Constant Pressure Furnace Air System Control in Biomass Power Plant Using Adaptive Control Theory

Gowrishankar Kasilingam

Abstract- This paper outlines the importance of maintaining constant pressure in automated furnace air system using PLC. This work focuses the demand for high quality, greater efficiency and automated machines in this globalised world. This paper gives importance to the furnace air system, so as to make the inputs to the boiler suitable enough towards efficient functioning of the boiler and also maintaining constant required temperature in the boiler. And also the paper focuses pressure control for injecting fuel from bunker to air – box of the Furnace air system. On the basis of the constant-pressure principle and variable-frequency principle applied to traditional furnace air system, this paper presented the overall structure of furnace air system using PLC (programmable logic controller) as main controller, and newly used the switched adaptive control principle to optimize air supply. The systematic analysis was carried on by combining the system with its mathematical model. The simulation data using visual c++ confirms the system's rationality, stability and superiority. The automation is further enhanced by constant monitoring using SCADA screen, which is connected to the PLC by means of a communication cable. This paper has proved to be very efficient practically as the need for automation.

Keywords - Constant-Pressure Air Supply, Switched Adaptive Control, PLC.

I. Introduction

OVER the years the demand for high quality, greater efficiency and automated machines has increased in the industrial sector of power plants. Power plants require continuous monitoring and inspection at frequent intervals. There a possibilities of errors at measuring and various stages involved with human workers and also the lack of few features of microcontrollers. Thus this paper takes a sincere attempt to explain the advantages the companies will face by implementing automation and also supplying constant air pressure to the furnace air system in order to maintain desired temperature in the boiler.

In order to automate a power plant and minimize human intervention, there is a need to develop a **SCADA (Supervisory Control and Data Acquisition)** system that monitors the plant and helps reduce the errors caused by humans. While the SCADA is used to monitor the system, **PLC (Programmable Logic Controller)** is used for the internal storage of instruction for the implementing function such as logic, sequencing, timing, counting and arithmetic to control through digital or analog input/output modules and various types of machines processes.

Gowrishankar Kasilingam is with the AIMST University, faculty of Engineering & Computer Technology, Kedah Darul Aman , Malaysia.
(Corresponding Author e-mail:gowri200@yahoo.com).

The system is used to monitor and control a plant or equipment in industries such as telecommunications, water and waste control, energy, oil and gas refining and transportation.

Furnace air supply system needs to inject fuel frequently to the boiler to maintain constant temperature. Furnace Air - pressure system adjusts air pressure using closed air-pressure tank and its reliability is greatly affected by changes of air. Traditional constant-pressure air supply system has simple and reliable structure, but it can not meet the need of modern air supply. Therefore, air supply system of energy-efficiency, automation and reliability is in urgent need of development [1]. From comprehensive comparison of the above ways, this paper designed a furnace air system to maintain constant air pressure for injecting fuel from the bunker to the air-box with the help of switched adaptive control theory.

II. System Overview

As known to us all, air is delivered to furnace system through pipelines. The system using switched adaptive control algorithm can provide stable, efficient and reliable air supply.

2.1 Brief Introduction of the System

Air flows into the switched adaptive control system through pipelines and then will be delivered to furnace system with constant-pressure. The system can automatically adjust and switch operating parameters according to changes of air consumption depending upon the temperature maintenance in the boiler. Shown in **figure 1**, the system mainly consists of PLC control body and switched adaptive control body. PLC control body includes CPU (Central Processing Unit), pressure transmitters (Attached in every tap), converters, etc. The main theoretical basis is the combination of MRAC (Model Reference Adaptive Control) and SS (Switched System).

