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Grey Wolf Optimizer Based PI-PD Cascade Controller for Automatic Generation Control of Integrated Wind-Thermal Power System

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Abstract—*Higher penetration of wind power in power system introduces many challenges in load frequency control due to uncertainties in wind speed and lack of inertia support to the system from wind turbine (WT). However these adverse effects can be minimized by using pitch angle control for variable wind speed and secondary inertia control for inertia support. This paper addresses the effective application of Grey Wolf Optimizer (GWO) technique to optimize the controller gain in automatic generation control (AGC) of three interconnected unequal areas with reheat thermal system and doubly fed induction generator (DFIG) wind turbine.*

1. INTRODUCTION

Automatic generation control plays an important role in power system to balance generation-load demand. System frequency can be used as measurement tool to measure balance between generation and load demand. Hence AGC is responsible for interchanging power through tie-lines and frequency control for individual area by adjusting the power output of generating units. Primary control re-balances the generation and demand within system area at a frequency different from rated frequency, where this primarily depends upon the governor droop characteristics; whereas Secondary control alters the operating points of individual generators and restores the system frequency at rated value. Gain tuning of controller comes under secondary control [2].

The configuration of modern integrated power system becomes more complex due to integration of renewable energy sources. Among these renewable energy sources wind power is one of the most prominent technologies. The integration of wind turbine generator (WTG) creates more vulnerable disturbances in grid frequency. In case of DFIGs, the turbine inertia is effectively decoupled from grid because of power electronics converters. With the reduction of system inertia, rate of change of grid frequency increases [12]. Due to large penetration of wind power in power system, participation of DFIG based wind turbine in load frequency control along with conventional generators is desirable [9]. Many control techniques have been developed till which allows WTG to participate in AGC i.e. pitch angle control, rotor speed control, inertia loop control and droop control [7-13]. For above or below base speed pitch angle control provides power regulation or limits the power output of WT.

The main objective of present work is to use Grey wolf optimization algorithm for parameter estimation of PI-PD cascade controller in three areas ten reheat steam turbine generators system, gain parameter of speed controller and pitch angle controller in WTG system in three controlled unequal areas. The cascade controller improves the performance of a control system in the presence of a disturbance because inner loop reduces the sensitivity and nonlinearity of plant in closed loop, therefore outer loop experiences less parameter perturbations. Different cases which are examined till date have been considered in my work which includes nonlinearities in thermal units i.e. GRC, different step load changes and different wind power penetration in system.

2. SYSTEM INVESTIGATED

System which was investigated mainly consists of three unequal generating areas comprising single reheat thermal systems with 3% /min GRC and a DFIG based wind turbine.

Area1: 2000 MW capacity, three single reheat turbines and a DFIG based WT.

Area2: 4000 MW capacity, four single reheat turbines and a DFIG based WT.

Area3: 8000 MW capacity, three single reheat turbines and a DFIG based WT.

The basic block diagram of i^{th} area is shown in Figure 1 and the relevant parameters are given in Appendix 1 [2].

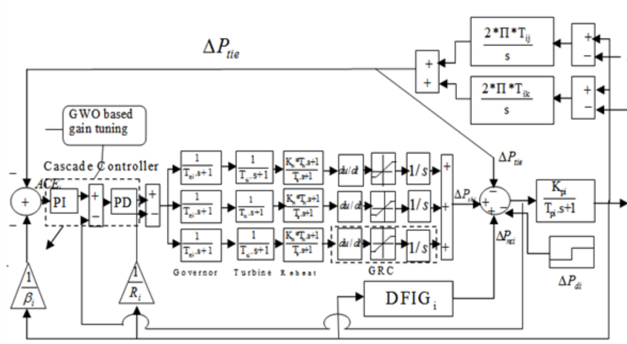


Figure 1: Basic block diagram of i[th] area

2.1. DFIG Based WT

The block diagram of DFIG based WT [11] is shown in Figure 2. Inertia control, droop control, pitch angle control are provided to WT. The purpose of secondary inertia loop as shown in figure is to provide inertia support to WT. Literally, rate of change of frequency depends on system inertia ΔP_f is used provide inertia support to WT which is directly proportional to dΔf/dt [12]. Droop control of WT is similar as in conventional generators. Pitch angle control maintain the output power at desired value for variable wind speed.

