A comparative Study between Lead Acid and PKL Battery

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Abstract
The paper presents an experimental study on overall energy efficiency of Bryophyllum Pinnatum Leaf (BPL) cell and detailed practical case study on 12V-35Ah BPL battery system production cost, unit cost of electricity and monthly savings in comparison with 12V-35 Ah existing lead acid battery system for roadside floating fruit sellers community. The experimental result shows that the BPL cell energy efficiency is about 99.96%. Additionally, in practical case scenario the 12V-35Ah BPL battery production cost is calculated 300 BDT whereas, same rating lead acid battery will cost 6800 BDT. Unit cost of electricity for 75Wh/day discharge (fruit seller energy requirement) from BPL battery is calculated 3.375 BDT whereas it will be 9.00 BDT for same amount of energy requirement if the battery is lead acid. It turns out the monthly savings on energy bill will be a substantial amount for such low-income community or even businesses with similar type of energy need. Moreover, such off-grid DC supply from BPL battery system will highly reduce the unauthorized load pressure on National Electricity Grid if a large number of floating roadside fruit-seller start using BPL batteries in lieu of existing grid supply charged low graded lead acid batteries.

Keywords: PKL battery, Biomass energy, Lead acid battery, Comparative Study

I. Introduction:
The performance of cell is an important issue. There are some parameters through which we can measure the performance of the cell or battery. A brief outlines of key parameters used to characterize a cell or battery are discussed below. Also it is shown that how these parameters may vary with the operating conditions. The demand for energy (in terms of electricity) is increasing day by day. Smart Grid and Cyber physical power systems are evolving including renewable energy system to shift the world electricity production to green electricity [1-20]. Energy production from fossil fuel emits greenhouse gas which is detrimental for environment, but due to their availability energy is being extracted from fossil fuels such as natural gas, coal, crude oil etc. and this is rapid depletion of fossil fuels. Existing study showed the current energy condition of several countries and their probable future indicating shift towards green energy. Most of the people of Bangladesh live in rural areas and majority of them are poor [21-30]. The rural people in Bangladesh are tied to poverty and they needed small amount of energy in terms of electricity of doing most important works (e.g., to charge mobile phone) in their daily life [31-32]. So, to reduce poverty of that majority part of the countryside it is important to provide proper electricity to them. This is a great challenge for the government of Bangladesh to meet the future demand of electricity in rural areas. Electricity generation from biomass energy can be a most promising possible solution for rural areas of Bangladesh. Generation of electricity from pathor kuchi leaf (Bryophyllum Pinnatum), is an addition in the list of renewable energy [33-40]. This invention occurs in Bangladesh. Pathor Kuchi tree grows everywhere in Bangladesh and the produced juice from the leaf can be preserved for a long time which can be used to produce electricity. The acidity of PKL or BPL (Bryophyllum pinnatum Leaf) is the key responsible factor for production of electricity via electrochemical process. Like fuel cells (i.e. PEMFC, AFC), PKL cell can perform efficiently [42-55]. M. K. A. Khan et al. has conducted research work on Electrochemistry of PKL, Chemistry of PKL Electricity, Design of PKL Quasi Voltaic Cell and Conversion Efficiency of PKL Cell, BPL’s unit
cell, Process of Electricity Production and Public desire of BPL Electricity, Voltage Regulation, Capacity of PKL and Energy efficiency of PKL system, Discharge Rates, Capacity & Discharge Time, Pulse Performance and Cycle life & Deep Discharge, Ideal Characteristics of BPL Electricity, Electricity generation from BPL and an overview of BPL Electricity Power plant, A hybrid model of BPL Electricity module and Solar (PV) Cell designed and analyzed at different operational conditions, I-V characteristics curve of PKL, maximum energy conversion efficiency, practical testing of PKL, BPL fueled cell and BPL Nano power plant are discussed in, respectively. Author of this paper discussed about Discharge Rates, Capacity & Discharge Time, Pulse Performance and Cycle life & Deep Discharge. The key aim of this paper is to study on overall energy efficiency of *Bryophyllum Pinnatum* Leaf (BPL) cell and detailed practical case study on 12V-35Ah BPL battery system production cost, unit cost of electricity and monthly savings in comparison with 12V-35 Ah existing lead acid battery system for roadside floating fruit seller’s community [56-70].

II.  Methodology

II A. Discharge Curves

The nominal voltage of a galvanic cell is fixed by the electrochemical characteristics of the active chemicals used in the cell. The actual voltage appearing at the cell terminals at any particular time depends on the load current and the internal impedance of the cell and this also varies with the temperature, the state of charge and with the age of the cell. The fig.-1 shows typical discharge curves for cells using a range of cell chemistries. The X axis shows the cell characteristics as a percentage of cell capacity. Each cell chemistry has its own characteristic nominal voltage and discharge curve. Some chemistry such as Lithium ion have a fairly flat discharge curve while others such as Lead acid have a pronounced slope.