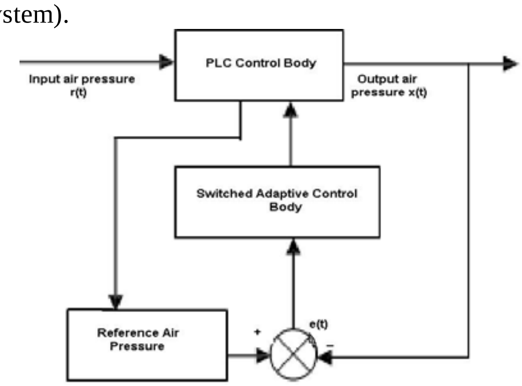


Fig.1. Block diagram of the system

2.2 Air Pre-Heater

The air required in the boilers for combustion is preheated in the pre-heaters by means of flue gases leaving the economizer and thus the heat in the outgoing gases is recovered. It has been found that a drop of 20 to 22°C in the gas temperature increases the boiler efficiency by about 1%. The Air pre-heater divides the air into two:

- Primary air
- Secondary air

Primary air used for burning the raw material. Secondary air is used to force the fuel on the duct from the bunker to the heating chamber. Heat transfer is maintained to reduce the heat loss.

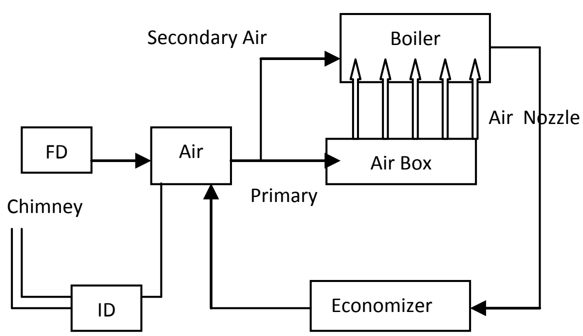


Figure2. Air Pre heater

2.3 Economizer

Economizer is one of such heat recovering devices, in which the temperature of feed water is raised by means of outgoing flue gases, before it is delivered to boiler drums. If an increase in feed water temperature by economizer is approximately 6°C, then the boiler efficiency is increases by 1%. High cost of fuel consumption, high load factor, high pressure and temperature conditions all justify the use of economizers. For pressure of 70 bar or more, the economizer becomes a necessity.

2.4 Structural Composition of PLC Control Body

PLC is core controller of the system. It sets reference air pressure (general air pressure *12psi*) through its internal programs. Reference pressure is compared with real-time ones monitored by pressure transmitter to get deviation. Then, based on the deviation and switched adaptive control algorithm, PLC gives appropriate instructions to converter. Converter, according to established switching modes, alters status of pump groups to keep water pressure constant. Pressure transmitter embedded a/d (analog/digital) inverter is of the latest intelligent digital type, and can communicate directly with plc via recommended standard. All the components constitute a stable closed-loop control system.

As shown in figure **3**, r *(t)*, real-time air pressure in

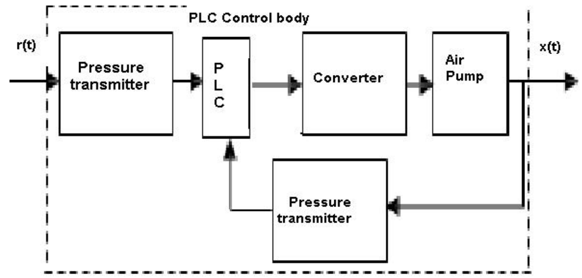


Fig. 3. Block diagram of PLC control body

III.THEORETICAL ANALYSIS

Most of the existing furnace air supply system use ac (alternating current) variable-frequency technology, that is, micro controller unit, as core controller, monitors real-time air pressure and controls the system. But its features, like nonlinear, large inertia, time delay and so on, make the classical control theory out of use. Then modern advanced control theory is chosen to satisfy the control need.

3.1 Constant-pressure Principle

As in different applications and different time, air supply to the boiler unit is uncertainty, and it is hard to express with a fixed or unified mathematical model. Feedback principle tells that to maintain a physical constant or fundamental unchanged should introduce reference value to compare with and form a closed-loop system [3]. In accordance with the above principle,

(1) if air absorbed from atmosphere > air supplied to the plant, pressure rises.

(2) if air absorbed from atmosphere = air supplied to the plant, pressure keeps constant.

(3) if air absorbed from atmosphere < air supplied to the plant, pressure drops.

