International Journal of Smart Electrical Engineering, Vol.4, No.4,Fall 2015
pp.185:190
ISSN: 2251-9246
EISSN: 2345-6221

Frequency Control of Isolated Hybrid Power Network Using Genetic Algorithm and Particle Swarm Optimization

Mahdie Hasanpour Qadikolai[1], Sina Mohammadi[2]

[1] Baran Niroo Beshel Corporation, Savadkooh, Iran,Email: Mahdiekd2@yahoo.com
[2] Baran Niroo Beshel Corporation, Savadkooh, Iran,Email: Amard.mathworks@gmail.com

Abstract

This paper, presents a suitable control system to manage energy in distributed power generation system with a Battery Energy Storage Station and fuel cell. First, proper Dynamic Shape Modeling is prepared. Second, control system is proposed which is based on Classic Controller. This model is educated with Genetic Algorithm and particle swarm optimization. The proposed strategy is compared with Classic Controller. The robustness of suggested strategy in the front of nature of wind energy and Environmental conditions led to Parameter changes and load changes. It was investigated and simulated in MATLAB and the result was observed. As a result of simulation, control system has reflected a better behavior rather than load changes. The proposed methods are applied on various situations with actual climate data.

Keywords: Classic Controller (PID); Genetic Algorithm (GA); Particle Swarm Optimization (PSO); Control system;

© 2015 IAUCTB-IJSEE Science. All rights reserved

1. Introduction

Environmental impact, lack of energy and concerns about the overconsumption of fossil fuels resulted in the application of different types of energy sources. Nowadays electrical energy is most common type of energy but this kind of energy is produced through the process of burning fossil fuels which confronts many limitations [1][2]. These limitations led to new tendencies toward the Renewable and long-lasting power generation technologies such as wind turbines and solar power. Meanwhile utilizing the wind turbines is one of the best ways to produce energy. Wind turbine can be applied in isolated areas not reachable to energy supply systems as a complementary or even to replace the central power stations [3]. Energy must be saved because the wind power is erratically changing. Applying an energy storage system, a low-cost electrical source can supply the peak of demands effectively [4][5][6].

In this paper, Battery Energy Storage Unit and Fuel Cell Energy Storage System are suggested to promote the dynamic performance of wind power system [7]. So far, several ways have been provided to control wind hybrid power by the use of energy storage unit to reach the best dynamic performance and the most energy efficiency. A common approach is applying PID controller. First strategy in this essay is using classic controller. In the following GA and PSO are used to determine gain parameter of classic controller. In simulation result part, it will be indicated that the suggested controllers with Genetic Algorithm and Particle Swarm Optimization had a good performance in front of changing charge situation rather than PID controller.

2. Configuration and explanation of the system

In this paper, structure of the recommended independent network included a wind turbine, battery energy storage unit and fuel cell is indicated in “Fig. 1,”. These modes were made using MATLAB software. In this model, wind’s speed was considered partial actual and the simulations were made for the moment of time at 300 seconds. They were done to illustrate variations of the production and consumption of the charge during a day.

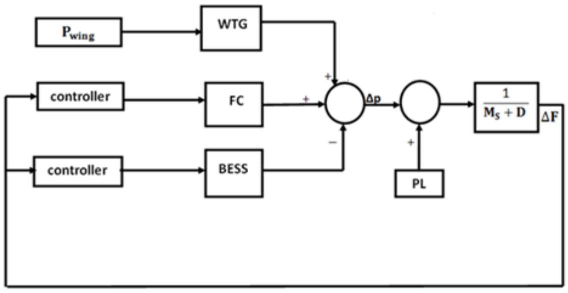

Fig. 1. Structure of the independent network

3. Production Model of Wind Turbine Generators

Output power of the wind turbine generators is dependent on the wind speed. Mechanical power of the wind turbine was provided in"(1)," [8].

$$P_{Wind}=1/2\ \rho\ A_r\ C_P\ V_W^3 \tag{1}$$

Where ρ A_r and C_P represent air density, effective surface area of the blades and power coefficient respectively as a function of tip speed ratio of a blade.