According to aerodynamics rule, the wind power output can be calculated as:

$$P_m = \frac{1}{2} C_p(\lambda, \theta) \rho A v_w^3 \quad (1)$$

where,

$\lambda = \frac{\omega_t r}{v_w}$ = tip speed ratio,

$$C_p(\lambda,\theta) = 0.5176\left(\frac{116}{\lambda_i} - 0.4\theta - 5\right)e^{-\frac{21}{\lambda_i}} + 0.0068\lambda$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\theta} - \frac{0.035}{\theta^3 + 1}$$

ω_t is rotor speed, r is rotor radius, v_w is wind speed and θ is pitch angle.

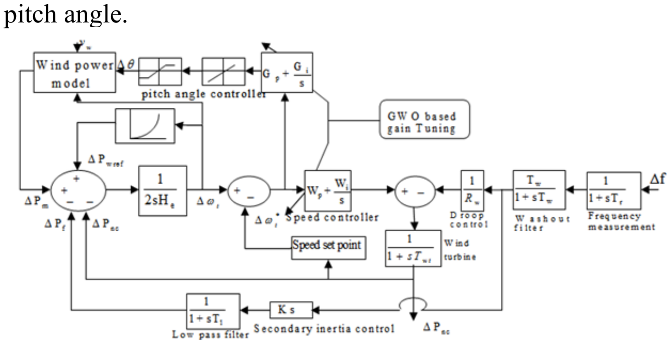


Figure 2: DFIG based WT

3. GAIN TUNING OF CONTROLLER

A recent meta-heuristic optimization technique, known as GREY WOLF OPTIMIZER, developed by Seyedali Mirjalili and Andrew Lewies [4] is used to optimize controllers gain. The objective function, to be minimized is integral of time multiplied squared error (ITSE). The objective function for present work can be defined as follows

$$J = \int_0^{t_{sim}} \left(\sum_i |\Delta f_i| + \sum_i |\Delta P_{tie,i-k}| + \sum_i |e_i| \right)^2 .tdt \quad (2)$$

where,

Δf_i is frequency deviation in i[th] area, $\Delta P_{tie,i-k}$ is incremental change in tie line power between areas i and k, e_i is deviation in wind turbine speed.

2.2 Grey Wolf Optimizer

Grey wolf optimizer (GWO) is a population based meta-heuristic technique inspired by grey wolves. Mathematical model can be designed by using social hierarchy of wolves. In the entire population, the fittest solution is considered as alpha (α) which is leader and decision maker. The second and third fittest solution are consider as beta (β) & delta (δ) and rest are assumed to be omega (ω). Beta and delta assist alpha in decision making and omega follows alpha, beta and delta.

The GWO technique can be defined by following equations:

$$\vec{X}(t+1) = \vec{X}_p(t) - \vec{A}.\vec{D} \quad (3)$$

$$\vec{D} = |\vec{C}.\vec{X}_p(t) - \vec{X}(t)| \quad (4)$$

where,

t = iteration number,

$\vec{X}_p(t)$ = Position vector of prey,

$\vec{X}(t)$ = Position vector of grey wolf,

$\vec{A} = 2.\vec{a}.r_1 - \vec{a}$,

$\vec{C} = 2.r_2$,

$\vec{a}$ =2-2(iteration no./maximum iteration),

r_1 & r_2 = random number between 0 and 1.

Because of no idea about location of prey (minima point) in abstract search space, it is assume that α, β and δ know better location of prey. So the positions of ω updated according to positions of α, β and δ.

$$\vec{D}_\alpha = |\vec{C}_1.\vec{X}_\alpha(t) - \vec{X}(t)| \quad (5)$$

$$\vec{D}_\beta = |\vec{C}_2.\vec{X}_\beta(t) - \vec{X}(t)| \quad (6)$$

$$\vec{D}_\delta = |\vec{C}_3.\vec{X}_\delta(t) - \vec{X}(t)| \quad (7)$$

$$\vec{X}_1(t) = \vec{X}_\alpha(t) - \vec{A}_1.\vec{D}_\alpha \quad (8)$$

$$\vec{X}_2(t) = \vec{X}_\beta(t) - \vec{A}_2.\vec{D}_\beta \quad (9)$$

$$\vec{X}_3(t) = \vec{X}_\delta(t) - \vec{A}_3.\vec{D}_\delta \quad (10)$$

$$\vec{X}(t+1) = \frac{\vec{X}_1(t) + \vec{X}_2(t) + \vec{X}_3(t)}{3} \quad (11)$$

Each solution candidate positions updated using eq. (11) and in the end alpha is considered as optimum solution.

