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Multi area load frequency control using particle swarm optimization and fuzzy rules

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Abstract

This paper present heuristics based study of multi area power network. Heuristic procedures involving Particle Swarm Intelligence and Fuzzy based inferences have been employed to effectively obtain the optimized gains of PID controller. Any change in the load demand causes generator's shaft speed lower than the pre-set value and the system frequency deviates from the standard value results in malfunctioning of frequency relays. A five area load frequency model is constructed in Matlab/simulink by implementing the PID (Proportional, Integral and Differential) controllers to control the frequency deviations. The effect of interconnection of multi area power system as ring connection has been discussed. Simulations performed show the effectiveness of the current approach over simple fuzzy inferences in terms of performance as well as execution efficiency.

*Keywords:*Load Frequency Control; Particle Swarm Optimization ; Fuzzy Rules;Error Analysis.

1. Introduction

The term LFC(Load Frequency Control) in an interconnected power system which consists of large number of control areas, signifies to maintain the frequency of each area within predefined standard limits and to keep tie-line power flows within some pre-specified tolerances by adjusting the MW (mega-watt) outputs of the generators so as to accommodate fluctuating load demands. A well designed and controlled power system provides damping to the transients produced due to the load and system disturbances.

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Nomenclature

dŧɨ	Frequency deviation	dƤ$_{mech_n}$ɨ	Governor Valve position
dƤc ɨ	Controller output actuation signal	dƤ$_{tie-N}$	Net tie-line power flow
dƤLɨ:	Change in demand power or load	Ḫ ɨ	Equivalent inertia constant
Đ ɨ	Equivalent damping coefficient		
Ŧ ɨ ɉ	Tie-line synchronizing coefficient with area ɉ		
Ǥ ɨ (s)	Transfer function Turbine-Generator unit in cascade.		
Ƀ ɨ	Frequency bias	ʋ̆	Area interface
Ʀ ɨ	Droop characteristic	AFCE	Area frequency control error
ϕ_n ɨ	Participation factors	Ḿ (s)	Governor–turbine dynamic model
Ꝁ$_{PID}$(s)	Dynamic PID(Proportional Integral and Differential) controller		

Also, it should provide acceptable high level of power quality while maintaining both voltage and frequency within desirable tolerance limits. Load-frequency control (LFC), or automatic generation control, is a very important issue in power system operation and control for supplying sufficient and both good quality and reliable electric power [1-3]. In order to improve the transient response, advanced control techniques have been proposed, which include PID controller incorporated with soft computing and optimization techniques such as Fuzzy logic, PSO (Particle Swarm Optimization) Genetic Algorithms and advanced self adjusting fuzzy[4-13] and [14,15]. GA and PSO tuned fuzzy controller for AGC in three area power system proposed in [16-19]. Nowadays the complexity issues in power system are being solved with the use of GAs, PSOs, bacterial foraging optimization algorithm(BFA). But in the present scenario due to penetration of the DFIG-WT(Doubly fed Induction Generator based Wind Turbine) and diesel based power system into the main grids, give rise to stability issues of system frequency, active and reactive power under load demand disturbances[20-23]. So, in keeping view of the present status of the power system, a DFIG-WT and diesel based power system is added in the LFC model of the three area power system which is consist of thermal-hydro. In this paper a five control area LFC model has been made using Matlab/simulink. The performance of fuzzy and PSO based PID controllers is verified for the same load disturbances. An error based comparative analysis has been carried out to reach effective conclusion as described at the last.

2. Control area model description

2.1. Load Frequency Model of a single area with non-reheat steam and Hydro Generating Unit.

The LFC model of control area '*ɨ*' consist of conventional steam unit connected to a hydro unit in a power system comprised of N control areas interconnected through same tie-line is represented by the block diagram [1] as shown in fig.1.The output of power system block is change in system frequency (*dŧi*) corresponds to load disturbances and act as feedback signal which is compared with reference signal at the input and give rise to an error signal AFCE (Area Frequency Control Error) [1-3]. The regulated output of the controller is given to governor valve to reduce down the deviations in the system frequency, tie line power and mechanical power. For *N* interconnected control areas, the total change in tie-line power between area *i* and other areas is given by [1] as follows:

$$dP_{tie,i} = \sum_{\substack{j=1 \\ j \neq i}}^{N} dP_{tie,ij} = \frac{2\pi}{s}\left[\sum_{\substack{j=1 \\ j \neq i}}^{N} Ŧ_{ij} df_i - \sum_{\substack{j=1 \\ j \neq i}}^{N} Ŧ_{ij} df_j\right] \tag{1}$$

