BATTERIES FOR HOMES

Rechargeable batteries for domestic energy storage

This Building Technology Resource provides information on battery technologies available for domestic installation. Its goal is to help consumers and builders make informed choices about the most suitable battery to use for energy storage in relation to solar photovoltaic systems or standalone applications.

As more and more households recognise the benefits of installing solar photovoltaic (PV) systems, a growing number are finding that installing a battery to store some of the electrical energy generated can be an attractive proposition. As feed-in tariffs for excess solar PV energy settle at relatively low levels, the case for installing energy storage can now be made more often on financial grounds.

With the advent of affordable solar panels, people in rural areas outside the electricity grid can now build their own power systems based on PV technology and batteries, as well as a diesel-fuelled generator for emergency power. Although the industry associated with so-called 'remote area power supply' systems has matured, it remains a small, niche market. By comparison, interest in large batteries is fast becoming mainstream, as retailers and regulators try to keep up with rapid growth in demand. Coinciding with – and probably influencing – this growth has been the huge increase in the accessibility of state-of-the-art residential battery storage systems.

WHAT IS A BATTERY?

A battery is an arrangement of electrochemical cells in series or parallel (Figure 1). In each cell, two electrodes and an electrolyte undergo a reduction-oxidation (or redox) reaction – two chemical processes that transfer electrons from one electrode to the other. The positive electrode, or cathode, comprises an oxidising material (which gains electrons), while the negative electrode, or anode, comprises a reducing material (which loses electrons). The electrolyte is a solution of ions in a solvent. The transfer generates a difference in electrical potential between the electrodes, which is measured in volts (V).

Batteries store electricity until it is needed and provide it on demand. Battery power refers to the instantaneous output of electricity that is discharged at any given moment. Battery energy (also expressed in terms of discharge capacity) is the measure of the work that a battery can do over a given time period.

BATTERY PROPERTIES

Several terms are used to describe a battery's general technical specifications and its specific condition at a particular point in time.

BATTERY SIZE

The basic measure of a battery's size is its discharge capacity, which is the amount of charge that the device can deliver at a specified rate of discharge, or discharge current. Although the most widely used unit of charge is the coulomb (C), the battery industry favours the ampere-hour (Ah; 1 Ah = 3600 C).

The size of different batteries operating at the same voltage (e.g. 12 V car-starter batteries) can be compared easily using their

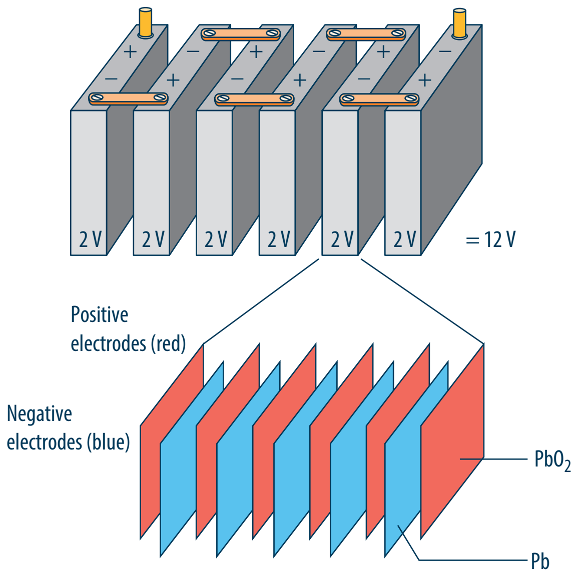

FIGURE 1 The typical arrangement of cells in a 12 volt lead-acid battery.

discharge capacity. However, the inputs to domestic solar PV systems typically allow a range of battery voltages, so customers may have to compare batteries that differ in both voltage and discharge capacity. For this reason, battery size is increasingly expressed in terms of energy, with the maximum rate of discharge often given in terms of power rather than current.

Power (watts, W) is the product of current (amps, A) and voltage. The watt, or kilowatt, is a sensible unit to use, so that household loads (the power used by ovens, fridges and other domestic appliances) are all expressed in the same units. The maximum output of a battery for connection to a house might be 2–5 kW.

