Design of a New 2-DOF PID Controller for Gun-san Gas Turbine Generation Plant

Dong Hwa Kim

Abstract - The main role of the gas turbine lies in the utilization of waste heat which may be found in exhaust gases from the gas turbine or at some other points of the process to produce additional electricity.
Up to date, the PID controller has been used to operate under such difficult conditions, but since the gain of PID controller manually has to be tuned by trial and error procedures. Getting a optimal PID gains are very difficult to tune manually without control design experience. In this paper parameter separation type 2-DOF PID controllers are proposed based on the gas turbine control system. Gas turbine transfer function is achieved from operation data of Gun-san gas turbine and Tuning algorithms of parameter separation type 2-DOF PID controller is ANFIS. Results represents satisfactory response.
Key Words - Intelligent control, Neuro control, PID control, Gas turbine control

1. Introduction

The studies on the control of gas turbine have been a subject of interest for many years, since the gas-turbine engines have been widely adopted as peak load candidates for electrical power generation. Especially, the fully automatic start-up function and the fast run-up characteristic of gas turbine systems are very important for peak-load lopping and standby power supply purposes.

The start-up procedure for a modern gas turbine consists of many stages such as, warming up of main steam pipe line, warming up of turbine parts, turbine run-up, synchronization, loading. So, because control procedure is very complicated, the various methods has been studied about control in each step from start-up to run need to have a stability and a safety.[1, 2]

Especially, Start-up and shut-down procedures are the most challenging problems for control applications to develop new control algorithms. They require the sequence of operations to be successfully performed leading a gas turbine and associated power plant components through a sequence of safe states. At the same time many variables must be monitored and checked to ensure safety of operation.

Moreover, minimum time and minimum energy losses during the start-up or run-up procedures would be desirable. But control is especially difficult in case of CC(Combined Cycle) gas turbines because, in this case, interconnections between components occur not only through the electric network but also on the heat exchange side, i.e. flows of gases, and flows of steam.

An effective control is required to maintain system stability following a system disturbance. Failure to do so will cause an inevitable plant shut-down, from which a loss of production and considerable damage to the plant may result. So, there is an increasing demand for a more accurate gas-turbine control technique than those previously studied[1-3], to enable the system response be stabilized and improvements to the associated control system made.

Especially, the various tuning method of the PID controllers, such as fuzzy, neural network, sliding mode in which the simple controller structure has been introduced and studied for improving the performance by allowing controller parameters to vary with local control conditions in the complex start up procedure of gas turbine.

We proposed a new 2-DOF PID controller tuning with the aid of ANFIS(Adaptive Neural Fuzzy Inference Systems) for Gun-san gas turbine.

Especially, in a gas-turbine engine for power plant, since the fuel flow is a true dependent variable with respect to the parameters such as, the compressor discharge pressure, the exhaust gas pressure, the exhaust gas temperature and the exhaust gas power that can give to an effect to efficiency and stability. we need to study the optimum control method of fuel flow in gas turbine.

Also, it is important to note that control loop assignment and set point specifications may differ for these different conditions.

2. Structure and Characteristics of Gas Turbine Control

2.1 Structure Turbine and Characteristics of Gas Turbine

The main components of gas turbine are compressor (multistages) with air inlet, combustor with fuel supply system such as, gas fuel system, oil fuel system, 3-stage turbine, exhaust gas duct, cooling system. The output of

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contemporary gas turbines has electric power in range up to 200 MW, and the outlet gas temperature is about 550℃ when the combustion gas temperature reaches 1200℃. For example fluid flows depend on the power produced, in case of the gas turbine GE Frame 9 the fuel flow is around 9kg/s, the air/fuel ratio is 670% and the water injected to the combustor is around 3.5kg/s at full load)[4].

