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Integrated tuning of PID-derivative load frequency controller for two area interconnected system

Preeti Sonkar[1]*, Ashwani Chandel[2], O. P. Rahi[2]

[1]Department of Electrical Engineering, National Institute of Technology Hamirpur, INDIA*
[2] Department of Electrical Engineering, National Institute of Technology Hamirpur, INDIA
[*]e-mail: riddhma@gmail.com

Abstract

PID-derivative filter has been considered better than the normal PID control when it comes for the stability analysis of a power system. This paper presents a PID-derivative filter load frequency controller for the two thermal-thermal and hydro-thermal interconnected areas. The proposed controller has been based on cascading of derivative filter with PID controller. The Ziegler- Nichols (Z-N) tuning method has been used for tuning the controllers. Results of the proposed derivative controller have been compared with conventional proportional integral derivative controller in time domain analysis. A remarkable improvement in stability of the system has been observed with PID-derivative filter controller justifying its applicability. Simulated results given in the paper show the feasibility of the proposed PID-derivative filter controller.

*Keywords:*controller; derivative filter; tie line; two area

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1. Introduction

The adequate operation of interconnected power system requires the matching of total generation with total load demand and associated systemlosses. As the demand deviates from its nominal value with an unpredictable small amount, the operating point of power system changes, and hence, system may experience deviations in nominal system frequency and scheduled power exchanges (Elgerd et al., 1970; Ibraheem et al., 2005; Kundur, 2008; Nagrath et al., 2011; Nanda et al., 2008).The objectives of load frequency control are to maintain system frequency at or very close to a specified nominal value and to maintain the scheduled value of interchange power between control areas (Elgerd, 1983).

Due to the increased complexity of modern power systems, advanced control methods are proposed in LFC (load frequency control), e.g. optimal control (Cavin, 1971), variable structure control (Bengiamin, 1982), adaptive and self-tuning control (Pan, 1989) and robust control (Azzam, 1999;Khodabakhshian and Golbon, 2005; Ray et al., 1999;Wang et al.,1993; Wang et al., 1994).A literature survey depicts the preference of PI or PID controllers for LFC over other controllers due to their simplicity in implementation. Step response method and frequency response method are developed by Ziegler and Nichols in 1942(Ziegler et al.,1942). Frequency response method is based on a simple characterization of the frequency response. In frequency response method, dynamic characteristic of the process is represented by the ultimate gain (K_C) of a proportional controller and the ultimate period of oscillation (T_C) of the loop. It usually determines the ultimate gain and period from the actual process. The controller parameters are calculated in term of ultimate gain and ultimate period of oscillation. The step response method is based on processing the information in the form of the open loop step response. This method can be viewed as a traditional method. The PID controller involves four parameters viz. proportional gain (K_P), integral time constant (K_I), derivative time constant (K_D), filter constant (N). However, these methods are designed for three parameters K_P , K_I , K_D ,of the PID controller and then also use a default choice for the derivative filter constant (N).

Generally, the LFC is exposed to noisy environment. This is because of the numerous on/off switching in the load side which produces considerable noise in the frequency measurement. The noisy environment has made it difficult to implement the differential feedback loop. The main disadvantage of derivative filter as an integral part of PID provided gain with some factor at higher frequency. Hence, new combination of a PID controller is necessary which performs better than the conventional PID controller. The present work has been directed in this direction. The proposed controller is based on cascading of low pass filter with PID controller in order to overcome this disadvantage. PID-derivative filter controller is a technique which is implemented in many fields such as pulp and paper industries (Astrom and Hagglund, 2002; Eker, 2003;Liu, 2001)and has been implemented in the work on two area power system.

The present paper is organized as follows. Section 2 discusses the PID-derivative filter controller, section 3 discusses two area interconnected system section 4 provides simulation results of different test cases considered in the work and finally conclusions drawn in section 5.