3.2 Principle of Variable – Frequency Control

Variable-frequency control is to adjust ac motor’s drive power frequency to change its speed in the use of converter. It not only can change speed continuously, but also can adjust the relationship between voltage and frequency based on load characteristics so that motor is always running efficiently. To control pumping capacity by adjusting motor speed can maintain constant air pressure. Principle of variable-frequency control in detail as follows,

- Slip of asynchronous motor

$$S = 1 - (n / n1) \tag{1}$$

- Synchronous speed of asynchronous motor

$$n1 = 60\, f / P \tag{2}$$

- Speed of asynchronous motor

$$n = 60\, f\,(1\text{-}S) / P \tag{3}$$

where,

n_1 : ideal load-free speed of asynchronous motor

n : rotor speed of asynchronous motor

f : stator power frequency of asynchronous motor

P : pole pair number of asynchronous motor

From **eq.3**, when pole pair number p remains the same, motor rotor speed n is proportional to stator power frequency *f*. Thus, to adjust rotor speed *n* of asynchronous motor can adjust the motor's synchronous speed n1 by altering its stator power frequency *f* smoothly.

3.3 Switched Adaptive Control Theory

SS (Switched System) is composed of a series of switched subsystems and certain switched rules, in which subsystem may be stable or unstable and switched rule can be fixed or random. The whole SS is controlled by switched rule called switched law, switched signal, switched strategy or switched function. SS is an important branch of hybrid system defined as the combination of DEDS (Discrete Event Dynamic System) and CVDS (Continuous Variable Dynamic System).

Adaptive system has a certain ability to adapt to changes of environmental conditions (such as load change, climate change, etc.) and can automatically regulate control actions to get desired or optimal results. As **Figure 4** shows, the system, using reference input *r(t)*, control input *u(t)*, object output *y(t)* and known external interference, grasps its current performance, compares with given performance index and makes decision [6].

This paper integrates the above two control theories to form the so-called switched adaptive control algorithm. It can solve part of the problem during frequency switching. The switched theory is mainly used to control converter to adjust motor's speed for energy saving, while the use of MRAC can help the system regulate its operating parameters to expand its application.

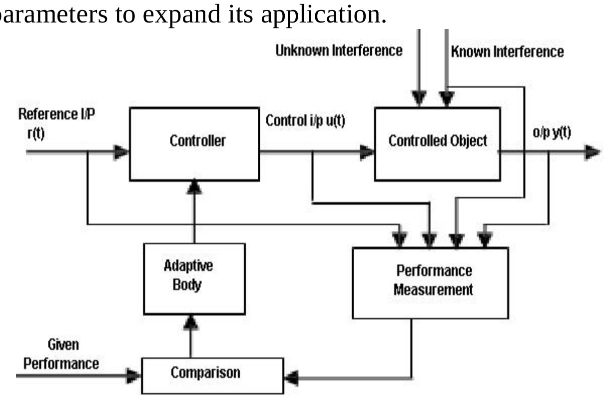


Fig. 4. Block diagram of adaptive control system

IV. SYSTEM MODELLING AND SIMULATION

From figure1, the system is equivalent to a SISO (Single Input Single Output) one, that is, real – time air pressure is input of the system and constant air pressure is the output.

4.1 Mathematical Modeling

Intelligent digital pressure transmitter monitors real-time input and output air pressure. Its outcome is accurate, but pressure measurement is of great time delay. So compensation is needed to ensure the accuracy of real-time data.

On the basis of variable-frequency control theory, choose

$$V/f = kC_0 \qquad (4)$$

PWM (Pulse Width Modulation) mode,

Where,

V : Output voltage of converter

f : Output frequency of converter

C_0 : Nonnegative constant

k : n discrete nonnegative constants (n determined by the number of interfering factors)

Consider characteristics of the system, assuming $n=4$, namely, k has four discrete nonnegative constants. Based on the features of various interference factors, the values of k shown in table1.

TABLE 1. VALUE OF *K*

k	*k1*	*k2*	*k3*	*k4*
Value	0.5	1.0	2.0	0.0

Corresponding to Table 1, customized converter frequency-voltage curve shows in **Figure 5**.When converter is at startup or very low speed, motor's output voltage is low as well, which makes the motor not get enough rotational force, so the initial start point moves to point $(0, V_0)$ as a compensation for torque. Motor can start or run properly at point (F_1, V_1) when increasing slope can save energy. At point (F_2, V_2), the slope soars to ensure steady air supply during peak period. Point (F_3, V_3) is the rated saturation point of converter, where output voltage does not vary with frequency.

