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Community Energy Storage sizing for grid management optimization

Relatore:
Arturo Lorenzoni

Laureando:
Marco Costa
Matricola: 1059050

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Chapter 1

Introduction

The European Union aims to cut greenhouse gas emissions to 20% below 1990 levels by 2020 as part of the strategic 2050 roadmap [1]. Other countries such as USA and Japan have similar objectives. From the generation supply side, renewable energy (RE) technologies and the use of flexible vectors such as electricity, heat and hydrogen are some of the key technologies to achieve these ambitious objectives. Among different RE technologies, solar photovoltaic (PV) is expected to play an important role during this transition pathway and its rise has already started. PV energy was the fastest-growing power technology worldwide between 2000 (1.5 GWp cumulative capacity) and 2010 (40 GWp cumulative capacity) with 7.4 GW installed in Germany alone [2]. The cumulative global market for solar PV is expected to triple by 2020 to almost 700 GW, with annual demand eclipsing 100 GW in 2019. Solar demand will likely be almost entirely market-based in 2020, a dramatic shift from 2012 when almost all demand was premised on direct incentives. One implication of an increasingly unsubsidized market is that management and governance of the electric grid will change dramatically, creating both new opportunities and challenges for solar companies. This transformation is already underway with the implementation of market-based mechanisms for PV procurement and solar companies exploring innovations in business model design [3]. According to the recently published report by the United Nations Environment Program (UNEP), more than 50% of the investment in renewable energy worldwide flows into solar [4].

From an energy point of view, the PV energy source is a proved alternative to traditional fossil fuels but like wind energy, PV is characterized by intermittent and fluctuating power generation. The increasing penetration of PV is contributing to relieving the loading of residential grids. This is a positive aspect if we consider that demand in the residential sector is continuously increasing. However, day-night cycles, weather conditions, and clouds passage are some of the natural phenomena that make PV a non-dispatchable and fluctuating energy source as wind power.

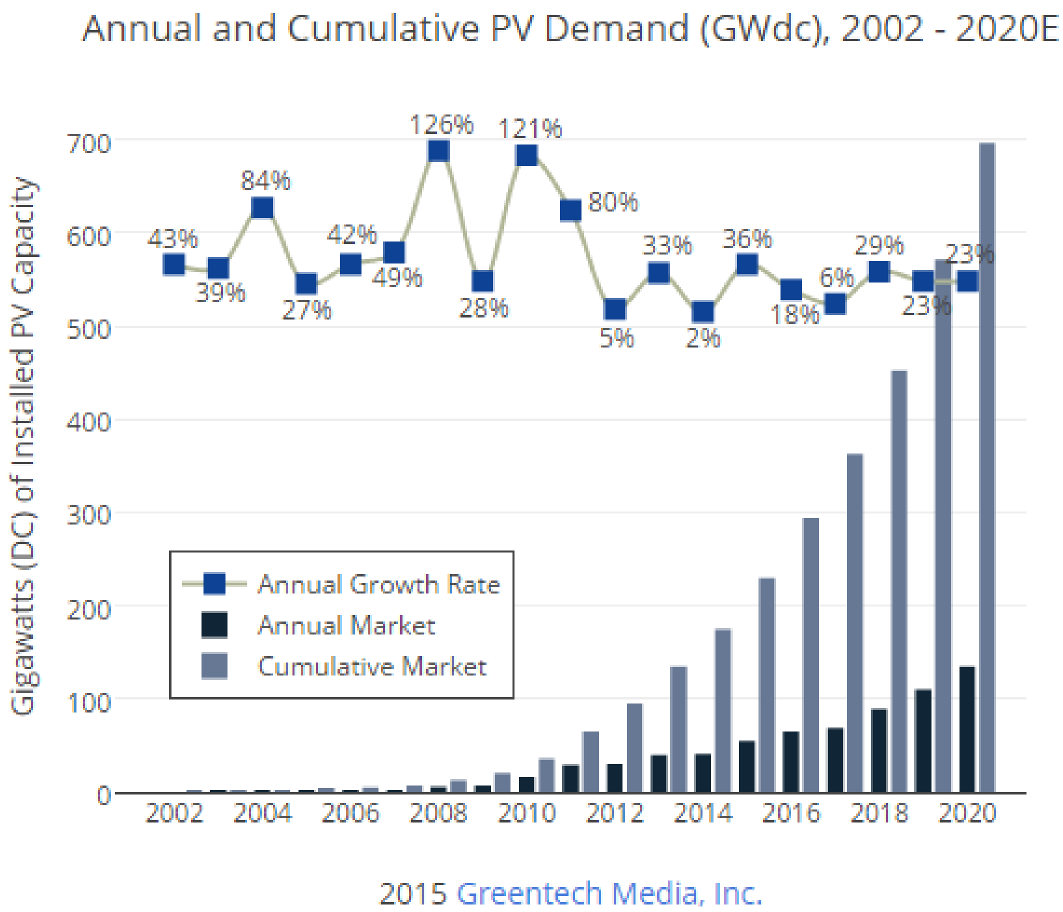


Figure 1.1: Annual Cumulative Photovoltaic Demand

Unlike wind turbines, PV systems are well suited in low voltage (LV) distribution grids, in urban or rural areas, in public places or private households. This is mainly thanks to their static operation and to a lower visual and noise impact compared to wind turbines.

From a power-system perspective, PV shows a good correlation between generation and demand in LV grids: in fact, PV power is generated during the day when the demand is relatively high compared to overnight. Additional benefits from PV are related to loss reduction, as a consequence of the reduced power flow from the transmission and distribution grid downstream to the consumers.

Nevertheless, because of the uncertainty of PV power generation, LV grids encounter new operational challenges nowadays. One major concern is to ensure voltage quality along LV feeders.

If the demand is low, the power generation from decentralized PV systems can

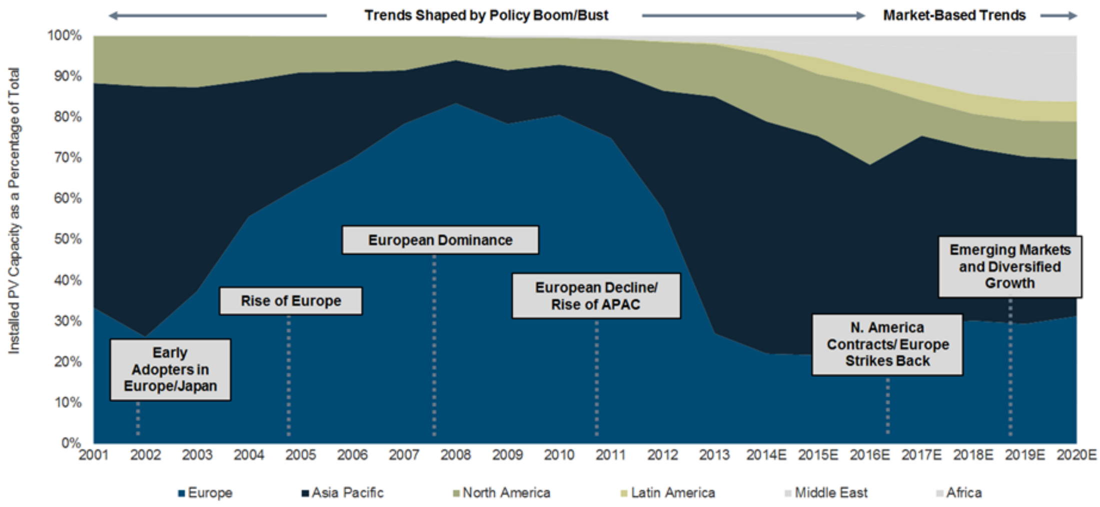


Figure 1.2: Global PV Dominance

cause situations of power-flow inversion in LV feeders, which can lead to significant variations in the voltage magnitude and consequent deterioration of voltage quality [5].

It is the most widespread power technology in the built environment due to its modularity, free-maintenance and quiet performance [6]. Additionally, continuous progress has reduced the system cost dramatically. According to the International Energy Agency (IEA), the costs of PV exhibits a learning rate of 19.3% being defined as the reduction of cost for every doubling of global capacity and the efficiency has increased steadily (fromabout 12% to 17% for commercial crystalline silicon panels) [7].

Latest performance index had been published by NREL (National Renewable Energy Laboratory) in Figure 1.3.

In traditional electrical networks, electricity flows from centralized fossil generation plants to the point of consumption. Coal, natural gas and diesel generation plants usually offer a certain level of schedule therefore they can be considered as load following generators. Typically, nuclear plants run at more constant power, supplying a base load. The penetration of PV and other RE technologies will affect the whole energy system which was designed and built according to flexibility offered by fossil fuels. However, PV technology and other RE technologies depend on the weather conditions. This means that they do not offer the same level of demand matching capability as traditional generators do as it is not possible to forecast with total accuracy the PV power output [8] PV generation follows daily and seasonal patterns proportional to the local irradiance and this behaviour is more marked at latitudes further from the equator. In the case of the built environ-

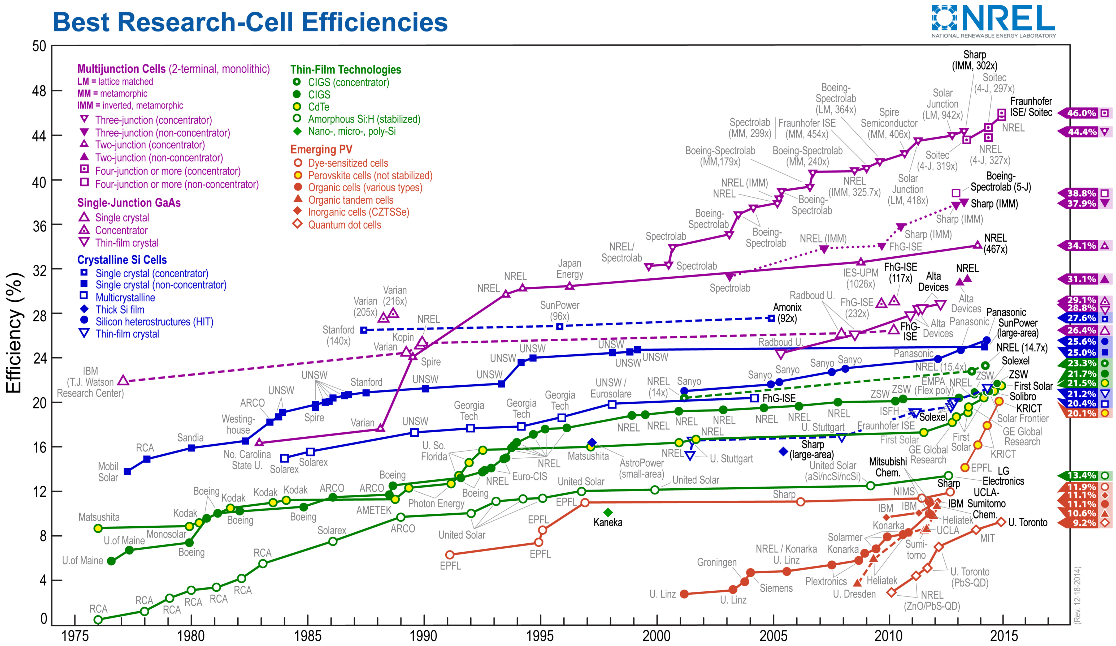


Figure 1.3: State of the Art PV technology performances

ment, there can be a mismatch between the PV generation and the local demand e.g. the annual mismatch for a 4.5 kWp PV installation and the electrical load of a single dwelling was found to be 81% [9]. However, for energy communities with several dwellings, it has been found that the mismatch between PV generation and domestic demand reduces with the number of households due to random load coincidence [10]. Another interesting finding was that for arrays with a rating up to 1 kWp per household, almost all electricity produced is consumed by the local demand loads, reducing the losses in the distribution area. The ability of different PV array orientations, demand-side management tools and energy storage (ES) to improve the matching capability of distributed PV at high-latitude areas was compared by Widén et al. [11]. According to the findings, ES is the most effective technology to shift the PV generation to meet the demand load at high PV penetration levels. Therefore, understanding the cost, value and profitability of the ES in communities and their dependence on the performance of ES, is key for the deployment of ES and the penetration of more PV technology.

Chapter 2

Electricity Storage Services and Benefits

2.1 Why to use Energy Storage

Italian Energy Authority defines Energy Storage Systems as "a set of devices, equipment and logics of management and control, functional to absorb and release electricity, designed to operate on a continuous basis in parallel with the grid with compulsory connection by third parties or can cause them to deteriorate profile exchange with the electricity grid (injection and / or withdrawal). The storage system can be integrated or not with a production plant (if present). This definition doesn't cover systems used in emergency conditions, which works only when a power system failure occurs from the power supply for reasons beyond the control of the entity involved" [12];
The primary reasons for the need of energy storage include:

- growth in renewables implies intermittent spikes in power generation and voltage, which could lead to grid instability at higher penetration rates ($10-15\%5+$ grid capacity or generation). This was notably illustrated by the California Independent System Operator (CAISO) in late 2013 as it modeled issues in achieving 33% renewable energy by 2020.

- Behind the meter batteries would smooth the peak demand during the evening, while utility scale batteries could provide the rapid response time and fluctuation response necessary to support large scale variable generation.

- Increased shift towards distributed generation; which is prompting some utilities to fight net metering, interconnection, or other solar incentives

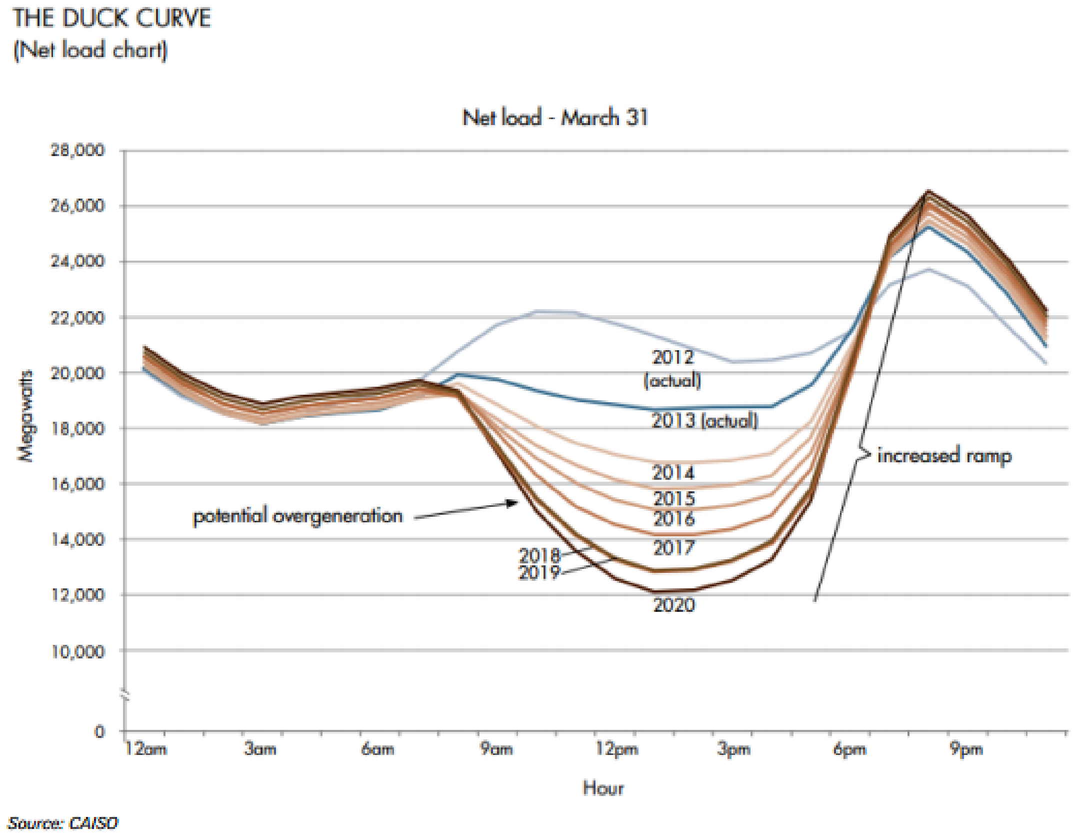


Figure 2.1: The "Duck Curve"

- Increase in electricity prices; which makes systems with grid storage more economical
- Electrification of underserved areas of the world can be implemented effectively through micro-grids with storage systems inside.

In the future smart grid environment, energy storage can potentially deliver multiple benefits that will enhance grid performance, operability and security together with reducing energy production and delivery costs [13]. The many functions of energy storage include its ability to :

1. providing backup power to homes, businesses or utilities;
2. cutting peak-demand charges;
3. providing firm peak capacity to the grid;
4. providing frequency regulation and improving relationship between distributed generation producer and utility with smart grid implementation.

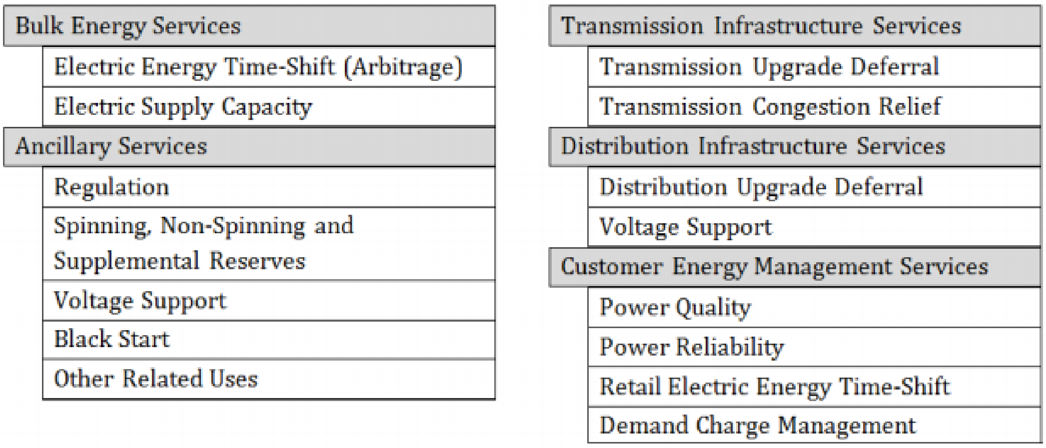


Figure 2.2: Energy Storage Services

2.2 Bulk Energy Services

2.2.1 Electric Energy Time-shift (Arbitrage)

Electric energy time-shift involves purchasing inexpensive electric energy, available during periods when prices or system marginal costs are low, to charge the storage system so that the stored energy can be used or sold at a later time when the price or costs are high. Alternatively, storage can provide similar time-shift duty by storing excess energy production, which would otherwise be curtailed, from renewable sources such as wind or photovoltaic (PV).
Technical considerations:

- Storage System Size Range: 1 – 500 MW
- Target Discharge Duration Range: $<$1 hour
- Minimum Cycles/Year: 250 +

Storage used for time-shifting energy from PV or smaller wind farms would be in the lower end of the system storage size and duration ranges shown above, whereas storage for arbitrage in large utility applications or in conjunction with larger wind farms or groups of wind and/or PV plants would fall in the upper end of these ranges.
Both storage variable operating cost (non-energy-related) and storage efficiency are especially important for this service. Electric energy time-shift involves many

possible transactions with economic merit based on the difference between the cost to purchase, store, and discharge energy (discharge cost) and the benefit derived when the energy is discharged. Any increase in variable operating cost or reduction of efficiency reduces the number of transactions for which the benefit exceeds the cost. That number of transactions is quite sensitive to the discharge cost, so a modest increase may reduce the number of viable transactions considerably. Two performance characteristics that have a significant impact on storage variable operating cost are:

1. round-trip efficiency of the storage system
2. the rate at which storage performance declines as it is used.