2. Proposed PID-Derivative Filter Controller

The transfer function of a measurement y and controller output u of a PID controller is given in (1) according to (Astrom and Hagglund, 2002).

$$G_{PID}(s) = K\left(1 + \frac{1}{sT_I} + sT_D\right) \tag{1}$$

The derivative term provides high gain and makes controller noise sensitive;therefore there is a need to limit the high frequency gain of the derivative term. This is achieved byapproximation of derivative term given as (2).

$$G_{PID\_Approx}(s) = K\left(1 + \frac{1}{sT_I} + \frac{sT_D}{1 + \frac{sT_D}{N}}\right) \tag{2}$$

The controller has a constant gain and is given in (3). It is desirable to roll off the controller gain at high frequency.

$$\lim_{s \to \infty} G_{PID}(s) = K(1+N) \tag{3}$$

This can be achieved by an additional low pass filter of the control signal. The transfer function of such a filter is given in (4).

$$F(s) = \frac{1}{(1+sT_f)^n} \tag{4}$$

where, T_f is the filter time constant and n is the order of the filter. The choice of T_f is a compromise between filtering capacity and performance. If the derivative time is used, $T_f = \frac{T_D}{N}$ is a suitable choice for PID-low pass filter. If the controller used is PI, then $T_f = \frac{T_I}{N}$. To overcome the disadvantage of PID controller as described in eqn. (1), PID-low pass filter is used in the present work. The controller is implemented by using (5).

$$G_{PID-Filter}(s) = K\left(1+\frac{1}{sT_I}+sT_D\right)\times\left(\frac{1}{(1+\frac{sT_D}{N})^n}\right) \tag{5}$$

where,

N = filter constant

K = proportional gain

n = order of filter

The order of filter has been taken 1 for analysis in the present work.

3. Introduction to Two Area interconnected System

In two-area system, two single area systems are interconnected via a tie line. Interconnection of the areas increases the overall system reliability.

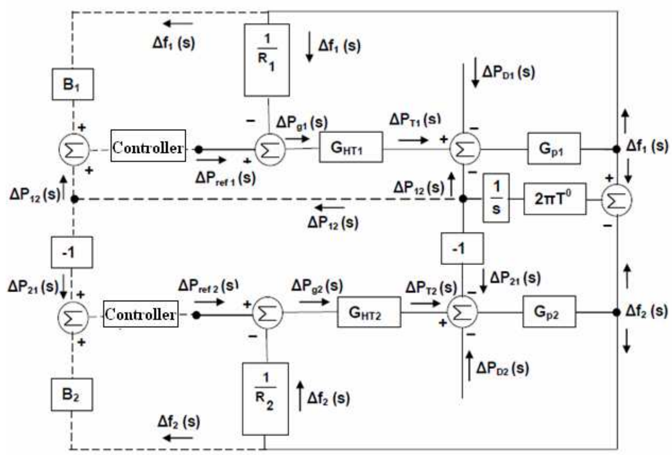

Figure 1. Block diagram of two area interconnected power system

In two area interconnected power system load change in one area will affect the generation in all other interconnected area. Tie line power flow should also be taken into account other than change in frequency.In this paper, two area interconnected system considering different types of units as shown in Figure1 are considered for designing the proposed controller. An area is interconnected with each other by a tie line which is used for economy and continuity of power supply. There are different cases considered for analysis.

3. Simulations and discussion

The composite rated output power capacity and nominal load of the single area is 2000 MW, 1840 MW respectively. Either generating units controlled by a common controller or different controller for each units can be used. Common controller for thermal-thermal two area interconnected power system and thermal-hydro two area interconnected power system are considered for analysis. The frequency deviation responses are shown in Figure 2 to 11 at 2% and 1% step load perturbation in thearea 1 and area 2 respectively.

Following system parameters have been used for analysis in the present work (Kothari et al., 1988; Parmar et al., 2010a, 2010b).

