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Research Article

Applications of Tuning Control Actions for the Efficient Load/Frequency Control in Steam Turbine

Ali Thaeer Hammid[Á*]

[Á]CET Dept. AL-Yarmouk University College, Baghdad, Iraq

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Abstract

In this paper we will design as well as carry out the whole model of steam turbine by using the equivalent transfer function and see the output for uncontrolled case. We will discuss the output and apply more control on this model by using Proportional controller, Integral controller, Proportional plus Integral controller, Proportional plus Derivative controller, Proportional plus Integral plus Derivative controller. We will see and analysis these entire previous controller where it's effect in both cases transient response and steady state response. The tuning of control actions will be done by using Ziegler Nichols method and we have applied it in Simulink in Matlab.

Keywords: *Steam turbine, control Actions, control system, P-I-PI-PD-PID tuning controller.*

Introduction

Power system operation considered so far was under conditions of steady load. However, both active and reactive power demands are never steady and they continually change with the rising or falling trend. Steam input to turbo-generators (or water input to hydro-generators) must, therefore, be continuously regulated to match the active power demand, failing which the machine speed will vary with consequent change in frequency which may be highly Undesirable (maximum permissible change in power frequency is ± 0.5 Hz) (D P Kothari *et al*, 2010).

A proportional controller has a continuous linear relation between the outputs of the controller and actuating error signal and it could lead to offset between the desired set point and the actual output. This is because the process input which is controller output and the process output come to new equilibrium values before error goes down to zero. This is known as the proportional control action. The output of an integral controller is changed at a rate which is proportional to the actuating error signal. This is known as the integral control action. Now to make the controller output proportional to the integral of the error desired compensation is to be provided. This is known as the proportional integral control. As long as there continuous to be an error signal to the controller, the controller output will continue to change. Therefore, the integral of error forces the error signal to zero. Now add derivative control action that depends on the rete of the change of actuating error signal and accounts for current rate of change i.e. derivative of the error. This is known as proportional integral derivative control. Using knowledge of the error helps the controller to predict where in future the error is heading and compensate for it (S. Hasan Saeed *et al*, 2008), (B.S. Manke *et al*, 2010), (Ashfaq Husain *et al*, 2011).

The tuning of all these aforementioned controller parameters is done by Ziegler Nichols method and we have applied it by using Matlab/Simulink (Katsuhiko Ogata *et al*, 2010), , (M. Gobal *et al*, 2012).

In this paper, the steam turbine implementation has overshoot, undershoot, rise time and settle time in the considered system while performance in conventional way, But after implementation of a PI controller and PID controller to the process, removing almost all of those shoots can be seen. So finally both of them controllers are used to achieve a desirable output (Farhad Aslam *et al*, 2011), (E Venkata Narayana *et al*).

Case Study

Turbine model; Let us now relate the dynamic response of a steam turbine in terms of changes in power output to changes in steam valve opening. The dynamic response is largely influenced by two factors, (i) entrained steam between the inlet steam valve and first stage of the turbine, (ii) the storage action in the repeater which causes the output of the low pressure stage to lag behind that of the high pressures stage. Thus, the turbine transfer function is characterized by two time constants. For ease of analysis it will be assumed here that the turbine can be modeled to have a single equivalent time constant.

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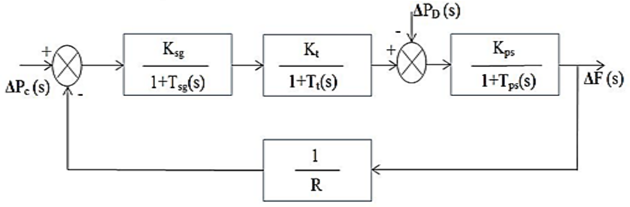
*Corresponding author: **Ali Thaeer Hammid**

A complete block diagram representation of an isolated power system comprising governor, turbine, generator and load is easily obtained by combining the block diagram of individual components, i.e.



Block diagram model of load frequency control
(isolated power system)

The model shows that there are two important incremental inputs to the load frequency system control $-\Delta P_c$, the change in speed changer setting ; and ΔP_D , the change in load demand .let us consider a simple situation in which the speed changer has fixed setting (i.e. $\Delta P_c = 0$) and the load demand change . This is known as *free governor operation* (D P Kothari *et al*, 2010).