ρ and A_r parameters in "(1)," was considered to be 1/25 Kg⁄m^{3}and 1735 m^2 respectively.

The value of C_P in "(1)," can be obtained by "(2)," [9]

$$C_P = (0/44 - 0/0167\ \beta)\ \sin\left[\pi\ (\lambda - 4)/\ (15 - 0/3\beta)\right] - 0/0184(\lambda\text{-}3)\ \beta \tag{2}$$

The value of λ in *"(2),"* can be obtained by*"(3),"*.

$$\lambda = (R_{blade}\ \ \omega_{blade})\ /\ V_W \tag{3}$$

The value of Rblade is the blade radius and ωblade is the blade rotational speed in "(3)," which were considered 23.5m and 3.14rad⁄s respectively.

The comparison between output power of wind turbine generators and wind speed has been illustrated in "Fig. 2,". This figure shows while wind speed was more than a certain limit, the output power will remain the same. In this study, when wind speed was more than 25m/s the system will fail because of the security of its initial tools. Also when wind speed was more than 15m/s output power of wind turbine generators was fixed in the peak. When wind speed was less than 4 m/s, the output power of wind turbine generators was fixed to zero.

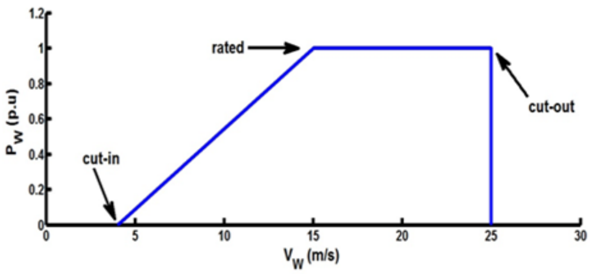

Fig. 2. Output power of wind turbine generators

Transfer function of wind turbine generators which was shown in "Fig. 1," is stated in "(4),"

$$G_{WTG}\ (S)\ \ = K_{\ WTG}\ /\ (s\ T_{\ WTG} + 1) \tag{4}$$

A) Fuel Cell Storage System Model

Fuel cells are static energy-conversion devices that can use Hydrogen and Oxygen to convert chemical energy into electric. A major problem of fuel cells is their slow dynamics in fuel supply system.

Transfer function of fuel cell that was shown in "Fig. 1," is stated in "(5)," [10].

$$G_{FC}\ (S) = K_{FC}\ /\ (T_{FC}\ s + 1) \tag{5}$$

B) Battery Energy Storage System Model

The best way for removing the problem of fuel cells is to use Battery Energy Storage System. Transfer function of Battery Energy Storage system that was shown in "Fig. 1,"was stated in "(6)," [9].

$$G_{BESS}\ (S) = K_{BESS}\ /\ (T_{BESS}\ s + 1) \tag{6}$$

4. The Proposed Model and control method

Modeling and control method will be described in this part. In this proposed model, wind turbine generator system was used as the basic source to generate the output power of the system. Power depends on the climate, but power will combine with the fuel cell to supply the demand of load that has been connected to network. In this paper, battery was used to supply the demand of load that has been connected to the network because of the slow dynamics in a fuel cell and the combination of a fuel cell system and a battery is satisfactory. Battery Energy Storage System and fuel cell are used as a backup system together.

The output power of the network includes wind turbine generators system, the fuel cell and the battery which can be obtained from "(7),".

$$P_{\ Net} = P_{WTG} + P_{FC} \pm P_{BESS} \tag{7}$$

The proposed control system uses the PID controller as its first strategy then in this essay we use GA and PSO to determine the gain parameter of the classic controller.

The first part of this section will describe GA and PSO because these two algorithms were used to improve operation of controllers and the second part will describe to design classic controller and set its parameters by GA and PSO.

The parameters used in the proposed system modeling are indicated in "TABLE 1.".