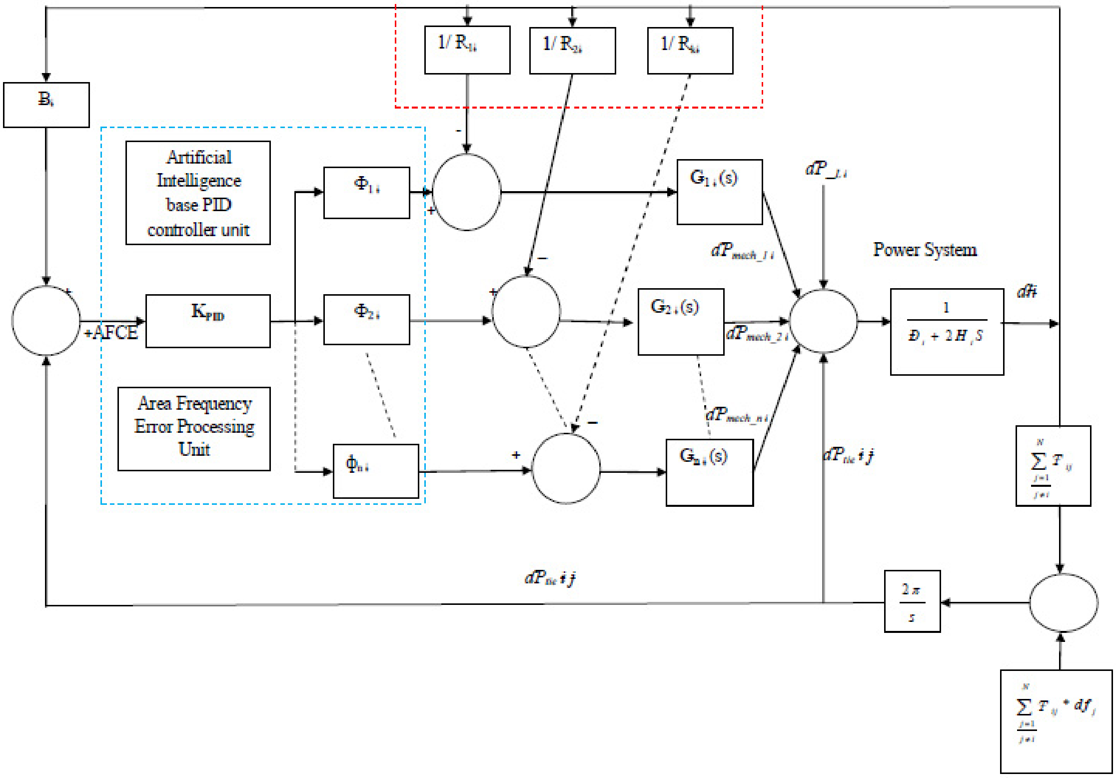

Fig.1. Control area *i* with Primary and Artificial Intelligence based Control unit [1]

The output of PID controller i.e. u_i proportional to area control error and is given by [1] as:

$$u_i = dPci = k_{pi} AFCE_i + k_{Ii} \int AFCE_i + k_{Di} \frac{d}{dt} AFCE_i \tag{2}$$

Where K_{pi}, K_{Ii} and K_{Di} are the gain constants of PID. dPci is the regulated actuating control signal. A control area is known as DISC-CA and a generating unit as GENC-GU [1]. GC is the gencos contribution matrix which shows the contribution of each GU in an N control area system. The rows of a GC correspond to GU and columns to corresponds CA . For example, for a large scale power system with m control areas (CA) and k generating units (GU), the GC will have the following structure [1].

$$GC = \begin{bmatrix} cf_{11} & cf_{12} & cf_{1(m-1)} & cf_{1m} \\ : & : & : & : \\ ; & : & : & : \\ cf_{n1} & cf_{n2} & cf_{k(m-1)} & cf_{km} \end{bmatrix} \tag{3}$$

Any entry in a GC that corresponds to a contracted load by a CA, demanded from the corresponding GU, must be reflected to the control area system. The generation of each GU must track the contracted demands of CA in steady state. The desired total power generation of GU*i* in terms of GC entries can be calculated as[1]

$$dP_{mi} = \sum_{j=1}^{N} cf_{ij} dP_{Lj} \tag{4}$$

2.2. *Dynamic Modelling of DFIG-Wind Turbine and Diesel Generator*

2.2.1 DFIG-Wind Turbine based Generating Units GU**:**

DFIG (Doubly Fed Induction Generator)-based wind turbine is represented by the small-perturbation model shown in Fig.2, [24]. Ŧ$_r$ is the transducer time constant, Ŧ$_w$ is the washout filter time constant for DFIG area dP_{N_ref} is the Incremental Wind Turbine active Power reference (non-conventional generation) and ω is the wind Turbine speed. The system behaviour depends on the choice of network parameters and DFIG-based wind turbine speed controllers are K_{wp} and K_{wi}. If several generators are connected to the system, the equivalent regulation droop can be determined from the eq. (5) as follows [24]:

$$\frac{1}{R}=\frac{1}{R1}+\frac{1}{R2}\dots\dots\dots+\frac{1}{Rn} \tag{5}$$

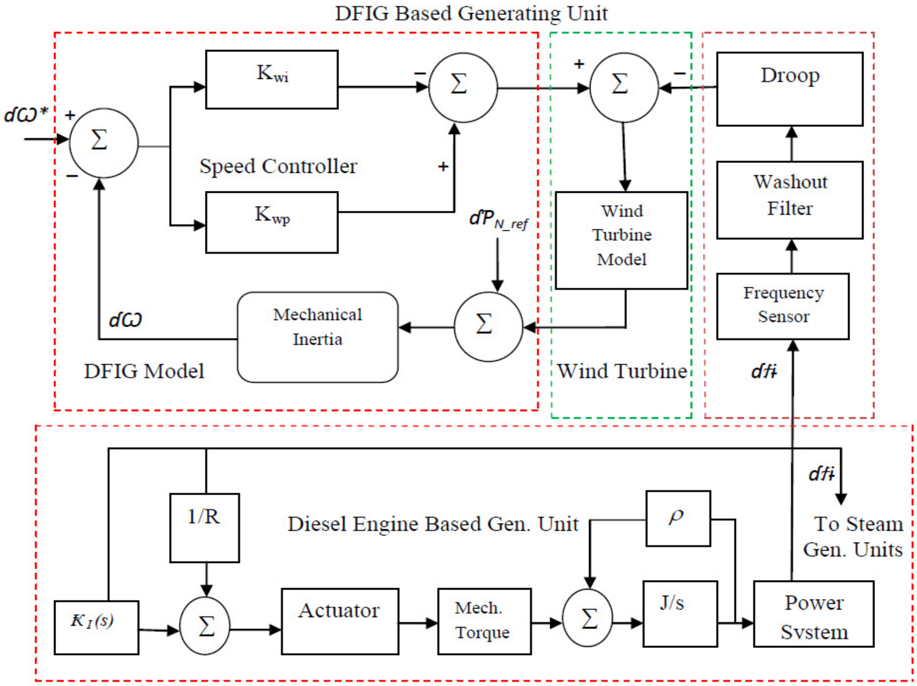

Fig.2. DFIG and Diesel based Area Load frequency control [24]

2.2.2 Diesel -Generator based Generating Unit GU

There are many methods already proposed for modelling a diesel generator [24,25]. It consists of fuel actuator system to regulate the speed of the engine and is usually represented as a first order network, which is characterized by gain K_2 and time constant t2. Fig.2. shows the actuator block having transfer function given by eq.(6)[25] , where K_3 is current driver constant. The output of the actuator is the fuel-flow phi(s) and the input current is I(s)[25,26].

$$\Psi(s)=\frac{K_3K_2}{(1+\tau_2 s)}I(s) \tag{6}$$

Fuel Flow Ψ (s) is then converted into mechanical torque Ŧ (s) .The objective of the control system is to maintain the system's frequency at the desired reference value i.e. drives the frequency error (fm – fr) to zero where fr is the reference frequency (50/60 Hz or 1 p.u.) and fm is the measured frequency. ρ is the viscous friction coefficient [24,25].Fig. 2. shows LFC model of diesel engine based generating unit.

