POTENTIALS OF A 5KW WIND ENERGY SYSTEM WITH INTEGRATED
STORAGE BANK FOR HOME ENERGY MANAGEMENT

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ABSTRACT
In this study, a 5kW wind energy system with an integrated storage bank is sized to supports a maximum of 2 households with a reliable daily energy need. For a successful implementation of this off-grid wind energy system, a 24-month wind data sampled on a 10m hub height and stored as 5-minute wind data are obtained for this study to anticipate the wind energy output at this site. Because of the variation of the wind, the energy output of this 5kW turbine is estimated using the statistical technique for the purpose of anticipating the energy output as the wind fluctuates. To mitigate the effect of the varying energy output as a result of the changing wind, the inclusion of battery bank is considered for a reliable energy supply. The annual mean wind speeds are estimated at 5.15m/s &4.99m/s and its equivalent wind power densities estimate at 165.0W/m² &149.8W/m² for the years 2009&2010, respectively. The daily energy generation at the site is estimated at 11.35kWh, average power required per household is estimated at 190.0W, and the daily energy consumption at 4.56kWh. The battery bank is sized at 200Ah, 240VDC; with a total of 40pcs, rated 12V at 100Ah and connected in series-parallel connection. Further, a 5kVA sine wave inverter is sized for a 48kWh battery bank.

KEY WORDS
Wind power density; battery bank & inverter; wind charge controller; load profile

1. INTRODUCTION
The small-scale wind energy system is one of the cost-effective home-based renewable energy systems used in location with sufficient wind resources for meeting the electricity needs. A small-scale wind energy system can be utilized for producing electric power primarily for remote areas or locations that do not have access to the national grid. Secondly, a small scale wind energy system can be used for net metering in residential or small commercial applications where the producer has excess power generation that can be sold to the neighborhood or utility. For net metering application, the wind energy system can be utilized as a grid-tie or stand alone which consists of a single small wind turbine or more units of not more than 1MW. Furthermore, it can be utilized for charging battery bank for backup power during the period of limited energy generation. Around the world, the small-scale energy system has found variety of applications in homes, farms, small businesses, remote monitor systems, hospitals, communication systems, banks, schools and institutions etc with no grid connection, limited electricity supply or for reducing the increasing electricity bills from the grid [1-2]. In order to improve the reliability of an off grid wind energy system for meeting the daily energy demand of the household, a storage system is required to compensate for the energy generation during limited or calm wind [3-5]. This is because the energy demand by the household is unpredictable especially during peak hours of usage. As a result, the energy storage systems are crucial for managing the varying energy generation of the wind turbine during limited generation.

In this study, a 5kW wind energy system with an integrated battery bank is proposed at Darling site for a reliable energy service of 1-2 households. To anticipate the daily energy output of the wind turbine for accurately sizing of the battery bank, the site wind resources for the period of 24 months at 10m height were accurately modeled. The modeled and evaluated wind resources were used to determine the wind power class of this site. Based on the wind power class, a 5kW wind turbine was accurately sized for the wind resources at this height. The hourly, daily, weekly, monthly and annual energy outputs of the turbine were estimated. Due to the intermittent nature of the wind at Darling, an inclusion of storage/battery bank to mitigate the varying energy output of the 5kW turbine is considered. To determine the number of households that can be supported with a 5kW wind energy system, the load profile of each household was determined. Based on the estimated hourly energy demand, the daily energy consumption per household is determined. The daily energy generation and energy consumption per household is used to estimate the maximum number of household that can be supported.

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with a reliable energy supply. The energy balance analysis shows that a maximum of 2 households can be supported with a reliable electricity supply. The battery bank is sized for low current drainage providing a reliable energy services for the period of 48hours to the household(s). For peak loads, the energy storage can only be utilized for the period of 12.03 hrs per household and 6.01 hrs for the 2 households. As a result, it is assumed that the 2-households are able to manage the energy generation and storage to ensure a reliable supply for the period of 48hrs. The network is designed in a way that during energy generation, the battery bank is been charged and electricity is been supplied to the households at the same time. The maximum hours of charging with the hourly current discharge of the battery bank have been estimated. Results show a strong agreement with the hourly energy generation of the 5kW wind power plant and the hourly energy demand per household. The most cost-effective battery bank design for these household are 40pcs of 100Ah batteries rated at12V, connected in series-parallel connection to make a 200Ah at 240VDC.

