

# ENHANCEMENT OF TRANSIENT PERFORMANCE OF LOAD FREQUENCY REGULATION IN ELECTRICITY MARKETS USING INERTIA VARIANT PSO

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**Abstract:** *This paper proposes an potent method to obtain load frequency regulation in electricity markets using Particle Swarm Optimization (PSO) with Global-Local best inertia weight strategy. Load frequency regulation is gaining its importance in the emerging electricity markets. A constant gain controller for load frequency regulation does not offer effective control when the system is subjected to sudden disturbances. Hence to retain the performance closer to its global optimum point, it is advisable to track the system disturbances and accordingly re-evaluate the controller gains. In this work, load frequency regulation with PSO optimized integral controller is carried out with an objective taking in account of time domain specifications of error signals in the system. The effectiveness of this method is evident from the simulation results and it is validated that the proposed method is more efficient in reducing the steady state error due to the action of integral controller with optimized gain. The consideration of time domain specifications in the objective function of PSO helps in reducing the settling time of error signals in the frequency regulation of electricity markets.*

**Key words:** *Electricity Markets, Frequency regulation, Particle Swarm Optimization, Inertia weight, Contract, transient response*

## 1. Introduction.

Currently the power industry is being re-regulated from the traditional vertically integrated power system to competitive electricity markets with number of entities for different ancillary services. Such electricity market comprises of generation companies (GENCOs), distribution companies (DISCOs), and transmission companies (TRANSCOs) and independent system operator (ISO). The ISO is an independent agent which coordinates controls and monitors the functioning of electrical power system through various ancillary services. Automatic Generation Control (AGC) or Load Frequency Control (LFC) comes under these ancillary services. When widely fluctuating loads are connected in an electricity market it results in more complicated frequency oscillations, hence there is need to regulate the system frequency at each and every instant of time. The prime goal of the frequency

regulation method is to maintain the frequency at the prescribed value and to minimize the tie line power flow deviations from the scheduled value.

The implementation of AGC in traditional power system is discussed in [1]-[3]. The AGC in a deregulated power system [4] is addressed first with certain generating units automatically following load changes on the HVDC connections. Donde et al [5] has proposed the ideal of LFC in restructured power system considering Disco participation matrix (DPM), bilateral contract and contract violation. In [6] decentralized multi area AGC for a competitive electricity market with areas of different ratings has been discussed. A game negotiation approach for load dispatching with electricity price is addressed in [7]. In [8], different new optimization algorithm have been employed to optimally tune the gain value of proportional-integral-derivative controller under fuzzy based AGC in a multi-area thermal generating plants Hosseini et al [9] addressed the ANFIS based approach for AGC in electricity market using PSO optimized integral gains. In [10], a method of tuning PID controller in a decentralized manner is explained with an assumption that the power flows in the tie-lines are nulled out.

From literature it is evident that there has been considerable progress of intelligent algorithm based controller for effective control of AGC systems. Among various Optimization algorithms particle swarm optimization [11] outperforms by its easy to implement feature and there are few parameters to adjust to reach the global optimum point. Hence in this work, an attempt has been made to incorporate swarm intelligence based model for load frequency regulation on two area electricity market with unilateral, bilateral and contract violation case. The main contributions of this paper are as follows:

- i. To design and propose PSO based integral controller for load frequency regulation in electricity markets with global local best inertia weight strategy.

- ii. Analysis of transient characteristics of dynamic responses of two area test system with PSO based integral controller.

This paper is structured as follows. Section 2 enunciates the load frequency regulation model suitable for electricity markets with bilateral contracts incorporated in it. Section 3 demonstrates the implementation of particle swarm optimization for the optimization of integral controller gains in the two areas. Section 4 presents the simulation results for the test system and remarks on the results. Finally Section 5 concludes the paper.

