ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 4, April 2014

Integral Control AGC of Interconnected Power Systems Using Area Control Errors Based On Tie Line Power Biasing

Charudatta B. Bangal

Professor, Electrical Engineering, Sinhgad Academy of Engineering, Pune, India

Abstract: The following work is to propose a new method of defining the area control error for implementing integral control AGC scheme for an interconnected power system. Conventionally, the area frequency deviations are biased with a parameter 'Frequency Bias (B)' and added to tie line power deviation to compose the area control errors. However, deciding a suitable value of 'B' has been a crucial and debatable issue over years. Many researchers have proposed different ways of deciding 'most appropriate' value of B for a given system. In the proposed method, the tie line power deviation is biased with regulation 'R' and added to frequency deviations to compose the area control errors. Exhaustive simulations and investigations have been carried out on models of interconnected power systems with the proposed method and the results have been compared with that of the conventional method. The present discussion and remarks are not for challenging the usefulness of the conventional method, however, efforts have been made to show that, the proposed method can give better results and it can have some additional advantages over the conventional method. Further, this method is quite simple to adopt. The present investigations have been kept limited to the aspects such as magnitude of excursions, transients & settling time. The proposed method is found to give satisfactory performance at various combinations of governor regulation, prevailing loading condition & simultaneous load perturbations. A simple two area thermal (non-reheat) interconnected power system is used to demonstrate the proposed method. Further investigations on the proposed method for any other aspects are open for the researchers to strengthen the scope of the present method and to explore its hidden merits.

Keywords: Interconnected Power Systems, Automatic Generation Control, Area Control Error, Area Frequency Response Characteristic, Frequency Bias.

I. NOMENCLATURE

ACE	Area control error
B	Frequency bias (pu MW/Hz)
β	Area frequency response characteristic (AFRC)
P_D	Prevailing load in each area (pu MW)
P_r	Rated capacity of each area (MW)
fr	Rated frequency (Hz)
D	Rate of change of prevailing load with frequency
ΔP_{D1}	Load perturbation in area 1(pu MW)
ΔP_{D2}	Load perturbation in area 2 (pu MW)
Δf_1	Frequency deviation of area 1 (Hz)
Δf_2	Frequency deviation of area 2 (Hz)
ΔP_{tie}	Deviation of tie line power (pu MW)
Tg	Governor time constant (Second)
Tt	Turbine time constant (Second)
Tp	Power system time constant (Second)
Kp	Power system constant (Hz/pu MW)
K	Integral controller gain
R	Governor regulation (Hz/pu MW)
Ts	Synchronizing coefficient of tie line (pu MW/rad)

II. INTRODUCTION

The modelling procedures of interconnected power systems with integral control AGC schemes are well established [1-5][8][10].

An interconnected power system with two identical thermal (non-reheat) areas along with conventional integral control scheme (simulated in MATLAB) is shown in Fig. 1.

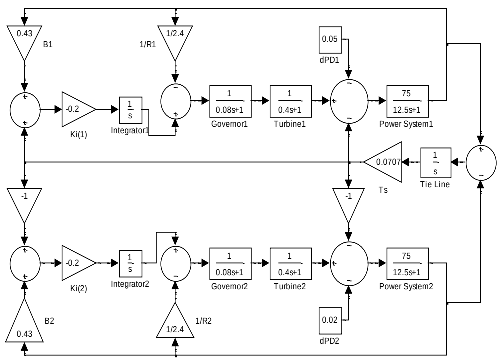

Fig. 1 Two area power system with conventional control

Conventionally, the area control errors are composed as;

$ACE_1 = \Delta P_{tie} + B_1 \Delta f_1$

$ACE_2 = - \Delta P_{tie} + B_2 \Delta f_2$

The issue of selecting most appropriate value of frequency bias parameter 'B' has been much hotly discussed and debated in all the past years [2] [3] [6][7][10][11]. From most of the literature related to AGC of interconnected power systems, the value of 'B' is conventionally taken equal to the AFRC (β) for certain reasons [2].

i.e., $B = \beta = \dfrac{1}{Kp} + \dfrac{1}{R} = D + \dfrac{1}{R}$

Further, in majority of related literature and published papers, the analysis of interconnected systems is done with the help of power system models which almost always assume Kp = 120 and Tp = 20.

