



Australian Power Quality and Reliability Centre

Domestic Energy Storage

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UNIVERSITY OF
WOLLONGONG



The first part of the paper discusses the importance of the research and the objectives of the study. It then presents a literature review of the existing research on the topic. The second part of the paper describes the methodology used in the study, including the data collection and analysis techniques. The third part of the paper presents the results of the study, and the fourth part discusses the implications of the findings. The paper concludes with a summary of the main findings and a list of references.

The research was conducted in a systematic and rigorous manner, following the principles of good research practice. The data was collected from a large and diverse sample of participants, and the analysis was conducted using a range of statistical techniques. The results of the study are presented in a clear and concise manner, and the implications of the findings are discussed in detail. The paper is well written and easy to read, and it provides a valuable contribution to the field of research.

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1. Executive Summary

There is significant interest in the community related to the potential of battery energy storage systems (BESS) to reduce electricity bills and/or even allow disconnection from the electricity distribution network. This interest has been heightened by the strong marketing campaigns of suppliers such as Tesla and AGL. This Technical Note examines domestic (residential) energy storage, specifically electrochemical battery energy storage systems. The scope of the Technical Note is for domestic (residential) systems likely to be up to approximately 10 kW, however, much of the content can be applied to larger systems. The Technical Note deals mainly with BESS which are connected to utility owned electricity distribution networks (grid connected) although off-grid scenarios are also considered.

The Technical Note examines the theory of battery operation and outlines the characteristics and capabilities of BESS. The two main battery chemistries (lead-acid and lithium) available for domestic use are evaluated as are the requirements for BESS integration. Finally, an examination is made of the benefits of BESS to consumers followed by a financial analysis of the payback time for a typical BESS and renewable energy generation system.

2. Introduction

While there are many energy storage technologies available in various states of maturity, including examples such as pumped hydro-electric storage, compressed air energy storage and mechanical storage mechanisms such as flywheels, at present, the only viable technology for small scale domestic residential energy storage is battery energy storage. In most cases, other devices, such as inverters, are required to integrate batteries into the installation and hence such an arrangement is referred to as a battery energy storage system (BESS).

Traditionally, small scale BESS has been used either to mitigate power outages, such is the case with uninterruptible power supplies (UPS) or for electricity supply in remote area power supplies that are not connected to the wider electricity network. With increasing penetration of renewable energy systems, particularly solar photovoltaic (PV), integration of small scale BESS systems offers advantages to both electricity consumers and electricity network operators.

3. Fundamental Theory of Battery Operation

All batteries exploit the fact that when two dissimilar metals (electrodes) are immersed in an electrolyte a potential difference will develop between them. If a conductor is connected between the two metals outside of the electrolyte, an electrochemical reaction takes place and a current will flow. The basic building block of a battery is the cell. A single cell is composed of the two electrodes and the electrolyte. An electrolyte is a substance that conducts electric current as a result of dissociation into positively and negatively charged particles called ions. When some specific compounds are added to water, they get dissolved and produce negative and positive ions (anions and cations respectively) which form the electrolyte. Popular examples of electrolytes are almost all kinds of salts, acids, and bases. The electrodes of a cell are metal or metallic compounds. The positive electrode of the battery is termed the cathode and the negative terminal is termed the anode. The output voltage of a single cell is of the order of 1-3 V and is determined by the electrode materials, the electrolyte and the cell operating temperature. Figure 3.1 shows the open circuit voltage of a number of different cell types.

Figure 3.2 shows a simple diagram of the components and status of a fully charged cell, in this case for a lead-acid battery which consists of a lead anode, lead oxide cathode and a sulphuric acid electrolyte.

Many batteries require voltage levels above that produced by a single cell. This is achieved by connecting multiple cells together to achieve the voltage and current rating required of any particular battery. Figure 3.3 shows an example of cells connected in parallel to achieve a higher current rating.

Cell type	Nominal open-circuit voltage (V)
Lead-acid (Pb)	2.1
Nickel-cadmium (Ni-Cd)	1.24
Nickel-metal hydride (Ni-MH)	1.2
Lithium-ion (Li-ion)	3.6-3.7

Figure 3.1: Nominal Open Circuit Voltage for Various Cell Types[1]

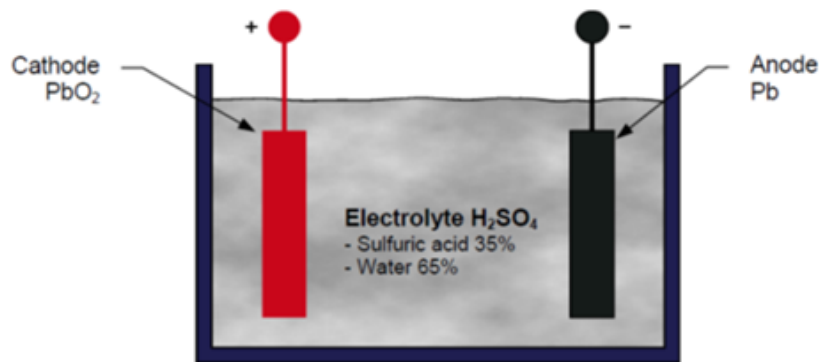


Figure 3.2: Components of a Fully Charged Lead-Acid Cell [1]

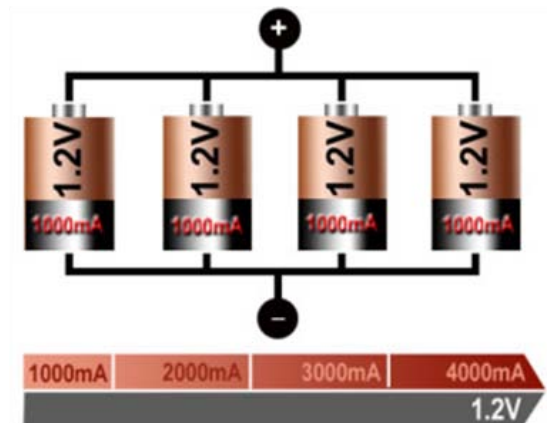


Figure 3.3: Example of Cells connected in Parallel to increase Current Rating of Battery [2]

3.1. Charge/Discharge

3.1.1. Discharge

When a load is connected between the two electrodes current will flow from the battery into the load. With the chemical reactions taking place as the battery discharges, the electrode material becomes more alike and changes will take place to the composition of the electrolyte. As an example, the chemical reactions that take place in a lead-acid battery during discharge are described on the following page.