2. STATISTICAL ANALYSIS OF WIND SPEED DATA

The wind varies continuously as a function of time and season, increasing heights, topography of the terrain, weather effect etc. The energy generated by a wind turbine at a given site depends on factors such as the mean wind speed, and direction, the terrain structure of the site, the power coefficient of the rotor blades, the swept area of the rotor blade, the positioning of the wind turbine and the overall efficiency of the wind energy system itself. However, the mean wind speed (MWS) is the most important factor considered when assessing the wind resources of a site for wind energy application. To assess and the wind resources at 10m height for a reliable energy supply to the N-household, the mean wind speeds are estimated using Eq. (1) [6]

\[ \bar{v} = \frac{1}{N} \sum_{i}^{N} v_i \]  
(1)

where \( v_i \) is the wind speed observation at \( i^{th} \) time, \( N \) is the number of wind speed data points, and \( \bar{v} \) is the mean wind speed.

Table 1 shows the summary of the monthly mean wind speed (MWS) and the estimated wind power densities (WPD) at 10m height above ground level. The estimated mean wind speed values are used for determining the wind power densities, the site power class for the selection of the 5kW wind turbine.

The variation of the wind speed is as a result of the effect of varying wind which propagates with the changing weather conditions. The wind speed variation at a given site is usually described using the wind distribution. To identify the suitable statistical distribution for describing the wind speed variation at a given site, the Weibull, Rayleigh, Gamma, Lognormal, Logistic functions have been used [7-11] etc. However, the two distribution functions considered for describing the wind speed variation at this site are the actual, and the Rayleigh functions. The mathematical modeling of the wind speed for this study has been discussed by olaofe et al [12]. For this study, only the Rayleigh distribution was considered for the estimation of the wind power densities and the power class.

3. WIND POWER ANALYSIS

The available wind power per unit swept area known as the wind power density (W/m²) is defined as

\[ P = \frac{1}{2} \rho(h) v^3 \]  
(2)

where \( v \) is the observed wind speed, \( \rho(h) \) is the varied air density sweeping the rotor blade, and \( P \) is the wind power density.

From Eq. (2), Equating \( v^3 = \int_{0}^{\infty} \rho(h) f(v)dv \) into Eq. (2), the actual wind power density \( P_A \) is obtained in Eq. (3)

\[ P_A = \frac{1}{2} \rho(h) \int_{0}^{\infty} v^3 f(v)dv \]  
(3)

where \( f(v) \) is the actual wind distribution and \( P_A \) is the actual wind power density.

The Rayleigh wind power density \( P_R \) is estimated as[12]
The electrical power of the wind generator is defined as

\[ P_e = \frac{1}{2} C_p \rho(h) A v^3 \]  

(6)

where \( A \) is the swept area of the rotor blades (12.57m²), \( C_p \) is the power coefficient (0.333), and \( P \) is the extracted wind power of the turbine (W).

The electrical power of the wind generator is defined as the measure of the instantaneous rate of electricity produced by the generator for a given wind speed \( v \):

\[ P_e(v) = \eta_g \cdot P \]  

(7)

where \( P_e(v) \) is the electrical power produced, \( \eta_g \) is the efficiency of the gearbox and the generator which is assumed at 98.5%.

In term of the site’s wind distribution, the electrical power output of the generator is defined by Eq. (8)

\[ P_{av} = \int P_e(v) f(v) dv \]  

(8)

where \( f(v) \) is the wind distribution obtained from the Rayleigh function; \( P_{av} \) is the average electrical power output of the turbine as the wind changes.

The energy output of the wind generator running at rated power of 5kW and working for \( N_h \) (hours) per day is estimated as

\[ E = N_h \left[ \int P_e(v) f(v) dv \right] \]  

(9)

where \( N_h \) is the number of working hours per day of the wind turbine; \( E \) is the energy yield of the 5kW wind turbine (Wh) using the Rayleigh wind distribution.