In addition, seasonal and diurnal electricity storage can be considered as a bulk service. It can be very useful for wind or PV if there are significant seasonal and diurnal differences.

2.2.2 Distribution Upgrade Deferral and Voltage support

A storage system that is used for upgrade deferral could simultaneously provide voltage support on the distribution lines. Utilities regulate voltage within specified limits by tap changing regulators at the distribution substation and by switching capacitors to follow load changes. This is especially important on long, radial lines where a large load such as an arc welder or a residential PV system may be causing unacceptable voltage excursions on neighboring customers. These voltage fluctuations can be effectively damped with minimal draw of real power from the storage system.
Technical considerations:

- Storage System Size Range: 500 kilowatts (kW) – 10 MW
- Target Discharge Duration Range: 1 – 4 hours
- Minimum Cycles/Year: 50 – 100

2.2.3 Retail Energy Time-Shift

Retail electric energy time-shift involves storage used by energy end users (utility customers) to reduce their overall costs for electricity. Customers charge the storage during off-peak time periods when the retail electric energy price is low, then discharge the energy during times when on-peak time of use (TOU) energy prices apply. This application is similar to electric energy time-shift, although electric

energy prices are based on the customer's retail tariff, whereas at any given time the price for electric energy time-shift is the prevailing wholesale price
Technical considerations:

- Storage System Size Range: 1 kW – 1 MW
- Target Discharge Duration Range: 1 – 6 hours
- Minimum Cycles/Year: 50 – 250

2.2.4 Demand Charge Management

Electricity storage can be used by end users (i.e., utility customers) to reduce their overall costs for electric service by reducing their demand during peak periods specified by the utility. To avoid a demand charge, load must be reduced during all hours of the demand charge period, usually a specified period of time (e.g., 11:00 a.m. to 5:00 p.m.) and on specified days (most often weekdays). In many cases, the demand charge is assessed if load is present during just one 15-minute period, during times of the day and during months when demand charges apply. The most significant demand charges assessed are those based on the maximum load during the peak demand period (e.g., 12:00 p.m. to 5:00 p.m.) in the respective month. Although uncommon, additional demand charges for 1) part peak or (partial peak) demand that occurs during times such as shoulder hours in the mornings and evenings and during winter weekdays and 2) base-load or facility demand charges that are based on the peak demand no matter what time (day and month) it occurs.

2.3 Stacked Services

Electricity storage can be used for any of the services listed above, but it is rare for a single service to generate sufficient revenue to justify its investment. However, the flexibility of storage can be leveraged to provide multiple or stacked services, or use cases, with a single storage system that captures several revenue streams and becomes economically viable. How these services are stacked depends on the location of the system within the grid and the storage technology used. However, due to regulatory and operating constraints, stacking services is a process that requires careful planning and should be considered on a case-by-case basis.
When connected to the grid at the transmission level, energy storage can provide grid-related service to ancillary markets under the control of ISOs while bidding into the energy market. Energy storage can also act as a peaker to provide system capacity. When placed on the distribution circuits, energy storage can help

solve local substation-specific problems (mitigating voltage problems, deferring investment upgrades, etc.) while providing ancillary services to the grid. On the customer side of the meter, energy storage system can shave the customer's peak load and reduce the electricity bill while improving power quality and reliability.

Application	Description	Size	Duration	Cycles	Desired Lifetime
Wholesale Energy Services	Arbitrage	10-300 MW	2-10 hr	300-400/yr	15-20 yr
	Ancillary services [2]	See note 2	See Note 2	See Note 2	See Note 2
	Frequency regulation	1-100 MW	15 min	>8000/yr	15 yr
	Spinning reserve	10-100 MW	1-5 hr		20 yr
Renewables Integration	Wind integration: ramp & voltage support	1-10 MW distributed 100-400 MW centralized	15 min	5000/yr 10,000 full energy cycles	20 yr
	Wind integration: off-peak storage	100-400 MW	5-10 hr	300-500/yr	20 yr
	Photovoltaic Integration: time shift, voltage sag, rapid demand support	1-2 MW	15 min-4 hr	>4000	15 yr
Stationary T&D Support	Urban and rural T&D deferral. Also ISO congestion mgt.	10-100 MW	2-6 hr	300-500/yr	15-20 yr
Transportable T&D Support	Urban and rural T&D deferral. Also ISO congestion mgt.	1-10 MW	2-6 hr	300-500/yr	15-20 yr
Distributed Energy Storage Systems (DESS)	Utility-sponsored; on utility side of meter, feeder line, substation. 75-85% ac-ac efficient.	25-200 kW 1-phase 25-75 kW 3-phase Small footprint	2-4 hr	100-150/yr	10-15 yr
C&I Power Quality	Provide solutions to avoid voltage sags and momentary outages.	50-500 kW	<15 min	<50/yr	10 yr
		1000 kW	>15 min		
C&I Power Reliability	Provide UPS bridge to backup power, outage ride-through.	50-1000 kW	4-10 hr	<50/yr	10 yr
C&I Energy Management	Reduce energy costs, increase reliability. Size varies by market segment.	50-1000 kW Small footprint	3-4 hr	400-1500/yr	15 yr
		1 MW	4-6 hr		
Home Energy Management	Efficiency, cost-savings	2-5 kW Small footprint	2-4 hr	150-400/yr	10-15 yr
Home Backup	Reliability	2-5 kW Small footprint	2-4 hr	150-400/yr	10-15 yr

1. Size, duration, and cycle assumptions are based on EPRI's generalized performance specifications and requirements for each application, and are for the purposes of broad comparison only. Data may vary greatly based on specific situations, applications, site selection, business environment, etc.
2. Ancillary services encompass many market functions, such as black start capability and ramping services, that have a wide range of characteristics and requirements.

Figure 2.3: Electrical Energy Storage Services Summary

Chapter 3

Electricity Energy Storage Technologies

A general and updated overview of current Energy Storage Technologies is presented:

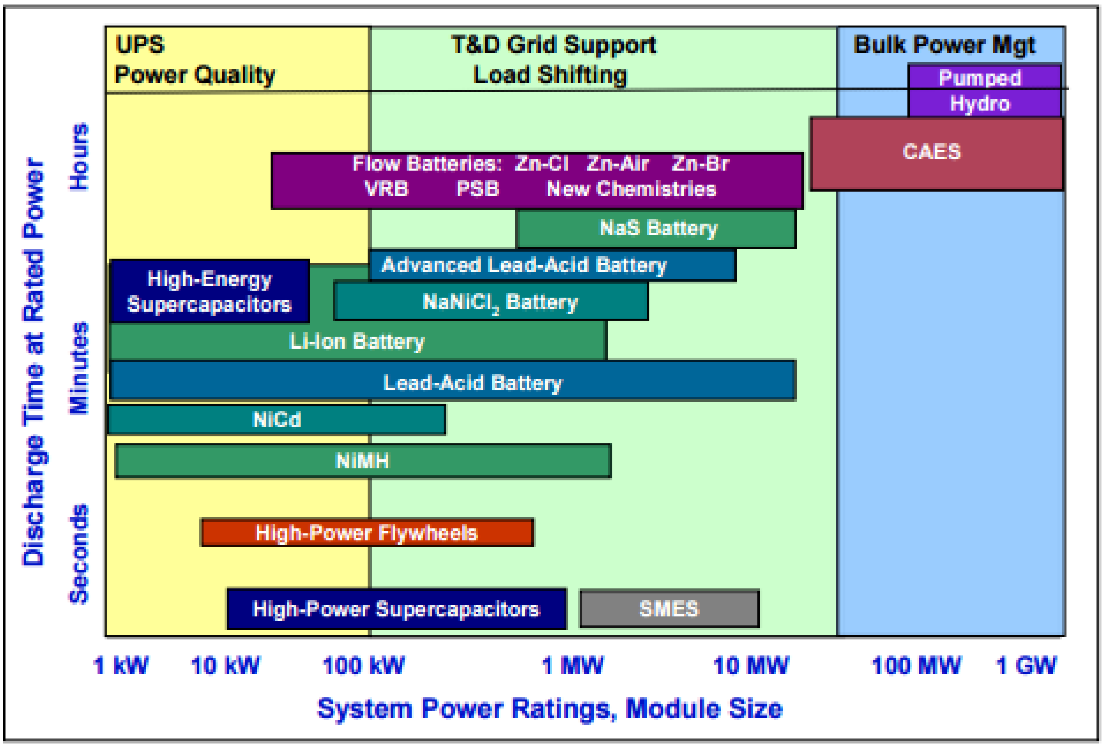


Figure 3.1: Electricity Energy Storage Technologies Overview

The portfolio of electricity storage technologies can be considered for providing a

range of services to the electric grid and can be positioned around their power and energy relationship. The figure shows that compressed air energy storage (CAES) and pumped hydro are capable of discharge times in tens of hours, with correspondingly high sizes that reach 1000 MW. In contrast to the capabilities of these two technologies, various electrochemical batteries and flywheels are positioned around lower power and shorter discharge times.
Installed cost estimates were developed for the specific services and are presented per kilowatt of discharge capacity installed ($/kW installed). Levelized cost of energy (LCOE) or lifecycle cost estimates are expressed per kilowatt-hour ($/kWh) of delivered energy. For technology screening-level studies, these cost estimates are conceptual estimates that will differ from site-specific project estimates for the following reasons: Project estimates are more detailed and based on site-specific conditions and use cases. Individual companies' design bases may vary. Actual owner costs as well as site-specific costs in project estimates are generally higher. Site-specific requirements, such as transportation, labor,interconnection, and permitting, also have an impact.
Since the purpose of this thesis is Distribution feeder level technologies, Pumped Hydro and Compressed Air Energy Storage (CAES) are omitted from the discusion because of their bigger operational scale size. Also Flywheel is not considered since the time range in which it operates (seconds) is not the one considered (15 minutes). Moreover NaS batteries are only available in multiples of 1-MW/6-MWh units with installations typically in the range of 2 to 10 MW according to NGK, leader in this technology market fragment.

3.1 Lithium-ion Batteries

The most promising and rising technology for Distribution feeder level is Lithium-based technolgy. A Li-ion battery cell contains two reactive materials capable of undergoing an electron transfer chemical reaction. To undergo the reaction, the materials must contact each other electrically, either directly or through a wire, and must be capable of exchanging charged ions to maintain overall charge neutrality as electrons are transferred. A battery cell is designed to keep the materials from directly contacting each other and to connect each material to an electrical terminal isolated from the other material's terminal. These terminals are the cell's external contacts.
Inside the cell, the materials are ionically, but not electronically, connected by an electrolyte that can conduct ions, but not electrons. This is accomplished by building the cell with a porous insulating membrane, called the separator, between the two materials and filling that membrane with an ionically conductive salt solution. Thus this electrolyte can serve as a path for ions, but not for electrons.

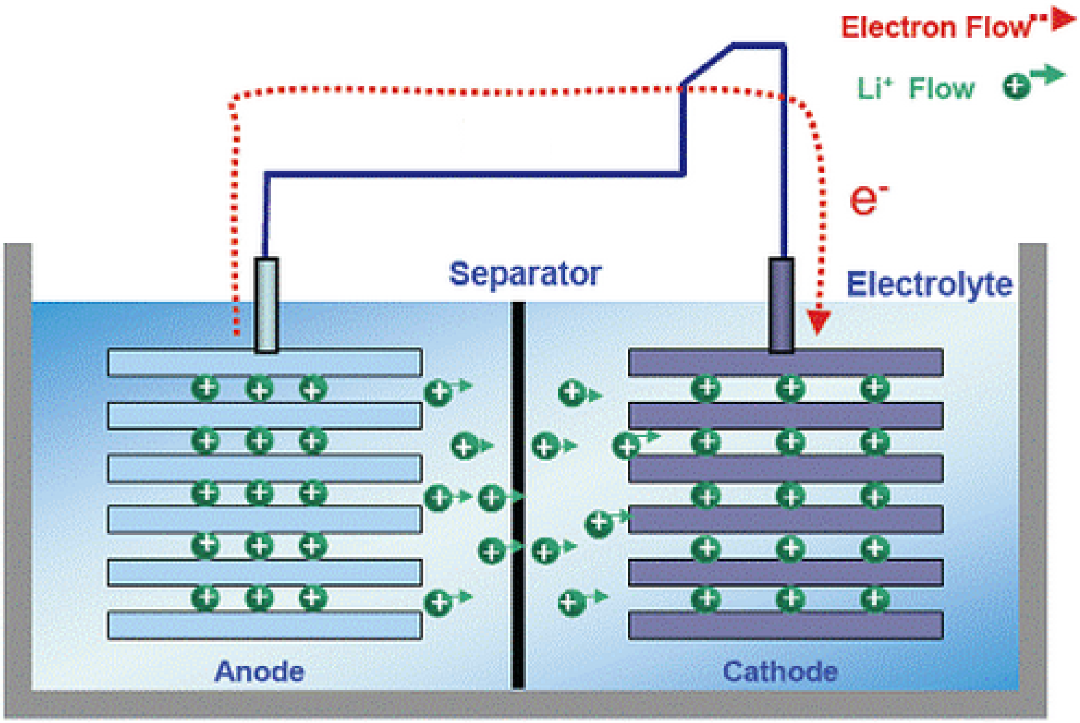


Figure 3.2: Li-Ion Battery Technology

When the external terminals of the battery are connected to each other through a load, electrons are given a pathway between the reactive materials, and the chemical reaction proceeds with a characteristic electrochemical potential difference or voltage. Thus there is a current and voltage (i.e., power) applied to the load

3.1.1 Maturity and Commercial Availability

The large manufacturing scale of Li-ion batteries (estimated to be approximately 30 GWh by the end of 2015) could results in potentially lower cost battery packs which could also be used and integrated into systems for grid-support services that require less than 4 hours of storage. Many stationary systems have been deployed in early field trials to gain experience in siting, grid integration, and operation. Early system trial demonstrations are underway using small 5 to $10kW/20kWh$ distributed systems and large 1-MW/15-minute fast-responding systems for frequency regulation. Several electric utilities are also planning to deploy Distributed Energy Storage Systems (DESSs) in the 25 to 50kW size range on the utility side of the meter with energy durations ranging from 1 to 3 hours. Some systems have islanding capability, which can keep homeowners supplied with power for 1 to 3 hours if the grid goes down. Several customer-side-of-meter commercial and residential applications are also underway. In 2014 Bjorn Nykvist and Mans Nilsson [14] published a comprehensive review about Li-ion costs with promising results about cost decreasing stating that it is faster than expected for the time range 2007-2014

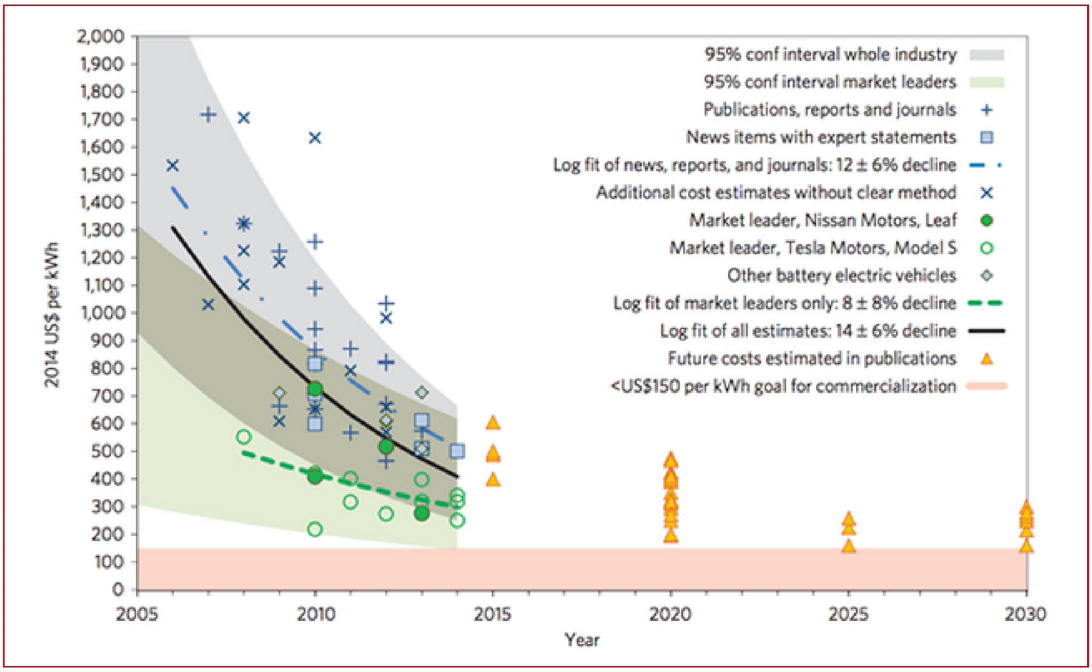


Figure 3.3: Li-Ion Battery Decreasing Cost trend

3.2 Lead Acid Batteries

Lead-acid batteries are the oldest form of rechargeable battery technology since they were originally invented in the mid-1800s. The positive electrode is composed of lead-dioxide, PbO_2, while the negative electrode is composed of metallic lead, Pb. The active material in both electrodes is highly porous to maximize surface area. The electrolyte is a sulfuric acid solution, usually around 37% sulfuric acid by weight when the battery is fully charged.

