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PID Controller Tuning by using Fuzzy Logic Control and Particle Swarm Optimization for Isolated Steam Turbine

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***Abstract*—PID controller is employed in every facet of industrial automation. . It is natural that it is necessary to improve quality of any production technology in a complex way, by means of replacing the technology itself, as well as by continuous optimization of operation. It is just here, where new opportunities of using fuzzy controller are opening, as a compensation for a man in control and optimizing processes. This paper presents design of PID controller using Ziegler-Nichols (ZN) technique and Fuzzy controller for isolated steam turbine. PID controller tuning using PSO is proposed in this paper. Simulation results are demonstrated. Performance analysis shows the effectiveness of the proposed Fuzzy logic controller as compared to the ZN tuned PID controller & and tuning by using particle swarm optimization.**

***Index Terms*— Ziegler-Nichols (ZN), particle swarm optimization (PSO).**

I. INTRODUCTION

Since many industrial processes are of a complex nature, it is difficult to develop a closed loop control model for this high level process. Also the human operator is often required to provide on line adjustment, which make the process performance greatly dependent on the experience of the individual operator. It would be extremely useful if some kind of systematic methodology can be developed for the process control model that is suits industrial process. There are some variables in continuous DCS (distributed control system) suffer from many unexpected disturbance during operation (noise, parameter variation, model uncertainties, etc.) so the human supervision (adjustment) is necessary and frequently. If the operator has a little experience the system may be damaged operated at lower efficiency.

One of these systems is the control of turbine speed PI controller is the main controller used to control the process variable. Process is exposed to unexpected conditions and the controller fail to maintain the process variable in satisfied conditions and retune the controller is necessary. Fuzzy controller is one of the succeed controller used in the process control in case of model uncertainties. But it may be difficult to fuzzy controller to articulate the accumulated knowledge to encompass all circumstance. Hence, it is essential to provide a tuning capability. There are many parameters in fuzzy controller may be adopted. The Speed control of turbine unit construction and operation will be described. Adaptive controller is suggested here to adapt normalized fuzzy controller, mainly output/input scale factor. The algorithm is tested on an experimental model to the Turbine Speed Control System. A comparison between Conventional method and Adaptive Fuzzy Controller are done and also compare the PID controller tuning by using particle swarm

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optimization. The suggested control algorithm consists of two controllers process variable controller and adaptive controller (normalized fuzzy controller).At last, the fuzzy supervisory adaptive implemented and compared with conventional method and also by using PSO

II. RELATED WORKS

To understand the various control techniques and to improve the speed control of steam turbine by tuning of controllers **.**The application of PID controller span from small industry to high technology industry. In this paper, it is proposed that the controller be tuned using Adaptive fuzzy controller. Adaptive fuzzy controller is a stochastic global search method that emulates the process of natural evolution. Adaptive fuzzy controller have been shown to be capable of locating high performance areas in complex domains without experiencing the difficulties associated with high dimensionality or false optima as may occur with gradient decent techniques. Using Fuzzy controller to perform the tuning of the controller will result in the optimum controller being evaluated for the system every time. For this study, the model selected is of turbine speed control system. The reason for this is that this model is often encountered in refineries in a form of steam turbine that uses hydraulic governor to control the speed of the turbine. The PID controller of the model will be designed using the classical method and the results analyzed. The same model will be redesigned using the AFC method. A steam turbine is a device that extracts thermal energy from pressurized steam and uses it to do mechanical work on a rotating output shaft. Because the turbine generates rotary motion it is particularly suited to be used to drive an electrical generator. The control of a turbine with a governor is essential, as turbines need to be run up slowly to prevent damage and some applications (such as the generation of alternating current electricity) require precise speed control. Uncontrolled acceleration of the turbine rotor can lead to an over speed trip, which causes the nozzle valves that control the flow of steam to the turbine to close. If this fails then the turbine may continue accelerating until it breaks apart, often catastrophically. The application of PID (proportional integral derivative) controller span from small industry to high technology industry. Tuning the parameters of a PID controller are very important in PID control. Ziegler and Nichols proposed the well-known Ziegler-Nichols method to tune the coefficients of a PID controller. This tuning method is very simple, but cannot guarantee to be always effective. This thesis investigates the effectiveness of different controllers for the speed control of Tandem compound single reheat steam turbine**.** In contrast to conventional control techniques, fuzzy logic control (FLC) is best utilized in complex ill-defined processes that can be controlled by a skilled human operator without much knowledge of their underlying dynamics. The basic idea behind FLC is to incorporate the "expert experience" of a human operator in the design of the controller in controlling a process whose input – output relationship is described by collection of fuzzy control rules (e.g., IF-THEN rules) involving linguistic variables rather than a complicated dynamic model. The utilization of linguistic variables, fuzzy control rules, and approximate reasoning provides a means to incorporate human expert experience in designing the controller.

