STEAM TURBINE PID VELOCITY CONTROL ENHANCEMENT APPLYING FUZZY LOGIC

Alvaro José Rey Amaya, ajrey@unab.edu.co
Universidad Autónoma de Bucaramanga
Francisco Ochoa Abaunza, francisco.ochoa@gmail.com
Petrosantander

Abstract. *This paper presents an enhancement of a proportional-Integral-Derivative (PID) control, applied to manipulate the velocity of a speed control, by using Fuzzy logic. To compensate the responses of the classic controller to the different disturbances of the system, a Fuzzy inference engine was integrated at the Feedforward path, to calculate the current signal which will act against the negative effects over the system stability caused by changes in the boiler pressure and in the condenser refrigerant volume. After implementing this technique on the thermal system, the results showed that the errors between the desired velocity and the one obtained by the sensor were reduced compared to those obtained from the PID controller.*

Keywords: *Fuzzy Logic, Feed Forward Controllers, Steam Power Plant*

1. INTRODUCTION

In power systems is of main importance the control and stability of the rotor coupled to the generator. If the generator shaft slows down, the frequency of the generator decreases. In order to bring the steady state of the velocity back to its nominal value after given variations of the system, a control system is designed which acts on the steam admission valve of the turbine.

Some studies and experiments in power-plant control provides improved solutions by modifications of certain basic control structures that seems to be the core of the nowadays control systems [1–3]. It is of major importance to identify those critical and basic aspects and relevant interactions of the system dynamics (ex. Boiler Dynamics) [1, 4, 5]. The thermal system involved in this study has two inherent disturbances that affect the actual control system. These elements, the boiler ON-OFF pressure control and the irregular condenser refrigerant (water) flow, make the system speed response unsteady.

The ON-OFF control used to keep the boiler pressure between two values (not a steady value) is not suitable for the PID control performance. When the pressure is raised or diminished, the controlled variable (turbine velocity) moves away from its set point value as a consequence. The same happens with water stream running into the condenser. It is not constant and a variation on its volume induces to a variation in the speed of the rotor. This happens because an irregular refrigerant flux causes variations in condenser pressure. Although this system is a multivariable nature process (consisting entirely of independent control loops) [1], There was not designed a control strategy consisting in sub loops (ex. water flux control, continuous boiler pressure control), because one of the purposes was to prove the effectiveness of the Feedforward control under these main disturbances. to manage these and other types of difficulties in industrial control (time lags, nonlinearities, multiple disturbances), some authors have suggested some strategies such as predictive [6], adaptive [7, 8],supervisory and intelligent control techniques, like neural networks or Fuzzy systems [10, 11].

The technique followed in this project implements Fuzzy reasoning, where a Fuzzy inference engine receives the disturbances signals (acting like a supervisor). Acts and sends to the control valve a compensation current according to the changes in the system conditions. Even though the classic control designed works reasonably well, and its several known advantages, like simple implementation, regulation of industrial processes with several operating conditions and that they can assure reliability bases on possible stability studies [10]. We aim to the improvement of its behaviour.

2. THE PLANT

In general, thermal plants use the energy of heat to make electricity. Water is heated in a boiler until it becomes steam. This steam is then lead through a turbine, which has many fan-blades attached to a shaft. As the steam moves over the blades, it causes the shaft to spin. This spinning shaft is connected to the rotor of a generator, and the generator produces electricity.

The plant in which this project was developed uses the energy of natural gas combustion to produce the steam, that goes through a pipe to the axial turbine, at its saturation temperature, for the boiler operating pressure. Once the low energy liquid steam mixture leaves the turbine, it enters to the condenser that is fed with water at the environment temperature.

After the condenser outlet it is a pump that carries the condensate to the boiler.

The manipulated variable in the plant is the current that moves the control valve, and the main goal is to maintain the

Figure 1. Control valve, turbine and condenser (bottom) setting.

velocity of the turbine in a desired value. The main disturbances are the changes in boiler pressure and in the water stream of the condenser.

There is a special characteristic of the plant in study. It has to be with the assembly of the control valve. It is placed far away of the turbine inlet rather than the commonly set ups that are seen in other power-plants. The latter was made on purpose, to add a significant time lag to the process.