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 4, April 2014

By definition, $Kp = \frac{1}{D}$; where, $D = \frac{\partial P_D}{\partial fr}$.

'D' is the rate of change of prevailing load with change in prevailing value of frequency. For example, if at a certain instant the prevailing load on power system is 50% of its rated capacity ($P_D = 0.5P_r$) and operating at rated frequency of 60 Hz, then any change of load on the system (ΔP_D) at this instant will cause $D = \frac{0.5}{60} = 0.008333$ pu MW/Hz and value of Kp at this instant will be $K_P = \frac{1}{D} = 120$ Hz/pu MW. Also, by definition, the power system time constant is given as $Tp = \frac{2H}{frD}$, where H = inertia constant (usually taken as 5 seconds). For the present example, Tp = 20 sec. Thus it is evident that, the values Kp = 120 and Tp = 20 correspond to a specific loading condition i.e., when $P_D = 0.5P_r$.

However, in practice, the load perturbations can occur at any random operating condition. Hence, the values of Kp and Tp solely depend on amount of prevailing load and frequency at the time of perturbation. Here we assume that, at the time of load perturbation, whatever is the amount of prevailing load, the frequency is at rated value. Assuming various values of prevailing load in the steps of 10%, the corresponding values of Kp and Tp are shown in TABLE I.

TABLE I
VALUES OF KP, TP AND D IN ENTIRE OPERATING RANGE

P_D	Kp	Tp	D
1.0 Pr	60	10	0.016666
0.9 Pr	66.6666	11.1111	0.015
0.8 Pr	75	12.5	0.013333
0.7 Pr	85.7143	14.2857	0.011666
0.6 Pr	100	16.6666	0.01
0.5 Pr	120	20	0.008333
0.4 Pr	150	25	0.006666
0.3 Pr	200	33.3333	0.005
0.2 Pr	300	50	0.003333
0.1 Pr	600	100	0.001666

It is therefore necessary to consider appropriate values of Kp & Tp while studying the behaviour of an interconnected power system under AGC scheme.
As mentioned, conventionally the value of 'B' is taken as

$$B = \beta = \frac{1}{Kp} + \frac{1}{R}$$

Corresponding to various loading conditions, the values of 'B' can be calculated for various values of governor regulation as shown in TABLE II.

TABLE II
VALUES OF B FOR R=3%, 4% & 5%

P_D	'B' with conventional method $B = \beta = \frac{1}{Kp} + \frac{1}{R}$		
	R=3%	R=4%	R=5%
1.0 Pr	0.572222	0.433333	0.350000
0.9 Pr	0.570555	0.431666	0.348334
0.8 Pr	0.568888	0.430000	0.346666
0.7 Pr	0.567222	0.428333	0.344999
0.6 Pr	0.565555	0.426666	0.343333
0.5 Pr	0.563888	0.425000	0.341666
0.4 Pr	0.562222	0.423333	0.340000
0.3 Pr	0.560555	0.421666	0.338333
0.2 Pr	0.558888	0.420000	0.336666
0.1 Pr	0.557222	0.418333	0.334999

In conventional AGC scheme for interconnected power systems, the optimum value of integrator gain is selected as 0.2 for a thermal area. In the present analysis, this value was considered for all simulations.

III. PROPOSED METHOD

In the proposed method, area control errors are defined as;
$ACE_1 = R\ \Delta P_{tie} + \Delta f_1$
$ACE_2 = -\ R\ \Delta P_{tie} + \Delta f_2$
where, R is the governor regulation.
Since the governor regulation (R) is a direct measure of change in area frequency as per change in power demand, it is chosen for biasing the tie line power deviation so as to define the ACEs and this is the central innovative idea behind the proposed method.

In the proposed method, the value of integrator gain needs to be varied slightly as per value of R to get results better than conventional method. The optimum values of K can be decided through simulations & trials on the power system model. For the model under consideration it was observed that, optimum values of K vary with R as per a hyperbolic function. For the model under consideration, K was found to vary from 0.12 to 0.028 when R was varied from 3% to 15%. Hence, in the present analysis, values of K were used as per the K-R characteristic obtained for the given model.