III. MODELING OF STEAM TURBINE

For this study, the model selected is of turbine speed control system. The reason for this is that this model is often encountered in refineries in a form of steam turbine that uses hydraulic governor to control the speed of the turbine as illustrated above in figure 1.

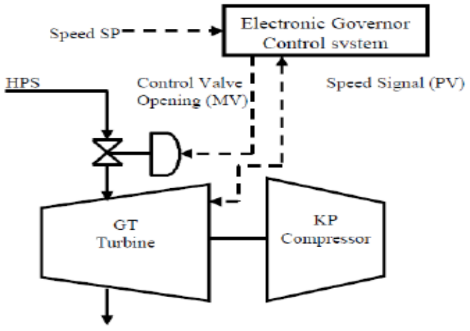

Figure.1. steam turbine model

The complexities of the electronic governor controller will not be taken into consideration in this dissertation. The electronic governor controller is a big subject by it and it is beyond the scope of this study. Nevertheless this study will focus on the model that makes up the steam turbine and the hydraulic governor to control the speed of the turbine. In the context of refineries, you can consider the steam turbine as the heart of the plant. This is due to the fact that in the refineries, there are lots of high capacities compressors running on steam turbine. Hence this makes the control and the tuning optimization of the steam turbine significant. The model used in this paper was presented .The transfer function of the open loop system can be approximated in the form of a third order transfer function:

$$1/s(s+5)(s+1)$$

The identified model is approximated as a linear model, but exactly the closed loop is nonlinear due to the limitation in the control signal

IV. PID CONTROLLER

The PID controller is the most common form of feedback. It was an essential element of early governors and it became the standard tool when process control emerged in the 1940s. In process control today, more than95% of the control loops are of PID type, most loops are actually PI control. PID controllers are today found in all areas where control is used. The controllers come in many different forms. There are stand-alone systems in boxes for one or a few loops, which are manufactured thousands yearly. PID control is an important ingredient of a distributed control system. The controllers are also embedded in many special-purpose control systems. PID control is often combined with logic ,sequential functions, selectors, and simple function blocks to build the complicated automation systems used for energy production, transportation, and manufacturing.

Many sophisticated control strategies, such as model predictive control, are also organized hierarchically. PID control issued at the lowest level; the multivariable controller gives the set points to the controllers at the lower level. The PID controller can thus be said to be the “bread and butter’ ’of control engineering. It is an important component in every control engineer’s tool box.PID controllers have survived many changes in technology, from mechanics and pneumatics to microprocessors via electronic tubes, transistors, integrated circuits. The microprocessor has had a dramatic influence on the PID controller. Practically all PID controllers made today are based on microprocessors. This has given opportunities to provide additional features like automatic tuning, gain scheduling, and continuous adaptation.