Lead-acid energy storage technologies are divided into two types: lead-acid carbon technologies and advanced lead-acid technologies. Lead-acid carbon technologies use a fundamentally different approach to lead-acid batteries through the inclusion of carbon, in one form or another, both to improve the power characteristics of the battery and to mitigate the effects of partial states of charge. Certain advanced lead-acid batteries are conventional valve-regulated lead-acid (VRLA) batteries with technologies that address the shortcomings of previous lead-acid products through incremental changes in the technology. Other advanced lead-acid battery systems incorporate solid electrolyte-electrode configurations, while others incorporate capacitor technology as part of anode electrode design. Lead-acid batteries are the most commercially mature rechargeable battery technology in the world. VRLA batteries are used in a variety of applications, including automotive, marine, telecommunications, and uninterruptible power supply (UPS) systems. However, there have been very few utility Transmission and Distribution applications for such batteries due to their relatively heavy weight, large bulk, cycle-life limitations, and perceived reliability issues (stemming from maintenance requirements).

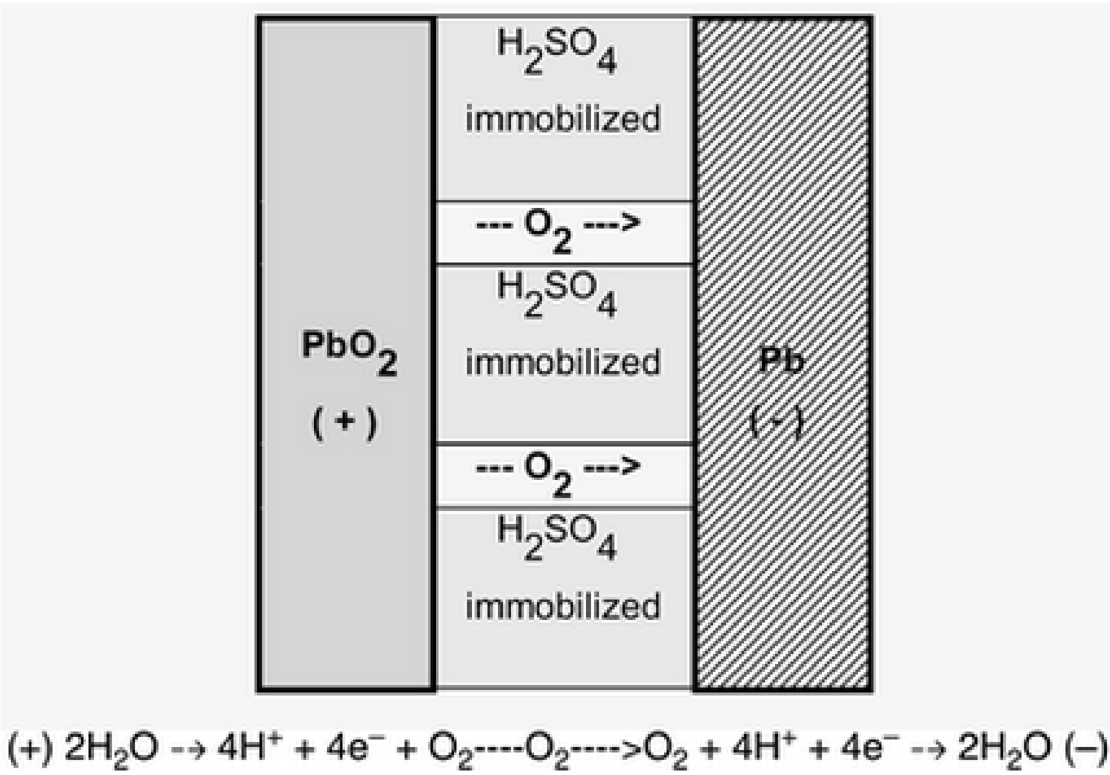
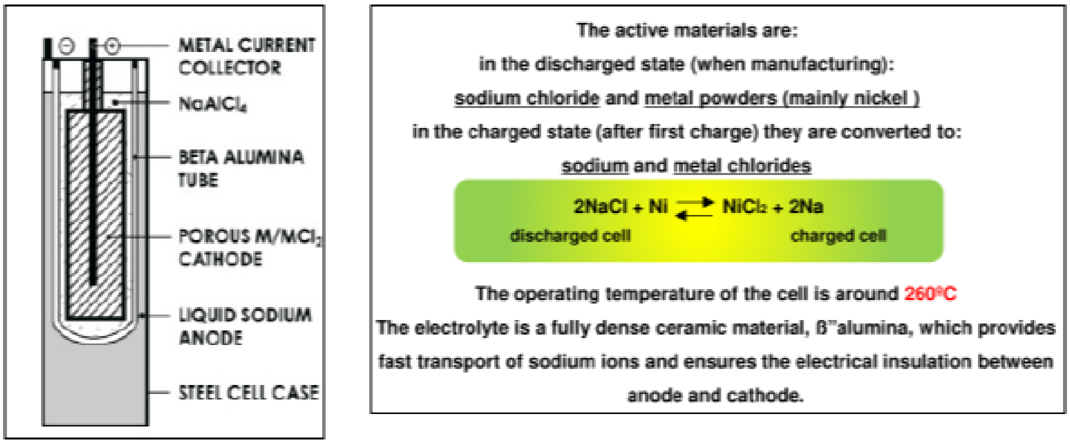


Figure 3.4: Lead Acid Battery

Two others technologies are here presented even if not considered for further simulations, but interesting for future local grid storage services

3.3 Sodium Nichel Chloride Batteries

Sodium-nickel-chloride batteries are high-temperature battery devices, like NaS. The figure below illustrates the design of this battery and key principles. When charging a Sodium-nickel-chloride battery at normal operating temperatures range (usually between 270 °to 350 °), salt ($NaCl$) and nickel (Ni) are transformed into nickel-chloride ($NiCl_2$) and molten sodium (Na). The chemical reactions are reversed during discharge, and there are no chemical side reactions. The electrodes are separated by a ceramic wall (electrolyte) that is conductive for sodium ions but an isolator for electrons. Therefore, the cell reaction can only occur if an external circuit allows electron flow equal to the sodium ion current. The porous solid $NiCl_2$ cathode is impregnated with a sodium ion conductive salt ($NaAlCl_4$) that provides a conductive path between the inside wall of the separator and the reaction zone. Cells are hermetically sealed and packaged into modules of about 20 kWh each.



Design and Principal Features of Sodium-nickel-chloride Batteries
(Courtesy FIAMM)

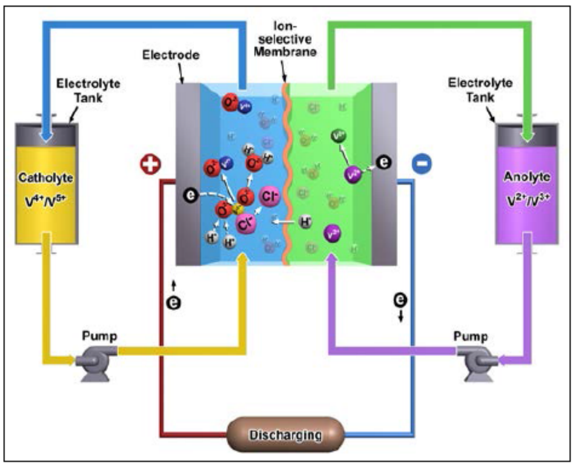
Figure 3.5: Sodium Nickel Chloride (NaNiCl) Battery Technology

The internal normal operating temperature is required to achieve acceptable cell resistance and must be thermally managed by design features. Two battery original equipment manufacturer (OEM) suppliers have production facilities operating and are starting to deploy systems in the size range of 50 kW to 1 MW.

3.4 Vanadium Redox Batteries

An interesting technology that according to many vendors is at the pre-commercial stage is Vanadium Redox Flow Batteries. Vanadium reduction and oxidation (redox) batteries are of a type known as flow batteries, in which one or both active materials is in solution in the electrolyte at all times. In this case, the vanadium ions remain in an aqueous acidic solution throughout the entire process. The vanadium redox flow battery is a flow battery based on redox reactions of different ionic forms of vanadium. During battery charge, V3+ ions are converted to V2+ ions at the negative electrode through the acceptance of electrons. Meanwhile, at the positive electrode, V4+ ions are converted to V5+ ions through the release of electrons. Both of these reactions absorb the electrical energy put into the system and store it chemically. During discharge, the reactions run in the opposite direction, resulting in the release of the chemical energy as electrical energy. In construction, the half-cells are separated by a proton exchange membrane that allows the flow of ionic charge to complete the electrical circuit. Both the negative and positive electrolytes (sometimes called the anolyte and catholyte, respectively) are composed of vanadium and sulfuric acid mixture at approximately the same acidity as that found in a lead-acid battery. The electrolytes are stored in external tanks and pumped as needed to the cell.

Individual cells have a nominal open-circuit voltage of about 1.4 V. To achieve higher voltages, cells are connected in series to produce cell stacks. Vanadium redox flow batteries have an important advantage among other flow batteries: the two electrolytes are identical when fully discharged. This makes shipment and storage simple and inexpensive and greatly simplifies electrolyte management during operation.



(Courtesy of the Pacific Northwest National Laboratory)

Figure 3.6: Vanadium Redox Flow Battery (VRB) Technology

Self-discharge is typically not a problem for vanadium redox systems, because the electrolytes are stored in separate tanks. Self-discharge may occur within the cell stack if it is filled with charged electrolyte, resulting in the loss of energy and heat generation in the stacks. For this reason, the stacks are usually elevated above the tanks, so that electrolyte drains back into the tanks when the pumps are shut down. The battery will then take a short while to come back into operation again. Alternatively, the pumps can operate in an idling state, which would allow charged electrolyte to be available at all times, at the price of a slightly higher parasitic loss. The life of a vanadium redox system is determined by a number of components. The cell stack is probably the limited life component, with a useful life estimated at 10 years; however, operational field data are not available to confirm these lifetimes. The tanks, plumbing, structure, power electronics, and controls have a longer useful life. The electrolytes and the active materials they contain do not degrade with time.

Vanadium redox systems are capable of stepping from zero output to full output within a few milliseconds, if the stacks are already primed with reactants. In fact, the limiting factor for beginning battery discharge is more commonly the controls and communications equipment. For short-duration discharges for voltage support, the electrolyte contained in the stacks can respond without the pumps running at all. The cell stack can produce three times the rated power output provided the state of charge is between 50% and 80%. The physical scale of vanadium redox systems tends to be large due to the large volumes of electrolyte required when sized for utility-scale (megawatt-hour) projects. Unlike many other battery technologies, cycle life of vanadium redox systems is not dependent on depth of discharge. Systems are rated at 10,000 cycles, although some accelerated testing performed by Sumitomo Electric Industries Ltd., produced a battery system with one 20-kW stack for cycle testing that continued for more than 13,000 cycles over about two years.

Other Flow battery technologies like Zinc-Bromine and Iron-Chromium are not here considered. Zinc-air technology is still in early Research and Development phase for stationary storage systems in grid services markets. Despite substantial technical obstacles faced in the past, this technology holds a great deal of potential because of its low capital cost for grid support and potentially for electric transportation applications [1].

[1] Vanadium Redox and NaNiCl Batteries will not be considered during economic evalutaions since data available is not enough to proper evaluate a realistic solution

Chapter 4

Community Energy Storage, existing examples

Community energy storage entails utility deployment of modular, distributed energy storage systems (DESS) at or near points in the utility distribution system that are close to residential and business end users. The genesis of the CES concept was investigated by American Electric Power(AEP) which will be analyzed in a further section. Though the actual value proposition for any specific CES deployment will vary significantly, important elements include:

- a) it can provide numerous benefits
- b) it is a flexible solution for many existing and emerging utility needs
- c) to one extent or another, eventually, utility engineers will include modular distributed storage as a standard alternative in their growing toolkit of solutions and responses. Utilities' conventional toolkit includes a fairly narrow set of solutions, primarily generators, transformers and wires. Before utility engineers can and will accept storage as a standard alternative, it is important to standardize utility specifications for the storage systems [1].

CES is expected to provide numerous benefits in many possible combinations. It can serve as a robust, fast-responding and flexible alternative to generation. It can store low priced energy and use that energy when the price is high. CES can also be used to provide most types of "ancillary services" that are needed to keep the electrical grid stable and reliable. Depending on the location, CES may reduce the need for transmission and distribution capacity because CES provides power locally, so less equipment is needed to serve the local peak-demand. CES can also

[1] AEP published "Functional Specifications for CES" as an open source standard

improve the local electric service reliability and power quality. An other interesting application is CES used to maintain a stable voltage in the distribution system.
CES can play an important role in the integration of renewable energy generation into the grid, including large scale/remote wind generation and distributed (e.g. rooftop) photovoltaics. CES addresses two notable RE generation integration challenges. First, CES can be charged with wind generation output, much of which occurs at night when the energy is not very valuable. In some circumstances,demand for energy is less than the amount being generated, so wind generation is curtailed (turned off) or the system operator [2] must pay someone to take the energy. By charging at night, CES takes advantage of the time when transmission systems are less congested and more efficient. Second, CES can be used to manage localized "power quality" related challenges posed by high penetrations of photovoltaics systems, especially in residential areas. Of particular note are undesirable voltage fluctuations that occur such as those associated with rapid variations of output due to passing clouds. CES is also designed to islanding-mode, so when a localized portion of the distribution system becomes electrically isolated from the rest of the grid, CES can "pick up" the end-user demand and can serve that demand while there is stored energy.
Although CES is not a value proposition per se, the concept is powerful. It entails use of a flexible, standardized, modular utility-owned solution to important existing and emerging challenges faced by utilities in the new electricity marketplace. It can be added as needed while providing numerous benefits. It is enabled by and enhances the value and effectiveness of the expanding suite of elements of the Smart Grid [3] [15].
Moreover, according to Paolo Borzatta of Milan Politechnic University CES has 3 major advantages [16]:

1. Can provide *Peak Shaving*: reducing demand peaks especially during daytime
2. Can provide *Load Shifting*: moving energy from peak to off-peak hours
3. Can provide *Predictable Profile* reduce Variability of energy exchanged on Electricity Markets

As said before, the third point is the focus of this thesis work. An important example of real application of Cimmunity Energy Storage is now exposed

[2] An individual at a control center (Balancing Authority, Transmission Operator The entity responsible for the reliability of its "local" transmission system, and that operates or directs the operations of the transmission facilities, Generator Operator, Reliability Coordinator) whose responsibility it is to monitor and control that electric system in real time

[3] devices, practices and protocols that enable rich monitoring and situational awareness and flexible and robust control of various parts of or entire power systems under varying conditions

4.1 Community Energy Storage, the American Electric Power (AEP) Experience

Starting in about 2005, to evaluate the prospects for and merits of locating advanced sodium sulfur (NaS) battery, rated at about 2 (MW), at substations. Eventually, AEP added a different twist on the concept involving numerous much smaller units, rated at 25 kW for three hours, or 75 kWh, that are distributed and located at or near end-user sites. So, instead of deploying one or two large battery systems with a power output of 2 MW at the utility substation the alternative is to deploy 80 individual systems, at or near end-user homes and businesses whose power output is 25 kW.

AEP describes the approach as “a fleet of small distributed energy storage units connected to the secondary of transformers serving a few houses controlled together to provide feeder level benefits.” Special design attention was given to making the CES resemble conventional utility equipment.

One notable advantage of using many smaller units is “unit diversity”. Because there are so many units, it is unlikely that a substantial amount of CES power will be out-of-service at any time. That is helpful if reliability is especially important.

These multiple small battery-based energy storage units are connected to the utility transformers’ 240/120 V secondary and controlled from a common remote control. AEP starting strategy is here reported : "Initially the individual CES Units will be pad-mounted and typically be deployed in Underground Residential Distribution (URD) settings adjacent to a single phase pad mount transformer. A large number of these small storage units will be aggregated regionally and controlled as a fleet"

The individual CES Units have controls to manage their individual charge and discharge activity in response to regional needs at the feeder, station, or system level. The regional needs will be managed by a CES Control Hub or by integration into another control platform, herein referred to as an Integration Platform. If used, the CES Hub will be deployed as hardware and software typically installed at the station for the feeder(s) on which its fleet of CES Units are installed. A utility may elect to implement the same control functionality in an Integration Platform which has broader application, possibly including other distributed resources. The Integration Platform would not require the hardware on which the CES Hub will implement this regional control functionality".