This time, added with the delay that the actuator has, (after the controller sends the signal to it, and before it starts to operate) is a significant difficulty to the control system. Perhaps the most difficult dynamic element [12] to deal with.

3. THE PID CONTROLLER

Due to the wide applications that the PID controllers have had over decades and the flexibility and good results shown in numerous stability challenges [13], the PID controller was seen as the first approach in seeking turbine velocity stability.

$$u(t) = K_p e(t) + \frac{K_p}{T_i} \int_0^t e(\tau) d\tau + K_p T_d \frac{de(t)}{dt}$$

The method used to tune the PID control was the open loop Ziegler-Nichols yielding the following constants for a step input (change in the manipulated variable) in the valve of 3 mA.

$$\begin{aligned} K_c &= 1.4x10^{-5} \\ \tau_I &= 44 \\ \tau_D &= 15 \\ K_I &= 3.2x10^{-7} \\ K_D &= 2.1x10^{-4} \end{aligned}$$

4. THE FUZZY-PID CONTROLLER

This idea of supervisory system evaluates whether any change in the boiler pressure or in the refrigerant water of the condenser occurs and can cause deviation from the desired performance. It calculates an action and executes it.

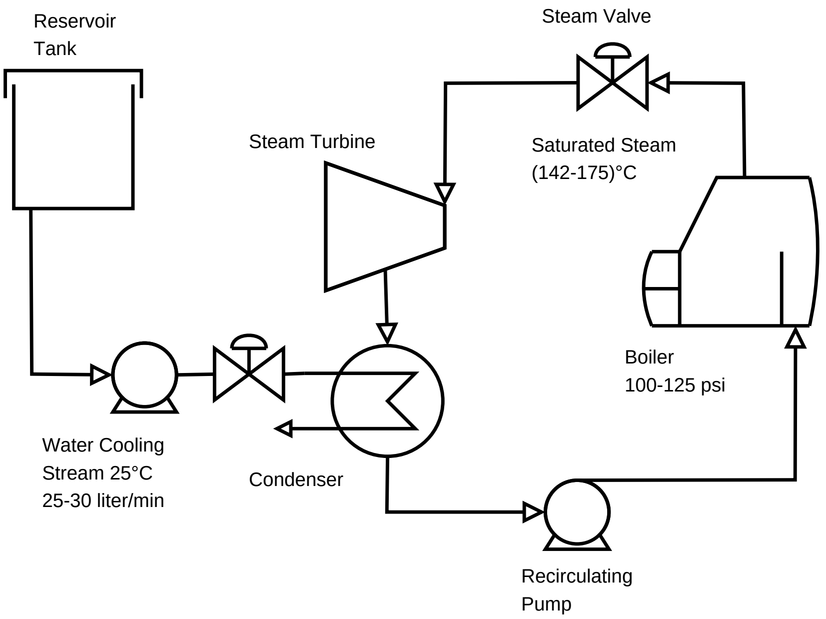

Figure 2. A schematic diagram of the thermal plant.

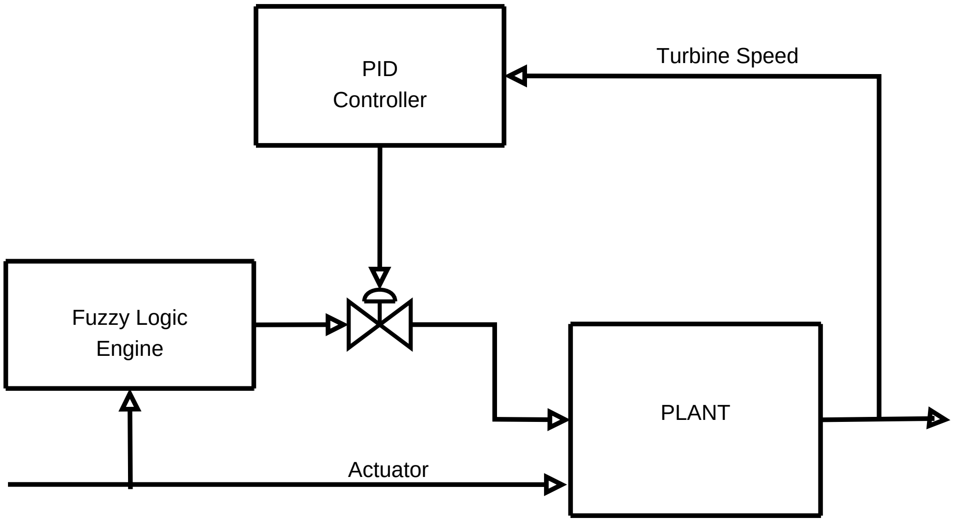

Figure 3. The FUZZY-PID scheme.

