AGC OF MULTI SOURCE MULTI AREA DEREGULATED POWER SYSTEM USING PID CONTROLLER

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Abstract: *In a power system network, customer demands the electrical power with rated voltage and frequency from power quality point of view. Automatic Generation Control (AGC) is the most used control in the entire power system for balancing of the generation with demand and preservation of the tie line power and frequency changes within allowable limits. Under deregulated environment, Independent System Operator (ISO) has the liability of ensuring the reliability and security of AGC. PID controller is used as a secondary controller in order to enhance the performance of the AGC in power system. Particle Swarm Optimization technique (PSO) is used for PID controller tuning. In this paper, a three area multi source deregulated power system is considered. The performances of the PID controller tuned by Zeigler Nichols and PSO methods for this three area deregulated power system are compared using MATLAB Simulink software. By tuning PID controller using PSO algorithm, the dynamic response of the system can be improved by using various combinations of performance indices. One of the combinations with objective function taken as the minimization of the sum of Integral Absolute Error (IAE), Integral Square Error (ISE) and Integral Time Square Error (ITSE) gave the optimal results for the system considered.*

Key words: *Automatic Generation Control, Multi Source Multi Area Power System, Deregulated Power System, Contract Participation Factor, Disco Participation Matrix, PID Controller, Particle Swarm Optimization, Zeigler Nichols Method.*

1. Introduction

In the present scenario, as the power demand rapidly changes with respect to time, there is a need to maintain the secure and reliable power to the customers. Therefore Control loops such as AGC and Automatic Voltage Regulators (AVR) are used in the power system network for balancing of real and reactive power generation with demand [1]-[3]. Besides balancing the power, AGC is used to maintain the changes in frequency and tie line powers and AVR is used to maintain the changes in voltages within allowable limits. As load increases than that of the generation, the frequency starts drooping down below its rated value. Similarly as load decreases, frequency rises. Both the cases may cause malfunctioning of the operation in power system resulting in blackouts. Large deviations in frequency, tie line powers and voltages may lead to failure of the power system network. Hence AGC and AVR are the essential control loops in the power system. These control loops in powers system are used to notice changes in the frequency and adjust the mechanical power input to the generator to set back the frequency to its rated value. To operate the power system with more reliability, secondary controller such as PID controller [19] can be used for AGC because of its simplicity and stability. It can be tuned manually or automatically by using some techniques such as Zeigler Nichols, Particle Swarm Optimization, Genetic Algorithm, Fuzzy Logic and many more evolutionary algorithms [14] – [19]. AGC modeling of deregulated power system is discussed in the following section.

2. Deregulated Power System

The power system that is discussed generally is a regulated power system, in which government sets the rules and defines how the power industry needs to work. In a deregulated power system [4] – [13], [22]-[23], all the norms and economic incentives are restructured to drive the power industry in an efficient way. Fundamentally both these power systems are of opposite ideas. Neither of them is good or bad, but according to the availability of conditions, either of them can be implemented. In deregulated environment, new entities are added to the entities that are already present in a regulated power system. Overall entities present in the power system after deregulation are Gencos, Transcos, Discos, PX, ISO, Rescos and Customers which are shown in fig 1. Gencos are the group of generating units or independent generating units which have the main objective of producing power. Transcos are the transmitting companies which have the primary responsibility to transmit electrical power from Gencos to the customers. Discos are distribution companies who buy electricity from the spot markets or through direct contracts from Gencos and supply that electricity to the customers.

Independent System Operator (ISO) is an entrusted unit to ensure security and reliability of the power system. It is an independent unit which does not participate in any transactions that held among Gencos, Transcos and Discos. Power Exchange (PX) operates mostly like a stock trade, which continuously updates and posts a Market Clearing Price (MCP). MCP is nothing but the present price at which transactions are carried out. Retail Energy Service Companies (Rescos) are the retailers of the electric power who buy power from the Gencos and sell directly to the customers. Finally, customers are the entities who consume electricity either directly from Gencos or by the transactions made by the ISO.

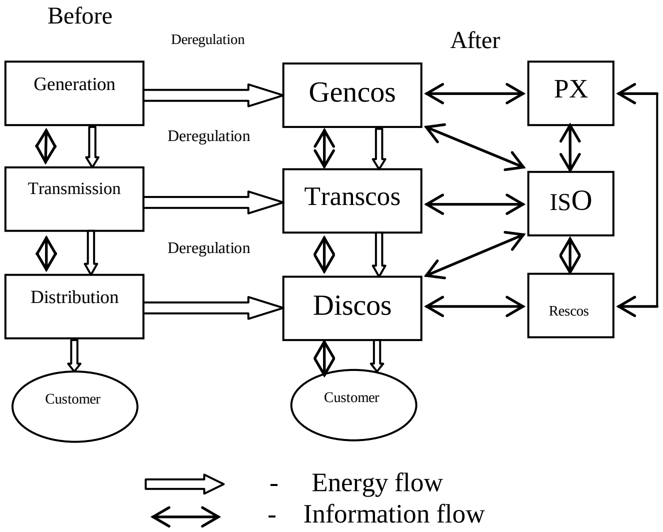

Fig. 1 Basic Structure of Deregulated Power System

The main intention of restructured power system is to provide choice to the customers by allowing competition among Gencos, Transcos and Discos. By this the price of electricity will be reduced and used efficiently. Even the excess power can be transmitted to shortage areas. In deregulated power systems also, AGC plays a crucial role in maintaining scheduled frequency and tie line interchange power flows which is performed by ISO based on the parameters defined by the generator participation factors. The first and foremost step in deregulation is the separation of generation from transmission and distribution. Then based on the requirements of electricity, agreements are made between Gencos and Discos. As there can be number of Gencos in a restructured power system, a Disco can make contract with any of the Gencos present in any area in the network. Such type of contracts are said to be bilateral transactions. Unilateral contracts are those in which Genco and Disco of same area participate to generate power. The factor that determines how a Disco is contracted to a Genco is known as Contract Participation Factor (CPF). The matrix that give information about how all discos are get contracted with all the Gencos in the power system is known as Disco Participation Matrix (DPM). In DPM, the number of rows and columns represents Gencos and Discos respectively in the network. Each and every value in the matrix is a fraction of power demand that a Genco can contribute to a specific Disco. Those values are given by

$$cpf_{ij} = \frac{i^{th}\ Genco\ contribution\ towards\ j^{th}\ Disco}{j^{th}\ Disco\ total\ power\ demand} \tag{1}$$

The DPM is defined as

$$DPM = \begin{bmatrix} Cpf_{11} & Cpf_{12} & \cdots & \cdots & Cpf_{1j} \\ Cpf_{21} & Cpf_{22} & \cdots & \cdots & Cpf_{2j} \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ Cpf_{i1} & Cpf_{i2} & \cdots & \cdots & Cpf_{ij} \end{bmatrix} \tag{2}$$

$$\sum_{i} cpf_{ij} = 1 \tag{3}$$

$$i = Genco \qquad j = Transco$$

Generation Participation Matrix (GPM) is the matrix that distributes the Area Control Error (ACE) among the Gencos that are present in the system considered. The factors that are present in GPM are ACE Participation Factors (APF). Sum of the APF's in an area must be equal to one and the matrix is defined as

$$GPM = \begin{bmatrix} Apf_{11} & Apf_{12} & \cdots & \cdots & Apf_{1n} \\ Apf_{21} & Apf_{22} & \cdots & \cdots & Apf_{2n} \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ Apf_{m1} & Apf_{m2} & \cdots & \cdots & Apf_{mn} \end{bmatrix} \tag{4}$$

$$\sum_{n} Apf_{mn} = 1 \tag{5}$$

where n is number of sources in a single area; m is the number of areas in the power system

By using GPM, DPM and the data of the power system, modeling of AGC for a deregulated power system can be done by using some secondary controller (PI, PD, PID etc). General Structure of the two area AGC in deregulated environment is shown in fig. 2.