System parameters

P_{rt} = 2000MW

EMBED Equation.DSMT4 ???(nominal load of the area)

f = 60 Hz, H = 5MW s/MVA

$$D = \frac{\partial P}{\partial f}\frac{1}{P_{rt}} \text{ p.u. MW/Hz}$$

$$K_{PS} = \frac{1}{D} \text{ Hz/p.u. MW}$$

$$T_{PS} = \frac{2H}{fD}$$

T_{SG} = 0.08 s, T_T = 0.3 s

$R_{HY} = R_{TH}$ = 2.4 Hz/MW

K_R = 0.3, T_R = 10 s,

T_{RS} = 5 s,

T_{RH} = 28.75 s

T_{12} = 0.215 s

To examine the step responses of PID - derivative filter load frequency controller for various cases of two area interconnected system as given below have been presented in subsections. These cases have been simulated and verified in MATLAB/SIMULINK ver. 2009 b.The broken line represents the response of PID-derivative filter controller. The solid line represents response of PID controller.

3.1 Uncontrolled two area interconnected thermal-thermal system (Case I): When there is a step load perturbation in area-1 there will be change in frequency from the nominal value of both the areas and also a change in the tie-line power flow between the areas from the desired range. Figure 2 and Figure 3 show the dynamic response of frequency in both areas and change in tie line power between the areas respectively when step load perturbation of 2% occurs in area-1 and 1% in area 2 without control action. Frequency of both the areas and tie-line power flow deviates from their nominal values and settles at a point (-0.0235 Hz, -0.0235 Hz and -0.01 p.u. Mw) below the nominal point at steady state condition.

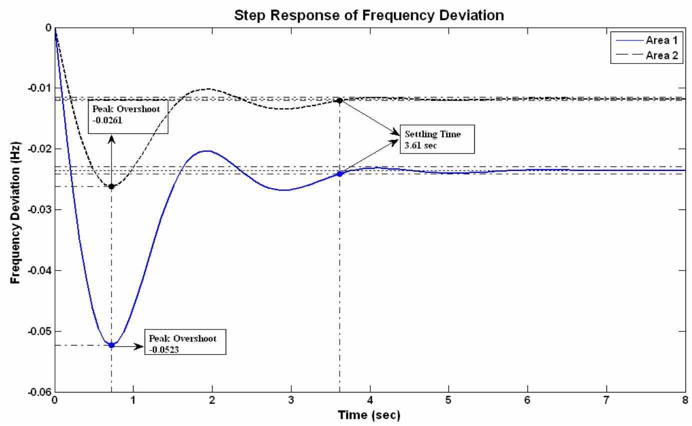

Figure 2. Step response of frequency deviation of area 1 and area 2 without controller

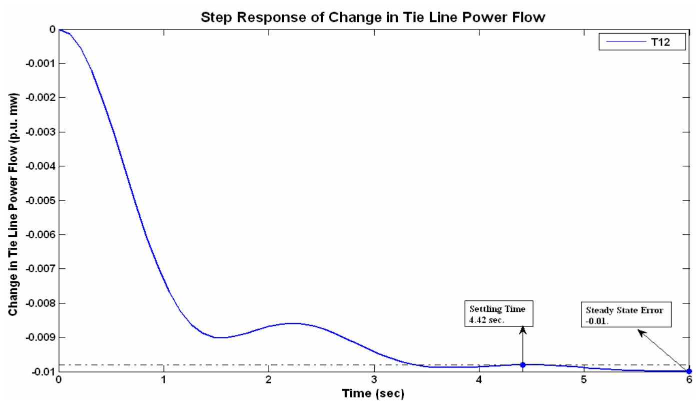

Figure 3. Step response of frequency deviation of change in tie line power flow

Table 1. Time domain results

Parameter Specification	Frequency Deviation in Area 1	Frequency Deviation in Area 2	Change in Tie Line Power Flow
Rise time (sec)	0.162	0.162	1.1
Peak time (sec)	0.718	0.718	6
Settling time (sec)	3.16	3.16	4.42
Peak overshoot	-0.0523	-0.0261	-0.00999
Steady state error	-0.0235 Hz	-0.0118Hz	-0.01 p.u.Mw

It is necessary that this frequency and tie line power comes back to the desired values. This is achieved by controller. Detailed results of this test case are summarized in the Table 1.