The two area power system with proposed method (as simulated in MATLAB) is shown in Fig. 2

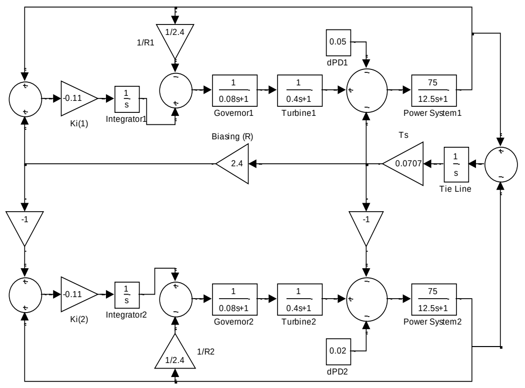

Fig. 2 Two area power system with proposed control

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 4, April 2014

IV. ANALYSIS & RESULTS

For different combinations of loading condition (P_D), area load perturbations (ΔP_{D1} , ΔP_{D2}) & governor regulation (R), both the methods were tested. The dynamic responses of frequency deviations (Δf_1 & Δf_2) & tie-line power deviation (ΔP_{tie}) were compared and studied. The integrator gain was kept fixed at 0.2 for conventional method, whereas, the integrator gain was changed as per the K-R characteristic for the proposed method. The values of various parameters used in the analysis are given in TABLE III.

TABLE III
VALUES OF PARAMETERS USED

Parameter	Symbol	Value	Unit
Rated capacity of each area	Pr	1.00	pu
Rated frequency	fr	60	Hz
Governor time constant	Tg	0.08	Second
Turbine time constant	Tt	0.4	Second
Synchronizing coefficient of tie line	Ts	0.0707	Pu MW/rad
Inertia constant	H	5	Second

The dynamic responses of Δf_1, Δf_2 & ΔP_{tie} for a few sample combinations as mentioned in TABLE IV are shown in Fig. 3 to Fig. 11. However, many such combinations in entire operating range, with wide range of simultaneous load perturbations & regulation values varying from 3% to 15 % were tested with both the methods.

TABLE IV
RESULTS

P_D (pu)	Load Perturbations (pu)		R (pu)	Figures
	ΔP_{D1}	ΔP_{D2}		
0.8 Pr	0.05	0.02	0.03	Fig. 3, 4, 5
0.5 Pr	0.03	0.06	0.04	Fig. 6, 7, 8
0.6 Pr	0.06	0.01	0.05	Fig. 9, 10, 11

