process set points of regulations level. Besides, this paper describes thermal power plant simulator developed by Matlab-Simulink.

Key-Words: - Thermal power plant, Boiler, Coordinated Control Mode, Optimal Controller, Fuzzy Logic.

1 Introduction

The number of construction of a new thermal power plant is relatively reduced. However, thermal power plants account for approximately 65% of the world's power supply. Recently, there have been concerns regarding the deterioration in the efficiency of existing thermal power plants. The efficiency of such type of power plant is very low and great amount of loss in thermal energy may be noticed [1]. In order to generate a required electric energy, the turbine needs an equivalent amount of thermal energy in addition to the loss. Minimizing the loss leads to a reduction of pollutants in the environment as well as production cost. Steam is merely a vehicle which transports the energy from the burners to the turbine shaft. The flow of steam is not only the parameter that should be determined, but also the temperature and pressure must be taken into consideration for a given value of power.

Nowadays, for improving the efficiency of the thermal plants, the control strategies with different hierarchical levels have been used. In the high levels, the control strategies are coordinated and the process set-points are determined. However, this work presents a new method of control strategy based on supervisor level that is required to determine automatically the optimal process set points of regulations level using Fuzzy logic. The supervisor level is based on an energy optimizer and considering the process operational constraints. Since combustion control in a utility boiler is one the most important control loops of power plant, for this reason the work focus has given to the boiler controllers.

2 A Simulator of Thermal Power Plant

2.1 Process Description

In a thermal power unit, steam is produced in boiler, is expanded in the prime mover (Turbine) and condensed before feeding it into the boiler again. The turbine shaft is coupled with alternator, which is used to produce electricity. The power plant can be divided into five main systems, namely a) Fuel and Ash system b) Air and Flue Gas system c) Fed water and steam system d) Condenser and e) Cooling water system. Schematic diagram of a typical thermal power plant is shown in the Fig.1. The feed-water is supplied to the drum, where the thermal energy of combustion products is transferred to the condensed water. Then, the feed-water passes through risers, where the furnace heat is used to increase the water temperature and eventually it causes the evaporation.

Thus, the circulation of the water and steam take place in the drum and risers. Steam generated in the risers is separated in the drum, from where it follows through the superheater to the high pressure turbine. Then, this steam is recycled to the boiler in the reheater where its energy content is increased.

2.2 Process Modeling

The main assumptions and equations of the thermal power plant components are presented [2-4].

The boiler equations are based on the following assumptions:

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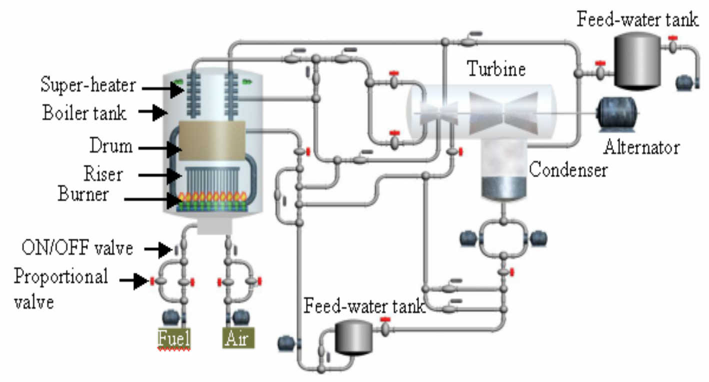

Fig.1 Schematic layout of a typical power plant.