C) Genetic Algorithm

Genetic algorithm was provided in 1970 with Holland, De Jong, and Goldberg [12]. This algorithm is set as a section of random optimization class. This algorithm is suitable to optimize complex problem with unknown search space. Genetic algorithm is one of the optimization and research technique that are based on genetic and inheritance rules in being to solve different issues. A group of random response is selected then this response with genetic rules will be evolved. Structure of genetic algorithm is provided in “Fig. 3,” [13].

Table.1.
Value of parameters used in a separated network

T_{WTG} = 1/5	K_{WTG}=1
T_{FC} = 4	K_{FC} = 1/100
T_{BESS} = 0/1	K_{BESS}= *-1/300*
(*M* = 0/2 , *D* = 0/012)	

D) Particle Swarm Optimization

James Kennedy, social psychologist and Russell Ebrhart, computer engineer are main owner of particle swarm optimization idea [14]. They first intended to use social models and social contact to make kind of computational intelligence that does not need specific individual’s abilities.

First simulations were done in 1995. They were shifted to simulate the behavior of birds for finding seeds [15]. This work was influenced of Rick Heppner and Ken Gernonder study that was simulated the bird behavior as nonlinear systems. Kennedy and Ebrhart work was leaded to make strong algorithm for optimization that was named as particle swarm optimization algorithm [16][17].

The overall structure of particle swarm optimization was provided in “Fig. 4,” [14][15][16][17]. Pfit is value of fitting function for each particle and pfit-best is the best particle fit among particle finesses also p-best is the value of best individual value and g-best is the value of the best overall response.

E) The Design of a PID controller

The purpose of the design of a PID controller is to determine K_D, K_I and K_P. Coefficients of system output can be stated in different ways.

Nowadays, more than 90% of controllers are PID and that is they are easy to understand, easy to describe to others and their feasibility. The most common kind of PID controller has three parts including proportional, Derivative, Integral or PID that have general form like the“(8),”[18]:

$$G(S) = K_P + K_I / S + K_D S \tag{8}$$

In this case, K_P factor was used for increasing the speed of the accuracy system response. If K_P is a big, the diversion rate increases and the system may become unstable.

K_D factor is used to increase and improve the dynamic performance of the system also K_I is used to eliminate the Steady-state error but if it becomes too high, it leads to the saturation state and it makes the system unstable.

F) The Design of the Suggested Controller

In this essay we use AG and PSO to determine the gain parameter of classic controller. We set limited area of minimum and maximum for each parameter. GA and PSO select the best value out of this limited area.

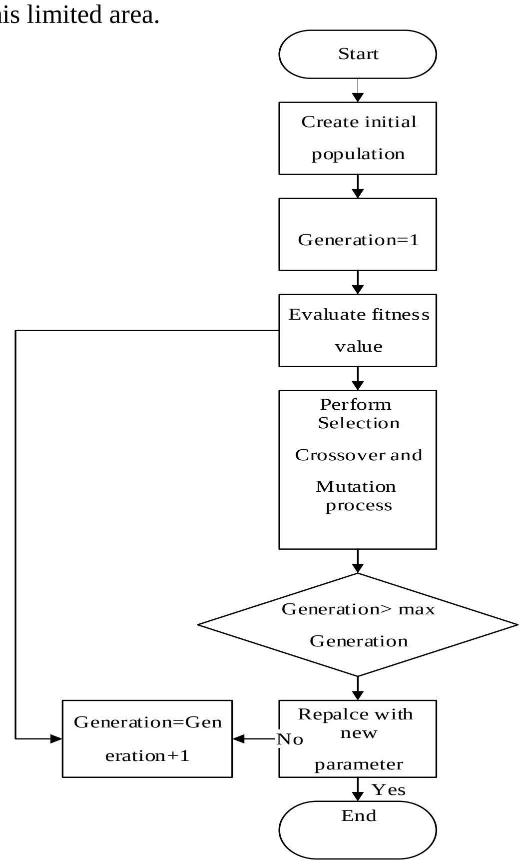

Fig. 3. Procedure of genetic algorithm

G) Parameters of Intelligent Optimization Algorithm

If we select the correct parameters, this method will be very effective. The applied parameter of intelligent optimization algorithm was indicated In “TABLE 2. “ and “TABLE 3. “.