Lead (Pb) of the anode and the lead dioxide (PbO₂) of the cathode combines with the sulphate (SO₄) of the sulphuric acid (H₂SO₄ – the electrolyte) to produce lead sulphate (PbSO₄) while both electrodes will gradually convert to lead sulphate. The chemical reaction between the anode and the electrolyte forces electrons out of the electrolyte at the anode. These electrons flow through the load to reach the cathode, where the electrons are accepted. The electric circuit is completed in the electrolyte by the flow of anions (negative ions) and cations (positive ions) to the anode and cathode, respectively.

Figure 3.4 (a) shows the status of the active materials in the battery during discharge and Figure 3.4 (b) shows the status of the electrodes and electrolyte after discharge.

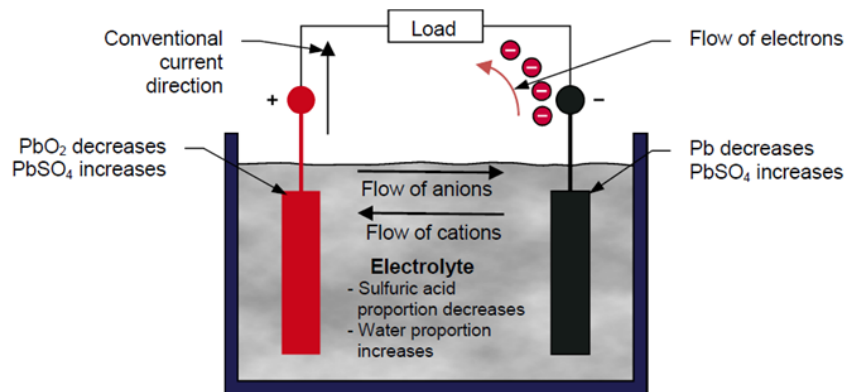


Figure 3.4: (a)

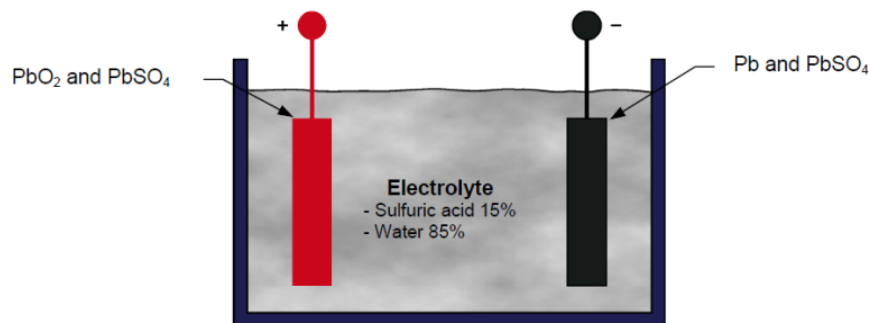


Figure 3.4: (b)

Figure 3.4: (a) Status of the Active Materials in a Lead-Acid Battery during the Discharge Cycle, (b) Status of the Active Materials in a Lead-Acid Battery after Discharge [1]

3.1.2. Charge

In simple terms, battery charging is a reverse of the discharge process. When a voltage source is applied across the electrode terminals, the reverse of the discharge process takes place. Continuing on with the lead-acid battery example, Figure 3.5 shows the status of the active materials in the battery during charging.

Proper charging of batteries is essential to maintain both battery life and performance as well as to ensure safety. There are a number of methods used to charge batteries, however, for lead-acid and lithium-ion batteries the most appropriate method is known as modified constant-voltage charging. This charging algorithm involves applying a constant current to the cell until the appropriate cell voltage is achieved. At this point, the battery will be partially charged. A constant voltage equal to the cell voltage is then applied until the charging current reduces to 10% or less of the current equivalent to the specified ampere-hour rating. Figure 3.6 shows the charge algorithm for charging a 4.2 V lithium-ion cell. Particular care must be taken with charging lithium-ion cells as these cells cannot accommodate either over charge or overvoltage. In the case

of overvoltage, highly volatile metallic lithium may be produced creating a significant safety risk. As such, it is essential that the correct charger be selected for each battery chemistry.

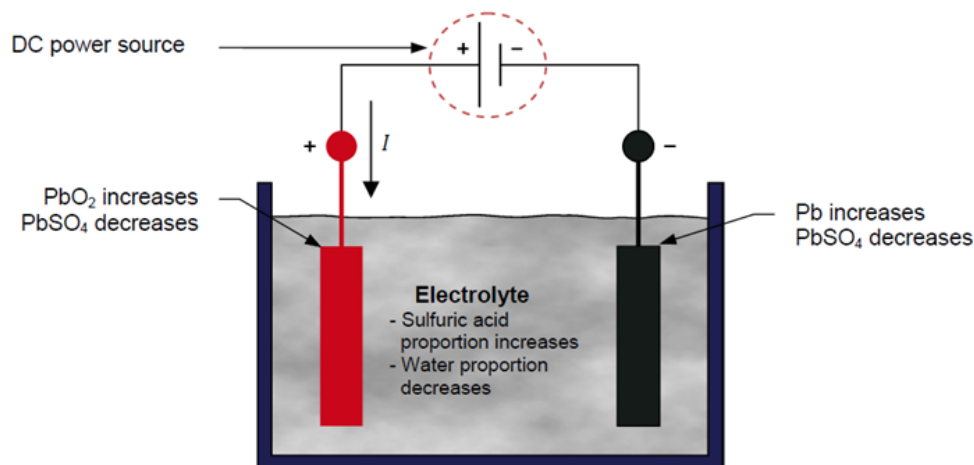


Figure 3.5: Status of the Active Materials in a Lead-Acid Battery during the Charge Cycle[1]