-Polynomials approximations of steam tables are used to establish the relations between the steam parameters, such as the enthalpy, density, temperature and pressure.
- The superheated and the exhaust gases of the furnace are considered as ideals.
The following physical thermodynamic equations are satisfied.
Heat balance

$$Q_{in} + w_{in} h_{in} = w_{ou} h_{ou} + V \frac{d}{dt}(\rho_{ou} h_{ou}) \quad (1)$$

Where, Q_{in} is incoming heat flow, win inlet mass flow, h_{in} inlet specific enthalpy, w_{ou} outlet mass flow, h_{ou} outlet specific enthalpy.
Mass balance

$$w_{in} - w_{ou} = V \frac{d}{dt}(\rho_{ou}) \quad (2)$$

Then, the main equations of steam turbine are given by :
Mass balance for steam

$$w_i - w_o = V \frac{d}{dt}(\rho_o) \quad (3)$$

where, w_i is inlet steam flow, w_o outlet steam flow,
Heat balance for steam

$$w_i h_i + w_o h_o = V \frac{d}{dt}(\rho_o h_o) \quad (4)$$

Where h_i inlet steam specific enthalpy and h_o is outlet steam specific enthalpy.

3 A Proposed Control Strategy

The most modern thermal generation plants use a control scheme that is usually named an integrated or coordinated control system. This type of controller simultaneously adjusts firing rate, pumping rate, and turbine throttling in order to follow changes in load demand. Such a coordinated control mode is shown in Fig.2. In this type of control, both pressure and generated output are fed back for the control of both boiler and turbine. In this manner, it is possible to achieve the stable and smooth load changes of the turbine-following mode and still enjoy the prompt response of the boiler-following mode. This is accomplished by making maximum use of the available thermal storage in the boiler. Both pumping and firing rates are made proportional to the generation error so that these efforts are stabilized as the load approaches the required value. Pressure deviation is controlled as a function of the thermal storage and the generation error.
Nowadays, the control strategies for the thermal plant is organized using different hierarchical levels. In the high levels, the control strategies are coordinated and the process set-points are determined. The proposed controller is based on supervisor level that is required to determine automatically the optimal process set points of regulations level using an economic optimizer and considering the process environmental and operational constraints. After that the supervisor level makes correction continuously through the use of Fuzzy logic to the existing conventional regulations.

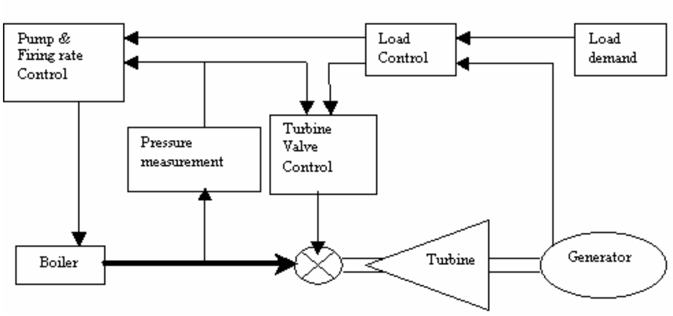

Fig.2 Coordinate control mode.

3.1 Implementation using Matlab/Simulink

Simulator has been developed for steam turbine generator using the powerful software program Matlab/Simulink. It includes one boiler steam turbine and generator as shown in Fig.3. Parameters that have been used for testing this simulator have been taken from steam turbine generator (SIEMENS-KWU-SGP) of 176 MW manufactured by consortium of Austria-Germane. The used conventional controllers which are simples in structure, are not suitable for non-linear, higher order, time delayed and complex systems that have no precise mathematical models. Besides, these controllers need frequent tuning that is not easy task and is also time consuming.
Several methods have recently been developed, most of them are based on controllers with fuzzy system without incorporating any on line adaptive structure and its applications particularly for combustion control of boiler.