## 2. Load Frequency regulation in electricity Markets

Consider a two-area system in electricity market in which there are two GENCOs and two DISCOs in each area. Let GENCO<sub>1</sub>, GENCO<sub>2</sub>, DISCO<sub>1</sub> and DISCO<sub>2</sub> be in area I and GENCO<sub>3</sub>, GENCO<sub>4</sub>, DISCO<sub>3</sub> and DISCO<sub>4</sub> be in area II. Fig 1 shows schematic diagram of two area system in electricity market. In competitive electricity markets, there will be trading of power from GENCOs to various DISCOs at emulous prices. Thus, DISCOs have the independence to prefer the GENCOs for contracts. The DISCOs may or may not wish to have contracts with the GENCOs existing in their area. This creates various combination of contact between GENCO and DISCO. At this juncture the idea of “DISCO participation Matrix (DPM) is introduced to understand contracts in a better way. DPM is a matrix in which the order of the matrix corresponds to the number of GENCOs and the number of DISCOs in the system under consideration. DPM gives information about the participation of a DISCO in a contract with a GENCO. Each element in this matrix can be considered of as a fraction of a total demand contracted by a DISCO with a GENCO. Thus, the  $ij^{th}$  entry represents the fraction of the total load power contracted by a DISCO  $j$  from a GENCO  $i$ .

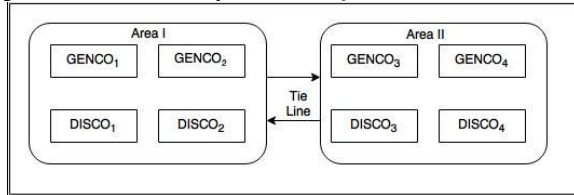


Figure 1. Simplified diagram of two area in electricity markets

The extrapolated rule for DPM with  $n$  GENCOs and  $m$  DISCOs is shown below

$$\text{DPM} = \begin{pmatrix} cpf_{11} & \dots & cpf_{1m} \\ \vdots & \ddots & \vdots \\ cpf_{n1} & \dots & cpf_{nm} \end{pmatrix} \quad (1)$$

$cpf_{ij}$  is the “contract participation factor”, which gives the participation factor of GENCO  $i$  in the load

demand of DISCO  $j$ . The sum of all the entries in a column of this matrix is unity. (i.e.  $\sum_{i=1}^n cpf_{ij} = 1$ ). As and when the load of a DISCO changes, it is viewed as a local load in the area where the DISCO belongs to. Since there are several GENCOs in an area of a power system, the AGC signal should be dispersed amid them allowing their participation in the AGC. Area control error (ACE) participation factors ( $apf$ ) are the coefficient factors which spreads the ACE among GENCOs. This is not present in the implementation of AGC in traditional system. The load frequency regulation block diagram to illustrate the behavior of the proposed method is shown in Fig.2.

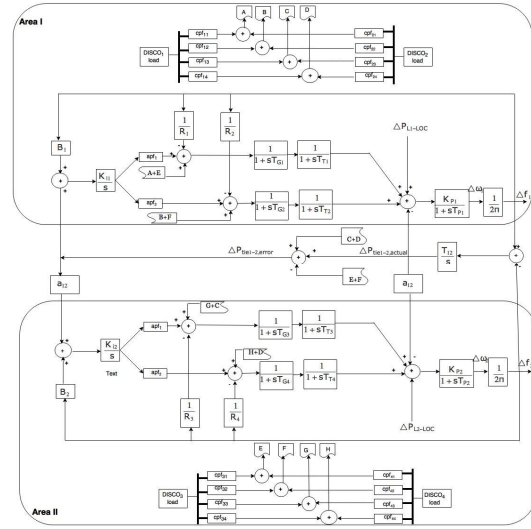


Figure 2. Two area Load frequency regulation block diagram in electricity markets

