Comparative performance assessment of different battery technologies used for solar lighting applications

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***Abstract*— Batteries are often used in PV systems for the purpose of storing energy produced by the PV module during the day, and to supply it to electrical loads as needed (during the night and periods of cloudy weather). Many types and classifications of batteries are manufactured today, each with specific design and performance characteristics suited for particular applications. Each battery type or design has its individual strengths and weaknesses. Issues with these technologies are that they are sensitive to environmental condition (mainly temperature) and their capacity reduces with life. This paper addresses the variation in battery performance with temperature and ageing. Most widely used battery technologies for used with solar lighting applications are Lead acid and Li-ion; therefore we selected these batteries for this work. This paper divided mainly in four sections, first section presents over view of available battery technology for solar lighting application, its advantages & limitations and section second presents overview of the battery testing facility available at Solar Lighting Laboratory, TERI. In the third section, performance assessment of lead acid & li-ion batteries at different temperature condition and long term performance assessment of both types of batteries have been described. However, analysis of experimental data has been described in section four. There is a lot of future work and battery tests have been identified on this theme which will help to improve the long term testing facility in India.**

Index Terms*— long term performance assessment, solar lighting systems, battery technology. Introduction *(Heading 1)

1. INTRODUCTION

1.1. Overview of Battery Technologies

The world is approaching peak oil and the ability to produce high quality, inexpensive, and economical extractable oil on demand is diminishing. Peak oil and the environmental impact of fossil fuel utilization, has encouraged a growth in the area of renewable energies such as wind and solar power. In remote areas stand-alone photovoltaic systems are most common. A typical stand-alone system incorporates a photovoltaic panel, regulator, energy storage system, and load [5]. The most commonly used storage technologies are lead acid battery, Nickel based batteries and Lithium ion battery [1]. Li-ion batteries are a relatively new technology, first marketed in the early 1990's whereas lead acid is conventional used battery since 1980's. Nickel based batteries are in use since 1950, they are not so popular because of presence of memory effect. Comparison among these technologies is shown in Table 1. Most important performance parameter of battery is its capacity. Previous studies have shown that capacity fade is accelerated with temperature, charge rate, ageing effect [11]. This paper addresses how capacity of battery changes with change in temperature and capacity degrade with its age.

1.2. Lead Acid Battery

In 1859, the French physicist Gaston Planté invented the first rechargeable battery, based on lead acid. Lead acid batteries, the most important of four classes, are made in a variety of sizes and shapes for many applications [4]. The material used for cathode anode and electrolyte are lead oxide, lead, water and sulfuric acid respectively. There are two main families of Lead-based batteries they are, Vented/flooded batteries which require maintenance for periodical water additions and Valve-Regulated Lead Acid (VRLA) batteries, which are sealed and maintenance-free [1]. Despite of having a very low energy-to-weight ratio and a low energy-to-volume ratio, they are the most widely used battery technology because of its low cost and wide availability and they have ability to maintain a relatively large power-to-weight ratio [5]. These features, along with their low cost, make them attractive for use. The main advantage of lead Acid battery is economical and simple to manufacture, self- discharge is lowest compared to all other batteries, capable of discharging at high rates and 98% of lead acid batteries are recycled with low maintenance requirements. The main disadvantages are energy density is low, short life, and cannot be stored in discharged condition, environmentally unfriendly due to presence of lead which is toxic in nature, relatively poor performance at low and high ambient temperatures [2].

1.3. Lithium-Ion Battery

Lithium-ion batteries were commercialised in the beginning of the 90's and, due to their specific features, immediately took over half of the small consumer portable market [1]. Li-ion batteries are a relatively new technology and research & development work is ongoing to improve safety and increase capacity, charge/discharge rate, and lifetime [2]. The commonly used material for anode is carbon or graphite, for cathode is metal oxide or li-cobalt or li-iron phosphate or li-magnese oxide, and for electrolyte is Li salt in organic solvent. Now Lithium-ion (Li-ion) batteries are becoming more common. They are maintenance-free, can handle a higher number of cycles and deeper discharges and have as well more consistent charging and discharging characteristics. Moreover these batteries are versatile and can be designed to perform for different energy patterns [1]. The main advantage of lithium-ion batteries is their high energy density, they have a long cycle life and do not suffer from the high self-discharge rate and memory effect, unlike sealed lead acid (SLA) Li-ion batteries do not contain toxic heavy metals. The main disadvantage of Li-ion batteries is that they require careful attention to safety, overcharging, overheating, or short-circuiting a charged Li-ion battery can result in fire or explosion and performance is affected by environmental conditions [15].

