International Journal of Advanced Computer Research (ISSN (print): 2249-7277 ISSN (online): 2277-7970)
Volume-4 Number-1 Issue-14 March-2014

Frequency Response Enhancement of Hybrid Power System by using PI Controller Tuned with PSO technique

Naresh Kumari[1], A. N. Jha[2]

Abstract

Hybrid power systems have been designed to consist of wind and diesel power plants, as these types of power systems can reduce the harmful effects of conventional diesel-only power plants. Wind power is more commonly used in this set up and preserves the generating margin of doubly fed induction generators (DFIG) under varying wind speeds and changing load conditions, which plays a significant role in the frequency response enhancement in this work. The generation load balance has been maintained using the PI controller optimized by the Particle Swarm Optimization (PSO) technique for diesel power plants as well as the preserved generating margin of the DFIG. The simulation results in MATLAB/SIMULINK show that the proposed scheme of enhancing the frequency response reduces the power demand on diesel power plants by using the preserved generating margin of wind power plants to maintain the generation load balance.

Keywords

Wind Diesel hybrid power plant, doubly fed induction generator, Frequency response, PI controller, Particle Swarm Optimization.

1. Introduction

Hybrid power systems with renewable energy sources are most widely used to reduce the pollution from conventional electric power sources. Because the sources of hybrid power plants have small ratings maximum up to 10 MW, these systems are mostly connected at the distribution voltage level [1]. In this work, a conventional non-renewable energy source, such as a diesel power plant, and a renewable energy source, such as a wind energy conversion system(WECS), have been integrated to form a hybrid power system. Hybrid power systems have become one of the most promising ways to supply power to remote areas that otherwise depend on conventional diesel generators [2]. The diesel gen set operation in a CERTS system is discussed in [3] where the proper interaction of gen sets with inverter based sources in microgrid has been proposed using a controller which enhances the power quality.

Different microgrids with diesel power operations are investigated in [4]-[6] where the microgrid operation in island and connected to main grid mode are demonstrated with different software simulations along with fault analysis. These studies have not used the computational intelligent technique such as PSO for fast and accurate frequency response enhancement along with generating margin of WECS. Wind energy is one of the most prominent sources of renewable energy that can be used in areas with an abundance of wind power. Generally, most wind power plants operate at maximum power production to pursue the maximum economic benefit. This type of operation at maximum power production does not help to preserve the generating margin that responds to frequency. Because wind power is a variable source of energy, the control of a wind turbine to generate the necessary active power output for frequency enhancement is a very challenging task. Many inertial and speed-droop controls of wind turbines for frequency response have been proposed [7]-[11]. The developed frequency control scheme is based on maintaining the generation load balance using a PI controller tuned with the particle swarm optimization technique for a diesel power plant along with a preserved generating margin of a wind power plant. Although the scheme does not make use of maximum wind power production, it still proves to be economical because energy storage systems with high installation costs are not required [12]. In this paper, the strategy for DFIG to provide frequency regulation was discussed, and the hybrid system frequency enhancement was designed assuming a medium wind speed.

Manuscript received February 23, 2014.
Naresh Kumari, Department of Electrical, Electronics and Communication Engineering, ITM University, Gurgaon, Haryana, India.
A.N. Jha, Department of Electrical, Electronics and Communication Engineering, ITM University, Gurgaon, Haryana, India.

2. Modelling of Hybrid Power System with Wind & Diesel Power Plants

The proposed self-sufficient remote microgrid consists of a small- rating wind power plant (310 KW) and a diesel generator (40 KW), as shown in Fig. 1. The net power available to the load is the sum of the powers from the renewable and controllable sources. A remote microgrid is not connected to the utility and operates mostly with decentralized control methods. The maximum power use is limited to local customers only.