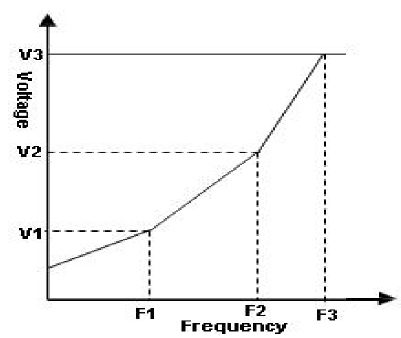


Fig. 5. Customized converter frequency – voltage curve

However, pump's curve fitting and the optimization of speed regulation strategy also need compensation.

Summarizing the above analyses, introduce a PI controller for the system to compensate all the mentioned shortages

$$G_c(s) = K_p\,(1+ 1/T_i s) \qquad (5)$$

From **Figure 3**, we can see that PLC controls converter directly, that is, output of PLC is converter's input. The output of PLC is

$$e_0(t) = x_0 - x(t) \qquad (6)$$

Where,

$e_0(t)$: Real-time water pressure deviation

$x(t)$: Real – time output air pressure

x_0 : Reference constant air pressure set by PLC program

e(t) is air pressure deviation compensated by PLC and then converter's input is

$$e(t) = e_0(t)\, G_c(s) \quad (7)$$

According to the working principle of converter

$$e(t)\,/V(t) = sgn(e(t))K_0 \quad (8)$$

Where,

Sgn() : Signal function

V(t) : Real – time output voltage of converter

K_0 : Non Negative constant (differing from the type of converter)

From **eq. (7)** and **eq. (8)** the output voltage of converter is

$$V\,(t) = e_0\,(t)\, G_c(s) \,/\, sgn\,(e_0\,(t)\, Gc(s))\, K_0 \quad (9)$$

Substitute **eq.** (9) into **eq. (4)** then the output frequency of converter is

$$F(t) = e_0(t)G_c(s) \,/\, sgn(e_0(t)G_c(s))K_0kC_0 \quad (10)$$

Substitute **eq. (10)** into **eq. (3)**, then the motor speed is

$$n(t) = 60(1\text{-}S)e_0(t)G_c(s) \,/\, sgn(e_0(t)G_c(s))K_0kC_0 \quad (11)$$

The similarity principle of pump shows that when speed changes, flow is proportional to the speed, that is

$$Q\,(t) = K_q\, n\,(t) \quad (12)$$

Where,

Q(t) : Real – time air output

K_q : Proportional Modulus

As pump's air output directly determines the output air pressure, Q(t) will be equivalent to the output of the system, thus forming a complete switched adaptive control structure.

4.2 System Simulation

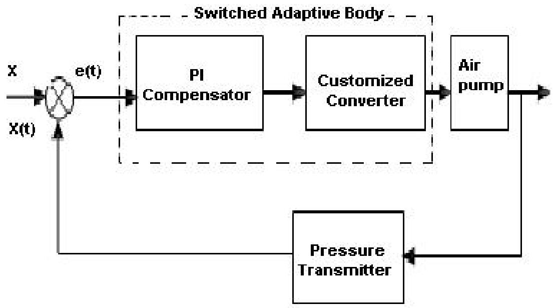


Figure6. Block diagram of switched adaptive body

Based on the above mathematical modeling, the corresponding block diagram of switched adaptive body is shown in **Figure 6**. From field debugging experience, take *Kp=12.63, Ti=12.63/0.087* and the reference air pressure $x_0 = 2.0$, then using Visual C++ programming and virtual sampling time, the simulation data are shown in **Figure 7** and **Figure 8**. In order to analyze the simulation data, defined the rate of deviation as

$$Rd = ([RT. - Ref\,] \,/\, Ref.) \times 100\% \quad (13)$$

And the rate of change as

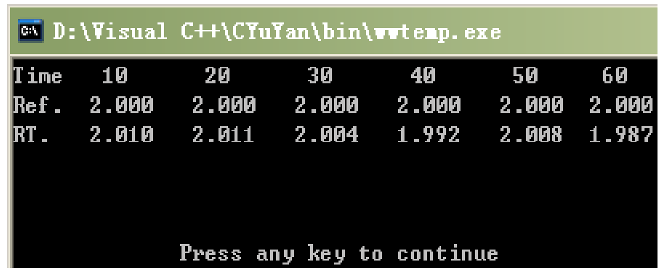
$$Rc = ([RT.2 - RT.1] \,/\, RT.2) \times 100\% \quad (14)$$