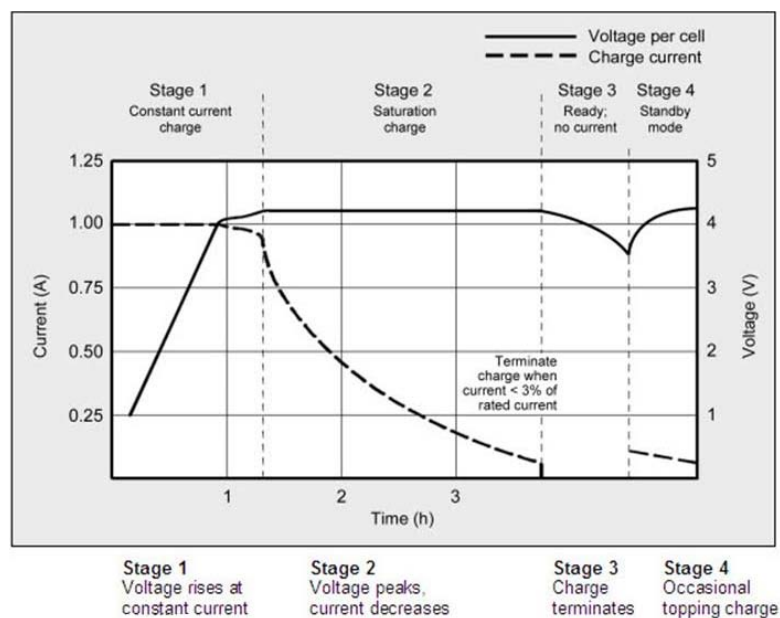


Figure 3.6: Charging Algorithm for 4.2 V Lithium-Ion Cell [3]

3.2. Battery Characteristics

There are a number of characteristics that describe the capability of a battery. These are detailed below:

Voltage is the rated voltage of the battery.

Capacity expressed in ampere-hour (Ah) defines the discharge current that a battery can deliver over time. In simple terms, a 1 Ah battery can discharge 1 A for 1 hour or 2 amps for ½ an hour and so on. Another measure of capacity is the watt-hour (Whr) which is the Ah rating multiplied by the battery rated voltage.

Specific Power is the amount of instantaneous power available. This is often expressed in W, kW or MW.

Specific Energy is the ratio of energy released during a complete discharge cycle to the battery weight.

Depth of Discharge is a measure of how deeply a battery is discharged. It is measured as the amount of energy removed expressed as a percentage of capacity. For example, 80% depth of discharge means that 80% of capacity has been removed.

C-rate specifies the speed a battery is charged or discharged. At 1C, the battery charges and discharges at a current that is on par with the marked Ah rating. At 0.5C, the current is half and the time is doubled, and at 0.1C the current is one-tenth and the time is 10-fold [3].

4. Battery Chemistries for Domestic Applications

There are two main battery chemistries which are currently viable for domestic energy storage. These are lead-acid and lithium-ion. Each battery technology is examined in detail below:

4.1. Lead-Acid Batteries

Lead-acid batteries are one of the oldest battery technologies still being used. The lead-acid battery was invented approximately 150 years ago. The anode of a lead-acid battery is metallic lead (Pb) while the cathode is lead dioxide (PbO₂). The electrolyte is sulphuric acid (H₂SO₄). Lead-acid batteries are a mature technology having been used extensively in vehicles and UPS systems.

4.1.1. Advantages and Disadvantages

Lead-acid batteries are relatively inexpensive and easy to manufacture. In addition, a lead-acid battery contains materials which are relatively abundant and most materials can be recycled once the battery has reached the end of its life. The lead-acid battery also has high specific power and is capable of high discharge currents (as is the case in motor vehicle starting).

However, lead-acid batteries have poor specific energy (i.e. a poor energy to weight ratio). They also have a limited cycle life (number of charge and discharge cycles) compared to some other technologies and are very sensitive to the depth of discharge with deep discharge resulting in a significant reduction in life as illustrated in Figure 4.1.

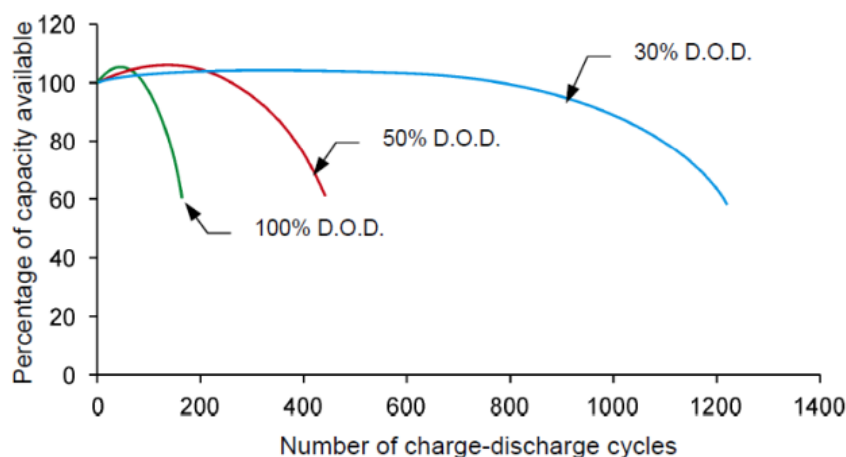


Figure 4.1: Depth of Discharge vs Cycle Life for Lead-Acid Battery [1]

Lead-acid batteries must be kept in a charged state. Failure to do so leads to a state called sulphation. Sulphation is crystallisation of lead sulphate (PbSO₄) on the battery anode. Deposit of lead-sulphate on the anode during discharge is normal. However, as stated in [1]:

“When formed, the lead sulphate is in a finely divided, amorphous form, which is easily converted back to lead, lead oxide and sulphuric acid when the battery is recharged. Over time, lead sulphate converts to a

more stable crystalline form, coating the battery's electrodes. Crystalline lead sulphate does not conduct electricity and cannot be converted back into lead and lead oxide under normal charging conditions."

Sulphation can severely reduce the capacity of the battery or effectively destroy it, exemplifying the need to ensure that lead-acid batteries are kept in a charged state.