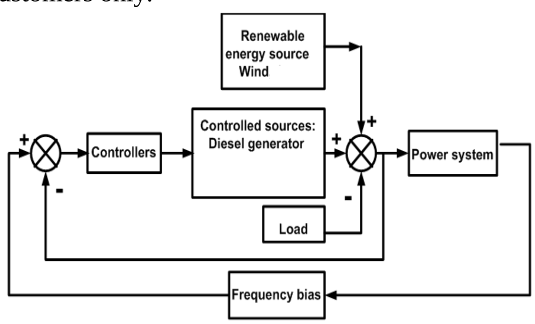

Figure. 1: Block diagram of the microgrid with diesel generator and wind power system

The transfer functions of the governor and turbine of the diesel generators are given by first-order transfer functions as follows:

$$Gdg(s) = Kdg / (1+sTdg) \quad (1)$$

$$Gdt(s) = Kdt / (1+sTdt) \quad (2)$$

where Tdg and Tdt are the time constants of governor controller and turbine of the diesel generator, respectively. The Kdg and Kdt are the gains of governor and turbine of the diesel generator. The parameters of the diesel generator and WECS are given in Table 1.When the power demand on any source increases/decreases, it cannot respond instantaneously, and the power output follows a ramp rate. This ramp rate limit is called the Generation Rate Constraint (GRC), which was, taken into consideration for the diesel generator [13]. The suitable Generation Rate Constraint that is taken into account for a diesel power plant is generally found to be 3%/min. The modified GRC was considered to obtain the same value of the input signal and output collected from the GRC of the microgrid, as shown in Fig. 2.

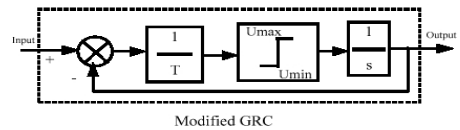

Figure. 2: Block diagram of modified GRC

The proper selection of the governor droop or governor speed regulation parameter (R in Hz/p.u. MW) is also very important for to obtain the zero steady state error in frequency. Thus Ri is also optimized with the PSO technique along with the Kp and Ki of the PI controller for the diesel power plant.
The different participating units to regulate service should reserve a certain amount of generating margin for governor actions; a similar idea has been applied to the wind power plant. Fig. 3 illustrates the frequency response control scheme for WECS [14]. The wind power plant is designed for medium wind speed condition [15]. The generating margin of the wind power plant for a given speed is calculated as follows:

$$Preserve = Pwtmax - Pgrid \quad (3)$$

The maximum power output of the doubly fed induction generator is given by the following:

$$Pwtmax = 0.5\, Cp(\lambda,\beta)\, \rho A Vw3 \quad (4)$$

Where Vw is the wind speed, ρ is the air density,
A is the cross section of the rotor for the DFIG,
Cp is the power coefficient, B is the pitch angle and
λ is the tip speed ratio.
The power coefficient, Cp(λ,β), of a wind turbine can be expressed as follows:

$$Cp(\lambda,\beta) = \sum \propto \beta^{i} \lambda^{j} \quad (5)$$

The equivalent speed droop, 1/Rwt,depends on the set frequency band, ΔFBD :

$$1/Rwt = P\,(reserve) \times 1/(\Delta FBD) \quad (6)$$

The speed droop yields the power adjustment, ΔP, according to the frequency deviation, ΔF, as given below:

