

# MODELING AND CONTROLLER DESIGN FOR THE VVS-400 PILOT SCALE HEATING AND VENTILATION SYSTEM

**M.F. Rahmat , N.A. Mohd Subha, Kashif M.Ishaq and N. Abdul Wahab**

Department of Control and Instrumentation Engineering  
Faculty of Electrical Engineering, University Teknologi Malaysia  
Skudai, 81310, Johor, Malaysia

Emails: [fuaad@fke.utm.my](mailto:fuaad@fke.utm.my), [adilla@fke.utm.my](mailto:adilla@fke.utm.my), [kashif9744@gmail.com](mailto:kashif9744@gmail.com), [aliza@fke.utm.my](mailto:aliza@fke.utm.my)

*Abstract- In this paper, a heating and ventilation model VVS-400 from Instrutek, Larvik, Norway is modeled using ARX model structure and linear black-box technique. The conventional PID controller and artificial Fuzzy controller are designed based on the approximated plant model and real plant model. The approximated plant model is estimated using System Identification approach while the real plant model is developed by interfacing the Real-time Windows Target toolbox in Matlab with real VVS-plant by using data acquisition (DAQ) card PCI-1711. An artificial Fuzzy controller approach is incorporated in two ways which are conventional Fuzzy logic controller (FLC) and a replacement of conventional fuzzy controller known as Single input fuzzy logic controller (SIFLC). Simulations and experiment validate the equivalency of both controllers. Results reveal that SIFLC found to be better than FLC due to its less computation time compared to conventional FLC.*

**Index terms:** System identification, estimation, ventilation, VVS-400, Autoregressive with exogenous input (ARX), PID, Fuzzy logic controller, Single input fuzzy logic controller

## I. INTRODUCTION

The heating and ventilating system is a common process in our daily life where certain desired temperature is controlled. In industries such as pharmaceutical, ability to control temperature is crucial to ensure the quality of the product always within control. However, most of heating and ventilation plants are complex with higher-order systems, which leads to unsatisfactory performance.

Therefore, in the recent years, there are many emerging control strategy approaches for controller's design of heating and ventilation systems such as robust PID controller [1], fuzzy



Matlab simulation (Section IV) and online implementation using Real-time Windows Target toolbox (Section V). Finally, discussion and conclusion are drawn.

## II. SYSTEM DESCRIPTION OF THE VVS-400

In this study, VVS-400 is used as a model system. The VVS-400 plant is a pilot scale of heating and ventilation system developed by Instrutek A/S, Larvik, Norway [10]. The schematic diagram of this system is shown in Figure 1. This plant can operate in three different modes: 1) Temperature control, 2) Flow control and 3) Cascade control. In this paper, only temperature control is studied (constant air flow rate). This model consists of a fan and heating element which is controlled by TRIAC. The fan blows air through the flow tube over the heating element. The temperature sensor, RTD platinum is located at the end of the tube. This plant model is also equipped by two independent local PID controllers to control the temperature and flow processes. However, in this study, local PID controller for temperature will be set as “off mode” which creates an open loop system for temperature while the air flow rate is fixed to a certain number and controlled by flow local PID controller.