3. Performance estimation of PID controller

In general, the PID controller design method using the integrated absolute error *(IAE)*, or the integral of time multiplied by absolute error, or the integral of squared-error *(ISE)*, or the integrated of time-weighted-squared-error *(ITSE),* is often employed in control system design because it can be evaluated analytically in the frequency domain [19,27].The *IAE*, *ISE*, and *ITSE* performance criterion formulas are as follows:

$$IAE = \int_0^\infty |r(t) - y(t)| dt = \int_0^\infty |e(t)| dt \tag{7}$$

$$ITAE = \int_0^\infty t\,|e(t)| dt \tag{8}$$

$$ISE = \int_0^\infty e^2(t) dt \tag{9}$$

$$ISTE = \int_0^\infty t e^2(t) dt \tag{10}$$

4. Particle Swarm Optimization (PSO)

PSO is derived from the social-psychological theory, and has been found to be robust in complex systems. The PSO algorithm has been successfully applied to solve various optimization problems [19, 27]. After any iteration, all particles update their positions and velocities to achieve better fitness values according to the following:

$$\begin{aligned} v_{j,g}^{(t+1)} &= w * v_{j,g}^{(t)} + c_1 * rand_1 * (pbest_{j,g} - x_{j,g}^{(t)}) \\ &+ c_2 * rand_2 * (gbest_g - x_{j,g}^{(t)}) \end{aligned} \tag{11}$$

$$x_{j,g}^{(t+1)} = x_{j,g}^{(t)} + v_{j,g}^{(t+1)} \qquad j = 1,2 \ldots\ldots\ldots\ldots, n \qquad g = 1,2 \ldots\ldots\ldots\ldots, m$$

where:

t is the current iteration number, $pbest_j$ is pbest of particle j, $gbest_g$ is gbest of the group, $rand_1$; $rand_2$ are two random numbers in the interval [0, 1], c_1; c_2 are positive constants and w parameter for controlling the impact of previous velocities is commonly known as the inertia weight. It influences the tradeoff between the global and local exploitation abilities of the particles. The inertia Weight is modified as:

$$\omega = \omega_{max} - \left(\frac{\omega_{max} - \omega_{min}}{iter_{max}} \right) itre \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

where ω_{min}, ω_{max}, iter, and $iter_{max}$ are minimum, maximum values of ω , the current iteration number and pre-specified maximum number of iteration cycles, respectively[19,27].

5. Fuzzy Based PID Controller

5.1 There are three principal elements to a fuzzy logic controller:

Fuzzy logic controller working on crisp information involves various stages to exploit fuzzy inference mechanism. Fuzzification Stage (Fuzzifier), Rule base and Inference engine stage and Defuzzification stage (Defuzzifier). For Load Frequency Control the process operator is assumed to respond to variables error (Ɛ) and change of error (cƐ) as shown in fig.3[28-30].

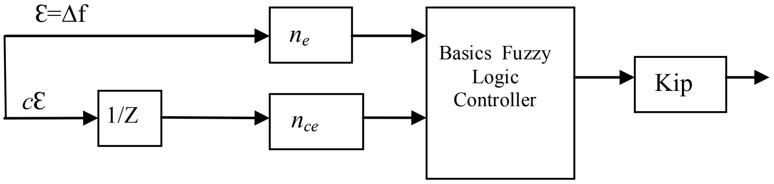

Fig. 3. Fuzzy Logic Controller (FLC).

The variable error is equal to the real power system frequency deviation (*dfi*). The frequency deviation '*f*' is the difference between the nominal or scheduled power system frequency (fN) and the real power system frequency (*f*). Taking the scaling gains into account, the global function of the FLC output signal can be written as.

$$dP_C=F[k_e\,\text{Ɛ}(k),\ k_{ce}\,c\text{Ɛ}(k)] \tag{13}$$

Where, n_e and n_{ce} are the error and the change of error scaling gains, respectively, and F is a fuzzy nonlinear function. FLC is dependant to its inputs scaling gains.[28-30] The block diagram of FLC is shown in fig.3. A label set corresponding to linguistic variables of the input control signals, Ɛ(k) and cƐ (k), with a sampling time of 0.01 sec is as follows[28]:

$$L(\text{Ɛ},C\text{Ɛ})=\{BN,MN,SN,ZE,SP,MP,BP\} \tag{14}$$

Where, BN = Big Negative ; MN = Medium Negative ; Small Negative (SN) ZE = Zero; SP=Small Positive ; MP = Medium Positive ; BP = Big Positive. Fuzzy logic controller has been used in three control areas comprised of hydro-thermal and three areas of DFIG-Thermal-Diesel inter connected in a ring. Attempt has been made to examine with five number of triangular membership functions (MFs) which provides better dynamic response with the range on input (error in frequency deviation and change in frequency deviation) i.e. universe of discourse is -1 to 1. The number of rules are 56. The results obtained are compared with the existing one and shown to prove better. In addition, several inputs have been tried out and dynamic responses are examined in order to decide suitable inputs to the fuzzy logic controller (FLC). Linguistic Rules for proportional gain *K* for Ɛ(k) and cƐ(k)[28,29]. Linguistic Rules for proportional gain K for Ɛ(k) and cƐ(k)

Ɛ(k) cƐ(k)	BN	MN	SN	ZE	SP	MP	BP
BN	BN	BN	BN	MN	SN	SN	ZE
MN	BN	MN	MN	MN	SN	ZE	SP
SN	BN	MN	SN	SN	ZE	SP	MP
ZE	BN	MN	SN	ZE	SP	MP	BP
SP	MN	SN	ZE	SP	SP	MP	BP
MP	SN	ZE	SP	MP	MP	MP	BP
BP	ZE	SP	SP	MP	BP	BP	BP

Ɛ(k) cƐ(k)	BN
BN	BN
MN	SN
SN	MN
ZE	ZE
SP	SP
MP	MP
BP	BP

For integral gain I where K is BN, Fuzzy logic controller is implemented to improve the dynamic performance of interconnected system.