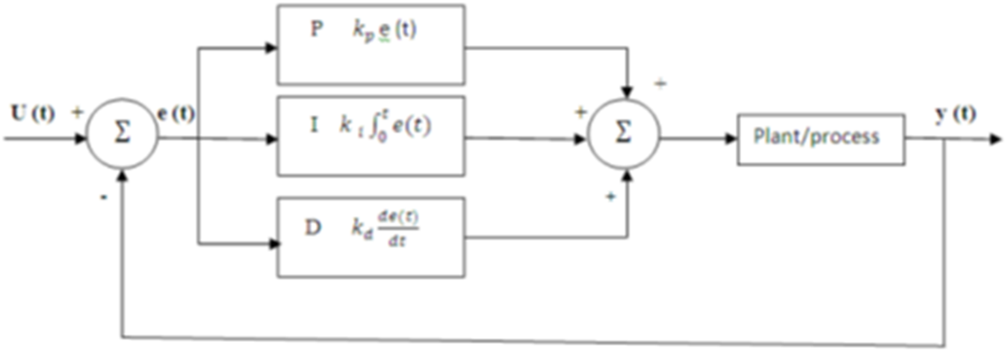

Figure 2 PID controller block

The controller attempts to minimize the error by adjusting the process control inputs. The PID controller calculation algorithm involves three separate constant parameters, and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted *P*,*I*, and *D*. Heuristically, these values can be interpreted in terms of time: *P* depends on the present error, *I* on the accumulation of past errors, and *D* is a prediction of future errors, based on current rate of change. The weighted sum of these three actions is used to adjust the process via a control element. Tuning the parameters of a PID controller is very important in PID control. Ziegler and Nichols proposed the well -known Ziegler-Nichols method to tune the coefficients of a PID controller. This tuning method is very simple, but cannot guarantee to be always effective. The PID control scheme is named after its three correcting terms, whose sum constitutes the

manipulated variable(MV). The proportional, integral, and derivative terms are summed to calculate the output of the PID controller.Defining as the controller output, $u\ t$ the final form of the PID algorithm is:
$u\ t = kp\ e\ t + ki\ e\ t\ dt + kd\ de\ (t)\ dt$
Where Kp: Proportional gain, a tuning parameter, Ki: Integral gain, a tuning parameter, Kd: Derivative gain, a tuning parameter ,e: Error
Tuning a control loop is the adjustment of its control parameters (proportional band/gain, integral gain/reset, derivative gain/rate) to the optimum values for the desired control response.

A. PID Tuning

Tuning is adjustment of control parameters to the optimum values for the desired control response. Stability is a basic requirement. However, different systems have different behavior, different applications have different requirements, and requirements may conflict with one another.
PID tuning is a difficult problem, even though there are only three parameters and in principle is simple to describe, because it must satisfy complex criteria within the limitations of PID control. There are accordingly various methods for loop tuning, some of them:
Manual tuning method, Ziegler–Nichols tuning method, PID tuning software methods.

B. Manual Tuning Method:

In manual tuning method, parameters are adjusted by watching system responses. Kp, Ki, Kd are changed until desired or required system response is obtained. Although this method is simple, it should be used by experienced personal.

C. One Manual Tuning Method Example

Firstly, Ki and Kd are set to zero. Then, the Kp is increased until the output of the loop oscillates, after obtaining optimum Kp value, it should be set to approximately half of that value for a "quarter amplitude decay" type response. Then, Ki is increased until any offset is corrected in sufficient time for the process. However, too much Ki will cause instability. Finally, Kd is increased, until the loop is acceptably quick to reach its reference after a load disturbance. However, too much Kd also will cause excessive response and overshoot. A fast PID loop tuning usually overshoots slightly to reach the set point more quickly; however, some systems cannot accept overshoot, in which case an over-damped closed-loop system is required, which will require a Kp setting significantly less than half that of the Kp setting causing oscillation.