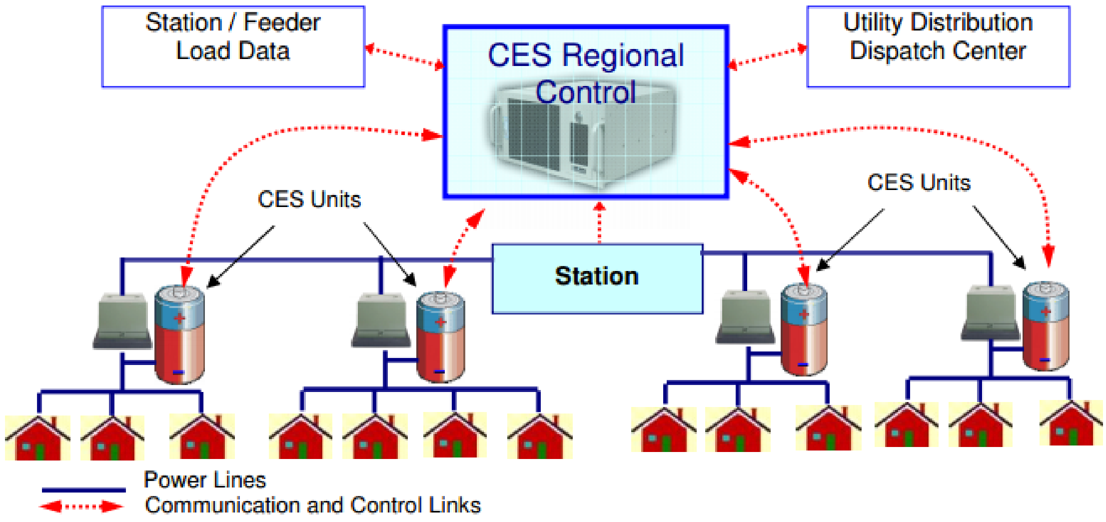


Figure 4.1: Electrical Energy Storage Services Summary

According to AEP, CES can provide capacity, efficiency, and reliability benefits through the following key functions: Grid functions:

- Serve as a load leveling, peak shaving device at the station level
- Serve as a power factor correction device at the station level (VAR support)
- Be available for ancillary services through further aggregation at the grid level. Other local functions include:
- Serve as backup power for the houses connected locally
- Serve as local voltage control
- Provide efficient, convenient integration with renewable resources

Chapter 5

Community Energy Storage for Predictable Profile Service

Most RES technologies are usually integrated at the distribution level because of the small generator sizes and the voltage they generate [17]. As a consequence, most of distributed Energy Storage (ES) research focused on ES supporting RE technologies. Wade et al. used simulation work prior to the deployment of a real distributed ES system taking place on a 11 kV distribution network and they investigated how a generic distributed ES system responded to voltage control and power flow management. The research concluded that distributed ES systems should be flexible enough to develop different tasks depending on the location and size, but the management should give priority to the events which add more value [18]. A benefit of ES on large-scale PV schemes is that using 1 kWh of storage per 1 kWp PV will reduce (and potentially eliminate) PV-induced over voltage events [19]. Usually the worst case scenario is for the smallest communities, because the more spiky demand profile required proportionately larger battery capacities, but at the same time overvoltage problems could occur if the community is too large and the CES is located near the point of common coupling, being unable to perform voltage support where it occurs (usually at the bottom of the considerd feeder). So the optimal match in community size has to be found taking into account these considerations [20]. Community Energy Storage (CES) is also considered because it could be the intermediate solution between single home ES systems and distributed ES systems for balancing local intermittent RE generation and dynamic demand loads in residential areas. Moreover it could be the link between RES and their active participation to Electricity Markets [21] [22] [20].
The main goal of this work is to understand if Community Energy Storage (CES) can be a valid solution for Renewable Energy Systems (RES) integration, especially Photovoltaic Systems (PV), according to a specific kind of service that the CES could perform in the future, the Predictable Profile Energy exchange with the

main grid.

5.1 Predictable Profile Battery Modelling and sizing

RES intermittancy is hardly acceptable by Systems operators, creating different problems such as harmonics and need for balancing at unexpected times. This is a limitating factor for an even deeper diffusion of Photovoltaic systems. Due to the still high costs of installations, Aggregators of Renewable energy systems could have an important role to manage energy profiles, taking advantage from actions in electricity markets .

5.1.1 General definition of Aggregators and their role

An Aggregator of Renewable Energy Resources can be conisedered part of the wider group of Virtual Power Plant (VPP) concept. VPP is a flexible representation of a portfolio for Distributed Energy Resources. A VPP is comparable to a trasmission connected generating plant which has a profile of characteristics like schedule of generation, generation limits, operating costs and so on. Using this profile, indivudual plant can interact directly with other market participants to offer services and make contracts. Via direct communication with the transmission system operator or through market-based transactions, a transmission connected unit can contribute to system management. Generation output and other associated services can be sold through interaction in the wholesale market or by direct contact with energy suppliers and other parties.
When operating alone many DERs don't have sufficient capacity, flexibility or controllability to make these system management and market-based activities cost effective or technically feasible. However, with the creation of a VPP from a group of DER, these issues can be overcome.
A VPP not only aggregates the capacity of many diverse DER, it also creates a single operating profile from a composite of the parameters characterising each DER and incorporates spatial (i.e network) constraints into its description of capabilities of the portfolio. The VPP is characterized by a set of parameters usually associated with a traditional transmission connected generator, such as scheduled output, ramp rates, voltage regulation capability, reserve and so on. Furthermore, as the VPP also incorporates controllable demands, parameters such as demand price elasticity and load recovery patterns are also used for the characterisation of VPP.
Some examples of generation and controllable load parameters for aggregation to characterise a VPP are:

Controllable Parameters

- Schedule of profile of generation
- Generation limits
- Minimum stable generation output
- Firm capacity and maximum capacity
- Stand-by capacity
- Active and reactive power loading capability
- Ramp rate
- Frequency response characteristic
- Voltage regulating capability
- Fault levels
- Fault ride through characteristics
- Fuel characteristics
- Efficiency
- Operating cost characterisitics

Controllable load parameters:

- Schedule or profile of load
- Elasticity of load to energy prices
- Minimum and maximum load that can be re-scheduled
- Load recovery pattern

Given that a VPP is composed of a number of DER of various technologies with various operating patterns and availability, the characteristics of the VPP may vary significantly in time. Furthermore, as the DER that belongs to a VPP will be connected to various points in the distribution network, the network characteristics (topology,impedences, losses and constraints) will also impact the overall characterisation of the VPP.

The VPP can be used to facilitate DER trading in the wholesale energy markets (e.g. forward markets and the power exchange), and can provide services to support transmission system management (e.g. various types of reserve, frequency and voltage regulation and so on). In the development of the VPP concept, these activities of 'market participation' and 'system management and support' are described, respectively, as 'commercial' and 'technical' activities, which derive the roles of commercial VPP (CVPP) and technical VPP (TVPP)[23]

5.1.2 Aggregators for Predictable Profile service

One of the crucial steps to permit Aggregators to act in agreement with Grid Operators is to be able to guarantee a predictable profile of their aggregated loads and productions. To do this they need a storage system which compensate the shifts in demand or production from the chosen profile. As will be shown in detail later, a predictable profile consists of step-based profile, with constant values of input or output power during a previously defined amount of time. Since the actual input-output profile wouldn't be flat but vary significantly over time, a storage system is used to perform the predictable profile. To properly evaluate the storage size ncessary to give this kind of service, several simulations with different possible configurations had been done.

5.1.3 System Description

A simple 19 nodes feeder with realistic characteristics was implemented.
Each node, except from the first one (point of common coupling) is a point of consumption. Each PV system had been chosen with $20m^(2)$ of surface corrisponding to approximately 3 kWp. This because Irradiation data, 15-minutes-based, were available and the output Energy from PV system could be so calculated as

$$E = Area * Irradiation * eta_{PV} * C_{corr}$$

Where E is the energy produced [Wh], Irradiation is the global incidence radiation that hit the solar panels, eta_{PV} is the solar system efficiency, combination of $eta_{Panels} = 20\%$ and $eta_{BOS} = 85\%$ (BOS states for "Balance of System") C_{corr} was assumed as 1.13 according to UNI10349, since the solar panels are assumed to have a tilt angle of 32 degrees (and 39 for the dutch case). Variables invloved in the simulations were:

- Number of PV producers (randomly located into the feeder nodes). Simulations had been carried out with 1,3,6,9,12,15,18 connected PV systems
- Number of Profile steps. Each profile step had been calculated as mean of the considered range of values taken into account. As an example if 3 steps were

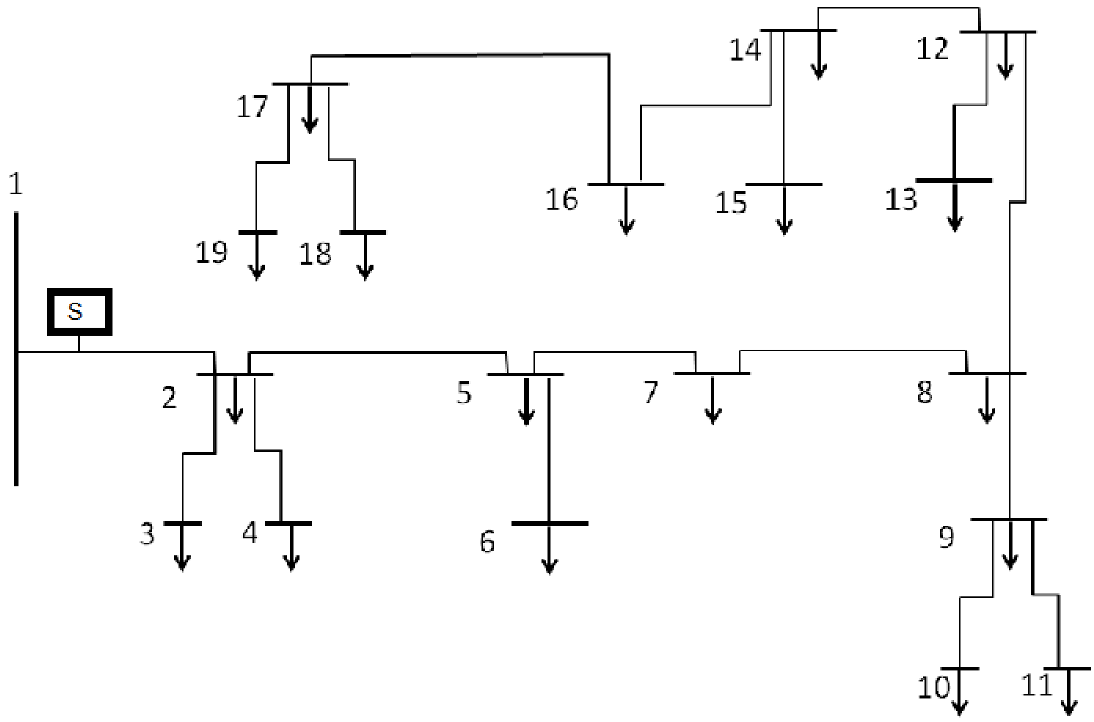


Figure 5.1: Considered Grid Topology

considerd, the range of values was 96/3 = 32. Simulations were conducted with 1,2,3,4,6,8,12,16 steps (with more steps the predictable profile tends to be so close to the real one getting the storage system unuseful)

In this way a total of 56 different configurations had been studied.

5.1.4 Assumptions

- Apparent Power= 10^5 VA
- Frequency= 50 Hz
- number of nodes= 19
- efficiency of photovoltaic system (eta_{PV})= 17%
- PV inclination (alpha)= 39 degrees
- PV system Area= $20m^2$
- storage round-trip efficiency=85%

5.1.5 Brief Code Description

To perform the simulations, a Matlab code had been written and it present this general structure:

- Input Data are defined including, cable data and Transformer data
- Topology of the grid with connections and distances between nodes.
- Irradiation, Loads and spot prices data are recalled from Excel files
- All variables, vectors and matrices are initialized
- Four cycles are run: the first regards the number of connected PV systems, the second for predictable profile resolution, the third for days in an year, the fourth for the 15-minutes time steps in a day. Into the four-level-for cycle are set up:
- Grid Parameters calculation according to the Y-Matrices method [24]
- Calculation of the Energy Exchanged with the grid considering PV production and Loads, an Input-Output matrix is created.
- Creation of Predictable Profile Matrix setting as the costant level the mean value of the considered range into Input-Output-Matrix vectors
- Storage profile calculations
- Economic Calculations are performed considering spot prices multiplied by the energy exchanged with the grid (buy or sell respectively)
- Battery Size Calculation is made by finding max and min values of storage necessary to perform the required service, the range between these values is the Battery size. Increasing of the 20% the previously found value the real size is obtained (it's assumed a roundtrip efficiency of 85% for the battery as stated before)

Two case studies were developed considering the dutch and the italian context. For both of them irradiation data and markets prices were used as inputs. Irradiation data were given by "Technical University of Eindhoven" and "Centro Nazionale delle Ricerche" (Bologna) [1]. Electricity Market Prices were obtained by "Tennet" and "Mercato Elettrico" from their website respectively [2].

[1]Istituto di Scienze dell'Atmosfera e del Clima (ISAC) - Consiglio Nazionale delle Ricerche (CNR) comes from the meteo station operating in Bologna within project 2009/B.04 Osservatorio BSRN, National Antartic Resarch Programme

[2]www.tennet.nl and www.mercatoelettrico.org

Predictable Profile Resolution is defined as: each vector of the exhanged energy matrix (representing a day) is divided into equal parts, corresponding to the resolution required. For each part the mean value is calculated. This mean value is replied as many times as the numerosity of the considered part. In this way a new vector (and consequently Matrix) is created. For example if the resolution is 3, each vector will present 3 sets of equal values like in this picture:

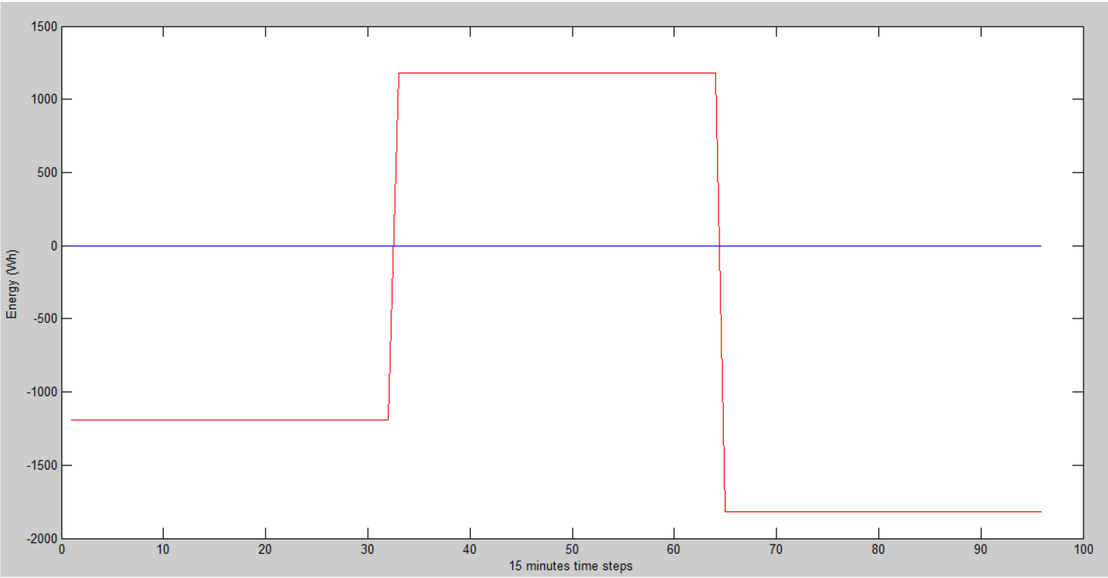


Figure 5.2: 3 step resolution predictable Profile

5.2 Results

5.2.1 Single day Simulation

At first was verified that over-voltage problems didn't occur in all possible configurations with different PV penetration levels and predictable profile resolutions. Since the final result present a certain level of complexity it's better to start its explanation from the basic elements of the whole simulation. As an example here we consider a PV penetration level of 50% correspondig to 9 connected PV systems, and a resolution of 3 steps for the Predictable Profile. If we consider 2 randoms days of a year (1 in summer and 1 in winter), the energy exchanged with the grid and the Predictable Profile are showed in red. Black bars represent the storage behaviour necessary to guarantee the Predictable Profile. The physical feasibility of this behaviour had not been verified even if it is possible to deduct that very steep variations from charge to discharge are stressfull for the battery and this could significatively reduce its storage capacity and life time.

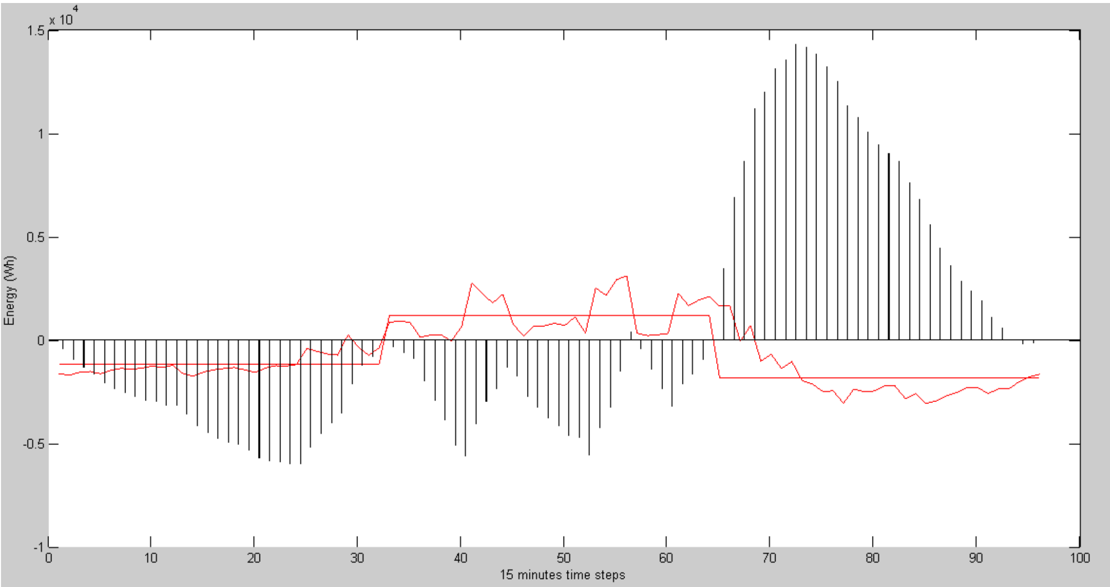


Figure 5.3: Random Summer Day simulation result

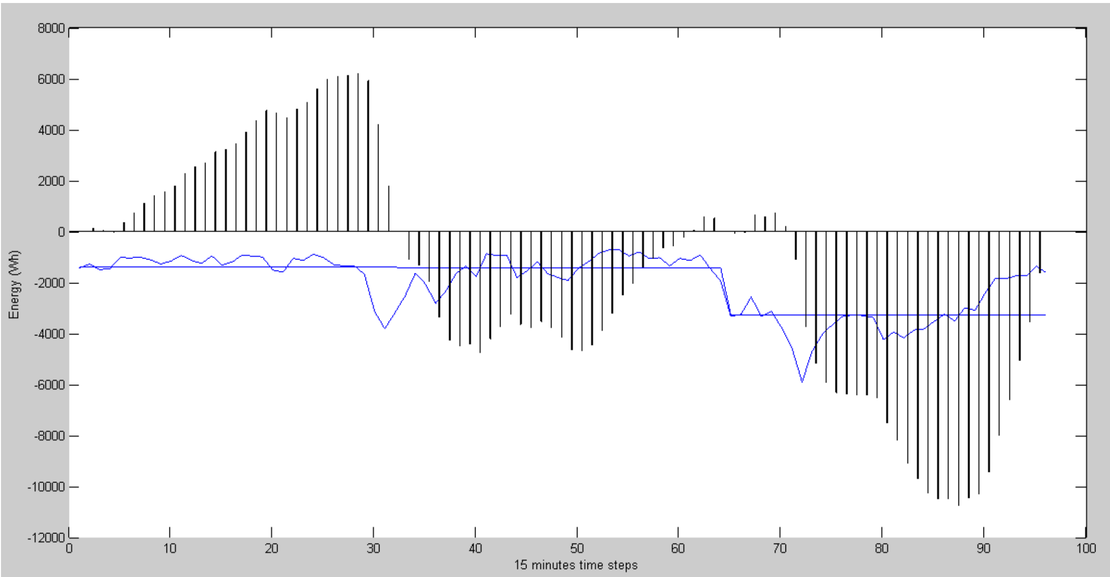


Figure 5.4: Random Winter Day simulation result

If the battery was dimensioned for these two days only it would have resulted as: $20.3kWh$ and $16.9kWh$ respectively

5.2.2 Whole Year Simulation

If the simulation is run for the whole year with same previous conditions, it's possible to see the range in which the Predictable Profile space during the year (always expressed in Wh on Y-axe).