$$\Delta P = -\Delta F \times 1/Rwt \quad (7)$$

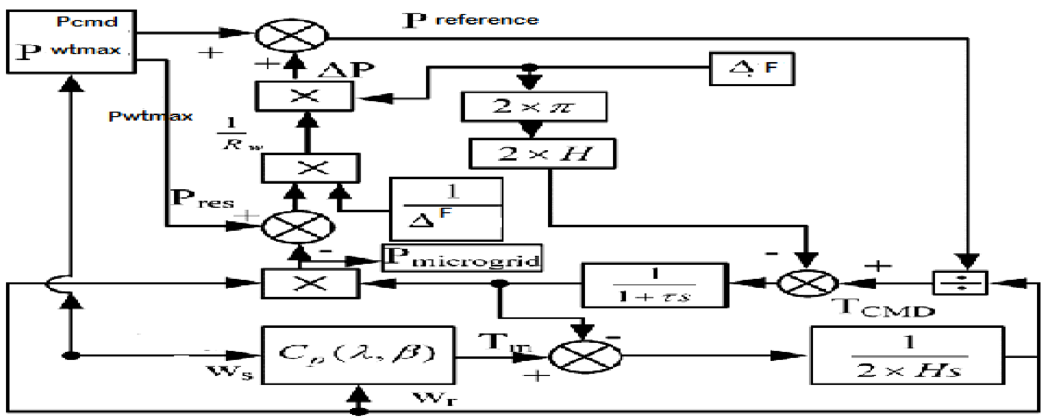

Figure. 3: Block diagram of Wind Energy Conversion system

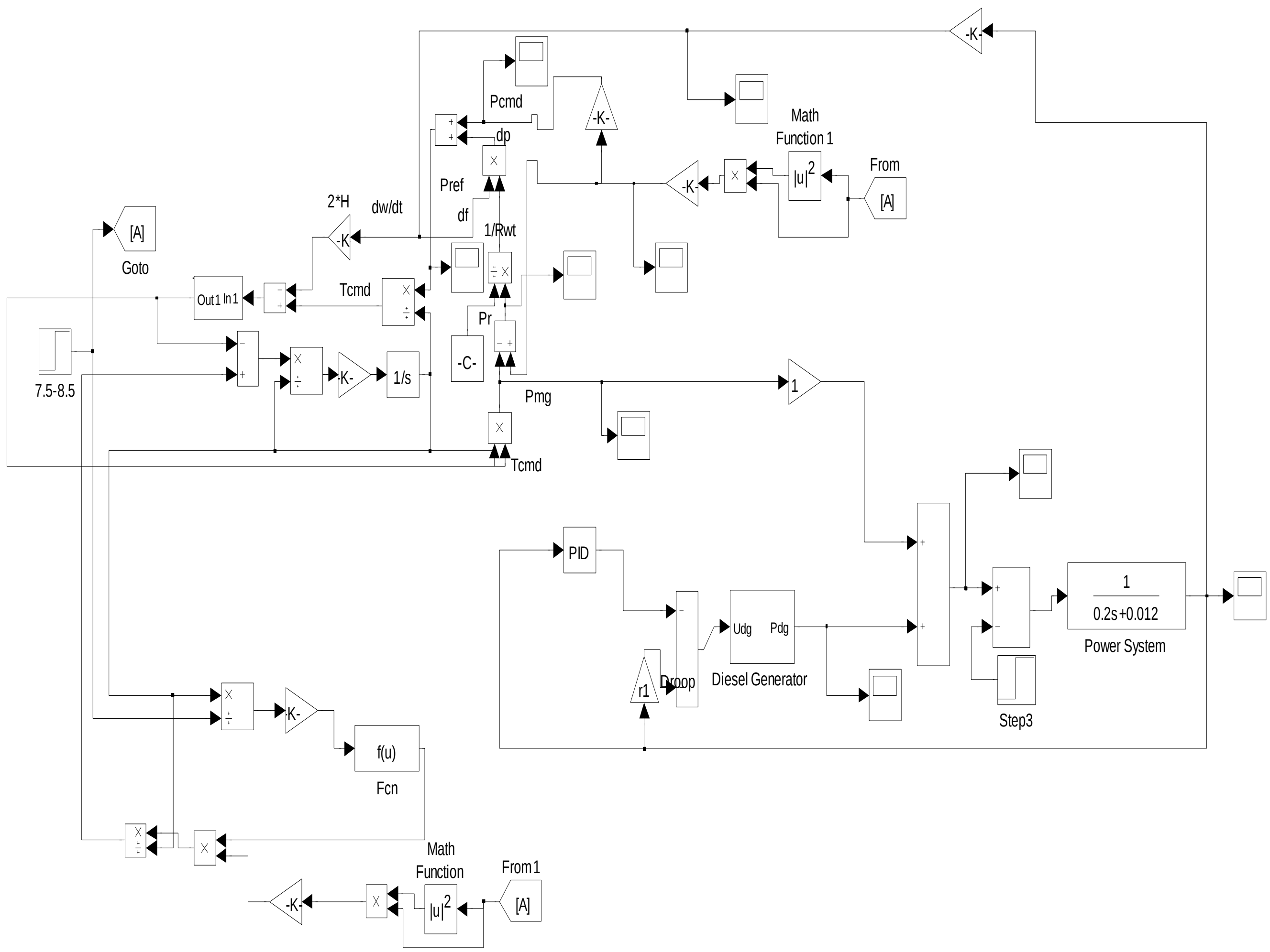

Figure. 4: Transfer Function Model of Hybrid Power System with WECS and Diesel Power Plant in MATLAB/SIMULINK

The reference power, Pref, given in equation (8) is reduced to the torque reference, which is added to the inertial response to give the torque command, T_{CMD} for the rotor of DFIG.

$$Pref = Pcmd + \Delta P \qquad (8)$$

The hybrid system designed in MATLAB/SIMULINK is shown in Fig. 4. This model has been designed by using the different equations from 1 to 8 as stated above. The diesel power plant model has been developed using equation 1 and 2.The WECS is designed with equations 3 to 8 considering the medium wind speed range 7.5 to 8.5 m/s.

