Fuzzy Logic Controlled Microturbine for Distributed Generation Systems Application

Sanjeev K Nayak and D. N. Gaonkar, *Member, IEEE*

Abstract- **The advance development and successive operation of microturbine as distributed generation resulting in commercial and scientific approach is due to its flexible control and reliable operation. There are several advance methods to control the speed of microturbine, but still lack of in the research field of microturbine anti interference problem has been not solved due to very high speed. To interface the microturbine model, this paper investigates the fuzzy logic based speed governor of the microturbine as an alternative to nominal PI controller or lead lag based transfer function system. The development of fuzzy logic based speed governor includes the membership function with input and output relations, which improves the stability of the microturbine system through load change and robust simulation. The superior performance of this type of governor is compared with lead lag base transfer function governor. This model is developed in the MATLAB/Simulink system library**.

Keywords, **Microturbine, Fuzzy Logic Controller, Speed Governor.**

I. Introduction

The control algorithms based on fuzzy logic have been implemented in many processes. The application of such control technique have been encouraged because of several reason such as it improves the robustness over the conventional linear control algorithm, simplified control design of a difficult system module into simplified implementation [1].

The microturbine is one of the most promising alternative sources that demonstrate high potential to meet the user need as a distributed generation and delivering the quality power. They are one part of general evolution in gas turbine technology, techniques incorporated into the larger machine to improve the performance can typically found in microturbines as well. The recuperation, low NOx technologies, and the potential use of advanced material such as ceramics for hot section parts [2].

Sanjeev K Nayak is a full time research scholar in the Department of Electrical and Electronics Engineering, at National Institute of Technology Karnataka Surathkal, Mangalore-575025 Karnataka, India (e-mail: saneevnayak_82@yahoo.co.in).

D. N. Gaonkar, is an Asst. Professor in the Department of Electrical and Electronics Engineering, at National Institute of Technology Karnataka Surathkal, Mangalore-575025 Karnataka, India (e-mail: dngaonkar@ieee.org).

The microturbine has many advantages like durability, greater efficiency, power quality, reliable operation, low emission and fuel flexibility. The microturbines are developed with advanced technology of turbo-chargers, gas turbine and auxiliary system. Microturbines are simple and small gas turbine which consists of components like compressor, combustor, turbine and recuperator to increase the efficiency. The atmospheric air is compressed with high pressure by the compressor, thus compressed air mixes with the fuel and this mixture is ignited in combustor to increase the pressure of gas which in turn is utilized to run the turbine.

The mathematical model of microturbine generator is complex and very strong nonlinear, and there is strong interference due its speed, so it difficult to control it. The nonlinear control methods based on model cannot solves various control problem in microturbine, some of the advance control have been applied to control the microturbine such as lead lag transfer function controller(governor) PI controller or PID controller [3].

In conventional control, the amount of control is determined in relation to number of data inputs using a set of equation to expresses the entire control processes. Conveying this to human knowledge in the form of mathematical equation is a bit difficult task otherwise may not be possible, fuzzy logic provides a simple tool to interpret into the reality.

This paper presents the fuzzy logic based microturbine speed governor for various loading and unloading operations. A comparative study has been made between the conversional lead lag transfer function governor and fuzzy logic based speed governor. The simulation results clearly demonstrate the superiority of fuzzy control over the lead lag transfer function. The functioning of fuzzy logic based speed governors and transfer function generates transients on loading and unloading.

II. Microturbine

There are basically two types of microturbine designs, one is high speed single shaft microturbine where the compressor and turbine are mounted on the same shaft and rotates at a speed of 50,000 to 120,000 rpm. The frequency of generated voltage is around 1.5 to 4 KHz. However, to reduce the frequency to 60Hz or grid frequency the power electronic converters and inverters are used towards the load side. Another type of microturbine design is split shaft microturbine which uses the rotating power at 3600 rpm and the conventional generator is connected through a gear box. These two are small scale generation turbine [4] [5]

The simplified single shaft microturbines with control system is show in fig.1, The model consists of temperature control, fuel control, turbine dynamics, speed governor, and acceleration control blocks. This model mostly works for the control of slow dynamics. It is presumed that all other operations are under normal condition excluding the fast dynamics.