Math

As frequency changes, the motor load changes being sensitive to speed, the rate change of load with respect to frequency, i.e. and it can be expressed as:

$B = (\partial P_D/\partial f) / P_r$

P_r (in P_u MW / Unit change in frequency)

For 250 MW machine with an operating load of 125 MW, let the change in load be 1% for 1% change in frequency (scheduled frequency = 50 Hz) then;

$(\partial P_D/\partial f) = 1.25 / 0.5 = 2.5$ MW/Hz

$B = (\partial P_D/\partial f) / P_r = 2.5 / 250 = 0.01$ P_u MW/Hz

It is also recognized $K_{ps} = 1/B$ = power system gain

$K_{ps} = 1/ 0.01$ since $K_{ps} = 100$

For Dynamic response of change in frequency for a step change in load $K_{ps} = 100$

The speed governor gain is easily adjustable by changing lengths of various links. Let it be assumed for simplicity that Ksg is so adjusted that

$K_{sg} K_t = 1$

For a 250 MW machine quoted earlier, inertia constant H = 5 kW-sec/kVA

$T_{ps} = 2H/Bf$ = power system time constant

$= 2\times5/0.01\times50 = 20$ sec

Typically the time constant T_t lies in the range 0.2 to 2.5 sec. since, $T_t = 0.5$ sec

Where, $T_{sg} << T_t << T_{ps}$

Since, $T_{sg} = 0.4$ sec (D P Kothari *et al*, 2010).

Helpful Hints

K_t is fixed gain for the turbine

K_{ps} is fixed gain for the power system

K_{sg} gain of the speed governor

P_D is the load increment by assuming generator incremental loss to be negligible

P_r is the kW rating of the turbo-generator

H is defined as turbo-generator inertia constant

B is a positive for a predominantly motor load

R is the speed regulation of the governor (D P Kothari *et al*, 2010).

Simulation, Tuning testing, Results

The process is represented by transfer function given in fig. 1, and fig. 2 depicts the output of the process

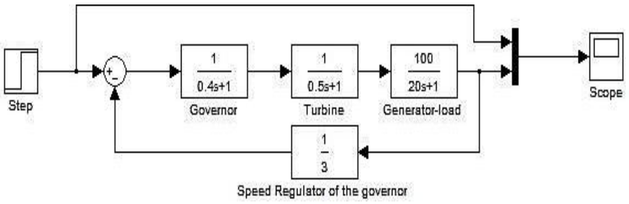


Fig.1: Process Model

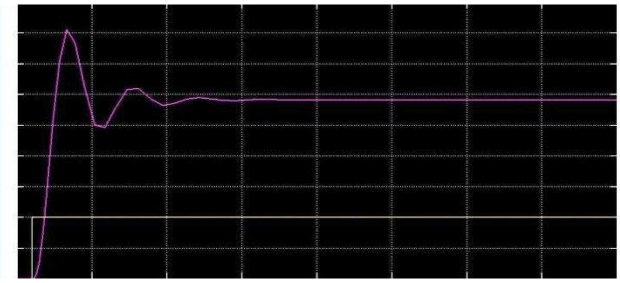


Fig.2: Time Response of Uncontrolled Process

When there is no control to the process, there is some time delay, maximum overshoot and inverted response and also the response is settled below the desired magnitude.

The process with Integral controller is shown in the fig. 3, and fig.4 depicts the output of the process.

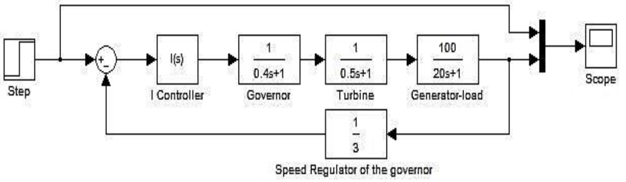


Fig. 3: Process model with I controller

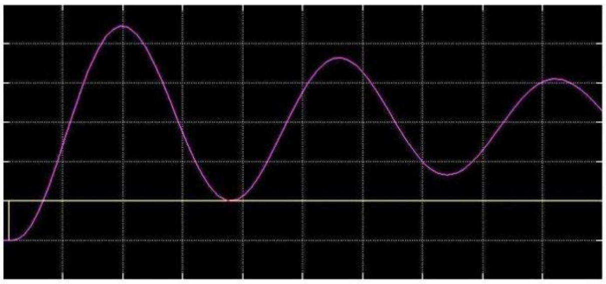


Fig. 4: Time response with I controller

As can be observed from the fig. 4,
Response time: 11.6 sec Rise time (t_r): 6.22 sec
Settling time (t_s): 347 sec peak amplitude: 1.81
Overshoot (%): 81.4 at time (Sec): 19
F.V of steady state: inf

By using I controller there is not just no any much effect to the output response as compared to uncontrolled process but, the output is being oscillated as well so that integral control action is never used alone practically.