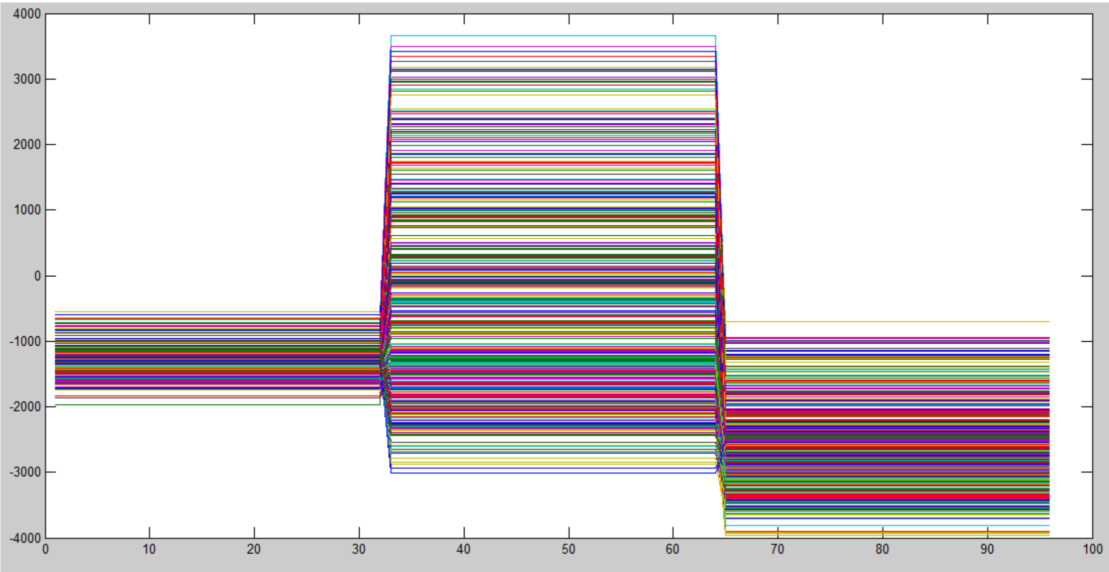


Figure 5.5: Predictable profile with 3 steps for the whole year

The aggregated profiles of stored energy profile all over one year are here showed in 2D and 3D:
The battery size that results from the entire year simulation in this case is: $45.09kWh$. For a realistic dimensioning has to be considered that battery state of charge (SOC) should never go below the 20% of the maximum storage capacity. So it's necessary to add 9018 Wh and the final size results: $54.108kWh$.

5.3 Whole Year Simulation with different amount of connected PV systems and Predictable Profile Resolutions

In order to see in a reliable way the results regarding different configurations of connected PV and resolutions of predictable profile, here some graphs are reported. The first one represent the storage size as it results from the Matlab ran code, for all the 56 pre-defined configurations. The storage capacity had been found analyzing

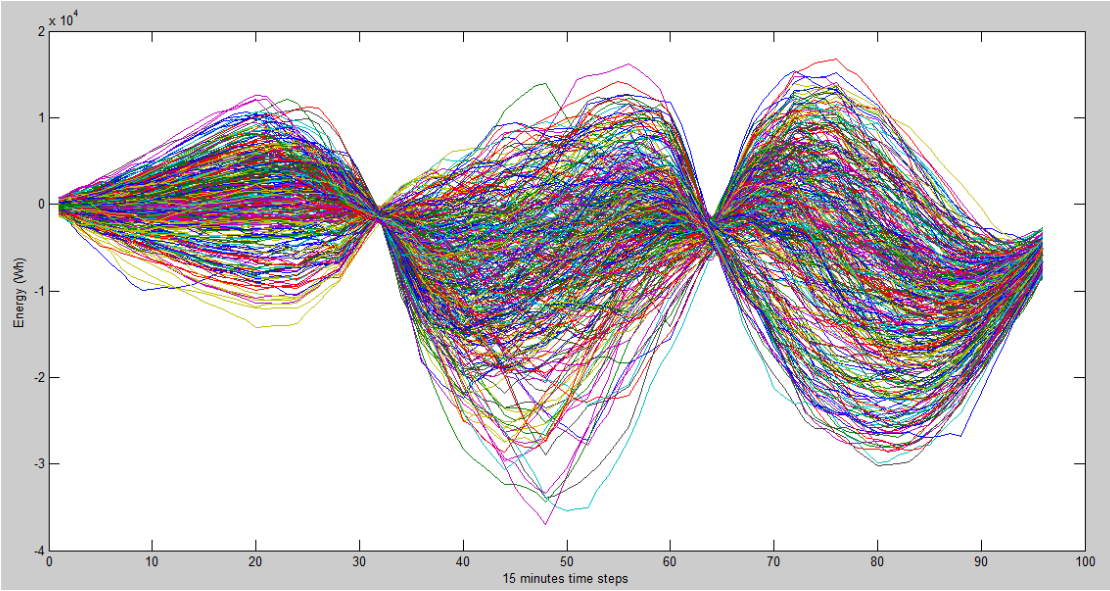


Figure 5.6: Storage profiles aggregated

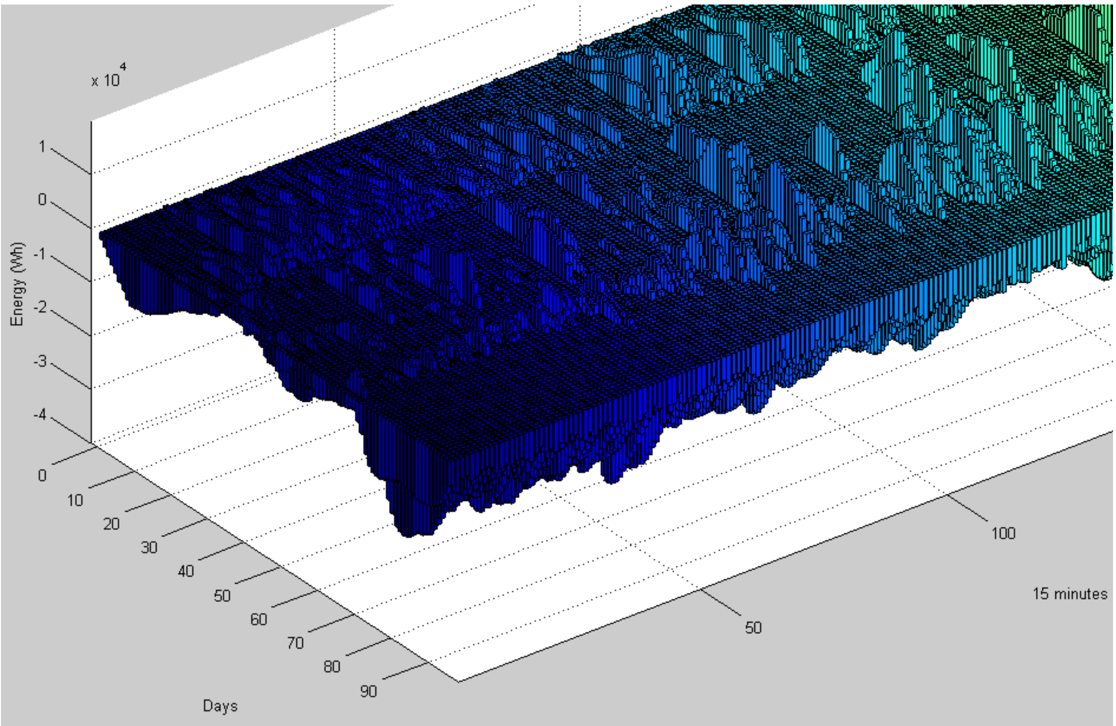


Figure 5.7: Storage profiles aggregated, a partial 3D view

all maximum and minimum storage needs for every time step, found max and min values for both of them in an year and calculated the range between them.

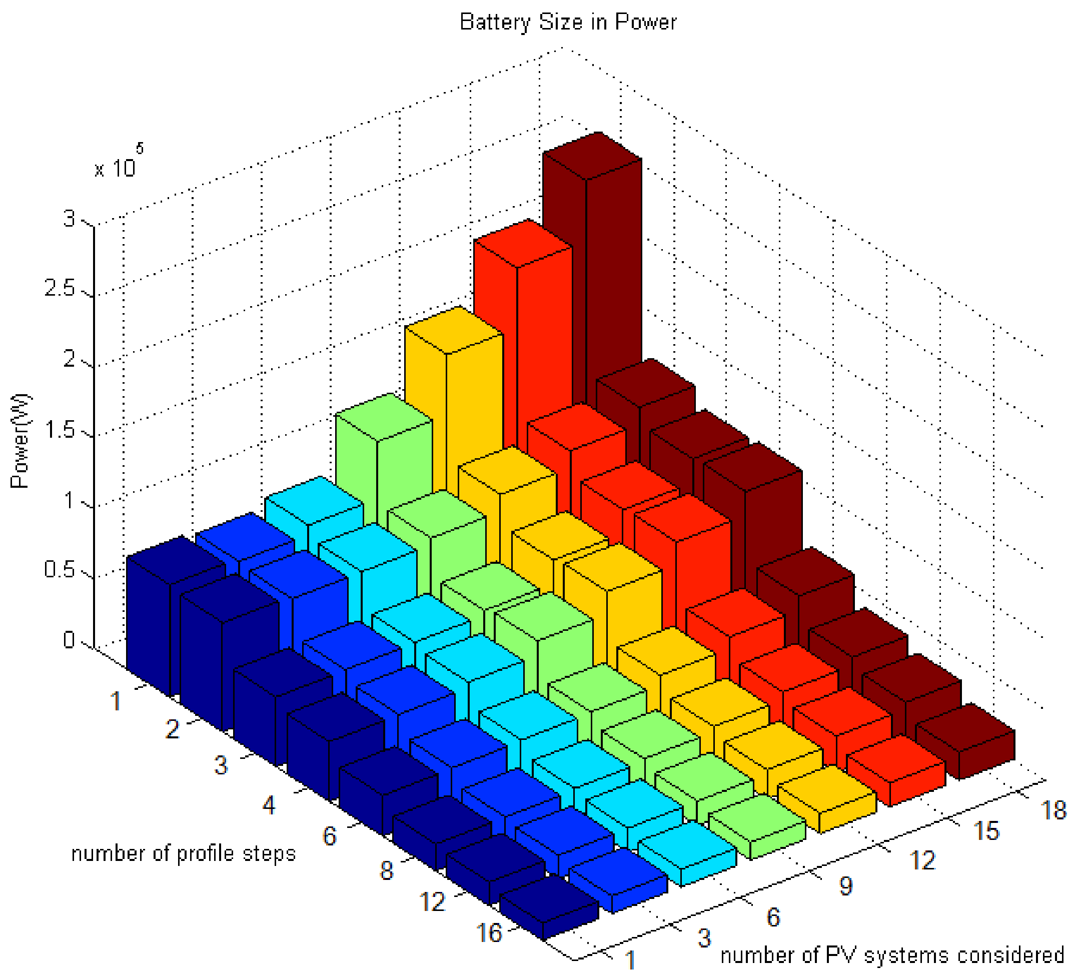


Figure 5.8: Storage Sizing Result

Results take into account that the minimum state of charge (SOC_{min}) is 20% of capacity and the roundtrip efficiency is of storage system is 85% as mentioned before. As could be expected a bigger size is necessary when PV penetration increases. On the other hand a general decreasing trend can be noticed increasing the resolution of the Predictable Profile since it tends to be closer to the real profile without storage (ideally no storage is needed when a resolution of 96 steps is set, because it's the same resolution of the available data). Analyzing numerical results, can be evidenced that with 3 steps and a high level of PV penetration the size is lower than the 4-steps case. This could be explained considering that a better fit of data is made with 3 steps matching the time-area where the solar production is located. With 4 steps this area is divided with more steps and the steep of "Input-Output" variation is bigger. So, for many days occur higher spikes in energy to be stored, resulting in a bigger battery size in the end.

BATTERY SIZE (kW)	1 PV	3 PV	6 PV	9 PV	12 PV	15 PV	18 PV
1 STEP	79,73	77,38	84,25	124,72	167,53	210,33	253,48
2 STEP	77,55	75,58	75,84	80,75	92,82	104,90	116,97
3 STEP	49,37	49,79	50,43	54,11	70,91	87,83	105,09
4 STEP	42,33	42,74	46,69	57,16	73,27	89,39	106,52
6 STEP	28,85	29,47	30,41	31,34	38,39	46,70	56,91
8 STEP	18,93	19,24	20,56	22,76	26,60	32,25	38,10
12 STEP	16,55	16,75	17,06	17,36	20,64	25,68	30,73
16 STEP	12,26	12,39	12,60	12,80	14,35	17,07	20,04

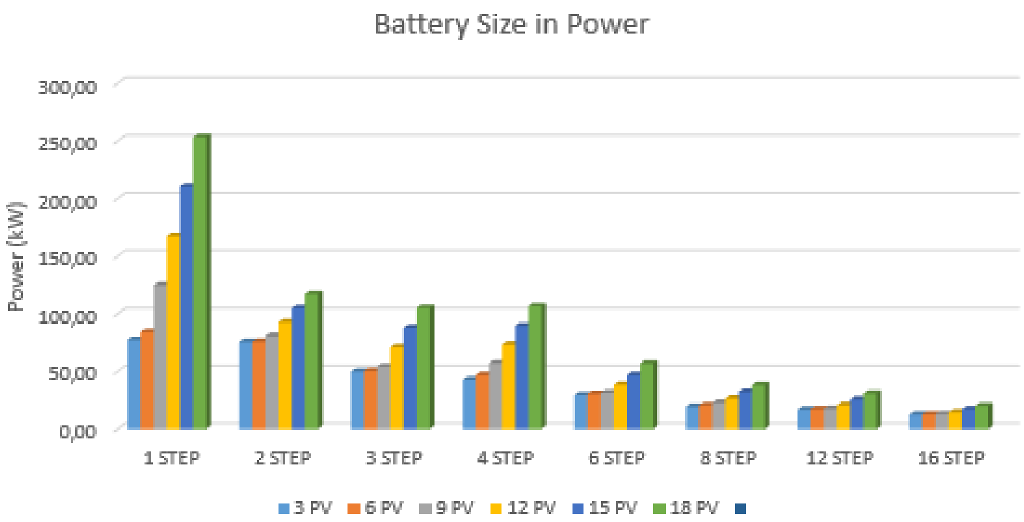


Figure 5.9: Storage Sizing Results

Chapter 6

Cost Benefit Analysis

A cost benefit analysis had been performed to understand if previously storage capacity results could give positive economically performances or not.

6.0.1 Benefits

Benefits are defined as the economic revenue from Inbalance avoidance.

$$Benefit = \sum_{i=0}^{n} \frac{E_{SR} * P_I}{(1+r)^i}$$

where *Benefit* is expressed in [€], E_{SR} is the Energy stored and released to avoid inbalance, P_I is the Inbalance Price, i represent years of system life, r is a discount rate set at 5%, n is the expected number of years of system life. Actually Benefit is computed for positive and negative inbalances considering energy stored and released respectively. The two resulting values are summed to give the whole Benefit.
It can be Levelized considering the whole-life cycled energy calculated as the total amount of energy stored and released during the pre-set number of life years (10 for Li-ion technology and 5 for Lead Acid one). This levelized parameter was called Levelized Benefit (LB)

$$LB = \frac{Benefit}{E_{Cycled}}$$

where LB has [€/kWh] as unit of measurement.

6.0.2 Costs

Costs are mainly represented by Investment costs (here considered only storage system, not PV). Previously found sizes can be evaluated considering different commercial examples in order to have a cost of the system [13].