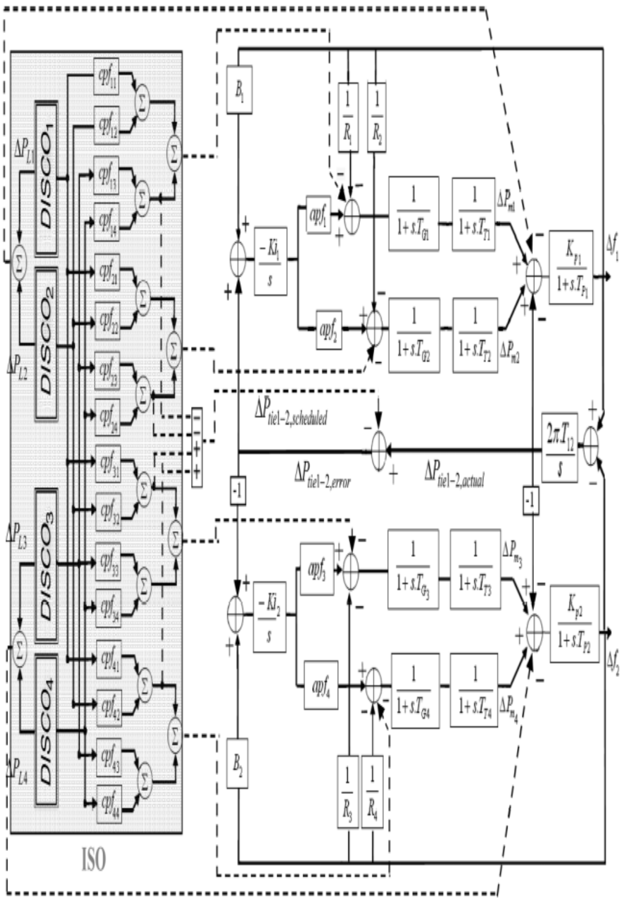

Fig. 2 Basic structure of AGC for two area deregulated power system

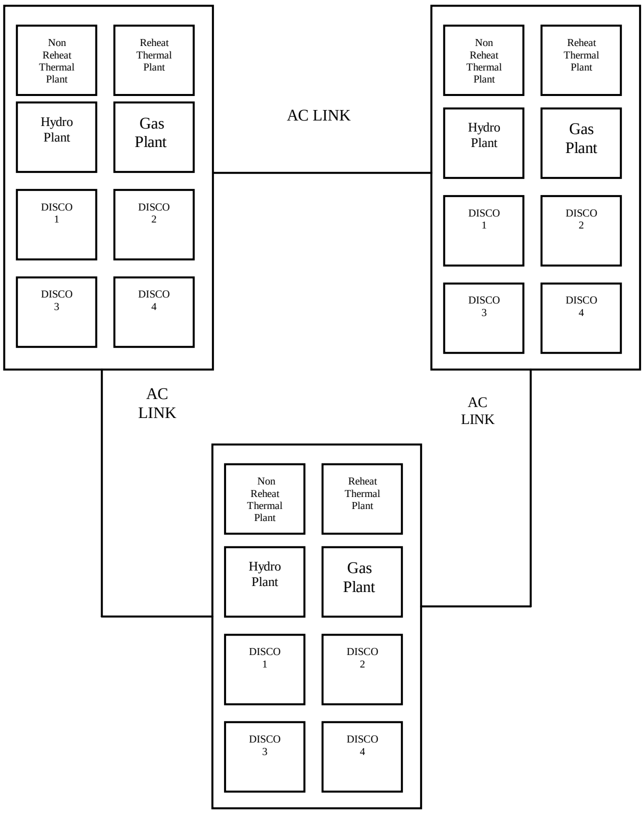

Fig. 3 Block diagram of three area deregulated power system

3. System Investigated

The structure of the deregulated power system that is investigated is shown in fig. 3. The power system that is considered for the present work is a three area power system with multiple sources in each area. Diverse sources present in each area are Non reheat thermal, Reheat thermal, Hydro and Gas units. Hence there are four Gencos and four Discos in each area contributing to twelve Gencos and twelve Discos in the overall deregulated power system. In the case investigated, any Genco can contribute its power to any Disco since bilateral contract is considered. All the three areas are interconnected by means of tie lines and in each area, an equivalent generator is considered for the sources present in that area. Equivalent generator modeling is given as

$$H_{eq}=\sum_{i=1}^{k}H_i \quad ; \quad D_{eq}=\sum_{i=1}^{k}D_i \quad ; \quad B_{eq}=\sum_{i=1}^{k}D_i+\sum_{i=1}^{k}\frac{1}{R_i} \qquad (6)$$

where H_{eq} is the equivalent inertia, D_{eq} is equivalent frequency sensitive load coefficient, B_{eq} is equivalent frequency bias factor and k is number of generators/sources present in an area.

4. Tuning of PID Controller

4.1 Zeigler Nichols Method

Zeigler–Nichols method is one of the simple and easy methods for tuning PID controller. This is a result based approach, which can be tuned based on the resultant waveform. It a heuristic technique which is executed initially by setting the integrator and derivative gain constants as zero. Then the proportional gain constant is tuned until the control loop output has stable and consistent oscillations. Thus the tuned gain and oscillation period are used for setting the parameters of PID Controller. In our case study Quarter Amplitude Decay Zeigler–Nichols Method [14] is used to tune the PID controllers.

4.1.1 Quarter Amplitude Decay Zeigler–Nichols Method

Quarter amplitude decay method is one of Zeigler–Nichols methods used in the case where consistent and stable oscillations are not obtained. In this method also, initially integral and derivative gains are set to zero. Then the Proportional Gain (K_p) is tuned until it reaches the ultimate gain (K_u) at which the control loop output has the quarter amplitude decay for the oscillations obtained.

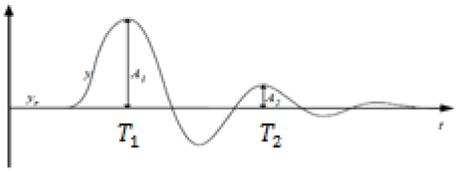

Fig. 4 Quarter amplitude decay waveform

$$\frac{A_2}{A_1} = \frac{1}{4} \qquad (7)$$

Ultimate gain and the oscillation period T_u (=T_2-T_1) are used for setting the P, I and D parameters of the controller.

$$K_P = 0.6K_u \;\; ; \;\; K_I = \frac{1.2K_u}{T_u} \;\; ; \;\; K_D = \frac{0.6K_u T_u}{0.8} \qquad (8)$$

4.2 Particle Swarm Optimization

Particle Swarm Optimization (PSO) is a population based optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995. It is also an evolutionary computation technique like Genetic Algorithm (GA). This technique initially starts with a random number of particles and goes on updating the generations to obtain an optimal solution. In the processing of updating the iterations, every particle updates by tracking two best values. One of them is the best solution achieved so far which is simply known as fitness function (pbest). The other best one is achieved by the particle swarm optimizer, which is not obtained so far by any other particle in the overall random population. This is known as global best (gbest). The best value is said to be local best (lbest), when a particle takes part of the population as its topological neighbours. After calculating the best values, the particle updates its position and velocity by using the equations below.

$$v_i(t+1) = wv_i(t) + c_1r_1[\hat{x}_i(t) - x_i(t)] + c_2r_2[gbest(t) - x_i(t)] \qquad (9)$$

$$x_i(t+1) = x_i(t) + v_i(t+1) \qquad (10)$$

where

$v_i(t)$ is the i[th] particle velocity at time t

$x_i(t)$ is the i[th] particle position at time t

$\hat{x}_i(t)$ is i[th] particle individual best solution at time t

gbest is the global best solution of the entire particles

c_1, c_2 are the learning factors $0 \leq c_1, c_2 \leq 2$

r_1, r_2 are the random variables $0 \leq r_1, r_2 \leq 1$

w is the weighting factor $0 \leq w \leq 1.2$

4.2.1 Application of PSO Algorithm for tuning PID Controller

Based on the PSO Algorithm, PID controller is tuned to obtain the values of the controller to get the best results. Here, particles in algorithm are nothing but the control parameters of the PID controller (from Simulink) that need to be tuned. Depending on the objective function, PSO algorithm goes on updating until maximum number of iterations is reached. Objective function is nothing but to minimize the performance indices. These indices are obtained or modified form of ACE. Performances indices are like ISE, IAE, ITSE or combination of any of them. The basic algorithm [16] – [17] for tuning PID controller using PSO algorithm is shown in fig (5)

