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AUTOMATIC GENERATION CONTROL INTEGRATED WITH RENEWABLE ENERGY USING PARTICLE SWARM OPTIMIZATION AND DIFFERENTIAL EVOLUTIONARY ALGORITHM

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ABSTRACT:- *This paper compares the effectiveness of two evolutionary algorithm of particle swarm optimization (PSO) and differential evolutionary (DE) for automatic generation control (AGC) of deregulated multi-area power system integrated with renewable energy source. The two area hydro- thermal power system is integrated with doubly fed induction generator (DFIG) based wind turbine in both areas. The challenge for interconnected multi-area power system is to maintain the constant frequency and tie-line interchange as per schedule. In order to eradicate the deviations in frequency and tie-line the gains are optimized usingpso and de algorithm. The results of both algorithms are discussed.*

KEYWORDS:- Automatic Generation Control, LFC, Disco Participation Matrix, Doubly-fed Induction Generator, Particle Swarm Optimization, Differential Evolutionary Algorithm

1. INTRODUCTION

The automatic generation control has been implemented so far in thermal and hydro generations. But, few years back focus has shifted to the renewable energy sources of power generation to reduce the global warming. Wind energy power source plays a vital role in renewable energy resources. The usage of wind energy sources increasing in recent trends of power generations.The penetration of wind energy conversion systems is significant the system operators are beginning to worry about the performance of the frequency regulation system.

New trend of restructured power system automatic generation control (AGC) that make easier to the bilateral contracts in the restructured power systems and it becomes one of the most important ancillary services to be controlled. But wind energy systems generally do not participate in the frequency regulation and tie-line power regulation and have lesser role in automatic generation control. So advanced wind turbine named Doubly-fed Induction generator (DFIG) based wind turbine used which can replace the conventional fixed speed induction generator wind turbines. Automatic Generation Control studies done on deregulated environment and including renewable energy sources considers the simplified models of hybrid multi-area deregulated power system.The physical constraints are considered into the system to get the accurate performance of the automatic generation control. The constraints are generation rate constraint (GRC), speed governor dead band and communication delay or time delays.

The objective of this paper is to optimize the gains of two-area hydro thermal interconnected deregulated power system with DFIG-based wind turbine used in both areas using particle swarm optimization algorithm (PSO) and differential evolutionary algorithm (D.E). The bilateral contracts between Gencoand Disco have been considered using disco participation matrix (DPM). Simulation experiments have been conducted using SIMULINK in MATLAB14.

2.MULTI-AREA DEREGULATED POWER SYSTEM

In deregulated power system, the Gencos and Discos made agreement with Gencos and Discos of interconnected area to supply the power. The transactions are given by Disco participation matrix (DPM)which gives the clear visualization of these contracts. Number of rows in DPM is equal to the number of Gencos and number of columns is equal to the number of Discos. The entries of DPM are contract participation factors (Cpf_{ij}), which represent the fraction of total load contracted by any DISCO $_j$ towards any GENCO$_i$. The DPM for a two area hydro-thermal system having two thermal GENCOs in area 1 and one hydro GENCO in area 2 is given in equation (1).