BATTERY SIZE (kW)	1 PV	3 PV	6 PV	9 PV	12 PV	15 PV	18 PV
1 STEP	79,73	77,38	84,25	124,72	167,53	210,33	253,48
2 STEP	77,55	75,58	75,84	80,75	92,82	104,90	116,97
3 STEP	49,37	49,79	50,43	54,11	70,91	87,83	105,09
4 STEP	42,33	42,74	46,69	57,16	73,27	89,39	106,52
6 STEP	28,85	29,47	30,41	31,34	38,39	46,70	56,91
8 STEP	18,93	19,24	20,56	22,76	26,60	32,25	38,10
12 STEP	16,55	16,75	17,06	17,36	20,64	25,68	30,73
16 STEP	12,26	12,39	12,60	12,80	14,35	17,07	20,04

COMMERCIAL SIZES		UNIT(X1)	UNIT(X2)
	25	25	
	50	50	
	75	50	25
	100	100	
	125	100	25
	200	200	
	250	250	
	275	250	25

PLANT COST (€/kW)	Li-ion	Lead Acid
25 kW	3250,99	2301,72
50 kW	3108,07	2204,676
100 kW	5120,42	4409,352
200 kW	5226,29	4936,039
250 kW	4820,47	

TOTAL PLANT COST (€/kW)	Li-ion	Lead Acid
25kW	81274,8	57543,01
50kW	155404	110233,8
75kW	236678	167776,8
100kW	512042	440935,2
125kW	593317	498478,2
200kW	1045258	987207,8
250kW	1205117	1097442
275kW	1286392	1154985

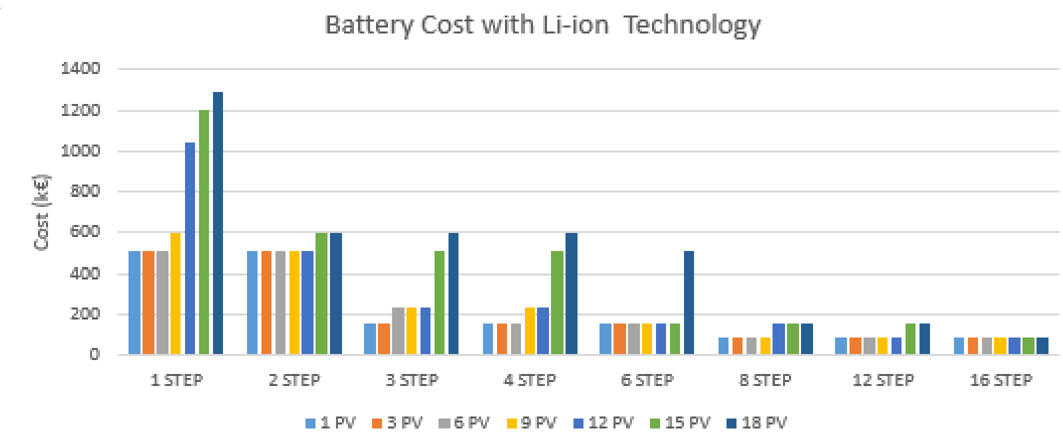
BATTERY SIZE (kW)	1 PV	3 PV	6 PV	9 PV	12 PV	15 PV	18 PV
1 STEP	100,00	100,00	100,00	125,00	200,00	250,00	275,00
2 STEP	100,00	100,00	100,00	100,00	100,00	125,00	125,00
3 STEP	50,00	50,00	75,00	75,00	75,00	100,00	125,00
4 STEP	50,00	50,00	50,00	75,00	75,00	100,00	125,00
6 STEP	50,00	50,00	50,00	50,00	50,00	50,00	100,00
8 STEP	25,00	25,00	25,00	25,00	50,00	50,00	50,00
12 STEP	25,00	25,00	25,00	25,00	25,00	50,00	50,00
16 STEP	25,00	25,00	25,00	25,00	25,00	25,00	25,00

Figure 6.1: Storage System Costs

Considering real commercial examples [13] reported on Appemdix, results can be derived as:

LI-ION							
BATTERY COST (€)	1 PV	3 PV	6 PV	9 PV	12 PV	15 PV	18 PV
1 STEP	512042,35	512042,35	512042,35	593317,16	1045258,05	1205116,89	1286391,71
2 STEP	512042,35	512042,35	512042,35	512042,35	512042,35	593317,16	593317,16
3 STEP	155403,62	155403,62	236678,43	236678,43	236678,43	512042,35	593317,16
4 STEP	155403,62	155403,62	155403,62	236678,43	236678,43	512042,35	593317,16
6 STEP	155403,62	155403,62	155403,62	155403,62	155403,62	155403,62	512042,35
8 STEP	81274,81	81274,81	81274,81	81274,81	155403,62	155403,62	155403,62
12 STEP	81274,81	81274,81	81274,81	81274,81	81274,81	155403,62	155403,62
16 STEP	81274,81	81274,81	81274,81	81274,81	81274,81	81274,81	81274,81

LEAD							
BATTERY COST (€)	1 PV	3 PV	6 PV	9 PV	12 PV	15 PV	18 PV
1 STEP	440935,16	440935,16	440935,16	498478,16	987207,76	1097441,55	1154984,56
2 STEP	440935,16	440935,16	440935,16	440935,16	440935,16	498478,16	498478,16
3 STEP	110233,79	110233,79	167776,80	167776,80	167776,80	440935,16	498478,16
4 STEP	110233,79	110233,79	110233,79	167776,80	167776,80	440935,16	498478,16
6 STEP	110233,79	110233,79	110233,79	110233,79	110233,79	110233,79	440935,16
8 STEP	57543,01	57543,01	57543,01	57543,01	110233,79	110233,79	110233,79
12 STEP	57543,01	57543,01	57543,01	57543,01	57543,01	110233,79	110233,79
16 STEP	57543,01	57543,01	57543,01	57543,01	57543,01	57543,01	57543,01



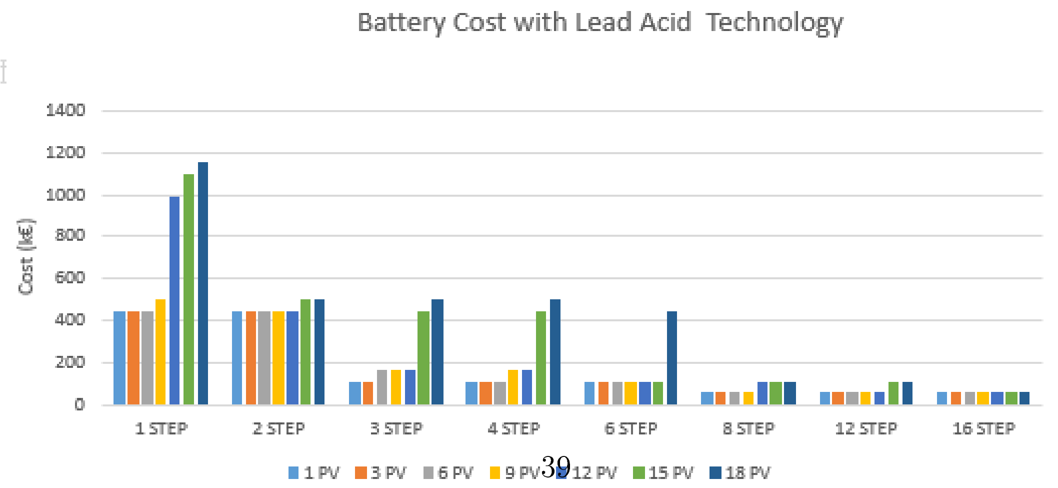


Figure 6.2: Investment Costs with Li-ion and Lead Acid technology

The cost difference is here evidenced:

A levelized investment cost (LCI) of Energy is defined as investment cost divided by cycled energy over life-time::

$$LCI = \frac{I}{E_{Cycled}}$$

LCI is expressed in [€/kWh] It is to be noticed that for Lead Acid Batteries 5 years of life are considered (instead of 10 for Li-ion)

Levelized costs of energy (LCOE) are obtained as:

$$LCOE_{Li-Ion} = LB - LCI_{Li-Ion}$$

$$LCOE_{LeadAcid} = LB - LCI_{LeadAcid}$$

LCOE are expressed in [€/kWh]

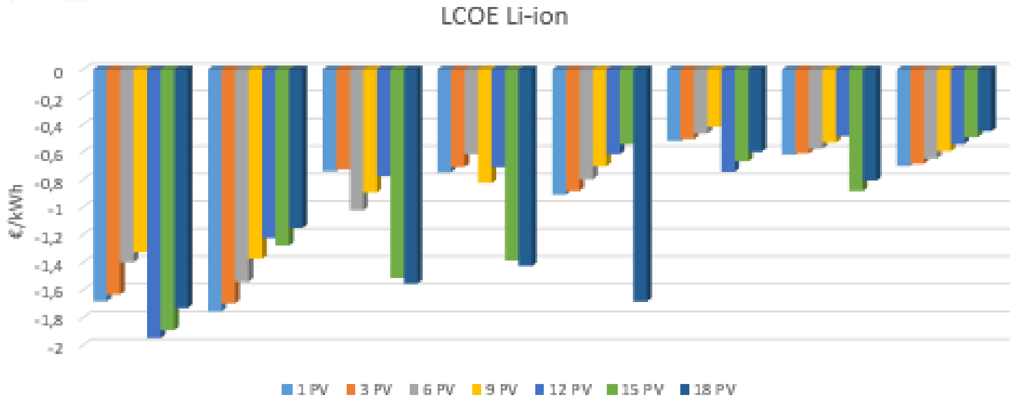
They can be seen graphically as:

These results state that this service is unprofitable because the LCOE is almost two times bigger than the average retail energy price. As will be suggested in the conclusions, several interventions need to be done, like lowering battery cost, better remuneration for this service and integration with other grid services.

6.1 The Italian Case Study

The same simulation had been ran for an Italian scenario. To have comparable results Load Profiles were the same as before with adoption of Italian irraiation data and Italian market Prices. Since during the overall year more energy has to be managed, it's possible to notice that battery size has bigger values in general, maintaining the previous trends in terms of PV penetration and Predictable Profile Resolution.

LCOE Li-ion €/kWh	1 PV	3 PV	6 PV	9 PV	12 PV	15 PV	18 PV
1 STEP	-1,683	-1,634	-1,399	-1,327	-1,949	-1,892	-1,732
2 STEP	-1,757	-1,698	-1,54	-1,374	-1,224	-1,277	-1,151
3 STEP	-0,74	-0,725	-1,022	-0,893	-0,776	-1,513	-1,555
4 STEP	-0,746	-0,707	-0,616	-0,824	-0,71	-1,387	-1,427
6 STEP	-0,91	-0,883	-0,798	-0,702	-0,615	-0,543	-1,684
8 STEP	-0,52	-0,505	-0,464	-0,415	-0,743	-0,666	-0,599
12 STEP	-0,62	-0,61	-0,576	-0,531	-0,485	-0,882	-0,806
16 STEP	-0,699	-0,686	-0,646	-0,594	-0,542	-0,493	-0,449



LCOE Lead €/kWh	1 PV	3 PV	6 PV	9 PV	12 PV	15 PV	18 PV
1 STEP	-2,93	-2,846	-2,44	-2,258	-3,717	-3,478	-3,142
2 STEP	-3,058	-2,956	-2,683	-2,397	-2,139	-2,175	-1,963
3 STEP	-1,068	-1,046	-1,467	-1,285	-1,117	-2,636	-2,641
4 STEP	-1,077	-1,021	-0,892	-1,186	-1,024	-2,419	-2,427
6 STEP	-1,309	-1,271	-1,15	-1,013	-0,891	-0,787	-2,93
8 STEP	-0,754	-0,733	-0,675	-0,606	-1,072	-0,962	-0,867
12 STEP	-0,896	-0,882	-0,833	-0,769	-0,704	-1,268	-1,16
16 STEP	-1,008	-0,989	-0,932	-0,859	-0,785	-0,715	-0,653

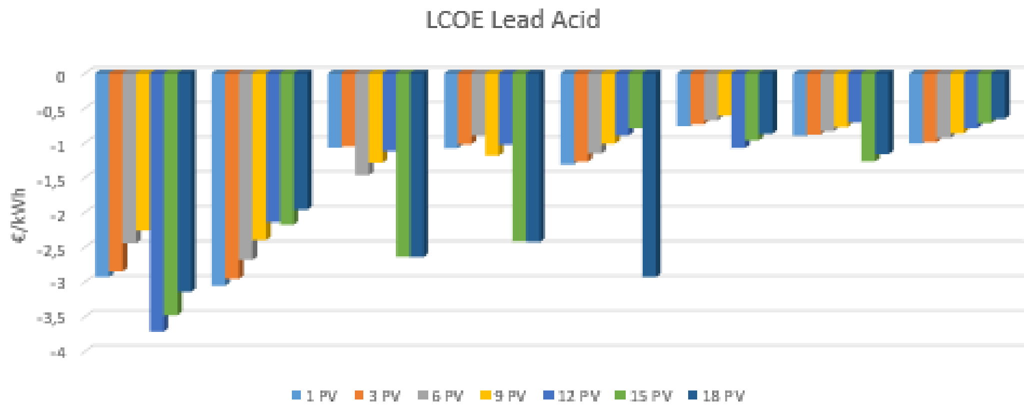


Figure 6.3: Levelized cost of Energy after Cost Benefit Analysis

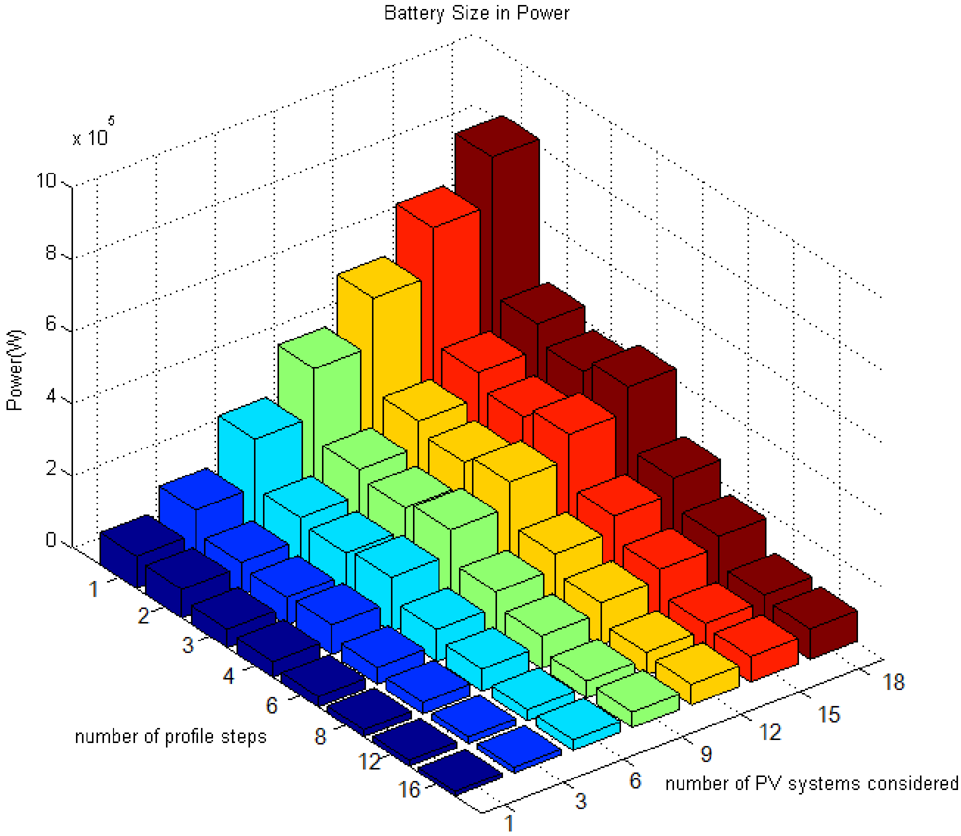


Figure 6.4: Storage Sizing Result

BATTERY SIZE (kW)	1 PV	3 PV	6 PV	9 PV	12 PV	15 PV	18 PV
1 STEP	86,65	128,67	221,31	327,33	433,35	539,38	645,56
2 STEP	80,82	104,78	144,44	184,72	231,25	290,48	349,79
3 STEP	49,21	53,80	86,91	134,01	181,22	228,43	275,65
4 STEP	42,47	62,24	108,96	162,07	219,44	276,92	334,40
6 STEP	28,57	31,44	66,38	101,33	136,27	171,22	206,17
8 STEP	18,91	22,82	45,41	69,49	93,56	117,64	141,71
12 STEP	16,46	16,49	28,04	40,20	52,36	64,61	77,29
16 STEP	12,19	12,61	23,68	34,75	45,83	56,90	67,98

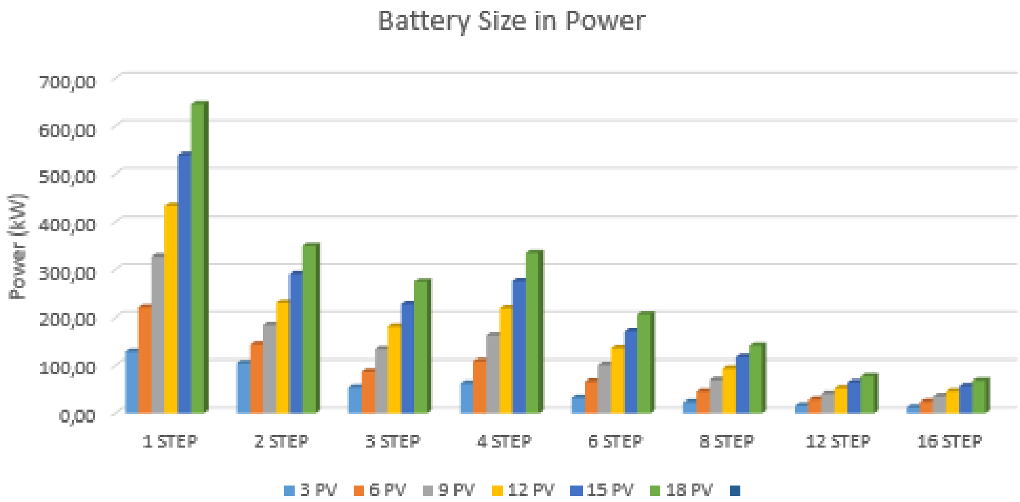


Figure 6.5: Storage Sizing Result

The difference between the dutch case study is due to a greater irradiance level during the entire year so mismatches between profile steps can occur resulting in a bigger need of storage in the end.

Matching results with commercial battery sizes (the same considered before) and battery investment costs we obtain these results.

