Gas turbine Control using Neural-Network 2-DOF PID Controller

Kim,, Dong Hwa, Taejon National University of Tech.
(Tel:042-821-1170, E-mail:kimdh@hyunam.tnut.ac.kr)

ABSTRACT

Since a gas turbine is made use of generating electricity for peak time, it is a very important to operate a peak time load with safety. The main components of a gas turbine are the compressor, the combustion chamber and the turbine. So, there also must be modeled a component of gas turbines for the control with safety but it is not easy.

In this paper we acquire a transfer function based on the operations data of Gun-san gas turbine and study to apply Neural-Network 2-DOF PID controler to control loop of gas turbine to reduce phenomena caused by integral and derivative actions through simulation.

We obtained satisfactory results to disturbances of subcontrol loop such as, fuel flow, air flow, turbine extraction temperature.

I. Introduction

Nowadays, a lot of energy is used for industrial fields and it is a very important to operate a peak time load with safety but most of power plants are constructed with a large scale. So, The gas turbine power plant is very useful for this peak time but when it is runned at a peak time it is not operated with optimum control because of many parameters to be tunned,

The main components of a gas turbine are the compressor, the combustion chamber, fuel system, and the turbine. So, each componets of gas turbines must be modeled for the optimum control of gas turbine but it is not easy.

Hussain[2] decomposed the gas turbine into just three sections i.e. comperssor, combustor, and turbine and made much simpler models. But we cannot control with this model and the conventional PID controller, effectively.

In this paper we designed a 2-DOF PID controller tuned by Neural Network to reduce the problems caused by integral and derivative actions of the conventional PID controller and applied this controller to turbine control loop of gas turbine power system.

2. Equations of gas turbine systems

2.1. Fuel loop

The fuel loop is consisted of the fuel valve and the actuator. The fuel flow out from the fuel systems results from the inertia of the fuel system actuator and of the valve positioner.

1) Fuel loop

$$f_f = \frac{k_{ff}}{T_f s + 1} P_{valve}$$

2) Valve positioner

$$P_{valve} = \frac{k}{as + c} P_{int}$$

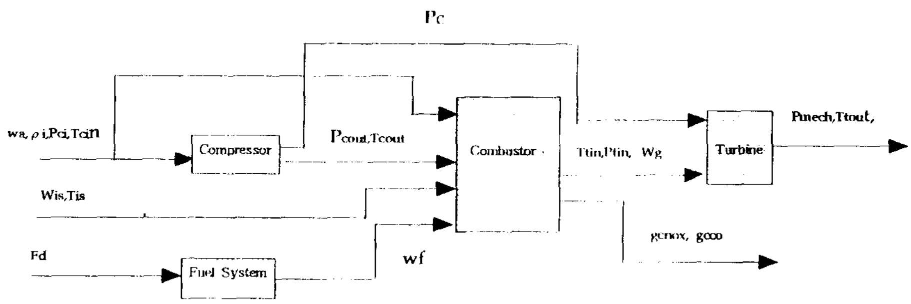


Fig 2.1 Gas turbine block diagram

3) Signal for valve positioner

$$P_{int} = P - k_f f_f + f_d \omega e^{st}$$

2.2. Compressor

The compressor can be expressed by the following equations.

1) One dimensional steady flow nozzle equation for a uniform polytropic compression

$$f_a = \sqrt{A_o\left[\left\{\frac{2m_a}{\eta_c(m_a-1)}\right\}\right]\rho_i\rho_{cin}\left(r_c^{2/m_a} - r_c^{(m_a+1)/m_a}\right)}$$

2) Polytropic index equation

$$m_a = \frac{\gamma_a}{\gamma_a - \frac{(\gamma_a - 1)}{\eta_c}}$$

3) Outlet air pressure equation

$$P_{cout} = P_{cin} r_c$$

4) Outlet air temperature equation

$$\left(\frac{T_{out}}{T_{cin}}\right) = r_c^{\frac{(\gamma_a - 1)}{\gamma_a \eta_c}}$$

