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2-DOF PID Control for the Steam Temperature Control of Thermal Power Plant

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Abstract - In thermal power plant, the efficiency of a combined power plant with a gas turbine increases, exceeding 50%, while the efficiency of traditional steam turbine plants is approximately 35% to 40%. Up to the present time, the PID controller has been used to operate this system. However, it is very difficult to achieve an optimal PID gain without any experience, since the gain of the PID controller has to be manually tuned by trial and error procedures. This paper focuses on the neural network tuning of the 2-DOF PID controller with a separated 2-DOF parameter (NN-Tuning 2-DOF PID controller), for optimal control of the Gun-san gas turbine generating plant in Seoul, Korea. In order to attain optimal control, transfer function and operating data from start-up, running, and stop procedures of the Gun-san gas turbine have been acquired, and a designed controller has been applied to this system. The results of the NN-Tuning 2-DOF PID are compared with the PID controller and the conventional 2-DOF PID controller tuned by the Ziegler-Nichols method through experimentation The experimental results of the NN-Tuning 2-DOF PID controller represent a more satisfactory response than those of the previously-mentioned two controllers.

1. INTRODUCTION

In the fossil-fired thermal power plant, the role of combined power generation plants has become more important in recent years, due to technological advances and the changing needs of the energy market.

Therefore, studies on the control of gas turbines have been the subject of interest, since gas turbine engines have been widely adopted as peak load candidates for electrical power generation [1]. The fully automatic start-up function and the fast running-up characteristics of gas turbine systems have made them particularly suitable for peak-load lopping and stand-by power supply purposes.

The start-up procedure for a gas turbine consists of several stages: warming up of the main steam pipeline, warming up of turbine parts, turbine run-up, synchronization, and loading.

So, the various studies on control at each step, from start-up to loading, are required to ensure stability and safety [3]. Start-up and shutdown procedures are the most challenging problems to consider when developing new control algorithms for the controller, the performance of the controller must be proven through a sequence of operating stages.

This paper focuses on the neural network tuning of a 2-DOF PID controller with a separated 2-DOF parameter (NN-Tuning 2-DOF PID controller). This controller was designed and tested after acquiring transfer function and operating data from start-up, running, and stop procedures of the Gun-san gas turbine generation plant in Korea. For optimal tuning of a designed NN-Tuning 2-DOF PID controller, a neural network is used.

2. Thermal Power Generating Plant

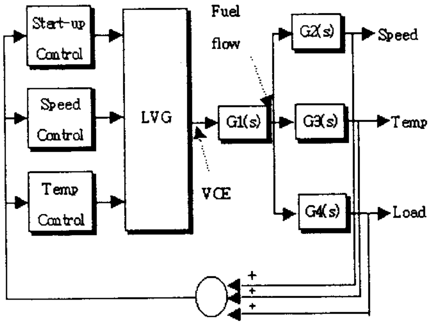

Fig. 1. Control system of the Gun-san gas turbine generating plant: VCE=fuel flow signal, G1(s)=transfer function of fuel system, G(s)=transfer function between fuel flow and turbine speed, G3(s)=transfer function between fuel flow and turbine exhaust gas temperature, G4(s)=transfer function between fuel flow and generator output.

2.1 Control system of Thermal Power Plant

The fuel system in the gas turbine consists of the fuel valve and the actuator, and these devices regulate the fuel flow to the plant.

Fig. 1. represents a simplified block diagram for a single-shaft Gun-san gas turbine generating plant. The control system includes speed control, temperature control, acceleration control, and upper fuel and lower fuel limits[4].

The speed controller operates on the speed error formed between the reference speed and the rotor speed. A droop governor is a straight proportional speed controller in which the output is proportional to the speed error.

Temperature control is the normal means of limiting gas turbine output at a predetermined firing temperature, independent of variation in ambient temperature or fuel characteristics. Acceleration and deceleration fuel schedules are basic control requirements for maintaining the operation of the gas turbine engine to operate within its safe margin, during steady state or transient conditions.