4.1 THE FUZZY INFERENCE SCHEME

An intuitive and reliable method, based on the knowledge and experimentation of the authors [6, 14], is used to derive the subsets, for the linguistic variables the same as for the rules. This heuristic approach for the design of control strategies for automatic process control is useful [13] and is the base of the Fuzzy Logic.

The Fuzzy engine designed for this application has two input sets (change in boiler temperature and change in refrigerant water volume of the condenser) and 1 output set (compensation current). Each set in the input is divided into 3 subsets identified with the following linguistic terms:

$$\begin{aligned} N &\rightarrow Negative \\ Z &\rightarrow Zero \\ P &\rightarrow Positive \end{aligned}$$

For the output set, there are 3 subsets defined:

$$\begin{aligned} C &\rightarrow Close \\ NO &\rightarrow No\,Operation \\ O &\rightarrow Open \end{aligned}$$

The Fuzzy engine receives both numerical signals, ΔT_p and ΔV_w . Then comes the fuzzification stage where the two values are converted into linguistic terms (N, Z, P).

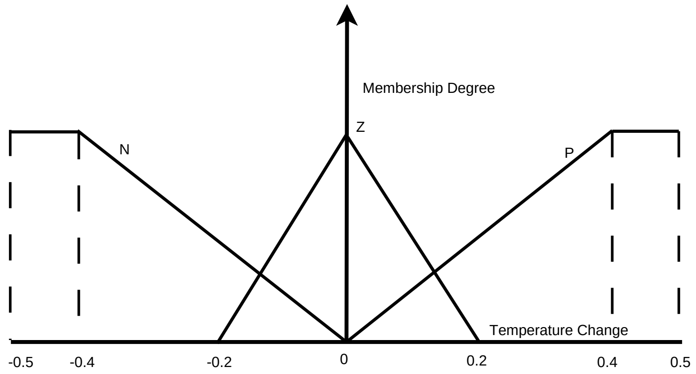

Figure 4. Boiler Temperature Delta Set

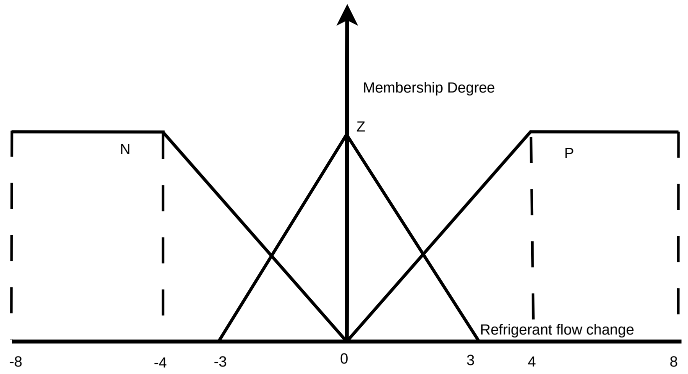

Figure 5. Condenser Refrigerant Delta Set

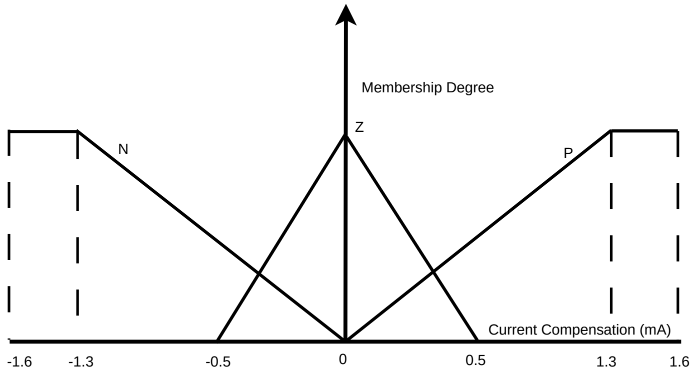

Figure 6. Current Compensation Delta Set

Inside the engine there is a previously defined matrix of rules that is in charge of choosing which subsets of the output set will act depending on the rules that have been fired.