The pseudo code of GWO is given as follows:

Initialize the population X_i (i=1, 2, 3……….NP);

Initialize parameters a, A and C;

Calculate fitness of each solution candidate;

X_α=solution candidate of best fitness;

X_β=solution candidate of second best fitness;

X_δ=solution candidate of third best fitness;

While t < maximum iteration

For i = 1: NP

Update position of solution candidate using eq. (11)

End for

Update value of a, A and C;

Evaluate fitness of each solution candidate;

Update X_α, X_β and X_δ;

t = t+1;

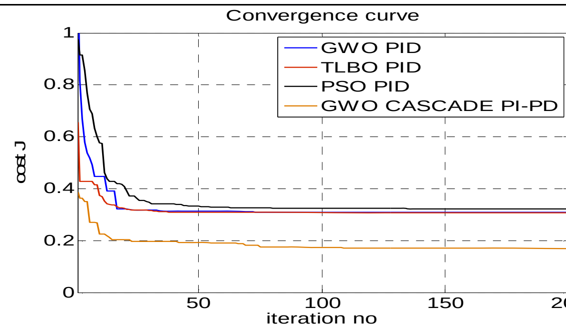
End while

x_α = optimal solution

4. SIMULATION RESULTS

4.1 Comparison of GWO, TLBO and PSO

To validate the controlling of proposed control scheme, Simulations exercise is performed in the Sim-Power environment of MATLAB software. In the simulation, the performance of the system using the designed GWO optimized controllers are compared with TLBO and PSO optimized PID controllers. The comparison is shown in Table 1.



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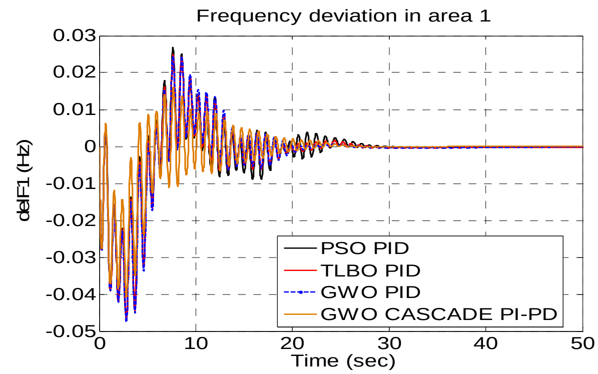

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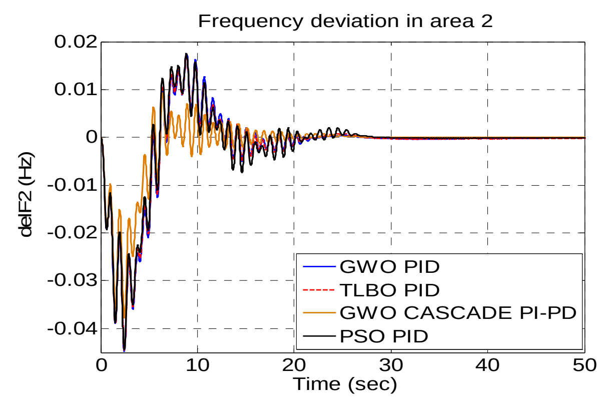

