OPTIMIZING HYBRID PV/DIESEL GENERATOR SYSTEM USING BAT ALGORITHM

Sudhir Sharma  
Associate Professor and Head,  
Department of Electrical Engineering,  
DAVIET, Jalandhar

Shivani Mehta  
Asst. Professor, Department of Electrical Engineering,  
DAVIET, Jalandhar

Gurpreet Kaur  
Research Scholar, Department of Electrical Engineering,  
DAVIET, Jalandhar

Abstract— The diminishing fossil fuel reserves and need for energy has created to surge for the renewable energy resources. Solar energy is the most viable energy resource available. With the help of Photovoltaic panels, sun energy is directly converted into electrical energy. In this paper, a remote rural area is considered. Bat optimization technique is implemented to optimize the number of photovoltaic modules and number of battery banks to fulfil the load demand of village; and the goal is to reduce the overall cost of the hybrid system.

Keywords — Hybrid PV/Diesel system, Bat optimization, optimal sizing, MATLAB.

I. INTRODUCTION

Good quality stable electricity can provide various benefits to our commercial, industrial and domestics areas. Often this can be provided by extending the main grid electricity network to the community or consumer. However, the grid based electricity in villages and remote areas in most cases is unstable and very unreliable. Therefore, renewable sources of electricity are thus very relevant. While such systems are already in place, there usage is very low. Literature portrays that their capital cost is very high [1]. Although this might be true, the subsequent operational cost could be much lower as compared to the grid based electricity [2]. In the recent times, due to the emerging technological trends, the need for energy has increased globally. Electrical energy has now become the base for almost every activity [3].

With the increase in the power demand and decrease in the fossil fuels, mankind has been forced to search new alternative techniques to fulfill the energy demand [4]. Power can be generated from non conventional resources of energy such as solar, hydropower, wind, geothermal, oceans and many more. These are the renewable sources of energy. Energy obtainable from such sources is pollution free. Moreover these sources are available in plenty [5].

Many techniques have been put forward to generate electricity from renewable energy sources. Solar radiations have been utilized to generate electricity on small as well as on large scale. But these solar radiations are not available at night. We can this system with diesel generator and battery banks. Battery banks are used to store the charge. The immense amount of energy produced by renewable resources can be used to charge the battery banks which can be used later when required[1],[5].
Diesel generator serves as a primary back up power generation source. Considering the effect of atmospheric emissions and need of fuel, diesel generator should not be used as primary power generation source. But only be used as backup power source [6], [7], [8].

II. DESIGN OF HYBRID SYSTEM
The designing of hybrid system for the remote rural village has three major subsystems: Solar PV panels, the battery units, and primary back up source which is diesel generator. Strategy of designing of sub-systems is described in the below subsections. Load of one day is shown in figure 2.

A. Solar Energy
The photovoltaic panels directly convert the sunlight into electricity. When solar panels are exposed to sunlight, the valence shell electrons get excited and move to the conduction band by generating charged particles known as electron-hole carriers. By putting P and N -type semiconductor together, a p-n junction gets formed which is able to separate holes and electrons. This process is possible when frequency of photon is above the critical frequency. The four types of solar panels are taken into account for the simulation process.

In a complicated system study, output power from solar panels depends upon the temperature. With the rise in temperature, the efficiency of system decreases. The relation between output from the solar photovoltaic panels with respect to temperature is expressed as [1] [6]:

\[ P_{pv,i}(t) = I_r \cdot \eta_{pv,i} \cdot \eta_{inv} \]  

(2)

Where \( \eta_{pv,i} \) and \( \eta_{inv} \) are the efficiencies of PV panels and of inverter respectively. \( I_r \) Stands for one PV panel surface in m\(^2\). \( I_r(t) \) Stands for solar irradiance in W/m\(^2\) in hour t.