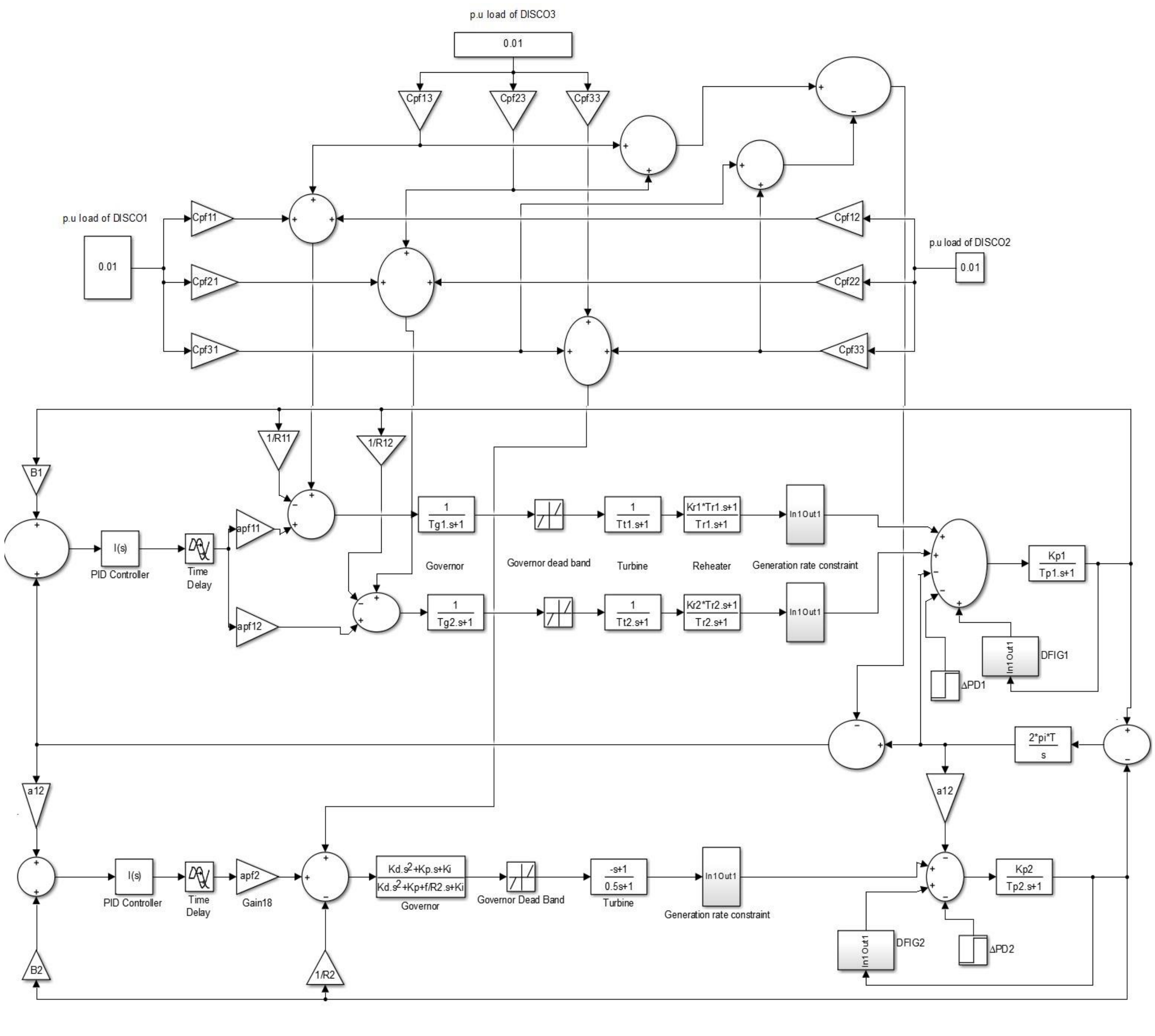

Fig-1: Two Area Hydro-Thermal Deregulated System WithDfig Based Wind Turbine

$$\mathrm{DPM} = \begin{pmatrix} Cpf_{11} & Cpf_{12} & Cpf_{13} \\ Cpf_{21} & Cpf_{22} & Cpf_{23} \\ Cpf_{31} & Cpf_{32} & Cpf_{33} \end{pmatrix} \quad (1)$$

Sum of all the entries in a column of this matrix is unity. As load changes take place in deregulated system, it takes care of its own area as defined by DPM. In addition to this, new information signals from DISCOs to GENCOs which are not in their area will flow that adjust the scheduled flow over the tie lines. The change in tie line power derives area control errors (ACEs) for the control areas involved. Depending upon the participation of ACE signal of that particular area in the AGC, a new participation factor is evolved known as ACE participation factor (apf).