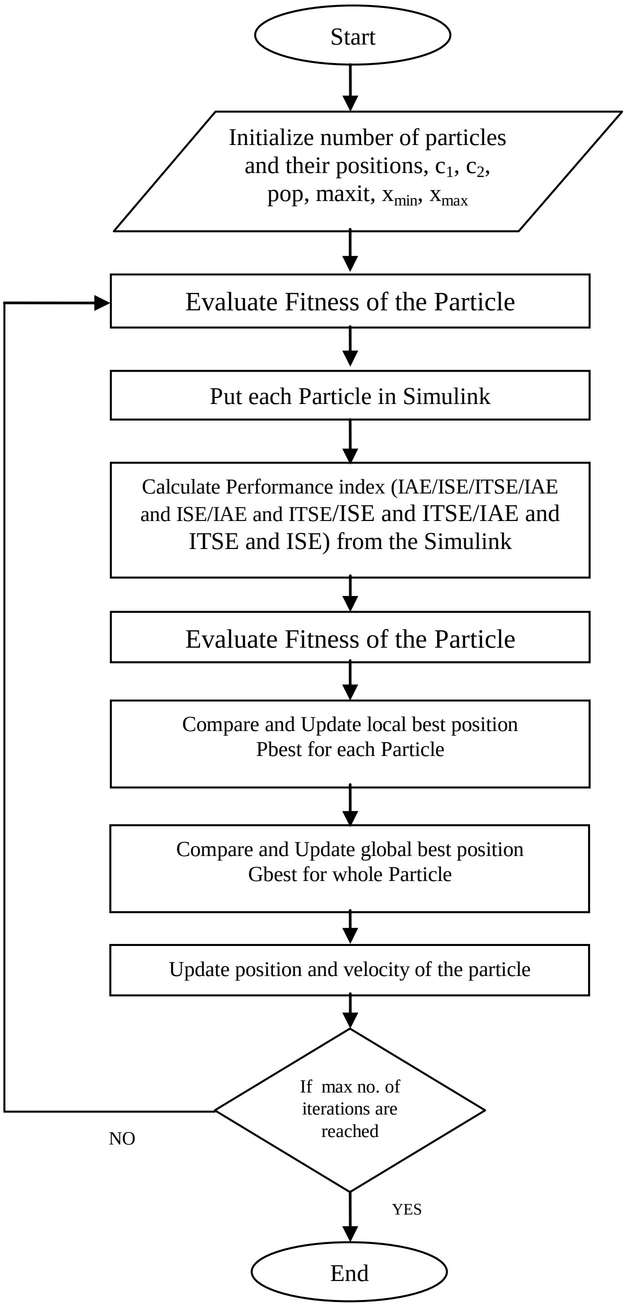

Fig. 5 Flowchart for tuning PID controller using PSO Algorithm

5. Design of Deregulated Power System

Modeling of AGC of deregulated power system remains same as that of the regulated power system. For a multi area multi source power system considered, equivalent generator needs to be found out using equation (6). With the data taken from [20] Appendix, AGC is modeled and the equivalent generator can be modeled for Area-1 as

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} = \frac{1}{0.05} + \frac{1}{0.05} + \frac{1}{0.05} + \frac{1}{0.05} = 80$$

$$H_{eq} = 5 + 5 + 3 + 3 = 16\ s$$

$$D_{eq} = 1.25 + 1.25 + 1 + 1 = 4.5$$

$$\therefore \frac{1}{2H_{eq}s + D_{eq}} = \frac{1}{2(16)s + 4.5} = \frac{1}{32s + 4.5}$$

$$B_{eq} = D_{eq} + \frac{1}{R_{eq}} = 4.5 + 80 = 84.5$$

Since the generator data considered for the sources in areas 2 and 3 are same as that of area-1, equivalent generator modeling remains same. To add to that, DPM and GPM are calculated using the equations (1)-(5) for a deregulated power system. For calculation of GPM, the only constraints present is that sum of APF's in an area must be equal to one. In such a way APF's are calculated appropriately.

$$GPM = \begin{bmatrix} 0.40 & 0.20 & 0.30 & 0.10 \\ 0.30 & 0.30 & 0.20 & 0.20 \\ 0.25 & 0.25 & 0.25 & 0.25 \end{bmatrix}$$

For calculation of DPM, demand of every Disco and amount of power available with Genco to transfer power to a particular Disco are required.

5.1 Data for calculation of DPM

Table 1: Disco – 1 with Demand of 0.1 p.u				
	Genco 1	Genco 2	Genco 3	Genco 4
Area 1	0.01 pu	0.01 pu	0	0.01 pu
Area 2	0.01 pu	0.01 pu	0.01 pu	0.01 pu
Area 3	0	0.01 pu	0.01 pu	0.01 pu

From eq (1), CPFs for Disco 1 are calculated as follows,

$$cpf_{11} = \frac{\text{Genco 1 of area 1 contributing its power to Disco 1}}{\text{Total demand of Disco 1}} = \frac{0.01\ p.u}{0.1\ p.u} = 0.1$$

$$cpf_{21} = \frac{\text{Genco 2 of area 1 contributing its power to Disco 1}}{\text{Total demand of Disco 1}} = \frac{0.01\ p.u}{0.1\ p.u} = 0.1$$

In a similar way, all the first column elements of DPM i.e., cpf_{i1} are calculated from the data of Disco 1. Using the same procedure, all the elements of DPM are calculated for the Discos present in the Deregulated power system and the DPM is given as

$$DPM = \begin{bmatrix} 0.1 & 0 & 0.04 & 0.06 & 0 & 0.12 & 0.07 & 0.05 & 0.1 & 0.05 & 0.1 & 0.02 \\ 0.1 & 0.05 & 0.05 & 0.07 & 0.08 & 0.05 & 0.08 & 0.07 & 0.05 & 0 & 0 & 0.12 \\ 0 & 0.1 & 0.15 & 0.2 & 0.15 & 0.06 & 0.13 & 0 & 0.07 & 0.13 & 0.16 & 0.06 \\ 0.1 & 0.15 & 0 & 0.07 & 0.23 & 0.4 & 0 & 0.13 & 0.08 & 0.12 & 0.04 & 0.02 \\ 0.1 & 0.025 & 0.036 & 0 & 0.14 & 0.09 & 0.16 & 0.12 & 0.13 & 0.07 & 0.03 & 0.17 \\ 0.1 & 0.1 & 0.2 & 0.15 & 0.07 & 0 & 0.04 & 0.02 & 0.08 & 0.08 & 0 & 0.13 \\ 0.1 & 0.25 & 0.024 & 0.07 & 0.05 & 0.15 & 0.09 & 0.11 & 0 & 0.05 & 0.13 & 0.05 \\ 0.1 & 0.025 & 0 & 0.05 & 0.11 & 0.22 & 0.03 & 0 & 0.14 & 0 & 0.07 & 0.08 \\ 0 & 0.05 & 0.18 & 0.08 & 0.02 & 0.07 & 0.15 & 0.2 & 0.13 & 0.11 & 0.08 & 0 \\ 0.1 & 0 & 0.06 & 0.15 & 0 & 0.05 & 0.14 & 0.1 & 0.1 & 0.21 & 0.25 & 0.15 \\ 0.1 & 0.25 & 0.2 & 0 & 0.1 & 0.09 & 0.02 & 0.1 & 0 & 0.12 & 0 & 0.2 \\ 0.1 & 0 & 0.06 & 0.1 & 0.05 & 0.06 & 0.09 & 0.1 & 0.12 & 0.06 & 0.14 & 0 \end{bmatrix}$$

Hence the modeling of AGC is done using the parameters designed above. For tuning of PID controller, PSO algorithm and Zeigler Nichols techniques are used for the system considered.