Care must be taken when charging lead-acid batteries as improper charging can lead to electrolysis of the water in the electrolyte. This creates hydrogen which leads to a safety concern (as hydrogen is highly flammable) and also changes the ratio of water to acid in the electrolyte which impacts battery life.

4.1.2. Advanced Lead-Acid Battery

Recent lead-acid battery developments have included Australian technology which combines an ultracapacitor with the lead-acid battery. The resulting battery is known as an advanced lead-acid battery or termed Ultrabattery™. Proponents of this technology claim that it improves on the performance of traditional lead-acid batteries by reducing sulphation. Thus, the battery exceeds the capability of conventional lead-acid cells across partial State of Charge (pSoC) applications and also negates the requirement to continually charge the battery to avoid sulphation. It is also claimed that it matches or exceeds the performance of non-lead-acid (i.e. lithium-ion) battery technologies in certain applications and is resistant to many of the typical lead-acid failure modes.

4.2. Lithium-Ion Batteries

Lithium-ion batteries were invented in the 1970s. The cathode of a lithium-ion battery is generally carbon (graphite) while the anode is a lithium metal oxide of which there are a number of variants (see Figure 4.2 [4]). Early versions of lithium-ion batteries used pure lithium as the anode, however, while pure lithium offered energy density advantages, it is highly reactive and presented an unacceptable safety risk. The electrolyte is a lithium salt in an organic solvent. Lithium-ion battery technology is a mature technology. These batteries are widely used in consumer electronics such as cordless tools and mobile devices (mobile phones and laptop computers). There are many lithium-ion battery chemistries available each of which has specific advantages and disadvantages. Figure 4.2 illustrates the features of a range of lithium-ion battery chemistries.

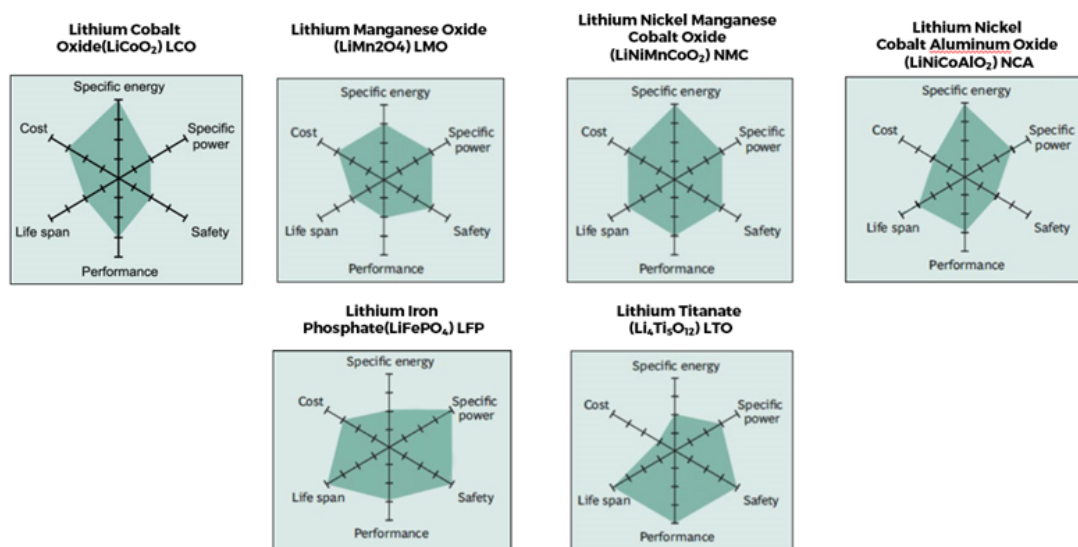


Figure 4.2: Comparison of Performance Characteristics of Various Lithium-Ion Battery Chemistries from [4]

4.2.1. Advantages and Disadvantages

Lithium-ion batteries offer substantial advantages over other technologies with respect to specific energy. They also have a long cycle life and low self-discharge (shelf life). The cost of lithium-ion batteries has also been decreasing rapidly and the price is expected to decrease by 50% over the next 5 years [5].

The main disadvantages of lithium-ion batteries are related to safety. Lithium-ion batteries require dedicated protection circuits to prevent thermal runaway (a destructive situation where an increase in temperature leads to a further increase in temperature which in many cases leads to destruction). There have been many cases of lithium-ion battery failures leading to fires and personal injury. However, the incidence of these events compared to the number of batteries sold each year is extremely small. The batteries should also not be exposed to temperatures above 45 degrees Celsius as this degrades battery life and performance. Lithium-ion batteries also should not be charged at temperatures below freezing as this leads to a safety issue. As a consequence of the sensitivity of the battery to temperature, many lithium-ion battery chargers will not operate at temperatures outside of 0 – 45 degrees Celsius range.

5. Cost Comparison of Battery Technologies

Figure 5.1 from [6] shows a comparison of current and projected costs for different battery technologies. If analysis is restricted to the lead-acid and lithium-ion technologies which are examined in this Technical Note, it can be seen that, at present, the cost of lead-acid and lithium-ion technologies is similar. However, the projections show a rapid decrease in lithium-ion cost over the next 5 years resulting in lithium-ion technology being much cheaper than lead-acid technology by 2020.

