가스터빈 제어 루프에 대한 신경망 튜닝 루프 보상형 2-자유도 PID 제어기의 응용

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Application a Loop Compensation type 2-DOF PID Controller tuned by Neural Network to Gas Turbine Control Loop

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Abstract

Since a gas turbine is still a significant contributor to peak time, it is very important to tune the gains of P, I, D to get a maximum power and stability within permissible limits. In the gas turbine, the main control loop must adjust the fuel flow to ensure the correct output power and frequency, but it is not easy, because the control loop is composed of many subsystems.

In this paper we acquire a transfer function based on the operations data of Gun-san gas turbine and study to apply a loop compensation type 2-DOF PID controller tuning by neural-network 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

The role of combined heat and electrical power generation system such as gas turbine has become more important over recent years due to technological advances, the changing needs of the energy, and reletively low capital cost.

. So, Modern advanced control technologies such as DDC, DCS, SCARDA are used to enable such systems to be rapidly analysed, get high efficiency.

In that control systems, because main control algorithms are PID control, a performance depends on the gain of P, I, D, but the main components is composed of many control loop such as the compressor, the combustion chamber, fuel system, and the turbine. So, tuning the gains of P.I.D is difficult.

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 to get acquired performances.

In this paper we designed a loop compensation 2-DOF PID controller tuned by Neural Network to get a performance and applied this controller to the 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.

2.1.1 Fuel loop

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

2.1.2 Valve positioner

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

2.1.3 Signal for valve positioner

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

2.2. Compressor

The compressor can be expressed by the following equations.

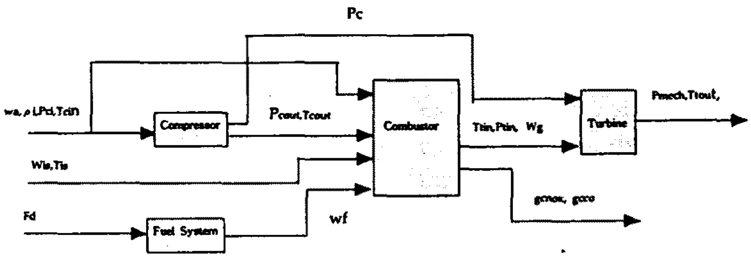


Fig 2.1 Gas turbine block diagram

2.2.1 One dimensional steady flow nozzle equation for a uniform polytropic compression

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

2.2.2 Polytropic index equation

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

2.2.3 Outlet air pressure equation

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

2.2.4 Outlet air temperature equation

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

2.2.5 Compressor and consumption equation

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

2.2.6 Overal compressor efficiency equation

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

2.2.7 Perfect gas isentropic enthalpy change equation

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

2.3 Combustion chamber

2.3.1 Exhaust gas mass flow

$$f_g=f_a=f_f+f_s$$

2.3.2 Combustion energy equation

$$f_gc_{pg}(T_{tin}-298)+f_f\delta h_{25}$$
$$f_acp_a(298-T_{cout})+f_{is}c_{ps}(298-T_{is})+0$$

2.3.3 Combustion chamber pressure loss

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

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

2.3.4 Polutant formation

$$g_{conox}=f_{g2}\left(\frac{f_{is}}{f_f}\right)$$
$$g_{cco}=f_{g3}\left(\frac{f_{is}}{f_f}\right)$$

2.3.5 Pollutant formation measurement dynamics

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

2.4 Turbine

2.4.1 Temperature-pressure relationship

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

2.4.2 Gas mass flow through the turbine

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

$$m_{cg} = \frac{\gamma_{cg}}{\gamma_{cg} - \eta_{\infty T}(\gamma_{cg} - 1)}$$
$$\rho_{tin} = f_{gtt}(T_{tin} P_{tin})$$

2.4.3 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

2.4.4 Power delivery

$$P_t = \eta_t w_g \delta h_i$$
$$P_{mech} = P_t - P_c$$
$$\delta h_i = c_{pg} T_{tin}\left(r_T^{R_a/c_{is}} - 1\right)$$

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.

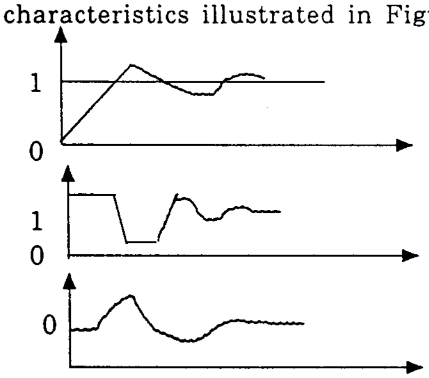


Fig. 3.1 Problem of reset windup

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 designed to overcome these problems caused by integral and derivative actions.

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 may 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 loop compensation 2-DOF PID controller tuning by neural network for gas turbine is proposed.