3. Swarm Optimization (PSO) - PI based frequency response control

PSO is a population-based optimization method that was first proposed by Eberhart. Some of the attractive features of PSO include the ease of implementation and the fact that gradient information is not required. It can be used to solve a wide array of different optimization problems. Particle swarm optimization (PSO) is a stochastic optimization technique based on a collection of populations (swarm) and inspired by the social behavior of the movements of birds or fish to find food sources.

To find the optimal solution, each bird, or in this case each particle, sets the search direction based on two factors, namely the previous best experience (pbest) and the best experience of all the birds that exist in this population (gbest). The PSO model consists of a set of particles initialized with a population of candidate solutions at random [20]. Particles moving through space with a d- dimensional problem to seek new solutions with fitness f can be calculated as a determined measuring quality. Each particle has a position that is represented by the vector-position xi (i is the index of the particle) and speed (velocity) that is represented by the vector velocity vi. Each particle has thus far resulted in the best position (pbest) in vector xik, and the value of the j-th dimension is xijk. The best position of the vector among the compounds (swarm) thus far (gbest) is stored in a vector x1, and the value of the j-th dimension is xjl. During this time of iteration (t), the particles update the previous speed with the newly determined speed. The new position is determined by the sum of the previous position and the new velocity.

The PSO algorithm aims to find the extreme point of the performance index. If the performance index is not properly selected, the algorithm may be stopped in the local extreme points. The initialization of the algorithm parameters is very important because the algorithm may never converge to the extreme point if these parameters are not carefully selected [21]. The important parameters of the PSO algorithm are the number of particles, particle dimension, particle velocity interval (V_{max}, V_{min}), C1, C2, the particle place interval (X_{max}, X_{min}) and W (inertia weight). The PSO algorithm can be summarized in the following ten steps:

1. The algorithm parameters, such as the particle dimension, particle velocity interval (V_{max}, V_{min}), particle place interval (X_{max}, X_{min}), C1, C2 and W (inertia weight), are selected.
2. The particles (x_i (t), V_i (t)) are arbitrarily initialized.
3. The p_{best} vectors for all of the particles, such as K_p, K_i and R_i in the present work, are initialized using the random initial values obtained in Step 2 for the position vectors. The initial values of xi(t) are chosen as zero and the population size is 100.

```
K_min=[1 1 1 ]*0;
K_max=[1 1 1 ]*6;

pop=100 ;

itermax=100;

vmax(n)= 0.1*(K_max(n)-K_min(n));
vmin(n)=-0.1*(K_max(n)-K_min(n));
```

4. The system parameters, such as K_p, K_i and R_i in the present study, are updated using the particle position vector x_i (t) and the cost function.
5. The gbest value is determined using the objective values of the particles.
6. The particle velocity vectors, V_i and positioning vectors, x_i, are updated according to (4) and (5).
7. The parameters of the system are updated by the position vector of each particle, and the objective value is calculated for each particle.
8. The pbest value is updated for each particle (K_p, K_i and R_i) as shown below :

```
for n=1:pop
  if(eval_fit(n)<fit_best(n))
    fit_best(n)=eval_fit(n);
    pbest(n,:)=population(n,:);
  end
```

9. The value of g_{best} is updated.

```
[A B]=min(fit_best);
gbest=pbest(B,:);
```

If the objective value of $g_{best}(t+1)$ is better than the objective value of $g_{best}(t)$, then
$g_{best} = g_{best}(t+1)$

10. When the stop condition i.e. ISE in the hybrid power system becomes zero , the PSO algorithm will stop and the optimal parameter values of Kp and Ki of the PI controller and frequency regulation parameter (Ri) are reached. Otherwise, the algorithm returns to step 6.