5.2 PSO Data for system investigated

Objective functions:

$$ISE = \int_0^T e^2(t)\ ;\ IAE = \int_0^T |e(t)|\ ;\ ITSE = \int_0^T t.e^2(t) \qquad (11)$$

where e(t) is the ACE taken from the simulation of the three area deregulated power system. Objective function varies for the different cases considered which are combination of the above three equations

Learning factors = (2, 2)
Number of Particles = 09
Population = 80
Maximum number of Iterations = 20
Control Variables $X = [K_{P_1}\ K_{I_1} K_{D_1}\ K_{P_2}\ K_{I_2}\ K_{D_2}\ K_{P_3}\ K_{I_3}\ K_{D_3}]$
Minimum Values of Control Variables of PID Controller for three areas = [0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1]
Maximum Values of Control Variables of PID Controller for three areas = [10 10 10 10 10 10 10 10 10]
Stopping Criterion = When maximum number of iterations are reached

5.3 Zeigler Nichols-Quarter Amplitude Decay Method

For the system considered, Using Quarter amplitude decay method, the ultimate gain $K_u = 2.0$ and the oscillation period $T_u = 1.1\ sec$. Hence the P, I and D gain constants of the three PID controllers present in the considered system are

$$K_P = 1.2; \quad K_I = 2.1818; \quad K_D = 1.65$$

6. Simulation and Results

The block diagram of the three area multi source deregulated power system considered is shown in the fig (3). Based on the values modelled, Simulation of considered system is carried out using PSO algorithm and Quarter amplitude decay method respectively. In case of PSO algorithm, different combinations of performance indices are taken as objective function. Fig (6) shows the simulation diagram of AGC of three area multi source deregulated power using PID controller tuned by PSO algorithm with objective function as combination of IAE, ISE and ITSE. Simulation diagram of AGC of the system using PID controller tuned by Zeigler Nichols method remains same in which the tuned values of the controller are placed with no objective function. Comparison of the resultant waveforms of the PID controller using PSO and Zeigler Nichols method are shown from the fig (8) – (13) for IAE+ISE+ITSE case. PSO convergence characteristics at the end of twenty iterations are shown in fig (6). The resultant waveforms of other cases are shown from fig (14) – (55).