Energy is the amount of power delivered over time, so it is measured in kilowatt hours (kWh). As household electricity usage is expressed in kWh, it makes sense to express the electrical storage of a battery in units of Wh (watt-hour) or kWh. The energy value can be divided by battery mass to produce gravimetric energy density (Wh/kg), known as 'specific energy', which is particularly relevant in situations where the energy density, or compactness, of a battery is important. Although batteries with high specific energy were originally developed for portable use, they are also light enough to be mounted on a wall.

DISCHARGE CAPACITY

A battery's available discharge capacity is commonly referenced to the quantity 'C', which is the maximum capacity that can be discharged in one hour. The discharge current used to determine C is the 'C-rate'. As battery discharge capacity varies with discharge

TABLE 1. EXAMPLE OF DEPTH OF DISCHARGE (DoD) ON THE CYCLE LIFE OF LITHIUM-ION BATTERIES.

Depth of discharge (DoD)	Number of full charge and discharge cycles until 80% of initial discharge capacity is reached	Total charge delivered by the battery during its cycle life[1]
100%	180	1
80%	300	1.33
70%	680	2.64
50%	1300	3.61

[1] Normalised to total charge for 100% DoD. Source: Guena & Leblanc (2006).

current, choosing an intermediate rate of discharge – namely one that is complete in one hour – allows manufacturers to standardise how they express discharge performance. The C/20 rate ('20-hour rate') refers to the current required to extend the discharge period to 20 hours. Although the C/20 rate is approximately one-twentieth of the C-rate, the exact figure will vary with a number of factors and across different battery technologies.

BATTERY LIFETIME

Many battery systems state their anticipated lifetime in years or cycle number. When making decisions using these numbers, it is important to be aware of how they are measured.

The cycle number is the number of times a battery can be discharged and then charged, ready for the next discharge (this constitutes one 'cycle'). The total number of cycles is referenced to specific charge and discharge C-rates because, in general, the faster a battery is charged and discharged, the lower its cycle number.

Battery manufacturers conduct extensive charge–discharge cycling of their products, from which they derive average values for the rate of capacity loss (also known as the battery 'fade rate', or rate of degradation per cycle). From there, they can estimate the battery's calendar life: the number of years before the battery's capacity falls to 80% of its original value. The figure of 80% is a generally accepted value meaning that, in most uses of batteries, a loss of 20% of the originally available capacity can be tolerated before replacement is needed.

Another crucial factor affecting estimated lifetime is the depth of discharge (DoD) – the percentage of a battery's discharge capacity, relative to its total capacity, that is removed in each cycle. A battery that is fully discharged and charged – that is, from 0% to 100% DoD and back again – will yield fewer cycles than the same battery cycled to 50% DoD. In fact, when its DoD is limited to 50%, a battery can delivery nearly four times as much charge over its usable lifetime (Table 1). This is a direct reflection of the increased stresses placed on the battery materials when all the available capacity is utilised.

BATTERY MATERIALS AND CHEMISTRY

Batteries used to be classified primarily as single-use or rechargeable, but an increase in the prevalence of rechargeable batteries means that classification now focuses on the type of materials in these batteries and the chemistry used to formulate the electrodes. Older technologies, which used lead, nickel-cadmium and zinc-bromine electrodes, have made way for newer technologies, such as those behind lithium-ion batteries (LIBs), which were first commercialised by Sony in the 1990s.

LITHIUM-ION TECHNOLOGY

LIBs encompass a range of technologies in which charging the battery results in lithium ions moving out of the positive electrode and into the negative electrode, while the reverse process occurs during discharging. The electrolyte solution provides a reservoir of lithium ions. The materials of both electrodes have crystalline structures that accommodate the reversible movement of lithium ions. For the different LIB chemistries, it is the unique properties of the respective electrode materials that result in the observed differences in performance and characteristics, such as voltage, capacity and C-rate (see Table 2 for examples).

Variations in how LIB electrodes are chemically formulated – for example, to optimise safety, cycle life and specific energy output – have led to an ever-growing family of reliable and affordable LIBs. They are often the cheapest, smallest and lightest option available, which increasingly makes LIBs the first choice for residential consumers.

USING BATTERIES

Once you have selected the most suitable battery for your residential requirements, it is important to install and maintain it properly to ensure its optimal operation.

