# Governor Controllers of Heavy-Duty Gas Turbine Performance Comparison using PI-Controller and Fuzzy Logic Controller

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***Abstract** – In gas turbine system, Governor controller plays an important role in the dynamic behavior of turbine system for automatically regulating the supply of fuel with respect to load and although to limiting the speed. Need of gas turbines and its applications nowadays more prominently increasing due to technology improvement towards their countries development is the main cause for it. So the controller system used in gas turbine system in various applications effective response must be required, for that concern governor system could be model with PI- controller. In which additionally another two methods are used such as Feed-forward and Back-tracing methods to improving the dynamic behavior and response time and also its load rejection response. In order to get better response to improving the stability and load rejection the Fuzzy Logic controller used in the place of PI-controller. So entirely in this paper the comparative response behavior of Heavy-Duty gas turbine system would be observe between PI-controller and Fuzzy Logic controller of governor system model design in MATLAB-SIMULINK platform.*

***Key Words : Gas turbine, governor, PI-controller, Fuzzy logic controller, Turbine exhaust temperature(TET), Inlet guide vanes(IGV) controller.***

## 1. INTRODUCTION

Generally gas turbine system has 3 components such as compressor, combustion chamber turbine and its shown in Fig -1. The operation gas turbine system is explained on the basis of Brayton cycle studied in [2]

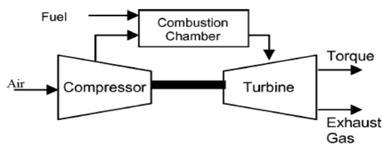



**Fig -1**: Open cycle gas turbine engine.

Nowadays gas turbine system applications increases in various fields such as in aircrafts, trains, ships, industrial sector and also in power generating plants etc. For that concern the flexibility , reliability, efficiency are the main consideration values towards system performance improvement. So the control system techniques are used in the system is effectively working require to eliminating mal-operations. For this purpose, the gas turbine design model can be withstand for different modes of operations and also to maintain stability had required.

Basic design model of gas turbine studied in [2]-[4], in this describe about Rowens model (GAST2A) which is a GE company first initiating model on gas turbine system. The governor controllers especially studied in [1], in which various types of governor controllers described. The fuzzy logic controller design model studied in [5]. The dynamics of the gas turbine system studied in [6] and load frequency control method studied in [7]. The modeling of Heavy duty gas turbine system parameters consider in p.u values.

## 2. TURBINE SYSTEM

In a gas turbine system components such as compressor, combustor, turbine exhaust and control system have steady state and transient behaviors, so this type systems should be model with dynamically

## 2.1 Power Dynamics

The power dynamics of gas turbine system could be model with delay blocks of fuel flow in pipes, combustion chamber and gas flow in hot paths represented by time constant $T_{cc}$ in sec and its transfer function is shown in Fig -2.

The turbine net power function is represented as

$$P_{GT} = A\dot{m_f} - B$$

Here $\dot{m_f}$ is referred as fuel flow, A is a constant, B is referred as power in full speed no load mode.

After substituting parameter values then obtain equation as

$$P_{GT} = 1.22\dot{m_f} - 0.23$$

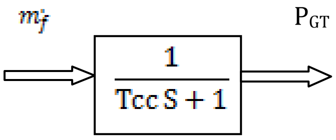



**Fig - 2:** Fuel flow transfer function

## 2.2 Turbine grid interaction system

According to Newton's second law

$$T_J = J\omega_n^2/P_n$$

Here $J$ is he rotor moment of inertia in kg/m², $\omega$ is rotor speed in rad/sec.

By multiplying on both sides by $w$ then

$$P_{GT} - P_{Load} = T_J n\dot{n}$$

and here $T_J = J\omega_n^2/P_n$

$\omega_n$ is the design value of the rotor speed in rad/sec,

$P_n$ is the turbine net power design value,

$T_J$ is the rotor aceleration time,

Which is adjusting by using run up controller in governor system, in order to avoid critical speeds during starting conditions.