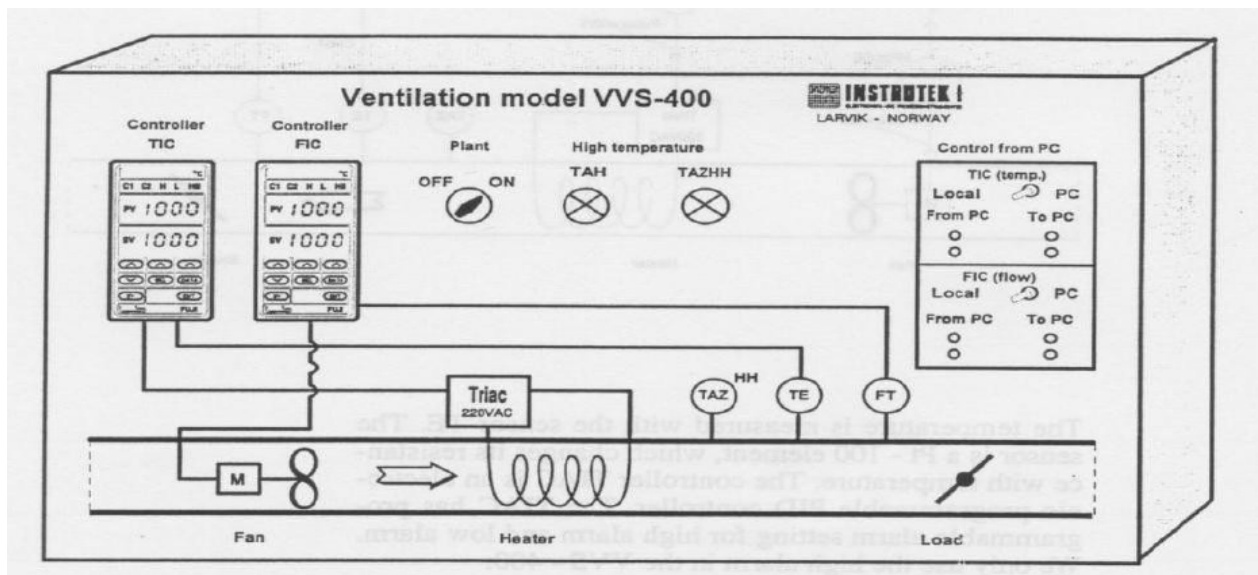


Figure 1: Schematic diagram of the VVS-400 heating and ventilation model



From Figure 2, it can be noted that

$$\text{Temperature}(\text{°C}) \propto K \times \text{Voltage}(\text{V}) \quad (1)$$

$$K = \text{constant} = \text{gradient} = 20$$

Hence,

$$\text{Temperature}(\text{°C}) = 20 \times \text{Voltage}(\text{V})$$

$$T_i = 20V_i \quad (2)$$

where  $i = \text{nth data}$

Therefore, process output must be multiplied with constant 20, since the output from the approximated plant and data acquisition (DAQ) card is in voltage. Temperature process study of VVS-400 plant has been conducted in [11] which reveal the temperature process is continuously nonlinear.

### III. PROCESS MODEL IDENTIFICATION EXPERIMENT

Initially, system model must be determined before control technique is applied. The system modeling part is the most challenging and vital part in designing the control system of VVS-400 due to its large time constant and slow process response [8]. In order to obtain a particular model for this system, the open loop identification experiment has been done using parametric approach. In this experiment, a system model is identified using data collected when the Pseudo Random Binary Sequence (PRBS) is perturbed into the system as can be seen in Figure 3. From Figure 3, there are 2297 samples of data with 2 seconds sampling interval. The PRBS input is generated in Matlab. The collection of data was performed by PCI-1711 interface card. The input-output data is then be analyzed by System Identification toolbox in Matlab [12].



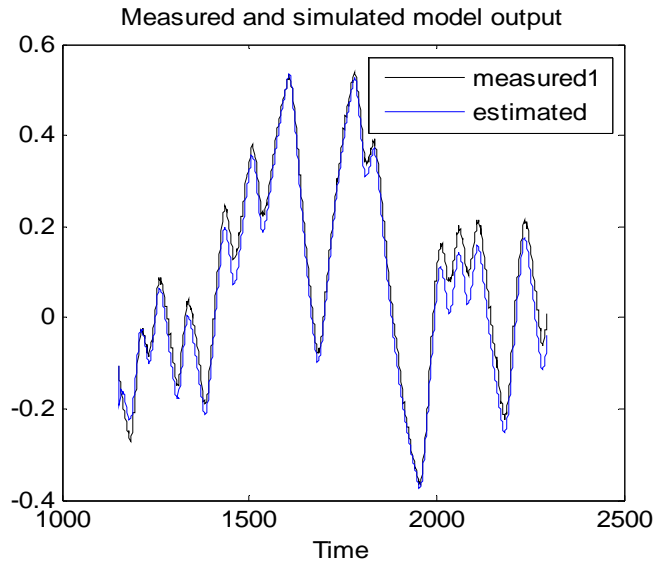


Figure 4: Measured and simulated model output

Then, Loss function = 0.0000123078 and Akaike's Final Prediction Error (FPE) = 0.000012567. Therefore, the pilot scale heating and ventilation VVS-400 plant can be approximated modeled by this following equation

$$\frac{B(q)}{A(q)} = \frac{0.0002502q^{-3} + 0.0008348q^{-4} + 0.0003908q^{-5} + 0.0003052q^{-6} + 0.0006835q^{-7} + 0.000266q^{-8}}{1 - 0.4776q^{-1} - 0.441q^{-2} - 0.774q^{-3} + 0.4322q^{-4} + 0.1352q^{-5} + 0.1308q^{-6}} \quad (6)$$

Hence, based on this approximated plant model, conventional PID and artificial Fuzzy logic controller will be designed to perform the closed loop system simulation. The approximated plant gives a higher order model where an excess model order is usually represent the noise. Since the ARX model incorporate with noise in the system model, the model might be influenced by this noise [13].