Acceleration control is used primarily during gas turbine start-up to limit the rate of rotor acceleration prior to reaching governor speed, thus ameliorating the thermal stresses encountered during start-up. This control serves a secondary function during normal operation, in that it acts to reduce fuel flow and limit the tendency to over-speed, in the event that the turbine generator separates from the system.

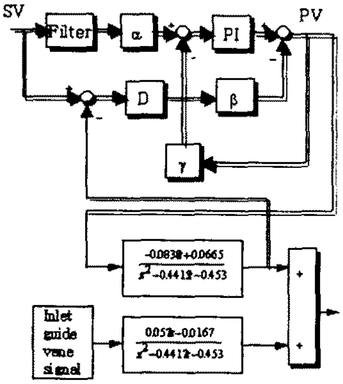

Fig. 2. The structure of 2-DOF PID controller for the combined plant.

These three control functions (speed governing under part load conditions, temperature control acting as an upper limit, and acceleration control to prevent over-speeding) are all inputs to a low value selector. The output of the low value selector, which is called VCE, is the lowest of the three inputs, i.e., whichever requires the least fuel. Transfer from one control to another is bumpless and without any time lags. The output of the low value selector is compared with maximum and minimum limits. The minimum limit is more important. This is because the minimum limit is chosen to maintain adequate fuel flow and to insure that a flame is maintained with the gas turbine combustion system.

The fuel gas control system consists of two valves in series, the first of which controls the pressure between the two valves as a function of speed. The second valve has a linear characteristic versus lift range, and is aerodynamically designed so that sonic velocities are attained at the controlling area with flange-to-flange valve pressure ratios as low as 1.25. If valve position is maintained proportional to the VCE signal, the actual result is a flow rate of fuel gas, which is proportional to the gas turbine speed [2].

Both the torque and exhaust temperature characteristics of the single-shaft gas turbine are essentially linear with respect to fuel flow and turbine speed over the 95 to 107% design rating. The exhaust temperature equations are somewhat less accurate at part load; however, since temperature control is only active at the design point, the impact of the part load inaccuracy is negligible to the overall simulation [3].

An ideal acceleration control allows the engine to accelerate at a reasonably fast rate without the engine being driven into the surge region or the engine components overheating. Following load rejection, a rapid reduction of fuel flow is required to limit the maximum speed rise.

3. 2-DOF PID Controller for the Combined Generating Plant

3.1. 2-DOF PID Controller with a Separated 2-DOF Parameter

A 2-DOF PID controller with a separated 2-DOF parameter for the Gun-san gas turbine generating plant is composed as in Fig. 3. The transfer function between the process value PV(s) and the settling value SV(s), and between the process value PV(s) and the manipulated value, MV(s) are given as the following equations, respectively:

$$G_{PVDV}(s)=\frac{PV(s)}{DV(s)}=\frac{G_d(s)}{1+K_p\left(1+\frac{1}{T_i s}\right)\gamma} \quad (1)$$

$$G_{PVSV}(s)=\frac{PV(s)}{SV(s)}$$

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

$$G_{PVG1}(s)=\frac{\left(\frac{\beta K_p K_d s}{1+\eta T_d s}\right)}{1+K_p\left(1+\frac{1}{T_i s}\right)\gamma}\, G_1(s) \quad (3)$$

where, $F(s)=\frac{1}{1+\beta T_i s}$: filter transfer function,

$PI(s)=K_p\left(1+\frac{1}{T_i s}\right)$: PI controller transfer function.

$D(s)=\frac{K_p T_d s}{1+\eta T_d s}$: D controller transfer function,

$G_1(z)=\frac{-0.083z+0.0665}{z^2-0.441z-0.453}$, $G_1(s)=\frac{0.057z-0.0167}{z^2-0.441z-0.453}$: plant transfer function.