## 2.3 Temperature Dynamics

In order to increase the lifespan of gas turbine system, the TIT (turbine inlet temperature) should not be exceed its limits on the design value, otherwise turbine blades deteriorate to causing decrement of gas turbine lifespan. To avoid these obstacles or of its mal-operations by measuring TIT and TET (turbine exhaust temperature) using six thermocouples. The thermocouple transfer function in terms of TIT Fig shown below,

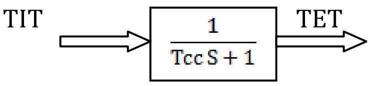



**Fig - 3:** Thermocouple transfer function

According to conservation of energy in gas turbine system using thermodynamics approach, the system equation can be written as

$$\dot{m_a} h_a + \dot{m_f} LHV = P_{turb} + \dot{m_{ex}} h_{ex} + Q_{loss}$$

$\dot{m_a}$ is the air mass flow, $\dot{m_f}$ is the fuel mass flow, $\dot{m_{ex}}$ is the exact gas mass flow, $\dot{m_a}, \dot{m_f}, \dot{m_{ex}}$ units are in kg/s, $h_a, h_{ex}$ are air and exhaust gas enthalpy in J/k, LHV is the low value of fuel in J/kg, $P_{turb}$ is the turbine net power in watts, $Q_{loss}$ is the heat loss.

The above equation general simplified form $T_{ex}$ as

$$T_{ex} = T_a + a + b\ \dot{m_f} + c\ IGV_c + d\ \frac{\dot{m_f}}{IGV_c}$$

Here a, b, c, d are constants.

$$IGV_c = f(IGV, n, \rho_a^*)$$

Here IGV(inlet guide vanes) = output position of $Y_{IGV}$,

n=rotor speed

Speed impact air flow function =1+2(n-1)

$\rho_a^*$ is the air density which is the function of ambient temperature and pressure site conditions.

Generally ambient conditions for HDGT is

Temperature =15°c, Pressure=101.3kpa

The TET function is mainly depends on the air mass flow and fuel mass flow function, so it can be modeled as multivariable system. The turbine model parameters is shown in table 1.

## 3. Governor System

### 3.1 Gas turbine governor system

Gas turbine governor system has three main important tasks such as load Control, frequency control, TET Control and also some sub tasks of controls, those are compressor output pressure gradient (COP) controller, Compressor pressure ratio controller, these are used for within reliable area of operation in gas turbine system. Various types of gas turbine governor system controllers are

1. *Load/Speed controller (Main Controller)*

It controls the frequency and load with respect to mode of operation. The main purpose this controller is to balancing the load requirement of power and frequency deviations. Deviation with respect to load is called the drooping of the system.

2. *Load limit controller*

This controller is used for limiting power permissible values on the base of system rating. By this action will improving mechanical stress in the system.

3. *Pressure Gradient Controller*

Pressure gradient at the rate of valve opening is limited by this controller and although improving thermal stress in the system.

4. *Pressure ratio controller*

The surge limit problem can be avoided by using this controller from the mal-operation conditions.

5. *Temperature controller*

This model generally suitable for base and peak load types of mode of operation. In its operation of control turbine inlet temperature could not be exceeding the maximum or minimum allowable values, which results deformation or creeping on turbine blades reduce, then system perform efficiently. The temperature controller is shown in Fig -6.

6. *IGV controller*

This controller is very important one among the above of them, because dynamic stability on the gas turbine system with respect load mostly depends on it. So its function is to balancing or controlling the required amount of fuel flow with respect to the load.

### 3.2 Main Controller

Main controller has operate in two modes

1. *Load frequency controller*

In this mode of operation input set values as load and speed. During in operation the deviation of load is the droop value to set in the system for maintaining stability, which is the load control mode of operation, it will convert into frequency mode of operation by setting very small dead band and droop values in the governor system.