The scheduled tie line power is

$$P_{tie}^{sch} = \begin{pmatrix} \text{Demand of Disco in area}_2 \\ \text{from Genco in area}_1 \end{pmatrix} - \begin{pmatrix} \text{Demand of Disco in area}_1 \\ \text{from Genco in area}_2 \end{pmatrix}$$

$$= (Cpf_{13} + Cpf_{23})\Delta P_{D1} - (Cpf_{31} + Cpf_{32})\Delta P_{D2} \quad (2)$$

Actual tie line power is

$$P_{tie}^{act} = \frac{2\pi T}{s}(df1 - df2) \quad (3)$$

The tie line power error is given by equation

$$dP_{tie} = P_{tie}^{act} - P_{tie}^{sch} \quad (4)$$

Area control error is given by

$$ACE_1 = B_1 df_1 + dP_{tie}$$

$$ACE_2 = B_2 df_2 + a_{12} dP_{tie} \quad (5)$$

Where $a_{12} = -\frac{P_{r1}}{P_{r2}}$

A. Generation Rate Constraint (Grc)

After a load disturbance in a power system, area control error (ACE) signals and control signals deviate from zero. The required power to compensate frequency deviations is provided through a specific ramp rate. The required power to maintain the system in normal condition is prepared by limit rate due to the GRC. The effect of the GRC will be more noticeable when the system encounters with greater step load perturbation

The main reason to consider GRC is that the rapid power increase would draw out excessive steam from the boiler system to cause steam condensation due to adiabatic expansion. Since the temperature and pressure in the high pressure (RP) turbine are normally very high with some margin, it is expected that the steam condensation would not occur with about 20% steam flow change unless the boiler steam pressure itself does not drop below a certain level. Thus, it is possible to increase generation power up to about 1.2 pu of normal power during the first tens of seconds. After the generation power has reached this marginal upper bound, the power increase of the turbine should be restricted by the GRC.

The GRC for thermal units is considered as 3%per minute for both minimum and maximum limit. For hydro it is 360% per minute and 270% per minute for minimum and maximum limit.

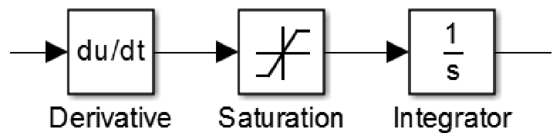

Fig-2: Generation Rate Constraint

B.Governor Dead Band

When the input signal is suddenly changed, the speed governor immediately cannot respond. So it has to wait until the input signal is reached to the particular value. The GDB is considered for hydro and thermal is 0.06% i.e., 0.036Hz.

3.MODELING OF DFIG WIND TURBINE

Wind Energy Conversion Systems (WECS) do not participate in system frequency support. Hence, wind turbines do not increase or decrease their production when the frequency falls or rises respectively. It results in system inertia and also in frequency disturbances. The growth in wind generation capacity, its contribution to total generation mix increases but the system inertia participating in frequency control is decreasing to inadequate levels for appropriate system frequency recovery following a power imbalance or grid disturbance. Due to thedoubly fed induction generator (DFIG) with modified emulated inertial is considered. The controller provides a power set point P_w^* based on measured speed and measured electrical power. The controller provides another power set point P_f^* which is based on deviation in frequency and rate of change of grid frequency. The power set point P_{NC} has two components i.e.,P_f^*&P_w^* .

$$P_f^* = -K_{fd}\frac{df}{dt} - K_{fp}\,df \quad (6)$$

$$P_f^* = \frac{1}{R}df' \quad (7)$$

$$\Delta P_W^* = -K_{wp}(\omega^* - \omega) + K_{wi}\int(w^* - \omega)dt \quad (8)$$

Where, Kwp and Kwi are constants of PI controller.

$$\Delta P_{NC} = \Delta P_f^* + \Delta P_W^* \quad (9)$$

High pass filter is used to responds for the permanent frequency deviation. Washout filter is used to respond transient frequency deviation.