Table 1: Comparison among Battery Technologies

Specification	**Lead Acid**	**Lithium ion**	
		Cobalt	**Phosphate**
In use since	1800s	1991	1999
Specific Density (Wh/Kg)	30-50	150-190	90-120
Cycle Life (80% Discharge)	200-300	150-190	90-120
Self-Discharge/Month (Room Temperature)	5%	<10%	
Cell voltage (nominal)	2V	3.6V	3.3V
Maintenance requirement	3-6 months	Not Required	
Toxicity	Very High	Less	

1.4. <u>Effect of Temperature on Battery Performance</u>

Charging at high temperatures might provide customers with the capacity higher than nominal but significantly decreases their cycle life [8]. To maintain the longer life and better performance, high ambient temperature should be avoided [9]. Chemical reactions internal to the battery are driven either by voltage or temperature. The hotter the battery, the faster chemical reactions will occur. High temperatures can thus provide increased performance, but at the same time the rate of the unwanted chemical reactions will increase resulting in a corresponding loss of battery life. The shelf life and charge retention depend on the self-discharge rate and self-discharge is the result of an unwanted chemical reaction in the cell. Temperature therefore affects both the shelf life and the cycle life as well as charge retention since they are all due to chemical reactions [18]. Generally any chemical or electrochemical process is accelerated by increasing temperature. This is true for batteries as well. Battery temperature can be increased by high ambient temperature or through the charging and discharging processes at high current rates. As a rule of thumb the lifetime of a battery is reduced by 50% with a temperature increase of 10 K. 10–20^{0}C is an ideal operating temperature for batteries. Low temperatures do not accelerate any irreversible ageing effects as long as the electrolyte is not freezing. Ice must be prevented from forming in a battery under all circumstances, as it is then practically impossible to operate the battery (in particular, a frozen battery can hardly be charged) and it is possible that the cell housing may burst (battery breakdown, contamination of the surroundings with sulphuric acid) [10]. Batteries must be protected against ambient high humidity environments, which might pass through dew point resulting in moisture condensation across the battery terminals. Such condensation would electrically shunt, shorting out the battery [12]. The two batteries were tested to investigate the effects of temperature on battery capacity and analysis is done on the basis of test results.

2. BATTERY TESTING FACILITY AT SOLAR LIGHTING LAB, TERI

Solar lighting laboratory (SLL) is a testing and evaluation center for solar lighting systems as well as other general purpose lighting system. The laboratory is located at Teri University, Vasant Kunj, New Delhi. It is established with the aim of testing of solar lighting system i.e. solar module, solar lantern, solar home lighting systems etc.

2.1. <u>Testing of Batteries at Different Temperatures</u>

Battery test bed is available to evaluate performance of batteries at different environment condition. The battery testing facility consists of data acquisition based battery test bed with two environment chambers as shown in *Fig 1(a)* and *Fig1(b).* The battery test bed consists of hardware and software. The hardware is designed in such a way that charging discharging rate, number of cycle and other parameters can be selectable and controlled through software. The system has provision for report generation through software. As name suggests environmental chamber, helps in maintaining different temperature. The environment chamber has sufficient space to keep four number of batteries simultaneously and temperature sensors available with battery test bed which is be used to log battery temperature simultaneously. Environmental chamber 1 is able to maintain positive temperatures while chamber 2 is able to maintain temperature below 0^{0}C.

2.2. *Long Term Performance Testing*

Solar lighting laboratory has outdoor testing facility for solar lighting systems. There is single axis manual tracker system installed for charging solar lighting system. Different rating and technology of solar modules can be installed these structure. Lab is well equipped for conducting long term performance assessment on solar lighting system. *Table 2* shows the specification of instruments used for this test.