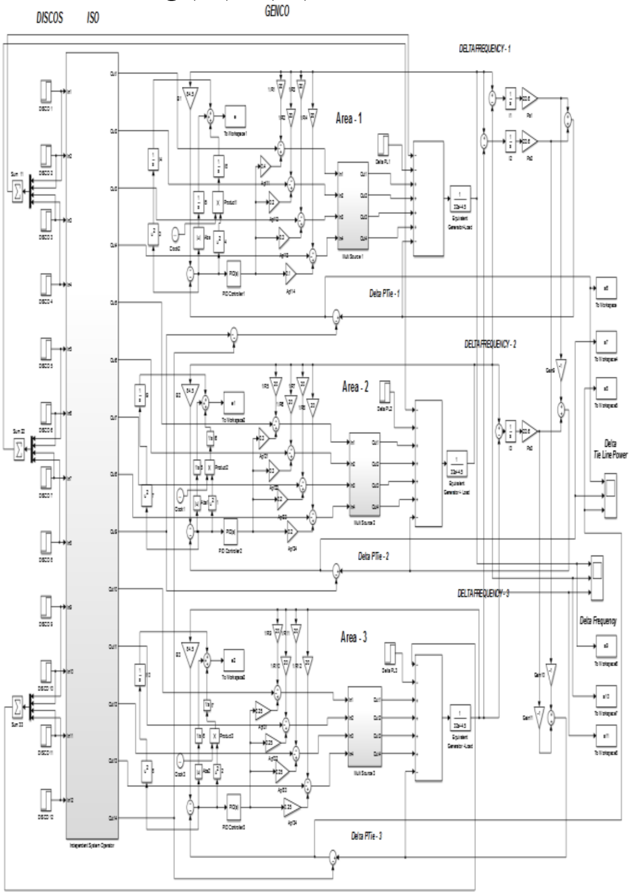

Fig 6. Simulation diagram of three area multi source deregulated power system

PSO_IAE+ISE+ITSE Vs ZN

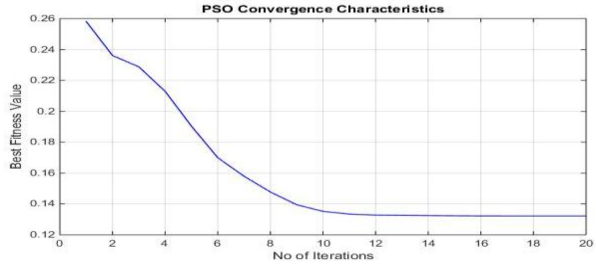

Fig 7. PSO Convergence Characteristics

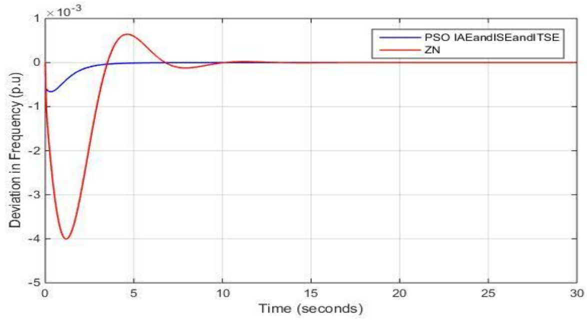

Fig 8. Deviation in Frequency of Area – 1

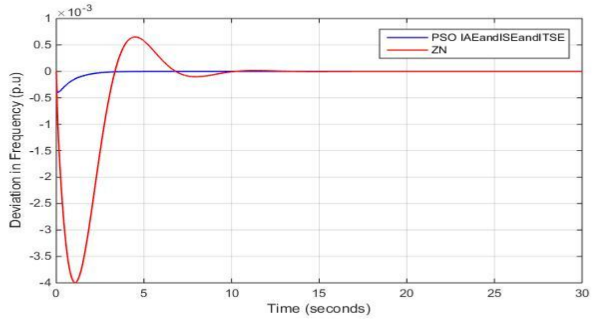

Fig 9. Deviation in frequency of Area – 2

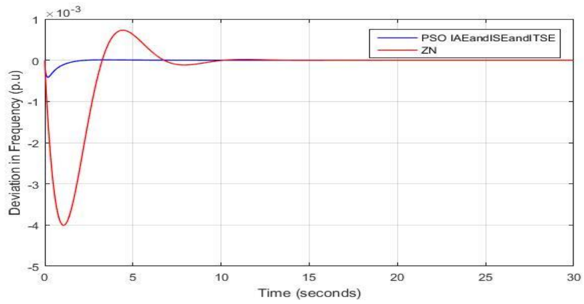

Fig 10. Deviation in frequency of Area – 3

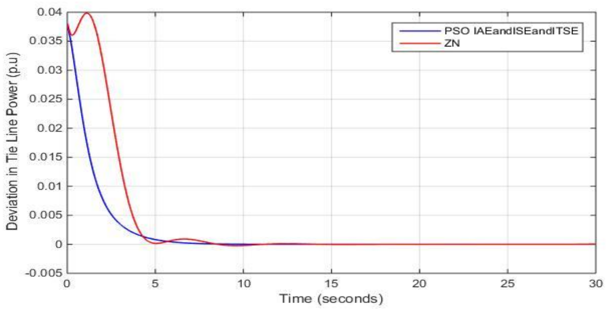

Fig 11. Deviation in Tie Line Power of Area – 1

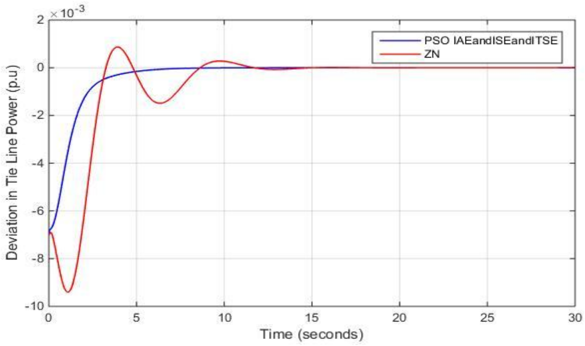

Fig 12. Deviation in Tie Line Power of Area – 2

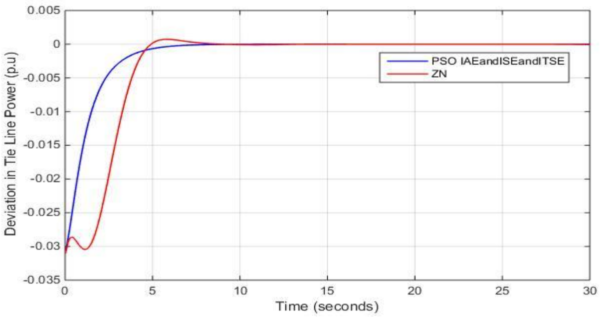

Fig 13. Deviation in Tie Line Power of Area – 3

PSO_IAE Vs ZN

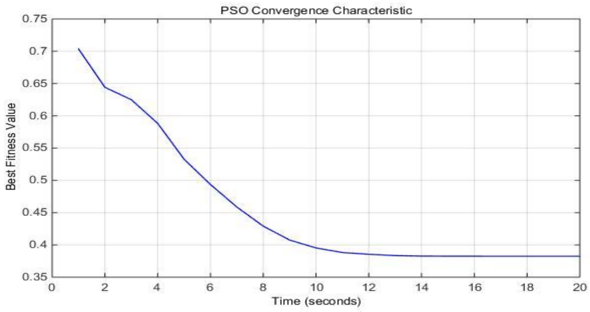

Fig 14. PSO Convergence Characteristics

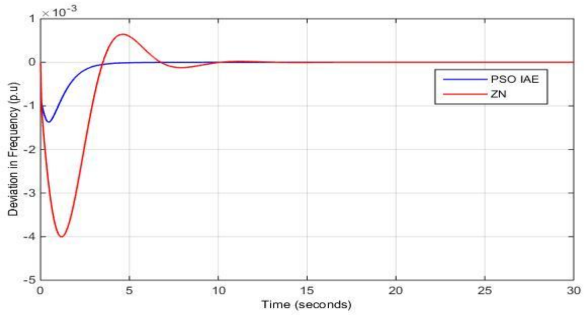

Fig 15. Deviation in Frequency of Area-1

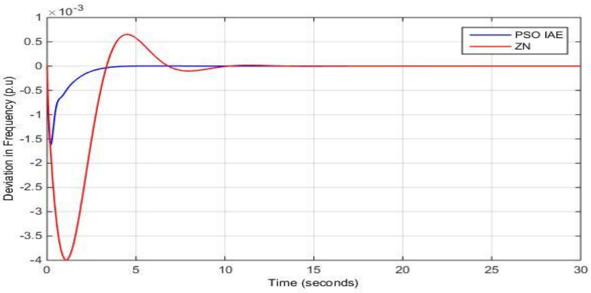

Fig 16. Deviation in Frequency of Area-2

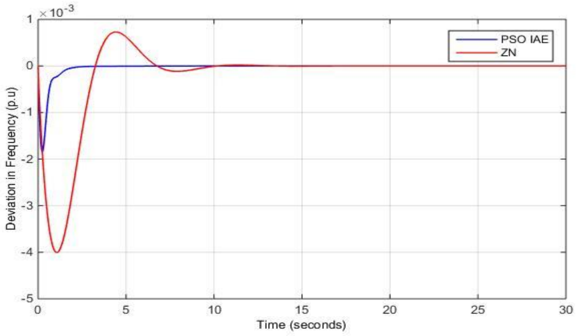

Fig 17. Deviation in Frequency of Area-3

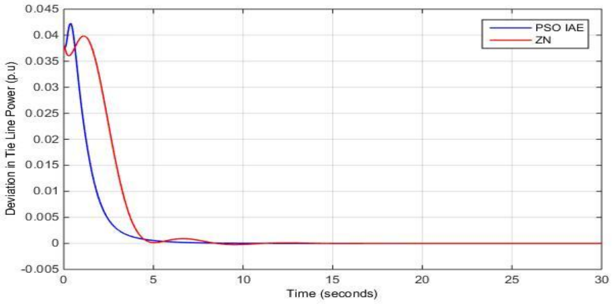

Fig 18. Deviation in Tie Line Power of Area-1

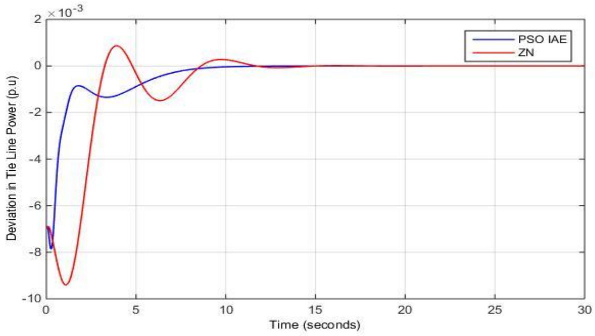

Fig 19. Deviation in Tie Line Power of Area-2

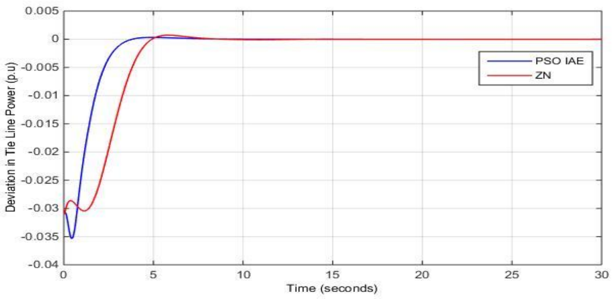

Fig 20. Deviation in Tie Line Power of Area-3

PSO_ISE Vs ZN

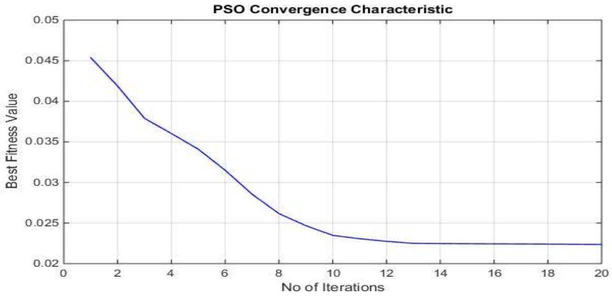

Fig 21. PSO Convergence Characteristics

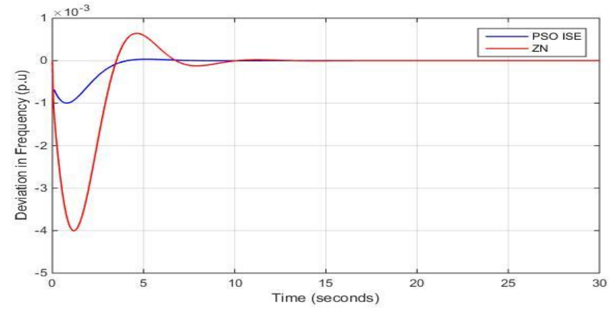

Fig 22. Deviation in Frequency of Area-1

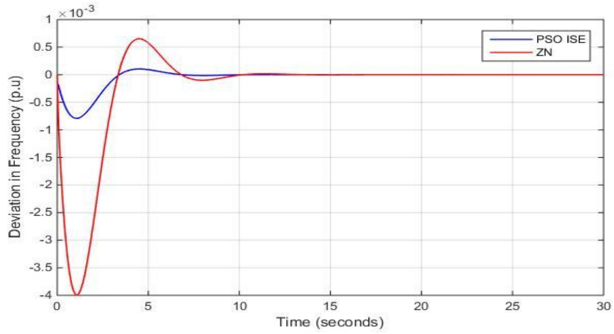

Fig 23. Deviation in Frequency of Area-2

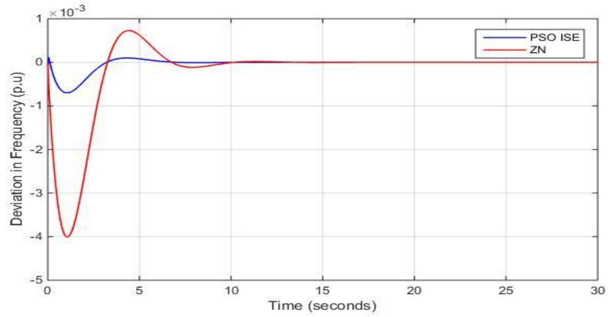

Fig 24. Deviation in Frequency of Area-3

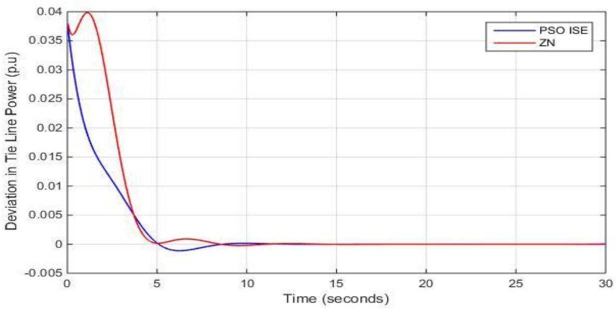

Fig 25. Deviation in Tie Line Power of Area-1