5) Compressor and consumption equation

$$P_c = \frac{F_{ain}\delta h_i}{\eta_c \eta_{trans}}$$

6) Overal compressor efficiency equation

$$\eta_c = \frac{1 - r_c^{\frac{(\gamma_a - 1)}{\gamma_a}}}{1 - r_c^{\frac{(\gamma_a - 1)}{\gamma_a \eta_c}}}$$

7) Perfect gas isentropic enthalpy change equation

$$\delta h_i = c_{pa} T_{cin}^{\,r_c^{\frac{R_a}{c_{pa}}} - 1}$$

2.3 Combustion chamber

1) Exhaust gas mass flow

$$f_g = f_a = f_f + f_s$$

2) Combustion energy equation

$$f_g c_{pg}(T_{tin} - 298) + f_f \delta h_{25}$$
$$f_a c p_a(298 - T_{cout}) + f_{is} c_{ps}(298 - T_{is}) + 0$$

3) Combustion chamber pressure loss

$$PT_{in} = P_{cout} - \delta P$$

$$\delta P = P_{cout}\left[\left\{k_1 + k_2\left(\frac{T_{tin}}{T_{cout}} - 1\right)\right\}\frac{R}{2}\left\{\frac{f_g}{A_m P_{cout}}\right\}^2 T_{cout}\right]$$

4) Polutant formation

$$g_{conox} = f_{g2}\left(\frac{f_{is}}{f_f}\right)$$

$$g_{cco} = f_{g3}\left(\frac{f_{is}}{f_f}\right)$$

5) Pollutant formation measurement dynamics

$$g_{cnox}(t) = g_{cnox}(t - \tau_m)$$
$$g_{cco}(t) = g_{cco}(t - \tau_m)$$

2.4 Turbine

1) Temperature-pressure relationship

$$\left(\frac{T_{tout}}{T_{tin}}\right) = r_t^{\eta_{cot}\frac{(\gamma_{cg} - 1)}{\gamma_{cg}}}$$

2) Gas mass flow through the turbine

$$f_g = A_{to}\sqrt{\left\{\left(\frac{2\eta_{\infty T} m_{cg}}{m_{cg}-1}\right)\rho_{tin}\rho_{tin}\left(r_T^{(2/m_{cg})} - r_T^{\frac{(m_{cg}+1)}{m_{cg}}}\right)\right\}}$$

$$m_{cg} = \frac{\gamma_{cg}}{\gamma_{cg} - \eta_{\infty T}(\gamma_{cg} - 1)}$$

$$\rho_{tin} = f_{gt4}(T_{tin} P_{tin})$$

3) Overal turbine efficiency

$$\eta_t = \frac{1-(r_T)^{\frac{\eta_{\infty T}(\gamma_{cg}-1)}{\gamma_{cg}}}}{1-r_T^{\frac{\gamma_{cg}-1}{\gamma_{cg}}}}$$

η_t : overall turbine efficiency

4) Power delivery

$$P_t = \eta_t w_g \delta h_i$$

$$P_{mech} = P_t - P_c$$

$$\delta h_i = c_{pg} T_{tin}\left(r_T^{R_a/c_{pg}} - 1\right)$$

3. Problems of control by the conventional PID controller

Since a PID controller has only three parameters as constant which have to be tuned to obtain desired closed-loop responses, Some problems exist where these simple controllers are used. that is, a reset windup and a derivative kick may arise when the integral element and the derivative input is used in the controller.

These problems may result in high overshoot and oscillation in the dynamic performance of control system as the windup characteristics illustrated in Figure 3.1.

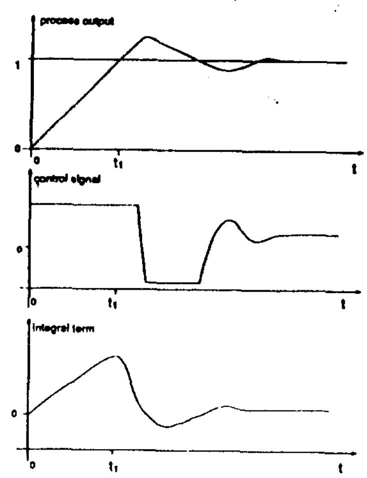


Fig. 3.1 Problem of reset windup

To improve the performance of a PID controller not only do the parameters have to be carefully determined but also the configuration of PID controllers should be desingned to overcome these problems caused by integral and derivative actions.