The main input and output variables for the control of the gas turbine are fuel flow, air flow(or air/fuel ratio), air temperature, water injection flow, parameters of the cooling system as inputs, and electric power produced (or load), frequency (speed of rotation), exhaust gas flow, exhaust gas temperature as outputs. So, when we start-up a gas turbine, the stages of start-up sequence is important for control stability and efficiency.

2.2 Control Technology and Characteristics of Gas Turbine

2.2.1 Sequence Control

Sequence control in gas turbine is associated only with the start-up or shutdown of each component of plant. For example, a fuel supply system cannot be started until a supply of lubricating oil has been provided for the bearings for safety. In case of large items of plant, because the associated sequences can be more complex, we should not operate if the overall plant performance is not to be adequate to meet the system demand. The main problems to be overcome in sequence control are the unreliability of signal and the diagnosis of failures.

2.2.2 Total Control Loop

The main control task in power plant is to control the balance between generator and load. This can be realized by measuring and monitoring the output frequency and the input parameter of each stage. If the frequency increases power produced is above the demand. Similarly, a frequency drop means that the power production is not sufficient. A frequency stabilization is the main control task of main controller and a load and frequency are adjusted by changes in fuel flow. Since the fuel flow is also used to control the inlet gas temperature, in the long run, the fuel flow regulates load and frequency and at the same time, the exhaust gas temperature. Moreover, the temperature control system can override the frequency or load control.

The turbine fuel system consist of two subsystems, that is, gas fuel system and oil fuel system. Most gas turbines also use inlet guide vanes to reduce load down to around 80% and maintain high efficiency. So, fuel flow, oil flow, gas temperature, guide vane opening is very important parameter in gas turbine.

2.2.3 Other Control Loops

In gas turbine control systems, there are many kinds of control loop such as, control of fuel flow to achieve a desired load, control of fuel/air ratio, to provide a correct output gas temperature, control of injected water flow to avoid NOx emission, control of lubricant oil flow and temperature, control of inlet guide vanes, condenser controls,

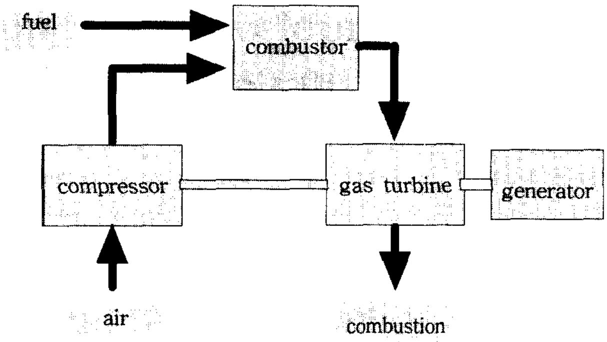
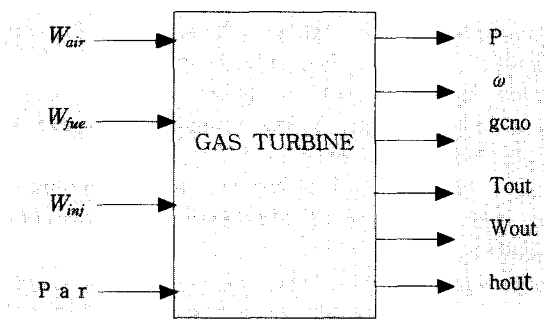


Fig. 1(a) The structure of gas turbine



W_{air} = air flow to the turbine,
W_{fuel} = fuel flow to the turbine
W_{inj} = steam(water) injection flow,
Par = enthalpy, density, pressure and temperature of inlet air, temperature of injection liquid,

