Battery Based Storage for Communities

Boyuan Zhu

Junwei Lu

Wayne Water

Markos Katsanevakis

Mojtaba Moghimi

Domagoj Leskarac

Sascha Stegen

2017

Table of Contents

Preface	1
1. Introduction	1
2. Technology of Battery Storage.....	1
2.1 Conventional and Advanced Lead-Acid Batteries	6
2.2 Lithim-ion Batteries.....	7
2.3 Sodium-Sulfur Batteries	8
2.4 Battery Storage in Power Applications	9
3. Challenges of EV Penetration in Distribution Grid.....	10
3.1 PEVs in Communities	10
3.2 EV charging technologies	11
3.3 Infrastructure and control	12
3.4 Grid stability	13
3.5 Limitations.....	14
4. Economical Aspects of Battery Storage	14
4.1 Cost Metric.....	14
4.2 Effective Cost of a Battery.....	15
4.3 System Cost Breakdown	15
5. Energy Consumption Pattern of a Community	17
5.1 Regulated Power Supply	17
5.1.1 Average Daily Power Usage – all samples.....	17
5.2 Energy Usage Pattern Classification.....	22
5.2.1 Double Peak Type	22
5.2.2 Single Peak Type	24
5.2.3 Mountain Type.....	25
5.2.4 Valley Type	26
5.2.5 Analysis	27
5.3 Peak Apparent Power (VA) Identification	29
5.4 Summary	31
6. Selection Process of Battery Storage	32
6.1 Criteria Participating in the Selection Processes	34
6.2 Weighting Description and TCFs Identification.....	36
7. Safety Consideration	38
7.1 Safety Hazard of Batteries and Mitigation.....	38

7.2 Location of Installtion	39
7.3 Battery Stroage Enclosure.....	40
7.4 Safety Policies and Standards	40
8 Conclusion.....	41
Reference	42

List of Figures

Figure 1 Concept of Community Energy Storage	2
Figure 2 American Electric Power Distributed CES [1]	3
Figure 3 DTE Energy Aggregated CES in Utility Territory [2]	3
Figure 4 Alkimos Beach Energy Storage Trail Concept Diagram [3]	4
Figure 5 Sonnen Virtual Grid across German [4]	4
Figure 6 The classic PbAc develops into an ALC battery [6]	6
Figure 7 PEV relationship between Residential, Industrial, and Commercial	11
Figure 8 Charging Station Infrastructure for different EV charging levels	13
Figure 9 Regulated power usage throughout 2012	17
Figure 10 Average power usage for household without regulated meter	18
Figure 11 Ratio of average daily power usage versus 90% peak power usage	19
Figure 12 Average power usage for household with regulated-power	19
Figure 13 Ratio of average daily power usage versus 90% peak power usage (household with regulated-power)	20
Figure 14 Average power usage for regulated-power system only	20
Figure 15 Ratio comparison between daily energy usage and 90% of maximum usage for regulated-power system only	21
Figure 16 Comparison of level of energy coverage for no hot water households (50% to 100% energy usage coverage), 186 samples	21
Figure 17 Comparison of level of energy coverage for no hot water households (50% to 100% energy usage coverage). 150 samples (represent as 80% of total sampling amount)	22
Figure 18 Double peak small usage (Device 228 → 5.54 kWh/day)	23
Figure 19 Double peak large usage (Device 119 → 20.83 kWh/day)	24
Figure 20 Single peak medium usage (Device 139 → 8.92 kWh/day)	25
Figure 21 Mountain type (Device 41 → 15.71 kWh/day)	26
Figure 22 With solar system (Device 229 → 20.28 kWh/day)	27
Figure 23 Percentage of each pattern type among 265 samples	28
Figure 24 Total energy usage across the time frames (extracted from transformer raw data)	28
Figure 25 Generalized results of daily energy consumption upon on different energy usage pattern	29
Figure 26 Generalized results of daily energy consumption ratio (90% days of coverage) upon on different energy usage pattern	29

Figure 27 Ratio of peak VA usage versus average daily energy usage	30
Figure 28 Peak VA usage sorted by average daily energy usage	31
Figure 29 Peak VA usage sorted by peak VA usage	31
Figure 30 Peak VA versus peak W usage	31
Figure 31 ESS for peak shaving and congestion relief	33
Figure 32 C_1 to C_{14} utilised for the comparison between the storage technologies	34
Figure 33 Column charts for comparison of the candidate storage technologies.....	36

List of Tables

Table 1 Major Concepts of Battery Storage	5
Table 2 Comparison of Different Li-ion Batteries	7
Table 3 Comparison of Battery Storage in Power Application	9
Table 4 Advantage and Cost Effect of Battery Storage in Power Application	9
Table 5 EV Charging Levels [12]	12
Table 6 Comparison of average energy usage upon on the energy usage pattern	28
Table 7 Comparison of energy usage when using 80% of people's behavior as the sample	32
Table 8 DM associated with C_1 , for comparison between the candidate energy storage technologies	35
Table 9 Criteria weighting for the application of energy shifting	36
Table 10 TCFs and suitability per energy storage technology, for the application of energy shifting .	37

Preface

Instantaneous load demand variations and fluctuations introduced by renewable energy sources (RESs) to the system, pose various challenges to the operation of the grid. Significant support to the grid can be provided by energy storage systems (ESSs) strategically placed and sized. In the presence of ESSs combined with RESs proximate to load centres, transmission losses are minimized and grid infrastructure upgrades are deferred, due to local generation and consumption of electric energy. This is without the need to transfer energy from remote power plants. Furthermore, ESSs introduce considerable flexibility to electric energy, which can now be consumed when it is needed the most (e.g., during the on-peak period). As a result, the loading levels of the grid components are reduced and the terminal voltages are maintained within the allowable limits. This chapter presents an in-depth study of battery storage for communities and an analysis of major battery storage technology and application. This includes another special form of distributed energy storage – the electric vehicle (EV).

1. Introduction

Renewable energy is no longer novel to those involved in the evolution of power, especially solar power and wind power due to their dramatically increased penetration. There is still some way to go in the take-up of solar energy as a means of powering our world. An incredibly large amount of small-scale PV installations in residential or commercial buildings are acting as virtual power stations, which decentralise power generation against the conventional utility. However, this introduces the problem of excess energy and unstabilized power, which affects existing electricity infrastructure. The concept of community energy storage (CES), as shown in Figure 1, has captured the interest of energy suppliers. It operates distributed energy storage systems (DESSs) at end-user homes and businesses rather than using one or a few large-scale units at the utility side. These decentralized storages are acting as buffers between intermittent power resources and the utility grid, which significantly eases the pressure on local transformers.

- CES is a young market but it is being driven quickly by multiple trends: (1) The increased penetration of intermittent renewable resources in the grid urgently requires buffer technology to smooth power. (2) The continued advances in power electronics provide solid technique support. (3) The rapid proliferation of electric vehicles significantly stimulates battery development and production, which makes battery storage economically viable. Therefore, CES is believed to provide numerous benefits with many possible combinations. Such benefits are as follows: It eases the burden on the centralised grid and increases the overall resilience of the power supply.
- Less transmission and distribution (T&D) equipment is needed for local demand in new development areas as it provides power locally, which reduces the need for T&D capacity.

- It extends the life of existing infrastructure by reducing the need to upgrade the transformer and network to meet local peak demand. The cost of the battery is more attractive compared to upgrading the grid.
- It serves as a robust, fast-responding and flexible alternative source of power generation. It can maintain the stability and reliability of the grid to overcome the integration challenge of renewable energy access.
- Low price energy can be stored during off-peak periods and used when the price is high. This creates a very economic environment benefiting energy users.

Figure 1 Concept of Community Energy Storage

In 2005, American Electric Power (AEP) located a 2 megawatt (MW) system with advanced sodium-sulfur (NaS) battery storage at a substation as a pilot project to evaluate the prospects and merits of the CES concept [1]. Unfortunately, the battery didn't perform to its stringent standards and the full-scale program was not resumed. Eventually around 2009, AEP deployed 80 individual distributed units of smaller scale systems, with 25 kW rated power and 25-75 kWh batteries, at or near end-user homes. (see Figure 2). It aimed to apply CES at small-scale of battery compared to megawatt-scale. The specification of the CES was published as an open source document for public use and feedback (as a guideline for further standardization).

Figure 2 American Electric Power Distributed CES [1]

Another trial project in 2010, led by DTE Energy, is another example of the concept of an aggregated CES system in utility territory [2]. There were twenty 25 kW/50 kWh battery storage systems on local transformers and another 500 kW/250 kWh integrated to the substation, as shown in Figure 3. It demonstrated CES's capabilities of voltage/VAR support, integration renewable generation, islanding during power outages and frequency regulation. The project used secondary EV batteries as storage, which identified an alternative application for the continuous life of EV type batteries.

Figure 3 DTE Energy Aggregated CES in Utility Territory [2]

Alkimos Beach community in Western Australia is currently leading the largest community-scale battery storage project in Australia and will enable Synergy to be on the leading edge of this technology [3]. The project installs a 300 kW/1.1 MWh fully contained Lithium-ion (Li-ion) energy storage system connected to the distribution network, as shown in Figure 4.

Figure 4 Alkimos Beach Energy Storage Trail Concept Diagram [3]

Sonnen, a German company who takes a step further in smart storage systems, launched Sonnen Community in 2015 to link all its customers' solar and storage devices into a virtual grid (as demonstrated in Figure 5). This allows subscribed members to trade electricity peer to peer and sell excess power into the wholesale market [4]. This aggregation creates a new economy of electricity trading that challenges conventional utility modes.

