

# FUZZY BASED CONTROLLER FOR HEAVY DUTY GAS TURBINE PLANT

**S.BALAMURUGAN**

Senior Lecturer, Dept of EEE., Amtita School of Engineering, Coimbatore, India  
[s\\_balamurugan@ettimadai.amrita.edu](mailto:s_balamurugan@ettimadai.amrita.edu), +91-98653-48580

**R.JOSEPH XAVIER**

Principal, Sri Ramakrishna Institute of Technology, Coimbatore, India

**A.EBENEZER JEYAKUMAR**

Principal, Government College of Engineering, Salem, India

**Abstract:** Gas turbine generators are normally used in isolated operation. Load fluctuations could cause these generators to become unstable. An effective control and design are required to maintain system stability. The PID controller has been designed using Ziegler-Nichols' method (ZN) and Genetic Algorithm. The Fuzzy Logic controller is also designed and compared with conventional PID controller. It is shown that by fuzzy logic controller, optimal time domain performance of the system can be achieved.

**Key words:** Fuzzy Logic, Gas Turbine Plant, Genetic Algorithm, PID Controller

## 1. Introduction.

Gas turbine generators are commonly connected to small networks or even in isolated operation such as oil fields in desert area, offshore installations and bio-gas plants. Such systems tend to become unstable after a severe disturbance. Therefore, there is a need for effective design and control to maintain stability, otherwise, may cause an inevitable plant shut down.

The transfer function block diagram of heavy duty gas turbine plant was developed by Rowen [1]. He has developed, designed, calculated and verified the system gains, coefficients and time constant by test and actual field experience accumulated from numerous installations in many different applications. His transfer function has been used in many works such as, the dynamic analysis of combined cycle plants [2], twin shaft gas turbine model [3], combustion turbine model [4] and even in micro turbine power generation [5].

The Rowen model has three controllers for speed, temperature and acceleration. The speed controller is found to be an essential controller for effective operation of gas turbine plant [6]. The speed control is done by the governor. It may be either droop or isochronous. The droop governor is found to be the appropriate governor for gas turbine plants [7]. The droop setting value is optimized [8].

Even after applying the optimized droop governor, the speed does not settle in the reference value so there is a need for an effective secondary

controller to make the steady state error zero. This paper discusses and illustrates the tuning of PID controller using Ziegler – Nichols' method and Genetic Algorithm for zero steady state error. It also shows that fuzzy logic controller replacing conventional PID controller yields optimum response.

## 1. Mathematical Model for Heavy Duty Gas Turbine Plant

The Simplified block diagram for single shaft gas turbine together with its control and fuel system is shown in Fig. 1. The speed governor is the primary means of gas turbine control. The droop governor operates on the speed error. The droop governor is a straight proportional controller in which output is proportional to speed error.

The gas turbine gets difference from steam turbine by the need for a significant fraction of rated fuel to support self sustaining no load conditions. This amount is approximately 23%. The fuel system consists of two time constants in which one is associated with the gas valve positioning system.

$$e_1 = \frac{a}{bs + c} F_d \quad (1)$$

The second is the volumetric time constant associated with the downstream piping and fuel gas distribution manifold.

$$W_f = \frac{K_f}{\tau_f s + 1} e_1 \quad (2)$$

The torque characteristics of gas turbine are essentially linear with respect to fuel flow and turbine speed.

$$f_1 = 1.3(W_f - 0.23) + 0.5(1 - N) \quad (3)$$

The rotor time constant is defined as the time necessary for the rotor to double its speed if the initial rate of speed change is maintained after removal of rated load torque. The rotor speed is compared with the reference speed and the error is given to the speed governor.

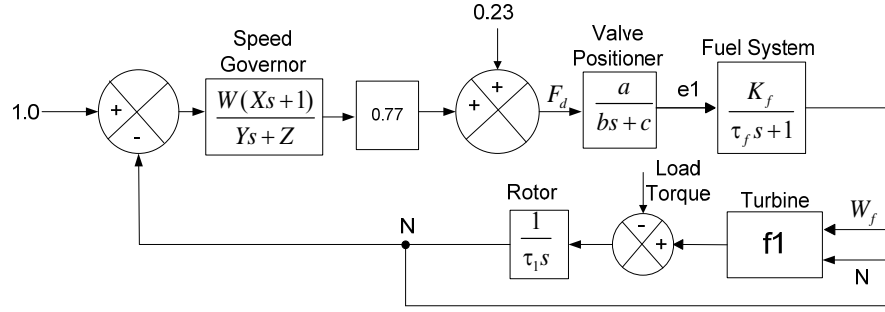


Fig 1. The Simplified transfer function block diagram of single shaft gas turbine plant

