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Application of Model Free Adaptive Control in Main Steam Temperature System of Thermal Power Plant

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Abstract**—**At present, the cascade PID control is widely used to control the superheating temperature (main steam temperature). As Main Steam Temperature has the characteristics of large inertia, large time-delay and time varying, etc., conventional PID control strategy cannot achieve good control performance. In order to overcome the bad performance and deficiencies of main steam temperature control system, Model Free Adaptive Control (MFAC) - P cascade control system is proposed in this paper. By substituting MFAC in PID of the main control loop of the main steam temperature control, it can overcome time delays, non-linearity, disturbance and time variation.

Keywords**—**Model free Adaptive Control, Cascade Control, Adaptive Control, PID.

I. Introduction

MAIN steam temperature control is one of the most difficult problem in thermal power plant. It is the process with large time lag, long time delay, large inertial behavior, non-linear time varying and with various disturbance factors. The dynamic characteristics of main steam temperature system in thermal power plant are close correlation to the operating conditions of the whole power units and the dynamic characteristic will change obviously when the load is changed. Therefore, maintaining the main steam temperature stability is necessary for safety and economical operation of power plant unit, and the steam temperature deviation must be maintained within ±10°C in transient process and ±5°C in steady state of the specified value [1]. For example, for 300MW super-critical boiler, main steam temperature should be maintained at 450±5°C, which means 455°C is the maximum temperature while 445°C is the minimum temperature for superheater. At present, the main control strategy for main steam temperature system in most thermal power plant is still conventional PID cascade control and it can't achieve satisfactory control performance when the operating conditions change much. Consequently, many researchers tried advance control strategies by incorporating advanced controllers with PID, PI and P to form new cascade control algorithm in main steam temperature system to get the better performance [2], [3].

Model Free Adaptive Control was proposed in 1994 which is based on a new pseudo gradient vector and pseudo-order. It uses a series of dynamic linear time-varying model (tight format, partial format, wide format linear model) to replace the discrete time nonlinear systems in the vicinity of the controlled system and this model uses the I/O data to estimate the pseudo-gradient vector of the process [4]. MFAC is not only parameter adaptive but also structure adaptive during recent years. MFAC is an adaptive control with lots of advantages such as: independent of systematic parameter model, without need of designing controller for a specific process and for adjusting parameters by manual controller, do not easily get in local optimization, with well tracking performance and strong robustness and can guarantee stabilization of the systematic closed loop.

After introduction, brief explanation of MFAC is given in Section II and MFAC-P in Section III. In Section IV simulation is carried out and results are compared with simple PID followed by conclusion and references.

II. Model Free Adaptive Control

A. Universal Process Model

Consider the general discrete-time Non-linear system,

$$y(k+1) = f[Y_k^{k-n}, u(k), U_{k-1}^{k-m}, k+1] \quad (1)$$

where, y (k) = one dimensional state output for k = 0, 1,…; u(k) = input variable for k= 0, 1, …; k = discrete time; m = unknown order of output y(k); n = unknown order of input u(k); f ( ) = general Non-linear function; Y_k^{k-n} = {y (k), …., y (k-n)}, n = positive integer; U_{k-1}^{k-m} = {u (l), …, u (k-m)}; m = positive integer.

The system in (1) needs to meet the following assumptions:

1. It is observable and controllable.
2. The partial derivative of f(.) about u(k) is continuous.
3. It is generalized Lipschitz, that is to say, Δy(k+1) ≤ b, Δu(k) is reasonable for any k and Δu(k) ≠0 where Δy (k +1) = y(k+1) - y(k), Δu(k) = u(k) - u(k −1), b is a constant.

Suppose that has a continuous gradient with respect to u(k). When the system is in the steady state, because of the condition ǁu(k)-u(k-1) ǁ = 0, we have y(k+1) = y(k). By using these assumptions, we have

$$\Delta y(k+1) = \varphi(k)^T \Delta u(k) \quad (2)$$

Equation (2) is known as Universal Model, which is to avoid modeling before controller design and φ(*k*) is pseudo gradient of $f[U_{k-1}^{k-m}, Y_k^{k-n}]$ [5]-[10].

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B. Model Free Adaptive Control Algorithm

For the control law algorithm, a weighted one-step ahead control input cost function is adopted as:

$$J(u(k)) = |y^*(k+1) - y(k+1)|^2 + \lambda |u(k) - u(k-1)|^2 \qquad (3)$$

where, y*(k + 1) = desired output and λ = penalty/ weighted factor

In (3), $|y^*(k+1) - y(k+1)|^2$ can reduce the steady tracking error and λ [u(k)-u(k-1)]2 can restrict the change in control output [9].