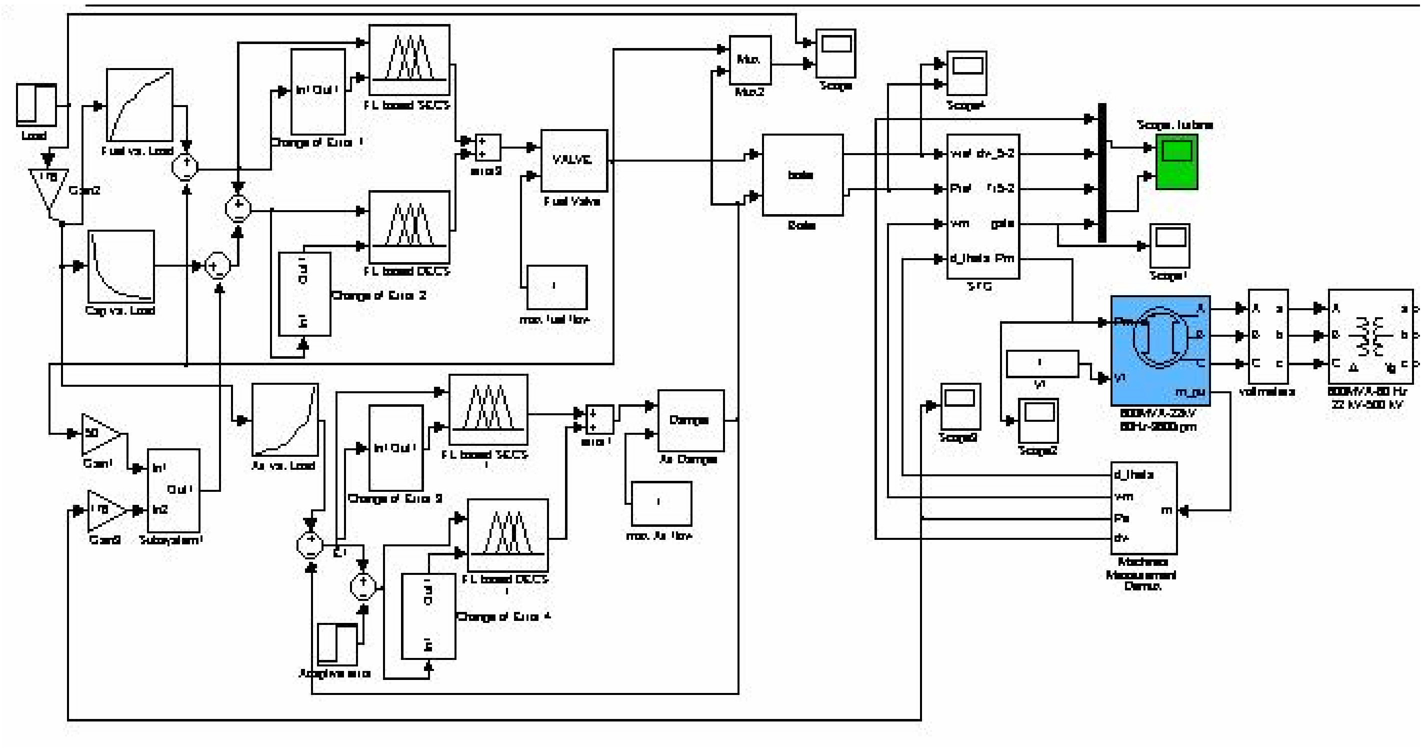

Fig.3 Complete system of power plant using Simulink.

Fuzzy systems, as an artificial intelligence approach, emerge in power plant as a complement to mathematical approaches. For a comprehensive survey of fuzzy set theory in power plants, the reader is referred to book[6]. Fuzzy-logic controllers (FLC) can be classified as knowledge based systems (KBS). There are principally two classes of KBSs; namely: supervisory expert control systems (SECS) and direct expert control system (DECS) [6,7]. SECS's use FL to tune the controller in the main loop.

3.2 Fuel and Air Controller Using Fuzzy Logic

The proposed fuzzy control for fuel and air control system is shown in Fig.3. The characteristics of thermal power plant (SIEMENS-KWU-SGP) have been used which are shown in two response graphs, one gives load as function of fuel and the other load versus airflow. The fuel and the airflow set points can be derived from the graphs in our simulator from these characteristics. The difference between the set point and the actual air or gas flow is computed as error signal.