5. Simulation Results

In this part, the designed controllers are applied in the aforementioned system. For this reason MATLAB Simulink software is used for simulation.

In this simulation, variations of the wind speed are considered as real values and modeling was performed in 300s. The simulations were done somehow to express the changes of production and consume of the load during 24 hours of the day.

In this paper, two scenarios for distinguishing the operation of the system and also the influence of the controller are used. In the first scenario the network does not have any controller and in the second scenario the influence of controllers was discuss.

For detecting the operation of the system we use "TABLE 4. " for simulation.

Output power of wind turbine was indicated in "Fig. 5,". Based on this picture power of wind turbine is 0.55 per unit during zero to 120 second then power of wind turbine is increased to 0.61 per unit during 120 to 240 second. In the last period during 240 to 300 second power of wind turbine is increased to 0.68 per unit. This increase in power of wind turbine indicates variations of wind speed during all day.

Changing of consumed load was indicated in "Fig. 6,"based on this figure of consumed power it was changing to indicate vast variation in load of network. According to this picture Changing of consumed load was considered as an actual Load curve and per unit.

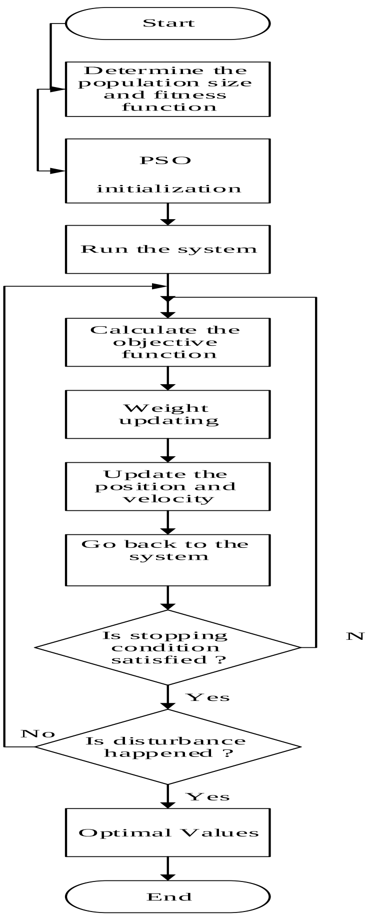

Fig. 4. Procedure of PSO performance

Table.2.
Parameter of pso algorithm

Parameter	Value
Population size	20
Maximum Number of Iteration	100
Inertia Weight	0.9
Personal Learning Coefficient	2
Global Learning Coefficient	2

Table.3.
Parameter of genetic optimization algorithm

Parameter	Value
Selection method	Selecting based on roulette wheel
Population size	20
Crossover probability	0.9
Mutation probability	0.1
Maximum Number of Iteration	100

Table.4.
Operation of the system was discussed

Time(s)	Controller	Subsystem	Testing
300	-	Wind Turbine, Load, Battery and Fuel Cell.	**1**
300	PID PID-GA PID-PSO	Wind Turbine, Load, Battery and Fuel Cell.	**2**

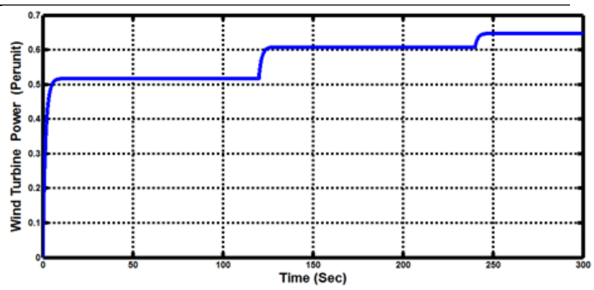

Fig. 5. Output power of wind turbine

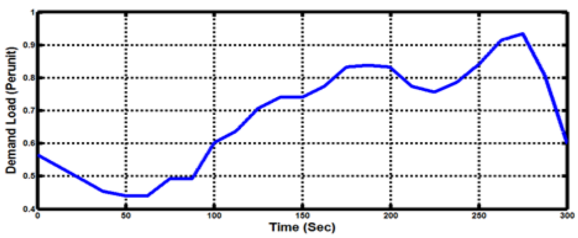

Fig. 6. Output power of consumed load of network

H) The first scenario

In this step, the assumption is that, in addition to the main source of wind, there exists some storage element in the network, but the system does not have any controllers.

