Design of a Hybrid PV/Wind/Diesel Generator Energy System for 120 Residential Apartments in Gusau

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Abstract - Gusau, a city in Zamfara state, Nigeria is faced with the challenge of inadequate power supply as electricity supply from the national grid is unstable and inadequate, besides majority of those in the remote areas are isolated from the grid. The location has a potential for renewable resources, to overcome this challenge of inadequate power supply, a hybrid electric power system which employs the use of battery storage, solar and wind energy system with a diesel generator as reserve to provide adequate power to 120 residential apartments in a settlement isolated from the grid is being designed. The solar and wind energy resources in the location were assessed; the data from the two renewable energy resources available in the location was collected for the year 2015 from the Nigerian Meteorological Agency, NIMET alongside the geographical coordinates and other useful parameters as input to the HOMER software simulator for analysis. The load profile of the location was carried out, the sizing of the energy mix from PV, wind, battery and generator was made using the software. The result of the simulation shows a yearly electricity production of 168,545KWh/yr, the early AC primary load is 67160KWh/yr. And the excess electricity is 88581Kwh/yr, this accounts for 52.6% of the total electricity generated hence, the hybrid energy system has the potential to provide the micro-grid with adequate power with high penetration of renewable energy.

Keywords— HOMER; NIMET; Radiation; apartment; reserve.

I. INTRODUCTION

The cost of energy and demand for electricity is both rising while the reserve for the sources is reduced e.g. fossil fuel globally is actually diminishing, and as such we are left with the idea that in years to come, the demand for electricity might exceed the supply of electricity from fossil fuel such that other sources of energy may be required, besides energy generation from fossil fuel gives rise to the emission of pollutants. As a result of the quest to cut down on pollution and prepare for the future energy demand requirement, the use of available renewable energy resources in every location for the provision of electricity is a necessity [1].

To enable us to meet the electrical load demand using renewable energy sources, a hybrid energy system is required, this will help us to employ the use of wind and solar resources to provide power and in the process overcome the challenge which energy generation from a single renewable energy source experiences [2].

Nigeria, popularly known as the giant of Africa, has a lot of mineral and renewable resources; daily average sunshine of 6.25 hours is experienced in the country, the period of sunshine hours varies from 3.5 hours in locations in the coast of the country to 9 hours towards the north end. As a result of the long duration of sunshine hours, the value of its annual average daily radiation ranges from 7.0 KW/m2/day at the north end to 3.5KWh/m2/day at the coastal area with annual average daily radiation of 5.25KWh/m2/day and as such a high amount of energy can be generated from the sun. Consequently, the potential for the use of renewable resources to provide alternative power supply is high provided the maximum use of the available renewable resources is adopted [3].

A. Description of research location and data

The major source of electric power in developing countries, for example Nigeria, is usually the national grid in which most cases have limitations, as some areas cannot have access to the grid due to the geographical location of the place like many areas in Gusau in Nigeria situated at Longitude: 6.77 Degrees East and Latitude: 12.17 Degrees North. Hence an independent and reliable source of power is essential, where the majority depend on fuel-based generators for power supply which is usually associated with heavy cost of maintenance and environmental pollution [4].

Gusau, the capital of Zamfara state was discovered to be one of the states in the country with a good potential for wind generated electricity and this is because the location experiences high temperature and long period of sunshine hours.

The data for the average sunshine hours alongside the minimum and maximum temperature in Gusau for the year 2015 were obtained from the Nigerian Meteorological Agency, NIMET as shown in fig 1 and 2 respectively.

Fig. 1: Average Monthly Sunshine hours for Gusau in 2015.
From figure 1, it can be observed that the least of the sunshine hours are above 11 hours and the peak of the sunshine hours is slightly above 12.5 hours which implies there is an abundance of sunlight in the area. Conversely from figure 2, the peak of temperature in this location is around 38°C which puts the temperature of the location high. Other data obtained from NIMET include the monthly solar radiation for Gusau in the year 2015 as shown in table 1.

Unlike in Europe, wind resources are low in several areas of Nigeria but the distribution is appreciable in some part of the country, including the location of study as shown in fig. 3. The areas in green in the figure are the areas in the country where there is a good potential for wind energy.