3.2 Controlled two area interconnected thermal-thermal system (Case 2): Two area interconnected thermal-thermal system case both are identical non-reheat unit. A 2% and 1% step load perturbation of considered in area 1 and area 2 respectively. Time domain analysis of frequency deviation in area 1, frequency deviation area 2 and change in tie line power flow with PID and PID-derivative filter controller is as shown in Figure 4, Figure 5 and Figure 6. Detailed results of this test case are summarized in the Table 2.

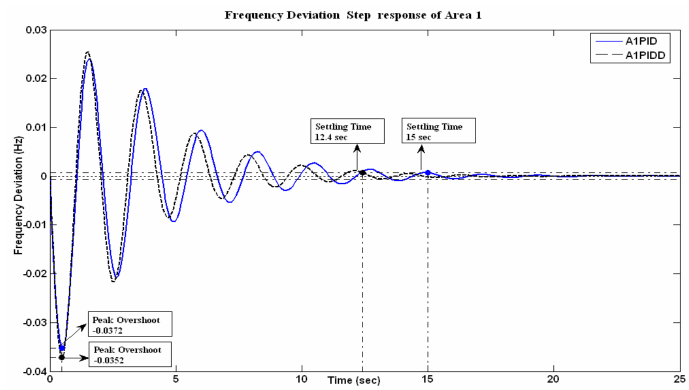

Figure 4.Step response of frequency deviation of area 1

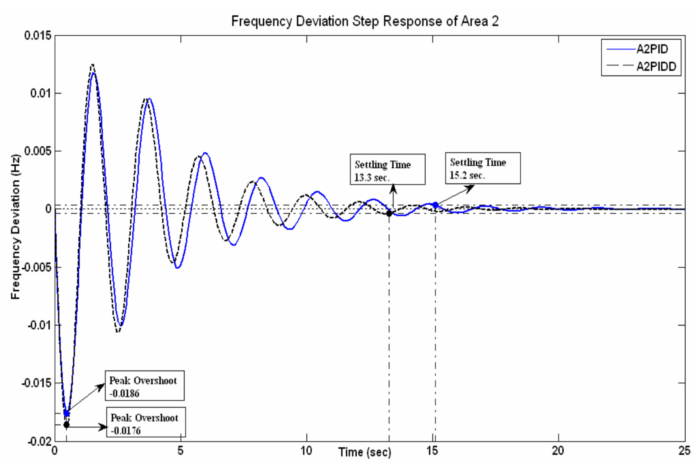

Figure 5. Step response of frequency deviation of area 2 with

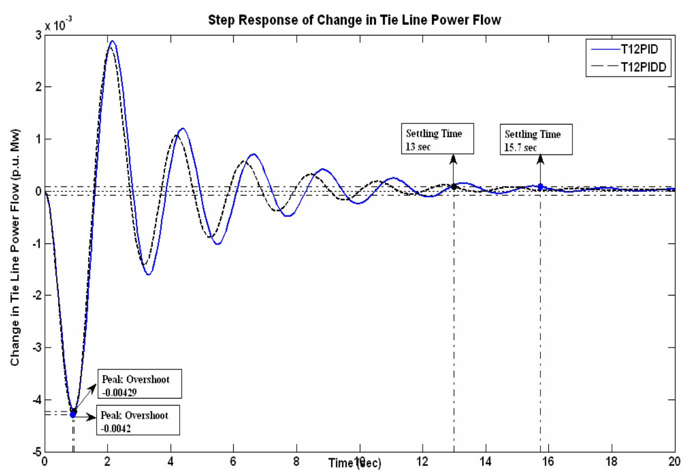

Figure 6. Step response of change in tie line power flow

The settling time of frequency deviation in area 1 and area 2 is reduced by 17.33%, 14.32% respectively. The settling time of change in tie line power flow is reduced by 17.19%. The first peak of PID-derivative filter is high but the subsequent peaks are low. Hence the response of two area interconnected thermal-thermal system with PID-derivative filter controller is improved.