D. Ziegler–Nichols tuning method:

This method was introduced by John G. Ziegler and Nathaniel B. Nichols in the 1940s. The Ziegler-Nichols' closed loop method is based on experiments executed on an established control loop (a real system or a simulated system). The tuning procedure is as follows:
1.Bring the process to (or as close to as possible) the specified operating point of the control system to ensure that the controller during the tuning is "feeling" representative process dynamic and to minimize the chance that variables during the tuning reach limits. Process is brought to the operating point by manually adjusting the control variable, with the controller in manual mode, until the process variable is approximately equal to the set-point.
2 . Turn the PID controller into a P controller by setting set Ti = ∞ and Td = 0. Initially, gain Kp is set to "0". Close the control loop by setting the controller in automatic mode.
3. Increase Kp until there are sustained oscillations in the signals in the control system, e.g. in the process measurement, after an excitation of the system. (The sustained oscillations correspond to the system being on the stability limit.) This Kp value is denoted the ultimate (or critical) gain, Kpu. The excitation can be a step in the set-point. This step must be small, for example 5% of the maximum set-point range, so that the process is not driven too far away from the operating point where the dynamic properties of the process may be different. On the other hand, the step must not be too small, or it may be difficult to observe the oscillations due to the inevitable measurement noise. It is important that Kpu is found without the control signal being driven to any saturation limit (maximum or minimum value) during the oscillations. If such limits are reached, there will be sustained oscillations for any (large) value of Kp, e.g. 1000000, and the resulting Kp-value is useless (the control system will probably be unstable). One way to say this is that Ku must be the smallest Kp value that drives the control loop into sustained oscillations.
4 . Measure the ultimate (or critical) period Pu of the sustained oscillations.

5. Calculate the controller parameter values according to Table 4.3 , and these parameter values are used in the controller. If the stability of the control loop is poor, stability is improved by decreasing Kp, for example a 20% decrease.

TABLE I. CONTROL PARAMETERS VALUES

Control type	**Kp**	**Ki**	**Kd**
P	0.5*Ku	-	-
PI	0.45*Ku	1.2*Kp/Tu	-
PID	0.6*Ku	2*Kp/Tu	Kp*Tu/8

Derivative mode improves stability of the system and enables increase in gain K and decrease in integral time constant Ti, which increases speed of the controller response. PID controller is used when dealing with higher order capacitive processes (processes with more than one energy storage) when their dynamic is not simillar to the dynamics of an integrator (like in many thermal processes). PID controller is often used in industry, but also in the control of mobile objects (course and trajectory following included) when stability and precise reference following are required. Conventional autopilot are for the most part PID type controllers

V. FUZZY LOGIC CONTROLLER

Fuzzy controllers are inherently nonlinear controllers, and hence fuzzy control technology can be viewed as a new, cost effective and practical way of developing nonlinear controllers. The major advantage of this technology over the traditional control technology is its capability of capturing and utilizing qualitative human experience and knowledge in a quantitative manner through the use of fuzzy sets, fuzzy rules and fuzzy logic. There exist two different types of fuzzy controllers: the Mamdani type and the Takagi±Sugeno (TS, for short) type. They mainly differ in the fuzzy rule consequent: a Mamdani fuzzy controller utilizes fuzzy sets as the consequent whereas a TS fuzzy controller employs linear functions of input variables Although it is possible to design a fuzzy logic controller by a simple modification of the conventional ones, via inserting some meaningful fuzzy logic IF- THEN rules into the control system, these approaches in general complicate the overall design and do not come up with new fuzzy PID controllers that capture the essential characteristics and nature of the conventional PID controllers. Besides, they generally do not have analytic formulas to use for control specification and stability analysis. The fuzzy PID controllers to be introduced below are natural extensions of their conventional versions, which preserve the linear structures of the PID controllers, with simple and conventional analytical formulas as the final results of the design. Thus, they can directly replace the conventional PID controllers in any operating control systems (plants, processes). The conventional design of PID controller was somewhat modified and a new hybrid fuzzy PID controller was designed. Instead of summation effect a mamdani based fuzzy inference system is implemented. The inputs to the mamdani based fuzzy inference system are error and change in error.
FLC is strongly based on the concepts of fuzzy sets, linguistic variables and approximate reasoning introduced in the previous chapters. This chapter will introduce the basic architecture and functions of fuzzy logic controller, and some practical application examples. A typical architecture of FLC is shown below, which comprises of four principal comprises: a fuzzifier, a fuzzy rule base, inference engine, and a defuzzifier.