Fig. 1(b) Control parameter of gas turbine

Fig. 1 The structure and the control parameter of gas turbine

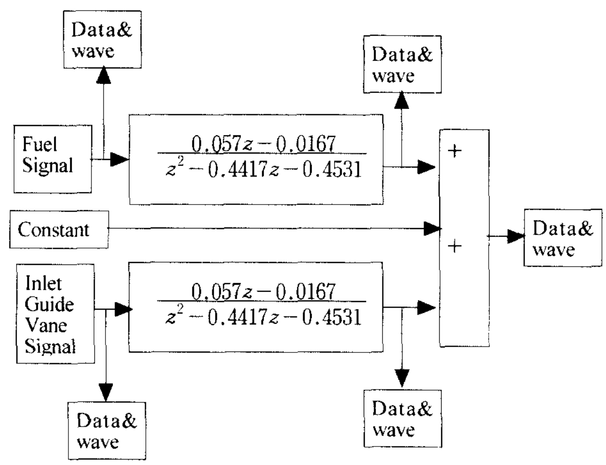


Fig. 2 Transfer function of Gun-san

feedwater system controls, controls for safety conditions.

Recently, DCS system is using in the gas turbine and applications software for control and monitoring is specifically related to the main task of configuring a DCS. The DCS usually contains a library of simple operations like a PID or lead/lag algorithm but it cannot extend to complex control algorithms and intelligent control system facilities.

3. PID Controller in Gas Turbine

The three-mode PID controller is widely used in plants due to ease of control algorithms and tuning in the face of plant uncertainties. Neverthless, the PID algorithm might be difficult to deal with processes or gas turbine plant with complex dynamics such as, those with large dead time, inverse response and highly nonlinear characteristics or complex control sequence.

Up to date, many sophisticated tuning algorithms have been used to improve the PID controller work under such difficult conditions.

On the other hand, it is important to how operator decide the gains of PID controller, since the control performance of the system depends on the parameter gains. Most control engineers can tune manually PID gains by trial and error procedures. However, PID gains are very difficult to tune manually without control design experience.

4. New 2-DOF Controller for Gas Turbine

4.1 Filler Parameter Separation Type 2-DOF PID Controller

A new 2-DOF PID controller proposed in this paper is designed to separate two degree parameter α, β into two part as shown in Fig.3. where, the transfer function of between process value PV(s) and settling value SM(s), process value PV(s) and disturbance DV(s) is given as the following equations, respectively;

$$G_{PVSV}(s) = -\frac{PV(s)}{SV(s)} = \frac{K_p(1+\frac{1}{T_i s})\alpha(\frac{a}{T_f s+b})}{1+(K_p+\frac{1}{T_i}s)-T_d s\ G(s)} \quad (1)$$

$$\frac{DV}{SV} = \frac{G(s)}{1+(K_p+\frac{1}{T_i}s)-T_d s\ G(s)} \quad (2)$$

In equation (1), the process value PV(s) depends on the two degree parameter α, filter parameter T_f, a, and b. However, numerator is the same as the conventional PID controller. Since integral time is $T_i T_f$, it is affected by filter gain. The proportional gain is also affected by the filter parameter a and two degree parameter α, respectively.

The disturbance is controlled by conventional parameter K_p, K_i, K_d and the load following function of settling value can be precisely improved by tuning filter and two degree parameter. The structure of controller with respect to Gun-san gas turbine is represented as Fig. 3.

4.2 Tuning of 2-DOF PID Controller by Neural Network

Generally, ultimate method, Z&N method are used for tuning of 2-DOF PID controller. where. we use a tuning method by ANFIS(Adaptive Neural Fuzzy Inference).

5. Application to Gun-san Gas Turbine

5.1 Transfer Function of Gas Turbine Control System by Operating Data

The transfer function based on the operating data of Gun-san combined gas turbine generation plant is acquired as the above equations (1 ~ 2) and operating response characteristics is like Fig. 4.

To compare the characteristics of these controller such as, PID, 2-DOF PID, new 2-DOF PID, we adapted these controller to transfer function based on the operating data of Gun-san turbine.

5.2 Simulation and Discuss

5.2.1 PID Controller in Gun-san Gas Turbine

Fig. 5 shows the response of each parameter by a operating data during start-up, runing, and stop procedures in case of without any control in Gun-san gas turbine. Where, FS is fuel signal, FF is fuel flow GT is gas temperature. IGVO is inlet guide vane opening.