Table 2. Time domain results

Parameter Specification	Frequency Deviation in Area 1		Frequency Deviation in Area 2		Change in Tie Line Power Flow	
	PID	PIDD	PID	PIDD	PID	PIDD
Peak time (s)	0.466	0.482	0.466	0.482	0.933	0.896
Settling time (s)	15	12.4	15	13.3	15.7	13
Peak overshoot	-0.035	-0.037	-0.0176	-0.0186	0.0042	-0.004

3.3 *Uncontrolled two area interconnected hydro-thermal system (*Case 3*):* From the Figure 7 and Figure 8 it is clear that when there is no control action is taken and load disturbance occurs 2% and 1% (increase in load) in area-1 and area 2 respectively, frequency deviates from their nominal values and settles at a point (-0.0118 Hz,-0.0235 Hz and -0.01 p.u. Mw) below the nominal point at steady state condition. For adequate operation, frequency and power has to come back on desired values via control action. The detailed time domain results are summarized in Table 3.

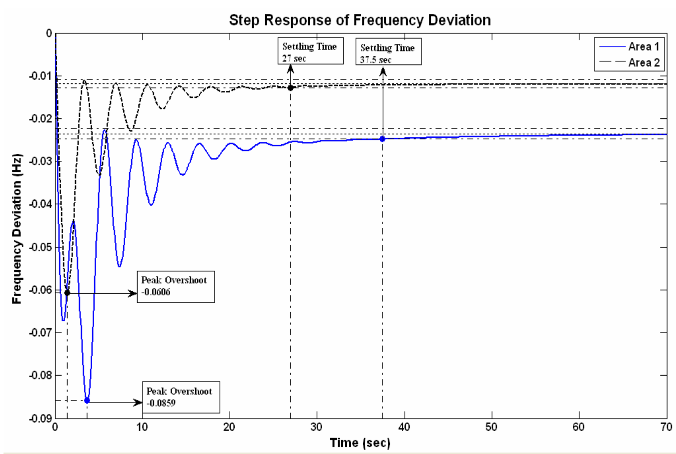

Figure7. Step response of frequency deviation of area 1 and area 2 without controller

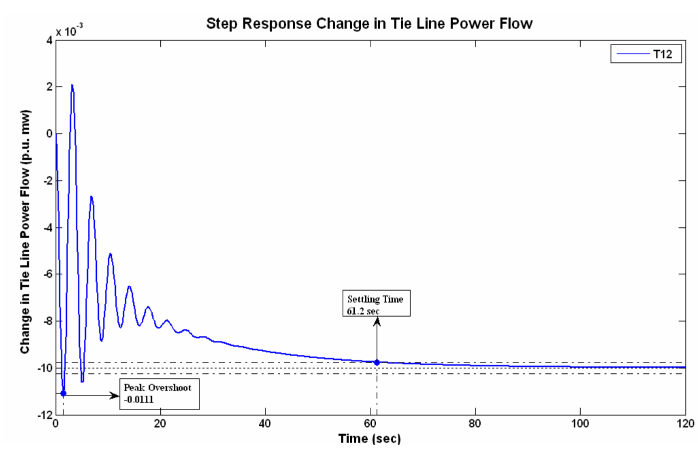

Figure 8. Step response of frequency deviation of change in tie line power flow

Table 3. Time domain results

Parameter Specification	Frequency Deviation in Area 1	Frequency Deviation in Area 2	Change in Tie Line Power Flow
Rise time (sec)	0.156	0.161	0.786
Peak time (sec)	1.38	3.69	1.43
Settling time (s)	27	37.5	61.2
Peak overshoot	-0.0606	-0.0859	-0.0111
Steady state error	-0.0235 Hz	-0.0118Hz	-0.01 p.u.Mw

3.4 *Controlled two area interconnected hydro-thermal system (Case 4):* Two area interconnected hydro-thermal system case one is thermal and another is hydro unit. A 1% and 2% step load perturbation of considered in area 1 and area 2 respectively. Time domain analysis of this case with PID and PID-derivative filter controller is as shown in Figure 9- 11.

