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Advanced Control of Boiler Drum Water Level Based on Cloud Model Theories

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Abstract. In order to implement an excellent control for boiler drum water level at a power plant, nonlinear systems with long time-delay, a new intelligent control algorithm based on cloud model theories is proposed. According to the requirements of boiler drum water level control system, a two-dimensional cloud model controller is designed by incorporating deviation signals and deviation changing rates of the drum water level as its inputs, three parameters of PID as its outputs which are adjusted real-time by generating cloud mapping rules to realize fast and accurate control for the drum water level. Computer simulation shows that the cloud model controller proposed in this paper can significantly reduce the overshoot and response time of drum water level.

Introduction

Boiler drum water level control system is one of the most important thermal control systems at a power plant. The control mode of conventional PID with fixed control parameters can't be adjusted online. The task of a boiler feed-water automatic control system is to make feed-water flow adequate for the evaporation capacity of the boiler to maintain boiler drum water level in a specified range and keep feed-water flow stable. If the drum water level is too high or too low, it will directly affect the safety and economy of the turbine. When the unit operates at a rated condition, a cascade three-element feed-water control system is generally used which cannot find control parameters adapting to all kinds of disturbances. When drum water level fluctuates significantly, the balance between flow and water will not be restored quickly inside the drum and the medium so that it affects the effectiveness and safety of drum water level control. At present, conventional PID control is usually used to realize drum water level control at a power plant, which is difficult, however, to obtain better control effects for relatively large interferences [1][2].

There has been a lot researches on boiler drum water level control in recent years. In [3], an output modification model is added to conventional PID control loop with two self-learning modules such as changing rate of drum water level and valve opening regulation, the output of feed-water valve opening regulation is modified by tracking and judging the fluctuation slopes of drum water level and self-learning results. With the continuous development of intelligent control technology, some advanced control strategies, such as predictive control, neural network control, expert control and fuzzy control systems have been applied to drum water level control. For example, a fuzzy self-adaptive PID controller [4] is designed, in which the PID parameters are adjusted online by expert reasoning of fuzzy control. In [5], internal model control based neural network is applied to boiler drum water level control, considering of the influences of load changing on drum water level. The steam flow signals are used to compensate for the disturbances of the steam flow by using feed-forward control to eliminate the phenomenon of "false water level".

On the basis of statistical mathematics and fuzzy mathematics, cloud modeling presents a new approach to represent the randomness and fuzziness between uncertainty language and precise numerical value in order to realize the conversion from the qualitative to the quantitative. Currently the cloud modeling theory has been applied to data mining, decision analysis, intelligent control and image processing. The cloud modeling is a model of uncertain transition between a linguistic term of a qualitative concept and its numerical representation [6-9].

In this study, the cloud modelling theory is incorporated into boiler drum water level control system. A determined membership function is not required to be given in the cloud model. For the same input values, complete different output values can be obtained each time. However it keeps the same tendency of fuzzy control method. The deviation and the deviation changing rate of drum water level are sampled as the inputs of two-dimensional cloud model controllers and the parameters of PID calculated by the cloud model reasoning algorithms are modified to be as the outputs of the controllers. With the help of cloud model in uncertain conversion, the stability requirements of the control system are satisfied to the greatest extent.

Adaptive PID Control of The Boiler Drum Water Level Based on Cloud Model Controller Section

The Design of Cloud Model Generator

The cloud model is used to realize the qualitative knowledge reasoning and control, which is not required to give an accurate mathematical model of the objects. The control experience is expressed by using a natural language value according to the qualitative rules of the controller to realize the stability control of the controlled object. The cloud generator of double conditions with single rule is composed of a two-dimensional former cloud generator and a one-dimensional consequent cloud generator as shown in Fig.1.

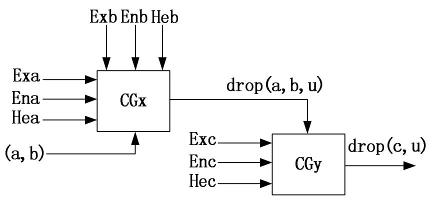

Fig.1 Double conditions with a single rule cloud generator

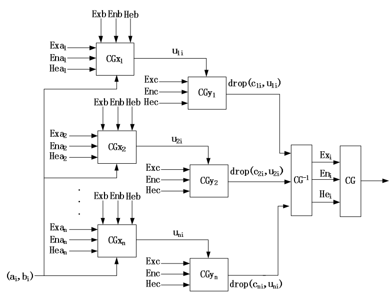

Fig.2 Multi-rules cloud generator

When a particular input (a,b) stimulates a two-dimensional former cloud generator CGx in the domain U1, CGx will generate a group of the uncertainty μ belonging to (a,b). The uncertainty μ is as the input of one-dimensional consequent cloud generator CGy, and randomly generate a group of droplets (c, μ) to meet the uncertainty μ. A statement of double conditions with single rule can be described as

If A and B then C

A multi-rules cloud model generator is constructed as shown in Fig.2.