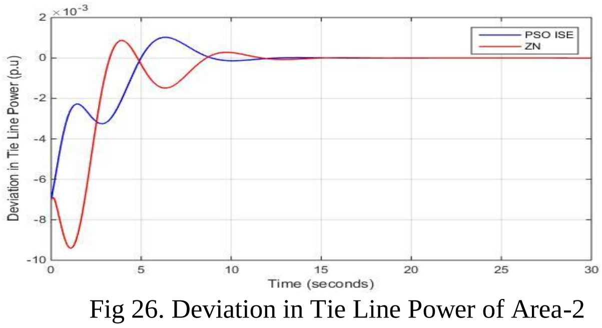

Fig 26. Deviation in Tie Line Power of Area-2

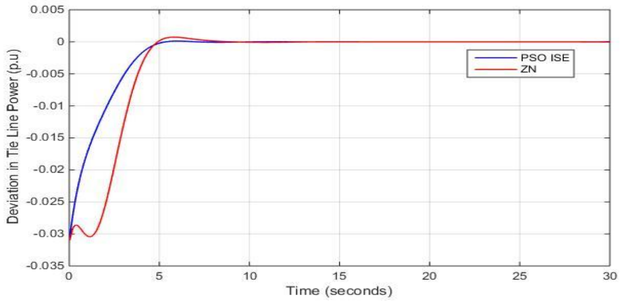

Fig 27. Deviation in Tie Line Power of Area-3

PSO_ITSE Vs ZN

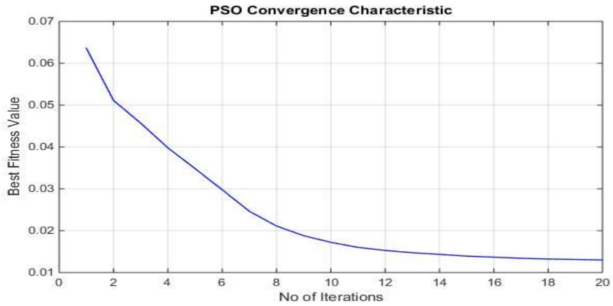

Fig 28. PSO Convergence Characteristics

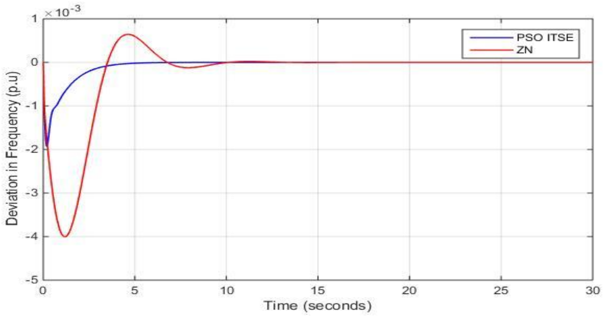

Fig 29. Deviation in Frequency of Area-1

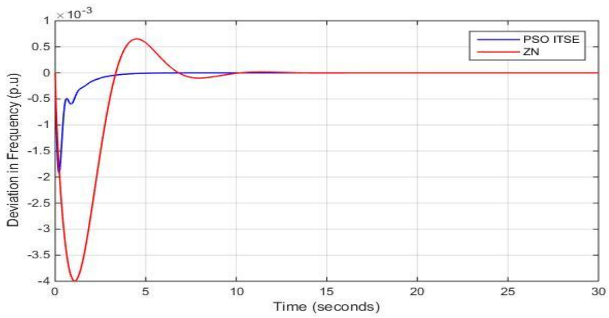

Fig 30. Deviation in Frequency of Area-2

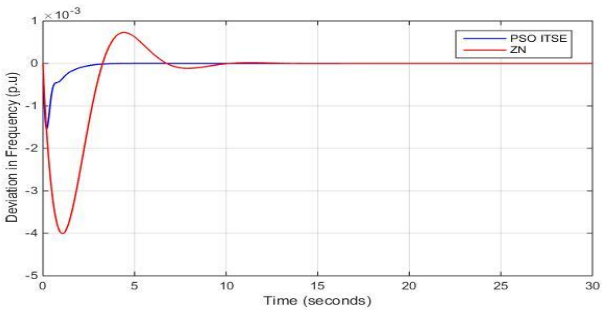

Fig 31. Deviation in Frequency of Area-3

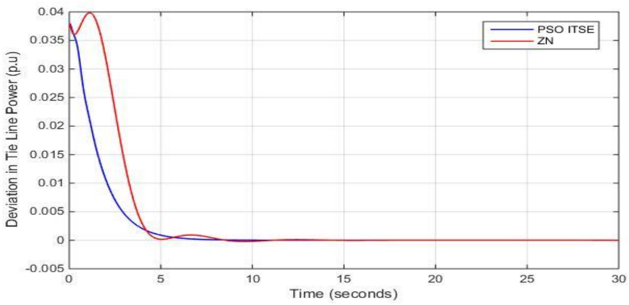

Fig 32. Deviation in Tie Line Power of Area-1

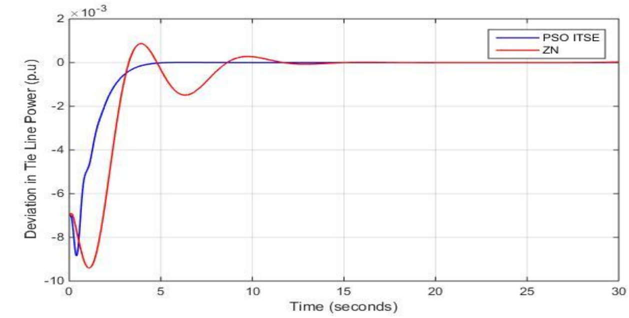

Fig 33. Deviation in Tie Line Power of Area-2

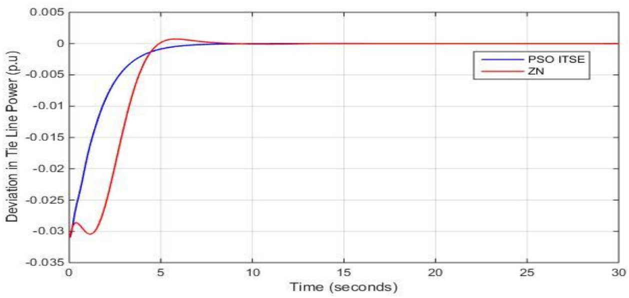

Fig 34. Deviation in Tie Line Power of Area-3

PSO_IAE+ISE Vs ZN

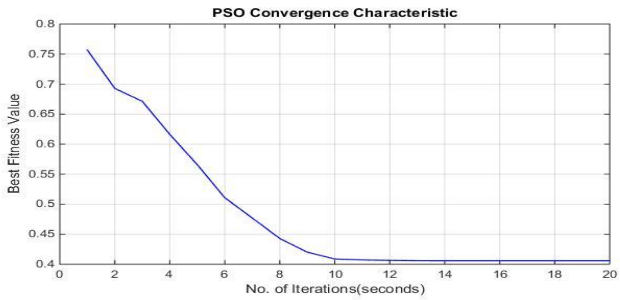

Fig 35. PSO Convergence Characteristics

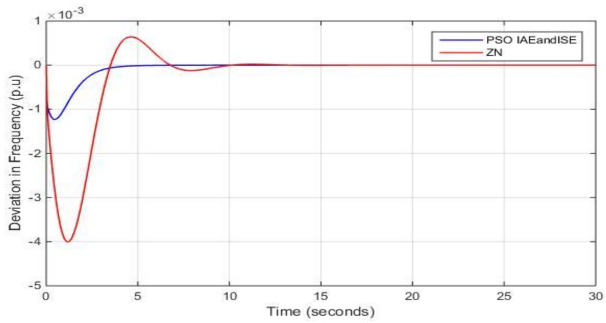

Fig 36. Deviation in Frequency of Area-1

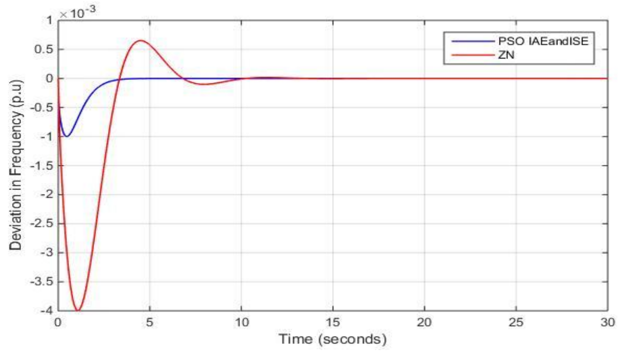

Fig 37. Deviation in Frequency of Area-2

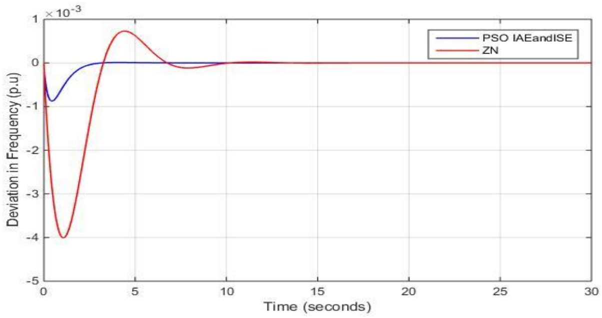

Fig 38. Deviation in Frequency of Area-3

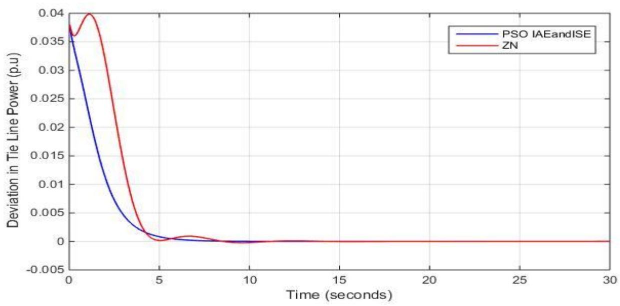

Fig 39. Deviation in Tie Line Power of Area-1

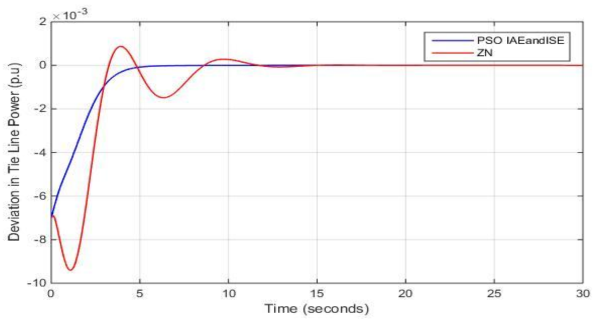

Fig 40. Deviation in Tie Line Power of Area-2

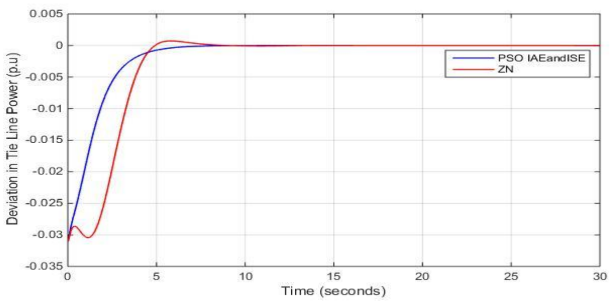

Fig 41. Deviation in Tie Line Power of Area-3

PSO_IAE+ITSE Vs ZN

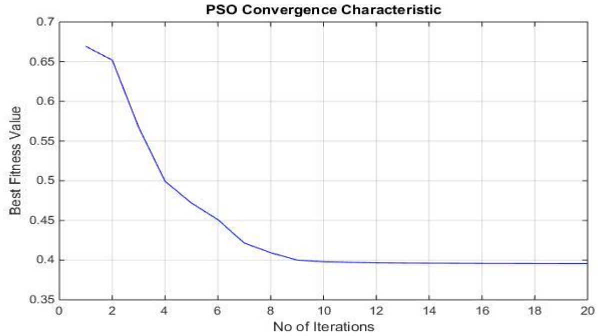

Fig 42. PSO Convergence Characteristics

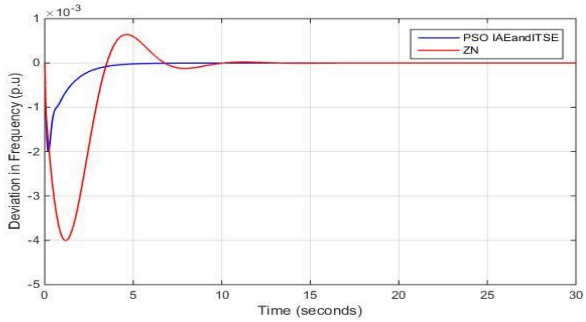

Fig 43. Deviation in Frequency of Area-1

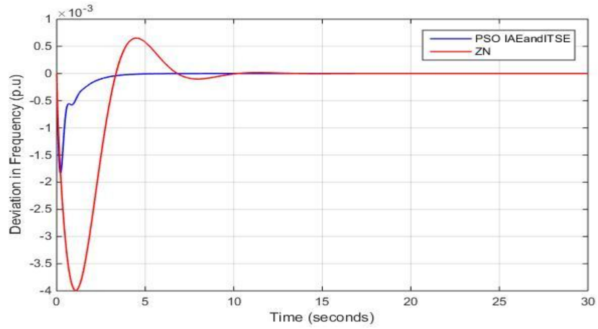

Fig 44. Deviation in Frequency of Area-2

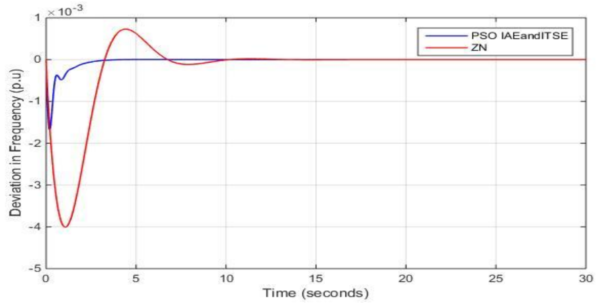

Fig 45. Deviation in Frequency of Area-3

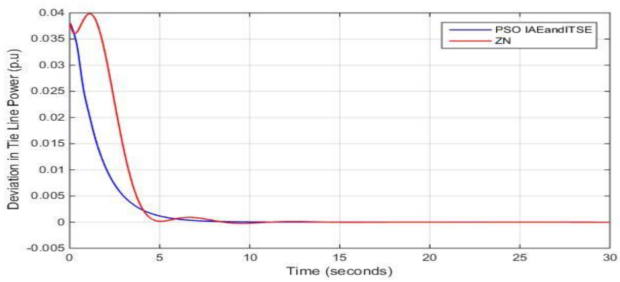