SELECTION

Different battery chemistries confer unique properties, including power, energy storage capability, response time, recommended temperature range of operation, and anticipated lifetime (Table 3).

TABLE 2. THE ADVANTAGES AND DISADVANTAGES OF SELECTED LITHIUM-ION BATTERY ELECTRODE MATERIALS.

Electrode materials		Pros	Cons
Positive electrode	LCO ($LiCoO_2$)	In use since 1991; properties are well known.	• Becomes unstable under overcharge. • Not ideal, due to cost and scarcity of cobalt. • Ultimately not durable.
	NMC ($LiNi_{1/3}Mn_{1/3}Co_{1/3}O_2$)	• Cheaper than LCO, as it has less cobalt. • Stable under overcharge.	Not ideal, due to cost and scarcity of cobalt.
	LFP ($LiFePO_4$)	• Components are cheap and abundant. • Excellent charge–discharge cyclability. • Electrode potential varies little during discharge.	Electrode potential is ~300 mV less than cobalt-based materials.
Negative electrode	Graphite	• In use since 1991; properties are well known. • Graphite is cheap and abundant. • Anode of choice for most LIBs.	Somewhat sensitive to choice of solvent; co-intercalation can cause early degradation.
	LTO ($Li_4Ti_5O_{12}$)	'Zero-strain' material that provides excellent cyclability.	Delivers only around half the specific energy of graphite-based equivalents.
	Silicon	Exceptionally high energy density, which will lead to more compact, lighter batteries.	Large difference in volume between charged and discharged states generates high levels of strain, which limit cyclability.

TABLE 3. PROPERTIES OF THE MOST COMMON BATTERIES USED FOR ENERGY STORAGE.

Technology	Property					
	Suitable application	Lifetime (years)	Lifetime (cycles)	Energy density (Wh/kg)	Cell voltage (V)	Recommended temperature range (°C)
Lead-acid	Energy	3–12	800–3000	30–50	1.75–2.35	–20 to 50
Advanced lead-acid	Energy	3–12	3000–6000	30–50	2.30–2.45	–20 to 50
Lithium iron phosphate	Energy, power	3–15	3000–6000	90–130	2.65–3.2	–20 to 60
Lithium cobalt oxide	Energy, power	3–15	3000–6000	195	2.5–4.2	–20 to 60
Lithium nickel manganese cobalt oxide	Energy, power	3–15	3000–6000	100–205	2.55–3.1	–20 to 60
Zinc bromine	Energy	5–10	300–1500	60–80	0.17–0.3	15 to 50
Vanadium redox	Energy	10–20	100 000*	10–35	1.15–1.55	10 to 40
Nickel-cadmium	Energy	15–20	2300–2500	45–80	0.9–1.2	–20 to 60

* Manufacturers' claims; this technology has not been in operation long enough to confirm this value.

Choose the most suitable battery for a particular application by matching these properties – as closely as possible – to those of the application's requirements.

INSTALLATION

Battery installation must comply with Australian Standards such as AS 5139 and should be carried out to maximise battery life. Batteries should be located in accordance with the manufacturer's recommendations. Consideration should also be given to the following:

- Localised heat sources should not be present (e.g. direct sunlight, generators, battery proximity to walls exposed to direct sunlight).
- Extreme ambient temperatures should be avoided, because low temperatures decrease battery capacity and high temperatures shorten battery life.
- The battery location should preclude contamination of the natural environment, damage to equipment and injury to personnel in the event of electrolyte spillage.
- The battery should not be located near combustible material or metal objects capable of falling across the battery terminals and causing the battery to short circuit – arc, flash or burn.
- The size of the battery enclosure or stand should allow for sufficient clearance to provide access for installation, maintenance, handling equipment and safety equipment.
- The battery enclosure or stand should comply with New Zealand Standard NZS 4219 or Australian Standard AS 1170.4, where relevant, which protect the batteries from damage due to seismic (earthquake) activity.
- The enclosure or stand should be strong enough to support the weight of the battery.
- The enclosure should be designed to resist the effects of electrolyte. Provision should be made for the containment of any spilled electrolyte. Acid-resistant trays in which the batteries sit should be designed to hold a volume of electrolyte equal to the capacity of at least one cell of the battery.
- If the enclosure is designed to enable a person to enter, any doors must allow unobstructed exit.
- Battery systems classified as explosive gas hazards must be installed with either natural or mechanical ventilation.