In Fig.2,when an input (ai,bi) stimulates the former of single rule generator, each of the former generator will randomly generate a set of the uncertainty μni and randomly stimulate each consequent generator to generate a set of droplets(cni, μni). All the cloud droplets are transformed into the expectations by the backward cloud generator as the output of the cloud model.

Adaptive PID Control Flowchart of Boiler Drum Water Level

The PID parameters are regulated adaptively by steam flow, feed-water flow, the deviation signals (e) and the deviation changing rates (ec) of the drum level [10]. When the control system is disturbed rapidly, it can realize the stability of the drum water level control by using the cloud model controller to regulate the PID parameters. The adaptive PID control flowchart of the boiler drum water level is shown in Fig.3.

The implementation steps of adaptive PID control method of the boiler drum water level control system for real time adjustment are as follows:
(1)set up the cloud model controller with two inputs and three outputs; (2)sample the deviation (e) of the control system in the last moment and calculate the changing rates (ec) of the deviation; (3) set (e) and (ec) as the inputs of the cloud model controller; (4)ΔP, ΔI and ΔD of the PID controller are given by the cloud model controller; (5)ΔP, ΔI and ΔD are substituted into the PID controller to modify the PID parameters, i.e.

$$u(t) = (K_p * \Delta P)e(t) + (K_i * \Delta I)\int_0 e(t)dt + (K_d * \Delta D)\frac{de(t)}{dt} \quad (1)$$

(6)ensure the valve opening according to the PID controller after being tuned; (7)Repeat 2-6.

The Implementation of Boiler Drum Water Level Control Based on Cloud Model Controller

The Establishment of Cloud Model Controller for Boiler Drum Level Control

Set the domain of water level deviation e, water level deviation estimator ê, water level deviation integral ei and control output u are all [-1,1]. The range of e is [-20mm,+20mm], the range of ê is [-5mm,+5mm], and the range of u is [-50,+50]. Define the numbers of the subset with cloud model, here N takes 5. Use the digital feature (Ex, En, He) of normal distribution to represent two-dimension cloud model controller. The sets of the cloud model are constructed by using fuzzy theory [13]. In this paper, after e, ec, ΔP, ΔI and ΔD are normalized, e, ΔP, ΔI and ΔD are divided into five parts which represent "Negative Big", "Negative Less", "Zero", "Positive Less" and "Positive Big". In the cloud model controller, the digital characteristics of the cloud model can be described as {Ei , ECj , OPi , OIi,ODi,|i=1,2,3,4,5;j=1,2,3}.The curves that the sets of cloud model are constructed by using fuzzy theory are shown in Fig.4.

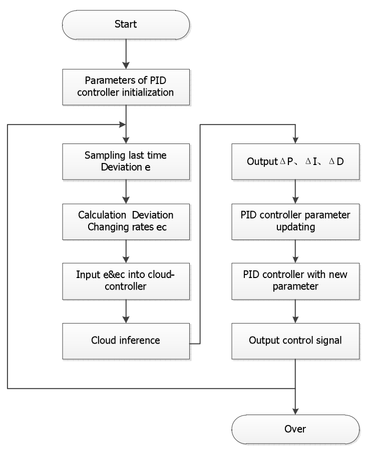

Fig.3 Adaptive PID control flowchart of the boiler drum water level

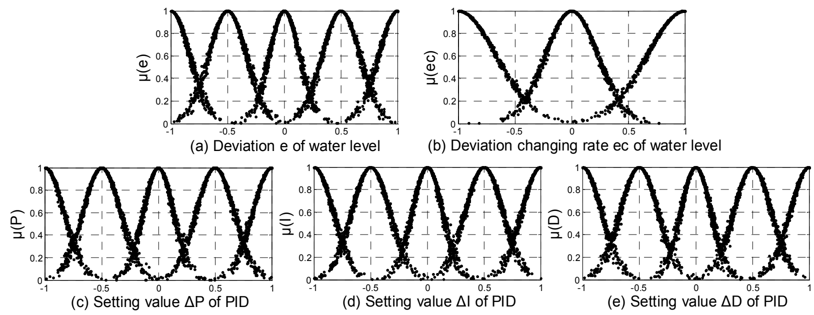

Fig.4 The sets of the cloud model are constructed by using fuzzy theory

The corresponding rules are shown in Table.1. The various parameters are substituted into the established multi-rule controllers and finish the establishment of the cloud model controller.