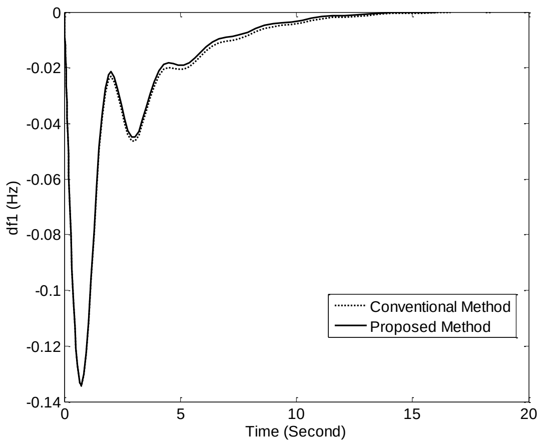

Fig. 3: PD=0.8 pu, dPD1=0.05 pu, dPD=0.02 pu, R=0.03 pu

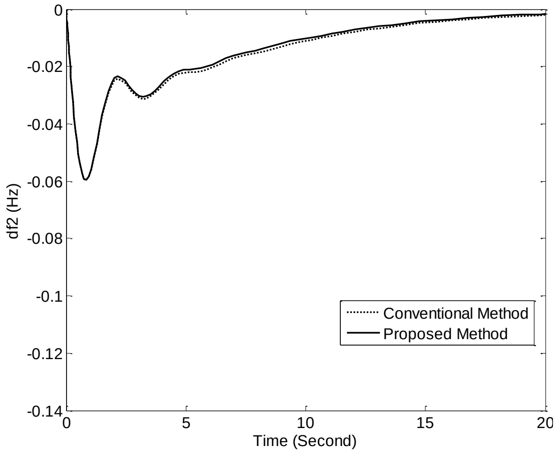

Fig. 4: PD=0.8 pu, dPD1=0.05 pu, dPD2=0.02 pu, R=0.03 pu

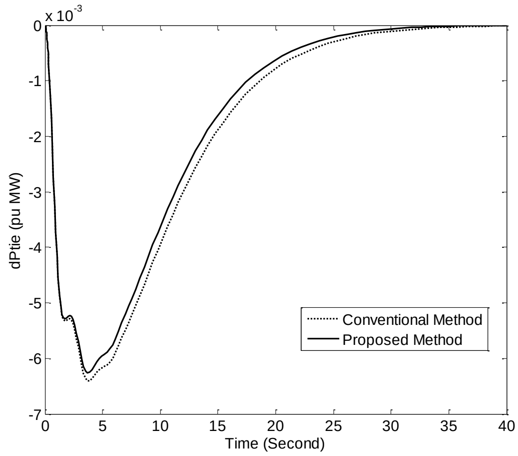

Fig. 5: PD=0.8 pu, dPD1=0.05 pu, dPD2=0.02 pu, R=0.03 pu

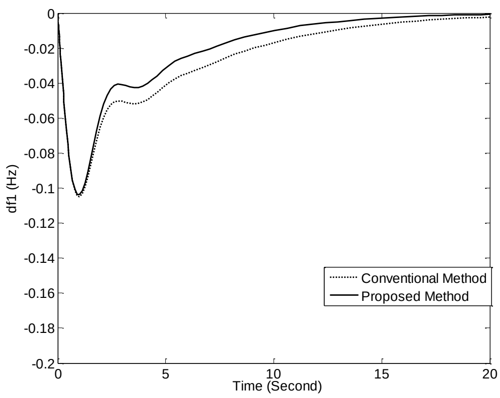

Fig. 6: PD=0.5 pu, dPD1=0,03 pu, dPD2=0.06 pu, R=0.04 pu

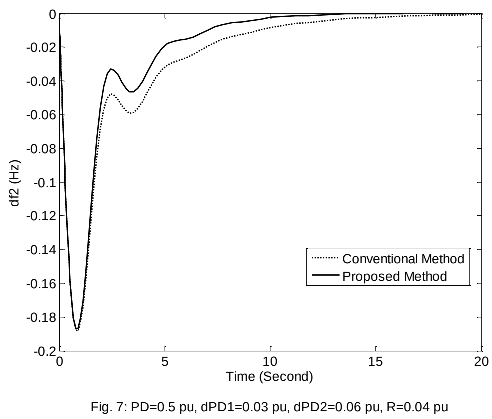

Fig. 7: PD=0.5 pu, dPD1=0.03 pu, dPD2=0.06 pu, R=0.04 pu

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 4, April 2014

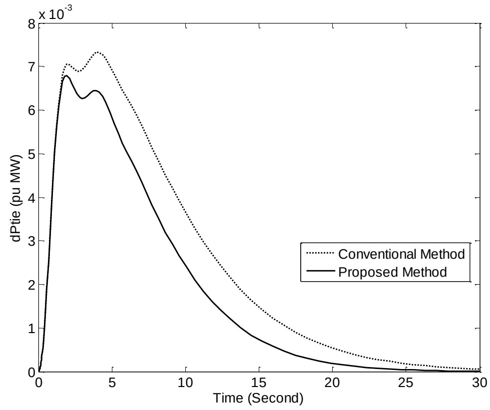

Fig. 8: PD=0.5, dPD1=0.03 pu, dPD2=0.06 pu, R=0.04 pu

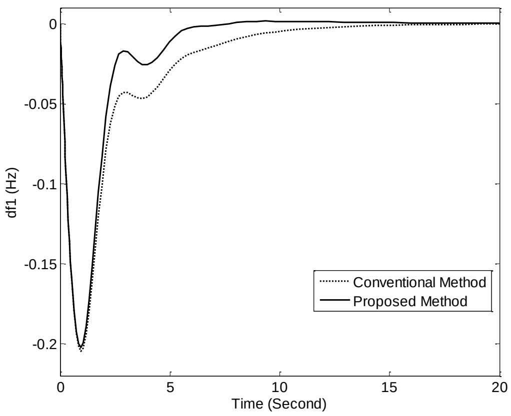

Fig. 9: PD=0.6 pu, dPD1=0.06 pu, dPD2=0.01 pu, R=0.05 pu

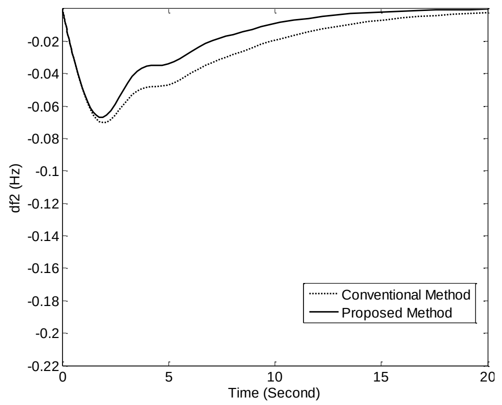

Fig. 10: PD=0.6 pu, dPD1=0.06 pu, dPD2=0.01 pu, R=0.05 pu

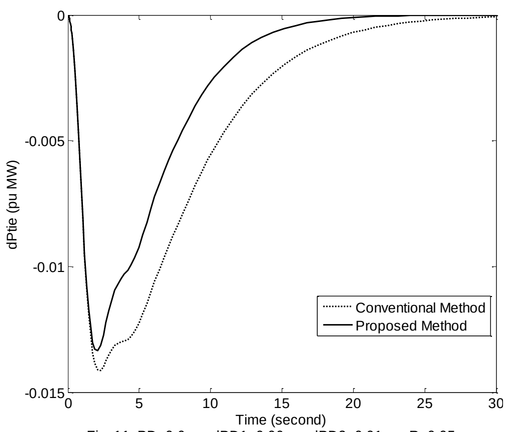

Fig. 11: PD=0.6 pu, dPD1=0.06 pu, dPD2=0.01 pu, R=0.05 pu

V. OBSERVATIONS AND REMARKS

Exhaustive simulations and trials were carried out on the power system model under consideration with conventional as well as proposed method for studying the dynamic responses of Δf_1, Δf_2 and ΔP_{tie} under different combinations of loading condition (P_D), area load perturbations (ΔP_{D1} & ΔP_{D2}) and governor regulation (R). The dynamic responses of Δf_1, Δf_2 and ΔP_{tie} for both cases were studied for various aspects like magnitude of excursions, time to settle to zero (or close to zero upto an accuracy of about 10^{-4}), presence of transients etc. The sample cases are shown in Fig. 3 to Fig. 11. It is evident that, the present method can give better performance than the conventional method.

A few advantages of proposed method over conventional method are:

1) In reality, the power system is always subjected to shifts in loading conditions with time and hence D is always changing. In conventional method, the ACEs are dependent on value of B. Further, B depends on D & R. Although R is practically not changed so often, still B has to be changed 'in real time' according to changes in D. Thus there is a need of always monitoring the prevailing loading condition and adjusting the value of B accordingly for a proper control. In the proposed method, the ACEs depend only on R and hence they are practically independent of loading conditions.