Fig. 6 illustrates the response of each parameter for only start up process. As we can see in Fig. 6, Fuel flow(FF) does not follow flow signal(FS) well and gas temperature(FGT) depends on the guide vane opening and the fuel flow. Fig. 7 ~ Fig. 10 is the response of applying PID controller to a fuel flow of gas turbine control system.

Fig.7 is in case of P=1.24, I=0.01, D=0 and Fig.8 is in case of P=1.35, I=0.01, D=0.1. In Fig.7, in case of D=0, FF is having a stable shape against FS's disturbance but as D value increases, FF do not follow FF well in running part. So, if we use PID controller in start-up and running of gas turbine, we figure out that we can not control satisfactorily by PID controller. Fig.9 represents the response in case of application PID controller to a temperature control loop of gas turbine. As we know from this figure, fuel is not controlled. Also, Fig.10 in case of total feedback(fuel flow signal+gas temperature signal+guide vane signal) is

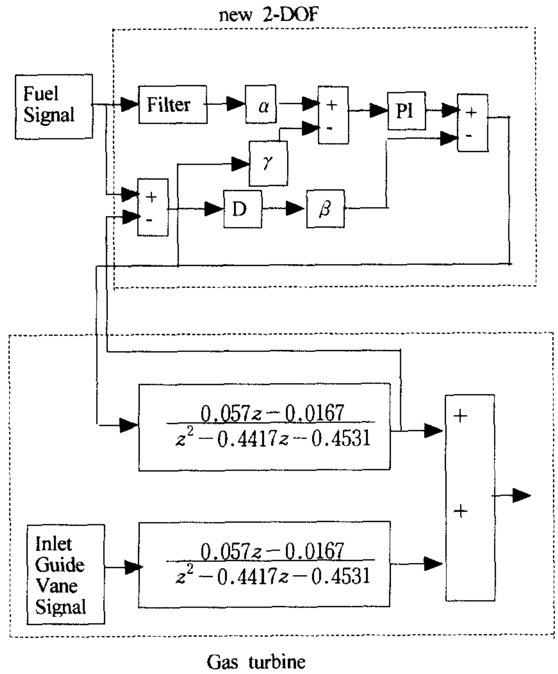


Fig. 3 The structure of Gun-san gas turbine control system with a new 2-DOF PID controller

not controlled.

5.2.2 The Conventional 2-DOF PID Controller in Gun-san Gas Turbine

Fig.11～13 illustrate the response in case of application the conventional 2-DOF(Two Degree Of Freedom) PID controller to gas turbine control system.

In Fig.11, in case of I=0.01, FF is having a stable shape against FS's disturbance and stable but as the I value increases, FF do not follow FF well in running part. So, if we use 2-DOF PID controller in start-up and running of gas turbine, we figure out that we can not control satisfactorily by 2-DOF PID controller.

Also, we can know that Fig.13 in case of total feedback(fuel flow signal+gas temperature signal+guide vane signal) is not controlled.

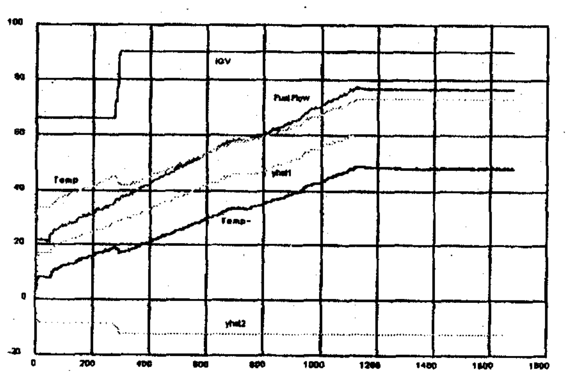


Fig. 4 Response of Gun-san gas turbine based on a operating data

5.2.3 A New 2-DOF PID Controller in Gun-san Gas Turbine

Fig.14～24 illustrate the response in case of application a new 2-DOF PID controller to gas turbine control system. From figure 12～19, even if parameter value P, I, D, α, β, γ change, the response of fuel flow is very stable in spite of the disturbance of fuel signal.