Table.1 The corresponding rules of the boiler drum water level

		Qualitative representation	Quantitative expression			Qualitative representation	Quantitative expression
Rules Former	e	Negative Big	E1（-1,0.5/3,0.01）	Rules Consequent	ΔI	Negative Big	OI 1（-1,0.5/3,0.01）
		Negative Less	E2（-0.5,0.5/3,0.01）			Negative Less	OI 2（-0.5,0.5/3,0.01）
		Zero	E3（0,0.4/3,0.01）			Zero	OI 3（0,0.43,0.01）
		Positive Less	E4（0.5,0.5/3,0.01）			Positive Less	OI 4（0.5,0.5/3,0.01）
		Positive Big	E5（1,0.5/3,0.01）			Positive Big	OI5（1,0.5/3,0.01）
	ec	Negative	EC1（-0.5,1/3,0.01）		ΔD	Negative Big	OD1（-1,0.5/3,0.01）
		Zero	EC2（0,0.7/3,0.01）			Negative Less	OD2（-0.5,0.5/3,0.01）
		Positive	EC3（0.5,1/3,0.01）			Zero	OD3（0,0.4/3,0.01）
Rules Consequent	ΔP	Negative Big	OP1（-1,0.5/3,0.01）			Positive Less	OD4（0.5,0.5/3,0.02）
		Negative Less	OP2（-0.5,0.5/3,0.01）			Positive Big	OD5（1,0.5/3,0.02）
		Zero	OP3（0,0.4/3,0.01）				
		Positive Less	OP4（0.5,0.5/3,0.01）				
		Positive Big	OP5（1,0.5/3,0.01）				

Here the drum level is measured with a water level sensor, the difference between it and the setting value is normalized to be as a quantitative input of the cloud model controller. The PID output is gained by using the cloud model inference rules and is converted into the valve opening so as to realize the drum level control.

The block diagram of the adaptive PID control system based on the cloud model controller is shown in Fig.5.

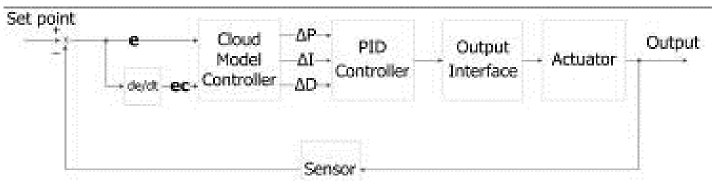

Fig.5 Block diagram of adaptive PID control system based on the cloud model controller

In Fig.5, when the inputs e and ec of the drum level simulate the formers of single rule, each rule former generator will produce the corresponding random uncertainty μ, these uncertainties are thus synthesized into a new uncertainty of the consequent to be input by soft AND method. The new uncertainty stimulates the rules consequent of the cloud generator, producing the cloud droplets that are converted into the expectations by backward cloud generator as the setting value to be output.

Simulation Example

The boiler drum water level is selected as the controlled plant, its transfer function between feed-water flow and water level is described as

$$G(s) = \frac{0.037}{30s^2 + s} \tag{2}$$

Simulation test of the drum water level control based on the cloud model controller is realized by Matlab/Simulink. The coefficient Kp of conventional PID controller takes 1.3, the integral coefficient KI takes 0.005, the differential coefficient Kd takes 30. The module of the control loop is shown in Fig.6

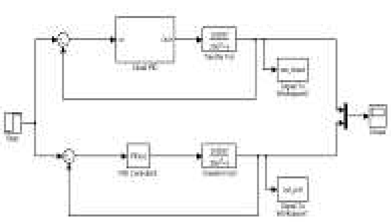

Fig.6 The module of the control loop

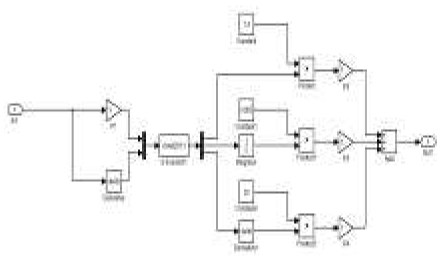

Fig.7 The subsystem of cloud-model controller

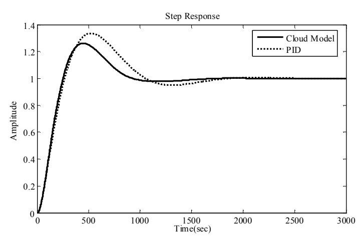

Fig.8 Drum level response curves using two kinds of control methods

The subsystem of cloud-model controller is shown in Fig.7. The controller adopts S function. The corresponding PID parameters still take 1.3, 0.005 and 30.

Under the action of the step input signal, the response curves of the drum water level are obtained by the above two methods respectively, as shown in Fig.8, where the dotted line represents for the response curve of the drum level obtained by conventional PID control and the solid line represents for the response curve of the drum level obtained by the cloud model controller.

It can be seen from Fig.8 that the drum level control obtained by the cloud model controller has the smaller system error and shorter rise time than that obtained by PID.

Conclusions

A two-dimensional cloud model controller has been established according to the characteristics of the boiler drum water level. The deviation signal(e) and the deviation changing rates (ec) of the drum water level sampled by the level sensors are regarded as the inputs of the controller, the three parameters of the PID controller are regulated real-time by cloud model multi-rule generators. The simulation test shows that the method proposed in this paper can realize the stable, fast and accurate control for the drum water level and effectively adjust the PID controller using the cloud model controller to improve the control quality of the drum level control system.

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