Figure 1(a): Battery Testing Room at SLL TERI

Environment Chamber -1 *Environment Chamber -2*

Figure 1 (b): Environment chambers available at SLL lab. TERI

Figure 2: Battery charging station at SLL, TERI

Table 2: Specification of equipment used

S.NO	Equipment Used	Specification
1	Lead Acid battery	6V/4.5Ah
2	Li- ion Battery	7.2V/2.2Ah
3	Environmental Chamber1	0-45^0C
4	Environmental Chamber2	-20 to Ambient temperature
5	Battery Analyser	0-20A
6	Clamp Meter	10A
7	Multimeter	100V
8	Solar Lanterns	2.41W
9	Solar Power Meter	1999W/m^2

3. METHODOLOGY OF TESTING

3.1. *Variation of Battery Capacity with Temperature*

For this work battery capacity of both li-ion and lead acid batteries have been determined at 45^0C, 25^0C and -20^0 C and comparison has been done on the basis of results. Capacity measurement at temperature of 45^0C and 25^0C has been done using environmental chamber1; however environment chamber 2 has been used to test battery capacity at -20^0 C. Battery capacity is automatically calculated by data acquisition system.

3.2. *Long Term Performance Assessment*

For conducting long term performance assessment on different battery technologies, LED based solar lantern has been taken. One lantern is powered by lead acid battery while other one is powered by li-ion battery. LED lanterns are selected in such a way that it consumes same power. Battery of solar lantern is charged during day time by using 3W solar modules and batteries have been discharged through load in the next day. Wh generated by the solar module and Wh consumed by the battery have been manually logged during charging. A total hour of operation provided by lantern has been calculated during discharging. After conducting charging and discharging cycles, battery capacity has been measured on periodic basis.

RESULTS AND ANALYSIS

Variation of Battery Capacity with Temperature

After test, capacity of two above mentioned battery at temperature of 45^0C, 25^0C and -20^0C capacities are obtained as shown in *Figure 3*. *Figure 3* shows capacities at different temperature for Lead Acid and Li-ion Battery. From *Figure 3* we can conclude that, at high temperature of 45^{0} C high capacity 5.02Ah is obtained for lead acid and 2.09Ah for Li-ion which is more than the rated capacity. At room temperature of 25^{0}C almost rated battery capacity is obtained, i.e. 4.19Ah for Lead Acid battery and 2.02Ah for Li-ion battery. At low temperature, -20^{0}C battery capacity reduces to 1.35Ah for Li-ion and 3.98Ah for Lead acid. Percentage change from rated capacity for different temperatures is evaluated and graph is shown in *Fig.4 and Fig.5*. If rated capacity is assumed to be 100% then 93% of rated capacity (i.e. 4.19Ah) of - lead acid Battery is obtained at room temperature, 25^{0} C. At high temperature of 45^{0} C, 115% of rated capacity of lead acid is obtained, i.e. 15% more than the rated capacity is obtained. While at low temperature of -20^{0}C, lead acid battery capacity reduces to 88%. In case of li-ion battery, at room temperature 25^{0} C 93% of rated capacity is obtained at temperature of 45^{0} C, 95% of rated capacity is obtained while at temperature of -20^{0}C, 88% of rated capacity is obtained. This shows that battery capacity varies with temperature. At high temperature high capacity is obtained whereas at low temperature capacity reduces. From *Fig.3*, *Fig.4* and *Fig.5*, it can be concluded that performance of Li-ion is highly affected by variation of temperature whereas effect of temperature is less on Lead acid battery performance.