### 3. PID Controller

PID Controller is widely used because of its versatility, high reliability and ease of operation [9]. The standard form of the controller is given by

$$u(t) = k_p e(t) + k_i \int_0^t e(t) dt + k_d \frac{de(t)}{dt} \quad (4)$$

The Controller  $u(t)$  is the summation of three dynamic functions of the error  $e(t)$  from a specified reference output. The proportional control has the effect of increasing the loop gain to make the system less sensitive to load disturbance. The integral control is principally used to eliminate steady state errors. The derivative control helps to improve closed loop stability. To meet the prescribed performance criteria, the parameters of PID controller have to be chosen properly. In this paper Ziegler-Nichols' method (ZN) and Genetic Algorithm have been used for the PID tuning.

#### 3.1. Optimization of PID Gain by ZN Method

The standard method for setting the PID parameters was proposed by Ziegler and Nichols [10]. This technique was developed empirically through the simulation of a large number of process systems to provide a simple rule. In this method the process is kept under closed loop Proportional (P) control, the gain of the P controller at which the loop oscillates with constant amplitude has been defined as the ultimate gain ( $K_{cu}$ ). Ultimate period ( $T_u$ ) is the period of these sustained oscillations. The higher the ultimate gain, the easier it is to control the process loop. The ultimate gain is the gain at which the loop is at the threshold of instability. These parameters are used in tuning the controller for a specified response.

#### 3.2. Optimization of PID Gain by Genetic Algorithm

The base of Genetic Algorithm (GA) is rooted in natural evolutionary and biological process that ensures the "Survival of the Fittest". That is, the species, which can adopt external environment more efficiently, will survive. In the GA [11] just like natural genetics a chromosome (a string) will contain some genes (some binary bits). These binary bits are suitably

decoded to represent the character of the string.

A population size is chosen consisting of several parent strings. The strings are then subjected to the evaluation of performance index  $J$ , which is the fitness function in the study. The string with less value of  $J$  will only survive for the next generation. The string with more  $J$  will die. This process is called as selection and copying.

The former strings now produce new off springs by crossover and some offspring undergo mutation operation depending upon mutation probability to avoid premature convergence to sub optimal condition. In this way, a new population different from the old one is formed in each generic iteration cycle. The whole process is repeated for several iteration cycles till optimal or near optimal population is reached in which  $J$  of an off spring is the minimum. Then, that string is the required optimal solution.

### 4. Fuzzy Controller

The concept of fuzzy set theory was introduced by Zadeh in 1965 [12] and it was first introduced in 1979 for solving power system problems. The fuzzy controller involves four essential steps as i) Fuzzification of input and output variables. ii) Formation of fuzzy rule base. iii) Fuzzy inferencing. iv) Defuzzification to obtain the crisp output as shown in Fig. 2.

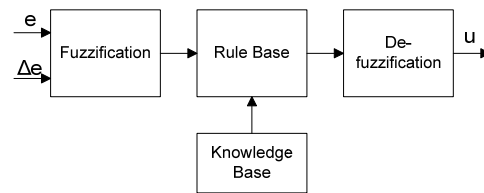


Fig. 2. Block diagram of fuzzy logic control

The inputs to the fuzzy controller are error( $e$ ) and change in error( $\Delta e$ ). To convert the measured input

variables into suitable linguistic variables, using the seven fuzzy subsets NB (Negative Big), NM (Negative Medium), NS (Negative Small), Z (Zero), PS (Positive Small), PM (Positive Medium) and PB (Positive Big). The Membership functions of these subsets are triangular and symmetrical as shown in Fig. 3.

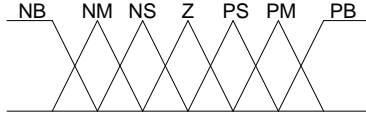


Fig. 3. Membership function

Based on the past experience of manual tuning of a controller, the rule table is formed. Both the inputs of the fuzzy controller have seven subsets. Thus the Fuzzy rule Table shown in Table 1 is constructed with 49 rules. These rules are used to relate the input signal to the output (control) signal. These decision rules, which are summarized by a Fuzzy relation matrix using membership functions, form the basis of the Fuzzy Logic operation performed by the Fuzzy Controller.