Next, by observing the pole-zero plot of the model, there is one zero outside the unit circle of the z-domain as shown in Figure 5. This specific zero is called non-minimum phase model. For a non-minimum phase process the converse is true, a non-minimum phase pole will tend to cause a +90° phase shift, and a non-minimum phase zero will tend to cause a -90° phase shift. Since the system is assumed to be stable, all the poles will have negative real parts.





where  $u(k)$  is the control signal,  $e(k)$  is the error between the reference input and the process output and  $T_s$  is the sampling time for the controller.

However, finding an optimum adjustment for this system is not trivial. Fine tuning is required for an optimum result.

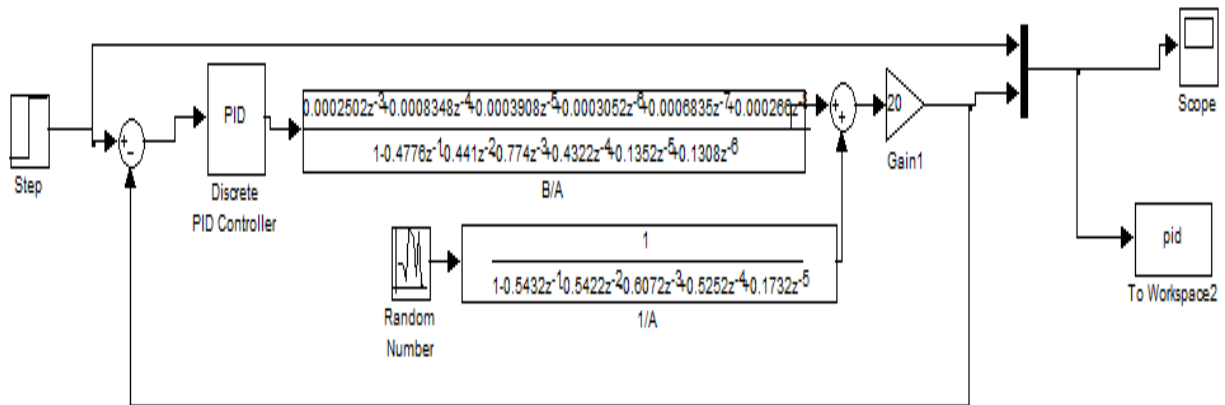


Figure 6: Simulink block diagram with PID controller

Figures 6 and 7 show the Simulink block diagram with PID controller and the process output, respectively. From Figure 7, the process output shows high overshoot with settling time is 100 seconds corresponding to step input reference. It can be seen that the response of this proposed controller is satisfactory.



Positive small, PM: Positive medium, and PL: Positive large as can be seen in Figure 9. The ranges of this membership function are -10 to 10.