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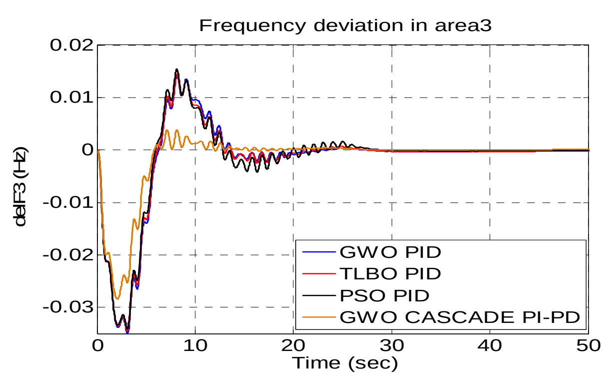

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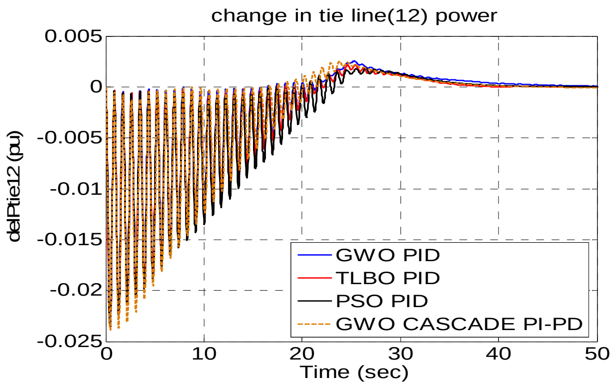

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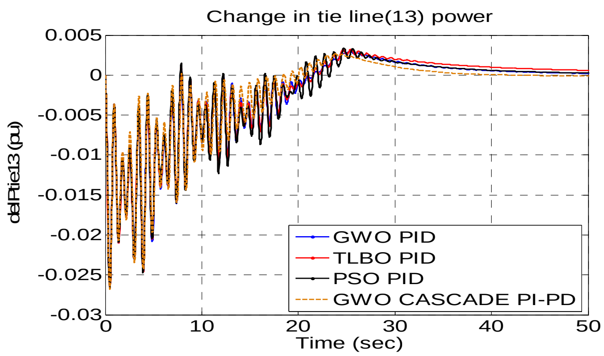

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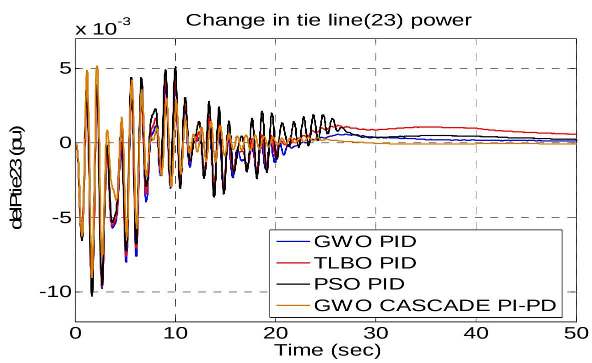
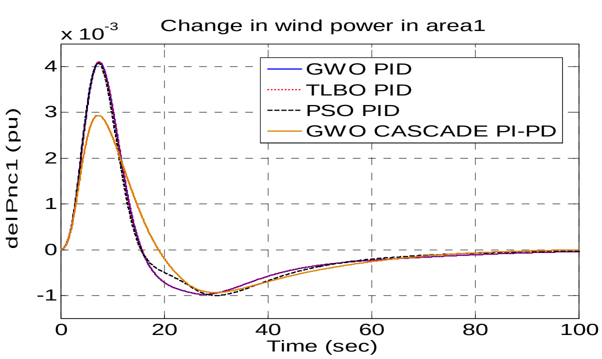


(g)



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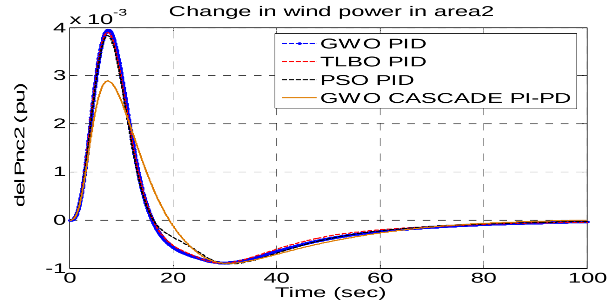
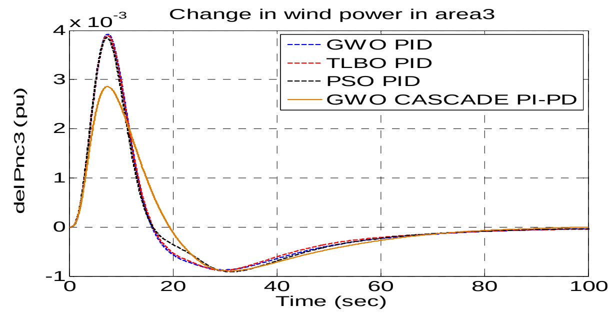


