Control of Gas Turbine’s speed with a Fuzzy logic controller

Surti Ammar, Ruting Jia
Electrical and Computer Engineering Department
California State University, Northridge
ammar.surti.729@my.csun.edu, ruting.jia@csun.edu

Wenyuan Xiao,
Electrical and Computer Engineering Department
The University of Texas at San Antonio
pfa233@my.utsa.edu

Abstract
A gas turbine generator is widely used across the globe for generating substantial power. There have been different control algorithms applied to control the speed of the turbine at different loads. Most commonly used control system is the PID control which is implemented on a large scale on these turbines. Newer technology has brought into the Fuzzy algorithm to improve the performance of these turbines. This paper presents the application of a Fuzzy logic control algorithm in a better and efficient way to control the gas turbine. The whole system is developed and simulated on MATLAB SIMULINK, along with the comparison showing the effectiveness of the proposed Fuzzy logic control algorithm compared to the traditional PID control.

Introduction
Gas/Diesel generators are usually the choice for power supply in island areas where you don’t have your grids connected. These generators are also good for those places where we have a lot of load shedding and power breakdowns. These generators are also used in industries outside USA where they need extra power due to restrictions on grid power consumption. So, these generators have been and are still being used worldwide to supply primary and backup power for both home and industries. Few of the disadvantages with use of diesel generators are that they require lot of servicing and maintenance. These include regular air and oil filter changes; coolant and coolant filter checkups; fuel filter and ignition system checkups; battery and ignition system checkups, etc. Further, these generators are comparatively expensive and take expertise to install. This installation is recognized as a start up cost, and is more than one fourth of the actual amount of the generator. Further, on the downside, diesel generators do not have clean exhaust when burning fuel like other fuel generators. Lastly, the generators while running are very noisy and have to be installed in areas with noise cancellation arrangement.

Design overview
The design includes a gas turbine with different control algorithms implemented to it. First the gas turbine is implemented using PID control. PID control was implemented using the self designed control parameters and then implemented using the auto tune function in MATLAB Simulink. Both responses are documented. The same gas turbine model control is then designed using Fuzzy logic. Different fuzzy membership functions and rules were applied to see the response of the system. And the best response is documented along with the others. The Fuzzy control depends on two things in the system. One is the “Error” and the other is “rate of change of the error”. The control is designed in a way to reduce the overshoot of the system at startup and a better and a quicker response of the system to stabilize when a load is applied to it. Then once the controller is designed, the gas turbine is then connected to a synchronous generator to produce 3-phase power to supply a load connected. This synchronous generator is set as a swing bus in the POWERGUI block on MATLAB. Any machine is set as a swing bus to make it the primary source of supply.

**Fuzzy logic control**

A fuzzy control system is a control system based on fuzzy logic-a mathematical system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 1 or 0. The diagram shows the block diagram of a fuzzy controller.

![Diagram of Fuzzy Controller](image)

**Fig. 1. Overview of the components for Fuzzy controller**

**Steps involved in fuzzy control**

1. The first step is to the design of a Fuzzy inference structure
2. Then define the Fuzzy Linguistic variables.
3. Create initial fuzzy logic rule base using all available knowledge (expert knowledge) on how the system should work.

4. The final step of designing a fuzzy logic controller is the Off-line debugging. This debugging helps you to understand the response of the fuzzy logic on your system. If you feel you have to make changes to your control, get back to step 1 and start making changes to your control according to your needs for the system. So it is very important to understand and monitor your off line debugging to judge the response of the system.
The system designed on MATLAB has 2 inputs and 1 output. Input is the estimated wind speed to the wind turbine, second input is the state of charge of the battery which is also known as the SOC. Output is linked to the inputs and is found by the Defuzzification method of fuzzy logic. The output is the value which will be fed to the discharge user-defined function show as blew.

Fig. 5. Fuzzy controller for gas turbine model

**POWERGUI BLOCK ON SIMULINK**

The POWERGUI block is a very important block in the SIMULINK library to work with power components in a system. This block is added to simulation when applied with the SIM power system library. Using power electronics devices and machines also require adding the POWERGUI block to the system.

Fig. 6. POWERGUI block
In this block, it’s really easy to modify initial parameters if any of the system. In this case, the synchronous generator is used as a swing bus. Also POWERGUI block could measure voltages and currents and all other variables in much more details and the parameters are defined precisely. State variables can also be set in this toolbox. One of advantage of this tool is updates and computes the values required to run the system smoothly. It does that automatically and updates the values for a better response for the system to work in order.

![Gas turbine model](image)

**Fig. 7. Gas turbine model**

The above block diagram shows the simplified version of the gas turbine. This turbine model is controlled with PID and Fuzzy logic and the results are compared and monitored.

**A. Gas Turbine Model Equations**

- Turbine is represented by the function $f_2$.
  \[
  f_2 = 1.3 \times (W_f - 0.23) + 0.5 \times (1 - N)
  \]

  \(N = \text{Per Unit Rotor Speed}\)

  \(W_f = \text{Output of Fuel System}\)

- The rotor of the turbine is represented by an integrator. In future this integrator is substituted by a synchronous generator.

  \[
  \text{Rotor} = \frac{1}{s}
  \]

- Load is inserted at the turbine side of the system.