Where,

RT.: Real time output air pressure

Ref.: Reference air pressure

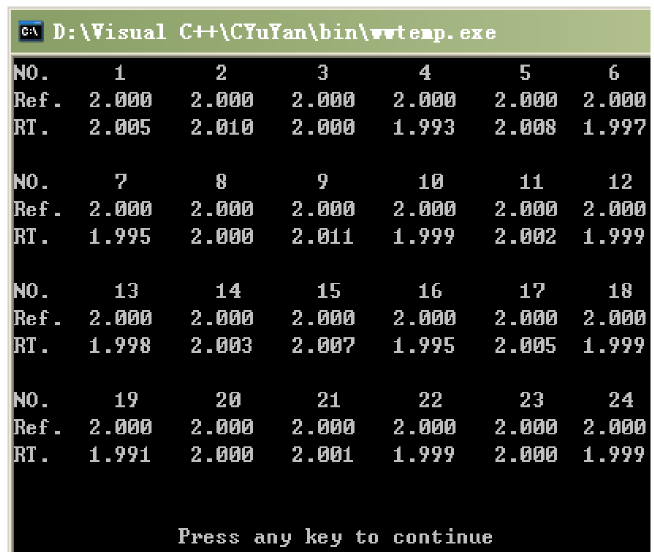
In **figure 7**, the data were collected every ten minute within one hour (virtual time), corresponding to six real-time output air pressures. As choosing random numbers to simulate real-time input air pressure, real-time output air pressure varied with them. But their rates of deviation rd and change *rc* were small, the largest *rd* was 0.65% and the largest *rc* was 1.06%. **Figure 8** was obtained by monitoring the system for 24 hours, and the simulation system outputted a real-time air pressure at each hour (virtual time). During different time periods, real-time output air pressure differed a lot, but they all fluctuated around reference one, namely, the system could generally adjust to changes and remain stable by altering operating parameters with the help of switched adaptive control technology.


D:\Visual C++\CYuYan\bin\wwtemp.exe

Time	10	20	30	40	50	60
Ref.	2.000	2.000	2.000	2.000	2.000	2.000
RT.	2.010	2.011	2.004	1.992	2.008	1.987

Press any key to continue

Fig.7. Data collected within one hour


D:\Visual C++\CYuYan\bin\wwtemp.exe

NO.	1	2	3	4	5	6
Ref.	2.000	2.000	2.000	2.000	2.000	2.000
RT.	2.005	2.010	2.000	1.993	2.008	1.997
NO.	7	8	9	10	11	12
Ref.	2.000	2.000	2.000	2.000	2.000	2.000
RT.	1.995	2.000	2.011	1.999	2.002	1.999
NO.	13	14	15	16	17	18
Ref.	2.000	2.000	2.000	2.000	2.000	2.000
RT.	1.998	2.003	2.007	1.995	2.005	1.999
NO.	19	20	21	22	23	24
Ref.	2.000	2.000	2.000	2.000	2.000	2.000
RT.	1.991	2.000	2.001	1.999	2.000	1.999

Press any key to continue

Fig. 8. 24– Hour real time monitoring data

V. CONCLUSION

From the comparison between reference air pressure and the real-time output ones shown in **figure 7** and **figure 8**, there were fluctuations, but their rates of deviation and change were to the extent permitted, which means the system basically remained dynamic balance and stable operation. The high reliability and stability of the system confirms its good characteristics.

It upgraded existing constant-pressure air supply system and improved current air supply technology by using switched adaptive control algorithm. Because the system switching by itself can achieve a good air supply effect, and the pumps can start or stop automatically based on the real-time signals. Switching variable-frequency step-less speed regulation technology used in the system to control air pressure also can reduce mechanical losses.