(i)



(j)

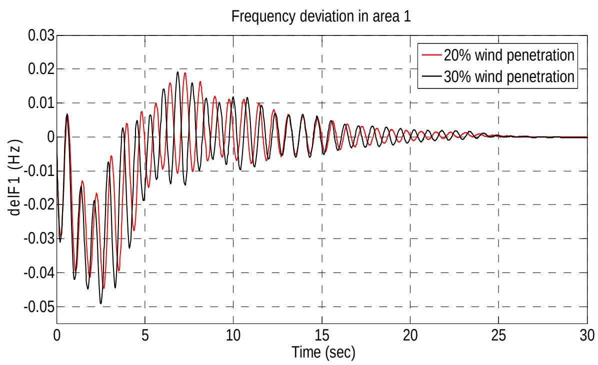
Figure 3. Dyanamic response of system with 3% SLP in area1

Table 1. Comparison of Different Techniques

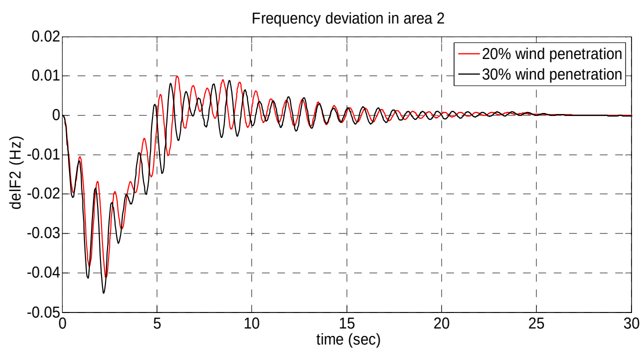
	PSO-PID		**TLBO-PID**		**GWO-PID**		**GWO- PI-PD Cascade**	
ITSE	**0.3231**		**0.3060**		**0.3094**		**0.1697**	
Parameters	ST(sec)	OS/US	ST(sec)	OS/US	ST(sec)	OS/US	ST(sec)	OS/US
delF1	29.80	-0.04697	27.77	-0.04719	26.58	-0.04736	25.83	-0.04079
delF2	27.05	-0.04442	22.72	-0.04448	21.90	-0.04478	25.20	-0.03799
delF3	28.86	-0.03414	26.83	-0.3450	26.30	-0.03495	24.37	-0.02841
delPtie12	44.50	-0.2354	44.15	-0.02352	45.07	-0.02244	39.85	-0.02387
delPtie13	59.80	-0.02672	62.05	-0.02666	58.77	-0.02667	36.16	-0.02682
delPtie23	98.30	-0.0102	109.9	-0.0102	82.54	-0.0103	26.07	-0.00923
delPnc1	131.2	0.004072	127.3	0.004104	129.4	0.004104	94.85	0.002935
delPnc2	101.8	0.003892	101.4	0.0039	101.4	0.003951	95.06	0.00289
delPnc3	100.96	0.003887	100.87	0.00389	100.80	0.00325	94.75	0.00276

Here, the wind speed in three areas is assumed at a constant value of 10 m/s. Figure 3(a)-3(j) shows the convergence curve of GWO, TLBO and PSO, deviation in frequency, tie-line, and wind power. As shown in Fig.3 PI-PD cascade controller gives effective results over PID controller, so for further analysis we use GWO tuned PI-PD cascade controller.