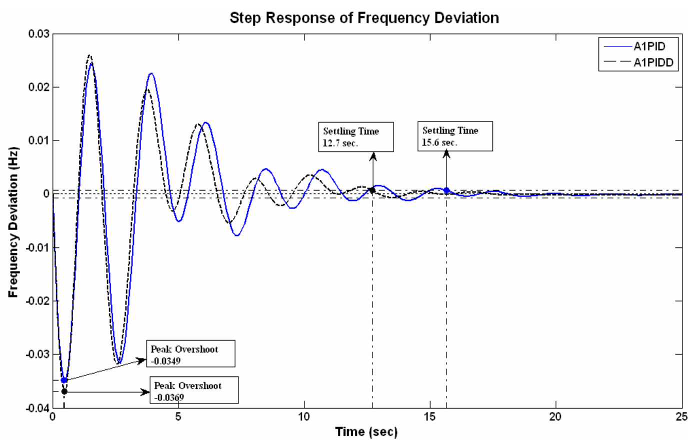

Figure 9. Step response of frequency deviation of area 1

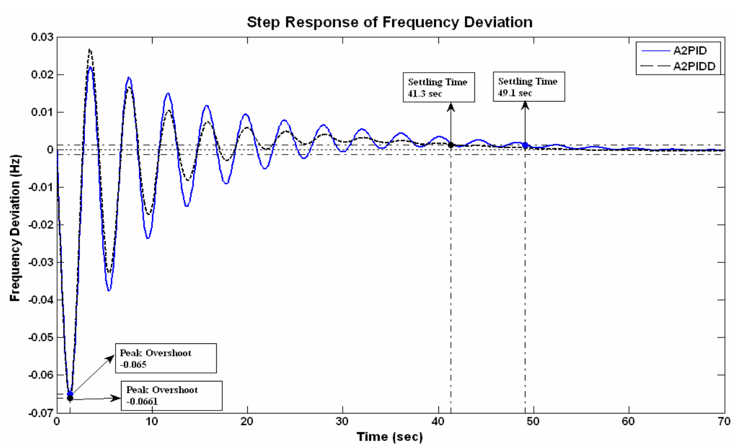

Figure 10. Step response of frequency deviation of area 2

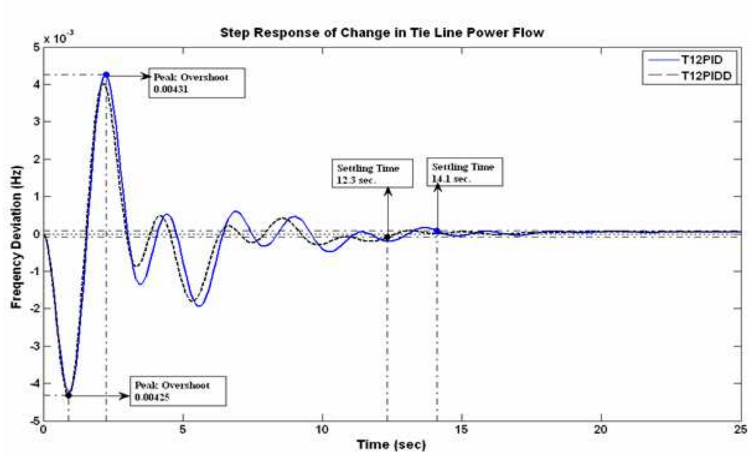

Figure 11. Step response of change in tie line power flow

Table 4. Time domain results

Parameter Specification	Frequency Deviation in Area 1		Frequency Deviation in Area 2		Change in Tie Line Power Flow	
	PID	PIDD	PID	PIDD	PID	PIDD
Peak time (s)	0.466	0.482	0.466	0.482	0.933	0.896
Settling time (s)	15	12.4	15	13.3	15.7	13
Peak overshoot	-0.035	-0.037	-0.0176	-0.0186	0.0042	-0.004