6. Five area LFC (load frequency control) model under study

Figure 6 shows simulink based test model of five area frequency model. The performance of PI controller based on fuzzy rules and PSO has been carried out for different operating conditions given in the next sections as follows.

6.1 LFC control with the help of conventional PI controller in main grids and I controller in micro-grids with arbitrary selected values.

For an individual participation of each GU will act as local demand to each CA. A five-control area power system shown in fig. 4 is considered as a test system. It is assumed that each main grid control area includes two Gencos and one Disco and each micro Grid control area include three gencos (Wind turbine, Diesel Generator and a Thermal plant). All the five areas are connected to form a ring configuration. The power system parameters are tabulated in Tables 1, 2 and in appendix A.

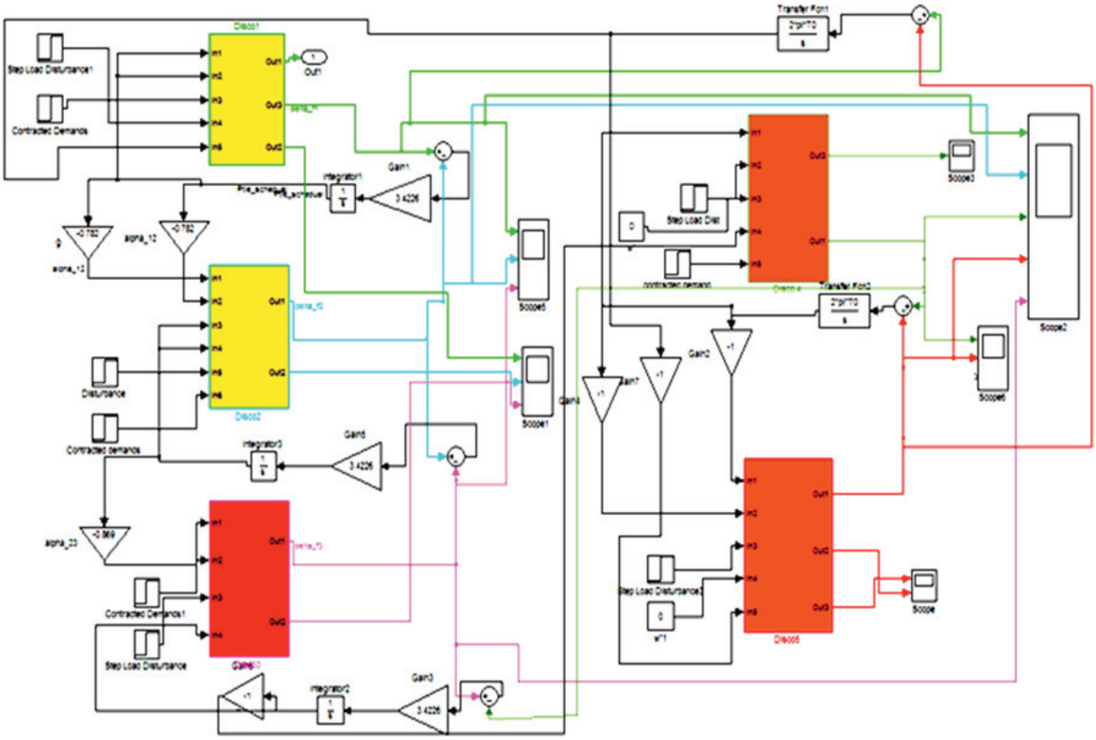

Fig. 4. Five Control Area Simulink Test Model

Table 1. Applied data for gencos of three Main grids[1]

Quantity	Gen 1	Gen 2	Gen 3	Gen 4	Gen 5	Gen 6
Rating (MW)	800	1000	1100	1200	1000	1000
R(Hz/pu)	2.4	3.3	2.5	2.4	3	2.4
Tt(s)	0.36	0.42	0.44	0.4	0.36	0.4
Tg(s)	0.06	0.07	0.06	0.08	0.07	0.08
Alpha	0.5	0.5	0.5	0.5	0.5	0.5

Table 2. Area wise data[1]

Quantity	Area1	Area2	Area3	Area4	Area5
D(pu/Hz)	0.0084	0.014	0.01	0.0161	0.0161
2H(pu)	0.1667	0.2	0.1667	0.1612	0.1612
B(pu/Hz)	0.8675	0.795	0.870	0.3483	0.3483
K(s)	0.2695 -0.3788/s	0.0418 -0.1806/s	0.2319 -0.3796	0.2695 -.3788/s 0.05	0.2695 -0.3788/s 0.05
Tij	0.545				

6.1.1 Scenario-regulated environment

It is assumed that a step increase in demand as dPL_1 = 100MW, dPL_2 = 70MW , dPL_3 = 60MW, dPL_4 = 20MW and dPL_5 = 10MW are applied to the control areas and each CA demand is sent to its local GU only, based on the following GC as given eq.(15) for a regulated system.

$$GC = \begin{bmatrix} 0.5 & 0 & 0 & 0 & 0 \\ 0.5 & 0 & 0 & 0 & 0 \\ 0 & 0.5 & 0 & 0 & 0 \\ 0 & 0.5 & 0 & 0 & 0 \\ 0 & 0 & 0.5 & 0 & 0 \\ 0 & 0 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 0.33 & 0 \\ 0 & 0 & 0 & 0.33 & 0 \\ 0 & 0 & 0 & 0.33 & 0 \\ 0 & 0 & 0 & 0 & 0.33 \\ 0 & 0 & 0 & 0 & 0.33 \\ 0 & 0 & 0 & 0 & 0.33 \end{bmatrix} \quad \text{.........(15)}$$