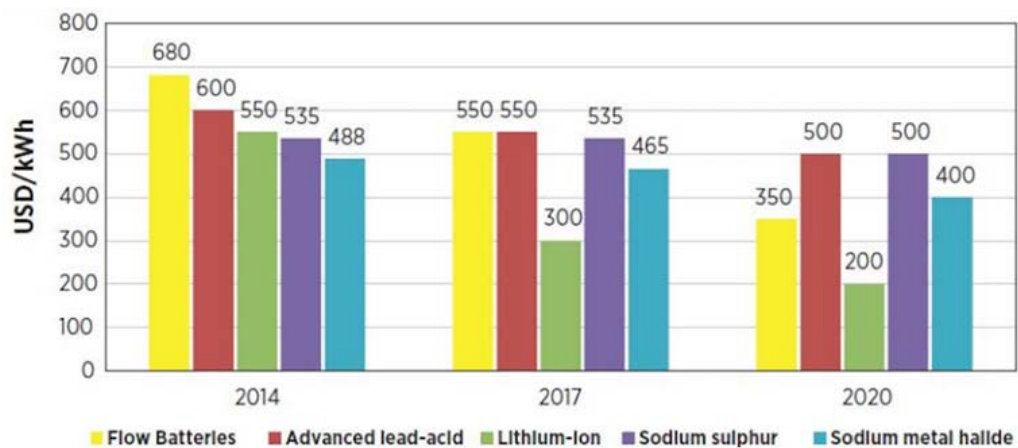


Figure 5.1: Comparison of Current and Projected Costs for Various Battery Chemistries [6]

6. BESS Integration

Although there are examples of installations with direct current (DC) reticulation and most appliances are ultimately powered by low voltage DC, the vast majority of installations and appliances require alternating current (AC) electricity in the first instance. As such, most of the time in order for the energy stored in batteries to be utilised the DC electricity produced by the battery must be converted to AC before use. This requires a DC to AC conversion device which is called an inverter (when used with batteries, the inverter is often termed a battery inverter). For off-grid applications (e.g. remote area power systems), there is a range of inverter options available

that provide a stand-alone conversion of the energy stored in the battery to AC. These inverters have varying quality of output waveforms and are generally unsuitable for connection to the electricity distribution network. As this technical note is not focused on these types of systems, they will not be discussed further. In Australia, for installations where the BESS will be connected to the public electricity distribution network (the majority of cases) all inverters must comply with AS4777 [7]. Such inverters are termed grid-tied inverters. Figure 6.1 shows the simplest method of integrating a BESS with a premises connected to the electricity distribution network. In this case the battery inverter controls the charging and discharging of the battery with the energy for battery charging coming directly from the grid.

At present, there is no financial justification for the connection method illustrated in Figure 6.1 and while the battery may be able to provide back-up power when the grid is not available (provided that the right type of inverter is used) little benefit is obtained due to the fact that Australian electricity distribution networks are generally highly reliable. Consequently, the majority of BESS installations are installed either in conjunction with or as an add on to local generation, most commonly, solar PV in order to better utilise the available generation (see Section 8 for further information). In such cases, there are two basic topologies for BESS integration. These are AC coupled and DC coupled. Each of these topologies is described in detail below.

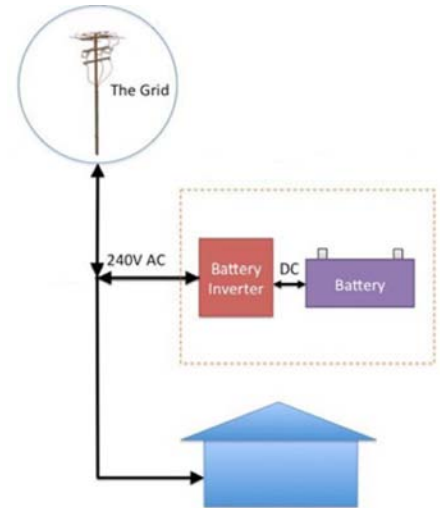


Figure 6.1: Simplest BESS Integration Method (adapted from [8])

6.1. AC Coupled BESS Integration

For AC coupled BESS, battery charging and discharging involves conversion of AC to DC and vice versa. The topology of an AC coupled BESS with local generation is shown diagrammatically in Figure 6.2. As can be seen, two independent inverters are included in the topology. The solar inverter converts the DC power generated by the solar PV to AC grid voltage. The battery inverter is also connected to the AC grid and converts AC to DC for battery charging and DC to AC for battery discharging. The battery is generally charged using excess solar PV generation but can also be charged directly from the grid. The advantages of this configuration is that there is a lot of flexibility in the inverters that can be chosen as they do not need to be compatible with each other. In addition, batteries or generation can be added or removed as distinct modules. This simple topology does not allow for the batteries to supply backup power (i.e. operate while grid voltage is not present, also known as islanding) since the inverters will disconnect (switch off) if grid supply is lost, as per the requirements of AS 4777.

Clearly, BESS do offer the possibility of continuing electricity supply in the absence of the grid albeit at limited loading and for a limited time period. If grid supply is not present, the BESS is effectively operating as a UPS. In this case, a special type of inverter is required and there are special wiring requirements. An inverter which is capable of operating in both grid-tied mode when the electricity distribution network is available and in stand-alone (also known as islanded) mode is known as a multi-mode inverter. A diagram of the topology of a BESS capable of operating as a backup power supply is shown in Figure 6.3. It can be seen that the topology is similar to that of the case where the grid is required. However, there are two very important differences. The first is the grid isolation switch which disconnects the installation on loss of grid supply. The second difference is that the solar inverter and the battery inverter must be capable of communicating with each other in order to control power flows. If the battery is fully charged, the solar PV generation must be curtailed otherwise the installation may be damaged. Battery inverters capable of operating in islanded mode are generally considerably more expensive than those without the capability.

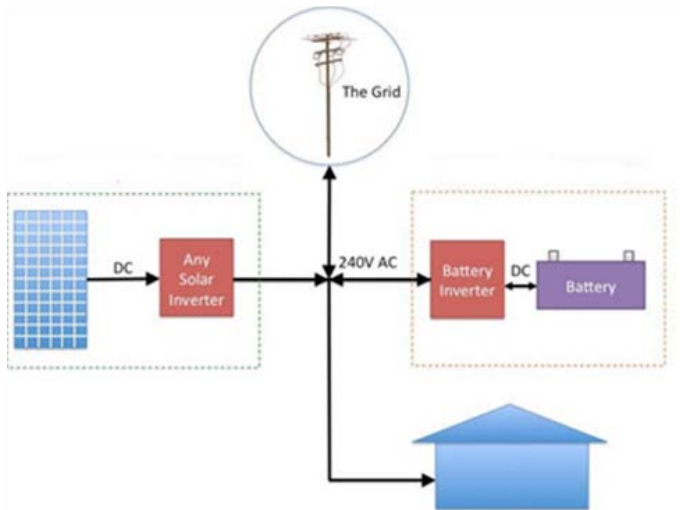


Figure 6.2: AC Coupled BESS Integration (adapted from [8])