MAINTENANCE

The manufacturer's information sheet should include specific instructions for battery operation and maintenance. In general, battery maintenance should include the following considerations:

- Treat batteries carefully, as they can be dangerous.
- Keep the terminals of lead-acid batteries clean and tight, and ensure that the electrolyte is kept above minimum levels. Use only distilled water when topping up electrolyte levels.
- For leaks of water-based battery electrolytes (for example, in lead-acid batteries), neutralise spilled or splashed electrolyte (for example, with sodium bicarbonate for flooded lead-acid cells) and wash it away with water at frequent intervals. Where a leak or spillage is detected, the battery should be inspected to identify the cause of the leak.
- For leaks of non-water-based electrolytes (for example, in LIBs), mop up the electrolyte using a chemical spill kit or absorbent material. Stop using the battery immediately, as it could pose a fire or health hazard, and contact the manufacturer for further advice.
- Ensure that metal tools and materials are kept away from the battery terminals and housing, as inadvertent contact could create a short circuit and destroy the battery.
- Ensure that any ventilation and cooling (such as air-conditioning) systems are working properly to keep batteries at their optimal working temperature.

Newer battery systems tend to come with their own monitoring software (and mobile phone apps), which provide information on usage and battery status, such as temperature, electrical current and voltage, capacity or energy, and input and output power.

All batteries have specific charging regimes, each of which is unique for the particular battery chemistry. Some lead-acid batteries require maintenance procedures such as periodic equalisation charging, a controlled and deliberate overcharge to remove sulfate crystals on their electrodes. The maintenance procedure is either controlled automatically by the system or requires the user to connect the battery to the grid, a generator or a specified charger at regular intervals (about once a month).

The best way to avoid problems with battery maintenance is to proactively inspect the system on a monthly basis and to have it serviced annually (or as recommended by the manufacturer) by an accredited installer. It is also important to display a monthly maintenance checklist and warning signage – in particular, the type of battery chemistry used for the storage system.

DISPOSAL

When batteries reach the end of their useful life, they must be disposed of correctly – not in landfill, but by following appropriate recycling or recovery processes. Lead-acid batteries contain toxic lead and corrosive acids, which cause significant environmental damage if released. LIBs have the potential to release toxic hydrogen fluoride fumes and to cause fires if punctured or short-circuited. Even if a battery is 'dead', it may still have sufficient charge to cause problems during disposal. All systems should be sent for specialist recycling or resource recovery. Information and pertinent laws regarding battery disposal can be found on state government agency or local council websites.

MORE INFORMATION

Australian government agencies providing information on battery disposal:

State or territory	Agency	Website
New South Wales	Environment Protection Authority	www.epa.nsw.gov.au
Victoria	Environment Protection Authority Victoria	www.epa.vic.gov.au
Queensland	Department of Environment and Science	www.ehp.qld.gov.au
Australian Capital Territory	Environment and Planning Directorate – Environment	www.environment.act.gov.au
Tasmania	Environment Protection Authority	www.epa.tas.gov.au
Western Australia	Environmental Protection Authority	www.epa.wa.gov.au
South Australia	Environment Protection Authority	www.epa.sa.gov.au
Northern Territory	Northern Territory Environment Protection Authority	www.ntepa.nt.gov.au
Australian Government	Department of the Environment and Energy	www.environment.gov.au

Additional information can be found in the following resources. Please check your local authorities for specific legislation, codes and guidelines, as they can vary between states and territories.

Australian Standard AS 1170.4-2007 Structural design actions. Part 4: Earthquake actions in Australia

Australian Standard AS 5139:2019 Electrical installations - Safety of battery systems for use with power conversion equipment

Guena T, Leblanc P (2006) How depth of discharge affects the cycle life of lithium-metal-polymer batteries. In INTELEC 06 – Twenty-Eighth International Telecommunications Energy Conference, 10–14 September 2006. Providence, RI, USA. Piscataway, NJ, USA: IEEE

New Zealand Standard NZS 4219:2009 Seismic performance of engineering systems in buildings