Especially, from figure 18, 20 in case of applying 2-DOF PID to gas turbine temperature loop, All parameters are having a stable response.

On the other hand, we can see that Fig.21, 22 in case of total feedback(fuel flow signal+gas temperature signal + guide vane signal) is controlled well but in case of PID, the conventional 2-DOF PID, it was not controlled in feedback loops.

So, we can see a new 2-DOF PID controller that we proposed in this paper is having a good characteristics against the PID and the conventioal 2-DOF PID controller.

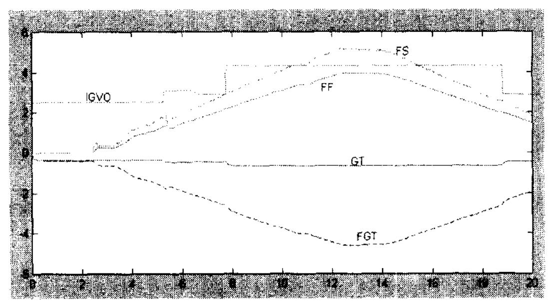


Fig. 5 A varying characteristics of each parameter in Gun-san gas turbine
(start up, running, stop process)

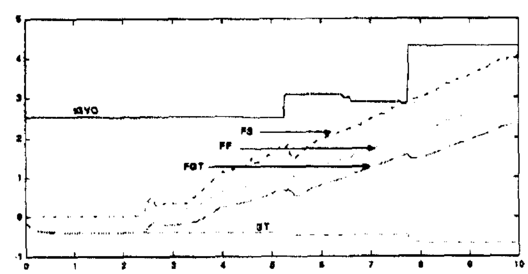


Fig. 6 Gas turbine response during start up by the conventional controller

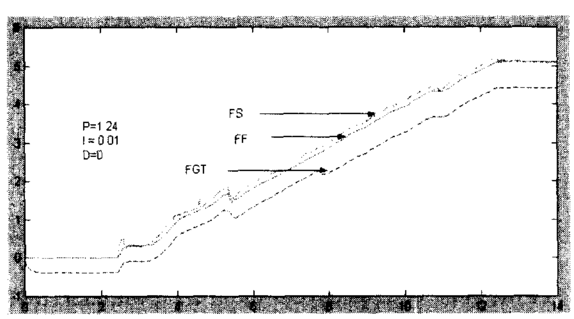


Fig. 7 Results in applied PID controller to fuel system of Gun-san gas turbine (P=1.24, I=0.01 D=0)

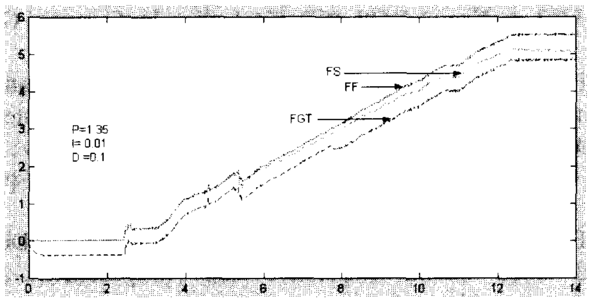


Fig. 8 Results in applied PID controller to fuel system of Gun-san gas turbine (P=1.35, I=0.01 D=0.1)