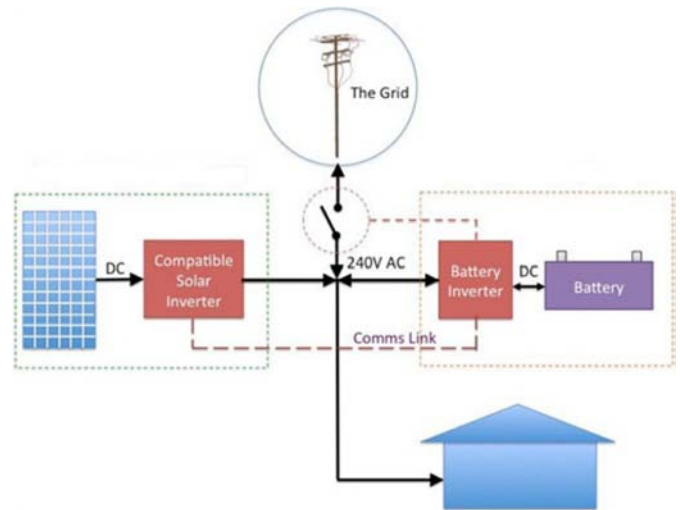


Figure 6.3: AC Coupled BESS Integration Capable of Operating without Grid (adapted from [8])

6.2. DC Coupled BESS Integration

For DC coupled BESS integration, battery charging and discharging is performed without conversion to AC. This requires a single specialised inverter. The topology of a DC coupled BESS is shown diagrammatically in Figure 6.4. While this topology is simpler than the AC coupled examples above due to the fact that only a single inverter is required, the specialised inverter required is considerably more expensive than the inverters used in the AC coupled systems. A block diagram of multi-mode (hybrid) inverter required for a DC coupled BESS is shown in Figure 6.5. The functionality of the uni-directional DC-DC, the bi-directional DC-DC and the bi-directional DC-AC are generally all included in the inverter. In addition to requiring a specialised inverter, this scheme has the limitation that the connection of additional batteries will be limited by the battery charge/discharge capacity of the inverter thus making it somewhat less modular than AC coupled systems.

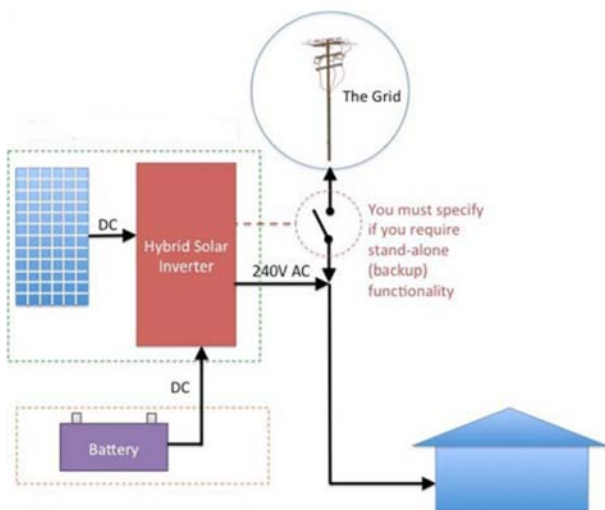


Figure 6.4: DC Coupled BESS Integration Capable of Operating without Grid (adapted from [8])

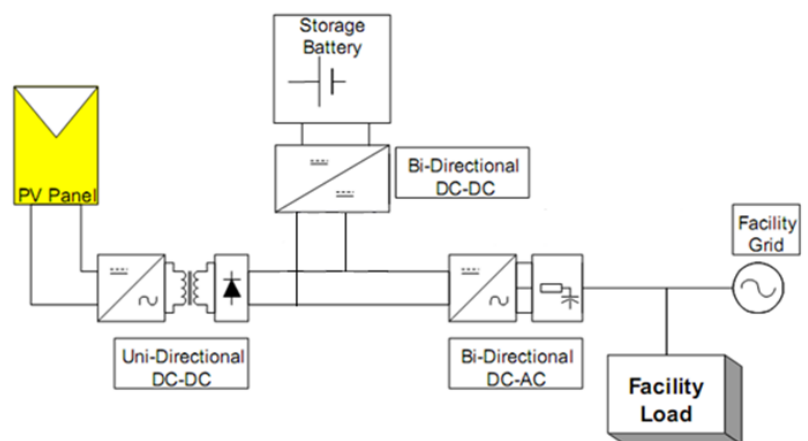


Figure 6.5: Detailed Block Diagram of a DC Coupled BESS with PV Generation

7. BESS Performance Parameters

The Australian Energy Storage Council's (ESC) Australian Battery Storage Guide [9] recommends that BESS Performance characteristics be specified using the following minimum set of performance parameters. The common parameters which allow comparison between system vendors quotes include:

- Usable Energy (kWh)
- Maximum Power output (kW) over what power factor range (if AC output)
- If AC output, operating pf range (leading to lagging)
- Battery System - life time to be minimum of 8 years
- BESS Maximum Surge Load (kVA)
- BESS Maximum Power output
- BESS output Power, time period of 1s, 30s, 1min, 30min and continuous
- Maximum Recharge Power available from source or Maximum or Minimum
- Recharge power allowed / required by storage device.
- Battery Total Energy Throughput (MWh)
- Standby SOC for storage device
- Response Time in ms.
- Storage Device self-discharge rate (usually %/month)
- Energy Storage Device maximum prospective fault current and protective device capability
- Energy Storage Device operating DC Voltage range (if applicable)
- Energy Storage Device maximum heat dissipation during operation
- Backup up Power - Yes /No
- Days of Autonomy - how long will the system support the load without renewable energy input
- Warranty on equipment
- Warranty on battery (including temperature ranges)
- Operating temperature range
- For AC Converters, fault clearance capability and protection devices included
- Standards compliance e.g. AS3000, AS5033, AS4777, AS5603

8. Advantages of BESS to Electricity Consumers

This section describes the potential advantages of BESS to consumers.