### TABLE 1
Characteristics of different types of PV panels [1]

<table>
<thead>
<tr>
<th>TYPE</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{\text{max}} ) (Volts)</td>
<td>17.6</td>
<td>17.8</td>
<td>18</td>
<td>18.3</td>
</tr>
<tr>
<td>( P_{\text{rated}} ) (kW)</td>
<td>0.125</td>
<td>0.130</td>
<td>0.135</td>
<td>0.140</td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Efficiency of inverter (%)</td>
<td>95</td>
<td>95</td>
<td>95</td>
<td>95</td>
</tr>
</tbody>
</table>

B. Diesel Generator
The application of diesel generator comes into play when the renewable source is unable to generate enough electricity which cannot meet the load demand. Then diesel generator act as a primary back up source. However other back up sources such as fuel cell, hydrogen cell can be used. But their application is suitable only for small load patterns. The size of diesel generator depends upon nature of load. It can be estimated by directly connecting it to the load demand. Hence the maximum load served by diesel generator would be its rated capacity. But here the sizing diesel generator is taken as the optimization variable which must be calculated by comparing its operation and operating cost with the other parts of the system [11].

C. Battery Banks
When the energy obtained from the non-conventional resources is less than the energy demand, the remaining power demand can be met with battery bank storage units. The state of charge of battery banks is calculated from the difference of energy produced by renewable resources and energy demand of an area [7]. If the energy produced by the non-conventional resources is more than the demand, it charges the battery banks. But when renewable sources do not serve the demand, the battery banks discharge and provide the required energy demand. Four different types of battery banks are considered for simulation [1], shown in the table II.

The charging and discharging of battery banks should be such that it satisfies the equation constraint given below [11]:

\[ SOC_{min,k} \leq SOC_k(t) \leq SOC_{max,k} \quad (3) \]

TABLEII
Characteristics of Different Types of Battery Banks [1]

<table>
<thead>
<tr>
<th>Type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{rated} )</td>
<td>6</td>
<td>6</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>( P_{rated}^{po} )</td>
<td>0.12</td>
<td>0.15</td>
<td>0.14</td>
<td>0.18</td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>85</td>
<td>85</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td>Cost ($/KW)</td>
<td>348</td>
<td>415</td>
<td>521</td>
<td>567</td>
</tr>
</tbody>
</table>

D. Proposed Framework

Block diagram of hybrid system is shown below in the figure 1. It is clear that generator act as back up source for non-conventional sources and battery units. The load pattern for one day has been shown in figure 2.

Fig. 1 Hybrid system

In our research work, we have to optimize the number of photovoltaic panels and battery banks from four different types as characterized in table I and table II. The modules are optimized such that load demands of the consumers are met while reducing the total cost for the hybrid system. For the optimization process, Bat optimization technique is implemented in SIMULINK/MATLAB.

Fig. 2 Load Pattern [1]

BAT ALGORITHM

Nature has always been an inspiration for research scholars. Many nature inspired techniques have been
put forward to solve real world problems. Some of these optimization techniques are - genetic algorithms, PSO, ant colony optimization, bat algorithm and many more. Bat algorithm is the optimization techniques which combines the functions of particle swarm optimization and genetic algorithm and offers better results [15].

Bat algorithm is a meta-heuristic algorithm developed by Xin-She Yang in 2010. Micro bats use echoes to find prey. They keep on varying their loudness, frequency and pulses rates to search the prey during their random walk. Hence they reached at best solution among the retrieved solutions while optimization ends. This technique of bats can be used to optimize the objective function of real world problems. In bat optimization we initialize type and limits for PV panels and battery modules. When the iteration starts random value and type for PV panels and battery modules is generated and kilowatt generated by modules is calculated and stored as fitness value. As the iteration loops precede, new bats from existing bats is selected i.e. new modules and types are selected for kilowatt generation. After comparing the fitness value for parent and child bats we choose best bat among all which gives best results with reduced cost. Hence it can be implemented in various engineering, industrial application for optimizing real world problems [16]. Flowchart of bat algorithm implemented for the optimization of hybrid system modules is represented in figure 3.