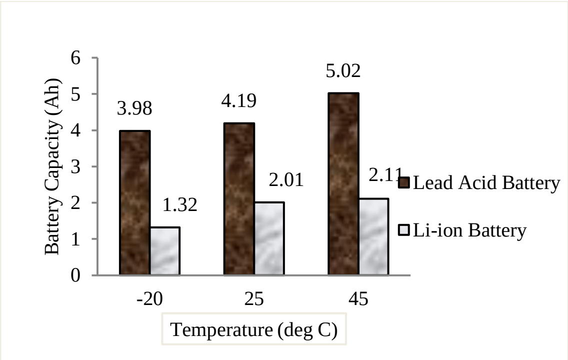

Figure 3: Capacities of Li-ion and Lead Acid Batteries at different temperature

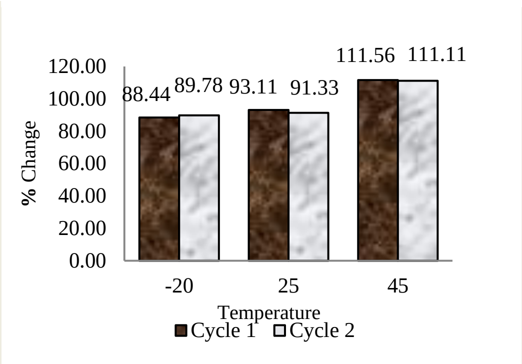

Figure 4: Percentage change in capacity of Lead Acid Battery with temperature

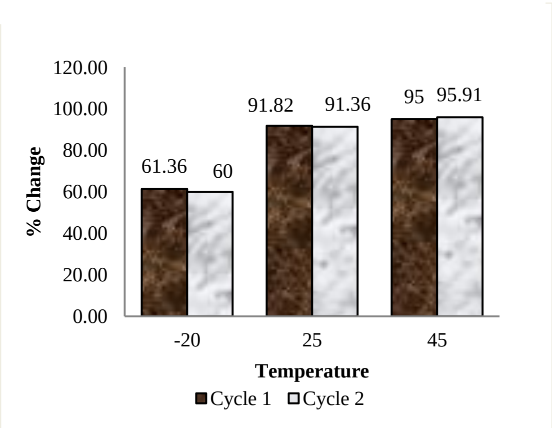

Figure 5: Percentage change in capacity of Li-Ion Battery Capacity with Temperature

<u>*Long Term Performance Assessment*</u>

Results of test indicate that capacity of battery reduces with life cycle. *Figure6 & Figure7* shows the experimental data. It is clearly examined from the figures that capacities of battery are slowly degrading with life cycle. Capacity of lead acid, before starting the test was 4.61Ah it started fading slowly and no one can imagine that after 45 cycles the capacity reduced to 2.54Ah, which is 56% of the first capacity. In case of Li-ion battery, first capacity was 2.2Ah and with cycle life it starts degrading. After 80 cycles the capacity of Li-ion battery reduced to 90% i.e. only 10% reduction in capacity. From *Fig.6 and Fig.7* we can clearly observed that in case of Lead Acid Battery there is 44% reduction in capacity within 45 cycles whereas the performance of Li-ion degrades to 10% even after 85 cycles. This much degradation in battery capacity may be because of overcharging at sunny day, undercharging in winter and rainy seasons, temperature effect but both Li-ion and Lead Acid are tested under same environmental condition.

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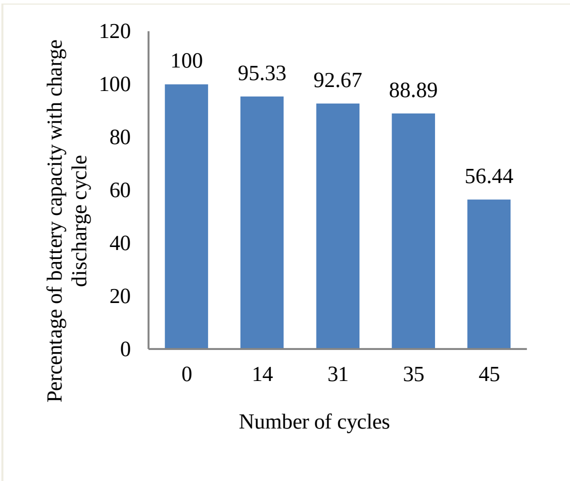

Figure 7: Variation in capacity of Li-Ion Battery with life cycle

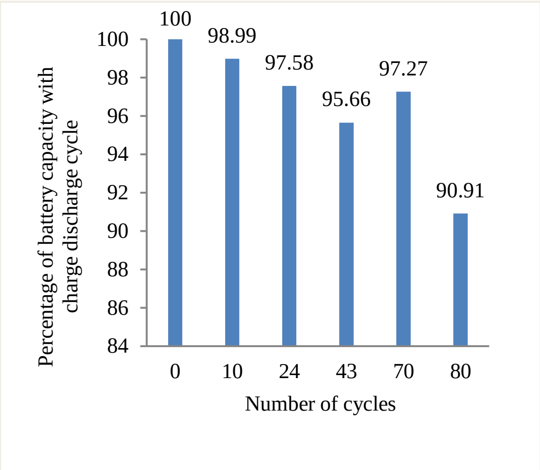

Figure 6: Variation in capacity of Lead Acid Battery with life cycle

CONCLUSION AND WAY FORWARD

From the experimental results it is concluded that battery capacity increases with increase in temperature and reduces with the reduction in temperature. Battery performance degrades with life cycle. Performance of Li-ion is highly affected by temperature variation whereas the performance of lead acid degrades with life cycle. Lead acid can be used in place where temperature variation is high whereas Li-ion can be for long term applications. There is a lot of work needs to done on testing and long term performance assessment on battery technology.

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