TABLE I. FUZZY RULES

		Error (e)						
		NB	NM	NS	Z	PS	PM	PB
Change in error ( $\Delta e$ )	NB	NB	NB	NB	NM	NM	NS	Z
	NM	NB	NB	NB	NM	NS	Z	PS
	NS	NB	NM	NS	NS	Z	PS	PM
	Z	NM	NM	NS	Z	PS	PM	PM
	PS	NM	NS	Z	PS	PS	PM	PB
	PM	NS	Z	PS	PM	PM	PB	PB
	PB	Z	PS	PM	PM	PB	PB	PB

For example rule 1 in Table 1 is:

IF e is NB and  $\Delta e$  is NB THEN U is NB

Once the membership values for the controller output have been computed, the centre of gravity method is employed for determining the controller output signal from these membership values.

## 5. Simulation Results

The transfer function model of the gas turbine explained in chapter 2 is simulated using MATLAB/Simulink [13] for unit step load disturbance. The response is shown in Fig. 4. The response shows the occurrence of the steady state error.

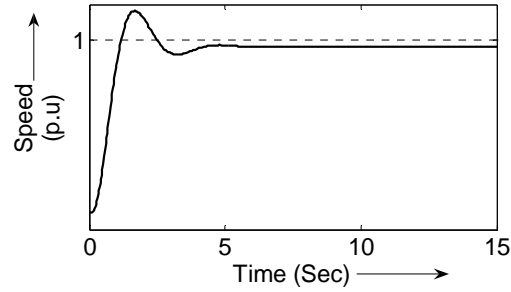


Fig. 4. Response of gas turbine plant without secondary controller

The optimal values of PID controller using ZN method and Genetic Algorithm is tabulated below

TABLE II. PID VALUES

Method	P	I	D
ZN Method	3.33990	0.6310	0.1577
Genetic Algorithm	15.5478	0.2633	3.1270

The gas turbine plant with the above mentioned PID controllers is simulated over a suitable time following an applied step in load at  $t=0$  and the response is shown in Fig. 5. The response shows that both the controller removed the steady state error. PID using genetic shows the smooth and better response.

The Fuzzy Logic controller replaces the PID controller and simulation is done. The response is shown in Fig. 6. The response shows that Fuzzy Logic controller has the optimum response and the response is smooth and fast. They have less settling time, compared with the other controllers.

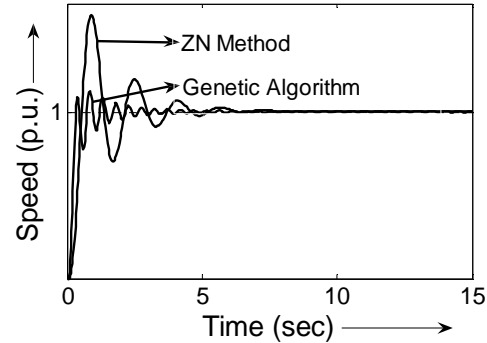


Fig. 5. Comparison of gas turbine plant response with PID controller, tuned using ZN method and genetic algorithm

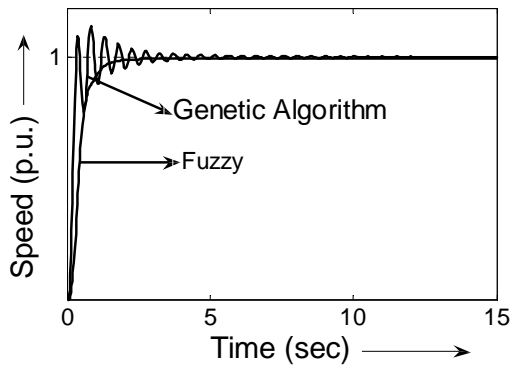


Fig. 6. Comparison of gas turbine plant with genetic tuned PID controller and fuzzy controller

## 6. Conclusion

Though there are many recent advancement in the field control engineering, PID controller still has its importance in industrial use today. In this paper the PID controller has been designed using both ZN method and Genetic Algorithm. The Genetic Algorithm yields appreciable results. A Fuzzy Logic controller for gas turbine plant has been presented in this paper. This controller consists of two input and one output and the rules are designed appropriately. It is shown that using fuzzy controller, the optimum response of the system is achieved when compared to PID controller tuned using ZN method and Genetic Algorithm.

