FUZZY BASED CO-GENERATION POWER PLANT OPTIMIZATION MODEL FOR SUGAR INDUSTRY

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ABSTRACT

The sugar manufacture process has wide variety of applications for a co-generation plant. The generated steam is used for Fuzzy Controlled power generation process. In a Sugar industry, Co-generation plant is the concept of producing two forms of energy from same fuel. One form of energy is heat and other may be electrical or mechanical energy. The objective of the paper is development of fuzzy controlled MATLAB simulink model. By monitoring and controlling different parameters, we can optimize system performance. Here we use operator experienced knowledge and field test in developing fuzzy model.

Keywords – Fuzzy Logic Model, Optimization, Power generation plant, Control System etc.

INTRODUCTION

India is currently the largest (10% of the world production) producer of cane sugar in the world. The private sectors aim for electric power co-generation that is reliable, reasonable and sustainable. The process of sugar manufacture has plenty scope for a co-generation plant. Sugar manufacturing plant investing in co-generation plants will have the benefit of generating the power required for operating the plant during the peak season. In off-season, generated power can be sold to Government or Private Agencies. This offers the double benefit to the sugar industry. In a Sugar industry the co-generation plant provides two forms of energy from same bagasse fuel. One form of energy is heat and other may be electrical or mechanical energies. The renewable energy technologies are a clean source of energy that has a much lower environmental pollution impact than conventional energy technologies. In every agricultural industry the largest byproduct is the biomass waste, which can be utilized for heat and power generation, thereby providing access to the modern energy services. Bagasse that is available after the crushing of sugarcane can be used in the boilers, for
generation of steam. The generated steam can be fed to the turbine for power generation process and extractions taken from the turbine can be used for the variety of low temperature thermal processes.

Plant operated manually suffers from more losses, higher labour charge. For improved energy conservation Sangamesh Y. G. al [1] suggested to adopt automation to control for the entire co-generation. The rapidly changing markets for sugar and energy provide an excellent opportunity to develop innovative methods to optimize the cogenerated power from the sugar plants that can reduce the energy shortage faced by the country. There is good scope to apply Fuzzy Logic for boiler parameter control demonstrated by Un-Chul Moon al [2]. They have studied various responses of PID and Fuzzy Logic Control Techniques. The pressure response of boiler is important in predicting the behavior of power systems. F. P. de Mello et al [3] have compared the various characteristic responses of individual part in Power generation plant. Fuzzy logic is a form of many-valued logic or probabilistic logic. It deals with reasoning that is estimated rather than fixed and precise. As Compared to the conventional binary variables, the fuzzy variables may have a truth value that ranges in degree between 0 and 1. The Fuzzy logic has been extended to handle the concept of partial truth, wherever the truth value may range between completely true and completely false. When linguistic variables are used, these degrees may be managed by exact functions. Fuzzy logic is the logic on which fuzzy control is based, is much close spirit of human thinking and natural language than traditional logical system. The FLC (Fuzzy Logic Control) is a set of linguistic control rules linked by the dual control concept of fuzzy implication and compositional rule of inference. The FLC provides an algorithm which can convert the linguistic control strategy based on expert knowledge into an automatic control strategy. Chuen Chien Lee et al [4] have discussed on Fuzzification, Defuzzification and fuzzy implication methods.

Figure 1: Model design of the controlling of energy generation plant in Sugar Industry
In a sugar industry boiler generates the high temperature steam inside a set of pipes. The pressurized steam reaches to the turbine to rotate mechanically. The output steam from the turbine is cooled down in the condenser and re-circulated to the water steam circuit. By rotation of the turbine mechanism of generator generating the Electricity and transmitted through power lines.

The Fuzzy Based Energy Generation plant model shown in Figure-1 is the controlling and monitoring system of various parameters. The simulation model is divided into five sections such as B oiler, Super Heater, High Pressure Turbine (HPT), Condenser and Water Tank.

A) Boiler

Boiler forms the main unit of sugar industry, which generates the steam. The steam so generated has two uses - one that is used for sugar manufacturing process and remaining being utilized in co-energy generation process. The heat generation process of a boiler depends on three input parameters viz. the Fuel, Air and Water. These parameters are used to control the generation of steam. The ratio of fuel, Air and Water are proportionally changed and as specified by 1: 3.8:1.9.

![Figure 2: FLC Module boiler](image)

The Fuzzy based model development, control and monitoring system are the one of the advanced technique for energy development plant in sugar industry. The Fuzzy Logic Control (FLC) Module and input parameter of Boiler are shown in Figure 2. The controlled parameter and their empirical equations are described in equations (1-6).

I) Amount of Fuel (Bagasse)

Fuel that is available after the crushing of sugarcane is used as fuel. A unit of the Fuel flow is Tone Per Hour (TPH), and equation of the required fuel is shown by equation (1).

\[ Q_F = \left( P_F - 0.09 G_S \right) \left( \frac{1}{35^2 + 45 + 1} \right) \]  \hspace{1cm} (1)

where

\[ Q_F=\text{Required Amount of Fuel}, \quad P_F=\text{Present Amount of Fuel} \]
\[ G_S=\text{Generated Steam flow} \]

II) Air

For better control of air flow ratio, combustion air flow is important and to achieve the field tests are carried out at various boiler loads, fuel flow measurement and measurement of percent of excess air by the gas analysis and the combustion equation is used to determine air
flow. Since we are concerned with relative measurement with respect to the amount of fuel, the air flow measurement is normally calibrated and presented on relative basis. The unit of air flow is Tone Per Hour (TPH). The equation (2) gives Air flow.