4. 2-DOF PID controller

4.1 The structure of loop compensation type 2-DOF PID controller

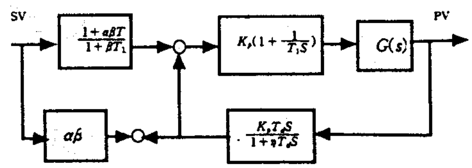


Fig.4.1. 2-DOF PID controller

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

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

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

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

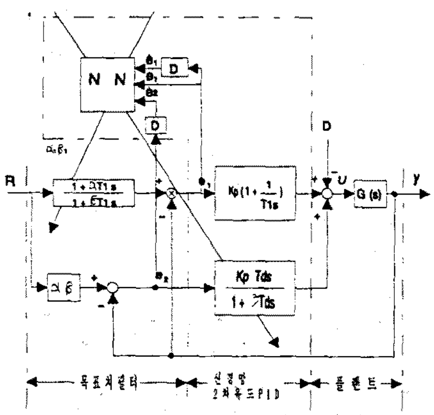
4.2 Tuning of 2-DOF PID controller

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.(3)

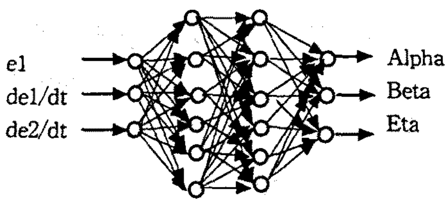
If we choose the parameter $\alpha, \beta, \gamma, \eta$ properly, optimal response is able to be get. Where, the tuning coefficient is given as the following equation.

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

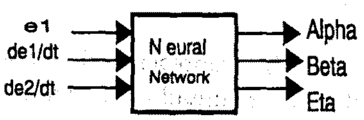
$$N = A\left(1+\frac{1}{[1+(\alpha-1)\beta T_i s]}\right) + \frac{1}{1+(\alpha-1)\beta}\left[\frac{T_d s}{1+\eta T_d s} + \frac{(\alpha-1)(1-\beta)\beta T_i s}{(1+\beta T_i s)}\right]$$
$$A = K_p[1+(\alpha-1)\beta]$$



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

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_d^* given in equation(3) is tuned.

A backpropagation is used as learning algorithms.

5. Simulation and results

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

Fig. 5.2 shows results in case of the disturbance. The proposed controller has more stable responses.

6. Conclusion

In this paper some auto-tunning 2-DOF PID controller methods have been presented for gas turbine.

The transfer function of the gas turbine is taken by a operating data.

A backpropogation learning algorithms of neural network is used as tuning method. this tuning method are very useful to tune PID controllers in gas turbine control systems where the plant dynamics are not precisely known.

Simulation shows a safactory results to a gas turbine control systm.

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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 : *compressor exit flow area*
η_c : *compressor 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_t : 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_l : 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
δF : 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_{g2} : experimental curve(NO_x mass flow as a function of steam to fuel mass flow ratio)
f_{g3} : 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_{g4} : 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_t : isectropic enthalpy change for a gas expansion from P_{tin} to P_{tout}

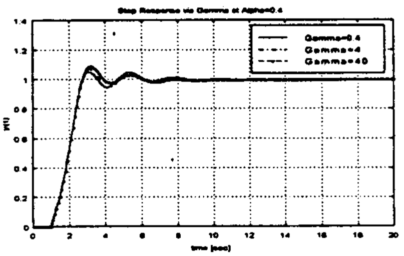

Fig. 1 Step Response via Gamma at Alpha=0.4

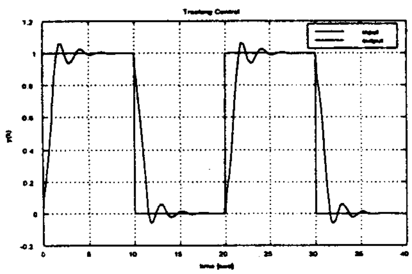

Fig. 2 Tracking Control

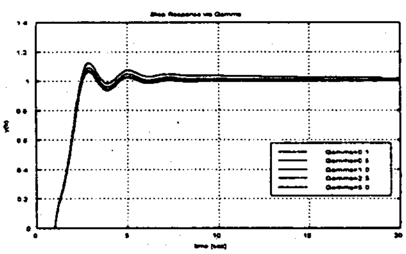

Fig. 3 Step Response via Gamma at Alpha=1

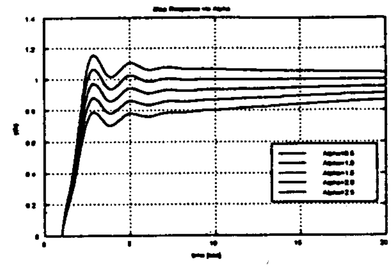

Fig. 4 Step Response via Alpha at Gamma=0.5

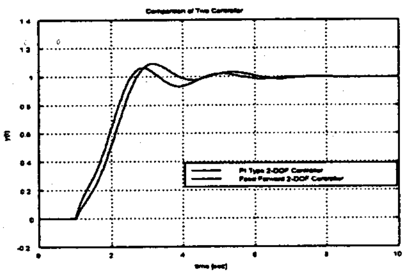

Fig. 5 Comparition of Two type Controller

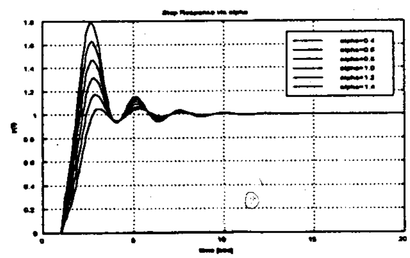

Fig. 6 Step Response via Alpha