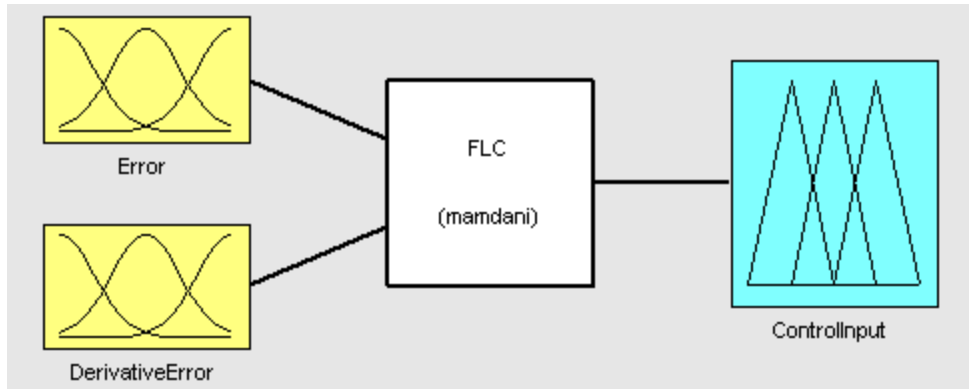


Figure 8: Fuzzy inference block

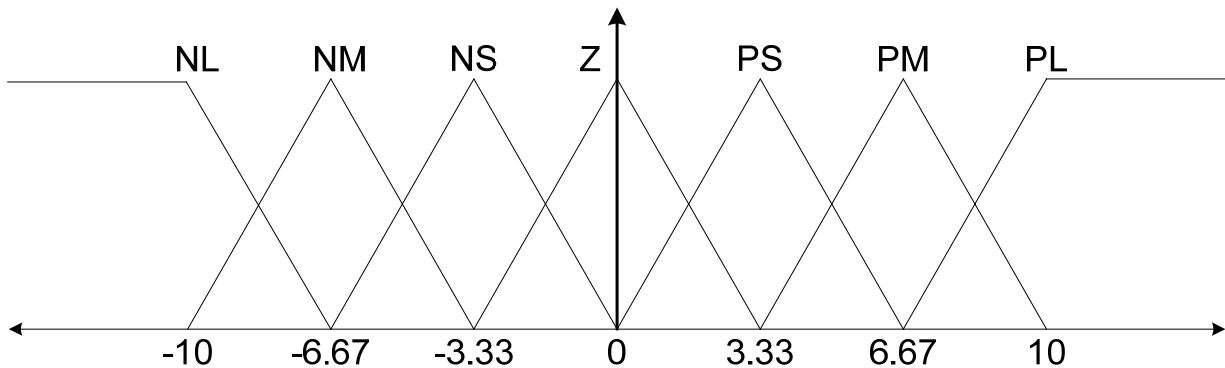


Figure 9: Membership function of error ( $e$ ), derivative of error ( $\dot{e}$ ) and control input,  $\Delta u$

Since we have 7 variables for each fuzzy input, it gives 49 fuzzy rules as illustrated in Table 2. The rules are written as;

IF error,  $e$  is PL AND derivative error,  $\dot{e}$  is NL, THEN control input,  $\Delta u$  is Z

Therefore, 49 fuzzy rules in Table 2 must be reads as mentioned and be performed in rule viewer of FIS editor in Fuzzy Matlab.



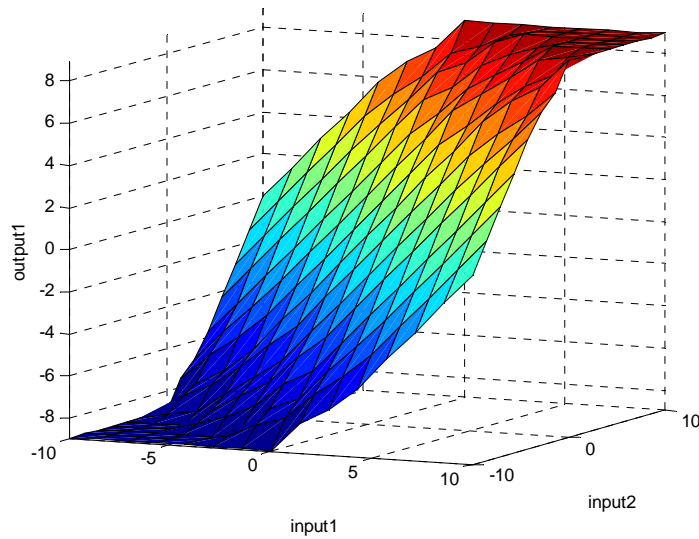


Figure 11: Linear control surface of Conventional FLC

The control surface of the conventional FLC is shown in Figure 11. This control surface represents the correlation between input and output in three-dimensional plot. From this figure, it is clear that conventional FLC behaves as linear controller.