## Appendix

$f_1$  = Turbine torque

$W_f$  = Per unit fuel flow

$K_f$  = Fuel System gain constant = 1

$\tau_f$  = Fuel system time constant = 0.4

$N$  = per unit turbine rotor speed

$s$  = Laplace operator

$e_1$  = Valve position

$F_d$  = Per unit fuel demand signal

$a, b, c$  = Fuel system transfer function coefficients

$a=1$ ;  $b=0.05$ ;  $c=1$

$W, X, Y, Z$  = Governor transfer function coefficients

$W=K_d$ ;  $X=0$ ;  $Y=0.05$ ;  $Z=1$

$K_d$  = Droop gain = 2 to 10%

$\tau_1$  = Rotor time constant = 12.2

$k_p, k_i, k_d$  = PID parameters

$t$  = time

$u(t)$  = control signal

$e(t)$  = error signal

## References

- [1]. W.I.Rowen, "Simplified Mathematical Representation of Heavy Duty Gas Turbines," ASME Journal of Engineering for Power, 105 (1893) 865-869.
- [2]. F.P. de Mello, D.J.Ahner, "Dynamic Models for Combined Cycle Plants in Power System Studies," IEEE Transactions on Power Systems, 9 (1994) 1698-1708.
- [3]. Louis N. Hannett, George Jee, B. Fardanesh, "A Governor / Turbine Model for a Twin Shaft Combustion Turbine," IEEE Transactions on Power Systems, 10 (1995) 133-139.
- [4]. L.N. Hannett, Afzal Khan, "Combustion Turbine Dynamic Model Validation Tests," IEEE Transactions on Power Systems, 8 (1993) 152-158.
- [5]. S.R.Guda, C.Wang, M.H.Nehrir, "Modeling of Microturbine Power Generation Systems, Electric Power Components and Systems," 34 (2006) 1027-1041.
- [6]. S.Balamurugan, R.Joseph Xavier, A.Ebinezer Jeyakumar, "Simulation of Response of Gas Turbine Plant with Controllers," Proceedings of National System Conference, Manipal, India 2007, ref no. P105.
- [7]. S.Balamurugan, R.Joseph Xavier, "Selection of Governor for Heavy Duty Gas Turbine Power Plant," National Conference on Modern trends in Electrical and Instrumentation systems, Coimbatore, India 2005, 365 - 371.
- [8]. S.Balamurugan, R.Joseph Xavier, A.Ebinezer Jeyakumar, "Selection of Governor and Optimization of its Droop Setting and Rotor Time Constant for Heavy Duty Gas Turbine Plants," Indian Journal of Power and River Valley Development, 57 (2007) 35-37.
- [9]. M.Gopal, "Control Systems Principles and Design," Second Edition, Tata McGraw Hill, 2002.
- [10]. J.G.Ziegler, N.B.Nichols, "Optimum Setting for Automatic Controllers," Transactions of ASME, 64 (1942) 759-768.
- [11]. D.E. Goldberg, "Genetic Algorithms in Search, Optimization and Machine Learning," Addison Wesley Longman, Inc., 1989.
- [12]. L.A.Zadeh, "Fuzzy Sets," Inform. and Control., vol. 8, (1965), 338-353.
- [13]. MATLAB User Manuals, Mathworks Inc., USA, 2000.

**S.Balamurugan** received his B.E. degree in Electrical and Electronics Engineering from Annamalai University, Chidambaram, India in 2001 and M.E. in Power Systems from Annamalai University, Chidambaram, India in 2002. He is working as Senior Lecturer of Electrical and Electronics Engineering department at Amrita School of Engineering, Coimbatore, India. He is doing research in the area of Power System Control at Anna University, Chennai, India. His areas of interest are power system control, fuzzy logic, neural networks and genetic algorithm.

**R.Joseph Xavier** graduated from Madras University, India in 1972 receiving B.E. in Electrical and Electronics Engineering. He also received his M.E. in power systems from Madras University, India in 1975. He received his Ph.D. from IIT-Madras, Chennai, India in Power Systems and High Voltage Engineering in 1990. He is having 33

years of teaching and research experience, out of which 10 years in administration. His areas of interest are power systems and high voltage engineering.

**A.Ebenezer Jeyakumar** received his B.E. in Electrical and Electronics Engineering from Annamalai University, India in 1972. He got his post graduation from College of Engineering, Guindy, India in 1974 receiving M.E. in Electrical Engineering. He also received his Ph.D. from Anna University, India in 1992 in High Voltage Engineering. His Areas of interest are power system, high voltage engineering, soft computing techniques and hybrid intelligent system application to power system control problem.

**Contact Address:**

S.Balamurugan,  
Senior Lecturer,  
Department of Electrical & Electronics Engineering,  
Amrita School of Engineering,  
Coimbatore, Tamilnadu, India.

Phone Number: +91-98653-48580

Email Id: [s\\_balamurugan@ettimadai.amrita.edu](mailto:s_balamurugan@ettimadai.amrita.edu)  
[s\\_bala\\_eee@rediffmail.com](mailto:s_bala_eee@rediffmail.com)