The process with Proportional controller is shown in the fig.5, and fig.6 depicts the output of the process.

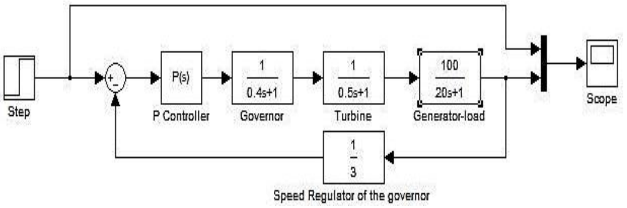


Fig. 5: Process model with P controller

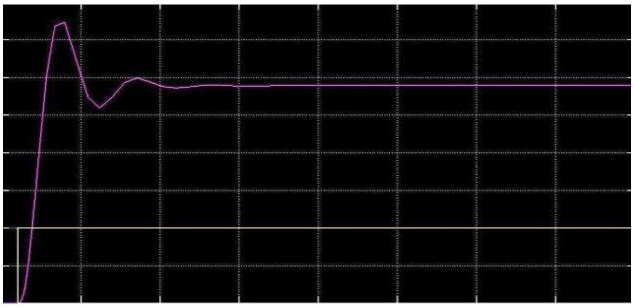


Fig. 6: Time response with P controller

As can be observed from the fig.6,
Response time: 1.85 sec Rise time (t_r): 1.08 sec
Settling time (t_s): 8.29 sec peak amplitude: 1.26
Overshoot (%): 31 at time (Sec): 2.68
F.V of steady state: 0.964

By using P controller there is not much effect to the output response as compared to uncontrolled process.

The process with Proportional plus Derivative controller is shown in the fig.7, and fig.8 depicts the output of the process

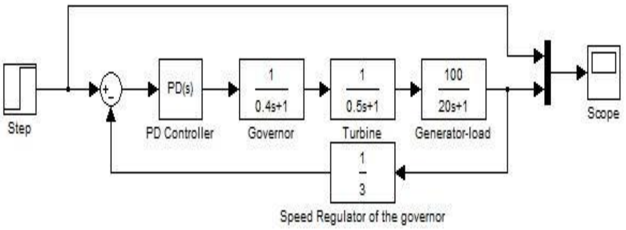


Fig. 7: Process model with PD controller

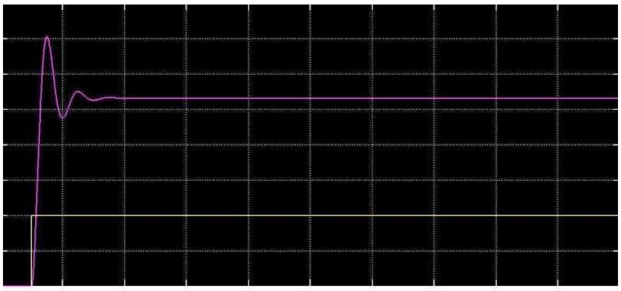


Fig. 8: Time response with PD controller

As can be observed from the fig. 8,
Response time: 0.343 sec Rise time (t_r): 0.207 sec
Settling time (t_s): 1.66 sec peak amplitude: 1.18
Overshoot (%): 32.4 at time (Sec): 0.496
F.V of steady state : 0.889

By using PD controller: Rise time reduces, improve the damping, improves the bandwidth, overshoot reduces and final response is not very stable.

The process with Proportional plus Integral controller is shown in the fig.9, and fig.10 depicts the output of the process.