4. Simulation Results and Analysis

The proper regulation of the d-axis rotor current, idr, of the DFIG can help to achieve active power control in wind power plants. This property is mainly due the fact that idr affects the electromagnetic torque, which in turn changes the turbine torque. The regulated electromagnetic torque and thus, the controlled rotor speed can give the variable active power output of a DFIG [16]–[19]. Furthermore, pitch angle control is initiated when the output power of the wind turbine exceeds the rating of the machine. In the present work, the wind speed was assumed to generate a turbine output that is always less than its rated power, so pitch angle control is not required. Furthermore, the PCMD command is set as 90% of the total maximum power generated from the wind power plant. Hence, 10% of the maximum power generated by WECS is kept as a generating margin, which can be used to enhance the frequency during the load variation condition. The 350 KW hybrid power system was designed as shown in Fig. 4, with the wind power plant rated at 310 KW and the diesel power plant rated at 40 KW.

The simulation studies assumed that the load variation on the hybrid system is 1% and the total load on hybrid the system becomes 306 KW, as shown in Fig. 5. In this case, the power supplied by the WECS for medium wind speed is 276 KW and the diesel power plant supplies 30 KW of power, as shown in Fig. 6 and Fig. 7, respectively. The reserved power of the WECS is kept as a generating margin at the medium speed for frequency enhancement with a further load variation of 31 KW, as shown in Fig. 8. The variation in the frequency of the system in response to a 1% load change on the microgrid is shown in Fig. 9 The frequency variation lies within the off nominal frequency band of ±0.1 Hz.

For the diesel power plant, the frequency is enhanced by using the PI controller tuned with a powerful computationally intelligent PSO technique. The objective function (ISE) of the system shown in Fig. 4 is given to the PSO technique. The population size is 100 and the maximum number of iterations is limited to 100. The variables c1 and c2 both equal 2 and wmax=0.8 and wmin=0.3. The values of Kp and Ki for the PI controller and frequency regulation parameter (R in Hz/p.u. MW) of the diesel power plant, which are optimized with the PSO technique, are given in Table 2. The performance Index is the Integral Square Error (ISE) given by the following:

$$ISE = \int\{(\Delta f_i)^2 + (\Delta Ptie_{i-j})^2\}dt$$

The variation of the Performance Index for the wind diesel hybrid power plant is shown in Fig. 10 The Performance Index as integral square error gets reduced to zero in 17 seconds only, which shows the fast response of the system with load variation.

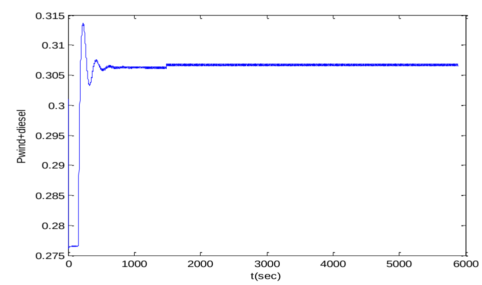

Figure. 5: Total power(MW) output of wind and diesel power plants of the hybrid power system for 1% load change in microgrid

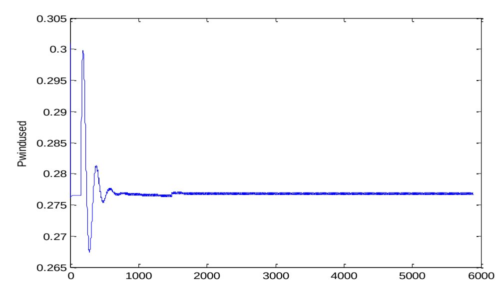

Figure. 6: Wind power used(MW) for 1% load change on hybrid power system

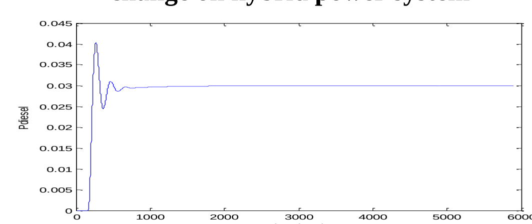

Figure. 7: Diesel power plant output power (MW) for 1% load change on the hybrid power system