A Mamdami Fuzzy system was developed and it has a set of rules $R^{(l)}$ with the format:
$R^{(1)}$: IF x_1 is F_1^1 and ...and x_n is F_n^1 THEN y is G^1
Where: F_n^1 and G^1 are Fuzzy sets.
The rules that describe the supervisor are included in Table 1.

Table 1. Rule Matrix

T_p Boiler Temperature Delta

ΔV_w Condenser refrigerant Delta

V_w \ T_p	N	Z	P
N	C	C	NO
Z	C	NO	O
P	NO	O	O

The deffuzification is where the final value to be sent to the valve is defined according to the any of the existing methods. In this work it was used COA (Center of Area) because it is the most used [15] and good results does not depend on the deffuzification method [16].

$$y = \frac{\sum_{l=1}^{M} y^{-l}(\mu_{B^l}(y^{-l}))}{\sum_{l=1}^{M}(\mu_{B^l}(y^{-l}))}$$

where y^{-l} represents the center of the set G^l (defined as the place where $\mu_{G^l}(y)$ reaches its maximum value), and the term $\mu_{B^l}(x)$ is calculated using the rules of the minimum (the minimum value of the 2 input values is chosen).

4.2 THE SUPERVISORY CONTROL

As we can show the controller where a disturbance is starting to act, it makes senses to use this knowledge in the design of a Feedforward controller in order to enhance the performance of the existing close loop system. The total current sent to the valve each time the controller reads all the variables and calculates its output is:

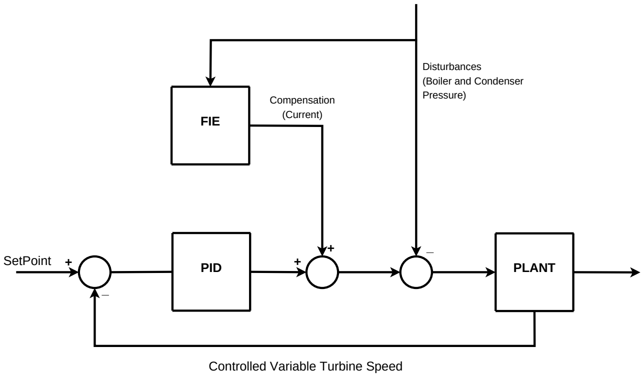

Figure 7. Controller Block Diagram

$$I = I_{FLE} + I_{PID}$$

5. RESULTS

The experimental results shown here, were taken during the tests that were carried out in the Planta Piloto Thermal Circuit of the Universidad Autónoma de Bucaramanga, on 18th of July, 2006. The controller was implemented in National Instruments LabWindows CVI in ANSI C code. During the experiment the sampling time was 4 seconds. The effectiveness of the controller was tested establishing a desired Set Point of 800 r.p.m. in the Steam Turbine velocity.

5.1 THE PID CONTROLLER

Here, the proposed PID controller is able to perform well around the Set Point even with continuous conditions variations in the Boiler Temperature and in the refrigerant flux shown in figures 4 and 5.
After the controlled variable reaches the Set Point its maximum peak over the desired value, is of 840 r.p.m and the minimum of 765 r.pm giving an error of 5% and 4.4% over and under the Set Point respectively.