If the case Δu(k) = 0 comes forth at certain sampling time, (1) can be transformed into Compact Form Dynamic Linearization (CFDL) model as:

$$y(k+1) - y(k-\sigma+1) = \varphi(k)[u(k) - u(k-\sigma)]$$

and

$$y(k+1) = y(k) + \varphi(k)\Delta u(k) \qquad (4)$$

By substituting (4) in (3) and solving $\frac{\partial J(u(k))}{\partial u(k)} = 0$, the control law u(k) is obtained as follows:

$$u(k) = u(k-1) + \frac{\rho \hat{\varphi}(k)}{\lambda + \| \hat{\varphi}(k) \|^2} \hat{\varphi}(k)[y^*(k+1) - y(k)] \qquad (5)$$

where ρ is the step factor. Thus control law (5) obtained is model-free, order-free and only I/O data-related.

C The Estimation Algorithm of Pseudo- Gradient-Vector

In the control law defined by (5), the only unclear parameter is the characteristic parameters φ(*k*), so the main task is to find φ(*k*). There are several ways for estimating φ(*k*) such as recursive least square approach, recursive gradient algorithm, the least-squares method with time varying factors, the least-squares with variance re-set, the time-varying parameter estimation method with Kalman filter, and so on [11], [12]. The necessary condition that the universal model (2) could be used in practice is that the estimation of φ(*k*), denoted as $\hat{\varphi}(k)$, is available in real-time, and is sufficiently accurate.

Consider the below estimation criterion function as

$$J(\varphi(k)) = |y^*(k) - y(k-1) - \varphi(k)\Delta u(k)|^2 + \mu |\varphi(k) - \hat{\phi}(k-1)|^2 \qquad (6)$$

It can be estimated as given by

$$\hat{\varphi}(k) = \hat{\varphi}(k-1) + \frac{\eta \Delta u(k-1)}{\mu + \Delta u(k-1)^2}[\Delta y(k) - \hat{\varphi}(k-1)\Delta u(k-1)] \qquad (7)$$

$$\hat{\varphi}(k) = \hat{\varphi}(1) \text{ if } |\hat{\varphi}(k)| \le \varepsilon \text{ or } |\Delta u(k-1)| \le \varepsilon \qquad (8)$$

Equations (5)-(7) are the Model Free Adaptive Control laws which do not need to specify a particular controlled system, are unrelated with the mathematical model and the order of the controlled system.

III. MFAC-P Cascade Control Scheme for Main Steam Temperature

MFAC-P cascade control of main steam temperature system is as in Fig. 1, where MFA is in inertia section and P is used in leading section.

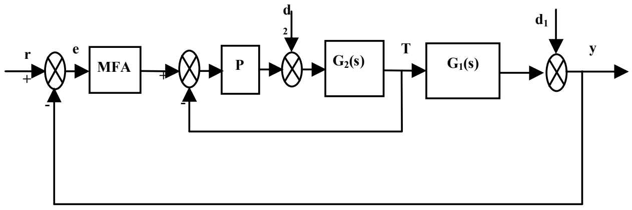

Fig. 1 Structure of MFAC cascade control system

$G_1(s)$ is the transfer function of superheater, $G_2(s)$ is the transfer function of desuperheater, d_1 is measurement disturbance of output, d_2 is measurement disturbance of control quality, r is set point and y is measurement output [13]. The inner loop use P controller because it gives a rapid control function and it eliminates water spraying disturbance. As MFAC has well adaptive parameter and it can control nonlinear and time delay object very well, it is used as main regulator and it maintains the superheated steam temperature. Besides, MFAC can overcome the object's retarding, inertia and model uncertainty.

IV. Simulation

To compare the effects of MFA cascade control and PID cascade control methods, simulation of main steam temperature control of 300MW Thermal Power Plant under different loads are done in MATLAB SIMULINK.

The transfer functions of main steam temperature system under different loads are as in Table I.

TABLE I
THE TRANSFER FUNCTIONS OF MAIN STEAM TEMPERATURE SYSTEM [3]

Payload %	Dynamic Characteristics	
	Leading factor $G_2(s)$	Inertial factor $G_1(s)$
30	$\frac{8.07}{(24s+1)^2}$	$\frac{1.48}{(46.6s+1)^4}$
44	$\frac{6.62}{(21s+1)^2}$	$\frac{1.66}{(39.5s+1)^4}$
62	$\frac{4.35}{(19s+1)^2}$	$\frac{1.83}{(28.2s+1)^4}$
88	$\frac{2.01}{(16s+1)^2}$	$\frac{2.09}{(22.3s+1)^4}$
100	$\frac{1.58}{(14s+1)^2}$	$\frac{2.45}{(15.8s+1)^4}$

Final value of step signal is set as superheated steam temperature steady state value 450°C and simulation time is set as 1000s.