The summary of the estimated monthly varied air density \( \rho(h) \), the average power \( P_{av} \) and energy output using the Rayleigh distribution \( E_R \) for the year 2009-2010 are shown in table 2. Column 2 shows that the air density varies with the air temperature and atmospheric pressure at the site. Columns 3 and 4 show that the average power and energy output of the 5kW turbine varies continuously as a function of time and season, weather effect, wind speed, and direction, power coefficient of the rotor blades \( C_p \), the efficiency of the wind turbine.

<table>
<thead>
<tr>
<th>Month</th>
<th>( \rho(h) ) kg/m³</th>
<th>( P_{av} ) kW</th>
<th>( E_R ) MWh</th>
<th>( \rho(h) ) kg/m³</th>
<th>( P_{av} ) kW</th>
<th>( E_R ) MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>1.201</td>
<td>0.774</td>
<td>0.576</td>
<td>1.201</td>
<td>0.839</td>
<td>0.624</td>
</tr>
<tr>
<td>Feb</td>
<td>1.193</td>
<td>0.709</td>
<td>0.477</td>
<td>1.193</td>
<td>0.465</td>
<td>0.312</td>
</tr>
<tr>
<td>Mar</td>
<td>1.196</td>
<td>0.465</td>
<td>0.346</td>
<td>1.196</td>
<td>0.406</td>
<td>0.302</td>
</tr>
<tr>
<td>Apr</td>
<td>1.216</td>
<td>0.410</td>
<td>0.295</td>
<td>1.216</td>
<td>0.458</td>
<td>0.330</td>
</tr>
<tr>
<td>May</td>
<td>1.220</td>
<td>0.410</td>
<td>0.305</td>
<td>1.220</td>
<td>0.438</td>
<td>0.326</td>
</tr>
<tr>
<td>Jun</td>
<td>1.234</td>
<td>0.543</td>
<td>0.391</td>
<td>1.234</td>
<td>0.299</td>
<td>0.215</td>
</tr>
<tr>
<td>July</td>
<td>1.240</td>
<td>0.270</td>
<td>0.201</td>
<td>1.240</td>
<td>0.212</td>
<td>0.158</td>
</tr>
<tr>
<td>Aug</td>
<td>1.233</td>
<td>0.361</td>
<td>0.268</td>
<td>1.233</td>
<td>0.307</td>
<td>0.228</td>
</tr>
<tr>
<td>Sept</td>
<td>1.225</td>
<td>0.499</td>
<td>0.359</td>
<td>1.225</td>
<td>0.421</td>
<td>0.303</td>
</tr>
<tr>
<td>Oct</td>
<td>1.218</td>
<td>0.593</td>
<td>0.441</td>
<td>1.218</td>
<td>0.527</td>
<td>0.392</td>
</tr>
<tr>
<td>Nov</td>
<td>1.208</td>
<td>0.754</td>
<td>0.543</td>
<td>1.208</td>
<td>0.617</td>
<td>0.444</td>
</tr>
<tr>
<td>Dec</td>
<td>1.195</td>
<td>0.598</td>
<td>0.445</td>
<td>1.195</td>
<td>0.684</td>
<td>0.509</td>
</tr>
<tr>
<td>Sum</td>
<td>1.215</td>
<td>0.532</td>
<td>4.647</td>
<td>1.215</td>
<td>0.473</td>
<td>4.143</td>
</tr>
</tbody>
</table>