Fig 46. Deviation in Tie Line Power of Area-1

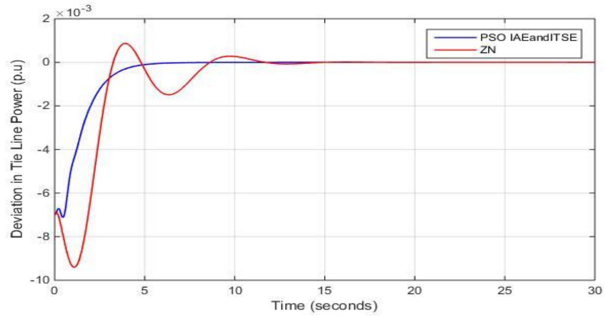

Fig 47. Deviation in Tie Line Power of Area-2

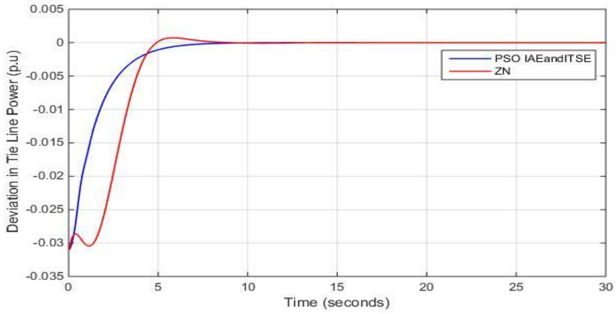

Fig 48. Deviation in Tie Line Power of Area-3

PSO_ISE+ITSE Vs ZN

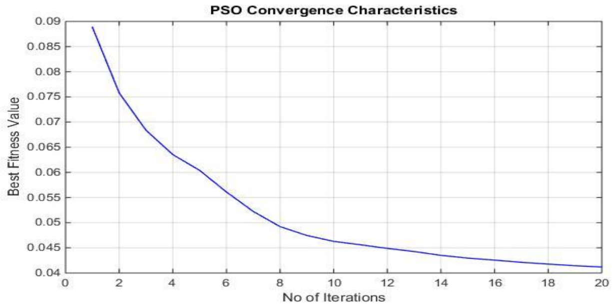

Fig 49. PSO Convergence Characteristics

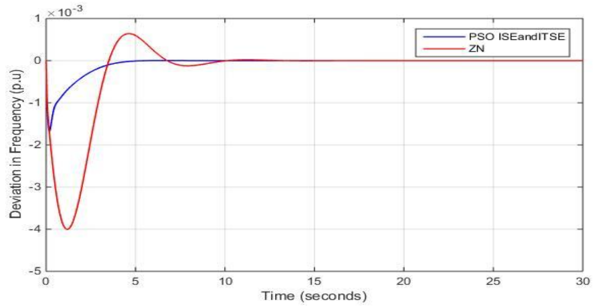

Fig 50. Deviation in Frequency of Area-1

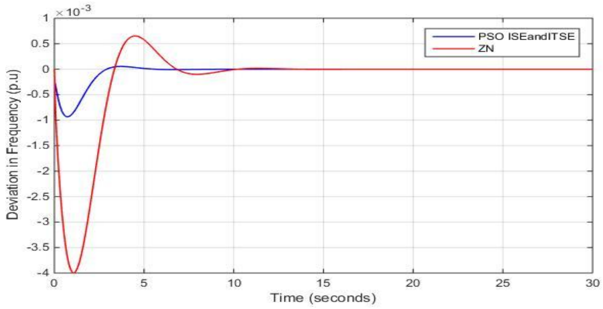

Fig 51. Deviation in Frequency of Area-2

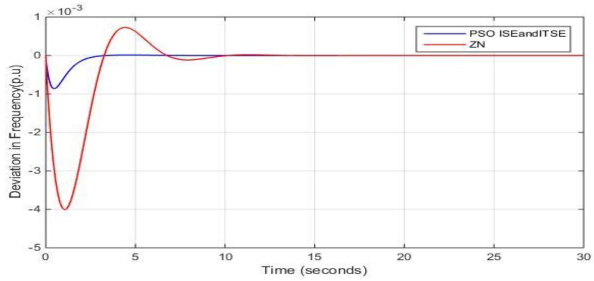

Fig 52. Deviation in Frequency of Area-3

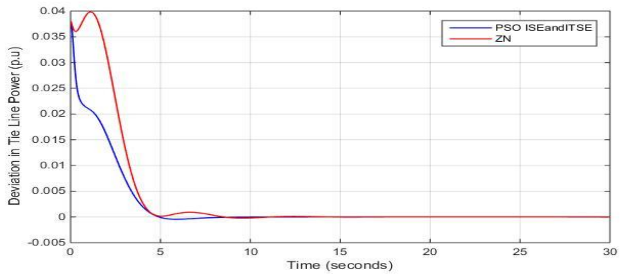

Fig 53. Deviation in Tie Line Power of Area-1

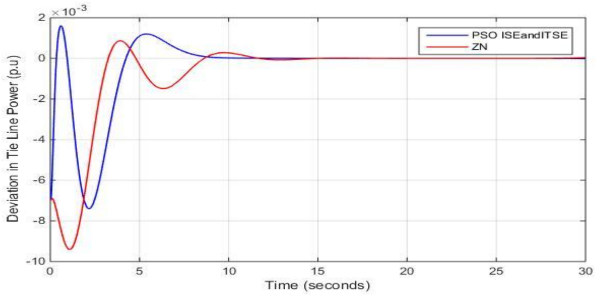

Fig 54. Deviation in Tie Line Power of Area-2

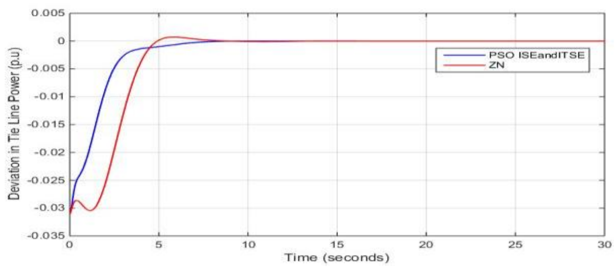

Fig 55. Deviation in Tie Line Power of Area-3

7. Discussion

Simulation of AGC of multi source multi area deregulated power system using PSO algorithm is done under 7 test cases. These test cases are different individual and combinations of the performance indices that are to be minimized considered as objective functions. Cases considered are IAE, ISE, ITSE, IAE+ISE, IAE+ITSE, ISE+ITSE and IAE+ISE+ITSE as objective functions respectively. All these cases are individually compared with Zeigler Nichols method. Case with IAE+ISE+ITSE as objective function gave the best results of all and the corresponding waveforms are shown in the figs (8)-(13). Remaining cases resultant waveforms are shown from figs (14) - (55). Those waveforms are compared with Zeigler Nichols method. From the PSO characteristics fig (7), it is observed that, at the end twelve iterations best fitness value i.e. minimum of IAE+ISE+ITSE is obtained. Comparison of settling times of the PID controller tuned by PSO (with