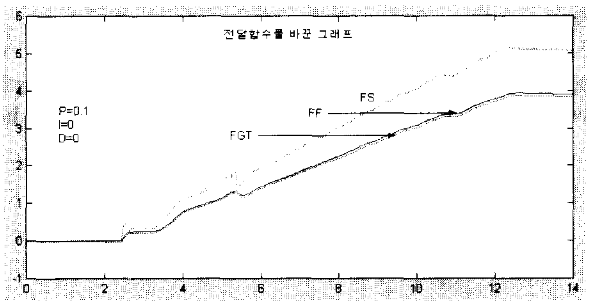


Fig. 9 Results in applied PID controller to fuel system of Gun san gas turbine

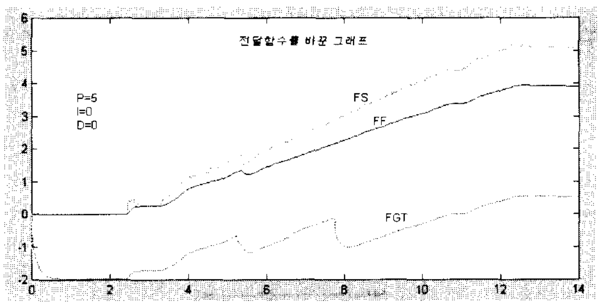


Fig. 10 Results in applied PID controller to gas temp. system of Gun-san gas turbine

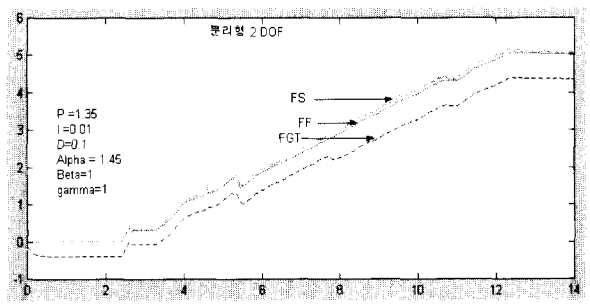


Fig. 11 Results in applied 2-DOF PID controller to fuel system of Gun-san gas turbine (P=1.35, I=0.01, D=0.01, α=1.45, β=1, γ=1)

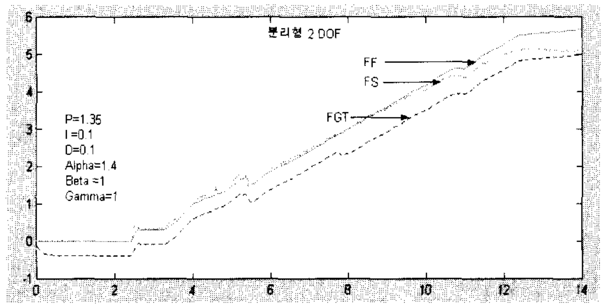


Fig. 12 Results in applied 2-DOF PID controller to gas temp. system of Gun-san gas turbine (P=1.35, I=0.01, D=0.1, α=1.4, β=1, γ=1)

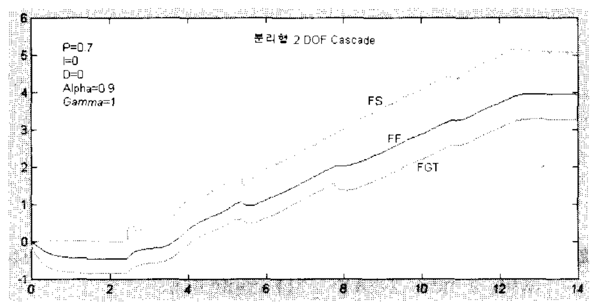


Fig. 13 Results in applied 2-DOF PID controller to total feed systeml loop of Gun-san gas turbine

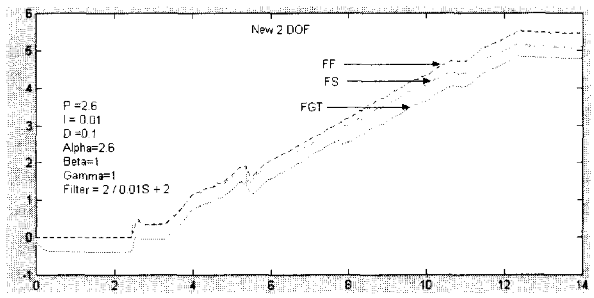


Fig. 14 Results in applied a new 2-DOF PID controller to fuel loop of Gun-san gas turbine (P=2.6, I=0.01, D=0.1, α=1.6, β=1 γ=1)