$$\frac{2H}{f}\frac{d\Delta f}{dt} = P_T - Ddf$$

$$= P_g + P_{NC} - P_{Tie} - \Delta PD - D\Delta f$$

Where, P_T is total power generated by hybrid power plant

P_g is the power generated by conventional power plant

$$2H^*\frac{df}{dt} = P_g + P_W^* - P_{tie} - \Delta P_D - D^*df \quad (10)$$

$$P_{NCref} = (\tfrac{1}{2}\rho A_r C_{pmax})w_S^3 \quad (11)$$

Where, ρ is density of air (kg/m³), Ar is rotor area (m2), Cpmax is maximum Cp(λ) curve at pitch angle β equal to zero, ω_s is the speed of wind. In fig.3 ω^* refers to the reference speed that is assumed to be zero during simulation the maximum power obtained from the wind and wind speed remains constant.

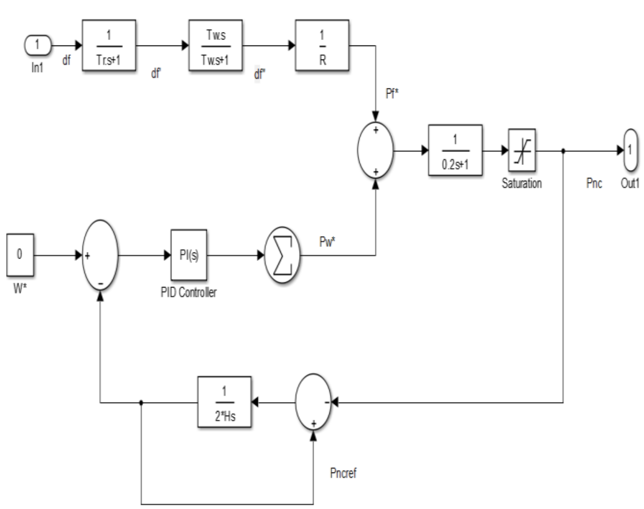

Fig-3:Dfig-Based Wind Turbine Control Based On Frequency Response

4.PARTICLE SWARM OPTIMIZATIONALGORITHM

Particle Swarm Optimization (PSO) is proposed by Kennedy and Eberhart in 1995. It is inspired from the nature social behavior and dynamic movements with communication of insects, birds and fish. It is a combination of self-experiences with social experiences.The idea is similar to bird searching for food, for example bird is particle, food is a solution, pbest is the personal best solution of a particle has achieved so far, gbest is global best of all particles with in the swarm. When a particle reaches a best solution it will be updated.

Let us consider the jth particle represented as $x_j=(x_{j,1}, x_{j,2}, \ldots, x_{j,g})$ in the gdimensional space. The best previous position of the jth particle is recorded and represented as $pbest_j=(pbest_{j,1}, pbest_{j,2}, \ldots, pbest_{j,g})$. The selection of best particle among all particles in the group is represented by the gbestg. The rate of the position change (velocity) for particle j is represented as $v_j=(v_{j,1}, v_{j,2}, \ldots, v_{j,g})$. The modified velocity and position of each particle can be calculated using the current velocity and distance from $pbest_{j,g}$ to $gbest_g$ as shown in the following formulas:

$$V_{j.g}^{(t+1)} = W.V_{j.g}^{(t)} + C_1 * rand(\ ) * (pbest_{j.g} - x_{j.g}^{(t)}) + C_2 * rand(\ ) * (gbest_{j.g} - x_{j.g}^{(t)}) \quad (12)$$

$$x_{j.g}^{(t+1)} = x_{j.g}^{(t+1)} + V_{j.g}^{(t+1)} \quad (13)$$

Where,

j=1,2,……..n, g=1,2,…….m, n- number of particles in group, m- number of members in particles, t- pointer of iteration (generations), $V_{j.g}^{(t)}$ – velocity of particle j at iteration t, w- inertia weight factor, C_1,C_2 – acceleration constant, rand( ) –random numbers between 0and1, $x_{j.g}^{(t)}$ –current position of particle j at iteration t, pbestj – pbest of particles j, gbestj – gbest of the group