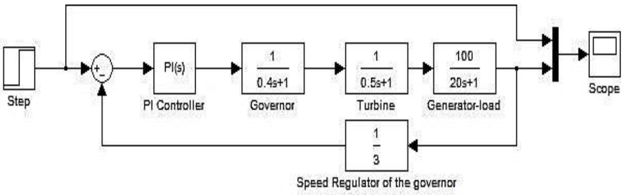


Fig. 9: Time response with PI controller

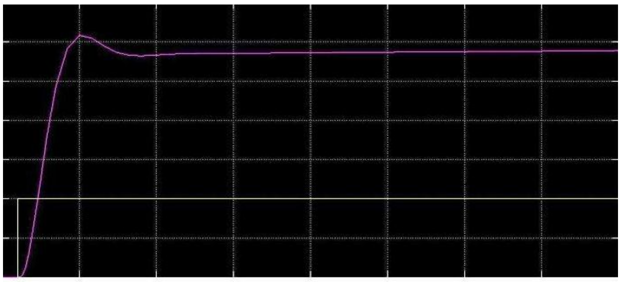


Fig. 10: Time response with PI controller

As can be observed from the fig. 10,
Response time: 3.24 sec Rise time (t_r): 2.9 sec
Settling time (t_s): 100 sec peak amplitude: 1.03
Overshoot (%): 2.88 at time (Sec): 4.19
F.V of steady state : 1

By using PI controller: Rise time increases, steady state accuracy improves, bandwidth decreases, overshoot reduces and final response is stable.

The process with Proportional plus Integral plus Derivative controller is shown in the fig.11, and fig.12 depicts the output of the process.

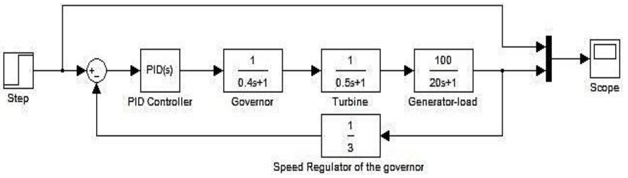


Fig. 11: Time response with PID controller

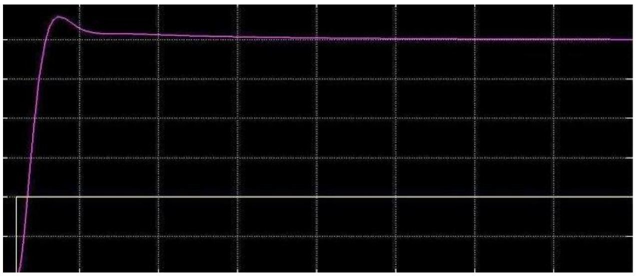


Fig. 12: Time response with PID controller

As can be observed from the fig. 12,
Response time: 1.96 sec Rise time (t_r): 1.2 sec
Settling time (t_s): 9.31 sec peak amplitude: 1.1
Overshoot (%): 9.85 at time (Sec): 2.72
F.V of steady state: 1

By using PID controller: briefly improve transient response and improves the steady state response. It has the benefits of all previous controllers and the troubles that have been appeared in PD and PI controller here it disappears from sight. It is the most useful at all.

Conclusion

From many other applications on this transfer function of steam turbine model, it gives real testing results, so it can be depended on it in any other applications but with real controller. In the case of integral tuning controller and proportional tuning controller you cannot use it alone since the oscillation and no effect. After testing proportional plus integral (PI) tuning controller, it has more effect on steady state response and has less effect in transient response, on the contrary proportional plus derivative (PD) tuning controller has real effect on transient response, but less effect on steady state response. Rather we can depend on proportional plus integral plus derivative (PID) tuning controller since it can effect on both cases response transient and steady state. Finally we can regard PD controller, PI controller and PID controller as a not adaptive controller or at least as a limited controller since limited of parameters and still the output has a little more amount of rise and settle time.

Appendix

Note: In fact there is no declaration on the value of tuning of controller parameters like K_P, K_I and K_D since it always has been changed by the user depending on capability of system sensitivity to controllers but, here we are declaring!
K_I = 0.0185846928 for I controller.
K_P = 0.8068564504 for P controller.
K_P = 0.2402864335, K_D = 4.687419966 for PD controller.
K_P = 0.4000284045, K_I = 0.004390432 for PI controller.
K_P = 0.6854174144, K_I = 0.06400890237, K_D = 0.2688529729 for PID controller.

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Ali Thaeer Hammid Has received his Bachelor Engineering degree in Electronic & Control from Technology college of Kirkuk-Iraq in 2010. He's obtained M-Tech in Electrical & Electronic Engg. (Control and Instrumentation) From SHIATS (Formerly Allahabad Agriculture Institute, Allahabad-India) in 2013. He worked one year in programmable logic control (PLC) and Scada filed as well as he worked one year in embedded system. Presently he is working as Assistant Lecturer at computer Engineering Techniques Department, AL-Yarmouk University College, Baghdad-Iraq.