8.1. Tariff Avoidance

Under this scenario related to tariff, consumers either use less electricity from the distribution network or use electricity during periods of low tariff to avoid using electricity during periods of high tariff. Consequently, the saving made is the difference between the cost of the energy to charge the batteries and that which would have been paid for the energy used during the peak time if the batteries were not available. This scenario is relevant for consumers with and without renewable energy generation to charge the battery. For the case where

renewable energy generation is present, surplus generated energy (i.e. that in excess required by the local load) is used to charge the battery. If this scenario is to be viable, the cost of charging the battery using the renewable energy resource must be less than the cost of drawing the energy from the grid. If renewable energy generation is not present, the batteries are charged during periods of low tariff and the energy is then consumed during periods of high tariff. However, at present, there is no financial case which can be made which supports charging using grid supplied electricity during off-peak periods and then discharge during peak periods. This is due to the fact that the difference in tariff is so small that the payback period of the BESS will be extremely long. Figure 8.1 graphically illustrates the tariff avoidance scenario. Note that the ENERGY IMPORTED may be from the grid or from other generation such as solar PV.

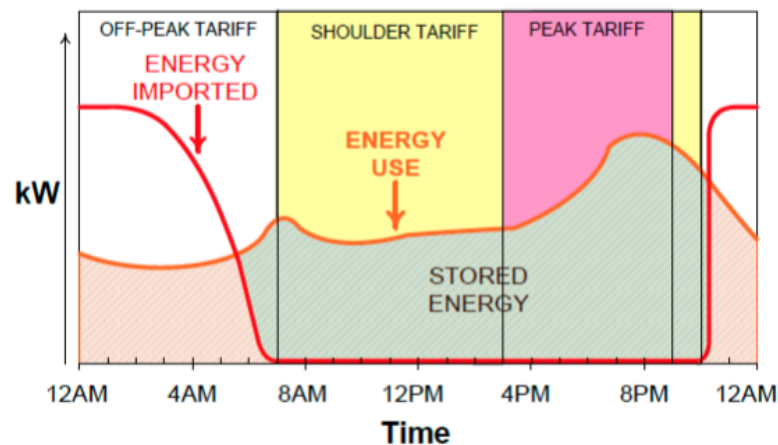


Figure 8.1: Example of Tariff Avoidance Scenario [9]

A number of customers view BESS in conjunction with renewable energy generation systems as a means by which they can disconnect from the electricity distribution network and avoid electricity bills. This is an extreme variant of the tariff avoidance measures outlined above. At present, there is no financial model which supports the application of domestic BESS as a means of disconnecting from the electricity distribution network. In order to maintain a reliable electricity supply under this scenario, it is necessary to invest in renewable energy generation and BESS which are much larger (and hence costly) than the relatively small scale installations commonly seen in domestic applications. There are a number of sources, e.g. [10], which suggest that the battery must be sized such that supply can be maintained without any generation for 3 days. From [11], the average Australian household uses between 103 and 156 kWh of electricity per week. This equates to between approximately 15 and 22 kWh per day. Consequently, to ensure supply for 3 days, a battery of a least 45 kWh is required. As a comparison, the Tesla Powerwall battery is nominally 7 kWh. A larger battery also requires a larger renewable energy generator to charge it. A solar PV system with a rating of 1 kW is capable of producing approximately 4 kWh per day in Sydney [12]. As such, in order to fully charge the aforementioned battery each day, a 12 kW solar PV generation system would be required.

8.2. Back-Up Security

BESS can conceivably be used as a large uninterruptible power supply and as such provide back-up security for mitigation of power outages. However, this usage scenario is not credible for most residential consumers who do not have equipment or processes that are sensitive to outages. Given the high overall reliability of the electricity distribution network, the BESS would only be in use to provide back up for a small number of hours each year.

8.3. Increased Renewable Energy Generation Penetration

BESS are often viewed as a means to increase small scale renewable energy penetration. This is achieved by using the battery to increase self-consumption as opposed to export of energy to the grid. In some cases, this is known as export limiting. One of the main impediments to increasing the penetration of small scale renewable energy generation, especially solar PV, has been the incidence of voltage rise due to a mismatch of generation to load on low voltage circuits during the peak solar PV generation periods (i.e. the middle of the day). In many cases, this issue has led to network operators limiting penetration and consumers experiencing inverter overvoltage trips. Batteries offer the advantage in that surplus energy can be stored and retained for use at a time when the load is higher. Figure 8.2 shows export limiting graphically.

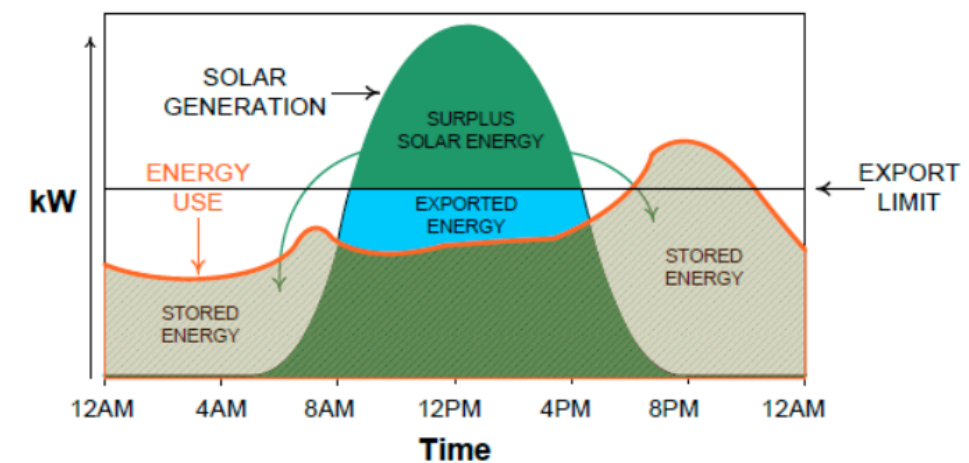


Figure 8.2: Graphical Representation of Export Limiting [9]

8.4. Energy Arbitrage

This potential benefit of BESS is similar to the tariff avoidance scenario above in that it involves charging the batteries with either renewable generation or low tariff grid energy. However, instead of self-consumption, this scenario involves selling the stored energy back to the grid during periods of high tariff. At present, this benefit cannot be realised due to the fact that the feed-in tariff for small scale generators is fixed at a relatively low rate and the difference between high and low tariff rates is not sufficient to make the investment in BESS financially viable.