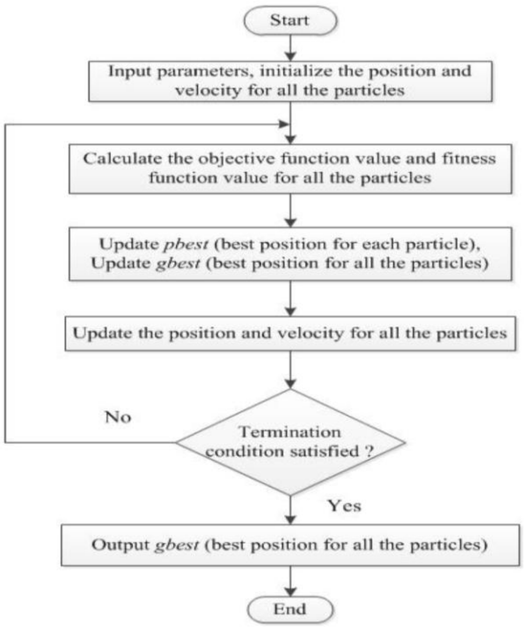

Fig-4: Flow Chart Diagram Of Particle Swarm Optimization Algorithm

5.DIFFERENTIAL EVOLUTIONARY ALGORITHM

Differential evolution is proposed by Storn and Price, it optimize the problem by repeated trying to improve a candidate solution with regard to give a measure of quality. A basic variant of the DE algorithm works by having a population of candidate solutions (called agents). The optimization process is conducted by four main operations initialization, mutation, recombination, selection.

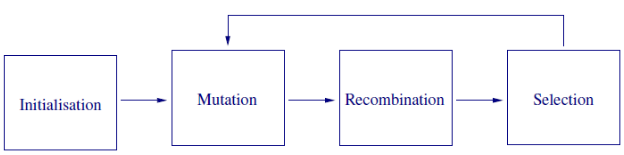

Fig-5:Evolutionary Algorithm Procedure

A. Initialization

First of all we need to define the upper and lower boundaries of each parameter i.e., $x_j^L \& x_j^u$, initiallyand the parameters values are randomly selected.

B. Mutation

The mutation expands the space search, for a given parameter vector$x_{i,G}$. It randomly selects the three vectors $x_{r1,G}, x_{r2,G}, x_{r3,G}$ such that indices i, r1, r2,r3 are distinct. Add the weighted difference of the two vectors to the third.

$$v_{i,G+1} = x_{r1,G} + F(x_{r2,G} - x_{r3,G}) \quad (14)$$

Where, F is a mutation factor constant,$v_{i,G+1}$ is donor vector, G is generation number.

C. Recombination

It takes the successful solutions from the previous generation, the trail vector$u_{i,G+1}$, is developed from the elements of the target vector and the elements of the donor vector. The donor vector enters into the trail vector with probability of CR.

$$u_{j,i,G+1} = \begin{cases} v_{j,i,G+1} & if\ rand_{j,i} \leq CR\ or\ j = I_{rand} \\ x_{j,i,G} & if\ rand_{j,i} \leq CR\ or\ j \neq I_{rand} \end{cases} \quad (15)$$

Where, i=1,2,……,N; j=1,2,…..,D

$Rand_{j,i}$~U[0,1], I_{rand} is random integer from [1,2,….D]

I_{rand} ensures that $v_{i,G+1} \neq v_{i,G}$

D. Selection

The target vector is compared with the trial vector and the one with the lowest function value is admitted to the next generation.

$$x_{i,G+1} = \begin{cases} u_{i,G+1} & if\ f(u_{i,G+1}) \leq f(x_{i,G}) \\ x_{i,G} & otherwise \end{cases} \quad i = 1,2,3 \ldots\ldots N \quad (16)$$

Mutation, recombination and selection continue until criterion is reached.