IV. RESULTS AND DISCUSSION

For the area under study, four various types of battery units and PV arrays are used for simulation. The characteristic of each type is presented in table I and table II. The sum of installation and investment cost of PV panels is considered to be 4700 dollars per kilowatt of maximum output power. The maintenance cost of PV panels is considered to be 23 dollars per kilowatt of maximum output power of PV panels. The lifetime of batteries is considered to be 4 years. The sum of investments and installation cost of diesel generator is considered to be 900 dollars per each kW of its rated power. The operation and maintenance considered as 0.06 dollars per KW of output energy [1]. Cost of batteries of each type is shown in table II.

Fig. 3 Flowchart for optimizing modules using bat algorithm.
A. Results Retrieved From Bat Algorithm

The solution of BAT optimization problem for the hybrid system is represented in table III. The results are the best solutions retrieved from the BAT algorithm. The table represents the number of optimized modules of wind turbine and battery banks.

The objective function related to each subsystem of hybrid system is given as:-

Total cost

\[= \sum_{k=1}^{4} \left\{ N_{BAT,s,k} \cdot N_{BAT,p,k} \cdot \left[ cost_{BAT,inv,k} + \right. \right. \]
\[ \left. \left. Cost_{BAT,ins,k} + L_{P_{BAT,k}} \cdot Cost_{BAT,op,k} \cdot \frac{PH}{L_{T_{bat,k}}} \right\} \right\} + \]
\[\sum_{i=1}^{4} \left\{ N_{PV,s,i} \cdot N_{PV,p,i} \cdot \left[ Cost_{PV,inv,i} + Cost_{PV,ins,i} + \right. \right. \]
\[\left. \left. L_{P_{PV,i}} \cdot Cost_{PV,op,i} \cdot \frac{PH}{L_{T_{PV,k}}} \right\} \right\} + \]
\[Cost_{diesel,ins}(P_{diesel}^{max}) + Cost_{diesel,op}(P_{diesel}^{max}) + \]
\[\sum_{i=1}^{T} Cost_{diesel,op}(P_{diesel}(t)) \] (4)

Where, HK and T are the planning horizon in year and time respectively. LP refers to the lifetime of subsystem. N denotes the number of PV and battery units. Index i and k denotes the type of photovoltaic panels and battery banks.

TABLE III

Results for optimized number of modules

<table>
<thead>
<tr>
<th>Model</th>
<th>Type 1</th>
<th>Type II</th>
<th>Type III</th>
<th>Type IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photovoltaic Cells</td>
<td>-</td>
<td>-</td>
<td>79</td>
<td>-</td>
</tr>
<tr>
<td>Battery Bank</td>
<td>-</td>
<td>-</td>
<td>100</td>
<td>-</td>
</tr>
</tbody>
</table>

The results obtained from the simulation for the objective function is represented in the table IV. The total cost for the hybrid system has been calculated and output power curves for each subsystem is shown in the figures 4, 5 and 6. These curves indicate that the demand is served by hybrid system components.

TABLE IV

Results For Total Cost

<table>
<thead>
<tr>
<th></th>
<th>Cost of Photovoltaic</th>
<th>Cost of Diesel Generator</th>
<th>Cost of Battery Banks</th>
<th>Cost of Supply from the Grid</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment</td>
<td>$1797/year</td>
<td>$6/year</td>
<td>$391837/year</td>
<td>$0.07/kWh</td>
<td>$393635/yr</td>
</tr>
<tr>
<td>Diesel Size</td>
<td>0.0016667 kW</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost</td>
<td>0.07 $/kWh</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Cost</td>
<td>$393635/yr</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 4 PV panel power output

75
Fig. 5 Battery banks output

Table V gives the hourly comparison of power generated by optimized photovoltaic panels, battery banks and diesel generator with the load demand of an area. The power generated by hybrid system is enough to serve the load demand of the consumers.

V. CONCLUSION

A stand alone hybrid system comprising of Photovoltaic panels, diesel generator and battery banks for a rural area has been designed. The simulation results show the effectiveness of the Bat algorithm in designing the hybrid system. The objective was to meet the load demand of the consumers using our designed hybrid system, while minimizing the total cost of Hybrid system.

REFERENCES