Figure 5 Sonnen Virtual Grid across Germany [4]

CES raises a new transformation in the form of energy storage that aggregates a large amount of DESS. However, a new transformation is always accompanied by challenges. The government policy of renewable energy and market regulation are barriers to CES development and standardization. Some markets have low-cost electric power or are dominated by vertically integrated utilities. Selection of the right battery chemical and deployment of the right capacity size of DESS are key trade-offs in the economic benefit to users and the cost of the system. The battery is still not cheap enough, especially when the

entire community is considered to go off-grid. The proliferation of EVs can be considered as alternative storage but there is high demand for them when rapid charging is conducted. Forecast and control algorithms are extremely challenging due to the unpredictable nature of intermittent renewables, various customer behaviours and load patterns, strict operation logic and conditions to prolong battery life, and reliable communication methods.

2. Technology of Battery Storage

Battery storage is one of most significant technologies that change way of using energy. For a large upfront cost, solar panels can generate ‘free’ electricity but don’t work at night. Alternatively, off-peak power is much cheaper but only available in the middle of the night. Battery storage helps the grid to adopt variable forms of renewable energy and provides more flexible, reliable and efficient energy to customers. It is fully controllable and fast responding that plays an important role in maintaining a consistent energy balance within the renewable network by storing excess of generation and supplying additional energy to loads to compensate the deficit. A variety of pilot projects by means of different battery storage technologies are conducted over the world that demonstrates capability and maturity throughout grid and community.

Battery technology varies according to different criteria. Table 1 below introduces some major concepts that have to be understood before looking into battery storage.

Table 1 Major Concepts of Battery Storage

Name	Unit	Description
Chemistry		It refers to the chemistry in a battery operation.
Total Capacity	Ah	It refers to the total amount of electric charge battery can deliver at the rated voltage.
Usable Capacity	Ah	Limited by battery characteristic and operation condition, not all battery can healthily deliver the full amount of energy it stores.
State of Charge	%	The current state of a battery in use.
Depth of Discharge	%	An alternate method to indicate a battery’s state of charge.
Charge/Discharge Rate	C	Also known as C rate which indicates a rate at which a battery is charged or discharged relative to its maximum capacity.
Operating Temperature	°C	A temperature range that a battery can provide reasonably good performance.
Nominal Voltage	V	It is measured at the midpoint between fully charged and fully discharged based on a 0.2C rate.
Operating Voltage Range	V	Open-circuit voltages when a battery is fully charged and fully discharged.
Battery Management System		An electronic control system that monitors and controls the charging and discharging of the battery.
Hazards		Explosion, fire, leakage, toxic materials, gas emission, etc.
Self-discharge	%	Percentage of charge losses when stored at room temperature.
Cycle Life	Cycle	It is the number of complete charge/discharge cycles that a battery is able to perform before its end of life.
Calendar Life	Year	It indicates how long a battery is expected to last in terms of calendar years.

End of Life

When a battery's capacity fade under a certain percentage of its original capacity, typically 80%.

2.1 Conventional and Advanced Lead-Acid Batteries

Lead-Acid (PbAc) battery is the first rechargeable battery for commercial use which was invented in 1859 and is still in wide use today. The maturity of the conventional PbAc battery is dependable that it makes battery simple to manufacture and cost per watt-hour is really low. The conventional PbAc battery is good for power driven applications, commonly classified into three usages: automotive (starter or SLI), motive power (traction or deep cycle) and stationary (UPS), due to its high specific power, capable of high discharge currents and wide range of temperature performance. However, limitations of chemistry characteristic constrain its application in energy fields. This kind of battery has low specific energy and poor weight-to-energy ratio. It has to be charged slowly with correct voltage limits to avoid buildup of sulfation on the negative plate which robs battery performance. A full charge normally takes 14-16 hours and the battery must always be stored in full state-of-charge to prevent sulfation condition. Repeated deep-cycling reduces battery life. For example, a deep-cycle battery has limited cycle life around 400-500 cycles by half depth of discharge with 50% remaining [5].

It is believed that lead based technology has significant unused performance potential that can make the battery viable in the renewable applications by overcoming the core limitation of utilization of lead. In 2004, The Ultrabattery by Commonwealth Scientific and Industrial Research Organisation (CSIRO) of Australia combined the asymmetric ultracapacitor with the PbAc battery, which provided a fundamental structure for advanced lead-carbon (ALC) battery development. Followed by research and commercialization of Japanese researcher, ALC battery was applied and tested in the hybrid vehicle in 2008. The ALC solves sulfate accumulation, partial charge and ageing issues by adding carbon into the cathode plate which significantly improves the performance of charge and discharge, as well as cycle life. Figure 6 illustrates the classic PbAc cell with the lead negative plate being replaced with a carbon electrode to benefit from the qualities of a supercapacitor.

Figure 6 The classic PbAc develops into an ALC battery [6]

Unlike a regular PbAc battery, ALC battery is capable of eight times faster charging and three times in discharge power. Its lifecycle increases around six times up to 2,200 cycles with deep depth of discharge, between 30 and 70 percent. It inherits the maturity of manufacture, wide temperature performance and dependence from PbAc battery that makes it more cost-effective. Today, the ALC is used as a replacement for the classic starter battery in start-stop applications and in 48V micro and mild hybrid systems. Also, it is beginning to be widely used in energy storage of PV and wind application.

2.2 Lithium-ion Batteries

Lithium is the lightest metal in catalogue and has the greatest potential that can provide the largest energy density for weight. Therefore it is naturally ideal for energy storage but its inherent instability is standing in the way. The first rechargeable Li-ion battery was commercialized in 1991 by Sony Corporation. Li-ion is non-metallic lithium that has slightly lower energy density than lithium metal but much safer. The battery has a congenital advantage that it does not has memory effect that requires scheduled cycling and also very low in self-discharge. But its overall drawback is also obvious. Li-ion is fragile which needs an extra circuit to protect the cell from under-discharge and over-charge. Thermal runaway is still a major concern in the safety aspect. Therefore, manufacturers keep making rapid improvement in enhancing different chemical combination with Li-ion to increase battery charge/discharge rate, cycle and calendar life and reduce the cost which is very important to make the battery economical viable. Current available types of Li-ion battery in the market are lithium cobalt oxide (LCO), lithium manganese oxide (LMO), lithium nickel manganese cobalt oxide (NMC), lithium iron phosphate (LFP), lithium nickel cobalt aluminum oxide (NCA) and lithium titanate (LTO), as compared in Table 2.

Table 2 Comparison of Different Li-ion Batteries

Chemistry	Lithium Cobalt Oxide	Lithium Manganese Oxide	Lithium Nickel Manganese
Abbreviation	LCO	LMO	NMC
Application	Mobile phones, tablets, laptops, cameras	Power tools, medical devices, electric powertrains	E-bikes, medical devices, EVs, Energy storage
Snapshot			
Nominal Voltage	3.60V	3.70V (3.80V)	3.60V (3.70V)
Full Charge	4.20V	4.20V	4.20V (or higher)
Full Discharged	3.00V	3.00V	3.00V
Minimal Voltage	2.50V	2.50V	2.50V
Specific Energy	150-200Wh/kg	100-150Wh/kg	150-220Wh/kg

Charge Rate	0.3C (1C max)	0.7-1C (3C max)	0.3-1C
Discharge Rate	1C	1C,10C possible	1-2C
Cycle Life	500-1,000	300-700	1,000-2,000
Thermal Runaway	150°C (full charge promotes thermal runaway)	250°C (high charge promotes thermal runaway)	210°C (high charge promotes thermal runaway)

Table 2 Comparison of Different Li-ion Batteries (Cont.)

Chemistry	Lithium Iron Phosphate	Lithium Nickel Cobalt Auminum Oxide	Lithium Titanate
Abbreviation	LFP	NCA	LTO
Typical Manufacturer	Energy storage, EVs	Medical devices, industrial, electric powertrain (Tesla), grid storage	UPS, electric powertrain (Mitsubishi i-MiEV, Honda Fit EV), grid storage
Snapshot
Nominal Voltage	3.20V, 3.30V	3.60V	2.40V
Full Charge	3.65V	4.20V	2.85V
Full Discharged	2.50V	3.00V	1.80V
Minimal Voltage	2.00V	2.50V	1.50V
Specific Energy	90-120Wh/kg	200-260Wh/kg	70-80Wh/kg
Charge Rate	1C	0.5C	1C (5C max)
Discharge Rate	1-6C	1C	10C possible
Cycle Life	1,000-2,000	500	3,000-10,000
Thermal Runaway	270°C (Very safe battery even if fully charged)	150°C (high charge promotes thermal runaway)	One of safest

LCO is the original Li-ion which is average in all characters. It is widely used in mobile phones, cameras and laptops. An NCA battery is clearly the best in specific energy but shorter cycle life and less stability. It was widely used in Telsa electric powertrain for its EVs, produces by Panasonic. An NMC battery generally has a longer cycle life, more stability, and less energy density and less cost than NCA. In terms of specific power and thermal stability, LMO and LFP are superior. Thus NMC and LFP shares large partitions in EV and energy storage market nowadays. LTO is the best in lifespan and safety aspect but low in capacity and expensive in cost which is main technique obstacle in commercialization.

2.3 Sodium-Sulfur Batteries

A NaS battery is a type of molten-salt battery constructed from liquid sodium (Na) and sulfur (S). It uses molten salts as an electrolyte and gains conductivity which operates at a temperature of 250-350°C. This type of battery has a high-energy density, high efficiency of charge/discharge and long cycle life, and is fabricated from inexpensive materials. For example, the modern sodium-nickel-chloride battery is said to have an operating temperature from -40°C to 65°C with a cycle life of 3,500 at 80 percent depth-of-discharge, a level comparable with Li-manganese and Li-phosphate. It can be deployed to support the electric grid, or for stand-alone renewable power applications. However, pure sodium presents a hazard, because it spontaneously burns in contact with air and moisture, thus the system must be protected from water and oxidizing atmospheres.