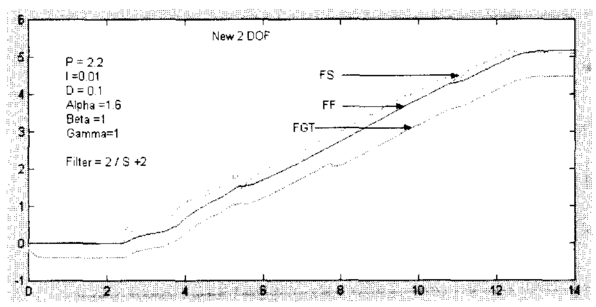


Fig. 15 Results in applied a new 2-DOF PID controller to fuel loop of Gun-san gas turbine(P=2.2, I=0.01, D=0.1, α=1.6, β=1 γ=1)

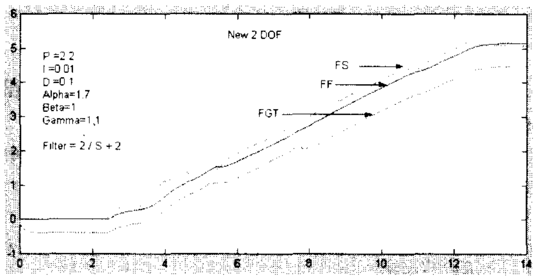


Fig. 16 Results in applied a new 2-DOF PID controller to fuel loop of Gun-san gas turbine(P=2.2, I=0.01, D=0.1, α=1.7, β=1, γ=1.1)

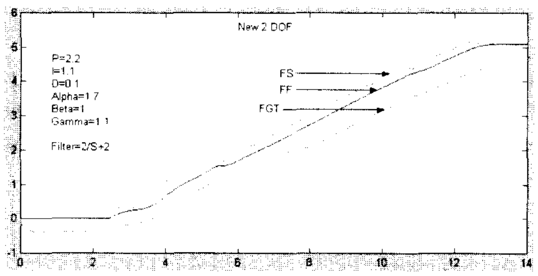


Fig. 17 Results in applied a new 2-DOF PID controller to fuel loop of Gun-san gas turbine(P=2.2, I=1.1, D=0.1, α=1.7, β=1, γ=1.1, 2/(s+2)))

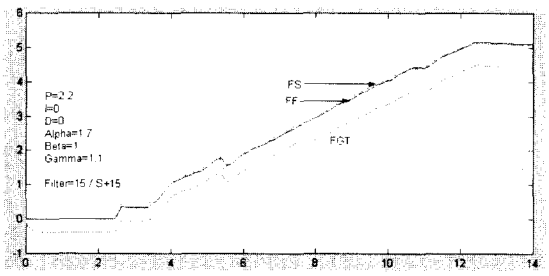


Fig. 18 Results in applied a new 2-DOF PID controller to fuel loop of Gun-san gas turbine(P=2.2, I=0, D=0, α=1.7, β=1, γ=1.1, 15/(s+15))

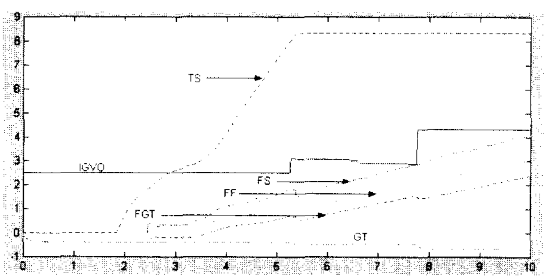


Fig. 19 Results in applied a new 2-DOF PID controller to gas temp. loop of Gun-san gas turbine

