SERIES 14

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SERIES **14** | MODULE **09** | **BATTERY STORAGE**

Grid-connected battery energy storage

by John Beardmore, managing director, T4 Sustainability Ltd.

As the rate of domestic PV installation has declined over the last couple of years, many installers have diversified into the sale of grid-connected battery storage products, either to retrofit to existing PV sites, or to sell with new renewable energy systems.

We have been involved in research projects which have aimed to gather practical experience of battery systems, and these comments are based on some of the measurements we've made, and the quirks we've observed.

Although these comments mainly refer to domestic and small industrial scale systems, some of the questions we raise here should also be asked of larger industrial and utility scale installations.

When choosing which device to buy, consumers are likely to have three primary objectives: to save money; to use more of the electricity they generate; and to minimise their environmental impact.

There are potential wider societal benefits too. Local storage can minimise stress on the grid caused at times of peak renewable generation in areas with high renewable energy uptake; minimise stress on generators and the grid at times of peak consumption; allow the greater uptake of renewables; and ultimately reduce global carbon and environmental footprints.

To these ends, an ideal system should have 100 per cent end-to-end efficiency. It would absorb any excess energy generated on site (or buy electricity at times of day when it was cheap). It would release energy at times when the user would otherwise import energy, (or at times when electricity could be exported at a high price, or at times of peak demand). With the exception of deliberate export to assist generators and network operators, it should start to absorb energy as soon as a building would otherwise export energy, and should start to release energy as soon as a building would import energy. Rates of charge and discharge would be continuously variable. It should respond quickly to any change in energy inflow or outflow. The behaviour of the system should be clearly defined and self evident, and as far as regulations allow, be under the control of the user. Local user interfaces should be meaningful and easy to understand. Networked interfaces should be simple to set up, even for naïve end users. Where a system is operated by some other party, there should be transparency about how the system is used, and who will benefit from its use. Its use should result in a net saving of money, a net reduction of carbon emissions, and a net reduction in environmental footprint. It should have unlimited capacity or, to be more pragmatic, should be sized appropriately for the energy source and load. It would also have unrestricted charge / discharge power, and last forever. It should be easy to wire up and aesthetically acceptable in a domestic setting. Levels of internet traffic should be moderate. Firmware should be well tested and stable. It should be recyclable, especially the battery.

If you are thinking of buying a system, you should ask about all these issues before you purchase to see how close to an ideal system available products have become.

What could go wrong?

So, in the real world, what could possibly go wrong?

We've installed and tested a number of systems including the Moixa Maslow, Powerflow Sundial, Victron Hub 4, SMA Sunnyboy Storage with Tesla Powerwall 1, and SMA Sunny Island with an LG 48 volt battery. All batteries used were lithium ion except the Hub 4, for which we used a lead acid battery, although it can be used with other battery types and is a very flexible system.

These are all AC coupled systems which are connected to mains AC electricity, and we have made no provision for them to operate in island mode. An alternative is to use a DC coupled system which takes DC electricity for example from PV panels, and puts it into a battery without conversion to AC. While this might reduce total energy losses, we have not evaluated these systems because the energy lost in a DC coupled storage system reduces the amount of Feed

Produced in Association with energy institute in Tariff received, as approved total generation meters measure energy at the point of connection to the AC mains electrical system.

We can't claim to have done exhaustive or detailed testing, but for each type of system we've had to install them, get them through their initial teething troubles, and where possible we've measured the end-to-end efficiency. All measurements were made on brand new equipment, and performance is only likely to go downhill to some degree as the batteries age. Our testing is 'quick and dirty'. We can't claim to have tested over a big range of load powers or charge rates, but given the near absence of independent testing that consumers can access, we have found our results interesting, and encourage other battery users to test their systems and share the results.

Our systems are charged in an industrial unit with 11kW of PV on the roof, a moderate consumption of around 200W baseload with typical daily demand (brief peaks) of about 5kW, and more sustained periods of consumption of around 3kW of which 2.5kW is electric car charging. This is similar to the magnitude of typical domestic loads, but by domestic standards, we have an unusually large PV system.

Deviations from the ideal

Here are some vices and ways systems deviated from the ideal in our sample.

We measured end-to-end efficiency using a pair of Elster A100C energy meters to measure kWh in an kWh out.