2.4 Battery Storage in Power Applications

Application of CES can demonstrate various capability under multi-mode operation via smart grid infrastructure, which includes frequency regulation, VAR support and voltage support, PV output shifting and levelling, demand response for peak shaving, islanding during outages, etc. Detail comparisons are listed in Table 3 and Table 4.

Table 3 Comparison of Battery Storage in Power Application

Demand	Battery Storage Installation Locations			
	Generation	Transmission	Distribution	Consumer
Charge and discharge arbitrage	✓	✓	✓	✓
Storage by seasons			✓	✓
Frequency regulation	✓		✓	
Voltage support			✓	✓
Load tracking			✓	
Black start	✓			
Transmission and distribution congestion alleviation		✓	✓	
Demand response for peak shaving			✓	✓
Off-grid		✓	✓	
Waste heat utilization	✓		✓	✓
Heating and cooling			✓	✓

Table 4 Advantage and Cost Effect of Battery Storage in Power Application

Application	Advantage	Cost Effect
Generation	<ul style="list-style-type: none"> • Reduce system capacity requirements; • Improve power plant utilization; 	<ul style="list-style-type: none"> • Reduce power plant investment and operating costs; • Reduce power generation costs;

	<ul style="list-style-type: none"> • Improve renewable energy plans to generate electricity 	<ul style="list-style-type: none"> • Increase power generation efficiency
Transmission and Distribution	<ul style="list-style-type: none"> • Delay investment in power transmission and distribution; • Improve asset utilization; • Improve the amount of renewable energy access. 	<ul style="list-style-type: none"> • Reduce investment in equipment and the loss of network.
Consumer	<ul style="list-style-type: none"> • Demand-side management; • Improve the allocation of electricity equipment resources. 	<ul style="list-style-type: none"> • Reduced electricity costs; • Improved quality and reliability.

3. Challenges of EV Penetration in Distribution Grid

An electric vehicle refers to a vehicle that is entirely powered by an electric drivetrain or a vehicle that is powered by a series hybrid electric drivetrain that needs to be plugged into the electricity grid for battery recharging. An electric car uses electric motors and motor controllers in place of an internal combustion engine. Generally, the energy for the motor is stored chemically in battery packs (e.g. Li-ion battery) that are located in the vehicle. These batteries are then charged at the home, at the workplace, or via publicly accessible recharge stations.

In a plug-in hybrid electric vehicle (PHEV), the drive wheels are powered by an electric motor. A smaller petrol engine is fitted to the vehicle to generate power for the electric motor. The on-board batteries can also be charged by plugging the vehicle into the electricity grid. In addition to charging from the electricity grid, most fully-electric vehicle and PHEVs take advantage of regenerative braking systems that charge the on-board batteries.

A key challenge associated with the widespread market acceptance of fully-electric vehicles is the current high cost of this technology relative to conventional vehicles, and limited operating ranges between vehicle recharging. This issue is being progressively addressed by significant investment in battery technology and battery management systems with a view to extending the operating range of these vehicles in the future.

All forms of battery electric vehicles (BEVs) now benefit from a gradual increase in range and a reduction in up-front costs. This gradual and substantial rise in plug-in EV (PEV) penetration will have an impact on distribution grids, as charging PEV can be more taxing on distribution infrastructure [7]. Charging methods, power capacities and vehicle to grid (V2G) integration are areas to consider within communities for the sustainable penetration of PEV. As the cost of energy storage continues to reduce, replacing the battery to restore range becomes more affordable. This brings about the market of second life electric vehicles batteries, with potential for battery energy storage in communities.

3.1 PEVs in Communities

There is a substantial growing trend with the uptake of EVs within numerous countries and communities including both the private and commercial sectors. There have been over a hundred times increase of BEV, from mere thousands in 2010 to over 700,000 in 2015. EVs have several benefits over traditional petrol vehicles with only a few drawbacks. Zero

emissions and noise at the point of use, low-maintenance costs, low energy costs and the potential for local energy production are all major benefits of EV over internal combustion engine vehicles. The primary disadvantage to date though has been the cost of the vehicles, stemming from high battery prices. This, in turn, limited the range of affordable EV and impeded market adoption. As the demand for lithium-based energy storage increased, the supply of energy storage became more predominant by reducing cost per kWh each year.

BEV, Hydrogen Fuel Cell EV (HFC), and PHEV are the three classes of vehicles constituting PEV. All of these vehicle types have the ability to interconnect onto the distribution network with varying energy storage capacities [8]. BEV typically would contain the largest battery energy storage as HEV and PHEV hybridize energy storage with liquid or high-pressure fuels. Nevertheless, all PEV vehicles can charge or absorb energy from the grid and in some instances return that energy through V2G integration [9]. V2G integration transforms PEV into a substantial distributable load and potential energy source. The role of PEV in communities is illustrated in Figure 7.

Figure 7 PEV relationship between Residential, Industrial, and Commercial load

Such mass storage has the capability to provide numerous benefits to both the energy supplier and local consumers of energy, residential, industrial and commercial. PEV owners would most likely have to charge facilities at their residential premises; some industries already include specified parking bays for PEV vehicles as do commercial buildings and parking lots. PEV integration is broadly seen as a future development in the Microgrid and Smart Grid.

3.2 EV charging technologies

One of the crucial challenges of EV penetration into the grid and increasing its usage in the communities is the charging capability and availability. The main concern of the consumers is to be able to charge EVs within the shortest possible time [10]. On the other hand, the EV charging stations are required to provide the charging capability for various EVs with different charging technologies. Therefore, it is necessary to develop EV charging technologies in parallel with the increasing EV usage in the communities.

To charge the EVs, two main charging technologies are available: Contact based charging and wireless charging. The contact based charging includes AC and DC charging methods. For the high power charging applications, AC on-board charging and DC off-board charging are currently used in the market. The benefit of DC over AC charging is mainly because of normalized voltage and current range, which is the same all over the world. Different sockets

are in use to charge EVs' energy storage. The sockets are designed for DC and single- or three-phase AC connections. Power delivery is limited to the socket technology and the type of charging. The combined AC/DC sockets have the benefits of both charging methods and higher energy transfer range [8]. On the other hand, the contactless charging technology or wireless charging provides another solution to the EV charging. However, requiring complex infrastructure and limited power transfer are of disadvantages of wireless charging. Among different battery technologies employed in the EV charging, nickel metal hydride (NiMH) and lithium-ion have gained more popularity [7].

There are different standards for EV charging systems considering safety, reliability, durability, rated power, and the cost of different charging methods [10]. Two of the main standards used in the literature are SAE J1772 [11] and IEC 61851-1 [12]. According to the standards, different charging levels are briefly explained [13]:

- Level 1 charging: It is mainly employed for slow single-phase on-board charging for domestic household applications or long-time EV parking.
- Level 2 charging: It is used for quick private and public EV charging.
- Level 3 AC and DC charging: It is for high power applications and utilized for fast public EV charging.

The summary of different levels of charging is presented in Table 5.

Table 5 EV Charging Levels [12]

Charge Method	Connection	Power (kW)	Voltage (V)	Location
Normal power	1-Phase AC connection	3.7	Single-phase 230 V AC	Domestic
Medium power	1- or 3-Phase AC connection	3.7-22	Single- or Three-phase	Semi-public
High power	3-Phase AC connection	>22	Three-phase 400 V AC	Public
High power	DC connection	>22	480 V DC	Public

3.3 Infrastructure and control

One of the benefits of integrating a large number of EVs into the power grid is to provide a great potential energy storage for the community. This potential can be in the form of EVs injecting energy back to the grid or using second-life EV batteries as energy storage. The benefits of integrating a large fleet of EVs into the grid is mainly for two parties: EV owners and utility grid [9]. To be able to engage EVs as the energy generation resources, a bidirectional Vehicle to Grid (V2G) infrastructure is required. Vehicle to Grid (V2G) technology provides many services to the community such as frequency and voltage regulation, active power support, reactive power compensation, power factor regulation, and supporting the integration of renewable energy resources [14].

One of the challenges in the V2G systems is the complexity of the bi-directional battery charger, which requires additional hardware and software to perform properly. The common components of a bi-directional battery charger are AC/DC converter, DC/DC converter, battery management system (BMS), and protection circuits. The DC/DC converter is employed as either buck or boost converter in the charging or discharging mode. The role of AC/DC converter is to rectify the AC power while charging the EV and invert the DC power to

give the power back to the grid. The overall structure of the V2G system is illustrated in Figure 8.

Figure 8 Charging Station Infrastructure for different EV charging levels

The integration of EVs to the grid can be coordinated by intelligently scheduling EVs to discharge them at the periods that energy has higher prices (peak hours) and charge them when the price of energy is lower (off-peak hours). To implement such a system and infrastructure, an advanced control, communication, and optimization system incorporated into the grid and EV management system is required.

3.4 Grid stability

One of the main challenges of EV penetration in distribution grid is to deal with grid stability especially in the case of large number of EVs. To fulfill the stability of the power grid, the impact of EVs on the load and generation side of the grid should be investigated. First, the generation units are required to meet EV charging demand. Therefore, it is important to control EV charging and mitigate the impact of EV loads as uncontrolled charging can lead to undesirable grid impacts such as power quality problems. In order to prevent extra EV load on the grid, the charging of EVs needs to be controlled and shifted to the off-peak hours and thus no need for additional power generation and consequently no limitation of EV penetration. To shift the EV charging to the off-peak hours, utilities employ Time of Use (TOU) tariff strategy. According to the TOU tariffs, the pay rate would be lower during the off-peak hours, which motivates the EV owners to charge their vehicle within this period. However, this should be taken into account that the load shifting to the off-peak hours requires an

optimized scheduling otherwise it can cause an even higher increase in peak load demand [10].