2. *Load-speed controller*

During no-load condition speed deviation becomes zero, later while applying load the deviation is cause to retarding or accelerating on the rotor. So it will compensated by droop feedback to set it in the input of governor controller put into zero value, this action will accomplish by increasing the speed set point mechanically. This mode is generally used in load rejection , because it is frequency control mode of operation rather than the power variations in the system. The turbine governor model with PI-controller is shown in Fig -8 and its model parameters is shown in table 3.

### 3.3 Fuzzy logic controller (FLC)

In FLC system process has mainly four stages such as fuzzifycation, rule base, inference engine, and defuzzyfication, is shown in Fig -9. In FLC has its input variables are change in speed(Δn) and change in load(ΔP) and output parameter is change of fuel flow controller position. For each input variable 7-linguistic variables are take to completing the designing of FLC. Therefore, total 49 fuzzy sets obtaining with gas turbine operating conditions. Here used mechanism in FLC based on the Mamdani technique. The FLC input and output variables membership function are Gaussian type and triangular type of waves are used is shown in Fig -10, Fig -11, and Fig -12. The rule base controller mechanism table is shown in table 2.

The FLC of a heavy-duty gas turbine (HDGT) model system is shown in Fig -13, like PI-controller of HDGT model with feed-forward and back-tracing methods, in FLC of HDGT model with Feed-forward method only used. This is a simplified model and effective system response has obtain with FLC. In FLC rule base, the control commands or linguistic variables are NB(negative big), NM(negative medium), NS(negative small), Z(zero), PB(positive big), PM(Positive medium), PS(positive small), these are all assigning with respect to Δn and ΔP .