Our definition of end-to-end efficiency is simply the number of kWh out of the system divided by the number of kWh in to it, multiplied by 100. Measurement will typically start at a known state of charge, e.g. empty or full, and measuring energy in and out during a period of activity which terminates at the same state of charge. Along the way you can measure things like the battery capacity.

In our tests, measured end-to-end efficiencies ranged from 64 per cent to 89 per cent. While the top end of the rnage is very encouraging, the bottom end is a mtter of some concern.. Some manufacturers will stress that the important thing is the efficiency of conversion of the energy coming out of the battery. I disagree with this, and consider any loss of hard won renewable energy to be a significant problem. I have likened this to marketing a car with poor MPG by emphasising that it has a really efficient

gearbox. To me as an environmentalist, taking PV energy off your roof, and losing up to a third of it as heat in your house in the middle of summer is a huge own goal.

Techniques to modulate if input and output power also vary between the various designs. Some appear to be able to vary their outputs continuously over wide range of power levels. Others modulate in large steps by switching a number of charger or inverter circuits on or off, sometimes in a few steps, each of over 100 watts.

A related issue is that some respond quickly to changes in generation and load and balance the grid effectively within a few seconds or a fraction of a second of a change. Others respond very slowly as they need to start G83 or G59 inverter modules from the powered off state, sometimes after waiting to see if the load increase persists, or if it's just a transient demand. The upshot is that some storage systems may not respond in the time it takes to boil a kettle.

One unit we tested was configured by default not to output any energy until the level of import reached 500 watts. In our industrial unit it didn't discharge overnight. Fortunately the manufactured can configure this setting over the internet, and they set it to 300 watts the following night. This didn't discharge either. After considerable persuasion, they set it to 160 watts which being less than our baseload did discharge. The manufacturer then revealed that to modulate the output down to lower levels, they could turn on the output inverters at the minimum fixed step, and then reduce the net output by turning on a charger circuit, eliminating export, but further reducing efficiency.

If you have a small evening baseload consumption, with only short periods of increased demand, these can make getting energy out of some battery systems efficiently and effectively surprisingly difficult.

With the exception of the Powerflow Sundial, all of the units we have tested have relied on an Internet of Things (IoT) approach to user interaction. Some systems have web-enabled interfaces for local configuration, and all had on line portals to allow the user to see what the system has been doing. Powerflow is working on internet connectivity, and by the time you read this it will probably be available. Even without this, the Sundial front panel display is clear and simple.

There are a number of issues around the IoT approach. Systems can upgrade themselves automatically; and in some situations they can be configured, optimised or operated remotely. There is a risk then, that even when functioning correctly, the reasons for the behaviour of the system may not always be obvious to the end user. Non-networked user interfaces can be poor; a few LEDs not well related to the apparent activity of the unit.

The Victron is a notable exception; the Colour Control user interface does show what's going on graphically, without the need to log in to anything. The quality of web portal interfaces is variable, but no doubt they will improve over time. The data displayed frequently lags behind current events. This isn't a problem if you just want to check occasionally that the system is doing the right sort of thing, but it's frustrating if you want to watch how the system copes with particular events in real time. Data on some portal graphs can be low pass filtered. This simplifies the graphics, but can lose information that you'd like to see. The process of linking new equipment to the Internet can be frustrating, and in extremis it can take some hours before you know if it's succeeded or failed. One unit we tested generated Internet traffic levels on the order of 150 megabytes per day; that's about a DVDs worth per month! Fortunately other units are much more modest.

IoT techniques knowledge

For most systems installers need some knowledge of Internet of Things techniques. If you don't have this background knowledge, diagnosing problems will require a lot more support calls.

Some manufacturers plan to use the equipment installed in end user properties in electricity trading schemes to support the network at times of peak demand. These schemes are in their infancy, but the broad idea is that the manufacturer or scheme operator will pay the system owner for this use, but the times when energy might be released from a battery store to meet the needs of the grid may not be at the time that the end user would use the energy. The benefits to the owner will depend on when the user would want energy, when the network needs it, and the payments made for this use of the system. These will need to be considered on a case-by-case basis.

Battery capacity and input and output power need to be matched to the energy sources and loads in use. Some batteries had capacities slightly smaller than indicated by the manufacturers, even when brand new.