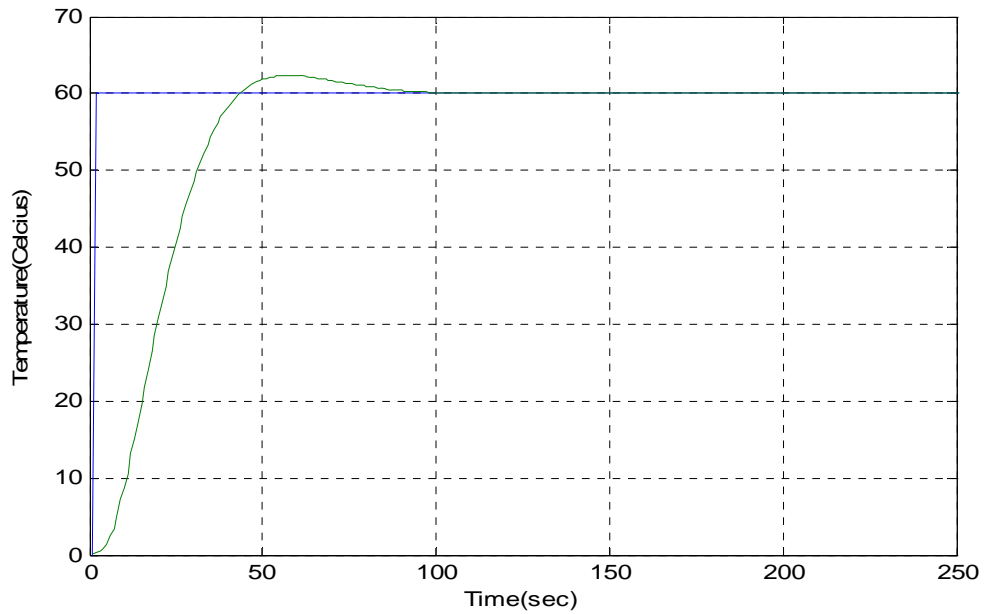


Figure 12: Temperature process response from simulation with conventional FLC



In order to obtain the distance,  $d$  value, the diagonal lines need to be calculated. The output of rule table for conventional FLC as shown in Table 2 can be represented in the constant number as follows

$$\begin{aligned} \dot{e} + \lambda e &= 0 \\ \dot{e} + e &= 0 \end{aligned} \tag{9}$$

Then, equation (9) will results seven diagonal lines correspond to seven input values that can be seen in Table 3. Therefore,  $d$  can have positive or negative values. The diagonal line that result “0” is called main diagonal line.

Table 3: The rule table with Toeplits structure

|                  |            |              |              |          |               |               |             |
|------------------|------------|--------------|--------------|----------|---------------|---------------|-------------|
| $e$<br>$\dot{e}$ | PL<br>“10” | PM<br>“6.67” | PS<br>“3.33” | Z<br>“0” | NS<br>“-3.33” | NM<br>“-6.67” | NL<br>“-10” |
| NL<br>“-10”      | 0          | -3.33        | -6.67        | -10      | -10           | -10           | -10         |
| NM<br>“-6.67”    | 3.33       | 0            | -3.33        | -6.67    | -10           | -10           | -10         |
| NS<br>“-3.33”    | 6.67       | 3.33         | 0            | -3.33    | -6.67         | -10           | -10         |
| Z<br>“0”         | 10         | 6.67         | 3.33         | 0        | -3.33         | -6.67         | -10         |
| PS<br>“3.33”     | 10         | 10           | 6.67         | 3.33     | 0             | -3.33         | -6.67       |
| PM<br>“6.67”     | 10         | 10           | 10           | 6.67     | 3.33          | 0             | -3.33       |
| PL<br>“10”       | 10         | 10           | 10           | 10       | 6.67          | 3.33          | 0           |

↙ Saturation region





FLC 95 seconds. This comparable performance is achieved by reducing the number of rules from 49 rules in FLC to 7 rules in SIFLC.

## V. CONTROLLER IMPLEMENTATION IN A REAL VVS-400 SYSTEM

In the previous section, three types of controller have been designed via simulation. However, it was not enough to ensure that all the design controllers are exactly capable to control the VVS-400 system model until it was implemented to perform an online control. This real system implementation is done using Real Time Windows Target (RTWT) toolbox in Matlab [17]. Two blocks called Analog Output and Analog Input from RTWT connect the Simulink Matlab to the VVS-400 plant using data acquisition (DAQ) card PCI-1711. The controller will respond to the online process with 2 seconds sampling interval. The output of the controller will be fed into the Analog Output and the process output is generated from the Analog Input. Since only voltage is applicable in this RTWT toolbox, the output from the Analog Output need to be converted into temperature by multiply with constant, 20 as given in the previous section. The simulink block diagram of the system with PID, conventional FLC and SIFLC controller are represented in Figure 15, 17, and 19, respectively. The system output with PID, conventional FLC and SIFLC controllers are shown in Figure 16, 18 and 20, respectively. However, to satisfy the output, tuning parameter requires a little adjustment since the simulation tuning parameter is designed based on the approximated plant.