BATTERY SIZE (kW)	1 PV	3 PV	6 PV	9 PV	12 PV	15 PV	18 PV
1 STEP	86,65	128,67	221,31	327,33	433,35	539,38	645,56
2 STEP	80,82	104,78	144,44	184,72	231,25	290,48	349,79
3 STEP	49,21	53,80	86,91	134,01	181,22	228,43	275,65
4 STEP	42,47	62,24	108,96	162,07	219,44	276,92	334,40
6 STEP	28,57	31,44	66,38	101,33	136,27	171,22	206,17
8 STEP	18,91	22,82	45,41	69,49	93,56	117,64	141,71
12 STEP	16,46	16,49	28,04	40,20	52,36	64,61	77,29
16 STEP	12,19	12,61	23,68	34,75	45,83	56,90	67,98

COMMERCIAL SIZES		UNIT(X1)	UNIT(X2)
	25	25	
	50	50	
	75	50	25
	100	100	
	125	100	25
	150	100	50
	200	200	
	250	250	
	300	200	100
	400	200	200
	550	500	50
	700	500	200

PLANT COST (€/kW)	Li-ion	Lead Acid
25 kW	3250,99	2301,72
50 kW	3108,07	2204,676
100 kW	5120,42	4409,352
200 kW	5226,29	4936,039
250 kW	4820,47	
500 kW	2676,67	

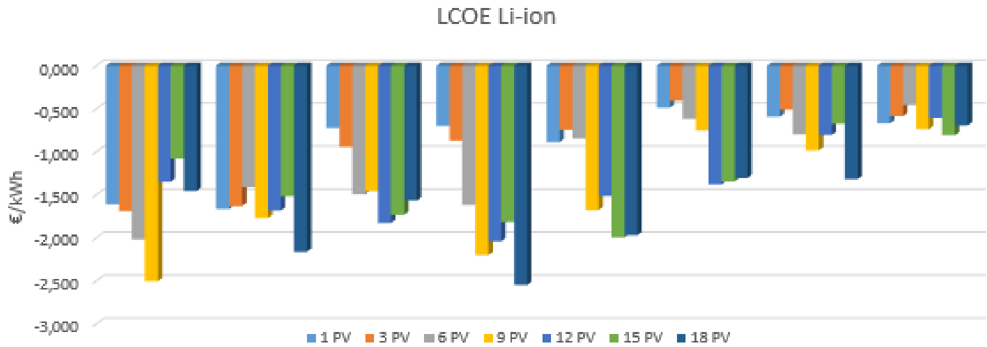
TOTAL PLANT COST (€/kW)	Li-ion	Lead Acid
25kW	81274,8	57543,01
50kW	155404	110233,8
75kW	236678	167776,8
100kW	512042	440935,2
125kW	593317	498478,2
150 kW	667446	551168,9
200kW	1045258	987207,8
250kW	1205117	1097442
300 kW	1286392	1154985
400 kW	2090516	1974416
550 kW	1493736	2525584
700 kW	2383591	3129400

BATTERY SIZE (kW)	1 PV	3 PV	6 PV	9 PV	12 PV	15 PV	18 PV
1 STEP	100	150	250	400	550	550	700
2 STEP	100	125	150	200	250	300	400
3 STEP	50	75	100	150	200	250	300
4 STEP	50	75	125	200	250	300	400
6 STEP	50	50	75	125	150	200	250
8 STEP	25	25	50	75	100	125	150
12 STEP	25	25	50	75	75	75	100
16 STEP	25	25	25	50	50	75	75

Figure 6.6: Storage Sizing Results

With the next charts LCOE for Li-ion and Lead Acid Technologies are evidenced

LCOE Li-Ion (€/kWh)	1 PV	3 PV	6 PV	9 PV	12 PV	15 PV	18 PV
1 STEP	-1,609	-1,688	-2,018	-2,503	-1,346	-1,076	-1,456
2 STEP	-1,663	-1,629	-1,405	-1,769	-1,682	-1,518	-2,162
3 STEP	-0,723	-0,943	-1,491	-1,458	-1,824	-1,731	-1,563
4 STEP	-0,698	-0,869	-1,616	-2,202	-2,040	-1,812	-2,549
6 STEP	-0,885	-0,744	-0,842	-1,678	-1,514	-1,995	-1,968
8 STEP	-0,488	-0,406	-0,617	-0,751	-1,376	-1,343	-1,302
12 STEP	-0,590	-0,509	-0,794	-0,984	-0,803	-0,672	-1,315
16 STEP	-0,668	-0,584	-0,453	-0,737	-0,605	-0,805	-0,693



LCOE Lead (€/kWh)	1 PV	3 PV	6 PV	9 PV	12 PV	15 PV	18 PV
1 STEP	-2,624	-2,455	-3,303	-4,366	-4,359	-3,548	-3,709
2 STEP	-3,061	-3,047	-2,579	-3,654	-3,303	-2,912	-4,309
3 STEP	-0,953	-1,145	-2,208	-2,113	-3,081	-2,858	-2,575
4 STEP	-1,045	-1,320	-2,877	-4,343	-3,846	-3,348	-4,909
6 STEP	-1,215	-0,980	-1,105	-2,633	-2,359	-3,580	-3,423
8 STEP	-0,709	-0,591	-0,886	-1,071	-2,371	-2,254	-2,146
12 STEP	-0,848	-0,725	-1,115	-1,373	-1,125	-0,947	-2,237
16 STEP	-0,962	-0,835	-0,649	-1,042	-0,858	-1,134	-0,979

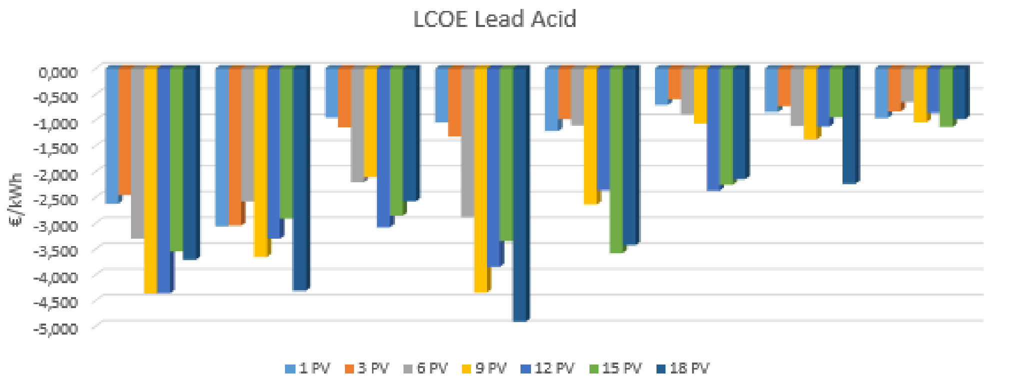


Figure 6.7: LCOE with Li-ion and Lead Acid technology

Also with the italian case are present negative economic results and it's possible to notice that the best configuration shifted to 3PV and 8 step resoultion instead of 9PV and 8 step resolution with dutch scenario. This is due to the bigger ittadiation levl that set the best performance with a lower level of PV penetration. In order to understand this results is here showed the influence of LBOE and LCI on LCOE[1]. It's clear that investment cost is generally from 8 times to more than one order of magnitude bigger than the revenues obtained by participating the Balancing market and this is unacceptable for an economically sustainable implementation of this service.

LBOE (€/kWh)	1 PV	3 PV	6 PV	9 PV	12 PV	15 PV	18 PV
1 STEP	0,0545	0,0550	0,0554	0,0555	0,0555	0,0555	0,0555
2 STEP	0,0545	0,0554	0,0567	0,0576	0,0581	0,0585	0,0588
3 STEP	0,0597	0,0593	0,0593	0,0593	0,0594	0,0594	0,0594
4 STEP	0,0592	0,0599	0,0607	0,0611	0,0613	0,0615	0,0616
6 STEP	0,0601	0,0602	0,0604	0,0605	0,0606	0,0606	0,0607
8 STEP	0,0598	0,0601	0,0605	0,0607	0,0609	0,0610	0,0611
12 STEP	0,0602	0,0606	0,0611	0,0614	0,0617	0,0618	0,0620
16 STEP	0,0607	0,0609	0,0612	0,0615	0,0616	0,0618	0,0619

LCI LI-ion (€/kWh)	1 PV	3 PV	6 PV	9 PV	12 PV	15 PV	18 PV
1 STEP	1,663	1,743	2,074	2,559	1,402	1,132	1,511
2 STEP	1,717	1,685	1,462	1,827	1,740	1,576	2,221
3 STEP	0,783	1,002	1,550	1,517	1,884	1,791	1,623
4 STEP	0,757	0,929	1,677	2,263	2,101	1,873	2,610
6 STEP	0,946	0,805	0,902	1,738	1,574	2,056	2,029
8 STEP	0,548	0,466	0,677	0,812	1,437	1,404	1,363
12 STEP	0,650	0,570	0,855	1,045	0,864	0,734	1,377
16 STEP	0,729	0,645	0,515	0,799	0,666	0,866	0,754

Figure 6.8: Battery LCI and LBOE comparison

Since the economic results are stronlgy influenced by investment cost,which is directly linked to battery size (function of peak energy stored and released over time) this means that with the italian case study, where greater values of irradiation are present the mismatch between energy-consumption moments and energy-exporting ones is bigger. Consequently, since the predictable profile is defined as the average of "Input-Output" energy values the range between lowest and highest values is bigger, resulting in a bigger storage size. An other difference between the dutch and the italian LCOE results is that in the dutch case it that best value is with 9 connected PV systems and in the italian with 3 (both of them with 8 time steps). This could be still related to the bigger irradiance for the italian case study having the best performance with a lower level of PV penetration. The fact that LCOE is quite similar for both case studies can be explained considering that Italian Balancing market is more rewarding than the dutch one, especially during "selling time" (average values around 150 €/MWh instead of 30-40 €/MWh). This counterbalance bigger investment costs for the italian scenario.

[1]here Li-ion technology, but with Lead Acid the result is not so different

6.2 Conclusions

An overview of Community Energy Storage (CES) available technologies, service possibilities and examples had been done. The Predictable Profile Service for CES had been studied in more detail in order to define a proper sizing of storage required for different possible configurations (1,3,6,9,12,15,18 PV system connected and 1,2,3,4,6,8,12,16 profile steps). A cost and benefit analysis (considering balancing market participation and investment costs) for all different configurations had been performed. A Matlab tool had been developed to run simulations with a detail degree of 15 minutes for an entire year of available data and these conclusions can be achieved:

- Required dimensions can be reached with commercially available storage batteries considering LI-ion and Lead Acid Technology
- The Predictable Profile service is per-se unprofitable and need to be linked to other storage services, like peak shaving and load shifting for better economic performances
- The storage system investment cost, for both considered technologies (Li-ion and Lead Acid) is dominant and need to be decreased by at least the 50% in order to compete with nowadays energy prices. Positive signals are given by an intersting decreasing trend in cost especially for Li-ion technology and the previuos statement could be reached between 2020 and 2025 [2].
- Simulating the entire year with a pre-difined time range for a specific profile resolution can lead to an over dimensioning of the storage because, especially during summer mornings and evenings, the sun rise earlier and set later compared to winter time. This leads to a strong mismatch between the predicted profile and the real one resulting in a bigger amount of energy to be stored and released, creating peaks in storage requirements. To gain better results, personalized profiles for different moments of the year could be studied
- Since these kind of services will be needed more and more in the future to allow renewable energy systems integration, a properly redefined remuneration system must be studied and adopted to guarantee their economical sustainability

[2]These studies were based on historical data so a certain degree of uncertainity occurs when forecasts becomes unavoidable for real time operations, this could decrease even more economic performances if we consider that unbalances must be paid

Chapter 7

APPENDIX

Storage Profiles for dutch case are he reported in order to show Storage behaviour required to perform Predictable Profile service for all the previuosly defined configurations:

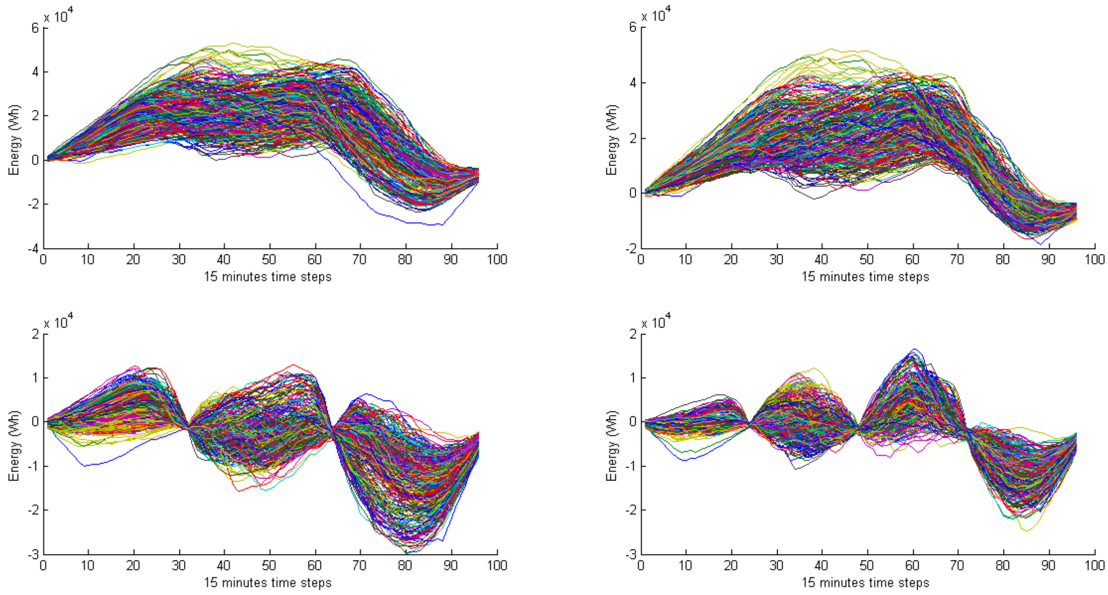


Figure 7.1: Storage Profiles with different Predictable Profile resolutions with 1 PV connected

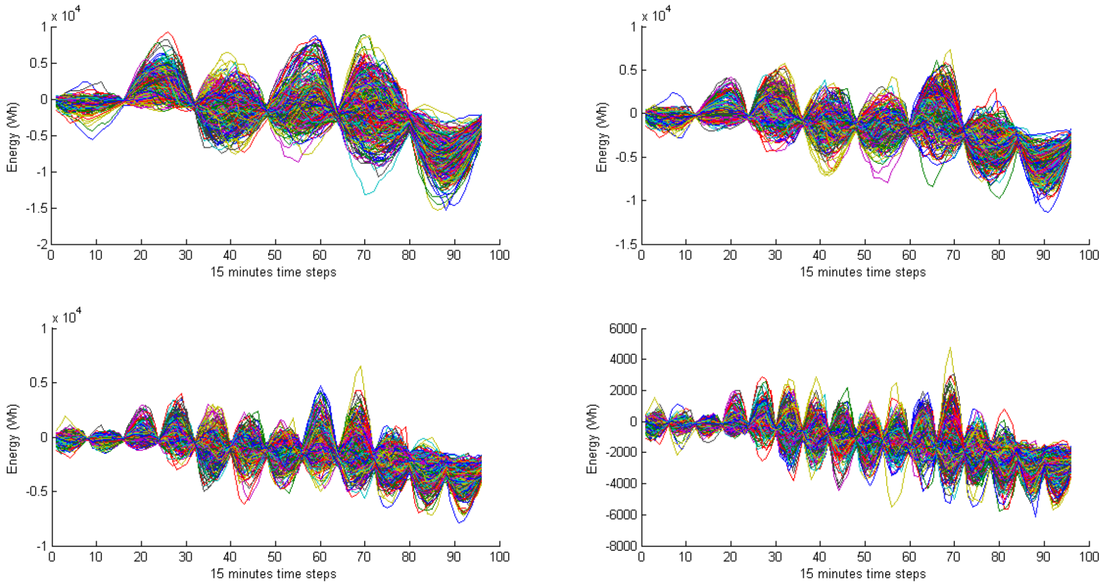


Figure 7.2: Storage Profiles with different Predictable Profile resolutions with 1 PV connected

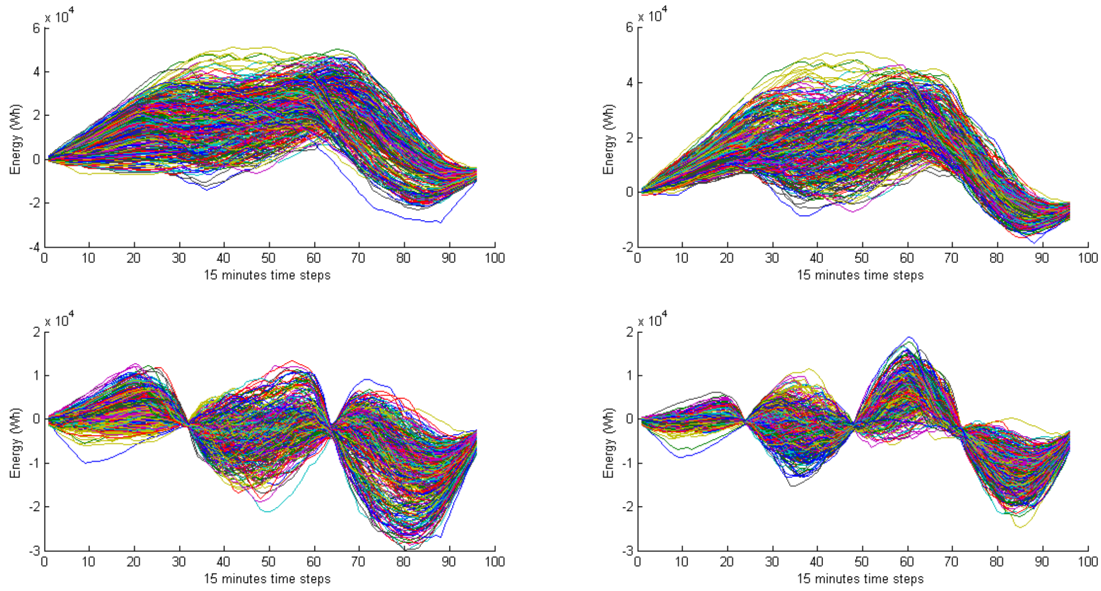


Figure 7.3: Storage Profiles with different Predictable Profile resolutions with 3 PV connected

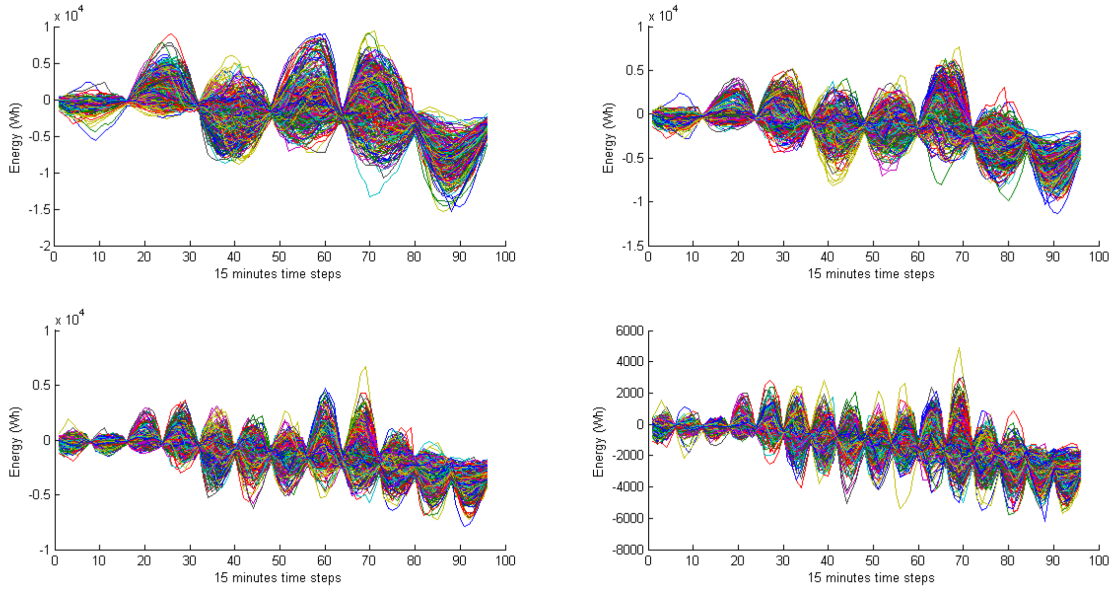


Figure 7.4: Storage Profiles with different Predictable Profile resolutions with 3 PV connected