Little environmental data is available to assess whether the use of battery systems will result in a net reduction of environmental or carbon footprint. This is something of an 'elephant in the room' given that much of this equipment is being sold into a community which is quite

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The environmental impact will depend on the battery chemistry, the life of the battery, and the end to end efficiency of the system as a whole. Lithium batteries have higher energy density than other common batteries, but cost per kWh capacity is a factor which keeps some of the other options open. Lead and lithium are both highly toxic materials, and after high profile coverage of fires caused by some types of lithium ion battery, fire risk too should be assessed. It has been suggested that salt water electrolyte batteries may be a technology with lower environmental impacts (but also lower energy density); I haven't seen any data to confirm this yet though. I've asked manufacturers for life cycle analysis data, but none has been forthcoming for domestic systems.

Part of the complex web of environmental issues is battery recycling. Some manufacturers have recycling schemes in place, others have promised them but have not yet established them. Will these companies still be trading in five or ten years time? If you are involved as a supplier or installer, consider whether you might have any liability under WEEE or other post-Brexit legislation.

The financial case for batteries should be considered with care, and generally seems to improve with the size of the system.

If the battery is sized to fully exploit excess generation in summer it may seem under used in winter, but might last longer because a larger battery will be stressed less by a given rate of charge/discharge than a smaller battery would, and it would experience fewer deep discharge and charging cycles. Sizing the battery to fully discharge and recharge once or more per day is currently normal practice but may not optimise the financial or environmental return.

According to the manufacturers, typical lithium ion batteries might offer lives of 6,000 charge discharge cycles or ten years, though some manufacturers will offer shorter warranty periods for batteries which are cycled more than once per day. When comparing batteries, make sure you look at the number of usable kWh. Lead acid batteries in particular will fail quickly if fully discharged. Also look at the warranty period (as opposed to the expected life), and the conditions attached to the warranty.

One of the smaller systems we looked at might cost £2,500 for an installed system. Depending on the amount and time of electricity use, the user might save £50 to £100 per year. If participating in the manufacturers energy trading scheme the user might receive an additional income, but indications are that this would be less than £100 per year. Even if the battery lasts 10 years, it is hard to imagine that this equipment is going to increase its owner's net wealth. The notion that batteries will help to address fuel poverty seems flawed, at least for the time being.

Justify large-scale rollout

For systems which offer neither quantifiable environmental benefit, nor any real expectation of financial return, end users must ask themselves carefully what they are trying to achieve. Small-scale trials seem justified to learn about these systems and assess their performance, but where this is poor, repetition of the experiment with the same equipment should perhaps be avoided. Ask carefully if you can justify any large-scale rollout of this technology. Beware of vanity projects.

The aesthetic impact of the systems we've looked at varies between relatively tidy single box solutions with built in battery (Maslow and Sundial), two box solutions (Sunny Boy Storage with Powerwall 1 and Sunny Island with LG battery), through to the Victron system which has the battery, the Hub (charger/inverter), user interface/ controller, battery fuse and battery current shunt. With five things to mount on the wall and wires to run between them, this system looks more at home in plant room than a house.

Most systems of the types discussed will be connected into the domestic wiring via a dedicated circuit in a consumer unit, and will have a two pole lockable rotary isolator to provide isolation. Additionally, all need some kind of current transformer, Rogowski coil or bidirectional energy meter (which in turn may need an external current transformer). This measures whether energy is being exported or imported so that the battery may be charged or discharged to minimise export to, and import from the grid.

In some circumstances the single box systems might be installed in the inhabited parts of a house, but in general, the appearance will dictate that they be installed in a garage or outhouse. Some systems such as the Sunny Boy Storage with the Powerwall 1 can be mounted outdoors. All systems needed to be mounted on a strong wall. Batteries are dense and even a small system can weigh over 25kg. Large domestic systems might weigh over 100kg, especially if lead acid batteries are used, and if the battery can stand on the floor, that will probably be the best option.

Documentation for the systems we've looked at has been very variable. In some cases, notably the Victron, naïve end users will either need to leave it to the installer or become quite technically literate, and the reams of documentation provided still don't tell an installer all they need to know to use the system in this application.

As the market for battery systems grows, so does the attendant guidance and regulation. The recently introduced "Engineering Recommendation G100 (2016) - Technical Guidance for Customer Export Limiting Schemes" will apply to many battery storage systems[1], and over then next year, the IET is expected to produce a code of practice for electrical energy storage systems. It is hope that this will clarify issues which are not well covered by the 17th Edition of the wiring regulations such as earthing arrangements in island mode.