The settling time of frequency deviation in area 1 and area 2 is reduced by 17.33%, 14.32% respectively. The settling time of change in tie line power flow is reduced by 17.19%. The first peak of PID-derivative filter is high but the subsequent peaks are low. Hence the response of two area interconnected thermal-thermal system with PID-derivative filter controller is improved.

4. Conclusions

A new PID-Derivative filter controller has been proposed for load frequency control of thermal-thermal two area interconnected power system and one hydro and one thermal power plants interconnected power system. The proposed controller has enhanced the stability of the two area interconnected power system. Different cases have been considered and compared to justify the suitability of the PID-derivative controller. From Table II and Table IV it is found that subsequent peak overshoots, peak time and settling time have improved with the PID-derivative filter controller in as compared to conventional PID controller, which is the major contribution of this research paper.

Nomenclature

f Nominal system frequency, Hz

D System damping of area, p.u. MW/Hz

K_{PS} Power system gain, Hz/ p.u. MW

K_R Steam turbines reheat constant, s

P_{rt} Rated capacity of the area, MW

R_{TH} Governor speed regulation parameters of thermal generating unitHz/ MW (p.u.)

R_{HY} Governor speed regulation parameters of hydrogenerating unit Hz/MW (p.u.)

T_{GH} Hydro turbine speed governor main servo time constant, s

T_{PS} Power system time constant, s

T_R Steam turbine reheats time constant, s

T_{RS} Hydro turbine speed governor reset time, s

T_{RH} Hydro turbine speed governor transient droop time constant,s

T_{SG} Speed governor time constant, s

T_T Steam turbine time constant, s

T_w Nominal starting time of water in penstock, s

Δf Incremental change in frequency, Hz

ΔP_D Incremental load change, p.u. MW

ΔP_{GG} Incremental change in power outputs of thermal, hydro and gas generating units, respectively, p.u. MW

ΔP_{GTH} Incremental change in power outputs of the rmal unit p.u. MW

ΔP_{GHY} Incremental change in power outputs of hydro unit p.u. MW

PID PID controller
PIDD PID –derivative filter controller

Appendix

The frequency response method is based on knowledge of the point, where Nyquist curve of the process transfer function intersect the negative real axis. This point can be characterized by two parameters the frequency w_{180} and the gain at that frequency K_{180} .The point names as the ultimate point and characterized by the parameters $K_c = 1/K_{180}$ and $T_c = 2pi / w_{180}$, which are known as the ultimate gain and the ultimate period. These parameters are determined by following. K_I and K_D are set to zero and only K_p value is increased until it creates a periodic oscillation at the output response. This critical K_p value is attained to be ultimate gain (K_c) and the period where the oscillation occurs is ultimate period (T_C). As a result, the entire process depends on two variables and the other control parameters are calculated according to the Table V (Astrom and Hagglund, 2002;Ziegler, J.G. and Nichols,N.B., 1942)**.**

Table 5. Ziegler- Nichols tuning formulae

Control type	K_p	K_I	K_D
P	0.50 K_c	0	0
PI	0.45 K_c	0.8 T_C	0
PID	0.60 K_c	0.5 T_C	0.12 T_C

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Biographical notes

Preeti Sonkar is of the Department of Electrical Engineering, National Institute of Technology Hamirpur, India

Ashwani Chandel and O. P. Rahi are of the Department of Electrical Engineering, National Institute of Technology Hamirpur, India

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