4.1 Performance of System with different Wind Penetration



(a)



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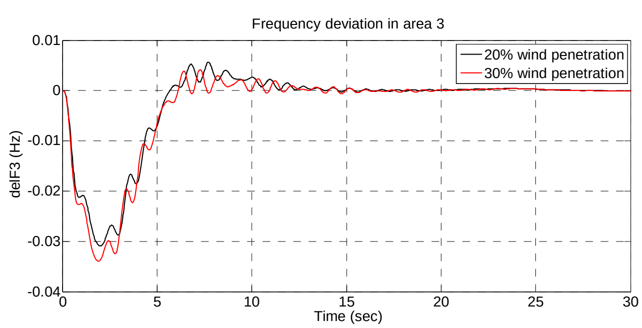

(c)

Figure 4. System response for 3% SLPin area1 with differenet wind penetration

The response of system with different wind penetration and 0.03% SLP in area1 is shown in Figure 4(a)-4(C). System response of x% increase in wind penetration can be evaluated by increasing permanent droop by x% and decreasing system inertia by x%, with all other conditions remaining constant.

4.2 Effectiveness of Pitch Angle Control for Wind Speed above Base Speed

In this case the value of wind speed in all three areas is considered as 14 m/s. The frequency deviation for a 3% SLP in area1 is shown in Figure 5.

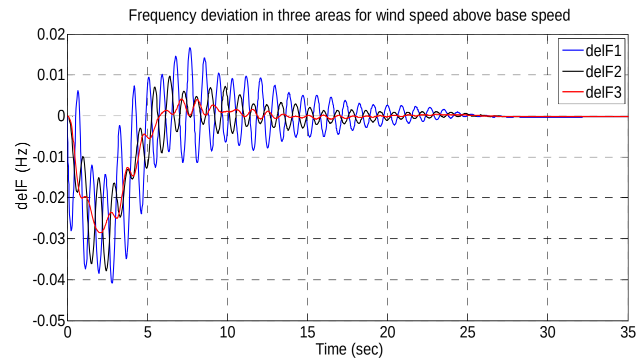

Figure 5. System response for 3% SLP in area1 and wind speed 14 m/s

4.3 System Response for Variable SLP

Load variation and system response is shown in Figure 6.

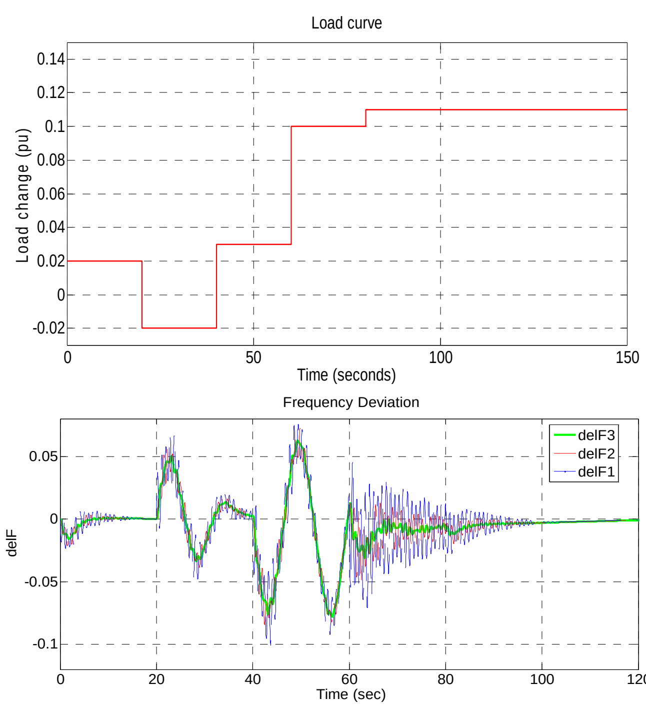

Figure 6: System response for different load disturbances

5. CONCLUSION

In this work the system with 3% GRC in thermal generation, different wind speed and various SLP have investigated. The GWO optimized PID controller has given best result among GWO, TLBO and PSO. However GWO and TLBO have given approximately same result but by simulation, GWO technique is 3-4 times faster than TLBO. PI-PD cascade controller give better results than PID controller, it gives less peak values and settling time. From our study it has also been found that as wind penetration in system increase, the frequency deviation and settling time increases for same load disturbance.

