Optimal Sizing of Stand-Alone PV/Wind/Battery Hybrid Micro-Grids for Charging Electric Vehicles with Capability of Connecting to the Grids

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ABSTRACT: In this paper, optimal sizing of the distributed generations including a hybrid grid-tied microgrid that utilizes Photovoltaic (PV), batteries, fuel cell (FC) technology and electric vehicles with capability of connecting to the grids is proposed. Particle swarm optimization (PSO) algorithm is utilized for minimizing the microgrid cost in distributed generation sizing model. In this research, 3 models are analyzed and finally, electrical vehicle effects on the optimal size of both distributed generations in the microgrid and also the microgrids reliability are analyzed.

Keywords: optimal sizing; microgrid; renewable energy; particle swarm optimization, PV/Wind/Battery Hybrid Micro-grids, electric vehicles

1. INTRODUCTION

The future in energy generation is renewable energy sources. There is an attempt worldwide for applying the environmental friendly energy sources, like solar and wind power. Recently, the tendency in transport is a mutation from petrol-fueled mobility to electric mobility. A composition of the two considered tendencies could lead to an electric mobility system powered by green energy. This could be actualize by installing wind turbines and photovoltaic systems along the roadside and employ the generated energy to power/charge the electric vehicles (EVs) passing-by.

The main disadvantages that electric vehicles have in comparison with traditional cars are the determined driving limit and the high costs, which are both, depended on the technology and the characteristics of today’s batteries. The employed batteries which are utilized in electric vehicles are expensive, have a limited capacity, a short lifetime and a high cost.

The design of localized, distributed energy production systems is a significant research discussion, especially as the employment of renewable energy sources increases (Jiayi et al. 2008).

The control of energy flows and electrical power quality from a large number of resources is thoroughly different from the highly-centralized electrical distribution system in the U.S. and other industrialized countries (Meliopoulos et al. 2002, Colson et al. 2009).

Furthermore, there exists the tendency to develop energy security at the local level by networking a system of Distributed Energy Resources (DERs) with the installation of small, renewable energy sources into a so-called microgrid (Lasseter et al. 2006).

Microgrids are of specific interest to zones where energy independence and/or energy safety are especially significant, such as military bases, remote cities, medical complexes and island communities (Shaffer et al. 2006, Ashok et al. 2007, Gupta et al. 2010).

In addition, rather than existing in a load-following state, where electricity generation is ramped up to meet demand, microgrids can have the ability of controlling the loads as well, through smart switches and circuit breakers that are centrally-controlled. Smart grid technologies offer the tendency of decreasing power demand during peak times and further increasing the independence and reliability of the microgrid.

Former research has shown that plug-in vehicles can be a complementary technology to microgrids (Gage et al. 2003, Tomić et al. 2007, Galus et al. 2008). Both battery electric vehicles and plug-in hybrid electric vehicles can be linked with a microgrid to store off-peak renewable energy and either utilize it for vehicle propulsion or return some of that stored energy to the microgrid during times of peak energy use. This can maximize the application of
renewable energy sources, decrease fossil energy utilization and the greenhouse gas footprint of the microgrid area. This is doubly superior in that this vehicle/microgrid system leads both transportation energy utilize as well as electrical energy use. This coerce formulating a coordinated, system-level design and control problem that examine the microgrid and its individual DER elements and control strategy as well as the design and control of the electrified vehicles that connect to the microgrid.

The main purpose in this paper is to analyze the electrical vehicle effect on the optimal size of the considered units in the microgrids and also their reliability.