The objective function considered by using integral time absolute error (ITAE).

$$J = \int (|\Delta f_1| + |\Delta f_2| + |\Delta P_{Tie}|).t.dt \quad (17)$$

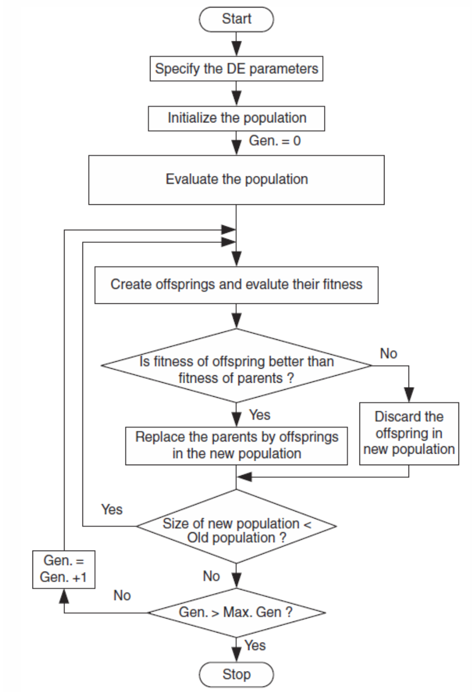

Fig-6:Flow Chart Of Differential Evolutionary Algorithm

6.SYSTEM INVESTIGATED AND SIMULATION RESULT

The simulations have been conducted in two area hydro thermal deregulated multi area integrated with DFIG based wind turbine. The simulations have been conducted in matlab14. The load perturbation of 0.01 in both areas area1 and area2.In open access market scenario the Gencos and the Discos have bilateral contract, the Disco Participation Matrix is given as in eq(18). Each disco demand has considered as 0.01 p.u MW power. The parameters values are given in Appendix-Aand the optimized gain are given in table 1. In table 1 the gain Ki1 represents the integral gain for area1 and Ki2 represents integral gain of area2. Kp1 & Ki11 represents the DFIG PI controllers in area1. Kp2 & Ki22 represents the DFIG PI controller in area 2

$$DPM=\begin{pmatrix} 0.3 & 0.4 & 0.5 \\ 0.3 & 0.5 & 0.2 \\ 0.4 & 0.1 & 0.3 \end{pmatrix} \quad (18)$$

Table-1:Optimized Controller Gain Using Algorithms

Controller gains	PSO optimized	DE optimized
K_{i1}	0.1091	0.2328
K_{i2}	0.1104	0.0870
K_{p1}	0.4171	1
K_{i11}	0.6616	1
K_{p2}	0.6902	0.9433
K_{i22}	0.8951	0.9978

Table-2:Performance Values Of Frequency And Tie Line

Parameters	PSO optimized			DE optimized		
	Peak overshoot	Under overshoot	Settling time (sec)	Peak overshoot	Under overshoot	Settling time (sec)
Δf_1	0.0217	-1.6498	60	0.0164	-1.687	50
Δf_2	0.0185	-1.5868	60	0.0112	-1.826	47
ΔP_{tie}	0.308	-0.132	80	0.3643	-0.019	90

