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.
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].

\[ P_{\text{Wind}} = \frac{1}{2} \rho A_c V^3 \]  \hspace{1cm} (1)

Where \( \rho \), \( A_c \), and \( V \) represent air density, effective surface area of the blades and power coefficient respectively as a function of tip speed ratio of a blade.

\( \rho \) and \( A_c \) 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]

\[ C_p = (0.44 - 0.0167 \beta) \sin \left[ \pi (\lambda - 4)/ (15 - 0/3\beta) \right] - 0.0184(\lambda - 3) \beta \]  \hspace{1cm} (2)

The value of \( \lambda \) in “(2),” can be obtained by “(3),”

\[ \lambda = \left( R_{\text{blade}} \omega_{\text{blade}} \right) / V \]  \hspace{1cm} (3)

The value of Rblade is the blade radius and \( \omega_{\text{blade}} \) 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.

\[ P_{\text{Net}} = P_{\text{WTG}} + P_{\text{FC}} + P_{\text{BESS}} \]  \hspace{1cm} (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>
<thead>
<tr>
<th>Table 1. Value of parameters used in a separated network</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{WTG} = 1/5$</td>
</tr>
<tr>
<td>$T_{FC} = 4$</td>
</tr>
<tr>
<td>$T_{BESS} = 0/1$</td>
</tr>
<tr>
<td>$(M = 0/2, D = 0/012)$</td>
</tr>
</tbody>
</table>

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 Ehrhart 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]:

$$G(s) = K_P + K_I / s + K_D s$$

(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.

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.

### Table 2.
Parameter of pso algorithm

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population size</td>
<td>20</td>
</tr>
<tr>
<td>Maximum Number of Iteration</td>
<td>100</td>
</tr>
<tr>
<td>Inertia Weight</td>
<td>0.9</td>
</tr>
<tr>
<td>Personal Learning Coefficient</td>
<td>2</td>
</tr>
<tr>
<td>Global Learning Coefficient</td>
<td>2</td>
</tr>
</tbody>
</table>

### Table 3.
Parameter of genetic optimization algorithm

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selection method</td>
<td>Selecting based on roulette wheel</td>
</tr>
<tr>
<td>Population size</td>
<td>20</td>
</tr>
<tr>
<td>Crossover probability</td>
<td>0.9</td>
</tr>
<tr>
<td>Mutation probability</td>
<td>0.1</td>
</tr>
<tr>
<td>Maximum Number of Iteration</td>
<td>100</td>
</tr>
</tbody>
</table>

### Table 4.
Operation of the system was discussed

<table>
<thead>
<tr>
<th>Time(s)</th>
<th>Controller</th>
<th>Subsystem</th>
<th>Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>Wind Turbine, Load, Battery and Fuel Cell.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>PID-GA</td>
<td>Wind Turbine, Load, Battery and Fuel Cell.</td>
<td>2</td>
</tr>
<tr>
<td>300</td>
<td>PID-PSO</td>
<td>Wind Turbine, Load, Battery and Fuel Cell.</td>
<td>3</td>
</tr>
</tbody>
</table>

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. 14. Frequency deviation in network with PID controller and PID-GA
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 performance 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