To increase the number of EVs integrated into the grid, optimized charging/discharging algorithms that consider the benefits of EV owners and utilities are required. To maximize the benefits of the utility, the optimization algorithms are employed to minimize the impact of EVs on the grid, total electricity generation costs, energy losses, and infrastructure costs. Furthermore, different demand response strategies are applied to flatten demand profile in case of high integration of EVs [13]. On the other hand, to provide the benefits of EV owners while considering grid constraints, optimization algorithms are employed to minimize the charging costs and maximize the discharging profits [14]. Additionally, charging rate and charging time are factors that should be taken into account in the design of optimization algorithms as they have an impact on the EV owners' benefits [15]. By fulfilling the requirements of EV owner and utility, the grid stability is less of a concern.

3.5 Limitations

As many benefits are imagined for EVs and V2G systems, there are challenges and limitations to overcome as well. Among many of the challenges, battery degradation, high investment cost, and social barriers can be pointed out [14]. The batteries have a limited lifetime and many factors influence on the aging rate. One of the main reasons of aging is the charge and discharge rate, as higher rates would result in quicker battery degradation. However, a degraded battery may not be functional in EV and V2G system but does not mean it has no more benefits for the community. The EV batteries can be repurposed and reused for the stationary and utility applications after the end of their lifetime in the EV [16].

One of the other limitations is high investment cost of EV industry. The cost of EVs in the market and the required infrastructure is still high compared to that of combustion engine cars. In other words, there needs to be a high investment on the development and implementation of V2G infrastructure and different EV components such as batteries, battery chargers, and control systems. Energy losses and safety issues are also among the challenges, which need to be specifically considered for the EVs and V2G systems in the communities. One of the reasons of the high price of EVs is the low acceptance by the society. In order to increase the number of EVs and EV charging stations in the community, a comprehensive and reliable network of V2G is required to guarantee the requirements of EV owners at all the times [14].

4. Economic Aspects of Battery Storage

Differentiating between price point and cost of battery storage is paramount to evaluate any battery storage with regard to performance and real value over the life of the project. Battery manufacturers commonly quote their up-front price based on per watt hour (Wh) on battery system only. However, the true cost of energy delivered during the usable lifetime of the battery is a more accurate and reliable method for estimating its economic value for projects and ROI of customers.

4.1 Cost Metric

Apart from the environmental benefit, economic viability of battery storage is dominating the speed of its deployment. The upfront cost of battery storage is a critical factor that determines if it is economically viable as it takes a very large part of the overall cost. Power and energy are two basic orientations in battery storage applications. The cost metric of “\$/Wh”, “\$/kWh”, and “\$/MWh” are frequently used in measuring the normalized cost of energy storage devices. The other useful cost metric is based on power capacity that measured in watts, “\$/W”. They are very different from each other and have to be understood clearly when looking at the upfront cost of energy storage.

4.2 Effective Cost of a Battery

The effective cost of a battery is always hard to calculate while it is always a major concern for users when selecting and comparing different batteries for the application. Most common way is simplifying the figure based on the \$/kWh capacity value which is the price divided by the nominal storage capacity at full charge, as in Equation 1. It seems this metric is useful in comparing batteries across various brands and models but actually very misleading. That is because the simplified calculation only considers the claimed battery capacity but not the real one during operation.

$$\text{Cost per capacity (\$/kWh)} = \frac{\text{Total Cost of Battery (\$)}}{\text{Battery Capacity (kWh)}} \quad (1)$$

The ultimate value of the battery is all about the total energy it can store and deliver. There are three important factors have to be taken into account: the cycle and calendar life of the battery, depth of discharge, and round-trip efficiency.

- The cycle life indicates the number of times that a battery can be charged and discharged. The calendar life tells how long a battery can last in storage, typically by calendar years. No matter whether a battery is in use or storage, degradation is irreversible that brings it to the end of life.
- Depth of discharge (DoD) specifies what percentage of the battery capacity is actually used. Battery manufacturers normally specified a recommended maximum value of DoD for a nominal cycle life because the cycle life of a battery tends to decrease if DoD is increased.
- Round-trip efficiency (RE) is dependent on the battery’s DoD. It indicates the amount of energy that can be extracted from a battery as a percentage of total storage. The loss of energy is generally caused by heat or other inefficiencies within the system.

Therefore, a revised calculate of cost per storage can be derived as in Equation 2.

$$\text{Cost per storage (\$/kWh)} = \frac{\text{Total Cost of Battery (\$)}}{\text{Battery Capacity (kWh)} \times \text{Cycle Life} \times \text{DoD} \times \text{RE}} \quad (2)$$

Besides the performance profile of the battery itself, ancillary costs are not included in the equation. They are also very important, especially for those project developers and contractors. These costs vary case by case, which may include shipping cost, installation cost, ongoing maintenance cost and so on.

4.3 System Cost Breakdown

Most battery based storage systems are DC power and interconnected to the utility grid or customer's load at AC side. Common component levels in a DC battery storage system are:

- **Battery cells**
Normally it refers to the smallest unit of battery that chemistry is packed into. They are a most basic unit of energy storage which is assembled into battery banks or modules.
- **Battery banks/modules**
A group of battery cells are packed into a battery bank or module. It is generally standardized and mass produced by the manufacturer as an intermediate component of battery energy storage which can be easily replaced or repaired.
- **Battery strings/racks**
Multiple battery banks or modules are connected in series or parallel to form battery strings/racks.
- **Battery container**
Groups of battery strings/racks can be installed in a container to build large battery energy storage. It is normally used in commercial, industrial and grid application.
- **Battery control unit (BCU)/Battery management system (BMS)**
BCU/BMS cost is generally added into the price of the battery as a whole by the manufacturer.

However, to install and commission a complete AC energy storage system to a customer site, there are additional costs at AC side which can include:

- **Power conversion system (PCS)**
Grid Tied Energy Storage mediums are predominately direct current (DC) in nature. To effectively utilize the energy storage capacity on the present electric utility grid, the energy must be converted to a standard Alternating Current (AC) level and regulated through a converter. It bi-directional converts from AC to DC and DC to AC which interconnects and controls of multiple DC sources to provide regulated, stable and controllable power flow.
- **Isolation transformer**
In certain circumstance, an isolation transformer is needed to transfer electrical power from AC power source to some equipment while isolating the powered device from the power source. For example, some PCS is delta connection and needs delta to star isolation transformer when connects to the four-wire network.
- **Switchgear**
Electrical disconnect switches, fuses or circuit breakers are necessarily needed to control, protect and isolate battery and other electrical devices in the system.
- **Cabling**
AC cable, DC cable and communication cable cost can not be ignored. Normally it is included in the price of battery or other equipment. However, additional cost has been counted among interconnections.
- **Installation**
Mostly it is the transportation, labour and machine cost for installation.

Therefore, it is important to clarify costs in different segments when faced with a value for battery storage cost in \$/Wh. The most basic level is the cost of cells only which generally used by the battery manufacturer. However, ultimately customer would like to have the cost at most complete solution level which is also known as “all in one” cost of an installed and commissioned battery storage system.

5. Energy Consumption Pattern of a Community

This is an analysis of energy usage data obtains from Ergon Energy Australia with effective measurements of 265 samples in a residential community throughout the year of 2012. It identifies the sufficient number of energy storage as well as the maximum power rating of power electronics used to get the rural household completely self-sustainable. Due to the privacy concern, details of the raw data cannot be disclosed, neither the designated household with regards to its address and the appliance information. However, the result shown can still be a very good reference for understanding the basic requirement of power electronics used for the off-grid energy storage system.

5.1 Regulated Power Supply

The energy usage of regulated power usage is temperature dependent as shown in two example figures in Figure 9. Almost every household has the same energy usage pattern that the peak usage occurs during July period. The differences are the magnitude and the variation degree of the energy usage. Since it is a controlled-source power supply, the energy usage versus hours pattern is not showing. On the other hand, the peak usage during a day is depending on the size of the hot water system (likely the biggest energy consumption device of a household). By looking at the top 10 peak energy usage within a period of time (e.g., one week), it can be justified whether there is a regulated power supply in the household if these readings are consistent.

Figure 9 Regulated power usage throughout 2012

5.1.1 Average Daily Power Usage – all samples

In order to analyze the household energy usage, we firstly classify 265 samples into two groups: household with regulated power supply and household without regulated power supply. In the following figures, the x-axis is the number of household samples and the y-axis

shows the energy usage in kWh. “Usage/day” is the average energy usage throughout a period, and “90% Usage” represents as the peak kWh energy usage required to cover 90% of days throughout the year. The “90% Usage” factor characterizes the peak energy usage required in the hourly scale, and this gives a good indication on the specification of power electronics required. For example, reading 30 kWh for “90% Usage” means the battery storage needs to be at least capable of exporting 30 kWh of energy. The actual requirement for the power electronic system will be higher. However, due to the details it involved, we will be focusing on the energy pattern in the hourly scale.

There are 182 samples for household without regulated power supply. The average power usage curve, as well as their daily usage ratio at 90 %, is shown in Figure 10 and Figure 11. To simplify the problem, we can focus our observations on 80% of people’s energy usage behaviour (roughly for a number of household below 145) and following summaries are made:

- For general households, the average daily energy consumption is less than 19 kWh per day;
- 57 % of households (among 182 samples) uses 5~15 kWh per day;
- The ratio of peak energy usage to the average daily usage is about 1.72.