There are some circumstances in which control algorithms may improve system dynamic performance.

4. 2-DOF PID controller

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 linear PID algorithm might be difficult to deal with processes or plants with complex dynimics, such as those with large dead time, inverse response and highly nonlinear characteristics.

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.

In this paper a design methodology of a feedforward typed-neural network tuning 2-DOF for gas turbine is propsed.

4.2 The structure of Filter typed 2-DOF PID controller using tuning of neural network

Fig.4.1 illustrated the structure of neural network tuning 2-DOF PID controller.

$\frac{1+\alpha\beta T_1 s}{1+\beta T_1 s}$ is filter, $K_p(1+\frac{1}{T_1}s)$ is the transfer function of PI controller, respectively.

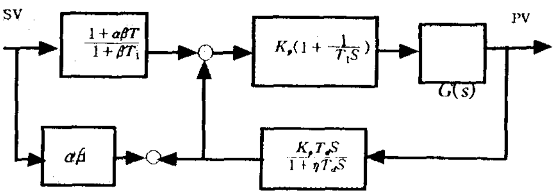


Fig.4.1. 2-DOF PID controller

$$G_{pm}(s) = K_p\left(1 + \frac{1}{T_i s} - \frac{T_d s}{1+\eta T_d s}\right) \quad (1)$$

$$G_{sm}(s) = K_p\left(\alpha + \frac{1}{T_i s} - \frac{(1-\alpha)(\beta-1)}{1+\beta T_i s}\right) + \frac{\alpha\gamma T_d s}{1+\eta T_d s} \quad (2)$$

Equation (1), (2) represent the transfer function between manipulating value and process value, setpoint and process value, respectively.

4.3 Tuning of 2-DOF PID controller

1) Tuning of control parameter

Generally, ultimate method, Z&N method are used for tuning of 2-DOF PID controller.

where, the numerator deformed from equation (4) is as the following equation.

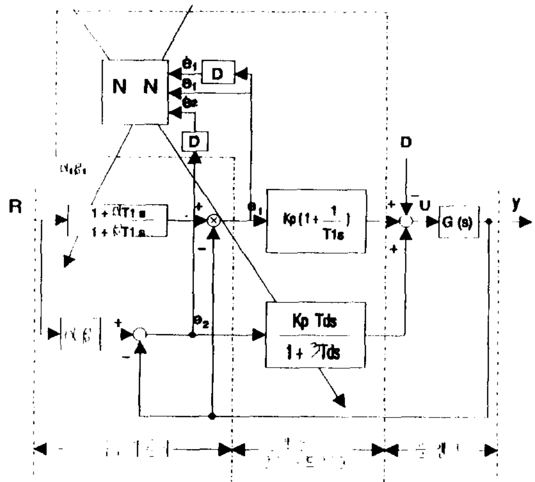
$$N = A\left(1 + \frac{1}{[1+(\alpha-1)\beta T_i s]}\right) + \frac{1}{1+(\alpha-1)\beta}\left[\frac{T_d s}{1+\eta T_d s} + \frac{(\alpha-1)(1-\beta)\beta T_i s}{(1+\beta T_i s)}\right] \quad (3)$$

$$A = K_p[1+(\alpha-1)\beta]$$

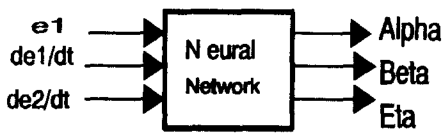
If we choose the parameter $\alpha, \beta, \gamma, \eta$ properly, optimal response is able to be get. Where, the tuning coefficient is given as the following equation.