![Fig. 1: Typical discharge curves for cells.](image)

The power delivered by cells with a sloping discharge curve falls progressively throughout the discharge cycle. This could give rise to problems for high power applications towards the end of the cycle. For low power applications which need a stable supply voltage, it may be necessary to incorporate a voltage regulator if the slope is too steep. A flat discharge curve simplifies the design of the application in which the battery is used since the supply voltage stays reasonably constant throughout the discharge cycle.

II B. Discharge Characteristics of PKL Cell

To measure the discharge characteristics of PKL cell a module of PKL was taken. It considered as 6 volts PKL system. We connected a constant incandescent lamp load of 6 volts. The arrangement of measuring is shown in Fig.2. For simplicity we show the PKL system as a unit cell.
Fig-2: Arrangement of measuring discharge characteristics.

We observed the voltage and current as listed below in table-1. We continue the taking the load test 120 minutes i.e. 3 hours from beginning. It may be pointed out here that initially when we connected the load a substantial voltage drop occurs and this drop is 0.48 Volts which is around 8% of system voltage. We also show a column for power drawn by the load in the table multiplying voltage and current.

<table>
<thead>
<tr>
<th>Time duration (min)</th>
<th>Load Voltage , V (Volt)</th>
<th>Load Current, I (A)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5.52</td>
<td>0.76</td>
<td>4.2</td>
</tr>
<tr>
<td>5</td>
<td>5.51</td>
<td>0.75</td>
<td>4.1</td>
</tr>
<tr>
<td>10</td>
<td>5.51</td>
<td>0.74</td>
<td>4.1</td>
</tr>
<tr>
<td>15</td>
<td>5.50</td>
<td>0.73</td>
<td>4.0</td>
</tr>
<tr>
<td>20</td>
<td>5.50</td>
<td>0.72</td>
<td>4.0</td>
</tr>
<tr>
<td>25</td>
<td>5.50</td>
<td>0.71</td>
<td>3.9</td>
</tr>
<tr>
<td>30</td>
<td>5.49</td>
<td>0.70</td>
<td>3.8</td>
</tr>
<tr>
<td>35</td>
<td>5.49</td>
<td>0.69</td>
<td>3.8</td>
</tr>
<tr>
<td>40</td>
<td>5.48</td>
<td>0.68</td>
<td>3.7</td>
</tr>
<tr>
<td>45</td>
<td>5.46</td>
<td>0.67</td>
<td>3.7</td>
</tr>
<tr>
<td>50</td>
<td>5.45</td>
<td>0.66</td>
<td>3.6</td>
</tr>
<tr>
<td>55</td>
<td>5.45</td>
<td>0.65</td>
<td>3.5</td>
</tr>
<tr>
<td>60</td>
<td>5.44</td>
<td>0.64</td>
<td>3.5</td>
</tr>
<tr>
<td>65</td>
<td>5.43</td>
<td>0.63</td>
<td>3.4</td>
</tr>
<tr>
<td>70</td>
<td>5.41</td>
<td>0.62</td>
<td>3.4</td>
</tr>
<tr>
<td>75</td>
<td>5.39</td>
<td>0.61</td>
<td>3.3</td>
</tr>
<tr>
<td>80</td>
<td>5.37</td>
<td>0.60</td>
<td>3.2</td>
</tr>
<tr>
<td>85</td>
<td>5.35</td>
<td>0.58</td>
<td>3.1</td>
</tr>
<tr>
<td>90</td>
<td>5.32</td>
<td>0.56</td>
<td>3.0</td>
</tr>
<tr>
<td>95</td>
<td>5.30</td>
<td>0.54</td>
<td>2.9</td>
</tr>
<tr>
<td>100</td>
<td>5.27</td>
<td>0.52</td>
<td>2.7</td>
</tr>
<tr>
<td>105</td>
<td>5.25</td>
<td>0.48</td>
<td>2.5</td>
</tr>
</tbody>
</table>
Based on the observed result we plot three characteristics of PKL cell. These are for voltage, current and power graph for the load. All these are on same time frame. These graphical representation show how voltage, current and power changes with time.