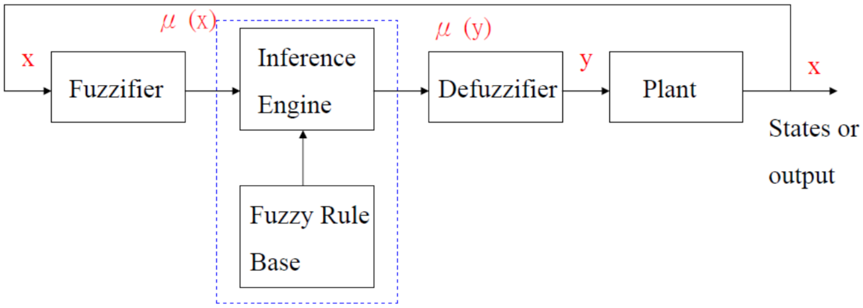

Figure 3 Typical architecture of FLC

If the output from the defuzzifier is not a control action for a plant, then the system is fuzzy logic decision system .The fuzzifier has the effect of transforming crisp measured data (e.g. speed is 10 mph) into suitable linguistic values (i.e. fuzzy sets, for example, speed is too slow). The fuzzy rule base stores the empirical knowledge of the operation of the process of the domain experts. The inference engine is the kernel of a FLC, and it has the capability of simulating human decision making by performing approximate reasoning to achieve a desired control strategy. The defuzzifier is utilized to yield a non fuzzy decision or control action from an inferred fuzzy control action by the inference engine

A. FUZZY Inference Engine

The main difference is that these fuzzy PID controllers are designed by employing fuzzy logic control principles and techniques, to obtain new controllers that possess analytical formulas very similar to the conventional digital PID controllers in a fuzzy logic system, the membership function is the operation that translates crisp input data into a membership degree The principle of fuzzy self-tuning PID is firstly to find out the fuzzy relationship between three parameters of PID and error (e) and error changes (ec). Fuzzy inference engines modify three parameters to be content with the demands of the control system online through constantly checking e and ec . Thus, the real plant will have better dynamic and steady Performance

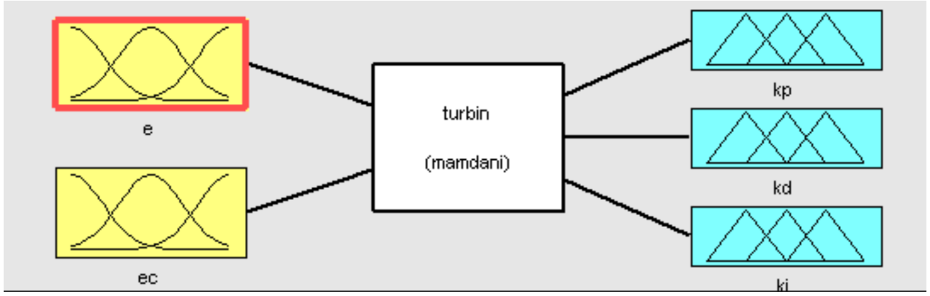

Figure 4 Two input and three outputs of the FLC

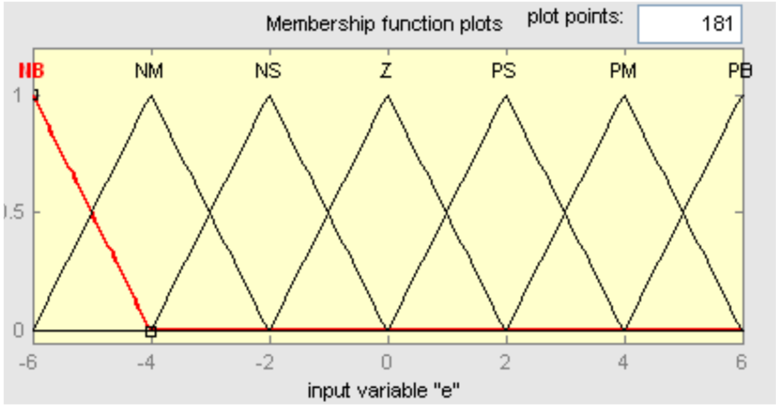

Figure.5 The membership functions of e and ec

The inference engine is the kernel of FLC in modeling human decision making within the conceptual framework of fuzzy logic and approximate reasoning. The generalized modus pones (forward data-driven inference) plays anespecially important role in approximate reasoning. The generalized modus pones can be rewritten as