The method that has to be used relies on varied objectives like superior quality, increased efficiency, high profit and other such points depending upon the purpose of the company that implies it. With the prime objective of catering to these necessities and the needs of the industrial sector, significance has been given here to automation. The new method ensures the system can maintain constant air pressure basically in 24 hours. It is more stable and reliable with the use of PLC. The modeling and simulation of the modified system demonstrated its superiority. It will be able to further its promotion and development in the future.

ACKNOWLEDGMENT

I would like to thank my Faculty Dean, Colleagues and my family members for their moral support.

REFERENCES

[1] Gongfa Li, Jianyi Kong, "Research of Intelligent control of Air compressor at constant pressure", Journal of computers, Vol 7 No. 5, May 2012, Page: 1147 – 1154.

[2] Akayleh Ali, mohammed Al_soud, Essam Abdallah, Salah Addallah, "Water pumping system with PLC and frequency control", Jordan Journal of Mechanical and Industrial Engineering 2009, Vol 3, Page: 216 – 221.

[3] Eker. Lyas, "Operation and Control of Water Supply System", ISA Transactions, July, 2003, 2(3): 461–473

[4] A. Beghi, Luca Cachinnate, "Modeling and adaptive control of small capacity chillers for HVAC applications", Journal of Applied Thermal Engineering, Elsevier Publications, 2011, Page: 1125 – 1134

[5] K.Gowrishankar, "Control of Boiler operation using PLC – SCADA, IMECS 2008, Vol 2, Hongkong, ISBN – 978-988-17012-1-3.

[6] G. C. Goodwin and K. S. Sin, "Adaptive filtering prediction and control",(Information and System Science Series), Englewood Cliffs, NJ: Prentice-Hall, 1984

[7] A.Hendookalaei, N. Bahrami Ahmadi, " Neural Indirect Adaptive Control applied in Thermal Power plant Boilers", Canadian Journal on Electrical & Electronics Engineering, Vol 3 No.6, July 3012.

[8] G. Kelefenz , " Automatic Control of Steam Power Plants " , Speyer, 1986.

Mr. K. Gowrishankar is currently working as Lecturer, FECT, AIMST University, Kedah, Malaysia. He graduates in Electronics & Instrumentation engineering from University of Madras, Tamilnadu. He secured his M.Tech degree from SASTRA University, Thanjavur. He is in teaching profession for 9 years. He is a life member of ISTE. His main areas of interest include Instrumentation, Process control and Control system based system design

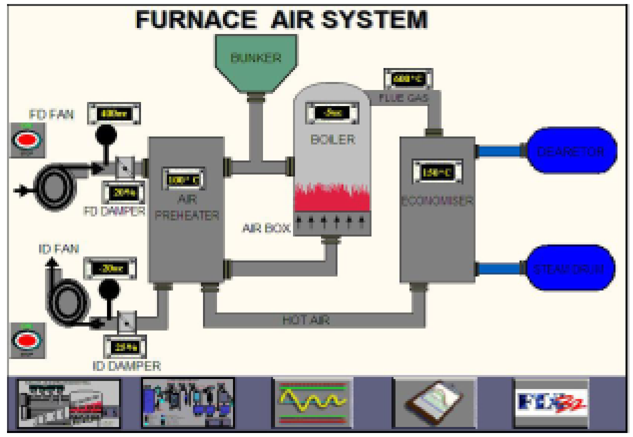


Fig. 9. Furnace Air System

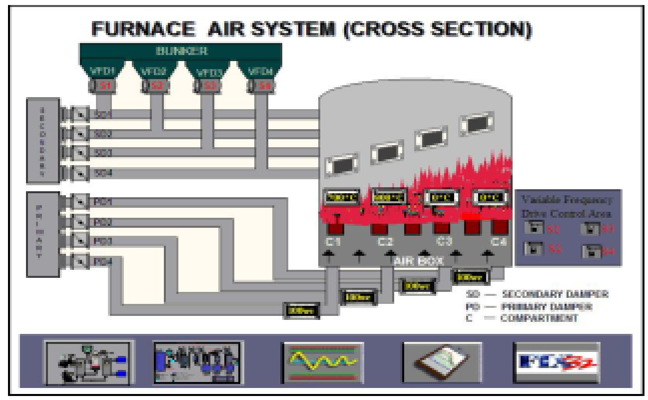


Fig. 10. Furnace Air System (Cross Section)