If there are  $m$  number of GENCOs then

$$\sum_{i=1}^m apf_i = 1 \quad (2)$$

Here, redeveloping the scheduled tie line power is done which is present as same as in the conventional AGC. The scheduled value of steady state tie line power is given as

$$\Delta P_{tiei-j,scheduled} = \left( \begin{aligned} & \left( \text{Demand of DISCOs in area 'j' from GENCO in area 'i'} \right) - \\ & \left( \text{Demand of DISCOs in area 'i' from GENCO in area 'j'} \right) \end{aligned} \right) \quad (3)$$

Then the tie line power error  $\Delta P_{tiei-j,error}$  is expressed as

$$\Delta P_{tiei-j,error} = \Delta P_{tiei-j,actual} - \Delta P_{tiei-j,scheduled} \quad (4)$$

and it becomes zero in the steady state condition, since the actual value of tie line power matches the schedule tie line power. Similar to traditional AGC, the  $\Delta P_{tiei-j,error}$  is employed to produce the corresponding ACE signals.

Area Control Error (ACE) of an  $i^{\text{th}}$  area will be given as

$$ACE_i = \sum_{j=1}^n \Delta P_{tie1-j,error} + (B_i * \Delta F_i) \quad (5)$$

Where, n is the number of neighboring areas.

### 3. Particle Swarm Optimization for Load Frequency regulation in electricity Markets

These days, in spite of remarkable advancement in the field of control systems, integral controllers are being widely used in several applications of industry, science and engineering such as in electrical power systems. It is due to the fact that it works well for a wide variety of process. In addition, it provides robust performance for different operating conditions. Moreover the implementation of such controllers using hardware is simple and it is well known to engineers work in this field. In this work, Integral controller is used for the solution of Load frequency regulation problem. As far as the transient performance of the power system with regard to the regulation of system frequency and power flow in the tie-lined are concerned, it clearly depends upon the correct tuning of the Integral controller's gain parameters. It is well known that the conventional methods to tune Integral controller parameters are not capable enough to reach the globally optimal point to achieve the acceptable level of system robust performance. Power systems are complex in nature and it involves multi-variable operating conditions, hence conventional methods takes more time and it is tedious. With an intention to overcome the above said drawbacks and to impart optimal control, PSO algorithm is suggested to optimally tune the Integral controller's parameters under various working conditions. The overall flowchart of Global local best inertia weight [12] based PSO tuned Integral controller to solve the load frequency regulation problem for each control area is shown in Fig. 3.

The gains  $K_i$  of integral controller of two areas are tuned using PSO technique and then the Integral controller generates the control signal that applies to the governor set point of each area. It is important to note that proper choice of objective function is a prime factor in achieving the desired level of robust system performance. In this work, the following performance index  $J_1$  with Integral of time multiplied Integral Square error (ISE) criterion and  $J_2$  a function with Integral of time multiplied Integral Square error (ISE) criterion and settling time of error signals with suitable weights are employed.

$$J_1 = \int_0^t (\Delta f_1^2 + \Delta f_2^2 + \Delta P_{tie1-2,error}^2) dt \quad (6)$$

$$J_2 = w_1 * \int_0^t (\Delta f_1^2 + \Delta f_2^2 + \Delta P_{tie1-2,error}^2) dt + w_2 * (t_{s,\Delta f_1} + t_{s,\Delta f_2} + t_{s,\Delta P_{tie1-2,error}}) \quad (7)$$

Where  $\Delta f_1, \Delta f_2$  and  $\Delta P_{tie1-2,error}$  are the error in frequency deviations of area 1 and area 2 and error in tie line power respectively,  $w_1$  and  $w_2$  are the suitable weight factors and  $t_{s,\Delta f_1}$  and  $t_{s,\Delta f_2}$  are the settling time of frequency deviations in area 1 and 2,  $t_{s,\Delta P_{tie1-2,error}}$  is the settling time of tie line power deviations.