- Value positioner and fuel system are represented by these transfer functions:
\[ \text{ValuePositioner} = \frac{1}{0.5s + 1} \]
\[ \text{FuelSystem} = \frac{1}{0.4s + 1} \]

**Gas turbine with PID control**

The above figure shows the PID response of the gas turbine model. The above system response is for the self defined parameters of the PID. If you notice, there are a couple of problems with response:

- There is an overshoot in the system of 0.5.
- The settling time of the system when a load is applied to it is around 7 seconds.

**Fig. 8. PID response of gas turbine model**

**Fig. 9. Self-tuned PID response of gas turbine**
The above figure shows the PID response of the gas turbine model. This response was generated with an auto tune function on MATLAB for the PID. You could find the same problems in the system as for the self designed PID control:

- There is an overshoot in the system of around 0.2.
- The settling time of the system when a load is applied to it is around 10 seconds.
- The important thing is that the self tuned PID has values of around 400, which is not practical when actually implementing the system.

**Gas turbine with Fuzzy logic control**

![Graph showing PID response](image)

**Fig. 10.** Testing with 5 member functions and load at when t = 0 seconds

The fuzzy system above shows the membership functions and rules created initially to get the response of the system. Here we are assuming that the load is applied at time = 0 seconds. These rules were designed accordingly to the assumption.

![Graph showing fuzzy system response](image)

**Fig. 11.** Testing with 5 member functions and load at when t = 50 seconds

The above rules were created with the same membership functions to get the response shown above when a load was applied to the system at t = 50 seconds. Notice that the error in this system is close to 27%, which is not acceptable in any case.
The above simulation was done to get a better system response when a load was applied. Here in this case, 7-membership functions were created so that the system is more sensitive to small changes in values for the error. Any small change in error would result in an abrupt change in the output of the fuzzy with respect to the rate of change of the error. Notice that with this simulation, we achieved an error of about 10% in this system. At full load, the system stabilizes at a speed of around 0.9pu (per unit).

The above picture shows the membership functions used to design for the fuzzy logic control for the gas turbine. There are 2 inputs to the system and 1 output. The first input is the error signal generated with reference to the constant 1 defined in the model. The second input to the system is the change in error signal. This input is the derivative of the error signal and inserted in the fuzzy control. The inputs to the system range from -1 to +1. The output of the system ranges from -10 to 10. We need a larger value at the output of the fuzzy control because the feedback of the gas turbine has a turbine function which multiplies the signal to a larger value, so for that reason we need a larger output from the fuzzy to compensate that value from the turbine.

The following figure shows the reduced rules for the working of the Fuzzy control on gas turbines. These rules were created by constant monitoring of the system with different values and with different outcomes and compared to the output required. These rules now work perfectly with the fuzzy control algorithm designed for the gas turbine.
Fig. 14. Fuzzy rules for gas turbine

Fig. 15. Fuzzy response of the system with 50% load

Fig. 16. Fuzzy response of the system with 80% load

Fig. 17. Fuzzy response of the system with MAX load
The above three figures shows the response of the system with 50%, 80% and 100% loading. But when a full load is applied to the gas turbine operated by fuzzy control. You can notice that there is no overshoot in the system and also it takes around 3 seconds for the system to stabilize to a value which is 4% to an error from the max speed which is 1.

Fig. 18. Gas turbine connected with a synchronous generator

Fig. 19. Subsystem of gas turbine with sync generator

The above Simulink system shows the implementation of the gas turbine model with a 2KVA synchronous generator to produce 3-phase power to supply a 1KW load. The above subsystem is the gas turbine and is shown on Fig. 19.

Fig. 20. Voltage and current at the load
The above figure shows the 3-phase voltage and 3-phase current generated by the synchronous generator to supply the 1 kilowatt load. The synchronous generator is set at a rating of 480Vrms and 2KVA power.

**Summary and Conclusions**

The basic objective of this paper was to design a gas turbine model using simple implementation of Fuzzy logic control. From the above simulation results we can say that the system is stable when different loads are applied to it. Initially for designing the gas turbine with fuzzy control, uniformly distributed 5 membership functions were implemented and simulated. That resulted in a poor response of the system with an error of more than 20% when a load was applied to it. Later on, improved models of the fuzzy control were designed and implemented, but the best results were generated while using 7 membership functions with an edited range and with self defined rules. This resulted in an error of 4% and less. Then when the gas turbine model was connected to the synchronous generator, the 3-phase power produced was also supporting the load as required and expected.

**References**


AMMAR SURTI
Surti Ammar is currently a master student at the Electrical and Computer Engineering Department, California State University, Northridge. His research area is intelligent control and its applications.

RUTING JIA
Dr. Ruting Jia currently serves as an Assistant Professor of Electrical and Computer Engineering at California State University Northridge. Her research interests include nonlinear Control, optimal control, system modeling and controller design in renewable energy area, predictive control of biomedical systems.

Wenyuan Xiao
Wenyuan Xiao is currently a master student at the Electrical and Computer Engineering Department, The University of Texas at San Antonio. His research area is intelligent control and its applications.