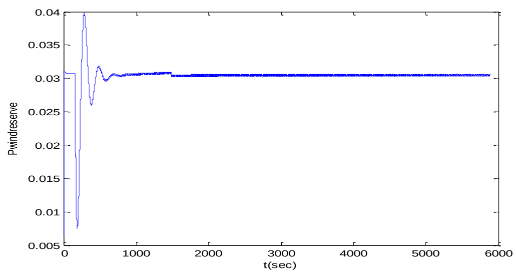

Figure. 8: Reserved wind power (MW) for frequency enhancement

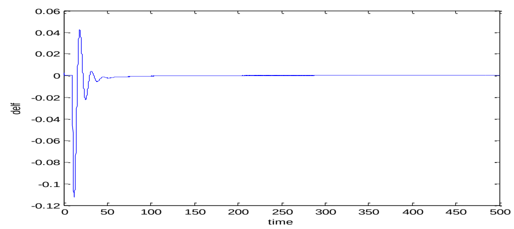

Figure. 9: Frequency response of wind – diesel hybrid power plant for 1% load change on the hybrid power system

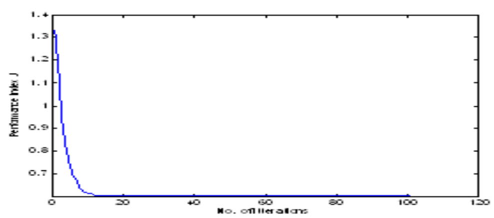

Figure. 10: Performance Index for wind diesel hybrid power plan

5. Conclusion

Frequency regulation is very important for AC microgrids under load variation conditions and during the uncertainties of power production from renewable energy sources. In this paper, a hybrid power system in an isolated mode has been designed with a wind power energy conversion system and diesel power plant. A load frequency control strategy has been implemented for a hybrid microgrid with wind and diesel power plants. The wind turbine designed here is a variable wind speed turbine designed to operate in a medium wind speed range. The generating margin is preserved for a wind power plant in order to control the active power output from a wind turbine, which provides frequency control upon the load changes and during the different wind speed conditions. The PI controller tuned by powerful computational technique PSO has been used to enhance the frequency response for the diesel power plant. The simulation results using MATLAB/SIMULINK show that the PI controller used for the diesel power plant and generating margin of wind energy conversion system effectively controls the frequency change along with the load change and wind speed variation.

Appendix

Table 1: Nominal Parameters of Hybrid Power System Simulated

Density of air = 1.25 kg/m3 Gear ratio =70	T_{dg} = 2 s
Radius of turbine blade= 45 m	D = 0.012 MW/Hz
wind velocity= 7.5-8.5 m/s	T i (wind) = 3s
H=5 sec	Tpt(wind) =10 s
F= 50 Hz	GRC dg = 3%
$K_{dg} = K_{dt}$ = 1 s	T_{dt} = 20 s

Table 2: Optimized values of system variable using PSO technique

Interconnected Areas	**Optimum Parameters**	**Controller and System parameters optimized by PSO**
Diesel Power System	Kp1	2.0539
	Ki1	0.0655
	R1	0.4219

References

[1] S R Bull, "Renewable energy today and tomorrow", Proceedings of IEEE, volume 89, issue 8, pp 1216–1221, 1989.

[2] W B Lawrance, C V Nayar and S J Phillips, "Solar/Wind/Diesel Hybrid Energy Systems for Remote Areas", Proceedings of the 24th Intersociety Energy Conversion Engineering Conference, pp 2029-34,1989.

[3] S Krishnamurthy, T M Jahns and R H Lasseter, "The operation of diesel gensets in a CERTS microgrid", Proc. IEEE Power and Energy Soc. General Meeting—Conversion and Delivery of Elect. Energy in the 21st Century, pp. 1–8, 2008.

[4] N Jayawarna, X Wu, Y Zhang, N Jenkins and M. Barnes, "Stability of a microgrid", Proc. 3rd IET Int. Conf. Power Electron., Mach. and Drives pp 316-320,2006.

[5] A Elmitwally and M Rashed, "Flexible operation strategy for an isolated PV-diesel microgrid without energy storage", IEEE Trans. Energy Conversion,vol 26, pp 235–244,2011.

[6] M Zhixin, A Domijan and F Lingling, "Investigation of microgrids with both inverter interfaced and direct AC-connected distributed energy resources", IEEE Trans. Power Delivery 2, pp 1634–1642, 2011.

[7] A Mullane and M Malley, "The inertial response of induction-machine- based wind turbines", IEEE Trans. Power Syst.20, 1496–1503,2005.