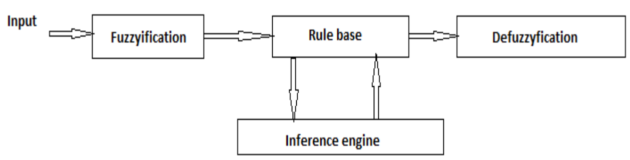



**Fig -** FLC process block diagram

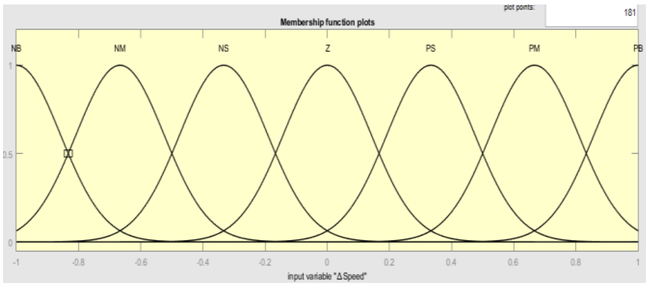



**Fig -** Gaussian membership function for input variable of a change in speed

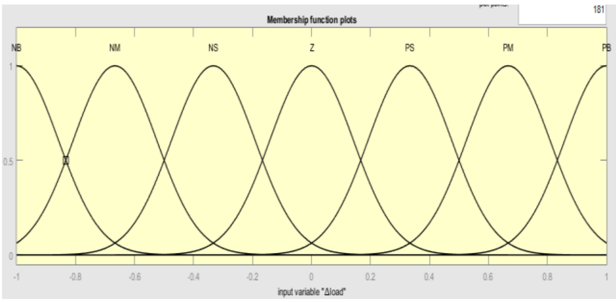



**Fig -** Gaussian membership function for input variable of a change in load

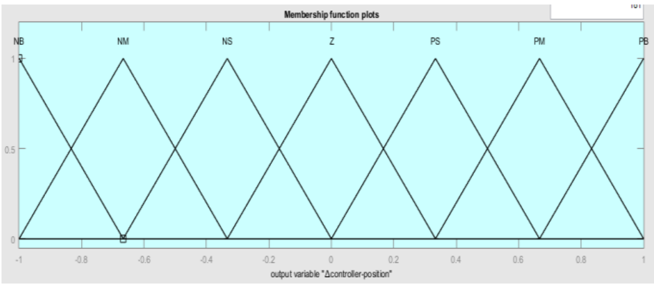



**Fig -** Triangular membership function for output variable of a change in fuel flow controller position

**Table -1:** Turbine Model Parameters

| **Parameter** | **Description** | **Value** |
|---|---|---|
| $C_v$ | Valve Correction | 1.25 |
| $T_J$ | Acceleration time (s) | 22.2 |
| $T_{cc}$ | Combustion time constant(s) | 0.8 |
| $T_{IGV}$ | IGV time constant (s) | 2.7 |
| $C_h$ | Heat transfer coefficient | 0.8 |
| $T_h$ | Heat transfer time constant(s) | 80 |
| $T_{Th}$ | Thermocouple (s) | 5 |

**Table -2:** Rule Base Control Commands

ΔP

Δn

| | NB | NM | NS | Z | PS | PM | PB |
|---|---|---|---|---|---|---|---|
| NB | NB | NB | NB | NM | NM | NS | Z |
| NM | NB | NB | NM | 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 | PM | PB | PB |