2) In the proposed method, even if the feedback from the tie line is missing due to some reason, all the interconnected areas would still continue to control the frequency deviations effectively because under these circumstances;

$ACE_1 = \Delta f_1$
$ACE_2 = \Delta f_2$

Hence all the areas would continue to get control signals as if they were isolated single area systems.

On the other hand, in conventional method, missing the feedback from tie line would give ACEs as:

$ACE_1 = B_1\,\Delta f_1$
$ACE_2 = B_2\,\Delta f_2$

which may not offer proper control to curb frequency excursions satisfactorily. Further, it was observed that, under these circumstances, the steady state error in tie line power is quite high in the conventional method.

3) It was found that, to have better control than the conventional method, the value of integrator gain in proposed method needs to be varied marginally as per value of regulation. With the proposed method, better results are obtained at K = 0.12 for R = 3% and at K = 0.028 for R = 15%. It was also found that, for the intermediate values of R, the optimum values of K vary as per the hyperbolic K-R characteristic, which can be easily determined through simulations. Thus, if K-R characteristic is obtained for the system under study, the appropriate value of K can be preset accordingly. It should be noted that, the governor regulation is almost fixed and it is not changed frequently in a given system. Thus, for a practical system, the value of K can be preset according to preset value of R and there is no need to change K

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 4, April 2014

thereafter for any operating condition from zero to rated output.

Following remarks need to be made for inviting further investigations on the proposed method.

1) Although the simulation model used in this study is relatively simplified (i.e., without involving nonlinearities or other issues such as generation rate constraint, use of reheat turbines, governor dead bands etc.), the proposed method can be tested under such circumstances.

2) The proposed method can be tested for comparative studies / investigations on interconnected systems involving areas with different characteristics. The optimum value of integrator gain (The K-R relationship) can be obtained for hydro or other types of prime movers.