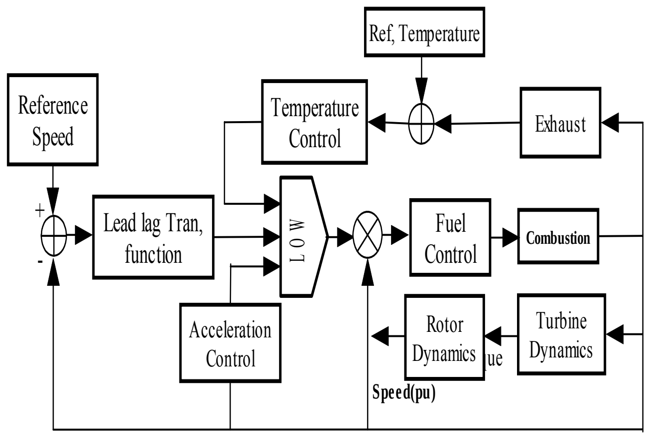

Fig. 1. Block diagram of microturbine.

A. Speed Contrller

Speed control is running of the microturbine under part load condition. It operates on the error formed between the reference speed and operating speed. It is operated mostly lead lag transfer function or by PID controller, in this type of functioning fuzzy logic based speed governor is implemented.

B. Acceleration Controller

The primary use of the acceleration controller is to limit the rate of rotor acceleration before it reaches its operating speed during start up. If the operating speed is close to the rated speed then acceleration controller is eliminated. The output of the governor goes to min value selector to decide the value of fuel demand signal.

C. Temperature Control

The other signals received by the low value selector from the temperature controller and thermocouple output, forces the output of temperature control to stay at maximum limit, permitting uninhibited governor/speed control. When the thermocouple output exceeds the reference temperature, the difference is negative. The fuel flow is reduced for burning in the combustor resulting in turbine torque and the exhaust gas temperature is measured by the thermocouple. The thermocouple output is compared with reference value, normally the reference value is greater then the temperature control output. To limit the rated output, the governor output formed value will pass through the low value selected [6] [7].

III. PI CONTROLLER

To achieve the dynamic performance and to provide accuracy, PI controller or lead lag transfer function is used. The main theme behind the controller is to actuate the rotor speed and reference speed until the deviation becomes zero. Integral controller provides zero steady state speed deviation and proportional controller reduces overshoot. The speed controller is based on tie line bias control where each area tends to reduce the Area Control Error (AEC) to zero.

The controller signals are

$$U_1 = -K_p * ACE_1 - K_i \int ACE_1 dt \qquad (1)$$

$$U_2 = -K_p * ACE_2 - K_i \int ACE2 dt \qquad (2)$$

Where K_P and Ki are proportional and integral gains, respectively for a PI controller the gain K_p and K_i has been optimized using integral square error criterion [8].

IV. FUZZY LOGIC APPROCH

The concept of fuzzy logic was developed by Lofti A. Zadeh (1965), which is widely, exists in modern engineering problems now a day. Zadeh processes were to approach emphasis modeling uncertainties that arises commonly in human thought processes. The first fuzzy controller was developed Mamdani and Pappis type in 1977 to control the steam engine and later used it for fuzzy traffic lights control. The method of fuzzification has found increased application in the control systems. The application of fuzzy sets signifies a major enhancement of control systems analysis by avoiding heuristic assumption in practical cases. This is because fuzzy sets have deployed property to represent the control system uncertainties. The advantage of fuzzy logic is that the controller is based on heuristic and able to incorporate human intuition and experience [8].