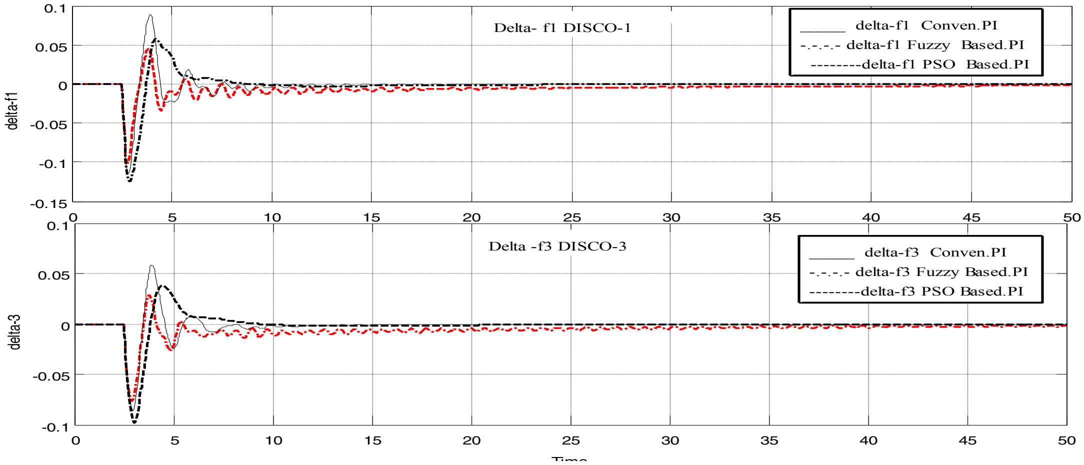

Fig. 5. (a) System response for frequency deviation

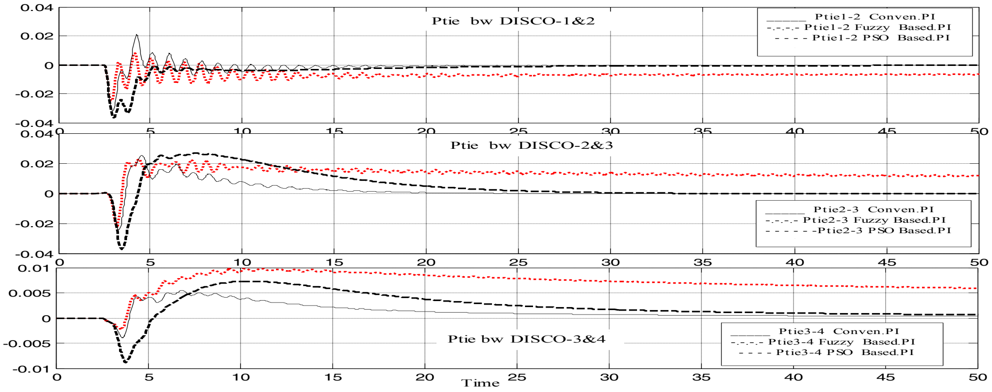

Fig. 5. (b) Changes occurred in Tie-line Powers

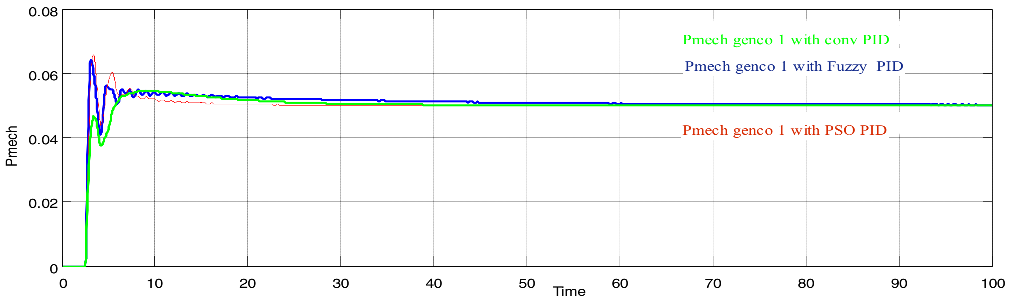

Fig. 5. (c) Changes occurred in Mechanical Powers

Table.3 Arbitrary Pre-Selected values of Conventional PI Gains with D=0 [1]

Discos	P	I
Disco 1	0.2695	-0.3788
Disco 2	0.0418	-0.1806
Disco3	0.2319	-0.3797
Disco 4	0	-0.05,-0.3788
Disco 5	0	-0.05,-0.3788

Table 4 Obtained Error Values with arbitrary PID values.

DISCOs and GENCOs		ISE	ITSE	IAE	ITAE
DISCO 1	1,2	0.01176	0.04013	0.1786	0.8685
DISCO 2	3,4	0.006143	0.02524	0.1834	1.167
Disco 3	5,6,	0.005196	0.01803	0.1197	0.5444
Disco 4	7,8	0.001426	0.008456	0.1348	2.052
	9	0.003619	0.0125	0.1115	0.6622
Disco 5	10,11	0.00334	0.00052	0.0962	1.688
	12	0.002158	0.006691	0.06766	0.3419

Table 5.Obtained Errors for PSO based optimised P=0.63, I=-0.1485, D=0

DISCOs	GENCOs	ISE	ITSE	IAE	ITAE
Disco 1	1,2	0.2303	0.08954	0.3638	2.603
Disco 2	3,4	0.01589	0.1002	0.4318	3.956
Disco 3	5,6	0.01421	0.05704	0.2672	1.816
Disco 4	7,8	0.004247	0.2177	0.6435	32.98
	9	0.02593	0.09716	0.3135	1.845
Disco 5	10,11	0.009276	0.05473	0.332	3.907
	12	0.04352	0.0181	0.5073	3.686

Table 6. Obtained Errors for Fuzzy based optimised P=0, I=0, D=0

DISCOs	GENCOs	ISE	ITSE	IAE	ITAE
Disco 1	1,2	0.005977	0.02062	0.1662	2.166
Disco 2	3,4	0.02585	1.148	1.518	75.4
Disco 3	5,6	0.002849	0.01335	0.168	4.234
Disco 4	7,8	0.007168	0.1964	0.7445	29.55
	9	0.004389	0.03694	0.3383	8.114
Disco 5	10,11	0.006146	0.2072	0.7304	31.09
	12	0.003916	0.03285	0.3315	7.734

The frequency deviation (*dfi*), tie-line power flow (*dP*tie) and mechanical power changes[1] are shown in Figs. 5(a),(b) and(c) for the closed-loop system. Since there are no contracts between areas, the scheduled steady-state power that flows over the tie-lines is zero. Figure 5(a) shows the change in tie line power of each disco and variations in the tie line power are found to be so small with PSO technique compared to fuzzy and trail approach. Table 4,5 and 6 shows that errors produced in each disco which indicates the level of variations in the frequency deviations and tie line power changes.