different cases considered) and Zeigler Nichols are shown in Table 2. ΔP_1, ΔP_2, ΔP_3 indicates deviations in tie line powers of area – 1, 2 and 3, whereas ΔF_1, ΔF_2 and ΔF_3 are the changes in frequencies of area – 1, 2 and 3 respectively. All the settling times are in seconds.

Table 2 : Settling times of Tie-line and Frequency deviations

Tuning of PID controller		ΔP_1	ΔP_2	ΔP_3	ΔF_1	ΔF_2	ΔF_3
ZN		8	11	8	10	10	10
PSO	IAE	5	5	5	4	3.5	3.3
	ISE	6	8	5	4	6	6
	ITSE	5.5	8	4.5	4	3.3	3.3
	IAE + ISE	6	5	6	3.5	3	2.5
	IAE + ITSE	5	8	5	4	5.5	5.5
	ISE + ITSE	5	8.5	5	4	3.5	3.5
	IAE + ISE + TSE	**5**	**5**	**5**	**3**	**2.5**	**2**

8. Conclusion

Since the load demand is increasing day by day, competition is increasing in the power generation, transmission as well in the distribution regions. Hence deregulated environment would be optimal for the customers as well as the power producers to have the balance of load demand with more security and reliability. Bilateral contracts case is chosen here for the study of the multi source three area deregulated power system. During these contracts, ISO plays a vital role in maintaining the AGC of the system considered. Here, the secondary controller i.e. PID controller is tuned by PSO algorithm for different combinations of performance indices IAE, ISE, ITSE and their combinations as objective functions. It is also tuned by Quarter amplitude delay method of Zeigler Nichols tuning method. Upon comparison from figs (7) – (55) and Table 2, AGC of three area multi source deregulated power system using PID controller tuned by PSO algorithm with objective function as IAE+ISE+ITSE gave the optimal results. Settling times and overshoots remain low for this objective function from PSO tuned PID controller.

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