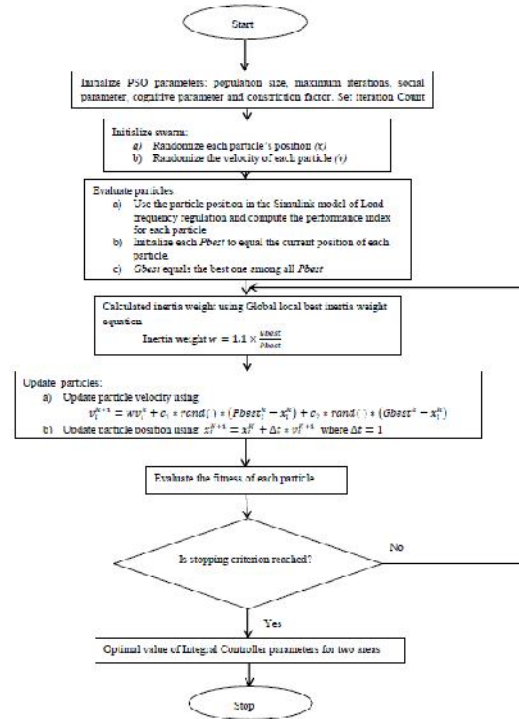


Figure 3. Proposed Inertia variant PSO for load frequency regulation in electricity markets

### 4. Results and Discussion

The load frequency regulation block diagram to illustrate the behavior of the proposed method is shown in Fig.2. The parameters of the test system are given in Appendix A. The test system is assumed to have both identical areas with identical governor-turbine units and speed regulation constant.

#### 4.1 Case 1 : Base Case – Unilateral Contract

In this case, GENCOs in each area participate equally in load frequency regulation. Hence  $apf_i = 0.5$ , where  $i = 1, 2, 3$  and 4. DPM matrix is assumed to be

$$DPM = \begin{bmatrix} 0.5 & 0.5 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Here it is considered that only in Area I the load changes. That is, DISCO<sub>1</sub> and DISCO<sub>2</sub> have a change in demand of 0.1 pu MW for each of them. The simulation results are depicted in Fig. 4(a) - (c). It is evident from the results that the system with performance index  $J_2$  outperforms in reducing the error and at the same time enhancing the settling down of error signals to zero compared to the system with performance index  $J_1$ .

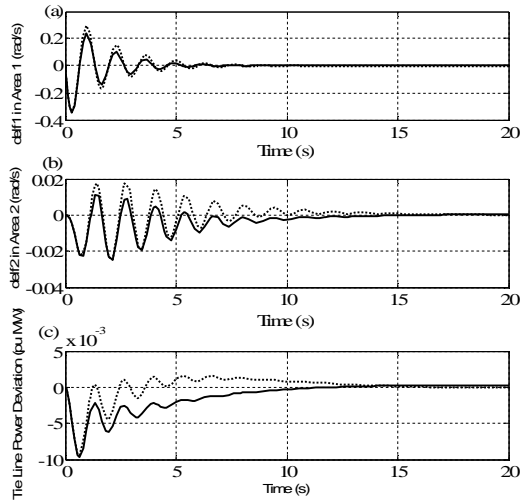


Figure 4. Case 1 : (a) Frequency deviations in Area (rad/s) (b) Frequency deviations in Area 2 (rad/s) . (c) Tie line Power deviations (pu MW) solid line : with  $J_2$  , dotted line : with  $J_1$

#### 4.2 Case 2: Bilateral Contract

In this case, the contract between the DISCOs and GENCOs will exist as per the DPM given below.

$$DPM = \begin{bmatrix} 0.5 & 0.25 & 0 & 0.3 \\ 0.2 & 0.25 & 0 & 0 \\ 0 & 0.25 & 1 & 0.7 \\ 0.3 & 0.25 & 0 & 0 \end{bmatrix}$$

Here, each DISCO in both the areas have a change in demand of 0.1 puMW from each GENCO as per the *cpfs* in DPM and each GENCO take part in load frequency regulation by the following *apfs*.  $apf_1 = 0.75$ ,  $apf_2 = 0.25$ ,  $apf_3 = 0.5$ ,  $apf_4 = 0.5$ . The response of load frequency regulation for this case is shown in Figs 5 (a) – (c). It is evident that the frequency deviation in Area I is more compared to Area II in this case, as the GENCOs in both the area respond to the load changes based on the DPM values and Area participation factors in order to settle down the frequency deviations and tie line power deviations.