Fuzzy logic is a new control approach with good attention and potential for real time applications, fuzzy logic controller is rule based controller where a set of rules represents a control decision mechanism to correct the effect of certain cause used for generation systems. In fuzzy logic, the linguistic variables are expressed by

Fuzzy sets defined on their respective universe discourse, to over come the difficulties of soft controller fuzzy logic found to be effective alternating to conventional control techniques,

The configuration of fuzzy logic is representation of system in four parts [1]-[9].

- Fuzzification – This has two functions i) to read, measure and scale the control variable and; ii) to transform the measured numerical values to the linguistic.
- Knowledge Base - Defines membership function for each control variables and the applicable rule to specify control goals using linguistic variables.

- Interface Mechanism - Simulates human decision making and influencing the control action based on fuzzy logic.
- Defuzzification - Converts the inferred decision of the linguistics variables from the numerical values.

The lead lag transfer function compensator is replaced by the equivalent fuzzy logic based speed governor, the design of PI-like fuzzy knowledge base controller works on the Area Control Error (ACE) and change in area control error (ΔACE) is considered as input to the fuzzy logic controller. The basic structure of the conventional PI controller is given by

$$U = K_{pe} + K_i \int edt \quad (3)$$

Where Kp and Ki are the preoperational and integral gains respectively and 'e' is the error signal. Taking the derivative of 'U' with respect to time equation (3) can be transformed into the following equivalent expression.

$$Uo = Kpeo + Kie \quad (4)$$

For automatic generation control problem the input to the fuzzy controller for i^{th} area at particular instant are ACE_i *(t)* and ΔACE_i *(t).*

Where

$$ACE_i(t) = \Delta P_i e_i + B_i \Delta f_i \quad (5)$$

$$\Delta ACE_i(t) = ACE_i(t) - ACE_i(t-1) \quad (6)$$

An output of fuzzy controller is ΔU, this is in accordance with (3) for a PI type of controller. The input and output are transformed into linguistic variables as VHS: Very High Speed, HS: High Speed, NC: No Change, NS: Normal Speed, LS: Low Speed, VLS: Very Low Speed, LN: Large Negative, N: Negative, P: Positive, LP: Large Positive, CLS: Close, OPN: Open, OPN_FST: Open Fast, CLS_FST: Close Fast, LP: Large Positive - respectively. All the variables of ACE, ΔACE and ΔU are considered in a symmetrical triangular membership function. The membership function of ACE over the operating range of minimum and maximum values of ACE is shown in fig.2 and fig.3

The membership function would perform a mapping from the crisp values to a fuzzified value, as shown in fig 2. One such particular crisp input ACE is converted to fuzzified value i.e. 0.8/VHS + 0.2/HS where 0.8 and 0.2 are membership grade

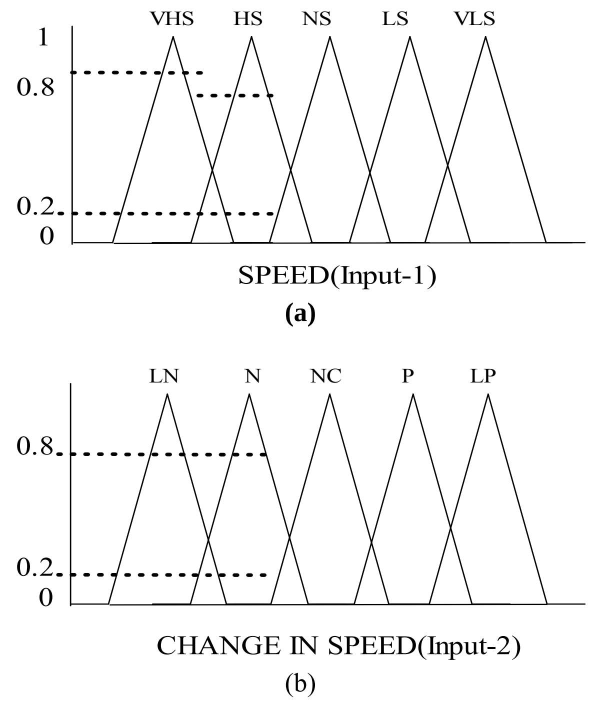

Fig 2 (a) & (b) Inputs of respective membership function.