The month, which experiences the highest sunlight is February with a daily radiation of 7.390KWh/m²/d, on the other hand, July had a daily radiation of 4.580KWh/m²/d, which is the least, from the month of March to July, the daily radiation reduces progressively with the following differences: (0.25), (0.51), (0.75), and (0.54). During this period of reduction in daily radiation, energy from the wind energy system can be of tremendous support, besides during the nights, the energy stored in the battery alongside the wind energy can support the system.

Conversely, the daily radiation increases progressively from the month of August to November with the following differences: (0.08), (0.58), (0.63), (0.89), after which it reduces in December by (1.01) followed by another increase in January and February by (0.95) and (0.69) respectively. A plot of the wind speed, solar radiation, maximum, and minimum temperatures in Gusau is as shown in fig 5.
The wind and solar energy resources in the location have the potential to provide adequate power supply to the community, but remains yet untapped and as a result the area is faced with inadequate power supply. Other reasons behind the challenge of inadequate supply in the area include:

- The power supply is majorly from fossil fuel, which is adequate and capital intensive
- Several people don’t have electricity as they are being isolated from the grid
- The efficiency of the Photovoltaic module reduces at the peak of the sun for those who can afford it.

In most households in rural areas including Gusau, fuelwood appears to be the major source of energy for cooking, trees are being fell indiscriminately, since access to adequate electricity becomes more difficult, and people realized they can access fuelwood resources with ease, besides for lighting, kerosene appears to be in high demand [7].

In a research carried out in the past [8] There has been no proof to confirm that those who live in remote locations make use of electricity supply from the grid. Solar and wind energy systems are still gaining awareness in the country as hydropower, energy from fossil fuel and fuelwood constitute the major source of energy consumed [9].

In order to find a solution to this lingering electricity crisis, the use of island mode of hybrid energy system is a necessity. The main essence of employing renewable energy to provide electricity to the affected areas is due to the fact that the use of renewable energy resources for power generation provides security of supply, it reduces the amount of pollutants, there is a power quality enhancement and in the process create some form of employment to those in the area [10].

The main contribution of this paper is to design a hybrid energy system to provide a stable and adequate power for a hundred and twenty residential buildings in the area with room for future expansion of the micro-grid.

II. METHOD

This project is specifically designed to provide electricity to people isolated from the grid and those who are connected to the grid but are dissatisfied with the use of electricity from the grid. A general description of this project is as shown in fig 6. The design requires energy majorly from renewable energy applications such as wind turbine and PV which requires battery storage, and a diesel generator as a reserve. The diesel generator is to serve in a situation where there is a failure of one of the sources or for the provision of reactive power to the micro-grid to help stabilize the voltage.

The method involves the general assessment of the location to identify the gravity of the power failure challenge in the area, the unavailability of the electricity grid, the extent of environmental pollution being experienced as a result of constant use of diesel generator as a source of power supply. The load requirement of the selected location was also designed; the data from the available renewable energy resources in the area, coupled with the geographical information of the study location were also gathered. HOMER software simulator was adopted for use to enable an efficient and reliable analysis of the energy requirement of the site in question and a systematic procedure for the implementation of the simulator software was used.

The wind turbine and diesel generator are connected on the AC Busbar while the PV array, battery bank are all connected to the DC Busbar. With this arrangement in place energy storage can be achieved from any of the electrical sources with the help of the converter. The diesel generator is controlled with the help of the electrical switch as it serves as reserve and will be put to use in the event of total power failure. When both the Wind turbine and PV array is ON, the battery bank charges and stores energy for use when the load demand is more than supply.

A. Load estimation of one hundred twenty residential apartments.

The system load profile design for the location was carried out and represented as shown in fig 7 and table 3, it’s a design for 120 residential apartments and as such a diversity factor of 0.4 was used in the design to aid the accurate determination of the total demand.
Table 4 represents a diversity factor table for residential apartments as specified by French standards NFC14-100 but this is used for a residential apartment that does not require electrical heating and this is applicable to the majority of the states in Nigeria but in a situation where electrical heating is required for space heating, then irrespective of the number of residential apartment involved, a factor of 0.8 is used.