The proposed DECS implemented for combustion process using fuzzy logic control has two inputs and one output for fuel and airflow respectively. The inputs are error signal and change in error signal. The universe of discourse of the controller variables are e, Δe and U respectively. The following are the range of database considered. Error (e) =-50% to +50%, Δe = -25% to +25%, control valve position (U)=10% to 100%. The number of linguistic terms for each linguistic variable is 5. (e) for fuel = {MN, N, Z, P, MP}, (Δe) for fuel = {VS,S,M,L,VL}, (U) for fuel ={VS, S,M,L,VL}, (e) for air = {MN, N,Z,P,MP}, (Δe) for air = {VS,S,M,L,VL}, (U) for air = {VS,S,M,L,VL}.

The triangular membership functions are used to represent the linguistic terms. (VS=very small, S=small, M=medium, L=large, VL=very large, MN=medium negative, N=negative, Z=zero, P=positive, MP=medium positive).

The processed signal from the fuzzy controller is defuzzyfied and applied to the respective adder circuit.

In the proposed FLC based SECS, the difference between feed-forward error and the adaptive error. The error and the change of the error are taken as inputs of the proposed SECS controller. The processed signal is defuzzyfied and applied to the respective adder circuit. The sum of the DECS and SECS output signal is supplied to the fuel control valve as well as the air damper.

3.3 Adaptive Error Factor

To improve the performance, an adaptive variable error set point has been developed to the SECS controller for fuel and air flow. When there is dynamic change due to load demand change the adaptive error calculation is proposed by taking into consideration the difference between the actual specific heat consumption and the required one. An adaptive error, which is equivalent to the required (adaptive) at particular load, is calculated as follows:

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$$e_a = C_{sp} - (k_c \frac{Q_f}{P_g}) \quad (5)$$

where, kc is constant (in this case 9.6), Pg generated power, and Csp specific heat consumption set-point determined from the characteristic of the power plant.

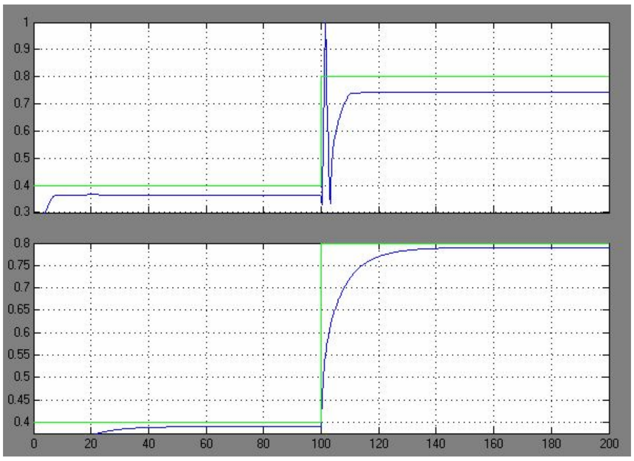

Fig.4 Fuel flow Controller response for positive step change in Load, (a) Upper without optimizer, (b) Lower with Optimizer.

4 Simulation Results and Discussion

The simulator based on the previous equations plus others non described in the paper [2] has been implemented as shown in Fig.3. This paper presents the simulation results that have been carried out on the combustion control of the boiler as shown in Fig.4. The control objective is to regulate fuel and air flow in proper ratio by including optimization and environmental criteria. The performance of SECS controller is demonstrated for positive changes in the load demand. The closed loop response of the proposed SECS controller scheme (Fig.4) shows satisfactory offset in the steady state output for optimizing the fuel consumption when compared to conventional controller without optimizer. Moreover, there is less oscillation in controller output.

5 Conclusion

This work presents a steam power plant simulator using Matlab-Simulink. Also the boiler evaluation tests are described in more details. After that, the thermal power plant control strategy design has been presented. It includes the supervisor level SECS control system based on adaptive error factor to correct the regulations level set points.

Work has performed on the test implementation by simulation of the proposed strategy controller. Then, this control system may be implemented in a real thermal power plant that is situated in Cap-Djenet, Algeria.

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Nomenclature

A	area, m2
C	specific heat, J/kg°C
h	specific enthalpy, W/m2°C
Q	heat flow, ppm
P	Power, W
V	volume, m3
w	mass flow, ppm
Greek Letters	
ρ	specific density, kg/m3

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