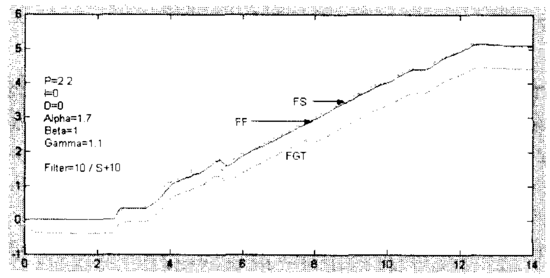


Fig. 20 Results in applied a new 2-DOF PID controller to gas temp. loop of Gun-san gas turbine

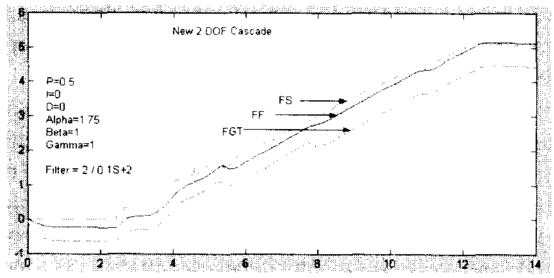


Fig. 21 Results in applied a new 2-DOF PID controller to total feedback loop of Gun-san gas turbine (P=0.5, I=0.0, D=0.0, α=1.75, β=1, γ=1.1, 2/s+0.1s+2))

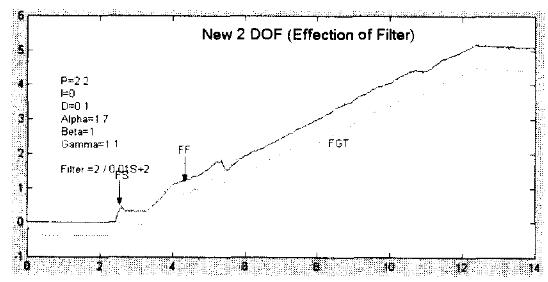


Fig. 22 Results in applied a new 2-DOF PID controller to total feedback loop of Gun-san gas turbine (P=2.2, I=0.0, D=0.1, α=1.7, β=1, γ=1.1, 2/(0.01s +2))

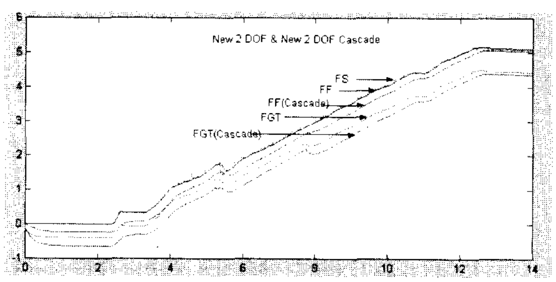


Fig. 23 The comparison of results in each application method of a new 2-DOF PID controller to Gun-san gas turbine

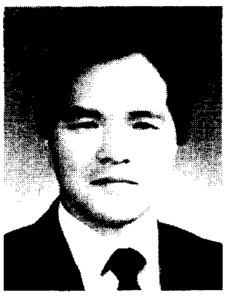
6. Conclusion

Since the efficiency of the gas turbine plant increases reaching over 50%, while the traditional steam turbine plants is approximately 35%~40% or so, The gas turbine in power plants play an important thing to reduce losses of energy.

Up to date, the PID controller has been used to operate in these systems. However, getting a optimal PID gains are very difficult to tune manually without control design experience, since the gain of PID controller manually has to be tuned by trial and error procedures.

In this paper, parameter separation type 2-DOF PID controllers are suggested based on the gas turbine control system. Its transfer function is achieved from operation data of Gun-san gas turbine.

This control method provide for a good system response against flow signal disturbance better than the conventional PID controller or the conventional 2-DOF PID. Tuning method used is neural network that can give a good response without prior knowledge of the process. These control method are very useful to tune or control in another process control systems.



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