The frequency deviation of the first scenario was showed in “Fig. 7,”. Based on this picture, the frequency deviation is too much in the system and it is because there is not controller in path of the storage elements. For this reason, the second scenario was investigated with the existence of controller to show importance of controller and influence on the network.

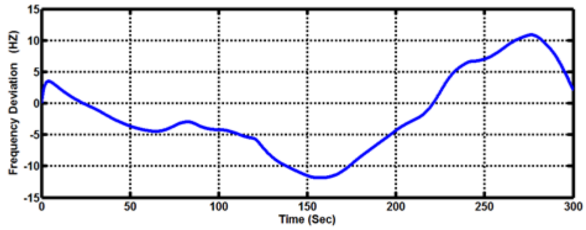

Fig. 7. Frequency deviation in first scenario

I) The second scenario

In order to reduce the deviation of frequency the assumption is that, in addition to the main source of the wind, the storage element exists in the network. In this method and the controller is put on the path storage element.

The power of the fuel cell is shown in “Fig. 8,”. Based on this picture, the power was reduced while production is more than consumption.

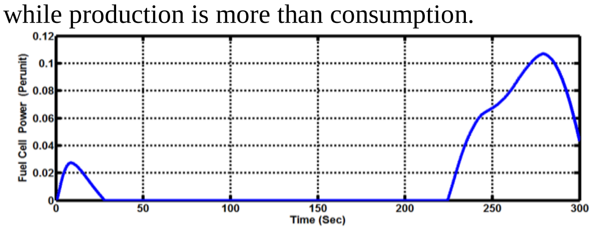

Fig. 8. Power of fuel cell network

The output power of the battery was shown in “Fig. 9,”. According to this graph the, battery is starts to charge once the production is more than consumption and it will discharge while production is less than consumption.

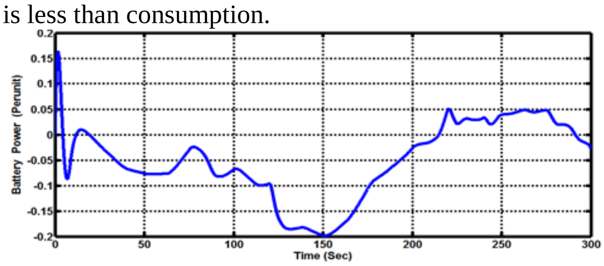

Fig. 9. Output power of battery

The frequency deviation of the system with a PID controller was shown in “Fig. 10,”. As a result, the frequency deviation was decreased remarkably.

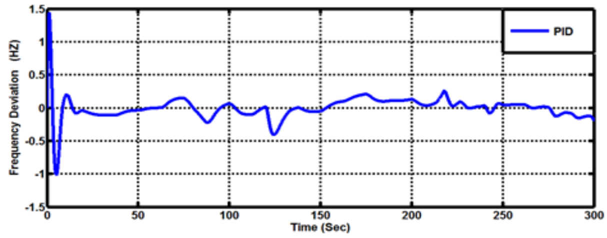

Fig. 10. Frequency deviation with PID controller

The frequency deviation of the system with PID-GA controllers were shown in “Fig. 11,”. As a result, the frequency deviation was decreased remarkably. As “Fig. 11,” shows the initial transient steady state which reaches to [0, 0.75] Hz which has reduction in comparison with PID controller is the ideal value of a network.