Simulation model of PID-P cascade, MFA-P control system is as shown in Figs. 2 and 3 respectively. Internal structure of MFA is shown in Fig. 4

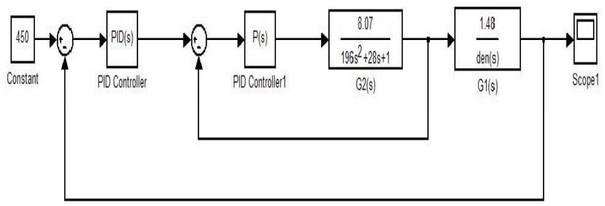

Fig. 2 PID cascade control system simulation model

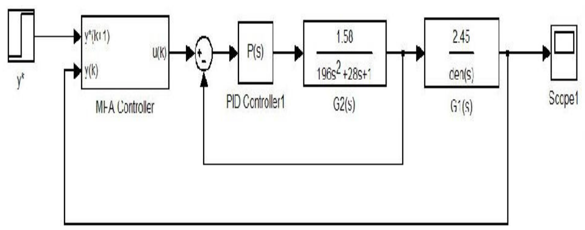

Fig. 3 MFA cascade control system simulation model

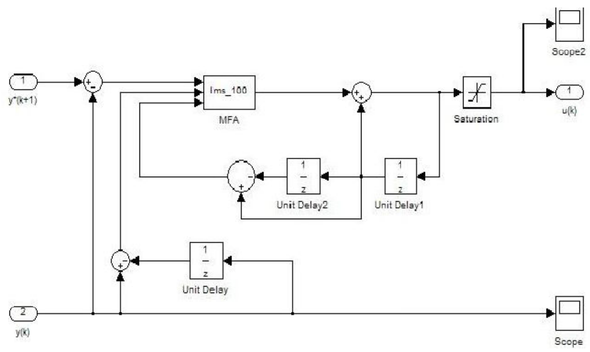

Fig. 4 Internal structure of MFA controller

TABLE II
THE CONTROLLERS' PARAMETERS OF THE PID CASCADE CONTROL UNDER DIFFERENT LOADS

	K_P	K_I	K_D
	At 30% load		
Main Controller (PID)	1.13219	0.00731	38.71598
Secondary Controller (P)	0.52489	-	-
	At 44% load		
Main Controller (PID)	0.99810	0.00753	28.87
Secondary Controller (P)	0.64099	-	-
	At 62% Load		
Main Controller (PID)	0.87979	0.00920	18.17460
Secondary Controller (P)	1.01849	-	-
	At 88% Load		
Main Controller (PID)	0.72749	0.00970	10.93024
Secondary Controller (P)	2.21174	-	-
	At 100% Load		
Main Controller (PID)	0.10874	0.005607	0
Secondary Controller (P)	2.58581	-	-

TABLE III
THE CONTROLLERS' PARAMETERS OF THE MFA CASCADE CONTROL UNDER DIFFERENT LOADS

	At 30% load			
Main Controller (MFA)	ρ=1;	η=1;	μ=0.8;	λ=0.05
Secondary Controller (P)		Kp = 0.00027		
	At 44% load			
Main Controller (MFA)	ρ=1;	η=1;	μ=0.8;	λ=0.8
Secondary Controller (P)		Kp = 0.00038		
	At 62% Load			
Main Controller (MFA)	ρ=1;	η=1;	μ=0.8;	λ=2.2
Secondary Controller (P)		Kp = 0.000809		
	At 88% Load			
Main Controller (MFA)	ρ=1;	η=1;	μ=0.8;	λ=2.4
Secondary Controller (P)		Kp = 1.620104		
	At 100% Load			
Main Controller (MFA)	ρ=1;	η=1;	μ=0.8;	λ=3.65
Secondary Controller (P)		Kp = 2.252605		

Under different loads PID and MFA-P are simulated, and results are compared. Controller parameters calculated for PID and MFA-P given are as in Tables II and III respectively