$$K_p^* = K_p/1+(\alpha-1)\beta$$
$$K_i^* = K_i/1+(\alpha-1)\beta \quad (4)$$
$$K_d^* = K_d/1+(\alpha-1)\beta$$

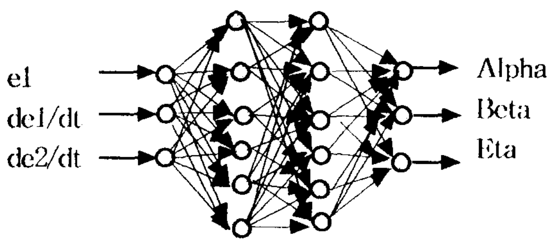
If the error signal e_1, e_2 is introduced to the neural network, it learn training the error and then regulate α, β, η. So, the proper value K_p^*, K_i^*, K_a^* given in equation(3.3) is tuned.



a) 2-DOF PID controller tuning with neural network



b) Input variables of neural network



c) Structure of neural network

Fig. 4.1 Structure of neural network tuning 2-DOF PID

A backpropagation is used as learning algorithms.

5. Simulation and results

Fig. 5.1-5.4 represents simulation results to a change of setpoint in case of the various parameter values in the proposed NN-tuning 2-DOF PID controller. The proposed method has a lower overshoot and more stable responses.

6. Conclusion

In this paper, we proposed the NN-tuning 2-DOF PID controller and applied this controller to the gas turbine system.

Simulation results represent that 2-DOF PID controller is satisfactory responses in characteristics such as, overshoor, stable.

References

1. K.J.Anstrom, "Towards intelligent PID control", Automatica, ol.28, no.1, pp.1-9, 1992.
2. J.G.Ziegler &N.B.Nichols,"Optimun setting for Automatic controllers", Transactions of The ASME, pp.759-768, 1942.
3. G.E.Coon, "How to find controller setting from process characteristics, Control Eng, pp.66-76, 1956.
4. K.J.Anstrom,"Intelligent tuning and a daptive control",1992,10,12-14, works sh orp in Seoul, Korea.
5. Kiochi Suyama, "A practical design method for PID control systems",SICE, vol.29, no.2, pp.236-238, 1993.
6. Kim,Dong Hwa,"A study on the PID controller to Turbo generator"'96, KIEE conference in Yong-Pyong.

Nomenclature

f_f : *fuel mass flow*
k_{ff} : *fuel system gain constant*
T_f : *fuel system time constant*
P_{valve} : *valve position*

k, a, c : *valve parameter*
P_{int} : *internal signal*

P : min*imum fuel signal,*
k_f : *feedbackcoefficient*
f_d : *fuel demand signal*
ω : *ratationspeedoftheturbine*
T : *fuel system pure time delay*
f_d : *fuel dema nd signal*
ω : *ratation speed of the turbine*

f_f : *fuel flow to the combustor*
f_a : *air mass flow the comprosso r*
A_o : *comprossor exit flow area*
η_c : *comprossor polytropic efficiency*
ρ_i : *inlet density*

$P_{\sim}$: *inlet pressure*
m_a : *polytropic index*
r_c : *pressure ratio*

$\gamma_a = \frac{c_{pa}}{c_{va}}$: ratio of specific heats for air

c_{pa} : specific heat at constant pressure for air

c_{va} : specific heat at constant volume for air

T_{out} : outlet air temperature

T_{cin} : inlet temperature

P_c : Compressor power consumption

δh_i : isentropic enthalpy change correponding to a compression from P_{cin} to P_{cout}

η_c : overal compressor efficiency

η_{trans} : transmission efficiency from turbine to compressor

c_{pa} : specific heat of air at constant prossure

R_a: air gas constant

f_f : fuel mass flow

f_{is} : injection steam mass flow

c_{pg} : specific heat of combustion gases(constant)

T_{tin} : Turbine inlet gas temperature

Δh_{25} : Specific enthalpy of reaction at reference temperature of 25^oC

c_{ps} : specific heat of steam(constant)