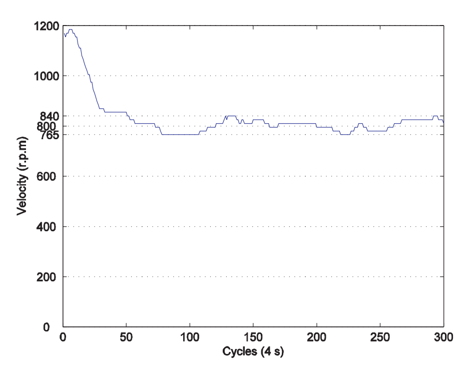

Figure 8. PID Controller Respond

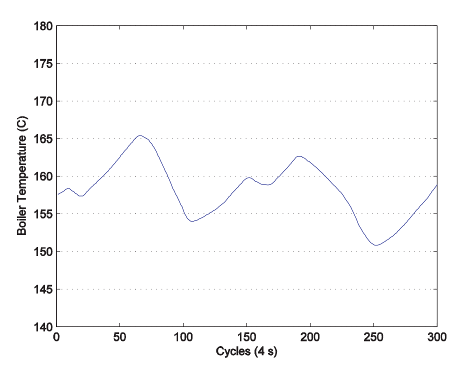

Figure 9. Boiler Temperature Gradient

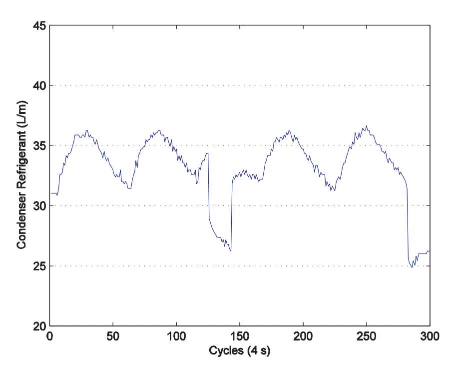

Figure 10. Condenser Volumetric Flow Transient

5.2 THE FUZZY-PID FEED FORWARD CONTROLLER

The Fuzzy-PID shows as it was expected, an improvement to the controller presented before. With significant disturbances exhibited in figures 12 and 13 it can be seen in figure 11 that the peaks do not exceed 3% and 2.5% over and under the Set Point respectively.

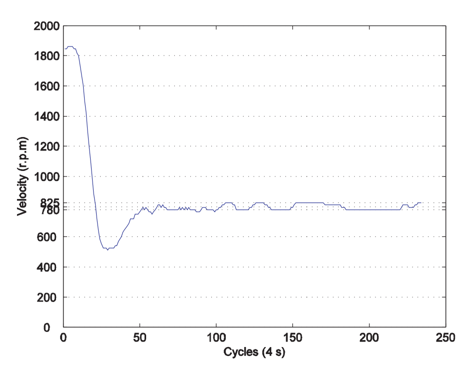

Figure 11. The Fuzzy-PID Feed Forward Controller Respond

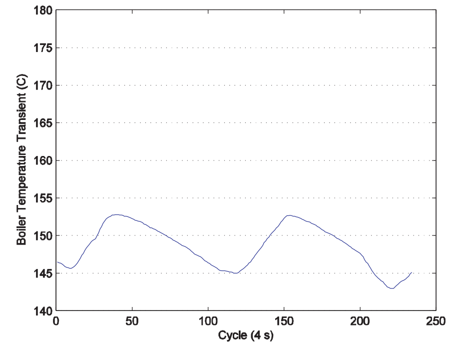

Figure 12. Boiler Temperature Gradient

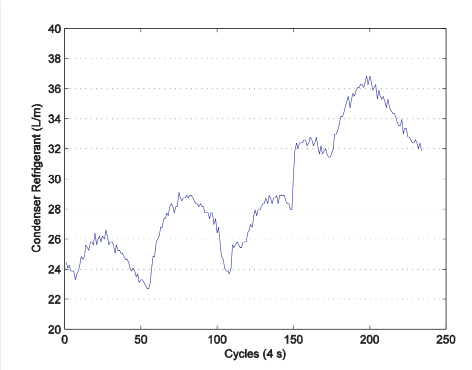

Figure 13. Condenser Volumetric Flow Transient

6. CONCLUSION

A Fuzzy supervisor strategy along with a PID controller, using the inherent disturbances of the system was applied to the Thermal Circuit of the Planta Piloto.
The process is characterized by different operating conditions as continuous boiler temperature and condenser refrigerant flux changes plus a significant time lag. The way of how these elements affect the steam turbine velocity were studied previously, aiming a good knowledge of plant behavior and a correct definition of the Fuzzy Inference Engine parameters. Experimental results showed the effectiveness of both controllers separately and the improvement of the classical con-

troller has been achieved.

7. ACKNOWLEDGEMENTS

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