Figure 10 Average power usage for household without regulated meter

Figure 11 Ratio of average daily power usage versus 90% peak power usage

There are 82 samples for household with regulated power. The average power usage curve, as well as the daily usage ratio at 90 %, is shown in

Figure 12 and Figure 13. If we analyze 80% of people's energy usage behaviour, the following comments are made:

- The average daily energy consumption is less than 19.7 kWh per day
- 54.9% of people use 5~15kWh per day
- The ratio of peak energy usage to the average daily usage is about 1.74

Figure 12 Average power usage for household with regulated-power

Figure 13 Ratio of average daily power usage versus 90% peak power usage (household with regulated-power)

We are also interested on the energy consumption behaviour of regulated power (controlled-power), and similar patterns are shown in Figure 14 and Figure 15. If we use 80% of people's energy usage behaviour, the following comments are made:

- The average daily energy consumption is less than 10.24 kWh per day
- 72.8% of people use 5~15 kWh per day
- The ratio of peak energy usage to the average daily usage is about 1.68

Figure 14 Average power usage for regulated-power system only

Figure 15 Ratio comparison between daily energy usage and 90% of maximum usage for regulated-power system only

Above results are based on 90% coverage of energy usage days throughout a year. On other words, above analysis are used to justify what is the minimum energy consumption per day to cover 90% of days throughout a year. However, what happens when the degree of energy coverage varies? The comparison result is shown in Figure 16 and Figure 17. The result showed here only focuses on household without controlled-supply. The household with or without controlled-supply has very similar energy consumption figure.

As it can be observed, it is impractical to cover 100% days of energy usage as peak usage in some of days is 3 times greater than its average daily usage. If the coverage of days is below 80% of days, the ratio can be effectively reduced to 1.3~1.5 by looking at 80% of samples. The ratio is further dropped by bringing coverage days to 70%.

Figure 16 Comparison of level of energy coverage for no hot water households (50% to 100% energy usage coverage), 186 samples

Figure 17 Comparison of the level of energy coverage for no hot water households (50% to 100% energy usage coverage). 150 samples (represent 80% of total sampling amount)

5.2 Energy Usage Pattern Classification

The general household energy usage can be classified into four groups upon on their energy usage pattern:

- Double peak type (Figure 18 and Figure 19)
- Single peak type (Figure 20)
- Mountain type (Figure 21)
- Valley type (Figure 22)
- Other types

5.2.1 Double Peak Type

The double peak energy usage pattern is the most commonly seen pattern form as shown in Figure 18. This type of household usually consisted by a single professional or a couple who has regular work routine from 09:00 to 17:00. During weekdays, the peak energy usage occurs from 07:00 to 08:30 in the morning then from 19:00 to 20:30 in the evening. In weekends, energy usage pattern is distributed more evenly with additional daily energy usage compared to weekdays. This behaviour also reflects a repeated pattern in the daily power usage figure that the regular peak energy usage occurring four times a month. Most of household energy usage pattern is very similar to the double peak type pattern, apart from that the peak time could be varied or the average daily usage could fluctuate upon on the work type or the size of families.

Figure 18 Double peak small usage (Device 228 → 5.54 kWh/day)

For example, Figure 19 shows the double peak energy usage pattern of the household with greater family sizes. The average daily energy usage has increased by 15 kWh/day compared to the small-scale household example. Similarly, two peak energy usages occur between 08:00 and 10:00 in the morning and between 18:30 and 21:00 in the evening. Interestingly, households with greater daily energy consumption consume slightly less energy during the weekend. This could be attributed by some of the family members go out for the weekend, or the family weekend activities.

Figure 19 Double peak large usage (Device 119 → 20.83 kWh/day)

5.2.2 Single Peak Type

Another type of the energy consumption pattern is the single peak pattern as shown in Figure 20. One interesting observation was made on this type of energy consumption pattern. The household with this type of energy usage pattern tends to use less energy compared to other types. Rarely household with this energy consumption pattern consumes greater than 10 kWh/day. Likely, this pattern is generated by young professionals or young independent who do not cook in the morning or does not have a regular work routine. Most of the single peak pattern has its peak energy usage at night, and only one or two households in samples perform differently.

Figure 20 Single peak medium usage (Device 139 → 8.92 kWh/day)

5.2.3 Mountain Type

Mountain type energy consumption pattern is shown in Figure 21. For energy usage patterns do not have an obvious peak usage during the day, it will be classified as the mountain type. For some households with the mountain type might still have the morning peak or the evening peak usage. However, the pattern will still be classified as mountain type as long as the afternoon energy usage is more than double of the early morning usage.

With this type of energy consumption pattern, it usually represents the household size is greater and consequently represents as a higher daily energy consumption. Because of the diversity energy usage behaviour among the family members, the figure pattern is smoother without having an obvious peak usage compared to the double peak pattern and single peak pattern type. During the weekend, the main energy consumption period starts from 08:30 instead of 07:30 during weekdays. This could possibly due to people gets up late, and all appliances start up later.

Figure 21 Mountain type (Device 41 → 15.71 kWh/day)

5.2.4 Valley Type

Energy usage pattern for households with solar system installation is very different from the previously introduced ones. Especially, the mountain type energy usage pattern can be easily observed when a large solar system is installed. Figure 22 shows a perfect example of energy usage pattern that the solar generation almost covers the energy usage during the daytime. As a result, the average daily energy usage decreases with increased solar generation and increases when the time comes to autumn and winter. During the weekend, daytime peak energy consumption occurred during the afternoon time between 13:00 and 15:00. This could be attributed to the operation of air-conditioning during the weekend period or due to heavy family activities.

As long as the afternoon power consumption is less than the early morning power consumption, the energy pattern is classified as valley type. The valley type energy pattern households will be excluded from the following analysis as we are more concern on the actual energy usage for the general household. The data of valley type pattern households are not valid for our following analysis. Furthermore, if the lower power consumption cannot be observed during the afternoon time, nor being classified into previous types, then it will be classified into other pattern types.

Figure 22 With solar system (Device 229 → 20.28 kWh/day)

5.2.5 Analysis

Statistic number of different pattern types is shown in Figure 23. Double peak energy usage pattern attributes the largest portion due to lifestyle and people live in the area. Also, if taking the double peak and the single peak energy usage pattern into account, it attributes almost 2/3 of overall system samples. 6% was attributed to other pattern types as their energy usage behaviour is difficult to distinguish to any of the particular patterns.

Figure 23 Percentage of each pattern type among 265 samples

The energy usage pattern of all samples is shown in Figure 24. As expected, the pattern is similar to the double peak type according to the result showing above. Peak energy usage occurs at 07:00~08:30 in the morning then 18:00~21:30 in the evening.

Figure 24 Total energy usage across the time frames (extracted from transformer raw data)

One interesting phenomenon in regards to the average energy usage upon on different energy usage pattern was observed. The comparison of the daily energy usage is tabulated in Table 6. The household with mountain type energy usage pattern consumes 20% more energy than average. This is can be attributed to a larger family size and consequently greater energy consumption accordingly. In comparison, households with single peak energy usage pattern have the least energy consumption.

Table 6 Comparison of average energy usage upon on the energy usage pattern

Type	Double Peak	Single Peak	Mountain	Valley	All
Average (kWh/day)	12.62	12.13	15.40	12.67	12.89

A similar outcome is obtained when plotting a generalized result upon on different energy usage pattern as shown in Figure 25. Keeping in mind that household with valley usage pattern has the solar system installed, and thus they consume less energy compared to users on other types.

Figure 25 Generalized results of daily energy consumption upon on different energy usage pattern

Once the household samples are classified into groups upon on their energy usage pattern, result figure of the daily energy average usage to the 90% covering days ratio is shown in Figure 26. The ratio result does not make much difference compared to results obtained in earlier section. The ratio still varies between 1.6 to 1.8 when looking at 80% to 90% of the overall household samples.

Figure 26 Generalized results of daily energy consumption ratio (90% days of coverage) upon on different energy usage pattern

5.3 Peak Apparent Power (VA) Identification

The reason we are looking into apparent power index is because it determines the size of the power electronics used in the energy storage system. The purpose of the above analysis is not

only justified the energy usage pattern but also help to determine the size of the energy storage system. The index of real power only shows the actual energy usage of the general households. However, the actual power flowing in the system is determined by the apparent power and the rating of power electronics in the system needs to satisfy it. Looking into household's average daily energy usage (kWh) and generalize it with its peak apparent power usage (VA), the relationship is shown in Figure 27. For households with daily energy usage less than 10 kWh/day, the ratio of peak VA to peak kWh are mostly greater than 1. However, with daily household energy consumption further increases, the ratio starts declining to as low as 0.5.

Figure 27 Ratio of peak VA usage versus average daily energy usage

Also, it can be justified that most of the households have the peak power consumption at <10 kVA as shown in Figure 28. In other words, a battery storage system with 10 kVA power electronics can satisfy >80% of household. Most of the households consume power from 4 kVA to 10 kVA according to results shown in Figure 29. Thus, a 10 kVA power electronic product is probably the best size to suit general households for battery storage systems.

Figure 29 Peak VA usage sorted by peak VA usage

Interestingly, the difference between peak real power and the peak apparent power has not much difference as shown in Figure 30. The ratio is almost identical to each other for all the samples. Generally, a lot of appliance in the households are inductive and it was expected that the peak VA is higher than the peak kWh. If this is the case, then a simple solution of capacitor banks can be used to compensate the power factor. However, according to the result shown in Figure 30, the peak power consumed is almost identical to the peak apparent power required, then an active var compensator device (ex. dStatcom) is recommended to install along with the system.

Figure 30 Peak VA versus peak W usage

5.4 Summary

- The energy usage comparison under different household samples is tabulated in Table 7. This comparison is based on 80% of people's energy usage behaviour. Interestingly, household with regulated-power even consumes more power than household without regulated-power supply. This could be attributed to the factor that household with

greater energy usage tends to utilize regulated-power supply on reducing their electricity costs.

- The peak energy required to cover 90% days of usage is roughly around 1.7 times greater than the average daily usage. However, this peak energy usage to daily energy usage ratio can be reduced to 1.3 to 1.5 with the coverage days reduced to 80%. When the coverage days decreases to 70%, the ratio is further reduced to 1.1~1.3.
- Peak instantaneous power required for a general household is roughly at about 10 kVA. The maximum power required is 14.23 kVA the worst case among all samples.