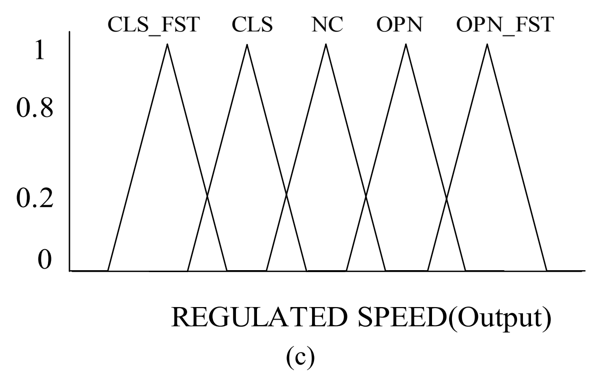

Fig.3 (c) Output membership function.

corresponding to the linguistics variables VHS and HS in fuzzy system. The membership grades are zero for all other linguistic values except VHS and HS.

Here the crisp value input to the system will be converted to fuzzified value considering several membership grades corresponding to each linguistic variable. Same way the other input of ΔACE and ΔU are fuzzified.

The output of the inference mechanism is a fuzzy value, and hence it is necessary to convert the fuzzy value to (crisp) real value sine, the physical process can't deal with fuzzy values. This operation which is inversely fuzzified is known as defuzzification. The well known centre of defuzzification method has been used for its simplicity.

The major drawback of Mean of Maximum (MoM) method is that it does not use all the information converted by the fuzzy command and hence it becomes difficult in generating commands that run the system smoothly. The control of ΔU

$$\Delta U = \frac{\Sigma(Membership\,{}^{I}\!/_{P} * Output\,corresponding\,{}^{I}\!/_{P})}{\Sigma(Membership\,of\,{}^{I}\!/_{P})} \tag{7}$$

is determined using the centre of gravity method

$$\Delta U = (\Sigma \mu j * Uj) / (\Sigma \mu j) \tag{8}$$

Where,
μj is the membership value of the lingivustic variables recommending the fuzzy control action,
Uj is the precise numerical value corresponding to the fuzzy control action.
The ΔU obtained from (5) is added with the existing previous signal to obtain the actual output signal U which is given to the microturbine [10].

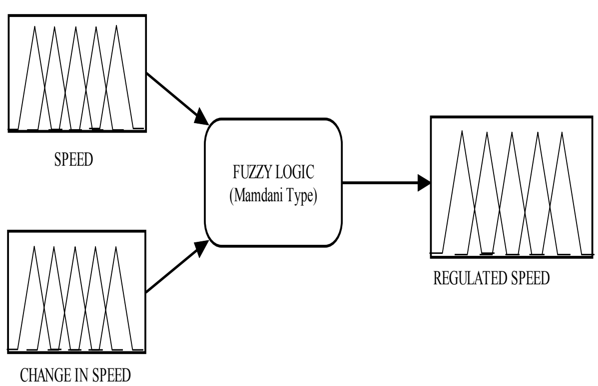

Fig-4 Mamdani type fuzzy rule base.

.