4. SYSTEM ARCHITECTURE OF A 5KW WIND ENERGY SYSTEM WITH BATTERY BANK

The system architecture of a 5kW wind energy system with an integrated storage bank is shown in figure 1. For this wind energy system, a 3-bladed, 5kW wind turbine(s) with the following specifications are considered: a rotor diameter of 4.0m, start-up-speed of 2.5m/s, cut-in-speed of 3.0m/s, nominal speed of 12.5m/s, cut-out speed of 25m/s, and survival speed of 63m/s, hub height of 10m, generator efficiency of 98.5%, and a yaw pitch power control regulation. The wind turbine has a dc voltage output of 240VDC, and a maximum charging current of 20.83A output. The circuit breaker (CB) rated 240VDC is incorporated into the network for over-voltage/current protection. The CB adopts overvoltage protection technique and when the input DC voltage exceeds 240V, the CB enters overvoltage disconnection state to protect the charge controller from damage. The charge controller adopts an autonomous power sharing.
technique; where part of the DC power are transfer to the household via the sine wave inverter while some of the DC power are stored in the battery bank as backup power in the event of limited generation. Secondly, the high DC voltage charge controller is sized to match the system voltage of the battery bank with the high DC voltage output of the turbine. In addition, the charge controller monitors DC amperage and voltage entering and leaving the system ensuring the storage bank received the required voltage and charging current needed to charge the battery bank. The charge controller regulates the energy flow into and out of the battery, and it has a two typical voltage level control; (i) the upper voltage level which measures the battery bank voltage and if the voltage exceed the floating voltage, it divert the excess power to the dump load and (ii) the lower voltage level which switch off the dump load when the battery voltage drops below the threshold. The charge controller is an important device used with storage system which controls the charging voltage level and the depth of discharge (DoD) of the battery bank. An electronic inverter is sized with the battery bank for the household appliances utilizing AC power. The sine wave inverter takes the incoming DC power from the battery bank via the charge controller and converts it to AC power which is sent to the households via the AC distribution bus. The centralized electronic load controllers (ELC) are used as an interface between the households and the AC distribution bus. The ELC act as a current regulator, monitoring, and ensuring the current drawn by individual household(s) doesn’t exceed the set current level [14]. The system is designed for a base load energy support and in the case of peak load; all the energy stored in the battery bank is drained within a short period of 6.26 hrs and this will cause energy imbalance between energy supply and demand.

A. Load Profile Realization Per Household

The load profile is defined as the chart that gives the total power rating of the household appliances, the number of appliances, the number of hours of usage and the energy consumption of each appliance. At Darling community, it is assumed that all the households use equally amount of electricity at the same period of time and the load profile of each household is shown in table 3. Table 4 shows the summary of the electrical appliances used within the period of time, and the hourly energy consumption. The load profile is used to indicate how the energy consumption of the household changes with a given time. Also, the load profile is important because it helps in enhancing the energy balance between generation, supply and storage. Between the periods of 23:00pm to 5:00am, there is no energy consumption by the household and the available energy of the 5kW wind turbine is stored in the battery bank. Between the periods of 5:00-7:00am, the energy demands by the household rises and is complimented by the energy storage bank because of the limited generation at these times. Beyond these times, there is no energy demand/consumption because it is assumed that the household has left for work. The energy generation at this site between the periods of 07:00-17:00pm is stored in the battery bank. At 17:30pm, the energy consumption starts to rise and reaches its peak at 19:00pm. Though the energy generation and demand are at its peak during this period, the output of the turbine is not adequate to meet the peak load. As a result, the energy stored during the periods of 07:00-17:00pm is used to support the wind energy system for a reliable energy supply. During the peak hours, most of the targets such as Geyser, Electric Iron, Computer system Television etc are on. At 21:50pm, the household relies on the energy output of the battery bank due to zero energy generation at this time. The energy storage is discharge rapidly and will continue to meet the energy demand till around 23:00pm. The energy generation and storage follow the same trend until when the energy demand begins to rise above the energy generation as shown in figures 2 and 3. During the peak hours, the 2 households will have to depend heavily on the battery bank storage to meet the demand as shown in figure 3.
Table 3
Estimated Load Profile for a Single Household

