ActiveLED® White Paper Series

SOLAR ENERGY

Batteries and Energy Storage

ActiveLED®
Energy Efficient Lighting and Controls

Energy Storage

There are many types of electrical energy storage; from capacitors, fly-wheel to rechargeable batteries of various technologies. However, in a home, office, factory or outdoor environment only a few are practical or affordable.

On the battery side, as the most practical form of storage, there are some challenges and trade-offs that have to be considered. For example the cost of batteries and their specific performance in terms of charging efficiency, discharging efficiency and self-depletion performance versus price.

Charging from Solar or Wind will be most economical for most applicable battery types such as Flooded Lead Acid, $LiFePO_4$ or Ni-Fe.

Types of Batteries

Lead Acid Batteries

A deep depleted 12 Volt flooded lead acid battery (10.7 volts at no load - DOD 50%) charged to about 87% of charge (13% depth of discharge - DOD) with an efficiency of ~91%. From an 87% to 100% charge state the charging efficiency drops to 55%. The initial cost for a raw watt hour (R-Wh) for flooded lead acid batteries is approximately $0.24.. $0.19. The size of the battery capacity also depends on the way you want to use the battery. There will be two numbers of importance, the cost per Usable Watt Hour (U-Wh) and the expected life time in cycle days.

The U-Wh are significantly lower than the R-Wh advertised by the manufacturer and depend on a number of other factors like the general area of operation between 55% discharge and 13% discharge. When operating in this area the charging efficiency is maximized to about 91% but the cycle life of a lead acid battery is greatly reduced and charts from the battery manufacturer have to be used to determine the realistic cycle life. When used with solar generation or load-balancing, a cycle day is a day of the year. If your energy use is lower at the weekends this can extend lead acid battery life as <i>anti-sulfurization charging</i> can be applied during that period.

Charging Efficiency 91% (at U-Wh 32% of R-Wh)

Battery Type	Expected Cycle-Life (days)	
Walmart 12 Volt Car Battery	300	(less than a year)
Marine Deep Cycle	400	(little more than a year)
Flooded Sealed Lead Acid (250 Ah/12V)	900	(2..3 years)
Flooded Managed Lead Acid (1000 Ah/12V)	1400	(4..5 years)

When flooded lead acid batteries are used in the area of operation between 90% charged and 70% charged (10% discharged to 30% discharged) the cycle life is greatly improved but the charging efficiency is not that good unless the batteries are charged very slowly in which case the charging efficiency can be improved to about 83%. In this case the dimensioning of the battery capacity is derived from the most efficient charging rate resulting in very large battery banks.

Charging Efficiency 55% (U-Wh 20% or R-Wh)

Battery Type	Expected Cycle-Life (days)	
Walmart 12 Volt Car Battery	350	(less than a year)
Marine Deep Cycle	450	(more than a year..1.5 years)
Flooded Sealed Lead Acid (250 Ah/12V)	1000	(5..6 years)
Flooded Managed Lead Acid (1000 Ah/12V)	1400	(7..10 years)

$LiFePO_4$ Batteries

When using $LiFePO_4$ or also known as Lithium Iron Phosphate batteries, the charging and discharging efficiency is significantly higher at around 95% at a higher percentage of U-Wh versus 100% of R-Wh, but the cost can be 3 to 6 times the cost of flooded lead acid having 2x extended cycle life at 80% of original capacity. Total economics work out to be exactly the same cost over 10 years as the equivalent flooded lead acid battery system for approximately the same storage and discharge performance. However, the storage space and weight for the same useable capacity is heavily in favor of $LiFePO_4$ with 1/3-rd of the volume and weight of lead acid batteries, and half the weight and volume of Ni-Fe batteries.

Charging Efficiency 95% (U-Wh 70% of R-Wh)

There are numerous manufacturers of that technology and prices per useable Wh range from US$0.43 to US$0.91. (Last researched in December 2015)

Like lead acid batteries, $LiFePO_4$ requires battery management that prevents over-charging and over-discharging. 48V-DC appliance manufacturers normally consider this in their system designs so the devices will stop working below a certain supply voltage to prevent over-discharge. Equipment made for Lead Acid batteries has to be adjusted to lower drop-out voltages; for example a 12 Volt $LiFePO_4$ battery is fully discharged at 8.4 Volts whereas a 12 Volt lead acid battery is fully discharged at 10.7 Volts.

Nickel Iron Batteries

Charging Efficiency 90% (U-Wh 80% of R-Wh) There are a lot of myths about those batteries few of them are true. When space and weight are not critical a Ni-Fe Battery is a potential solution, it requires a storage and operating environment of 0°..45° C (32°..117°F) and therefore has to operate in-doors or in a crudely climate controlled area or more sophisticated cooling built into the battery cell. However, charging and discharging efficiency is high with 90% and the cycle time is in the 3000-plus cycles giving it a life time of 10 years plus. Ni-Fe batteries have been known to last 20 years retaining significant capacity.