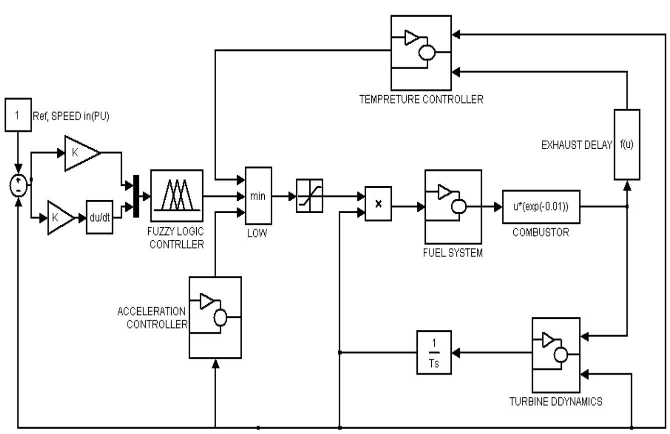

Fig -5 Simulink model of fuzzy controller in microturbine

V. SIMULATION AND RESULTS

Case 1 Lead Lag Transfer function governor
In this case study, the microturbine is governed by the lead lag transfer function, initially the microturbine is running at no load, at time t=45seconds a load is applied on microturbine, the fuel demand is increased with respect to load demand, as show in fig.6 at t=100 second another load is applied on a microturbine, the load torque is increasing along with fuel demand is as shown in fig.7 at t=190 seconds once again the load is increased and the same load is removed at t=315second, hence due to loading and unloading on the microturbine the power varies, as shown in fig.8.

Case 2 Fuzzy logic based speed governor
In this case study the PI Controller is replaced by fuzzy logic speed governor to control the microturbine. Till the load is applied the fuel demand on microturbine is 0.23(pu). The fuel demand, load torque, power output and the performance of fuzzy logic speed governor are shown in fig.6, fig.7 and fig.8 respectively with same time of loading and unloading as in case 1.

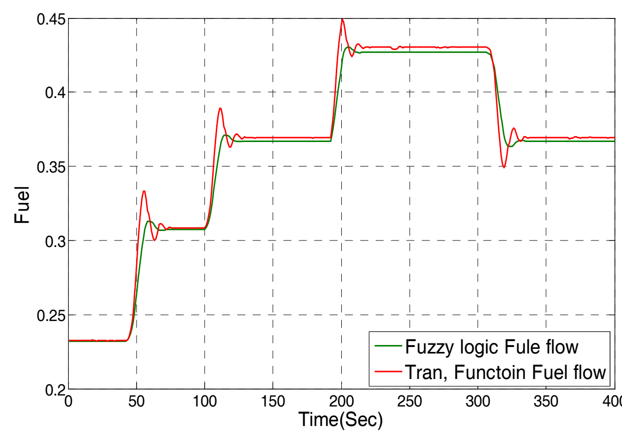

Fig. 6 Fuel demand of microturbine.

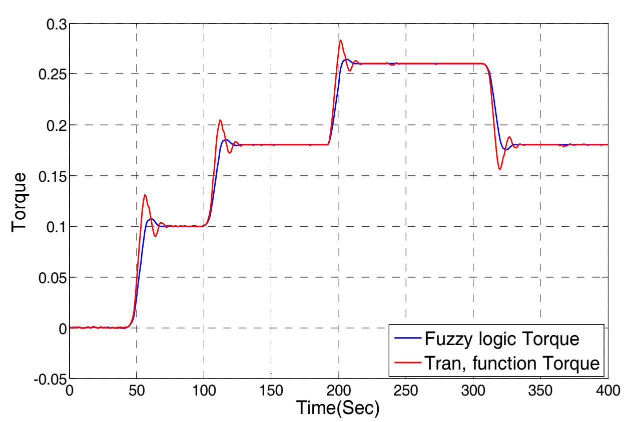

Fig. 7 Microturbine shaft torque.