<table>
<thead>
<tr>
<th>Appliances</th>
<th>Power rating (W)</th>
<th>Number of appliances</th>
<th>Hours of usage per day (h)</th>
<th>Daily energy demand (Wh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compact Fluorescent Lamp (CFL)</td>
<td>30</td>
<td>2</td>
<td>7</td>
<td>420</td>
</tr>
<tr>
<td>LCD Television</td>
<td>85</td>
<td>1</td>
<td>4</td>
<td>340</td>
</tr>
<tr>
<td>DVD/Decoder</td>
<td>40</td>
<td>1</td>
<td>4</td>
<td>160</td>
</tr>
<tr>
<td>Cell phone charger</td>
<td>20</td>
<td>2</td>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>Audio System</td>
<td>250</td>
<td>1</td>
<td>1</td>
<td>250</td>
</tr>
<tr>
<td>Electric Iron</td>
<td>1200</td>
<td>1</td>
<td>0.5</td>
<td>600</td>
</tr>
<tr>
<td>Microwave Oven</td>
<td>1000</td>
<td>1</td>
<td>0.5</td>
<td>500</td>
</tr>
<tr>
<td>Electric fan</td>
<td>60</td>
<td>1</td>
<td>5</td>
<td>300</td>
</tr>
<tr>
<td>Electric blender</td>
<td>400</td>
<td>1</td>
<td>0.5</td>
<td>200</td>
</tr>
<tr>
<td>Computer System</td>
<td>350</td>
<td>1</td>
<td>1</td>
<td>350</td>
</tr>
<tr>
<td>Geyser</td>
<td>400</td>
<td>1</td>
<td>3.5</td>
<td>1400</td>
</tr>
<tr>
<td><strong>Maximum power /energy demand</strong></td>
<td><strong>3835</strong></td>
<td><strong>-----</strong></td>
<td><strong>-----</strong></td>
<td><strong>4560.00</strong></td>
</tr>
</tbody>
</table>

Figure 2
5-minutes power chart for matching the daily energy demand and supply per household

Table 4
Hourly Load Profile Realization per Household

<table>
<thead>
<tr>
<th>S/N</th>
<th>PERIOD OF TIME (Hr)</th>
<th>APPLIANCES</th>
<th>TOTAL ENERGY CONSUMPTION (Wh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>23:00-05:00</td>
<td>-----------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>2</td>
<td>05:00-06:00</td>
<td>CFL, Audio System, Oven</td>
<td>185</td>
</tr>
<tr>
<td>3</td>
<td>06:00-07:00</td>
<td>-----------</td>
<td>685</td>
</tr>
<tr>
<td>4</td>
<td>07:00-17:00</td>
<td>Energy Storage</td>
<td>-----------</td>
</tr>
<tr>
<td>5</td>
<td>17:00-18:00</td>
<td>Electric blender</td>
<td>400</td>
</tr>
<tr>
<td>6</td>
<td>18:00-19:00</td>
<td>Cell-phone charging, CFL, LCD-TV, DVD/Decoder, Electric Fan, Geyser, Computer System</td>
<td>1245</td>
</tr>
<tr>
<td>7</td>
<td>19:00-20:00</td>
<td>-----------</td>
<td>685</td>
</tr>
<tr>
<td>8</td>
<td>20:00-21:00</td>
<td>-----------</td>
<td>645</td>
</tr>
<tr>
<td>9</td>
<td>21:00-22:00</td>
<td>-----------</td>
<td>245</td>
</tr>
<tr>
<td>10</td>
<td>22:00-23:00</td>
<td>-----------</td>
<td>470</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>-----------</strong></td>
<td><strong>4560.00</strong></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3
5-minute power chart for matching the daily energy demand and supply for 2 households

Table 5
Summary of the Annual, Monthly and Daily Energy Generation of a 5kW Wind Turbine at Darling Site

<table>
<thead>
<tr>
<th>Year</th>
<th>$E_A$ (MWh)</th>
<th>$E_M$ (kWh)</th>
<th>$E_D$ (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>4.143</td>
<td>345.25</td>
<td>11.35</td>
</tr>
<tr>
<td>2009</td>
<td>4.647</td>
<td>387.25</td>
<td>12.73</td>
</tr>
</tbody>
</table>

where $E_A$, $E_M$ and $E_D$ are the annual, monthly and daily energy generation of the 5kW wind turbine at Darling site, respectively
B. Sizing of an Battery Bank

There are different approaches for sizing of storage batteries for renewable energy applications. For this study, the battery bank capacity (Ah) is sized based on the total daily energy demand (Wh) and it is not designed for a peak load levelling. To accurately size the storage bank for reliable supply of electricity, the daily energy demand per household is estimated based on the load appliances. Once the daily energy demand is known, the daily energy generation at the site is estimated to determine the number of households that can be connected to this standalone system. Table 5 shows the summary of the daily, monthly, and annual energy generation of the 5kW wind turbine at the site for the year 2009-2010.