[8] G Lalor, A Mullane and M. Malley, "Frequency control and wind turbine technologies", IEEE Trans. Power System . 20,pp 1905–1913,2005.

[9] O Anaya Lara, F M Hughes, N Jenkins and G Strbac, " Contribution of DFIG-based wind farms to power system short-term frequency regulation", Proc. Inst. Elect. Eng., Elect. Power Appl.153,pp 164–170,2006.

[10] R G de Almeida and J A Peças Lopes, "Participation of doubly fed induction wind generators in system frequency regulation", IEEE Trans. Power Syst. 22 , pp 944–950,2007.

[11] M Shahabi, M R Haghifam, M Mohamadian and S A Nabavi-Niaki, "Microgrid dynamic performance improvement using a doubly fed induction wind generator", IEEE Trans. Energy Convers. 24,pp 137–145,2009.

[12] R Kamel, A Chaouachi and K Nagasaka, "Detailed analysis of micro-grid stability during islanding mode under different load conditions", Electrical Engineering. 3, pp 508–516, 2011.

[13] G Mallesham, S Mishra and A N Jha, "Automatic Generation Control of Microgrid using Artificial Intelligence Techniques", Power and Energy Society General Meeting IEEE, pp 1-8,2012.

[14] S Mishra, G Mallesham and P C Sekhar, "Biogeography Based Optimal State Feedback Controller for Frequency Regulation of a Smart Microgrid, IEEE Transactions on Smart Grid. 4,2013.

[15] Le-Ren Chang-Chien, Wei-Ting Lin, Yao-Chin and Yin, "Enhancing Frequency Response Control by DFIGs in the High Wind Penetrated Power Systems", IEEE transactions on power systems, pp 710-718,2010.

[16] R G de Almeida, E D Castronuovo and J A Peças Lopes, "Optimum generation control in wind parks when carrying out system operator requests", IEEE Trans. Power Syst. 21,pp 718–725,2006.

[17] J L Rodriguez Amenedo, S Arnalte and J C Burgos, " Automatic generation control of a wind farm with variable speed wind turbines", IEEE Trans. Energy Convers. 17 , pp 279–284,2002.

[18] R Pena, J C Clare and G M Asher, "Doubly fed induction generator using back-to-back PWM converters and its applications to variable speed wind-energy generation", Proc. Inst. Elect. Power Appl. 143, pp 231–241, 1996.

[19] J Ekanayake, L Holdsworth and N Jenkins, "Control of DFIG wind turbines", Power Eng. J. 17 pp 28–32,2003.

[20] S Naik ,K Chandra Sekhar and K. Vaisakh, "Adaptive PSO based optimal fuzzy controller design for AGC equipped with SMES", Journal of Theoretical and Applied Information Technology, pp 8-17,2005.

[21] H Bevrani, F Habibi, P Babahajyani, M Watanabe and Y Mitani , "Intelligent Frequency Control in an AC Microgrid: Online PSO-Based Fuzzy Tuning Approach", IEEE Transactions on Smart Grid. 3 , pp 1-10,2012.

Naresh Kumari received her B.E. in Electrical Engineering with Honours in 1996 from C.R. State College of Engineering, Murthal, Haryana. She did her M. Tech. in Instrumentation and Control from Rajasthan University, Udaipur in 2005 .She is currently pursuing her PhD under the supervision of Prof. A.N .Jha from ITM University, Gurgaon, India. She is also working as Senior Assistant Professor in Department of Electrical, Electronics and Communication Engineering, ITM University, Gurgaon. She has 16 years of teaching and research experience. Her research interests include power system stability, renewable energy sources, intelligent control and wind energy conversion systems.

A.N. Jha is working as Senior Professor in Department of Electrical, Electronics and Communication Engineering, ITM University, Gurgaon, India. He was Professor of Electrical Engineering in IIT, Delhi, India before joining ITM University, Gurgaon, India. He received his B.Sc. in Electrical Engineering from Bihar University, India in 1965 and M.E. (Electrical Engineering) in 1967 from University of Calcutta, India. He received his Ph.D. in Control System Engineering (Electrical) in 1977 from IIT Delhi, India. He has more than 40 years of teaching and research experience and has published/presented more than 120 papers in international and national journals/conferences. He has guided 70 M. Tech. and 7 Ph.D. students in their thesis /projects.