2. Studied Stand-Alone Microgrid Power System

The power system considered here is composed of five parts: photovoltaic units, wind turbine, battery bank, electrical vehicle and inverter. Photocell and wind turbine units generate electricity due to the local wind and solar energy resources, to supply load; the battery bank stores the energy that can supply the load when there is lack of electricity, and store the surplus power when the generated power exceeds the load. Fig.2 shows the studied microgrid in this paper:

3. Simulation model for sizing the microgrid

In this research a hybrid microgrid will be analyzed to supply the electric vehicles. As shown in the flow chart of the model, iterations for all possible forms of solar/wind/storage were made and those which could cover the load were saved. As a result, the output of the model includes a data structure containing all the possible sizing combinations for the given system.
4. Cost Function

Cost function includes the sum of all NPCs as below:

\[ \text{Fitness Function} = NPC_{\text{wind}} + NPC_{\text{PV}} + NPC_{\text{battery}} + NPC_{\text{DC/AC}} + NPC_{\text{PHEV}} + NPC_{\text{P}} + NPC_{\text{Pui}} \]  

(1)

Where \( NPC_{\text{wind}} \) is the wind turbine costs, \( NPC_{\text{PV}} \) is the photo cell units costs, \( NPC_{\text{battery}} \) is the battery storage cost, \( NPC_{\text{PHEV}} \) is the electric vehicle costs, \( NPC_{\text{DC/AC}} \) is the DC/AC inverter costs and \( NPC_{\text{P}} \) and \( NPC_{\text{Pui}} \) are belong to the penalty payoff costs for disconnect able and sensitive loads respectively.

Our purpose is to minimize the described cost function, while supplying the area load.


The noise block in the Matlab software is used to model the energy variations in the electric vehicles. The noise function output can be a positive or negative digit. In this paper, negative digit in the electric vehicle means that the vehicles are in discharging and the positive digits shows that the vehicles are in charging.

Therefore, when the noise output is a positive digit, the required total power for vehicles can be achieved as below:

\[ P_{\text{PHEV,T}}(t) = N_{\text{PHEV}} \times P_{\text{max,charge}} \times \text{noise}(t) \]  

(2)

Where \( P_{\text{PHEV,T}}(t) \) is the vehicles total power at time \( t \), \( N_{\text{PHEV}} \) is the vehicle numbers, \( P_{\text{max,charge}} \) is the storable maximum power in vehicles and \( \text{noise}(t) \) shows the noise block output at time \( t \).

In addition, when the noise digit is negative, the discharge power can be achieved as below:

\[ P_{\text{PHEV,T}}(t) = N_{\text{PHEV}} \times P_{\text{max,discharge}} \times \text{noise}(t) \]  

(3)

Where \( P_{\text{max,discharge}} \) represents the maximum dischargeable power of the vehicles.

Electric vehicles are stand with control in the microgrid; as in the peak times, electric vehicles getting discharge and by using the photocell units, wind turbine units and the battery supply the required power for the microgrid. Electric vehicles are also getting charged when the system is not in peak times.

In this paper, when the required power in the microgrid is greater than the mean value of the load around a year, the peak time has been considered and otherwise, it considered when the time is not in peak time.

6. Particle Swarm Optimization (PSO)

PSO algorithm is a heuristic based stochastic optimization technique which is introduced in 1995 by Kennedy and Eberhart. Particle swarm optimization inspired by the social behavior of birds flocking and fish schooling (Y. Shi, R. C. Eberhart, 1999). Formal PSO algorithm performs by owning a population of candidate (called a swarm) solution (called particles). These particles are moved around in the search-space to some specific formulae. After discovering the developed positions, these will then move to guide the motions of the swarm. The process is iterated and by evaluating so it is hoped, but not guaranteed, that a proper solution will finally be figured out (H. Y. Fukuyama); the swarm regulates based on the following two equations:
where \( n \) presents the number of particles, \( w \) is the weighted inertia, \( C_1 \) and \( C_2 \) are the positive constants, \( r_1 \) and \( r_2 \) illustrate two random numbers distributed within the range [0,1], \( t \) is the iteration number, \( P_i \) is the best position of the \( i^{th} \) particle and \( g \) is the best particle among the group members. By using equation (4), the particle updates its velocity based on the prior velocity and the distances to its current position from its own best historical position and the best positions of the neighbors in every iteration step, and then it flies towards a new position characterized by (5).

7. Results and Discussion

Case 1) achieved results of the optimal microgrids sizing without considering the electric vehicles:

In this case, the batteries which are installed to the microgrid when connecting to it, assumed fully charged. The present loads in the microgrid include disconnect able sensitive loads. At any time, 10% of loads are considered as disconnect able load and the rest 90% are considered as sensitive loads.