In equation (1), the numerator has a similar function as that of the conventional PID controller. That is, if we tune the proportional gain K_p with a greater value, the affect of disturbance G_d against plant output is smaller. However, in equation (2) and (3), the process value PV(s) and the plant $G_1(s)$ depend on the two degrees parameter α, β, γ, and the proportional gain is also affected by the parameter α, γ given for two degrees of

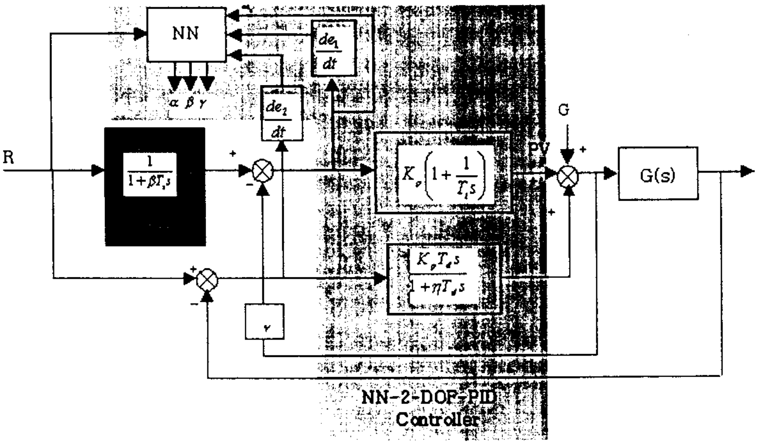

Fig. 3(a). The structure of the 2-DOF PID controller with a neurual network for the combined plant.

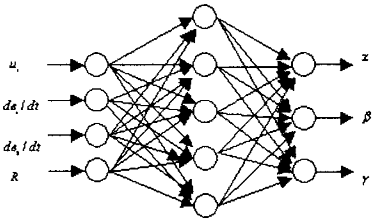

Fig. 3(b). The structure of the neural network

function. The equation (4), and the sigmoid function is defined as a logistic function of equation for tuning (5), respectively.

$$y_i(t)=f\left(\sum_{j=1}^{m} w_j\, x_j(t)+b\right), \qquad (4)$$

$$f(x)=\frac{1}{1+e^{-\lambda x}} \quad \frac{dx}{dt}=\lambda f(x)(1-f(x)). \qquad (5)$$

The network weights are minimized by the following performance index:

$$P(w)=\frac{1}{2}\left(\sum_{j=1}^{n}(d_i-y_i)^2\right)=\frac{1}{2}\left(\sum_{j=1}^{n}(d_i-w^T x_i)^2\right). (6)$$

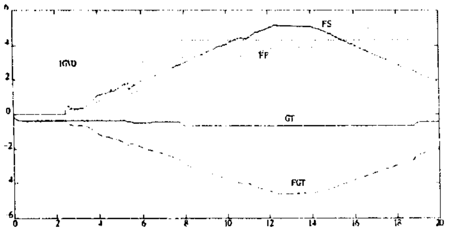

Fig. 4. Characteristics of each parameter during the start-up, running, and stop procedures of the combined plant.

3. Conclusion

Up to this time, the PID controller has been used to operate gas turbines. However, it is very difficult for an operator to obtain an optimal gain without experience, since the gain of the PID controller has to be manually tuned by trial and error procedures.

In this paper, a 2-DOF PID controller with a separated two-degrees parameter for the Gun-san gas turbine in Korea, which is tuned by a neural network, has been studied through experiments. The results of the NN-Tuning 2-DOF PID are compared with the PID controller and the conventional 2-DOF PID controller tuned by the Ziegler-Nichols method. The experimental results reveal that the performance of the NN-Tuning 2-DOF PID controller has a more satisfactory response than that of the PID controller or the conventional 2-DOF PID controller tuned by the Ziegler and Nichols method.

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