One concept that has been identified to promote this scenario is the concept of the virtual power station. This concept involves a wholesale energy marketer controlling a large number of small BESS systems such that the combined capacity is similar to that of a single centralised generator. Such a wholesaler would then negotiate to sell the BESS generation capacity that it manages to the electricity market.

9. Financial Analysis

There are a number of resources available online which enable consumers to estimate payback time on BESS. Examples include:

- Solar Choice Solar & Battery Storage Sizing & Payback Calculator
<https://www.solarchoice.net.au/blog/solar-pv-battery-storage-sizing-payback-calculator>
- Solar Storage Calculator
<https://solarcalculator.com.au/solar-battery-calculator/>

Most calculators and other sources indicate that at current pricing, BESS payback periods are reasonably long and in many cases exceed the rated lifetime of the battery. Consequently, from a strictly financial perspective there is no strong driver for installation of domestic BESS. However, with battery (and other components such as inverters) prices decreasing significantly over time (see Section 5) this equation may change rapidly.

9.1. Example Calculation

This section presents a simple financial analysis of the payback period for a typical BESS. It is provided to illustrate the considerations required when determining the simple payback period of a BESS system. The figures given in the example will date quickly as price movement in the BESS sector is occurring at a rapid pace. In spite of this, the methodology of the example should remain sound. The financial analysis is based on using renewable energy to charge the battery. The stored energy is then used as required. The analysis has been adopted from [13] and uses a lithium-ion battery as an example.

9.1.1. System Data

BATTERY	
Battery Capacity	7 kWh
Battery Efficiency	92%
Battery Cost	\$13,990 including 4 kW solar PV system and inverter (Battery alone ~\$12,000)
ELECTRICITY	
Tariff	21.81c/kWh
Feed-in Tariff	6 c/kWh
Solar PV Generation	15.6 kWh per day on average

9.1.2. Scenario 1: Low Self Consumption

Under this scenario, the energy produced by the solar PV system is used to first charge the battery. 90% of this energy is then fed into the grid. Given the efficiency of the battery and inverter, it will require approximately 7.5 kWh to charge the battery. The financial analysis is as follows:

ITEM	SAVING
Reduction in energy bill due to energy storage used when required: 6.4 kWh x 21.81c = \$1.40 per day	\$1.40 per day
Feed in tariff: (15.6 – 7.5) kWh x 0.9 x 6	\$0.44 per day
Total	\$1.84 per day

The above results in a saving of \$671 per year. This results in a payback period of 21 years which is much longer than the battery expected life of 10 years.

9.1.3. Scenario 2: High Self Consumption

Under this scenario, the bulk of the solar PV generation can be self-consumed. This results in a loss of feed-in tariff but a large increase in tariff avoidance. Assuming 90% of the generated solar PV energy can be self-consumed, the financial analysis is as follows:

ITEM	SAVING
Reduction in energy bill due to energy storage used when required: 6.4 kWh x 21.81c	\$1.40 per day
Tariff reduction due to self-consumption: 21.81c x 0.9 x (15.6 – 7.5) kWh	\$0.44 per day
Feed in tariff: (15.6 – 7.5) kWh x 0.1 x 6	\$0.05 per day
Total	\$3.04 per day

The above results in a saving of \$1,109.6 per year. This results in a payback period of 12.6 years which is still longer than the battery expected life of 10 years.

9.1.4. Summary

The financial analysis above is based on simple payback, it does not take into account either increases in the cost of electricity over the life of the battery or decreases in battery price and is based on one popular but perhaps expensive battery type. It is clear that the financial case for installation of BESS is not strong at present. However, if projected reductions in lithium-ion battery costs are achieved and these cost reductions flow through to residential BESS systems, there is a significant reduction in payback time. Using the above scenarios, and assuming a 50% reduction in installation cost, payback periods for the two scenarios considered reduce to 10.5 and 6.3 years respectively.

10. Conclusion

This Technical Note examined domestic (residential) energy storage, specifically electrochemical battery energy storage systems (BESS). Further, it mainly dealt with BESS which are connected to the electricity distribution network although off-grid scenarios are also considered.

The Technical Note examined the theory of battery operation and outlined the characteristics and capabilities of BESS. The two main battery chemistries (lead-acid and lithium-ion) available for domestic use were evaluated as were the requirements for BESS integration. Finally, an examination was made of the benefits of BESS to consumers followed by a simple financial analysis of the payback time for a typical BESS and renewable energy generation system.

11. References

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The first part of the paper discusses the importance of the research and the objectives of the study. It then moves on to a literature review, which provides a background on the topic and identifies the gaps in the existing research. The methodology section describes the research design, data collection, and analysis. The results section presents the findings of the study, and the conclusion summarizes the main points and offers suggestions for future research.

The research was conducted in a systematic and rigorous manner, following the principles of good research practice. The data was collected from a representative sample of the population, and the analysis was carried out using appropriate statistical methods. The results of the study are presented in a clear and concise manner, and the conclusions are based on the evidence gathered.

The study has several strengths, including a well-defined research design, a large and diverse sample, and the use of advanced statistical techniques. However, there are also some limitations, such as the cross-sectional nature of the data and the potential for self-report bias. Despite these limitations, the study provides valuable insights into the topic and contributes to the existing knowledge in the field.

The findings of the study have important implications for practice and policy. They suggest that there is a need for further research in this area, and that the results can be used to inform decision-making and the development of interventions. The study also highlights the importance of considering individual differences and the role of context in understanding the phenomenon being studied.

In conclusion, the study provides a comprehensive and detailed examination of the topic, and its findings are both novel and significant. It is a valuable contribution to the literature and has the potential to make a positive impact on the field.



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