The Number of households is determined as follows

To determine the \( N \) number of household(s) that can be connected to a 5kW wind energy system with the same daily energy demand of 4560.0Wh per day (with losses), Eq. (10) is used.

\[
x = \frac{\text{Annual energy generation}}{\text{annual energy demand per household}} \quad (10)
\]

The battery bank is sized as follows

The storage bank is sized in Amp-hour (Ah) and the deep cycle lead acid batteries are considered for this study. To size the energy storage capacity to support a maximum of 2 household(s) with a reliable energy supply, Eq. (11) is used

\[
C_b = \frac{E_d \times N_d}{V_b \times \text{DoD}} \quad (Ah) \quad (11)
\]

where \( C_b \) is the Amp-hour battery capacity, \( E_d \) is the daily energy demand (Wh), \( \text{DoD} \) is the maximum allowable depth of discharge which varies with battery type, \( N_d \) is the number of day(s) of autonomy, \( V_b \) is the system voltage of the battery bank [14].

In sizing of a battery bank for daily energy supply of 6270Wh per household, the following factors are considered: the daily energy consumption “Watt-hours per day”; the type and ratings of the electrical loads to be connected; number of day(s) of autonomy storage; the cycle and the life expectancy of the battery; the depth of discharge “DOD” of the battery; system voltage of the battery bank; energy losses in the storage bank and the ambient temperature the batteries will be exposed to. From table III, the daily energy demand for 2 households is estimated at \( E_d = 4560 \times 2 = 9.12 \text{kWh} \) per day. Allowing for a 25% safety factor because battery bank are not perfectly efficient in storing and dispensing energy; the storage bank is oversized by 25%. The batteries lose storage capability as the ambient temperature decreases and it’s assumed that the battery bank will be exposed to air temperature of 15.6°C/60°F. The daily energy consumption of the 2 households including battery losses and ambient temperature effect on the battery bank due to exposure is estimated at \( E_d = 9.12 \text{kWh} \times 1.25 \times 1.11 = 12.54 \text{kWh} \) per day. Also, it is assumed that the battery has a usable capacity (DoD) of 60% because the more deeply a battery is discharged on each cycle, the shorter the battery life. Using Eq. (11), the battery bank is sized at 174.17Ah at \( V_b = 240 \text{VDC} \).

To determine the numbers of batteries needed to build a 174.17Ah battery bank rated at \( V_b = 240 \text{VDC} \) Eq. (12) is used:

\[
N_b = \frac{\text{Amp-hour rating of the battery bank}}{\text{Amp-hour of the battery voltage}} \quad (12)
\]

Therefore, we must have a 200 AH rated battery capacity to provide a deliver a battery capacity of 171.17Ah. The total numbers of individual batteries needed to build a 200Ah, 240VDC battery bank are (i) 20pcs of 12V batteries rated 100Ah each and connected in series to make a system battery bank rated 100Ah at 240V and (ii) 2 battery bank rated 100Ah at 240V are connected in parallel to give a total of 200Ah battery bank at 240VDC. This design is the most cost effective design and will meet the daily energy requirement. To design a 200Ah battery bank at 240V, a total number of 40pcs batteries rated 100Ah at 12V per string are needed to meet the daily energy demand of 2households.

The current discharge from the battery bank

Usually, a 200Ah battery capacity is designed for a 20 hour rate of discharge. To determine the current discharge from a 200Ah battery bank to the electronic inverter over a period of 1 hour, Eq. (13) is used

\[
I_t = \frac{\text{Amp-hour rating of the battery bank}}{\text{period of hour of storage/discharge}} \quad (13)
\]

\[= 4.167A\]

For peak load, it will require a current discharge of 16.63A per hr over the period of 12.03 hrs instead of the proposed 48hrs.