T_{is} : temperature of insected steam

P_{tin} : pressure of combusion gases at turbine inlet

δP : combustion chamber pressure loss

k_1, k_2 : pressure loss coefficients

R_{cg} : universal gas constant for combustion gases

A_m : combustion chamber mean cross-section area

g_{cnox}: *mass flow of* NO_x

g_{cco} : mass flow CO

f_{gt2} : experimental curve(NO_x mass flow as a function of steam to fuel mass flow ratio)

f_{gt3}: experimental curve(CO mass flow as a function of steam to fuel mass flow ratio)

T_{tout} : gas temperature at exit of turbine

r_T: $\left(\frac{P_{tout}}{P_{tin}}\right)$outlet to inlet turbine pressure ratio

$\eta_{\infty T}$: turbine polytropic efficiency

γ_{cg} : $\left(\frac{c_{pg}}{c_{vg}}\right)$ ratio of specific heats for combustion gases

$g_{cnox}(t)$: delayed(measurement) NO_x mass flow

$g_{cco}(t)$: delayed(measurement CO mass flow

τ_m : measurement delay

m_{cg} : combustion gases polytropic index

ρ_{tin} : inlet gas density

f_{gt4} : gas tables function

f_g : turbine gas mass flow

P_T : mechnical power delivered by turbine

P_c : power required to derive the compressor

P_{mech} : net available mechnical power

δh_i : isectropic enthalpy change for a gas expansion from P_{tin} to P_{tout}

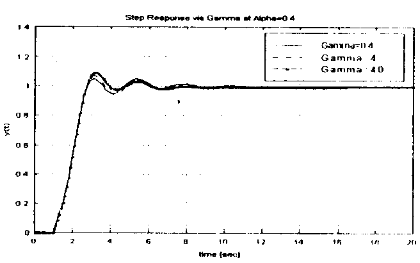


Fig.1. Step Response via Gamma at Alpha=0.4

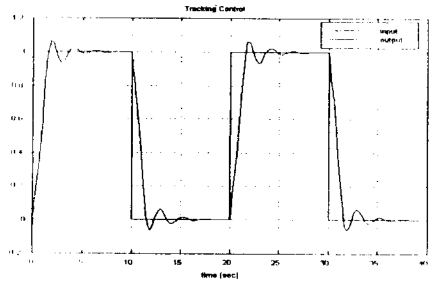


Fig.2. Tracking Control

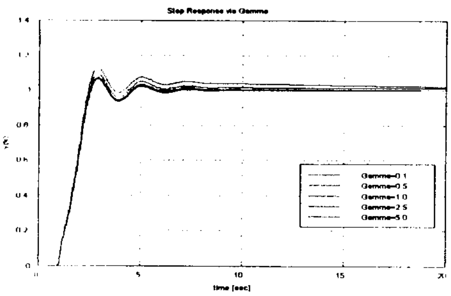


Fig. 3 Step Response via Gamma at Alpha=1

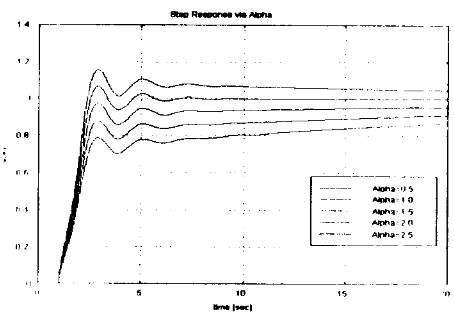


Fig. 4 Step Response via Alpha at Gamma=0.5

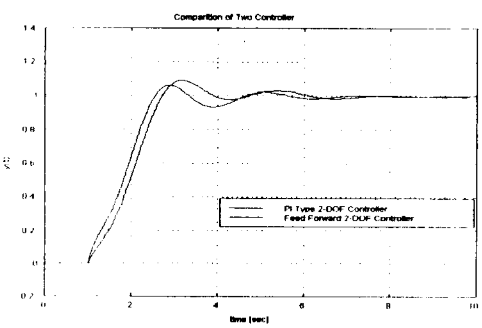


Fig. 5 Comparition of Two type Controller