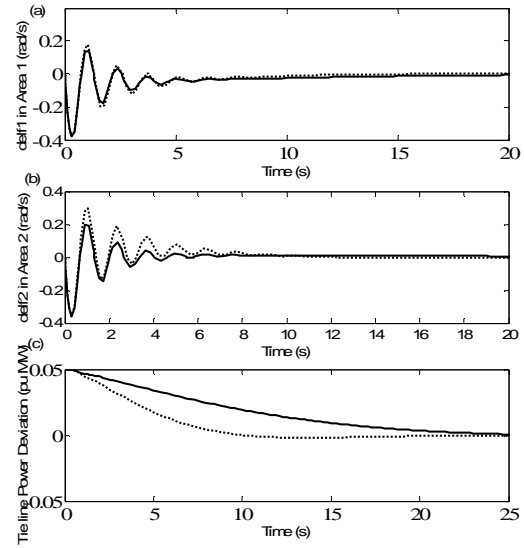


Figure 5. Case 2. (a) Frequency deviations in Area 1 (rad/s) . (b) Frequency deviations in Area 2 (rad/s) . (c) Tie line Power deviations (pu MW) solid line : with  $J_2$  , dotted line : with  $J_1$

#### 4.3 Case 3 : Contract Violation

In this case the DISCOs violate contract as it demands additional power than the value that was already specified in the bilateral contract case. This uncontracted power demand of DISCOs have to be met out by the GENCOs in the same area in which the DISCO exists. Let us assume that the DISCO<sub>1</sub> demands 0.1 pu MW of excess power while the rest of the DISCOs demands no excess power than the contract.

The total local load of Area 1 is given by

$$\begin{aligned} \Delta P_{L1,LOC} &= \text{Load of Disco}_1 + \text{Load of Disco}_2 + \\ &\text{Uncontracted demand of Disco}_1 \\ &= 0.1 + 0.1 + 0.1 = 0.3 \text{ p.u MW} \end{aligned}$$

Similarly the total local load of Area 2 (with no Uncontracted demand) is given by

$$\begin{aligned} \Delta P_{L2,LOC} &= \text{Load of Disco}_3 + \text{Load of Disco}_4 \\ &= 0.1 + 0.1 = 0.2 \text{ p.u MW.} \end{aligned}$$

From the simulation results Fig 6(a) – (c) it is evident that due to the existence of uncontracted demand in Area 1, it has predominant frequency deviations with relatively more amplitude compared to Area 2. It is also evident that the GL best inertia weight strategy pulls the convergence to occur faster compared with performance index  $J_2$  than with performance index  $J_1$ .

The convergence characteristics of performance index using inertia variant PSO for case 3 is shown in Fig. 7 and Fig. 8 and it depicts that the second objective

function  $J_2$  has good convergence compared to the first objective function  $J_1$ .