Charging of the battery bank

To determine the period of time to charge the battery bank by the wind turbine, Eq. (14) is used
\[ I_1 = \frac{\text{Amp-hour rating of the battery bank}}{\text{Current output from the wind turbine}} \] (14)

From Eq. (14), it takes a total of 9.21hrs to charge the 200Ah battery bank, and this shows a strong agreement with figures 3 and 4 where the power output of the turbine from the period of 7:00am to 17:00pm is un-utilized.

C. Sizing of the sine wave inverter

For pure sine wave inverter, the waveforms are purely sinusoidal and the phase angle between voltage and current is usually 36.9° (power factor = 0.80). To determine the rating of the sine wave inverter that is needed for a 240V, 200Ah battery bank, Eq. (15) is used.

\[ P_{\text{inv}} = \frac{\text{Power rating of the appliances}}{\text{power factor}} \] (15)

\[ = 4781.25 \sim 5.0\text{kVA} \]

where \( P_{\text{inv}} \) is the power rating of the electronic inverter (VA)

This means that a 5.00kVA sine wave inverter with a current delivery of 4.167A per hour from the battery bank will handle the daily energy requirement of the 2 households.

5. DISCUSSION

This study has presented the potentials of a 5kW wind energy system with integrated storage bank for home energy management. It is believed that the implementation of this design at Darling site with sufficient wind resources, and no grid-connected connection will be the most cost-effective approach for generation of electricity in meeting the daily energy needs. In order to improve the reliability of this energy system for electricity balance, a collection of 24-month wind data at a 10m height were accurately modeled and evaluated for sizing of the wind turbine for electricity generation. The evaluated wind resource shows that the wind resources at this height can be utilized for electricity generation. Figure 1 shows the monthly wind speed variation at 10m height for the year 2010. The estimated wind speed and the wind power density were used to determine the wind power class of the site for the selection of the 5kW wind energy system. Table 1 shows the summary of the monthly mean wind speed and its equivalent wind power density using the Rayleigh distribution. The annual mean wind speeds are estimated at 5.15m/s &4.99m/s and its equivalent wind power densities estimate at 165.0W/m² &149.8W/m², respectively for the years 2009&2010, respectively. The selected 5kW wind turbine at 10m height was used to estimate the energy generation at every 5-minute. Table 2 shows the summary of the monthly mean air densities, working days, the average power, and energy output of the turbine for 2010, respectively. Because of the variation of the wind, an integrated energy compensator during limited generation is incorporated as shown in figure 1. There are various types of energy compensator that can be utilized for home energy management but the deep acid lead acid battery is considered as the most cost-effective for these households. Because of the variation of the daily energy generation at this site, the load profile realization for the 2 households were obtained to determine the size of the storage bank needed for this application as shown in figures 3 and 4. In sizing of the battery bank for 2 households, the daily energy demand per household was compared with the daily energy generation of the turbine, and with the reliability of the 48kWh battery bank in meeting the peak energy needs. The inclusion of storage bank shows that the problem of the intermittency of the wind especially during peak hours of demand by the households can be managed. The charging current of the battery bank from the wind turbine was estimated at 20.83A for the period of 9.21hrs, and the hourly period of energy discharged was estimated at 4.167A. The estimated period of charging of the battery bank shows a strong agreement with the period of time (7:00am to 17:00pm) when the energy output of the turbine remains un-utilized by the households. At this period, the energy output is stored in the battery bank. Beyond the period of 9.21hrs, the wind charge controller switch on the integrated dump load to prevent over-charging of the battery bank. During peak hours of demand, the energy storage in the battery bank is dispatched to meet the energy demand till around 23:00pm as shown in figures 2 and 3. The energy storage in the battery bank is able to meet the energy demand between the periods of 18:00 to 23:00pm when the households’ appliances are fully utilized.

6. CONCLUSION

The evaluation of the wind resources at Darling on a 10m height for the period of 24 months have proven that the site wind resources can be utilized for home energy management and net-metering applications. The daily energy generation, storage and supply shows that a known load profile of each household will help in determining how much energy will be required at a given period of time. Finally, to support a maximum of the households with energy services, a minimum of 24 months wind data must be collected, accurately modeled and evaluated. Also, the wind energy system, battery bank, and the sine wave electronic inverter must be accurately sized for implementation of this stand alone wind energy system.
REFERENCES