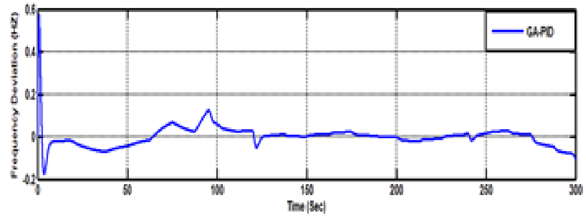

Fig. 11. Frequency deviation in network with PID-GA

The frequency deviation of a network with PID-GA controller and PID controller was shown in “Fig. 12,”. Base on this picture, the frequency deviation reaches a better value after optimization of the classic controller with genetic optimization algorithm that steady state and transient state were reduced.

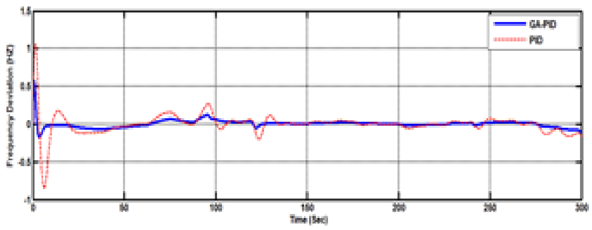

Fig. 12. Frequency deviation in network with PID controller and PID-GA

The frequency deviation of the system with a PSO-PID controller was shown in “Fig. 13,”. As a result, the frequency deviation showed a remarkable reduction. Base on this picture, the initial transient steady state reaches to [0, 0.3] Hz and it has decreased in comparison to PID controller. And also the steady state reached zero and it is the ideal value of a network.

The frequency deviation of a network with PID controller, GA-PID and PSO-PID was shown in “Fig. 14,”. Base on this picture, after optimization of the PID controller with particle swarm optimization and genetic algorithm, the frequency deviation achieves an idealistic value as steady state and transient state were decreased.

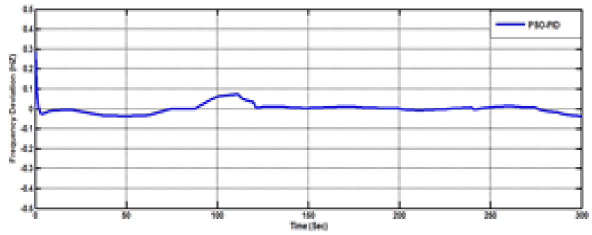

Fig. 13. Frequency deviation in network with PID controller and PSO-PID

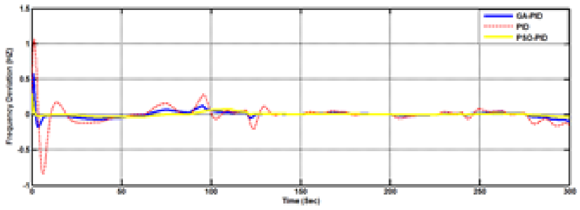

Fig. 14. Frequency deviation in network with PID controller, PSO-PID and GA-PID

6. Conclusion

Considering increasing the energy demand and fossil fuel limitations, using Hybrid systems is the best option for fulfilling the energy demands. This paper proposes a wind system with an energy storage element for batteries and fuel cells. The Dynamic of this new controller was proposed based on the uncertainty of the system.

Using a controller on the system leads to the stability of the system due to the variation of charge and other parameters of the system and it leads to a better energy controlling in a Hybrid system. The three proposed strategies for these systems were designed and simulated on Matlab and Simulink. It was indicated that these three methods have a good perforce and they are not sensible to the uncertainty of the parameter of the system. It was also shown that, the controller system, is able to compensate and manage the power with abrupt variation of load and the system will be safe even with charge demands. In the end, it is concluded that, the suggested PID controller strategy developed by PSO and GA, has a better performance in comparison to a PID controller alone.

References

[1] Dulal Ch. Das , A.K. Roy, N. Sinha, "GA based frequency controller for solar thermal–diesel–wind hybrid energy generation/energy storage system," International Journal of Electrical Power and Energy Systems, vol. 43, no. 1, pp. 262-279, December, 2012.

[2] Cuk Supriyadi A.N, Takuhei Hashiguchi, "Control Scheme of Hybrid Wind-Diesel Power Generation System," in From Turbine to Wind Farms - Technical Requirements and Spin-Off Products, www.intechopen.com, April 4, 2011, p. Chapter 5.