The optimal number for the present units in the microgrid structure and the total cost for the system are illustrated in the table 1. Disconnect able and sensitive loads values are also characterized in table 2.

<table>
<thead>
<tr>
<th>Table 1. optimal value for each of the units and micrigrid cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microgrid total cost by considering the penalty</td>
</tr>
<tr>
<td>3.5236×10^7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2. Disconnect able and sensitive loads values which cannot power supplied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penalty ($)</td>
</tr>
<tr>
<td>1.84183×10^7</td>
</tr>
</tbody>
</table>

In this case the ELF reliability index value is equal to 0.009992.

Case 2) achieved results of the optimal microgrids sizing with considering the random presence of electric vehicles:

The number of electric vehicles in the microgrids is considered as 200. The maximum storage able capacity in each of the cars are assumed as 4KWh. The electric vehicles performance is considered 80%.

After running the optimization software, the number of present optimal units in the microgrid structure and the total cost of the system are illustrated in table 3. Disconnect able and sensitive loads values which are not power supplied are shown in table 4.

<table>
<thead>
<tr>
<th>Table 3. Optimal value for each of the units and the cost of microgrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microgrid total cost by considering the penalty</td>
</tr>
<tr>
<td>3.8122×10^7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 4. Disconnect able and sensitive loads values which cannot power supplied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penalty ($)</td>
</tr>
<tr>
<td>1.9494×10^7</td>
</tr>
</tbody>
</table>

In this case, the ELF reliability index value is equal to 0.009999 which is enhanced toward the previous case. Therefore, the microgrid has less reliability toward the previous case. It can be seen that the cost of microgrid is enhanced and also disconnect able and sensitive loads are disconnected more than the prior case.

Case 3) achieved results of the optimal microgrids sizing with considering the controlled electric vehicles:

In this case, the electric vehicles are controlled and set into the microgrid as while the required power value in the microgrid exceeds the mean value of the power in a year, electric vehicles getting discharged and also when the required power value in the microgrid is less than the mean value of the power in a year, electric vehicles getting charged. Optimal number of the present units in the microgrid structure and the total cost of the system are illustrated in table 5. Disconnect able and sensitive loads values which are not power supplied are shown in table 6.
Table 5. Optimal value for each of the units and the cost of microgrid

<table>
<thead>
<tr>
<th>Microgrid total cost by considering the penalty</th>
<th>Microgrid cost ($)</th>
<th>Battery</th>
<th>photo cell unit</th>
<th>Wind units</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1488×10^7</td>
<td>2.9842×10^7</td>
<td>9309</td>
<td>1196</td>
<td>451</td>
</tr>
</tbody>
</table>

Table 6. Disconnect able and sensitive loads values which cannot power supplied

<table>
<thead>
<tr>
<th>Penalty ($)</th>
<th>Disconnected Sensitive loads (KWh)</th>
<th>Penalty ($)</th>
<th>Disconnected Disconnect able loads (KWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.62611×10^7</td>
<td>29.575×10^7</td>
<td>20.722×10^7</td>
<td>3.768×10^3</td>
</tr>
</tbody>
</table>

In this case, the ELF reliability index is equal to 0.00991. By considering the table 5, we can see that when the controlled cars get participated in the microgrid, its cost is decreased. This makes the microgrid enhance the reliability capability.

8. CONCLUSIONS

Optimal sizing for the considered units in a microgrid including the electric vehicles are implemented. In this paper, effects of electric vehicles on the optimal size of the present units in the microgrid and also its reliability are analyzed. When the electric vehicles used randomly, they make the consumption load peak increase and finally the microgrid cost is getting increased. By using the controlled electric vehicles and charging them in the no peak times and using them in the peak times make the microgrid cost and it’s disconnect able and sensitive loads decrease and finally it enhances the microgrid reliability. Utilizing the battery storage make the surplus produced power energy of the wind unit and photcell unit store. This stored energy in the battery can be injected to the microgrid when the wind and photcell units can’t withstand to supply the microgrid.

REFERENCES