Premise 1: IF x is A, THEN y is B.
Premise 2: x is A'
Conclusion: y is B'

where A, A', B and B'are fuzzy predicates (fuzzy sets or relations) in the
universal sets U, U ,V and V, respectively. In general, a fuzzy control rule (e.g. premise 1) is a fuzzy relation which is expressed as a fuzzy implication,

R = A→ B. According to the compositional rule of inference conclusion, B’ can be obtained by taking the composition of fuzzy set A’and the fuzzy relation (here the fuzzy relation is a fuzzy implication) A B: B’= A’ o R = A’ o (A→ B)

Fuzzy systems are indicating good promise in consumer products, industrial and commercial systems, and decision support systems. The term “fuzzy” refers to the ability of dealing with imprecise or vague inputs. Instead of using complex mathematical equations, fuzzy logic uses linguistic descriptions to define the relationship between the input information and the output action. In engineering systems, fuzzy logic provides a convenient and user-friendly front-end to develop control programs, helping designers to concentrate on the functional objectives, not on the mathematics. This introductory text discussed the nature of fuzziness and showed how fuzzy operations are performed, and how fuzzy rules can incorporate the underlying knowledge. Fuzzy logic is a very powerful tool that is pervading every field and signing successful implementations.

VI. PARTICLE SWARM OPTIMIZATION

In PSO, each particle contains these three components p, i, and d and updates the components in each iteration to find the Pbest and Gbest. Finally, the program runs to converge to the optimal solution. PSO has many similarities with evolutionary computation techniques like Genetic Algorithms (GA).The system is initialized with a population of random solutions and searches for optima by updating generations. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles.

It is demonstrated that PSO has advantages over other methods in respect to run time, cost and better result. Another reason that PSO is attractive is that there are few parameters to adjust. One version, with slight variations, works well in a wide variety of applications. Particle swarm optimization has been used for approaches that can be applied across a wide range of applications, as well as for specific applications focused on a specific requirement.

$$v_{new}[\ ] = v_{old}[\ ] + c_1 * rand(\ ) * (p_{best}[\ ] - present[\ ]) + c_2 * rand(\ ) * (g_{best}[\ ] - present[\ ])$$

where, : velocity of agent *i* at iteration *k*,

w: weighting function,

c: weighting factor,

rand: uniformly distributed random number between 0 and 1,

: current position of agent *i* at iteration *k*

pbesti: pbest of agent *i*,

gbest: gbest of the group.

VII. SIMULATION RESULTS

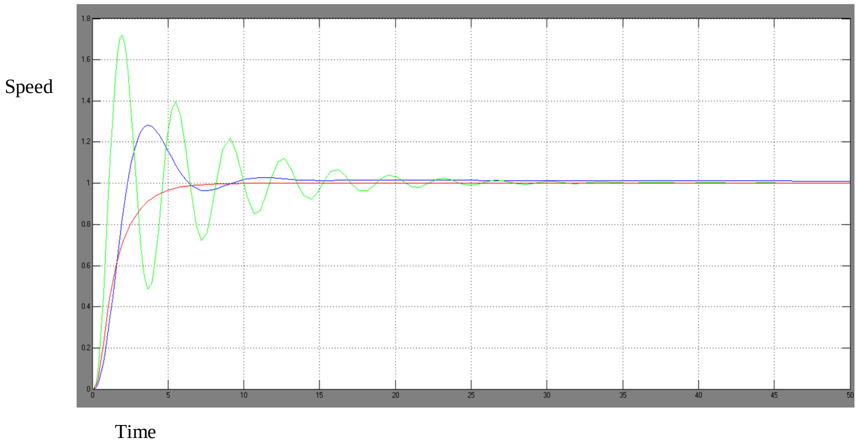

Figure 6 .Combined output of PID,FUZZY AND PSO

VIII. CONCLUSION

A fuzzy self-adapting PID controller for a Control Turbine Speed is used. The robustness of the system controlled by the AFPIDC is compared with the system controlled by the traditional PID controller. According to the simulation results in MATLAB, show that the AFPIDC can improve the robustness and small overshoot and fast response compared to the conventional PID. In the area of turbine speed control the faster response to research stability, the better is the result for the plant .when compared with proposed PSO and FUZZY, PSO has lower settling time lower over shoot and become more stable.

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