Table 7 Comparison of energy usage when using 80% of people's behaviour as the sample

	Maximum Usage (kWh/day)	80% Ratio	Average Usage(kWh/day)
No Regulated-Supply	19	1.72	5~15
With Regulated-Supply	19.7	1.74	7~17
Regulated-Supply	10.34	1.68	4~11

6. Selection Process of Battery Storage

Applications to be performed by energy storage systems (ESSs), can be found across the levels of the electricity grid. ESS applications include energy shifting from the low demand period to the high demand period aiming to shave the peak load, shifting the energy produced by renewable energy sources – such as Photovoltaics – from the morning to the evening hours where it is more favourable for the grid, frequency regulation, voltage support, congestion relief, to name a few. Considering that the above mentioned applications require different time horizons and number of cycles per annum, and also the existence of constraints such as spatial limitations and storage mobility, the appropriate storage technology should be identified, to perform the application effectively.

For example, an ESS employed for peak shaving and congestion relief, such as in Figure 31, should be placed downstream of the transmission line that is threatened with overloading, so that during the peak load period, the ESS supplies part of the load demand (e.g., 30%) while the residual load demand (e.g., 70%), is met by the power flow through the transmission line. Thereby transmission line congestion is avoided.

Figure 31 ESS for peak shaving and congestion relief

To identify the appropriate ESS technology for a specific application, 14 criteria are considered in the selection processes presented in this work. Prior to the deployment of the technology selection processes, a brief discussion of the traditional and the improved methods is realised [17]-[24].

A traditional ESS technology selection process, includes generation of a table for each of the candidate energy storage technologies, where the table is filled with the characteristics the ESS should possess to perform a specific application (e.g., energy shifting). Further, the table is also filled with values to indicate the competitiveness of one ESS technology compared to another. The selection is realised by examining one by one the characteristics and comparing the recorded values. This comparison will eventually lead to the selection of the appropriate storage technology for the application under consideration. This process is demonstrated in [17]. A table is also employed in [18], where there, the pros and cons per ESS technology are recorded, and by comparing them, competent technologies are selected for further evaluation. In [19], a discussion-based comparison is realised, leading to the selection of the appropriate ESS technology. The author in [20], combines all of the above selection processes, by creating a table with specific characteristics the storage technologies should maintain, and a value per characteristic is assigned, representing the competitiveness of the storage technology for a certain characteristic. The table in [20], also includes advantages and disadvantages per ESS technology. In turn the author, by considering the tabulated values as well as the advantages and disadvantages per technology, selects the appropriate ESS for energy shifting.

Other selection processes that exist in the literature are more precise, and they can include radar charts (RCs) [21], decision matrices (DMs) [22][23], or the selection is realised by

identifying the solution with the shortest distance from the ideal. The method that identifies the shortest distance is termed as technique for order preference by similarity to ideal solution (TOPSIS) [24].

The RC in [21], values from zero to 10 the extent to which the candidate storage technology meets each of the required criteria. The authors in [22][23] utilise DMs, where each candidate technology is compared with the others, and depending on which technology is better at a certain criterion, it receives higher total grades. One column chart is assembled per criterion, to compare the performance of one technology against the others, in turn the values of the column charts, serve as inputs to the TOPSIS method [24]. The selection processes continue, by assigning weights to each of the criteria, with the weights to be included in the calculations. The results establish a ranking of technology competitiveness factors (TCFs). For the RC and DM processes, the storage technology that presents the TCF with the highest percentage, is perceived to be the best match for the application. Since the storage technology that maintains the shortest normalised distance from the ideal solution is sought in the TOPSIS method, the technology with normalised distance 1 is better than the technology with normalised distance 2, since the technology with distance 1 is closer to the ideal solution.

6.1 Criteria Participating in the Selection Processes

The storage technologies that participate in the selection processes, as well as the fourteen criteria (Ci) that are considered in this work, to shed light on the storage capabilities, are visualised in the RC of Figure 32 [21]. Normalised values from zero to 10 are utilised in the RC of Figure 32, with the values prior to normalisation to be available in [17][25][26].

Figure 32 C₁ to C₁₄ utilised for the comparison between the storage technologies

Battery technologies mainly participate in the selection process, because of their consideration by many authors for a plethora of applications, such as energy shifting for peak shaving, renewable energy sources integration, frequency regulation, voltage support, congestion relief, etc. [27]-[32].

The storage technologies that are examined, include Li-ion, NaS, and PbAc batteries, because they maintain high efficiencies, long useful life, and low daily self-discharge losses. The Li-ion technology in addition to the previous, also maintains high energy and power densities among other competitive characteristics, while the NaS technology is well-known for high rated energy capabilities. The PbAc technology has been used extensively, and considerable experience is available, while it is also the lowest cost solution.

The comparison between candidate storage technologies, apart from RC utilisation such as in Figure 32, can also be realised by assembling DMs [22], as shown in Table 8. For each of the selection criteria (i.e., C1 to C14), another DM is generated, and one storage technology is compared with the rest in respect to the criterion associated with the DM. For example, in Table 8 is presented the comparison between Li-ion, NaS, and PbAc battery technologies in respect to energy density (i.e., C1), and it can be seen that the Li-ion technology receives the highest score (i.e., 9) resulting from the total grades (G_{tot1}) the technology received, when compared with the NaS and PbAc technologies.

Table 8 DM associated with C₁, for comparison between the candidate energy storage technologies

Grading Scale	C ₁	-	Li-ion	NaS	PbAc	G _{tot1}
1 - Poor	Energy density					
2 - Diminished						
3 - Similar	Li-ion			4	5	9
4 - Enhanced						
5 - Superior	NaS		2		5	7
	PbAc		1	1		2

Note: The grading scale is presented on the left of the table

Column charts is another option, to clearly identify the difference between the candidate storage technologies in respect to a specific criterion. For example in the column charts of Figure 33, it can be seen that the energy density of the Li-ion technology is superior to the energy density of the NaS and PbAc battery technologies. In terms of capital cost, the most competitive option is the PbAc battery, thereby this technology receives 10.

The numerical values of the column charts are utilised in the calculations of the TOPSIS method, thereby the TCFs of the TOPSIS method derive, as it is analysed in Section 6.2.

Figure 33 Column charts for comparison of the candidate storage technologies

In the case the feeder is dominated by residential loads, the energy shifting application performed by the ESS, involves charging the battery in the morning and discharging it in the evening, for peak load shaving and for congestion relief. Alternatively, when commercial loads are the majority at the feeder, the ESS pattern includes charging at night hours, and discharging the next morning and afternoon. In both of the above cases (i.e., residential or commercial feeder), similar operating periods are anticipated ranging a few hours a day. Regarding the cyclic requirements of the ESS, they can reach 250 cycles per annum [33], which is proximate to one complete cycle per workday.

6.2 Weighting Description and TCFs Identification

The weighting presented in Table 9 is adapted to the energy shifting application. Criteria such as operational constraints and safety (w9) and capital cost (w12), always receive high weights (i.e., $w_9=w_{12}=9$) to highlight their importance. Other significant criteria include energy and power densities (w1 and w2), specific energy and power (w3 and w4), and efficiency (w5), among others. Energy and power densities receive the weights of $w_1=w_2=7.5$, which is above the equitable weighting (i.e., 7.1428), because a storage technology with high energy to volume (i.e., kWh/m³) and power to volume (i.e., kW/m³) ratios is encouraged. This is because, higher amount of energy and power are provided by the technology (e.g., Li-ion), while the minimum volume is required. Similarly for specific power (kW/kg) and energy (kWh/kg), a storage technology that meets these two criteria to a high extent, is capable to provide high power and energy for the minimum weight requirements.

Table 9 Criteria weighting for the application of energy shifting

Weight	Value	Weight	Value
w1	7.5	w8	5
w2	7.5	w9	9
w3	7.5	w10	7.5
w4	7.5	w11	2
w5	7.5	w12	9
w6	7.5	w13	7.5
w7	7.5	w14	7.5

The storage characteristic of daily self-discharge receives a low weight (i.e., w11=2), because one complete charging-discharging cycle is performed by the ESS, almost every workday of the week (250 cycles pa [33]), therefore limiting the effect of the daily-self discharge.

For the calculation of the TCFs for each of the different selection processes discussed in Section 0, equation (3) to (6) are utilised. Values from the RC of Figure 32, are substituted into equation (3) and equation (4), and along with the weights of Table 9, a TCF per storage technology is identified. Values from the DMs, such as Table 8, are passed into equation (5), thereby the TCFs of the DMs method derive. For the calculation of the TCFs with the TOPSIS method, equation (6) is employed, with the criteria values to be supplied by Figure 33, and the criteria weights to be provided by Table 9.

$$App_{sum} = \sum_{i=1}^n w_i C_i, n = 14 \quad (3)$$

$$TCF_{RC} = \frac{App_{sum}}{\sum_{i=1}^n w_i C_{max}} 100, n = 14 \quad (4)$$

$$TCF_{DM} = \sum_{i=1}^n w_i \frac{G_{tot_i}}{G_{max}}, n = 14 \quad (5)$$

$$TCF_{TOPSIS} = \sum_{i=1}^n \left(\frac{w_i}{100} \right)^2 (C_i - C_{max})^2, n = 14 \quad (6)$$

The TCFs identified for the application of energy shifting, are presented in Table 10. From the table it is clear that the Li-ion technology is leading the competition thereby it is selected for the application, with the NaS and Pd-acid technologies to follow. Particularly, the TCF of the RC method, and the TCF of the DM method, both for Li-ion technology (+), termed as TCF_{RC}^+ and TCF_{DM}^+ , maintain the percentages of 76.74% and 70.30% in accordance. The TOPSIS selection process, that determines the most appropriate storage technology, by identifying the one that maintains the shortest distance from the ideal solution, results in $TCF_{TOPSIS}^+ = 1.14$. The value of 1.14 is the shortest normalised distance from the ideal solution, compared to the longer distance of 2.07 for NaS, and the even longer distance of 2.45 for PbAc battery technology.