6.1.2. Scenario de-regulatedeEnvironment

It is assumed that a step increase in demand as *dP*L1 = 100MW, *dP*L2 = 100MW , *dP*L3 = 50MW, *dP*L4 = 60MW and *dP*L5 = 20MW are applied to the control areas and each Disco demand is sent to its local Gencos only, based on the following GC matrix as given eq.(16) for a regulated system. Now, there are contracts between areas, the scheduled steady-state power that flows over the tie-lines is deviates from its previous steady state zero level as shown in Fig. 6(b). The actual mechanical powers are shown in Fig. 6(c) .

$$GC = \begin{bmatrix} 0.3 & 0.1 & 0 & 0.2 & 0 \\ 0.3 & 0 & 0 & 0 & 0 \\ 0 & 0.1 & 0 & 0 & 0.25 \\ 0 & 0.6 & 0 & 0 & 0 \\ 0 & 0 & 0.2 & 0.1 & 0 \\ 0.1 & 0.2 & 0.6 & 0 & 0 \\ 0.3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.1 \\ 0 & 0 & 0.2 & 0 & 0 \\ 0 & 0 & 0 & 0.1 & 0 \\ 0 & 0 & 0 & 0.25 & 0.35 \\ 0 & 0 & 0 & 0.35 & 0.3 \end{bmatrix} \qquad \ldots\ldots\ldots(16)$$