\[ Q_A = \left( P_A - 1.7G_s \right) \frac{5}{5s^2 + 4s + 1} \]  

\( Q_A = \text{Required Air flow}, \ P_A = \text{Present Air flow} \)

III) Water

Amount of water is the third input parameter of the system and stored into the tank. The temperature of the tank water is below 70\(^0\) as well as the pH of water is maintained about 8.8 to 9.2. The unit of the Water flow is TPH and amount of water is given by equation (3).

\[ Q_W = \left( P_A - 0.692G_s \right) \frac{3.2}{3s^2 + 4s + 1} \]  

\( Q_W = \text{Required Water flow}, \ P_W = \text{Present Water flow} \)

B) Super Heater

Super Heater reheats steam to increase the temperature as well as the steam pressure. Boiler generates the steam but pressure and temperature of the steam are low, but required pressure and temperature of HPT is high. The solution of this problem is to use Super Heater. Super Heater generates high pressure and temperature of the steam. This type of steam is called as dry steam, which is suitable for turbine operation. The temperature and pressure difference between a boiler and the input of HPT corresponds to 7.7% and 1.22. The equation (4) gives the super heater pressure.

\[ S_P = 1.22 \left( P_F - 0.09G_s \right) \frac{1}{3s^2 + 4s + 1} \]  

\( S_P = \text{Super Heater Steam Pressure} \)

The equation of the temperature of super heater is,

\[ S_T = 7.7 \ S_P \]  

\( S_T = \text{Super Heater Steam Temperature} \)

C) High Pressure Turbine (HPT)

In HPT, the high pressure steam from the Super Heater passes through the nozzles. When the steam comes out through these nozzles the velocity of the steam increases relative to the rotating disc. The resulting reaction force of the steam on nozzle creates the rotating motion of the disc and the shaft. This drives the generator that generates electricity. The Fuzzy implemented HPT perform linearly than conventional process [8]. The output of HPT is low pressure and low temperature steam goes to the condenser.
D) Condenser

Output Steam temperature of the HPT is 150°C to 300°C. For water generation process necessary temperature is below 100°C. This requirement is fulfilled by fuzzy cooler (Condenser) model shown in figure1. The Condenser FLC is a single input and double output with Input Steam, Output Steam and Water as variables. This Fuzzy Logic Control Module calculates the water temperature and output water.

E) Water Tank

The Level of water tank depends on the required water in the boiler and re-circulated (output) water. The tank level is below 40% of the cutoff range. Loss of re-circulated water flow is about 5 to 10% of input water and also water pH in the tank is maintained around 8.2 to 9.2.

RESULT AND DISCUSSION

I) Boiler performance
The Fuzzy Controlled boiler is a heart of the steam generating plant, for steam generation process required amount of Fuel, Air and Water are controlled. The required air is the first parameter of Boiler. The Air varies linearly from zero to above 200, after 200 then it remains constant. The present reading is at 187 TPH shown by green color line. As Compared to fuel flow and water flow air overshoot time is large shown in figure-5a. Similarly Water flow varies from 0 to 113 TPH linearly, after 113 TPH it remains constant (colored in Red). The required fuel is about 52 TPH (blue line). The output parameter of boiler is Steam, It varies from zero to 112, after 112 TPH it remains constant (black line).

II) Super Heater Performance

![Super Heater Performance Graph](image)

**Figure 5:** (b) Graph for the Super heater performance

The Fuzzy Logically Controlled Super Heater heats the steam to a desired level. The temperature and pressure are interdependent parameter of super heater. The temperature and pressure increases with time and after10s it remains constant. The Super Heater present temperature is $487^0C$ and pressure is 63.3 kg/cm$^2$. Pressure displayed by red color line and temperature displayed by Violet color line as shown in figure (5b).

III) High Pressure Turbine Performance

![High Pressure Turbine Graph](image)

**Figure 5:** (c) Graph for the High Pressure Turbine (HPT)

The highly heated steam (Dry Steam) is given to the HPT. It is used to generate electric power. The energy generation process is directly proportional to the applied steam. The applied steam is about 110 to 113 TPH and generated current are 22 to 25 Amps, shown in fig (5c).
IV) Cooler Performance

![Graph for the Condenser Performance](image1)

**Figure 5:** (d) Graph for the Condenser Performance

The output steam of HPT is low pressure and its temperature is above 150°C but we should convert high temperature steam to low temperature water. The temperature of condenser output water is about 50 to 70°C indicated as a green color line. Applied steam displayed by red color line as shown in fig (5d).

![Graph for the Water Tank Performance](image2)

**Figure 5:** (e) Graph for the Water Tank Performance

V) Water Tank Performance

The water tank is used for the storage of water. The green color line indicates as required water flow (113TPH). The blue color line indicates output water flow of model and it 102 TPH and the red color line indicate the tank level. The level of the tank is above 40% of cut-off point the model generate pulse from one to zero, the pulse is indicated turquoise color line as shown in fig. (5e). 50% water level in the drum is maintained for cut-off point. Fig (5e) shows the zero level is the cut-off point.

The fuzzy based energy generation plant is more efficient than the traditional system. By monitoring and controlling different parameters, we can optimize system performance. We can avoid major damage of the power system. Bagasse is locally available for power generation, which is fully utilized without transmission and distribution loss. Also we can reduce the environmental pollution. The conventional controller design requires deep
understanding of the system, exact mathematical models and precise numerical values. The main feature of Fuzzy Logic Control is that a process can be controlled strategy, learn through experience can be expressed by set of rules, to describe the behavior of system using linguistic terms which has wide scope to utilize in sugar industrial process.

REFERENCES