Table 10 TCFs and suitability per energy storage technology, for the application of energy shifting

Technology	TCF _{RC}	Suitability	TCF _{DM}	Suitability	TCF _{TOPSIS}	Suitability
Li-ion (+)	76.74%	1st	70.30%	1st	1.14	1st
NaS (*)	62.52%	2nd	58.95%	2nd	2.07	2nd
PbAc (Δ)	56.13%	3rd	53.95%	3rd	2.45	3rd

The results are somewhat expected, because the Li-ion technology outperforms the rest of the storage technologies in criteria 1 to 5 and 14, as it can be seen in Figure 32, while for the majority of the residual criteria, the Li-ion technology maintains competitive values. At this stage it needs to be noticed that the ESS technologies included in the selection process, were deemed competitive candidates for the application of energy shifting, therefore they were included in the process. Among the competitive candidates, the Li-ion technology was eventually selected because it presented the highest TCFs as it can be observed in Table 10.

In the case the selection process was intending to determine the most appropriate ESS technology for the application of frequency regulation, the candidate technologies would be different, and the selection process would include the technologies Li-ion, superconducting magnetic energy storage (SMES), and flywheel. Then the selection processes analysed in this section would be re-applied, and the appropriate storage technology for frequency regulation would be identified. For example, because the effect of charging-discharging cycles on the SMES is negligible compared to the effect of the cyclic operation of the Li-ion battery, the SMES technology would be a more suitable solution compared to Li-ion for frequency regulation.

Regarding the utilised selection processes, the RC and TOPSIS processes are more objective compared to the process that employs DMs. This is because the inputs of the RC and TOPSIS methods are precise values obtained from [17][25][26], and they precisely indicate the extent to which the storage technology satisfies the criterion. Conversely, the selection process that involves DMs, is based on a 1 to 5 grading scale that is applied subjectively. All the three methods discussed in this section are capable to identify the appropriate energy storage technology, with the RC and TOPSIS methods to be more objective.

7. Safety Consideration

As important as efficiency and lifetime, safety is a non-negligible fact of the system throughout design, installation and operation phases. Each individual device in the system has to meet the design specification with sufficient evidence and record of testing conducted under the regular and worst-case scenario. System integrator has to make sure all components meet factory specifications relative to their intended use cases. There is a lot needs to be considered regards to safety issues in battery based community storage, apart from meeting prerequisite international standards.

7.1 Safety Hazard of Batteries and Mitigation

Batteries, due to their intensive energy density and chemical nature, can be a serious safety risk if incorrectly installed and operated, potentially leading to electric shock, fire, flash burns, explosion or exposure to hazardous chemicals and released gases.

- Electric Shock

Banks of battery cells can induce a severe electrical shock if remain charge or other voltage applied to battery bank by another energy source in the system. As many battery banks are likely operating at a hazardous voltage which must be electrically isolated. Battery terminals

must be isolated with secure rated insulating materials and avoid direct contact. Minimum labelling for battery storage has to be permanently displayed at the prominent position as required.

- Energy Hazard

A battery has sufficient energy to cause an arc flash if it suffers a short circuit or fault. An arc flash can have temperatures above 12,000°C, capable of melting metal or causing fires and explosions. Generally higher battery energy storage capacities have a higher risk of arc flash. Arcing faults may cause catastrophic failure of battery cell enclosures unless the fault currents are removed quickly by correctly rated electrical protective devices. Batteries of all types and their associated DC cabling need to be protected from mechanical damage.

- Fire and explosion

Gas emission and thermal runaway are major causes of fire and explosion. Most PbAc batteries generate hydrogen and oxygen when charging that needs adequate ventilation. The chemistry of Li-ion batteries makes them prone to 'thermal runaway' if they are damaged or overheated by overcharging. It can also result from component failure, a short circuit or loose connections. Temperature monitor and control are essential for batteries in operation and storage. Location of BESS needs to be carefully considered when installing on a customer premise, especially for those have elevated ambient temperatures.

- Hazardous chemicals

Battery casings can degrade or be damaged by impacts. They can also rupture as a result of excessive temperatures and excessive pressure generated from a change in chemical reaction from over-charging or following a short circuit. Electrolyte (fluid or gel) can leak from a ruptured casing, resulting in toxic fumes, burns, corrosion or explosion. Some compounds produced during the failure of a cell can be extremely toxic. The cleanup, decontamination and disposal of damaged equipment may require specialised equipment and skills. Disposal of contaminated items or batteries at the end of their service life usually will require treatment as a hazardous waste. As MSDS is essential to determine risk mitigation methods regarding chemical hazards.

7.2 Location of Installation

The battery is preferred to be installed in a dedicated equipment room or area with restricted access to prevent access by unauthorised persons. It should also take into account by physical requirements of system characteristics, ventilation requirements, environmental factors and another risk of damage. Extreme ambient temperature or wide difference ambient temperature and humidity shall be avoided since battery life is shortened at a prolonged high temperature and battery capacity is degraded under low temperature, meanwhile temperature and humidity change may cause condensation issue.

- Indoor Installation

For domestic dwellings, it is not recommended to install batteries in habitable rooms for health and safety. Typically, garages, storage rooms and plant rooms are suitable for batteries

in these buildings, which comply with installation requirements as discussed. For nondomestic buildings, batteries need to be installed in a designated plant room or separate battery room which is separated from the remainder of the building. The separation shall be considered using construction with a fire resistance level (FRL) material.

- Outdoor Installation

Outdoor installation requires more protection on the battery itself. A fenced-off section that creates a restricted area for authorised persons only. Shade should be considered over the battery enclosure.

7.3 Battery Storage Enclosure

A stand-alone battery enclosure needs well designed to protect the battery from damage. It usually has lockable doors or covering the box with lid. Steel fabrication with IP 55 or NEMA 3R rating seems like a typical requirement to protect the battery from physical damage, dust and water. The prolonged explosion under the sun, charging and discharging operation and limited interior space brings insulation, cooling and ventilation into a combinational concern on the enclosure. All battery terminals inside the enclosure have to be readily reachable for maintenance and service. Also, the battery enclosure should be insect and vermin-proof.

7.4 Safety Policies and Standards

Safety policies and standards in the growing energy storage are key challenges in keeping the industry on the right track, especially for Li-ion batteries. Thus improving knowledge of safety hazards and renovating standards turns essential. In Australia and New Zealand, there are standards involving safety testing from cell level to system level already in place for battery installations that should be considered in the application of battery based community storage.

- AS 1170.4 Structural design actions – Earthquake actions in Australia
- AS 1319 Safety signs for the occupational environment
- AS 2676.1 Guide to the installation, maintenance, testing and replacement of secondary batteries in buildings – Vented cells
- AS 2676.2 Guide to the installation, maintenance, testing and replacement of secondary batteries in buildings – Sealed cells
- AS/NZS 3000 Electrical installation (known as the Australian/New Zealand Wiring Rules)
- AS 3011.1 Electrical installation – Secondary batteries installed in buildings – Vented cells
- AS 3011.2 Electrical installation – Secondary batteries installed in buildings – Sealed cells
- AS 4086.2 Secondary batteries for use with stand-alone power systems – Installation and maintenance
- AS/NZS 4509.1 Stand-alone power systems – Safety and installation
- AS/NZS 4509.2 Stand-alone power systems – System design
- AS/NZS 4777.1 Grid connection of energy system via inverters – Installation requirements
- AS/NZS 4777.2:2015 Grid connection of energy systems via inverters – Inverter requirements
- AS/NZS 5000.1 Electric cables – Polymeric insulated – For working voltages up to and including 0.6/1 (1.2) kV

- AS/NZS 5000.2 Electric cables – Polymeric insulated – For working voltages up to and including 450/750 V
- AS 60950.1 Information technology equipment – Safety – General requirements
- AS 62040.1.1 Uninterruptible power system (UPS) – General and safety requirements for UPS used in operator access areas
- AS 62040.1.2 Uninterruptible power system (UPS) – General and safety requirements for UPS used in restricted access locations
- NZS 4219 Seismic performance of engineering systems in buildings
- DR_AS 5139-2017 Electrical installation-safety of battery systems for use with power conversion equipment (revision of AS 4086.2-1997)

Several IEC standards are also developed.

- IEC 61427-1:2013 Secondary cells and batteries for renewable energy storage – General requirements and methods of test – Part 1 Photovoltaic off-grid application
- IEC 61427-2:2015 Secondary cells and batteries for renewable energy storage – General requirements and methods of test – Part 2 On-grid applications
- IEC 62109-1 Safety of power converters for use in photovoltaic power systems – Part 1: General requirements
- IEC 62109-2 Safety of power converters for use in photovoltaic power systems – Part 1: Particular requirements for inverters
- IEC 62619:2017 Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for secondary lithium cells and batteries, for use in industrial applications

Besides standards, there are guidelines for designers, installers and contractors. In 2014, German solar industry association, BSW Solar, created an extensive report Safety of Guidelines – Li-ion Home Battery Storage Systems. In 2016, Australian Clean Energy Council (CEC) issued Install Guidelines for Accredited Installers – Grid-connected Energy Systems with Battery Storage that provided interim guidance to designers and installers of grid-connected energy systems with battery storage systems. In the meantime, Energy Storage Council (ESC) published the Australian Battery Guide – Guide for Energy Storage System that gave guidance to the energy storage industry and consumers in the interim while formal Australian Standards and being developed for the sector.

8 Conclusion

This chapter has analysed the CES in-depth focusing on battery technologies. Recent studies have shown growing interest in the concept of applying batteries in a distributed manner at localised applications. It has benefits that target shifting renewable generation, managing load peaks, providing uninterruptible power, local reactive power support, and grid services when aggregated with many units. Most importantly, it easily adopts existing grid infrastructure which significantly reduced the cost of investment and eases the pressure of network upgrade.