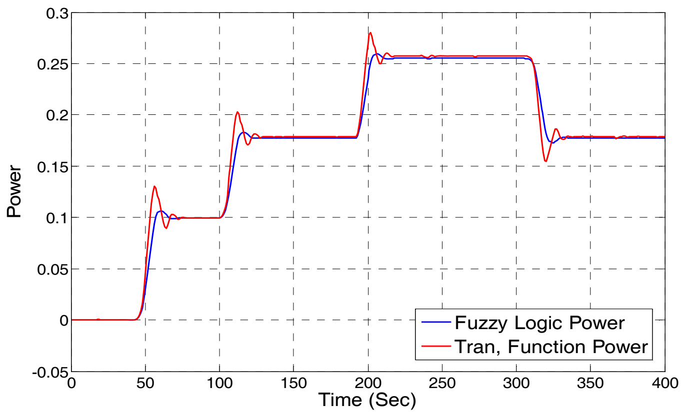

Fig. 8 Microturbine power output.

VI. CONCLUSION

The model of single-shaft microturbine is performed to operate on both lead lag transfer function and fuzzy logic based speed governed microturbine which is simulated and presented here. In comparison to the lead lag based transfer function, the fuzzy logic based speed governor gives clear result of fuel demand, torque output (soft controlling) and smooth operation which has been proved.

The power required to drive the same load is stable and reliable in the fuzzy logic based speed governors as compared to the nominal lead lag transfer function governor.

VII. REFERENCES

[1] Jenica Ileana Corcau and Eleonor Stoenescu "Fuzzy Logic Controller as a Power System Stabilizer" *International Journal of Circuits, system and signal processing*, Issue 3, Volume 1, 2007.

[2] Y. Zhu, and K. Tomsovic "Development of models for analyzing the load-following performance of microturbine and fuel cells" *Electric Power Research* 62 (2002), 1-11, December 7 2001.

[3] Shijie Yan and Xu Wang "Fuzzy control with tracking differentiator for microturbine" *IEEE*, *Sixth international conference on fuzzy system knowledge discovery*, pp.97-101, 14-16 Aug 2009.

[4] Huang Wei, Ziping, Niu Ming, Zhang Jianhua, Guo Yuanbo, and Wu Chong, "Dynamic Modeling and Simulation of Microturbine Generation System for the Parallel Operation of Microgrid"

[5] N. S Sisworahardjo, M. Y El-Sharkh , and M. S. Alam "Neural network controller for microturbine power plants" Electric Power System Research, J(78), V(2008) PP(1378-1384).

[6] D. N. Goankar and R. N. Paterl "Modeling and Simulation of Microturbine Based Distributed Generatin System" IEEE Conference, 2006,

[7] D N Goankar, R N Patel and G N Pillai "Dynamic Model of Microturbine Generation System for Grid connected/Islanding Operation" *Power India Conference*, 2006 IEEE.

[8] B. Anand and A. Ebenezer Jeyakumar "Fuzzy logic based load frequency control of hydrothermal systems with Non-Liberalities" *Internationals Journals of Electrical and Power Engineering*, 3(2), 112-118, 2009.

[9] U. YOLAC and T. YALCINOZ, "Comparison of fuzzy logic and PID controller for TCSC using MATLAB" dept, of electrical and electronics engineering,

[10] C. Srinivas Rao, S. Siva Nagaraju, and P. Sangameswar Raju "Automatic generation control of TCPS based hydrothermal system under open market scenario: A fuzzy logic approach" *Electrical Power Energy System*, Volume.7, pp 315-322, 2009.

VIII. BIOGRAPHIES

Sanjeev K Nayak received his M Tech degree from Kuvempu University Simogga Karnataka India in the year 2007, currently he is pursuing PhD in the Department of Electrical and Electronics Engineering at National Institute of Technology Karnataka Surahakal, His area of research is Distributed Generation, Micro-turbine Generation Systems, and Power Quality.

D. N. Gaonkar (M'2008) received his Ph. D. degree from the Indian Institute of Technology Roorkee, India, in the year 2008. He was a visiting research scholar at the university of Saskatchewan Canada in the year 2008. He has published papers in international journals and conferences. Presently he is working as an Assistant Professor in the Department of Electrical Engineering, National Institute of Technology Karnataka, Surathkal, India. His research interests are in the area of power system operation and control, power electronics and distributed generation systems.