3) The stability studies can be carried out on various types of power system models with the proposed method.

Certain comments about selection of conventional frequency bias parameter (B) from the report of AGC task force of the IEEE/PES/PSE/system Control Subcommittee, Transactions on Power Systems [9] are stated below:

i) The system natural response coefficient (β), is not a constant, neither it is accurately obtainable nor predictable. It depends on the current status and governor response characteristics of the presently online units and the sensitivity of loads. Depending on the magnitude of upset from the prevailing pre-disturbance frequency, the variable number of governors coming out of deadband causes β to be highly sensitive to upset size. Moreover, the observation or measurement of natural response can be obscured by normal system activities. E.g. generating units may be actively responding to prior control signals and, of course, individual system loads are constantly and arbitrarily changing.

ii) If every area used an underestimated value of B, operation of the interconnection would tend to show characteristics similar to those associated with constant net interchange control. On the other hand, indiscriminate use of over-estimated values for B would tend to yield inter-area generation oscillations. From the above comments it is evident that, in the conventional integral control method the issue of determining the appropriate value of B has still remained crucial and debatable. Hence the proposed method of defining the ACEs (biasing of tie line power deviation with governor regulation) needs to be investigated further for its usefulness in a broad sense and other hidden merits.

REFERENCES

[1] O. I. Elgerd, "Electric Energy Systems Theory", Mc-Graw Hill, Newyork (1983).
[2] N. Cohn, "Some Aspects of Tie Line Bias Control on Interconnected Power System", Amer. Inst. Elect. Eng. Trans., vol 75, pp 1415-1436, Feb. 1957.
[3] C. Fosha, O. I. Elgerd, "The megawatt frequency control problem: A new approach via optimal control theory," IEEE Trans. Power App. Syst., vol. PAS-89, no. 4, pp. 563–577, Apr. 1970.
[4] IEEE Committee Report, "IEEE Trans. Power App. Syst.,", vol. PAS-89, Jul./Aug. 1970. Standard definitions of terms for automatic generation control on electric power systems.
[5] IEEE PES Committee Report, "IEEE Trans. Power App. Syst.,", vol. PAS-92, Nov. 1973. Dynamic models for steam and hydro-turbines in power system studies.
[6] IEEE PES Committee Report, "IEEE Trans. Power App. Syst.,", vol. PAS-98, Jan./Feb. 1979. "Current operating problems associated with automatic generation control".
[7] B. Oni, H. Graham, and L. Walker, "Investigation of Non-linear Tie Line Bias Control of Interconnected Power Systems", IEEE Trans. Power App. Syst., vol. PAS-100, no. 5, pp. 2350-2356, May 1981.
[8] IEEE PES Working Group, "Hydraulic turbine and turbine control models for system dynamic Studies," IEEE Trans. Power Syst., vol. PWRS-7, no. 1, pp. 167–174, Feb. 1992.
[9] Nasser Jaleeli, Louis S. VanSlyck, Donald N. Ewart, Lester H. Fink, "Understanding Automatic Generation Control", a report of the AGC task force of the IEEE/PES/PSE/system Control Subcommittee, Transaction on Power Systems, Vol. 7, No. 3, August 1992)
[10] P. Kumar and Ibraheem, "AGC strategies: A comprehensive review," Int. J. Power Energy Syst., vol. 16, no. 1, pp. 371–376, 1996.
[11] Ibraheem, Prabhat Kumar, and D.P. Kothari, 'Recent Philosophies of Automatic Generation Control Strategies in Power Systems', IEEE Trans. on Power Systems, Vol. 20, no. 1, Feb. 2005, pp. 346-357.

BIOGRAPHY

Charudatta B. Bangal received the degree of B.E. (Electrical) & M.E. (Electrical Power Systems) from College of Engineering, Pune (COEP) (University of Pune, India) and Ph.D. in Electrical Engineering from Bharath University, Chennai, India. He has teaching experience of 29 years in various Engineering colleges in India. He is presently working as Professor of Electrical Engineering in Sinhgad Academy of Engineering, Pune (India) and presently supervising 2 Ph.D. research scholars of University of Pune in the area of power systems. He has authored 3 text books in Electrical Engineering subjects. He has reviewed a few research papers for IEEE Transactions of Power Systems and Power Delivery.