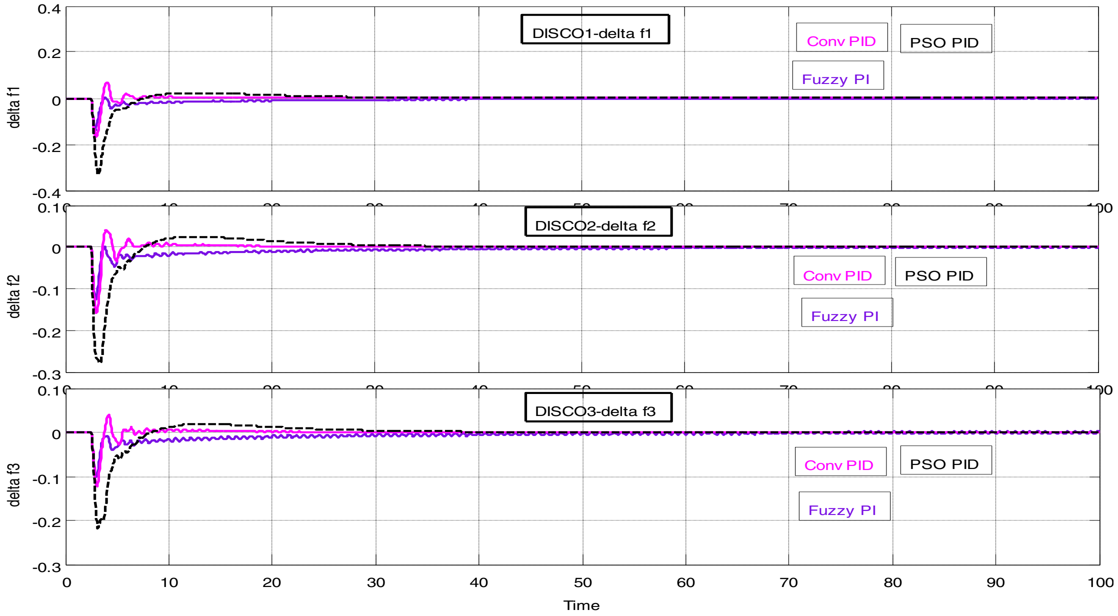

Fig. 6(a). System response for frequency deviation

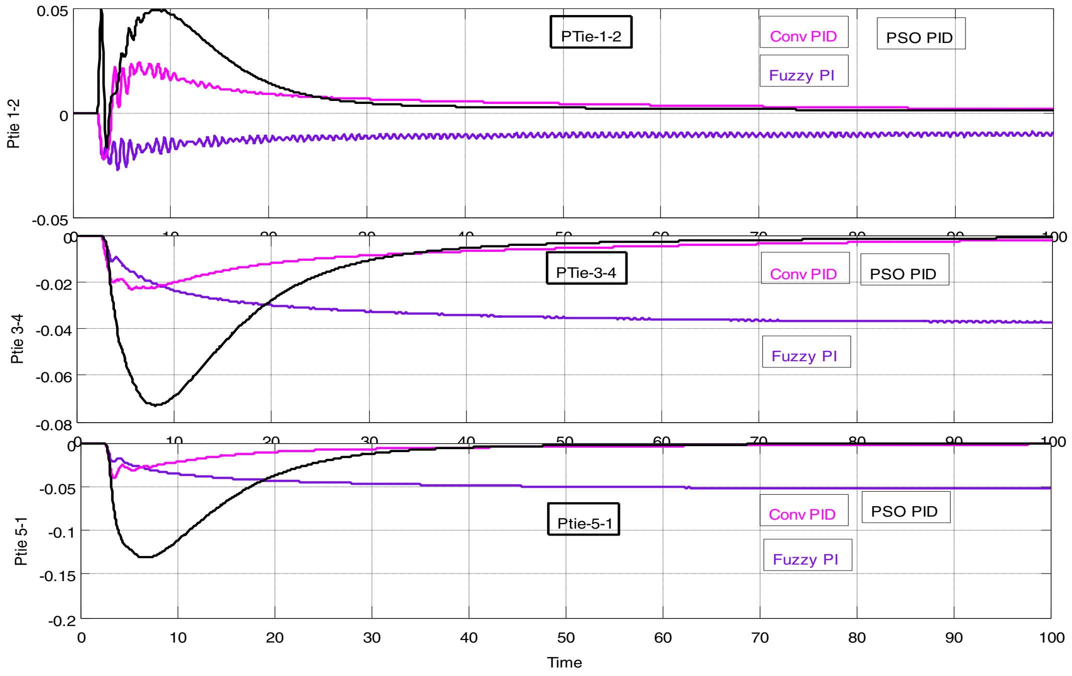

Fig. 6(b).Changes occurred in Tie-line Powers

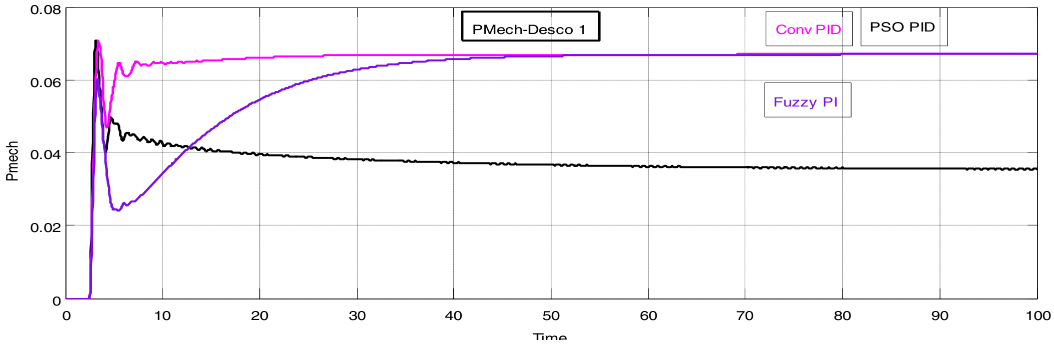

Fig. 6(c).Changes occurred in Mechanical Powers

Table 7. Obtained Error Values with arbitrary PID values.

DISCOs and GENCOs		ISE	ITSE	IAE	ITAE
DISCO 1	1,2	0.0228	0.07325	0.2205	0.9328
DISCO 2	3,4	0.03409	0.1596	0.5261	3.841
Disco 3	5,6,	0.005843	0.02109	0.1421	0.8165
Disco 4	7,8	0.006412	0.2355	0.7363	31.42
	9	0.005332	0.01898	0.1633	1.661
Disco 5	10,11	0.00845	0.1689	0.7238	24.611
	12	0.0008746	0.00322	0.06074	0.611

Table 8. Obtained Errors for PSO based optimised P=0.63, I=-0.1485, D=0

DISCOs	GENCOs	ISE	ITSE	IAE	ITAE
Disco 1	1,2	0.1743	0.8428	1.309	11.58
Disco 2	3,4	1.04	7.114	3.87	36.25
Disco 3	5,6	0.0229	0.09032	0.3414	2.514
Disco 4	7,8	0.1733	1.408	1.813	28.42
	9	0.03718	0.1736	0.5857	6.459
Disco 5	10,11	0.05181	0.6443	1.266	26.08
	12	0.04086	0.04086	0.2677	2.538

Table 9. Obtained Errors for Fuzzy based optimised P=-0.04, I=0, D=0

DISCOs	GENCOs	ISE	ITSE	IAE	ITAE
Disco 1	1,2	0.4103	20.42	6.258	319.3
Disco 2	3,4	0.2368	11.92	4.768	243.7
Disco 3	5,6	0.006867	0.01996	0.5913	26.63
Disco 4	7,8	0.01583	1.036	1.157	70.16
	9	0.01059	0.116	0.6112	15.68
Disco 5	10,11	0.1004	6.051	3.044	172.9
	12	0.006015	0.07706	0.5087	12.97

The frequency deviation (*dfi*), tie-line power flow (*dP*tie) and mechanical power changes[1] are shown in Figs. 6(a) and 6(b) for the closed-loop system. Table 7,8 and 9 shows the error obtained for contracted demands according to eq.16 with arbitrary, PSO optimized and Fuzzy based PID gains.

7. Conclusion

From the above listed case studies it has been concluded that all the five areas work very well if the GC matrix given in the equation (15) is used i.e. raised demand in a disco is sent to its local GUs .These error values actually decide the area control error input signal to the PID controller unit whose main function is to minimize the error at the output. Hence, from the above discussion, PSO technique gives much improved results than fuzzy and trail methods because fuzzy technique requires large execution time to execute large no. of linguistic rules in a multi-area system at same time. Secondly, requirement of correct linguistic rule matrix to reach desired results is a time consuming process. In a trial method, to reach perfect values of PID gains, there is need of large no. of iterations.

References

[1] H. Bevrani(2009) "Robust Power System Frequency Control" 1st Edition. 2nd Printing, Springer.

[2] H. Shayeghi , H.A. Shayanfar and A. Jalili (2009) "Load frequency control strategies: A state-of-the-art survey for the researcher" Energy Conversion and Management 50 ,pp 344–353.

[3] T.H. Mohamed , H. Bevrani and T. Hiyama (2011) "Decentralized model predictive based load frequency control in an interconnected power system" Energy Conversion and Management 52 ,1208–1214.

[4] Indulkar CS and RajB (1995) "Application of fuzzy controller to automatic generation control. ElectricMachinesandPowerSystems,23(2),pp 209–220.

[5] Chang CS and FuW(1997) "Area load frequency control using fuzzy gain scheduling of PI controllers. Electric Power System Research, 42, pp144–152.

[6] Denna M, MauriG and Zanaboni AM(1997) "Learning fuzzy rules with Tabu Search-an application to control. IEEE Transactions on Fuzzy Systems ,7(2), pp 295–318.

[7] Ghoshal SP (2003) "Multi area frequency and tie line power flow control with fuzzy logic based integral gain scheduling"Journal of Institute of Engineers ,84, pp 135–241.