Table 4: Diversity factor for residential apartments

<table>
<thead>
<tr>
<th>Apartment factor (Ks)</th>
<th>Diversity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-4</td>
<td>1</td>
</tr>
<tr>
<td>5-9</td>
<td>0.78</td>
</tr>
<tr>
<td>10-14</td>
<td>0.63</td>
</tr>
<tr>
<td>15-19</td>
<td>0.53</td>
</tr>
<tr>
<td>20-24</td>
<td>0.49</td>
</tr>
<tr>
<td>25-29</td>
<td>0.46</td>
</tr>
<tr>
<td>30-34</td>
<td>0.44</td>
</tr>
<tr>
<td>35-39</td>
<td>0.42</td>
</tr>
<tr>
<td>40-49</td>
<td>0.41</td>
</tr>
<tr>
<td>50 and above</td>
<td>0.40</td>
</tr>
</tbody>
</table>

B. System load variations

The load demand for this design varies from time to time during the day, from 11 pm in the night to 6 am in the morning as shown in table 3, the load demand is low, this is because most of the electrical devices are OFF and only the exterior lights and fridge are ON and also during this period the least load is observed when the fridge is not consuming energy, though there is a slight increase experienced by 6 pm. The load demand between the hours of 7am and 5pm is still low owing to less use of electrical devices, but the moment the time is 6pm, the load demand is observed to be at its peak (20.64KW) as most devices are in use since most individuals would have returned back home either from work, school etc. The load remains high from 6pm to 9pm and begins to reduce since most people are preparing to go to sleep. The procedure used to implement the design using a HOMER software simulator is as shown in fig 8.
B. Simulation results

Among the numerous simulations carried out, a section of the simulation results for sensitivity values of 5KWh/m2/d and 5m/s was considered as shown in table 5

Table 5: Simulation result

<table>
<thead>
<tr>
<th>Component</th>
<th>Production (KWh/yr)</th>
<th>Consumption (KWh/yr)</th>
<th>%</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV array</td>
<td>90,638</td>
<td></td>
<td>54</td>
<td>100</td>
</tr>
<tr>
<td>Wind turbine</td>
<td>77,907</td>
<td></td>
<td>46</td>
<td>100</td>
</tr>
<tr>
<td>Generator</td>
<td>0</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>168,545</td>
<td></td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Excess electricity</td>
<td>88,581</td>
<td></td>
<td>52.6</td>
<td>0</td>
</tr>
<tr>
<td>Unmet electrical load</td>
<td>0.00099226</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Capacity shortage</td>
<td>0</td>
<td></td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

As shown in table 5 and 6, 100% energy generation is from renewable energy sources with the diesel generator serving as reserve to serve the system in the event of system failure.

The monthly average electricity production is as shown in fig 10

From fig. 10, it can be observed that the peak period of electricity production is January, with December, January and February as the periods of abundant renewable energy resources, the electrical output reduces progressively from the month of February to September, after which it begins to rise gradually. The electrical energy generated is also stored in the solar energy battery bank, which also gives back the energy to the system and as a result of the energy stored by the battery system; the AC production achieves a big boost to enable it serve the AC primary load as shown in fig. 11.

The configuration of the battery bank is given in fig. 12, a total of 480 6FM200D batteries was implemented by the simulator software with 16 batteries in parallel in a string size of 30 for energy storage using a bus voltage of 360V. The minimum state of charge of the battery is slightly above 40%, the battery bank has a nominal capacity of 1,152 kW and autonomy of 90.2 hours, the battery bank gives out a total of 31,149 kWh/yr, with losses of about 7700KWh/yr and an expected life of 10years. The batteries monthly statistics show that in the month of January, February, March, April, May, June, July, November and December, the battery bank state of charge remains high and this is because there is enough energy produced by the mix that the battery does not need to be used up, but in the month of August, the state of charge of the battery drops and the least is obtained in September and that is the month when the least electricity production is obtained. In those months in which the energy generated is more than the load demand, the storage of the excess energy is done by the battery bank.
IV. CONCLUSION

From the Homer Software simulator output, the total yearly electricity production is 168,545KWh/yr., the yearly AC primary load consumption is 67160 KWh/yr. And the excess electricity is 88581Kwh/yr. The excess electricity accounts for 52.6% of the total electricity generated. Conversely, from table 3, it can be seen that the peak demand is 20.64 KW, and the AC primary served as shown in fig. 11 shows that the AC primary load for each month was met. Therefore, the hybrid energy system has the potential to provide the affected area with adequate power supply that is environmentally friendly (no emission of pollutants).

The next line of research in this work is the modelling of the hybrid PV/wind/diesel Gen energy system using MATLAB.

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REFERENCES