[3] Prabodh Bajpai, Vaishalee Dash, "Hybrid renewable energy systems for power generation in stand-alone applications: A review," Renewable and Sustainable Energy Reviews, vol. 16, no. 5, p. 2926–2939, February 2012.

[4] Hansang Lee, Byoung Yoon Shin, Sangchul Han, Seyong Jung, Byungjun Park"Compensation for the Power Fluctuation of the Large Scale Wind Farm Using Hybrid Energy Storage Applications," IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, vol. 22, JUNE 2012.

[5] Majid Nayeripour, Mohammad Hoseintabar, Taher Niknam, "Frequency deviation control by coordination control of FC and double-layer capacitor in an autonomous hybrid renewable energy power generation system," elsevier Renewable Energy , vol. 36, no. 6, p. 1741e1746, June 2011.

[6] Toshiaki Kaneko, Akie Uehara , Tomonobu Senjyu, Atsushi Yona, Naomitsu Urasaki, "An integrated control method for a wind farm to reduce frequency deviations in a small power system," Applied Energy , vol. 88, no. 4, p. 1049–1058, September 2010.

[7] Tomonobu Senjyu, Member, IEEE, Toshiaki Nakaji, Katsumi Uezato, and Toshihisa Funabashi, Senior Member, IEEE,, "A Hybrid Power System Using Alternative Energy Facilities in Isolated Island," IEEE TRANSACTIONS ON ENERGY CONVERSION, vol. 20, JUNE 2005 .

[8] Majid Nayeripour, Mohammad Hoseintabar, Taher Niknam, "Frequency deviation control by coordination control of FC and double-layer capacitor in an autonomous hybrid renewable energy power generation system," elsevier Renewable Energy , vol. 36, no. 6, p. 1741e1746, June 2011.

[9] Dong-Jing Lee and Li Wang, "Small-Signal Stability Analysis of an Autonomous Hybrid Renewable Energy Power Generation/Energy Storage System Part I: Time-Domain Simulations," IEEE TRANSACTIONS ON ENERGY CONVERSION, vol. 23, no. 1, pp. 311-320, MARCH 2008.

[10] Dulal Ch Das, A K Roy, N Sinha, Senior Member IEEE, "Genetic Algorithm Based PI Controller for Frequency Control of an Autonomous Hybrid Generation System," International Association of Engineers, Directory of Open Access Journals, 2011.

[11] Dulal Ch Das, A K Roy, N Sinha, Senior Member, IEEE, "PSO based frequency controller for wind-solar-dieselhybrid energy generation/energy storage system," Energy, Automation, and Signal (ICEAS), 2011.

[12] Goldberg, D.E., Genehc Algorithms in Search, Ophmizahon, and Machine Learning, Addison-Wesley, 1989.

[13] C. L. Karr and L.M.Freeman, "Industrial Applications of genetic Algorithms," CRC Press, 1999.

[14] M. Clerc and J. Kennedy, "The Particle Swarm: Explosion, Stability and Convergence in multi-dimensional complex space," IEEE Transactions on Evolutionary Computation, vol. 20, no. 6, pp. 58-73, 2002.

[15] P. Siarry, "Metaheuristics for Hard Optimizations," Springer-Verlag Berlin Heidelberg, 2006.

[16] B. Bullnheimer, R. Hartel and C. Strauss, "An improved ant system algorithm for the vehicle routing problem," Technical Report, University of Vienna, 1997.

[17] B. Bullnheimer, R. Hartel and C. Strauss, "A new rank-based version of the ant system: A computational study, Central European Journal of Operations Research and Economics," pp. 25-38, 1999

[18] H. Bevrani, Senior Member, IEEE, F. Habibi, P. Babahajyani, M. Watanabe, Member, IEEE, and Y. Mitani, Member, IEEE, "Intelligent Frequency Control in an AC Microgrid: Online PSO-Based Fuzzy Tuning Approach," *SMART GRID*, vol. 3, no. 4, pp. 1935-1944, DECEMBER 2012.