REFERENCES

[1] J. Nanda, A. Mangla, and S. Suri, "Some New Findings on Automatic Generation Control of an Interconnected Hydrothermal System with Conventional Controllers," *IEEE Trans. on Energy Conversion*, 21, 1, March 2006, pp. 187-194.

[2] J. Nanda, S. Mishra, and L. C. Saikia, "Maiden Application of Bacterial Foraging-Based Optimization Technique in Multi-Area Automatic Generation Control," *IEEE Transactions on Power Systems*, 24, 2, May 2009, pp. 602-609.

[3] P. Dash, L. C. Saikia, and N. Sinha, "Automatic Generation Control of Multi Area Thermal System using Bat Algorithm Optimized Pd–Pid Cascade Controller," *Electrical Power and Energy Systems*, 68, 2015, pp.364–372.

[4] S. Mirjalili, S. M. Mirjalili, A. Lewis, "Grey Wolf Optimizer," *Advances in Engineering Software* , 69, 2014 pp. 46-61.

[5] G. Ramtharan, J.B. Ekanayake and N. Jenkins, "Frequency Support from Doubly Fed Induction Generator Wind Turbines," IET *Renew. Power Gener*., 1, 1,2007, pp. 3–9.

[6] N. W. Miller, J. J. S. Gasca, W. W. Price, and R. W. Delmerico, "Dynamic Modeling of GE 1.5 and 3.6 MW Wind Turbine-Generators for Stability Simulations," in *Proceedings of the IEEE Power Engineering Society General Meeting*, Toronto, Canada, 2003, pp. 1977_83.

[7] Y. P. Verma, and A. Kumar, "Participation of Doubly Fed Induction Generator Based Wind Turbine in Frequency Regulation with Frequency Linked Pricing," *Electric. Power Components Syst*., 40, Oct. 2012, pp. 1586_604.

[8] L. Chang-Chien,C. Sun, and Y. Yeh, "Modeling of Wind Farm Participation in AGC", *IEEE Transactions On Power Systems*,29, 3, May 2014, pp. 1204-1211.

[9] G. Lalor, A. Mullane, and M. O'Malley, "Frequency Control and Wind Turbine Technologies," *IEEE Transactions On Power Systems*, vol. 20, no. 4, Nov 2005, pp. 1905-1913.

[10] P. Dahiya, V. Sharma, and R. N. Sharma, "Optimal Generation Control of Interconnected Power System Including DFIG-Based Wind Turbine," *IETE Journal of Research,* 2015.

[11] L. Shang, J. Hu, X. Yuan and Y. Chi, "Understanding Inertial Response of Variable-Speed Wind Turbines by Defined Internal Potential Vector," *Energies, 2017*, 10, 22.

[12] R. Yan, and T. K. Saha, "Frequency Response Estimation Method for High Wind Penetration Considering Wind Turbine Frequency Support Functions," *IET Renew. Power Gener.*, 2015, vol. 9, Iss. 7, pp. 775–782.

[14] Ibraheem, K. R. Niazi and G. Sharma, "Study on Dynamic Participation of Wind Turbines in Automatic Generation Control of Power Systems," *Electric Power Components and Systems*, pp. 43:44–55, 2015.

Appendix I

Parameter	Description	Value
f	System frequency	60 Hz
T_{gi}	Steam governor time constant	0.08 sec
T_{ri}	Steam turbine reheat time constant	10.0 sec
K_{ri}	Steam turbine reheat constant	0.5
H_i	Inertia constant of area i	5 sec
T_{ti}	Steam turbine time constant	0.3 sec
D_i	$\Delta P_{Di}/\Delta f_i$	0.00833puMW/Hz
		120 Hz/puMW
K_{pi}	$1/ D_i$	20 sec
		0.544
T_{pi}	$2H_i/fD_i$	2.4 Hz/puMW
T_{ij}	Synchronizing coefficient	3.5 sec
R_i	Governor speed regulation parameter	0.2 sec 0.425
H_e	Equivalent wind turbine inertia	1.225 kg/m^3
T_{wt}	Wind turbine time constant	0.2 sec
B_i	D_i+1/R_i	3
□	Air density	
T_l	Low pass filter time constant	
R_w	Regulation droop	