What this means for load-balancing systems based on batteries is that the cost for the equipment to charge the batteries efficiently as well as the correct battery size to optimize charging efficiency and life time (time to replacement) have to be carefully taken into account to determine system sizes that can produce a payback from load-balancing.

Battery Management Systems

Both systems, flooded lead acid and $LiFePO_4$, will benefit from each cell fully managed by an appropriate charger controller rather than using multi-cell batteries that do not allow individual cell management or replacement. Ni-Fe batteries are more forgiving to overcharge and under-charge but require water-refilling on a regular basis or an automatic system to accomplish their automatic maintenance

Battery Bank and Storage Requirements

How often you have to change your batteries or supplement with extra capacity will affect your ROI or cost per stored and released Wh. You may decide it is more cost effective to add 20% new batteries at the end of the 80% cycle life if your type of battery will continue to lessen its capacity at the same rate per cycle as it did up to the 80% capacity point. In this case you have to plan the space required for the extra 20% beforehand. You can then decommission 20% when the total capacity has reached 80% again and replace with 20% of new batteries and so on.

Tips for Selecting a Battery

Some battery manufacturers are masters in misrepresenting the true performance of their products.

Although a Retail Store battery has a 1 year warranty, it has no Ah nor a Wh rating and would only survive 150 deep discharge to fully charged cycles depleting its capacity to 50% or failing completely.

Do not use batteries for which you cannot obtain cycle life diagrams showing after how many deep cycles the 80% mark of capacity is reached.

Starting a car or tractor once a day is not a deep cycle, cranking power and cranking cycles have no relevance in a load balancing application.

A battery made for the application will have an Ah (Amp hour) and or a Wh (Watt hour) rating. Be aware that in the case where your application is mission critical that you have to take the end of life capacity into account.

Calculating the Battery Size for a Solar Application

You have to start with the energy user, let's say a streetlight application using two 50 Watt streetlights totaling 100 Watt. Next to consider is the hours the lights are on in the night and for our purpose we assume 12 hours per day followed by the number of days (of 12 hours) one battery charge should support the lights at full output, in our case 3.3 days. Total usable Wh the battery system has to provide at its end of life:

50W x 2 x 12 x 3.3 = 3,960 Wh

Lead Acid

A lead acid battery halves its capacity every 300 cycles, which means if you need 3,960Wh capacity at the end of 3 years you have to have a beginning capacity of:

3 x 3,960Wh = 11,880 Wh

As Lead Acid batteries are not advertised giving usable watt hours but Ah (Ampere Hours) the capacity has to be converted to Ah. Depending on the battery system voltage, for our purpose four batteries are connected in series resulting in a 48V system, results in:

11,880 Wh / 48V = 247.5 Ah

To even have a performance of halving capacity every 300 cycles you must not deplete a lead acid battery to more than 50% requiring the initial Ah capacity to be doubled:

2 x 247.5 Ah = 495 Ah

$LiFePO_4$

The same initial calculation of 3,960 Wh applies but as a LiFePO4 battery still has 85% of its capacity at 2000 cycles the following initial Wh applies for a 5 year life cycle:

3,960 Wh / 0.85 = 4,658 Wh

Converted to initial Ah in a 48V system:

4,658 Wh / 48 = 97 Ah

Or for a 10 year period (3650 cycles)*:

3,960 / 0.50 = 7,920 Wh

Converted to initial Ah in a 48V system:

7,920 Wh / 48 = 165 Ah

From this example we can deduce that a same performance 5 year life LiFePO4 system can be one fifth of the initial capacity of an equal performing lead acid system with a 3 year life.* 10 year periods using the same set of $LiFePO_4$ batteries are speculative at this point. However it is the consensus of some $LiFePO_4$ battery makers that this is a likely performance based on US/Canadian chemistry.

Considerations for the Operating Environment

Lead Acid batteries are suited for indoor applications or moderate environments where ambient temperatures are between 0°C and 40°C (32°F and 140°F) during charge or discharge operations.

Lead acid batteries (flooded or GEL) that are being charged at temperatures above 42°C (145°F) will gas and by doing so lose electrolyte causing their capacity to diminish much faster.

$LiFePO_4$ batteries are suited to operate from -20°C to +60°C (-6°F to 146°F) making them more suitable in colder and hotter environments.

All Battery Systems

General precautions should be taken to protect batteries from excess heat during charge time. This can be achieved in hot climates by storing the batteries in bright white containers to avoid additional heating by the sun this is especially important if the batteries are mounted on a pole.

Batteries can be mounted on the ground or in the ground using the ground as a heat sink or in colder climates protecting them from extreme cold.

Sub-Arctic or Arctic-Circle use may require heating the batteries and extreme thermal insulation.

Disclaimer

No claim is made in this white paper as to the accuracy of any values, prices or other information given as they are rough indications or estimations based on publicly available information and the author's experience.

Product manufactured in Georgetown, Texas.