The largest of the systems we've looked at offers roughly half the cost per kWh of the smallest, but financial break even within the life of the battery still seems unlikely with the systems we've tested so far. Although we install battery systems for various research projects, for the time being we don't promote them to end users for the reasons identified above. This is a fast moving field however, with new products coming out every month. We hope that the environmental case will become clearer, and that in the relatively near future it will be possible to use batteries with the prospect of a reasonable financial return. Having been pleased with the efficiency of the Sunny Boy Storage / Tesla Powerwall 1 combination, we look forward for example to the Tesla Powewall 2, which we hope will set new benchmarks for battery cost effectiveness and storage density.

Reference

http://www.energynetworks.org/electricity/engineering/distributed-generation/engineering-recommendation-g100.html

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CPD ENTRY FORM

SERIES 14 | MODULE 09 | MARCH 2017

BATTERY STORAGE

Please mark your answers on the sheet below by placing a cross in the box next to the correct answer. Only mark one box for each question. You may find it helpful to mark the answers in pencil first before filling in the final answers in ink. Once you have completed the answer sheet in ink, return it to the address below. Photocopies are acceptable.

QUESTIONS

1. **An AC coupled grid connected battery storage system is:**
   - ☐ linked directly to a PV array or wind turbine
   - ☐ typically linked to the electricity supply via a dedicated circuit
   - ☐ always more electrically efficient than a DC coupled system
   - ☐ always cheaper than a DC coupled system

2. **Which of the following is not an advantage of battery storage systems?**
   - ☐ Reduced export of energy to the grit at times of strong sunshine
   - ☐ Reduced import of energy at times of peak evening demand
   - ☐ Heat produced by the system warming your house
   - ☐ Reduces the need to reinforce the grid to accommodate more renewable energy systems

3. **How would you measure the efficiency of a battery storage system?**
   - ☐ Look at the efficiency of the battery charging circuitry
   - ☐ List to the sales staff
   - ☐ Measure the efficiency of the inverter
   - ☐ Measure kWh in and compare with kWh out

4. **For a building with a PV system that typically generates 10kWh per day in March and April, what PV battery storage system capacity might be appropriate if the house is unoccupied during weekdays?**
   - ☐ 1.5 kWh ☐ 4 kWh ☐ 12kWh
   - ☐ It isn't always easy to tell. Use manufacturers software to model the behaviour and examine a number of options.

5. **If a household buys electricity at 15p per kWh and a 4kWh storage system is installed which charges fully for 175 days of the year, what is the likely value of the time shifted electricity per year?**
   - ☐ Less than £500 ☐ Less than £200
   - ☐ Less than £50 ☐ Less than £20

6. **When considering the benefits of using batteries, what technique is likely to yield the most useful information?**
   - ☐ Environmental Impact Assessment
   - ☐ CUSUM analysis
   - ☐ BATNEEC ☐ Life Cycle Analysis

7. **Which of the flowing statements about lithium is untrue?**
   - ☐ Lithium batteries are cheaper per kWh than lead acid
   - ☐ Lithium salts are very soluble and might easily leach out of landfill
   - ☐ Lithium is powerful psychotropic drug
   - ☐ Lithium batteries should always be recycled

8. **How many charge / discharge cycles might a typical lithium ion battery achieve during its life?**
   - ☐ 60 ☐ 600 ☐ 6,000 ☐ 60,000

9. **How many years might a typical lithium ion battery last in service?**
   - ☐ 1 to 4 years ☐ 5 to 12 years
   - ☐ 12 to 18 years ☐ 18 to 24 years

10. **If a battery energy storage system saves £150 of energy purchase per year, and costs £3,500 to install, which of the following statements is untrue?**
    - ☐ The battery would need to be replaced before the capital cost of the system has been recovered
    - ☐ The system would recover its capital cost long before the failure of any component part
    - ☐ The cost of a replacement battery is likely to be a substantial proportion of the price of a new storage system
    - ☐ If the battery lasts ten years, other components (e.g. fans and electrolytic capacitors) may also have experienced significant wear and tear

Please complete your details below in block capitals

Name .... (Mr. Mrs, Ms)..........................

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This is the ninth module in the fourteenth series and focuses on **Battery Storage**. It is accompanied by a set of multiple-choice questions.

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