[8] Ertugrul CAM (2004) "Load frequency control in two area power system" Teknoloji 7(2), pp 197–203.

[9] Ertugrul CAM and Kocaarslan I (2005) "Load frequency control in two area power systems using fuzzy logic controller" Energy Conversion and Management , 46, pp233–243.

[10] Juang CF and LuCF(2005) “Power system load frequency control by genetic fuzzy gain scheduling controller” Journal of the Chinese Institute of Engineer 28 (6), pp 1013–8.

[11] Ghoshal SP(2005) “GA-fuzzybasedfastactingadaptiveactivepower-frequency control of interconnected multiple thermal generating areas.IE(I)Journal EL ,85, pp 209–215

[12] Du Xiuxia, Li Pingkang(2006) “Fuzzy logic control optimal realization using GA for multi-area AGC systems” International Journal of Information Technology ,12(7), pp 63–72.

[13] Juang CF and LuCF (2006) “Load–frequency control by hybrid evolutionary fuzzy PI controller” IEE Proceedings-Generation, Transmission and Distribution, 153(2), pp 196–204.

[14] Pothiya Saravuth, Ngmroo Issarachai, Runggeratigul Suwan and Tantaswadi Prinya (2006) “Design of optimal fuzzy logic based PI controller using multiple Tabu Search algorithm for load frequency control” International Journal of Control, Automation and Systems ,4(2), pp 155–164.

[15] Shayeghi Hossein, Shayanfar Heidar Ali and Jalili Aref (2007) “Multistage fuzzy PID load frequency controller in a restructured power system” Journal of Electrical Engineering ,58(2), pp 61–70.

[16] Sinha SK, Patel RN and Prashad R (2010) “Application of GA and PSO tuned fuzzy controller for AGC of three area thermal–thermal-hydro power system” International Journal of Computer Theory and Engineering, vol. 2 (2).

[17] Hemeida.AM (2010) “A fuzzy logic controlled super conducting magnetic energy storage, SMES frequency stabilizer” Electrical Power and Energy Systems ,80, pp 651–656.

[18] Sudha KR, Raju YB and Sekhar AC(2012) “Fuzzy C-Means clustering for robust decentralized load frequency control of interconnected power system with generation rate constraint” Electrical Power and Energy Systems ,37, pp 58- 66.

[19] Dhillon S.S, Lather J.S. and Marwaha S.(2014) “Robust load frequency control of micro grids connected with main grids in a regulated and deregulated environment” Proc. Of IEEE conference on Recent Advances and Innovations in Engineering, pp 1-9.

[20] Sudha KR and Santhi RV (2012) “Load frequency control of an interconnected reheat thermal system using type-2 fuzzy system including SMES units” Electrical Power and Energy Systems, 43, pp 1383–1392.

[21] Jagdeep Singh Lather, Sukhwinder Singh Dhillon, Sanjay Marwaha (2013) “Dynamic Modeling , Analysis and Simulation of Grid Connected Doubly Fed Induction Generator based wind Power under Different Operating Conditions” International Journal of Electrical and Electronics Engineering Research (IJEEER), Vol. 3, issue 2, June, 29-40.

[22] J.S. Lather, S. S. Dhillon, Sanjay Marwaha (2013) “5 MW Modified Structural Simulink Model of HAWT and Verification as Compared to FAST and Lumped codes” International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, vol. 2, Issue 6, pp-2140-2148.

[23] J.S. Lather, S. S. Dhillon, Sanjay Marwaha,(2013) “Modern Control Aspects in Doubly Fed Induction Generator based Power Systems: A Review” International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering,Vol. 2, Issue 6, pp 2150-2161.

[24] Mansour Jalali (2011) “DFIG Based Wind Turbine Contribution to System Frequency Control” a Master thesis of Applied Science in Electrical and Computer Engineering, University of Waterloo, Ontario, Canada.

[25] G. S. and G. N. Kariniotakis. , (1995)“ A general simulation algorithm for the accurate assessment of isolated diesel-wind turbines systems interaction. I. A general multimachine power system model. IEEE Transactions on Energy Conversion, 10(3), pp 577 – 583.

[26] B. Kuang, Y. Wang, and Y. L. Tan. (2000) “An Hinf controller design for diesel engine systems”. In Power System Technology, International Conference Proceedings, volume 1, pp 61 – 66.

[27] Soltani, M., Chaari, A. and Benhmida, F.(2012) “A novel fuzzy c regression model algorithm using new measure of error and based on particle swarm optimization”, International Journal of Applied Mathematics and Computer Science, Vol. 22, No. 3, pp 617-628,

[28] A. Magla and J Nanda. (2004) “Automatic Generation Control of an interconnected hydro – Thermal System Using Conventional Integral and Fuzzy logic Control”. In : Proc. IEEE Electric Utility Deregulation, Restructuring and Power Technologies.

[29] Timothy. J. Ross.(1995) “ Fuzzy logic with engineering application”. Mc-Graw Hill.

[30] Q.P. Ha.(1998) “ A Fuzzy sliding mode controller for Power System Load Frequency Control”. 2nd International Conference of Knowledge based Intelligent Electronic System. Adelaide, Austrilia.

Appendix-A Data for Micro Grids

He1=3.5;PU.MW.secHe2=3.5;PU.MW.sec, Kagc1=0.05;Kagc2=0.05;Kp1=62; HZ/PU Ki1=0.05; Ki2=0.05; Kwi1=0.1; Kwp1=1.61; Kp2=62; HZ/PU Kwi2=0.1;
Kwp2=1.61; B1=0.3483; B2=0.3827; R1=3; Hz/PU.MW R2=3; Hz/PU.MW
T0=0.07; PU.MW/Hz Ta1=0.2; Sec
Ta2=0.2;Sec Th1=0.1; Sec Th2=0.1; Sec,Tp1=10; sec,Tp2=10; sec, Tr1=0.1; Sec, Tr2=0.1; Sec, Tt1=1; Sec, Tt2=1; Sec, Tw1=6; Sec Tw2=6; Sec