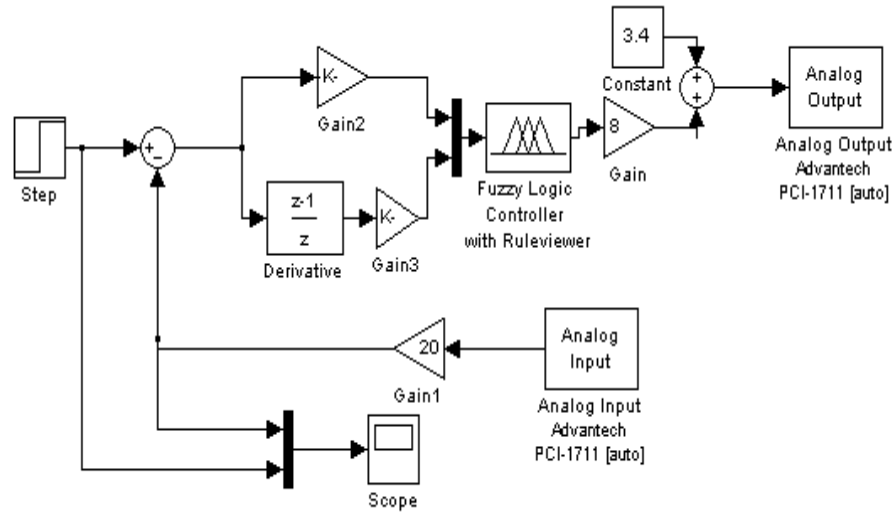


Figure 17: Simulink block diagram of real plant implementation with conventional FLC