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Current</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.23</td>
<td>0.48</td>
<td>2.5</td>
</tr>
<tr>
<td>5.20</td>
<td>0.46</td>
<td>2.4</td>
</tr>
<tr>
<td>5.18</td>
<td>0.44</td>
<td>2.3</td>
</tr>
</tbody>
</table>

As per this graph it is seen that the voltage is reducing gradually as time passes. If we compare it with other cells we find this change is relatively rapid. Fig.- 4 shows the current graph for the same system.

As per this graph it is seen that the load current is reducing gradually as time passes. If we compare it with other cells we find this change is relatively rapid. Fig.-5 shows the power graph for the same system.
We know, Power, $P = V \times I$, Where, $V =$ Voltage (volt), $I =$ Current (A)
Since voltage and current are reducing with time therefore as per this graph it is seen that the load power is also reducing gradually as time passes. For a sustainable system this going down process shall be lower.

II.C Self Discharge Characteristics
The self discharge rate is a measure of how quickly a cell will lose its energy while sitting on the shelf due to unwanted chemical actions within the cell. The rate depends on the cell chemistry and the temperature.

The following shows the typical shelf life for some primary cells:
- Zinc Carbon (Leclanché) 2 to 3 years
- Alkaline 5 years
- Lithium 10 years or more

Typical self discharge rates for common rechargeable cells are as follows:
- Lead Acid 4% to 6% per month
- Nickel Cadmium 15% to 20% per month
- Nickel Metal Hydride 30% per month
- Lithium 2% to 3% per month

The Fig. 6 below shows typical self discharge rates for a Lithium Ion battery.

II D: Self Discharge Characteristics of PKL Cell
Like other cells PKL cell also lose its power with time. Though it is not quantify yet and at this stage it is not needed so much therefore it is not done. But it shows a very interesting characteristic with time. If we keep it unused for some
time its capacity regains. Therefore, it shows better result on intermittent use with some time gap. And in this way it can be used for longer time than continuous use.

III.C Energy Efficiency of BPL/PKL Cell:
PKL cell is a renewable source which produces electricity through chemical process. This cell needs not to be charged. So, the conventional method of calculating energy efficiency is not applicable for this cell [71-90]. Conventional method of calculating energy efficiency is discussed. In next two sections, experimental data are tabulated in Table-1 and calculation of energy efficiency for one unit cell; experimental data of energy efficiency and % of PKL juice concentration are tabulated in Table-1 respectively [91-100].

Experimental Data:
During experiment we have collected several parameters data for 6 unit cells e.g., voltage (avg.) with load, current with load and energy efficiency which are tabulated in Table-1.

### Table -1: Experimental Data - Energy Efficiency

<table>
<thead>
<tr>
<th>Cell Number</th>
<th>Internal resistance (Ω)</th>
<th>Potential with Load (Avg.) (V)</th>
<th>Current flow with load (A)</th>
<th>Energy Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.6</td>
<td>3.500</td>
<td>0.154</td>
<td>97.43</td>
</tr>
<tr>
<td>2</td>
<td>0.6</td>
<td>3.102</td>
<td>0.111</td>
<td>98.96</td>
</tr>
<tr>
<td>3</td>
<td>0.6</td>
<td>2.489</td>
<td>1.74×10⁻³</td>
<td>99.96</td>
</tr>
<tr>
<td>4</td>
<td>0.6</td>
<td>3.271</td>
<td>0.109</td>
<td>98.4</td>
</tr>
<tr>
<td>5</td>
<td>0.6</td>
<td>3.358</td>
<td>0.166</td>
<td>97.12</td>
</tr>
<tr>
<td>6</td>
<td>0.6</td>
<td>3.404</td>
<td>0.192</td>
<td>96.73</td>
</tr>
</tbody>
</table>

Calculation of Energy efficiency for one-unit cell:
To calculate energy efficiency we have the following parameters:
Load voltage = 3.5 V, Load current = 0.154 A, Internal resistance = 0.6 Ohm, Therefore, we can find the output power using following equation: Output Power = (Load voltage)(Load Current) = (3.5 V)(0.154 A) = 0.539 W. Now, Power loss through internal resistance of the cell = 

\[ \text{Power loss} = (0.154 \text{ A})^2 \times 0.6 \text{ Ohm} = 0.014 \text{ W} \]

Therefore, Energy efficiency = \[ \frac{0.539}{0.539+0.014} \times 100\% = 97.47\% \]

III. B. Case Study:
Road Side Floating Fruit Seller Community

An extensive survey has conducted on floating fruit seller community at Mirpur 1, Dhaka, Bangladesh [101-125]. It was observed that majority of them are using low loads (in between 15-25 watt) at their places. They are using low graded conventional lead acid rechargeable batteries for cost minimization but it affects the overall battery performance and lifetime significantly. It results negative impact in their businesses [126-133]. On the other hands, it is hardly possible to buy good performance batteries with higher lifetime for them due to low monthly income (less than 9000 BDT). They demand for a comparatively better performance and lifetime with lower battery cost [134-160].