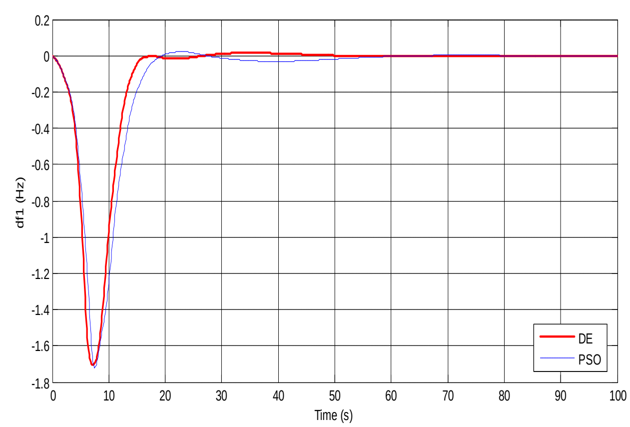

Fig-7:Frequency Deviation In Area 1

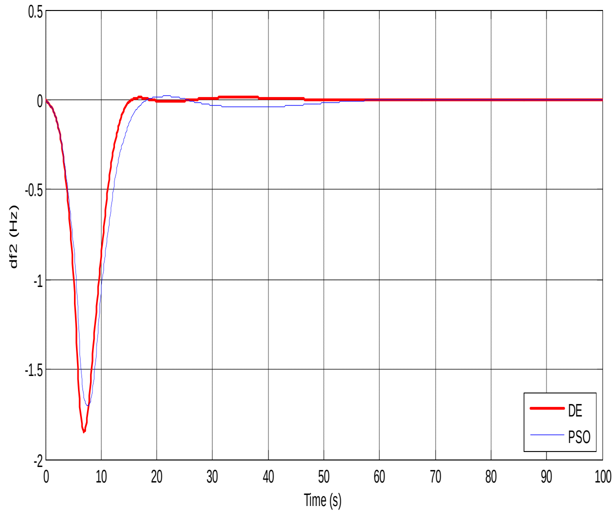

Fig-8:Frequency Deviation In Area2

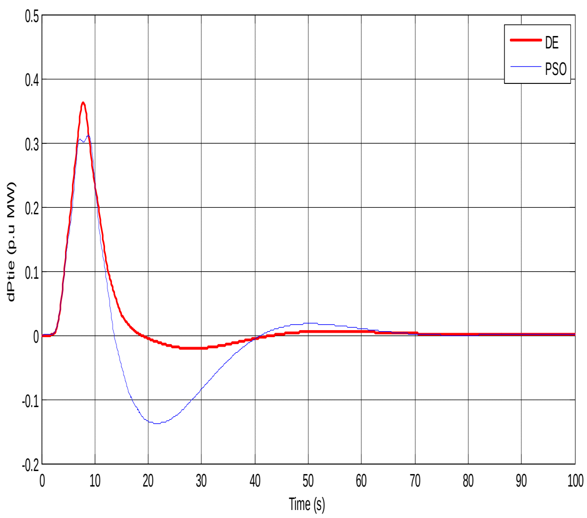

Fig-9:Change In Tie Line Power Interchange Between Area1 And Area2

7.CONCLUSION

In this paper, we have simulated an AGC for two area hydro thermal power system integrated with DFIG based wind turbine in both areas.In this system we have consider the generation rate constraint, governor dead band and time delay. Due to this the system performance is accurate. The objective function used to optimize the controller's gains is integral time absolute error (ITAE). The controllers gains are optimized by using the algorithm are particle swarm optimization and differential evolutionary algorithm. In comparison of the PSO and DE, the DE has less settling time than PSO.

APPENDIX- A

NAME	DESCRIPTION	VALUE
T_{g1},T_{g2}	Governor time constant	0.08sec
T_{t1},T_{t2}	Turbine time constant	0.3sec
T_{r1},T_{r2}	Reheater time constant	10sec
K_{r1},K_{r2}	Reheat gain	0.5
K_{p1},K_{p2}	Power system gain	60
T_{p1},T_{p2}	Power system time constant	20sec
K_d, K_p, K_i	Electric governor gains	3.9, 3.9, 4.6
R_{11},R_{12},R_2	Regulation drop	2.4
T_w	Water starting time	1sec
B_1,B_2	Frequency bias constant	0.4249
T	Synchronizing constant	0.0866 p.u. MW/Hz
H_1,H_2	Equivalent wind turbine inertia	3.5 p.u. MW sec
T_{a1},T_{a2}	DFIG turbine time constant	0.2 sec
T_{W1},T_{w2}	Washout filter time constant	6 sec
T_{r1},T_{r2}	Transducer time constant for DFIG	0.1sec
P_{r1},P_{r2}	Rated power	2000MW
a_{12}	$-P_{r1}/P_{r2}$	-1
F	Nominal frequency	60HZ

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