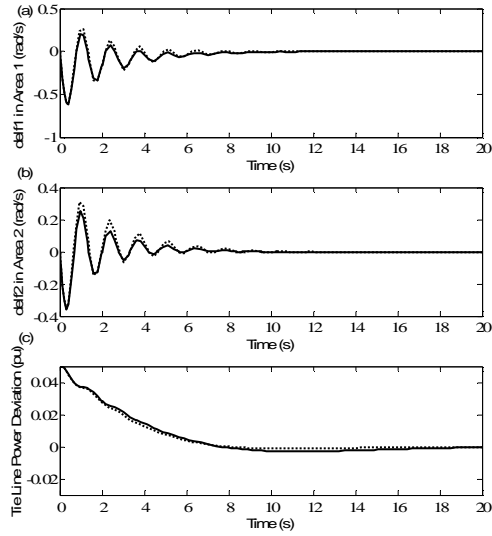


Figure 6. Case 3. (a) Frequency deviations in Area (rad/s). (b) Frequency deviations in Area 2 (rad/s) . (c) Tie line Power deviations (pu MW)  
solid line : with  $J_2$  , dotted line : with  $J_1$

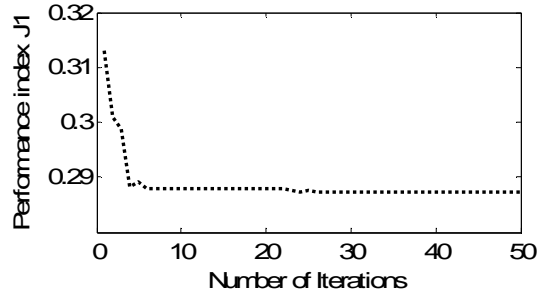


Figure 7. Convergence characteristics of  $J_1$  for Case 3

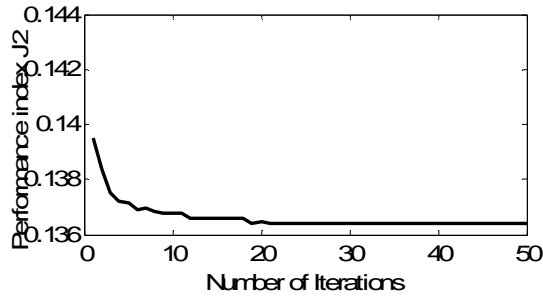


Figure 8. Convergence characteristics of  $J_2$  for Case 3

The parameters used for PSO algorithm is given in Table.1

Table.1 PSO parameters

S.No	PSO Parameters	values
1	Number of Particles	30
2	Number of Iteration	50
3	Cognitive parameter	2
4	Social parameter	2
5	Constriction factor	0.7

The optimized value of Integral controller gain for the three cases using the proposed method is given in Table 2.

Table.2 Optimized values of Integral Controller gains

Cases	PSO optimized Integral controller gains with $J_1$ as performance index		PSO optimized Integral controller gains with $J_2$ as performance index	
	$K_{i1}$	$K_{i2}$	$K_{i1}$	$K_{i2}$
1	0.6403	0.5713	0.09	0.0571
2	0.6321	0.0381	0.01	0.1497
3	0.9484	0.3285	0.5516	0.4670

## 5. Conclusion

In this work, Inertia variant PSO based Integral Controller employing two different objective optimization has been proposed for the load frequency regulation in electricity markets. It has been attempted to optimize the integral controller gains in such a way that the objective functions are minimized. A two area power system has been considered to illustrate the effectiveness of the proposed methodology. The objective functions are devised by considering the transient specifications and suitable selection of weighting factors. Simulation results prove that the proposed method with Integral Time multiplied Integral Squared error criterion and settling time of error signal as objective has favorable transient and steady state performance to nullify the frequency and tie line power deviation compared to PSO tuned Integral Controller with standard objective function of Integral Time Multiplied Squared Error Criterion.

## APPENDIX A

S.No	Parameters	values
1	Inertia Constant H	5 secs
2	Speed Regulation Constant R	2.4 Hz/pu
3	Speed Governor Time constant, $T_g$	0.08 secs
4	Turbine Time Constant, $T_t$	0.3 secs
5	Power System Time Constant, $T_p$	20 secs
6	Power System Gain , $K_p$	120 Hz /pu
7	Frequency Bias Control, B	0.425 pu
8	Synchronizing power coefficient, $T_{12}$	0.545 pu
9	$a_{12}$	-1

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