Fig 1: Number of users with respect to available lead acid rechargeable batteries in Ah [161-170]. It has been seen from above figure that the maximum consumers (around 100) are using 7 Ah batteries to the load [171-180]. The discharging time is 5 hours per day. So, 12V- 35 Ah battery is used for such system. The survey was done on 270 shops of fruit seller in the above-mentioned area.

III. C. Comparative Cost Calculation of 12V- 35Ah battery System: (Lead Acid vs PKL):
- Consumer Details: 1 Fruit seller
- Consumer Load: 15w (DC)
- Hours of use: 5 hours per day
- Energy demand: 5x15=75Wh (for 1 Fruit Seller)

III.D. Lead Acid Battery Details: (Existing)
- Rating: 12V-35Ah
- Manufacturer: JSK KAKA
- Retail Cost: 85 USD or 6800 BDT (Considering, 1 USD = 80 BDT)

III.E. 12V-35Ah PKL Battery Cost:

<table>
<thead>
<tr>
<th>Component name</th>
<th>Piece(s)</th>
<th>Price (BDT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn plate</td>
<td>1</td>
<td>52.5</td>
</tr>
<tr>
<td>Cu plate</td>
<td>1</td>
<td>92.4</td>
</tr>
<tr>
<td>Box (glass material + making cost)</td>
<td>1</td>
<td>105</td>
</tr>
<tr>
<td>Misc. (connectors + others)</td>
<td>-</td>
<td>50</td>
</tr>
<tr>
<td>Total production cost</td>
<td></td>
<td>300</td>
</tr>
</tbody>
</table>

III.F. Savings in terms of Battery Cost:
Lead acid battery retail price = 6800 BDT
PKL battery retail price = 300 BDT
Cost Savings = (6800 - 300) = 6500 BDT

III.G. Monthly electricity price for Lead acid battery:
Unit price of electricity in Bangladesh = 4 BDT/kWh; first slab (0-75 unit)
Consumer energy consumption = 75 Wh/day = 0.075 kWh/day = 2.25 kWh/month
(Considering, 1 month = 30 days)
Energy cost per month = 2.25 x 4 = 9 BDT

III.H. Monthly electricity price for PKL battery:
Per watt PKL battery cost = 0.3 BDT [ref]
Consumer requirement = 75 watt
Hours of use = 5 hours
Energy cost per month = = 3.375 BDT

III.I. Cost saving in terms of battery electricity price (Monthly):
Lead acid battery electricity price = 9 BDT
PKL battery electricity price = 3.375 BDT
Electricity price Savings = 5.625 BDT

IV. Discussions:
Fruit Seller’s community monthly saving on electricity price will be (270 x 5.625) = 1518.75 BDT. However, it will also reduce (2.25kWh x 270) = 607.5 kWh of energy required from grid electricity every month for 270 floating roadside fruit sellers. If it is considered to be a large community of 20,000 fruit sellers or even more the number of units saved per month will be a substantial amount which could be reduced the unauthorized connections pressure on National Electricity Grid. As the BPL battery is highly efficient over Lead Acid battery, the efficient performance with minimum cost could be ensured for longer period of time.

IV. Conclusion & Future Scopes:
It can be concluded regarding the *Bryophyllum Pinnatum* Leaf Battery (PKL electricity) and Lead Acid Battery System as follows:
- The utilization of PKL electricity for mobile technology is easy and simple but the Lead Acid Battery System is hard maintenance.
PKL electricity can help to set-up the small mobile charge centre for the betterment of the people those who are living at the off-grid areas but the Lead Acid Battery System is difficult to recharge.

Any people can set-up this technology easily.

Any people can earn 8-10 $ per day by setting-up a mobile charging centre using PKL electricity

Any handicapped person can set-up a mobile charge centre.

The cultivation of PKL for electricity generation is very easy.

There is no need for extra care to cultivate PKL.

The unused land like coastal areas, hilly areas, both sides of the road, forest areas are sufficient for cultivation of PKL for electricity production.

The internal resistance of the PKL cell depends on the Physical Characteristics of the PKL extract. The internal resistance becomes lower for smaller granular size of the of the PKL extract.

The internal resistance was increased at the contact point of electrodes and wires. So that it should be maintained with proper connection of electrodes.

The internal resistance of a PKL cell also depends on temperature of the extract

The voltage regulation of the PKL cell is comparatively low

It works same both rainy, day and night time

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