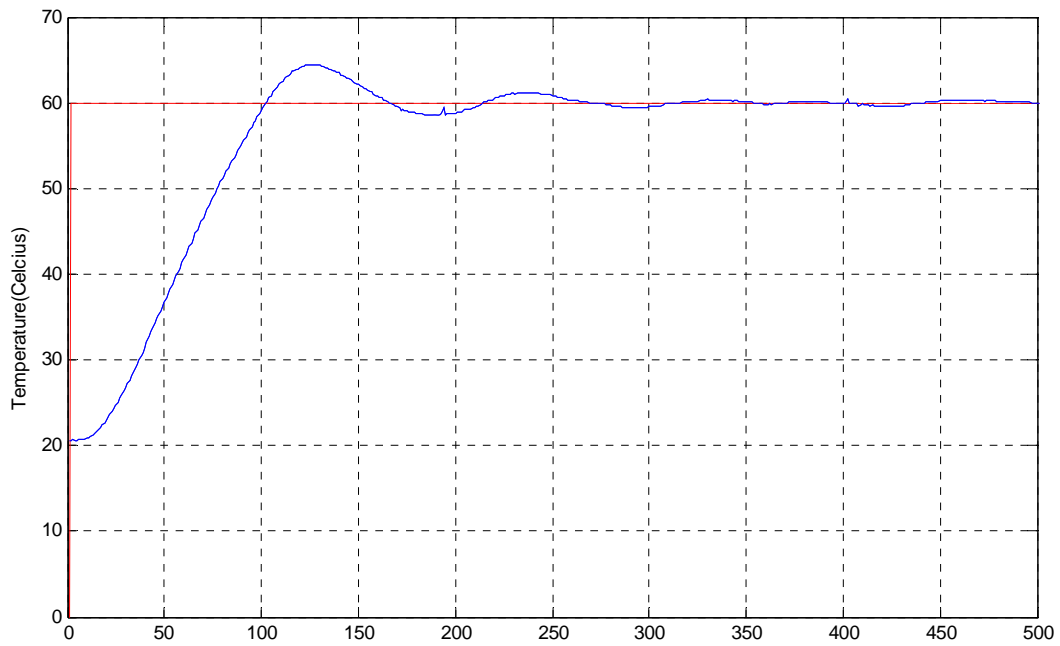


Figure 18: Temperature process response from experiment with conventional FLC



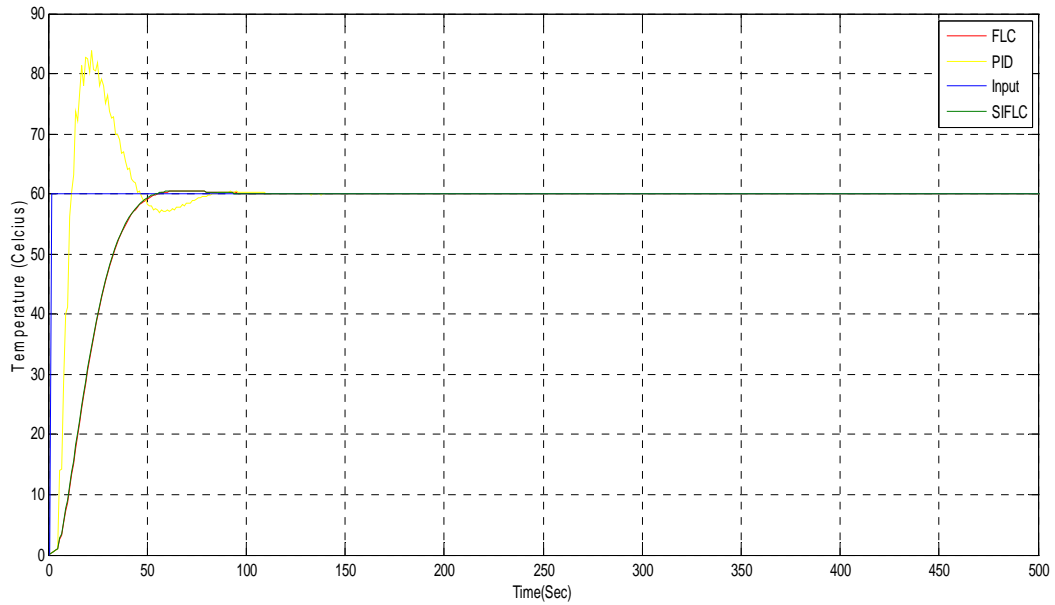


Figure 21: Temperature process response from simulation

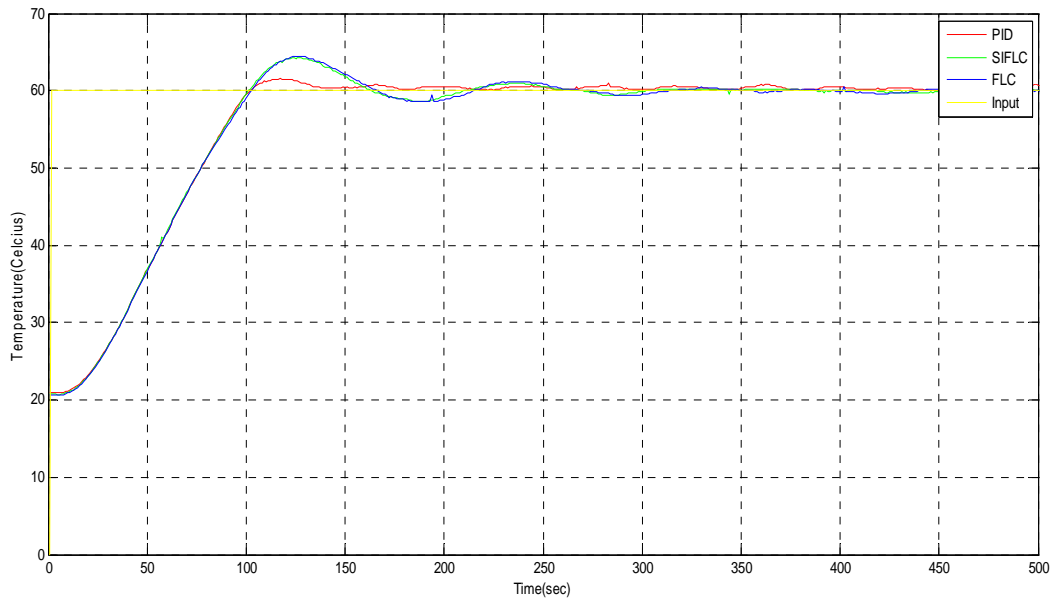


Figure 22: Temperature process response from real VVS-400 plant

The overall system outputs are shown in Figures 21 and 22. The PID controller gives high overshoot in the simulation result compare to FLC and SIFLC. In contrast, in the online



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