A. At 30% Load

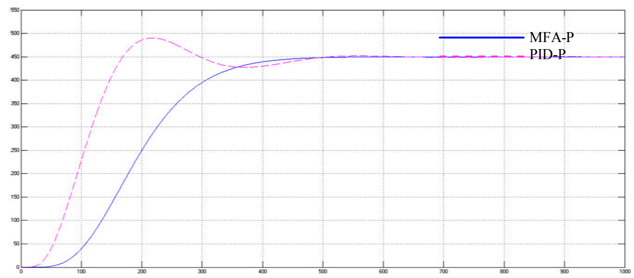

Fig. 5 Simulation results of (a) PID-P and (b) MFA Cascade Control at 30% Load

B. At 44% Load

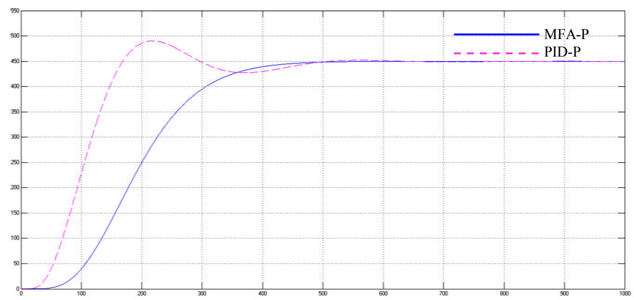

Fig. 6 Simulation Results of MFA-P and PID-P Cascade Control at 44% load

C At 62% Load

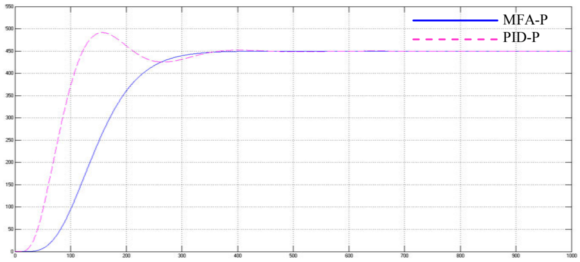

Fig. 7 Simulation Results of MFA-P and PID-P Cascade Control at 62% load

D.At 88% Load

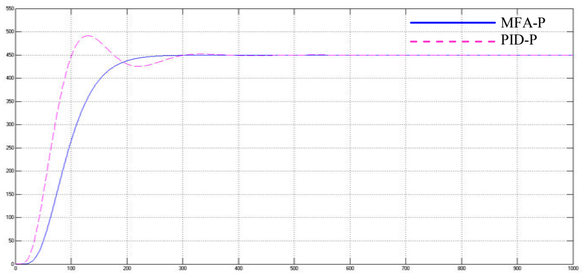

Fig. 8 Simulation Results of MFA-P and PID-P Cascade Control at 88% load

E. At 100% Load

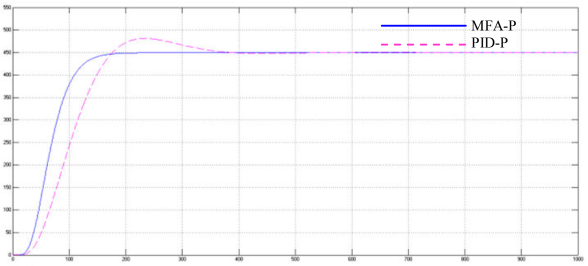

Fig. 9 Simulation Results of MFA-P and PID-P Cascade Control at 100% load

TABLE IV
OBSERVATIONS

	Delay Time (T_d)	Rise Time (T_r)	Settling Time (T_s)
	At 30% load		
PID-P	114.8	112.16	440
MFA-P	218.6	244	415.3
	At 44% load		
PID-P	99.38	96.92	379.4
MFA-P	188.76	209.7	357.2
	At 62% Load		
PID-P	72.85	68.62	285.4
MFA-P	143	155.53	266.92
	At 88% Load		
PID-P	60.4	56.82	236.32
MFA-P	90.29	108	180.74
	At 100% Load		
PID-P	95.82	102.41	280.18
MFA-P	65.06	75.85	129

Observations from the simulation results Figs. 5–9, are quantified in Table IV.

Although MFA-P cascade control has larger time delay and rise time compared to PID-P cascade control, it has shorter settling time, smoother transient process and no overshoot. Whereas, at 100% load MFA-P cascade control has faster performance, shorter rising time, shorter settling time, smoother transient process and no overshoot compare with PID-P cascade control.

V. CONCLUSION

In this paper, Model Free Adaptive control has been combined with conventional P controller to become MFA-P cascade control. The integrated modeling and control approach for process control is effective and practical. Simulation results have shown that the proposed controller has good transient, steady performance, anti-jamming capability and strong robustness than conventional PID-P cascade controller. In load change condition, proposed control scheme improve controller's applicability compared to PID cascade control scheme. It has better robust and self-adaptability and can overcome stronger disturbance even though object parameter varies with time.

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