Various battery technologies are viable for CES application. PbAc batteries were initially widely used for the industrial and residential UPS and automotive, and provide lower capital cost solutions. However, its implementation was very limited due to low charging speed and short life cycles. Thus, new ALC batteries are developed with significant improvements and now raising in renewable energy applications which PbAc is not capable of. Li-Ion has emerged as the technology of choice for short duration applications. Thanks to the popularity of EVs, Li-Ion batteries are gaining rapid development enabled by fast price reduction and performance improvement. Li-Ion batteries have been implemented in a wide variety of applications such as peak load management, renewable integration and diesel reduction. There are also many other battery technologies in competition with pros and cons targeting different applications in the field.

EVs, provide a special form of battery storage, potentially provided a significant amount of energy storage for the community. However, the gradual and substantial rise of EV penetration also has an impact on distribution grids, as large numbers of EVs on the load and generation sides challenge grid stability. V2G technology makes it possible to store surplus electricity generated from intermittent renewable solar and wind sources in EV batteries during non-peak periods and feed power back to the grid when needed, enhancing grid stability and reducing electricity costs at peak hours. CES is also a feasible application of those after vehicle batteries for many grid support applications and ancillary services for the grid.

Due to the rapid uptake of energy storage, safety integration introduced significant technical and regulatory challenges during implementation of battery storage. There is no specific standard for battery based CES, but relevant guidelines for battery storage of different chemistries are constantly improving. In general, battery hazards have to be investigated and identified to mitigate risks of application. Requirements for battery installation location and enclosure varies according to different battery chemistry. Safety policies and standards in the growing energy storage sector is a key challenge in keeping the industry on the right track, especially for Li-ion batteries. Australia is a pioneer country in regulatory intervention to drive adoption of energy storage.

Reference

- [1] Thomas R, P 2011, American Electric Power Community Energy Storage, IEEE Power Engineering Society Energy Storage – Super Session, accessed 29 June 2017, <https://www.smartgrid.gov/files/American_Electric_Power_Community_Energy_Storage_201109.pdf>.
- [2] Asgeirsson, H 2010, *Detroit Edison's Advanced Implementation of A123's Community Energy Storage System for Grid Support*, DTE Energy, accessed 29 June 2017, <http://www.sandia.gov/ess/docs/pr_conferences/2010/hawk_dte.pdf>.
- [3] Wearmouth, A 2016, *Alkimos Beach Battery Storage Trail*, Synergy, accessed 29 June 2017, <[http://ee aust.com.au/images/stories/virtuemart/category/presentation-to-the2016api-summer-school-alkimos-battery-storage-project_\(no-charge-curve\)-andy.pdf](http://ee aust.com.au/images/stories/virtuemart/category/presentation-to-the2016api-summer-school-alkimos-battery-storage-project_(no-charge-curve)-andy.pdf)>.
- [4] Sonnen 2017, *What is the sonnenCommunity*, accessed 29 June 2017, <<https://www.sonnenbatterie.de/en/sonnenCommunity>>.

- [5] Battery University 2017, *BU-201: How does the Lead Acid Battery Work*, accessed 4 July 2017, < http://batteryuniversity.com/learn/article/lead_based_batteries>
- [6] Battery University 2017, *BU-202: New Lead Acid Systems*, accessed 29 June 2017, <http://batteryuniversity.com/learn/article/new_lead_acid_systems>.
- [7] Dubey A, Santoso S. Electric Vehicle Charging on Residential Distribution Systems: Impacts and Mitigations. *IEEE Access*. 2015;3:1871-93.
- [8] D. Leskarac, C.Panchal, S. Stegen, and J. Lu. PEV Charging Technologies and V2G on Distributed System and Utility Interfaces. In: Lu J, Hossain J, editor. *Vehicle-to-Grid: Linking Electric Vehicles to the Smart Grid*. London, United Kingdom: The Institution of Electrical Engineers; 2015. p. 157-221.
- [9] Mwasilu F, Justo JJ, Kim E-K, Do TD, Jung J-W. Electric vehicles and smart grid interaction: A review on vehicle to grid and renewable energy sources integration. *Renewable and Sustainable Energy Reviews*. 2014;34:501-16.
- [10] Sbordon D, Bertini I, Di Pietra B, Falvo MC, Genovese A, Martirano L. EV fast charging stations and energy storage technologies: A real implementation in the smart micro grid paradigm. *Electric Power Systems Research*. 2015;120:96-108.
- [11] SAE. Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler. SAE J1772, 2016.
- [12] IEC61851. Electric vehicle conductive charging system. 2017.
- [13] Maheshwari P, Tambawala Y, Nunna HSVSK, Doolla S, editors. A review on plug-in electric vehicles charging: Standards and impact on distribution system. 2014 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES); 2014 16-19 Dec. 2014.
- [14] Tan KM, Ramachandramurthy VK, Yong JY. Integration of electric vehicles in smart grid: A review on vehicle to grid technologies and optimization techniques. *Renewable and Sustainable Energy Reviews*. 2016;53:720-32.
- [15] Moghimi M, Leskarac D, Nadian N, Stegen S, Lu J. Impact of PEV behavior on peak demand reduction in a commercial microgrid. 2016 Australasian Universities Power Engineering Conference (AUPEC); 2016 25-28 Sept. 2016.
- [16] Ahmadi L, Yip A, Fowler M, Young SB, Fraser RA. Environmental feasibility of re-use of electric vehicle batteries. *Sustainable Energy Technologies and Assessments*. 2014;6:64-74.
- [17] Chatzivasileiadi A, Ampatzi E, Knight I. Characteristics of electrical energy storage technologies and their applications in buildings. *J Renew Sustain Energy Revs*. 2013;25:814 - 30.
- [18] Yang B, Makarov Y, Desteese J, Viswanathan V, Nyeng P, McManus B, et al. On the use of energy storage technologies for regulation services in electric power systems with significant penetration of wind energy. *IEEE 5th International conference on European electricity market - (EEM)*. Lisboa 2008.
- [19] Suberu MY, Mustafa MW, Bashir N. Energy storage systems for renewable energy power sector integration and mitigation of intermittency. *J Renew Sustain Energy Revs*. 2014;35:499-514.
- [20] Poullikkas A. A comparative overview of large-scale battery systems for electricity storage. *J Renew Sustain Energy Revs*. 2013;27:778-88.
- [21] Saez-de-Ibarra A, Milo A, Gaztanaga H, Etxeberria-Otadui I, Rodriguez P, Bacha S, et al. Analysis and comparison of battery energy storage technologies for grid applications. *IEEE PowerTech*. Grenoble 2013.

- [22] Ibrahim H, Dimitrova M, Dutil Y, Rousse D, Ilinca A, Perron J. Wind-diesel hybrid system: energy storage system selection method. IEA ECES 12th International conference on energy storage - (InnoStock). Spain 2012.
- [23] Ibrahim H, Ilinca A, Perron J. Comparison and analysis of different energy storage techniques based on their performance index. IEEE Electrical power conference - (EPC). Canada 2007.
- [24] J.-J. Wang, Y.-Y. Jing, C.-F. Zhang, and J.-H. Zhao, "Review on multi-criteria decision analysis aid in sustainable energy decision-making", *Renew. Sust. Energy Revs.*, vol. 13, pp. 2263 – 2278, 2009.
- [25] Diaz-Gonzalez F, Sumper A, Gomis-Bellmunt O, Villafafila-Robles R. A review of energy storage technologies for wind power applications. *J Renew Sustain Energy Revs.* 2012;16:2154 - 71.
- [26] Mahlia TMI, Saktisahdan TJ, Jannifar A, Hasan MH, Matseelar HSC. A review of available methods and development of energy storage; technology update. *J Renew Sustain Energy Revs.* 2014;33:532 - 45.
- [27] H. Laaksonen, P. Saari, and R. Komulainen, "Voltage and Frequency Control of Inverter Based Weak LV Network Microgrid", 2005 IEEE International Conference on Future Power Systems, pp. 1-6, Amsterdam.
- [28] Y. Qi, and H. Jia, "Research on a New Voltage Control Strategy for Photovoltaic Grid-Connected System", 2011 IEEE International Conference on Electrical Machines and Systems (ICEMS), pp. 1 - 6, Beijing.
- [29] C.A. Hill, M.C. Such, D. Chen, J. Gonzalez, and W.M. Grady, "Battery Energy Storage for Enabling Integration of Distributed Solar Power Generation", *IEEE Trans. on Smart Grid*, vol. 3, pp. 850-857, 2012.
- [30] W.-j. Gao, T.-j. Jing, and M.-h. Yang, "A economic dispatch method of energy storage systems under time-of-use pricing in microgrids", 2012 IEEE China International Conference on Electricity Distribution (CICED), pp. 1 - 5, Shanghai.
- [31] Y. Li, D.M. Vilathgamuwa, and P.C. Loh, "Design, Analysis, and Real-Time Testing of a Controller for Multibus Microgrid System", *IEEE Trans. Power Electron.*, vol. 19, pp. 1195 - 1204, 2004.
- [32] B. Pokharel, O. Ojo, and A. Balogun, "Standalone operation of a DFIG-based wind turbine system with integrated energy storage", 2015 IEEE 6th International Symposium on Power Electronics for Distributed Generation Systems (PEDG), Aachen, Germany.
- [33] Eckroad S, Gyuk IP, Mears LD, Gotschall HL, Key T, Kamath H. EPRI-DOE Handbook of energy storage for transmission & distribution applications. Electric Power Research Institute (EPRI) - US Department of Energy. Palo Alto, California 94304 and S.W. Washington, DC 20585. 1001834. 2003.