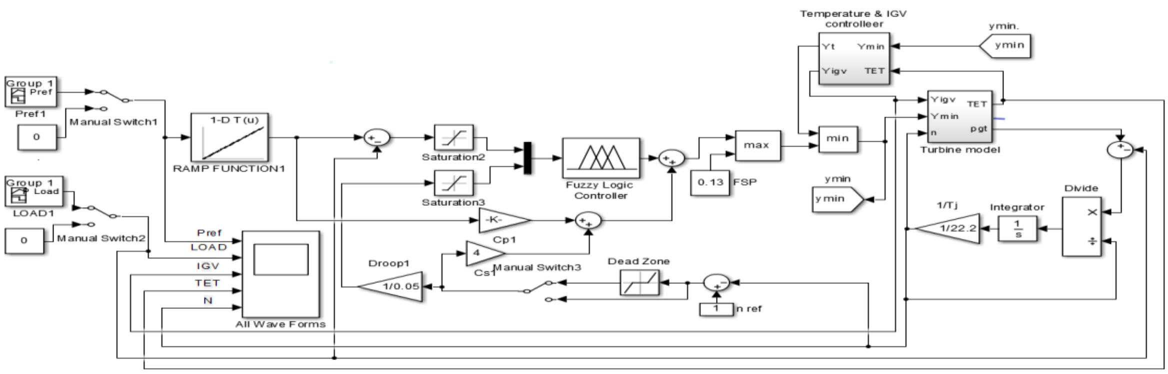



**Fig -** Heavy duty gas turbine model with Fuzzy logic controller

## 4.SIMULSTION RESULTS

**Fig :** Reference power generation

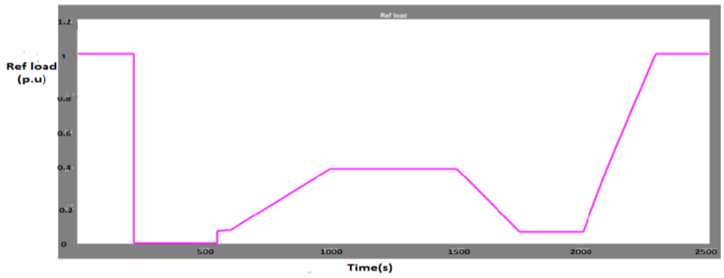


**Fig :** Reference load

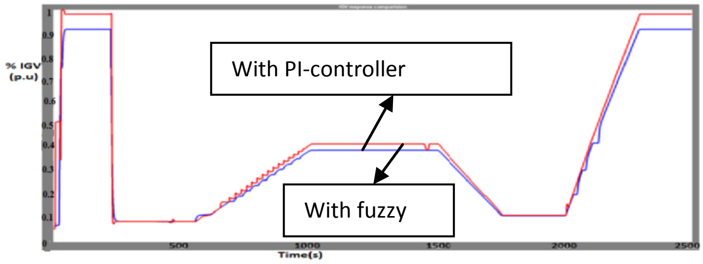



**Fig :** % IGV response Comparison

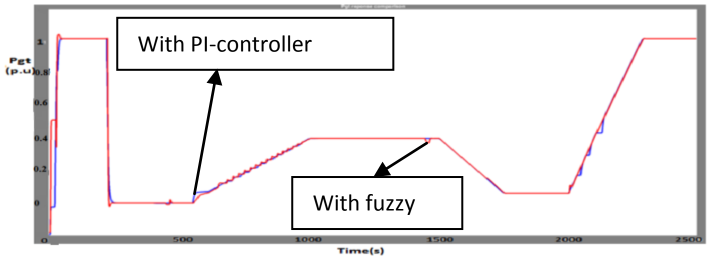



**Fig :** $P_{GT}$ response comparison

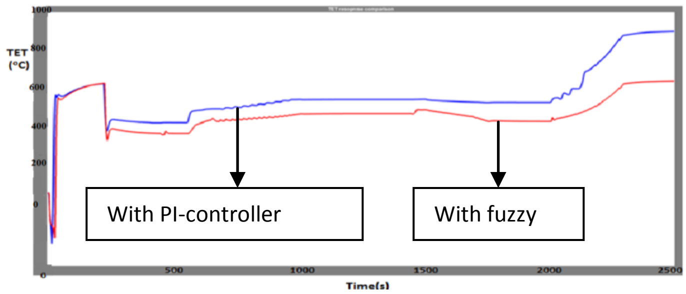



**Fig :** TET response comparison

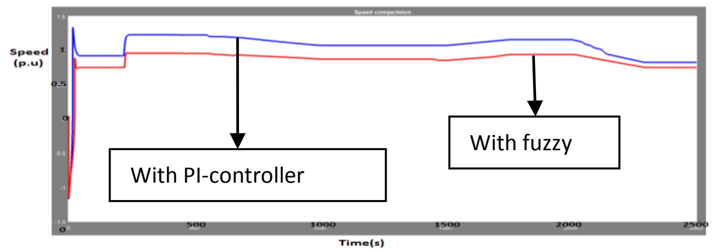



**Fig :** Speed response comparison

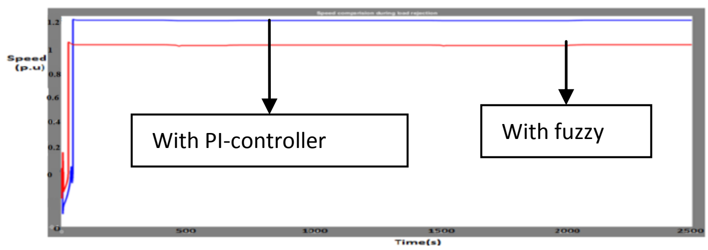
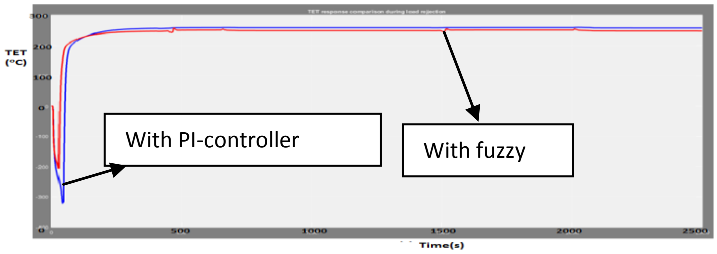



**Fig :** Speed response comparison during load rejection




## 5. CONCLUSION

HDGT design model is suitable for different modes of operation and also with reliable control mechanism used in the governor system. In this paper mainly describing on the comparison of PI-controller and FLC purposes used in governor system was discussed. In PI-controller of HDGT system studied with feed-forward and back-tracing methods, which are used for minimizing of speed overshoots and good IGV delay response purpose. Without using back-tracing method governor system should be handling with FLC to improving the system response. Entirely system physical mechanism also minimized with FLC rather than PI-controller in governor system.

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