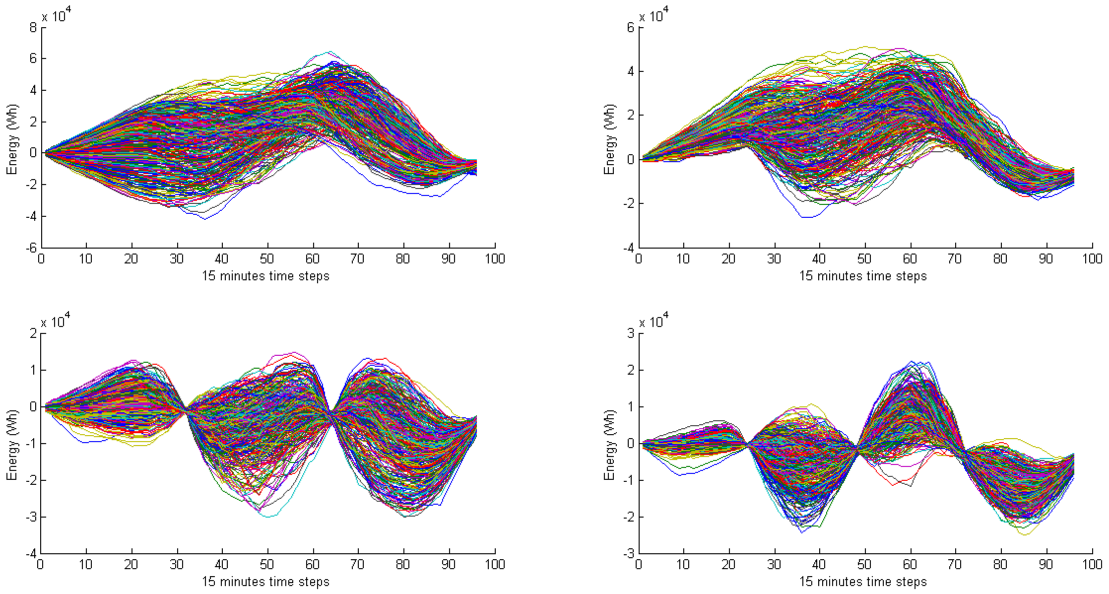


Figure 7.5: Storage Profiles with different Predictable Profile resolutions with 6 PV connected

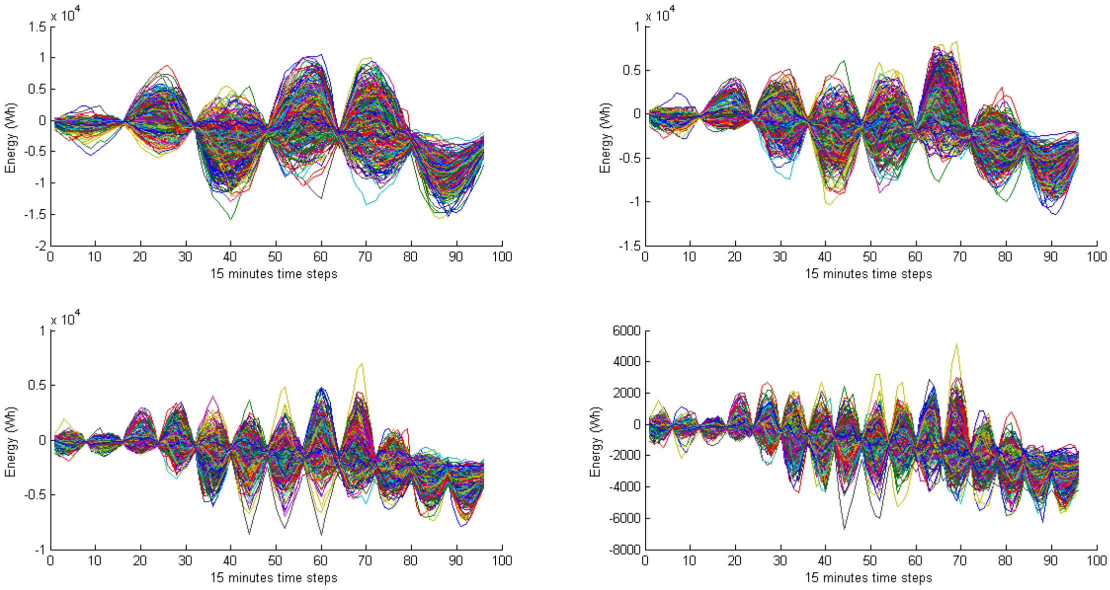


Figure 7.6: Storage Profiles with different Predictable Profile resolutions with 6 PV connected

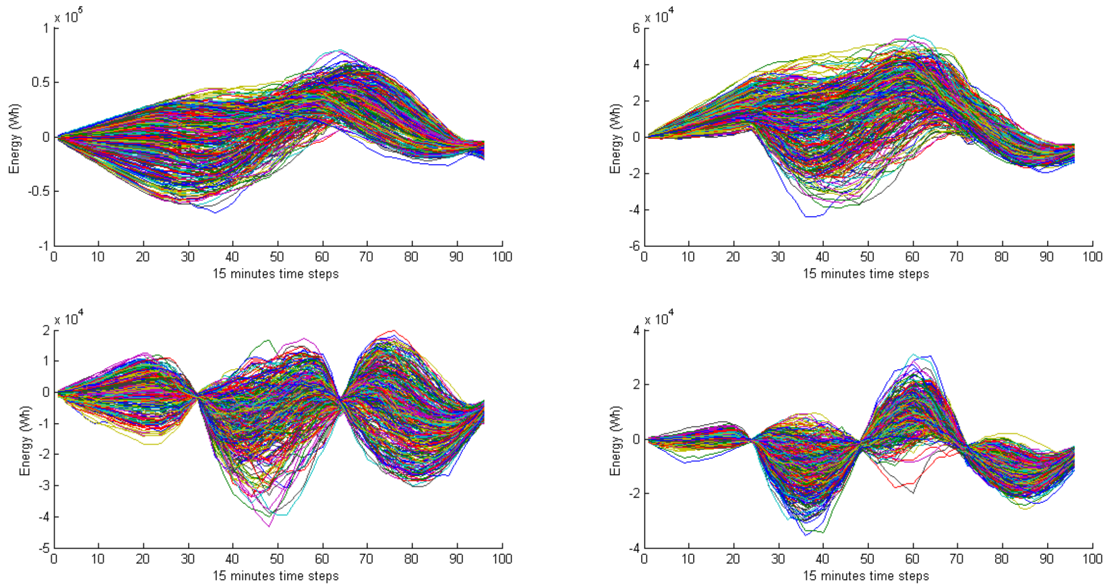


Figure 7.7: Storage Profiles with different Predictable Profile resolutions with 9 PV connected

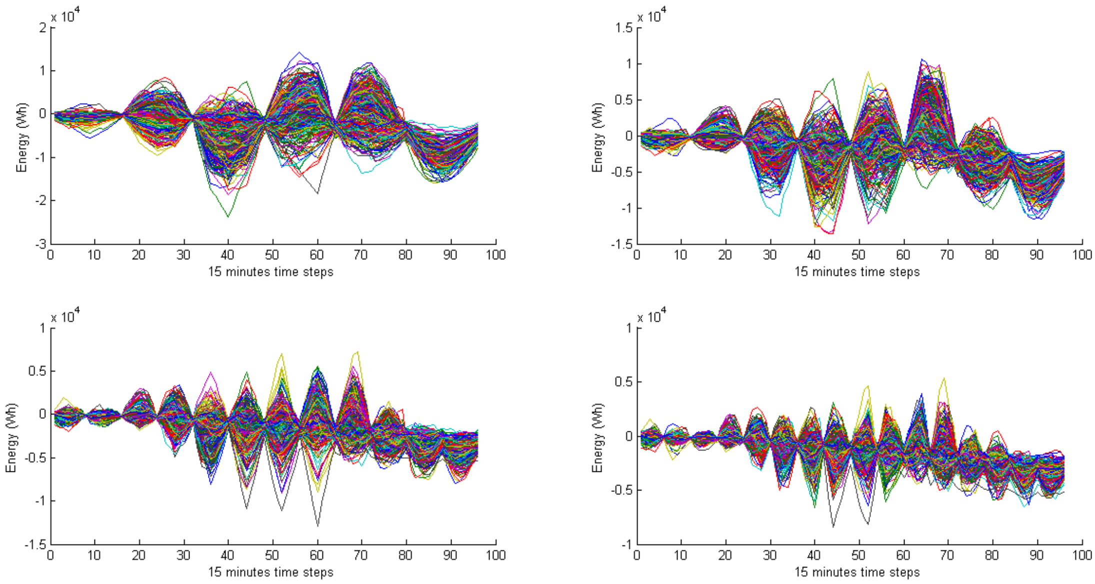


Figure 7.8: Storage Profiles with different Predictable Profile resolutions with 9 PV connected

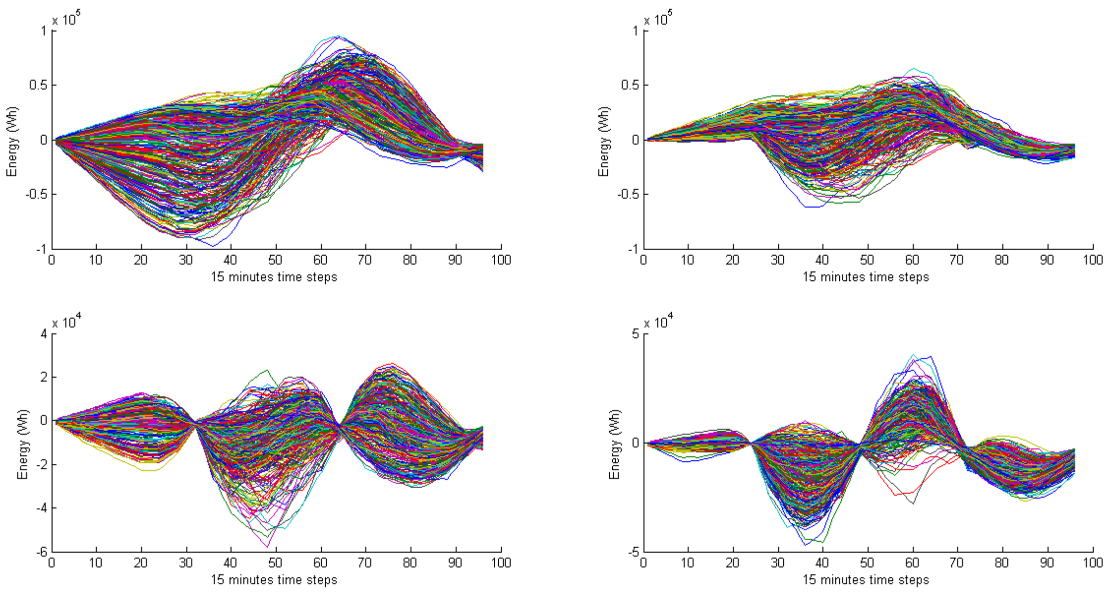


Figure 7.9: Storage Profiles with different Predictable Profile resolutions with 12 PV connected

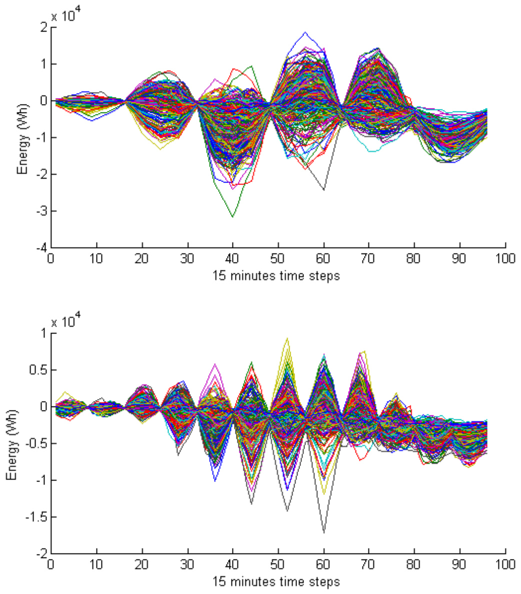


Figure 7.10: Storage Profiles with different Predictable Profile resolutions with 12 PV connected

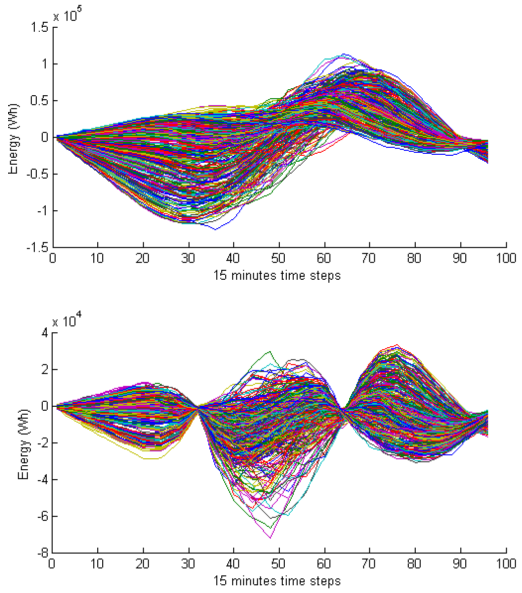


Figure 7.11: Storage Profiles with different Predictable Profile resolutions with 15 PV connected

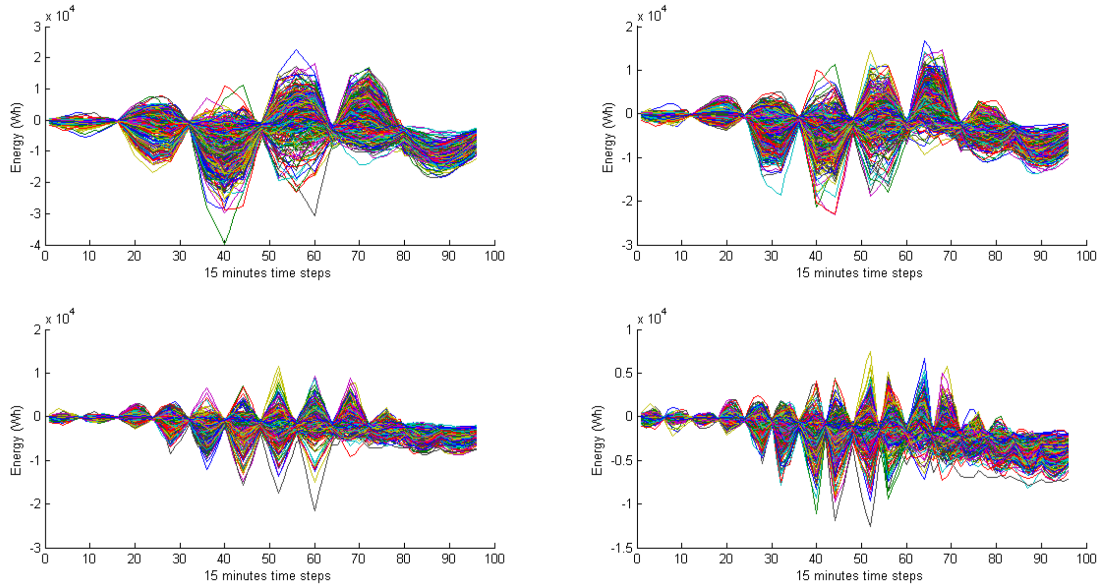


Figure 7.12: Storage Profiles with different Predictable Profile resolutions with 15 PV connected

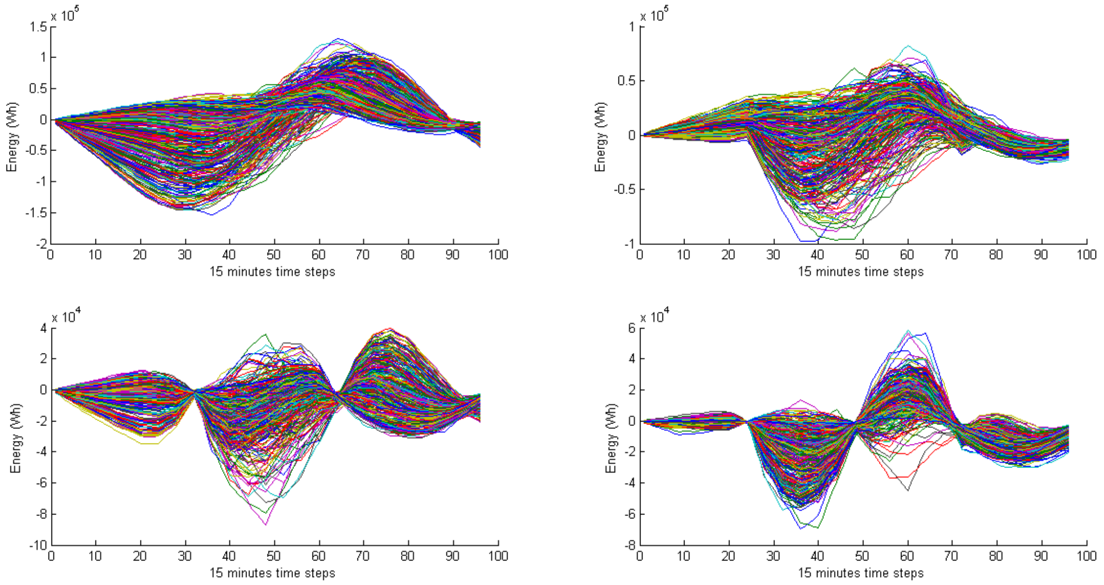


Figure 7.13: Storage Profiles with different Predictable Profile resolutions with 18 PV connected

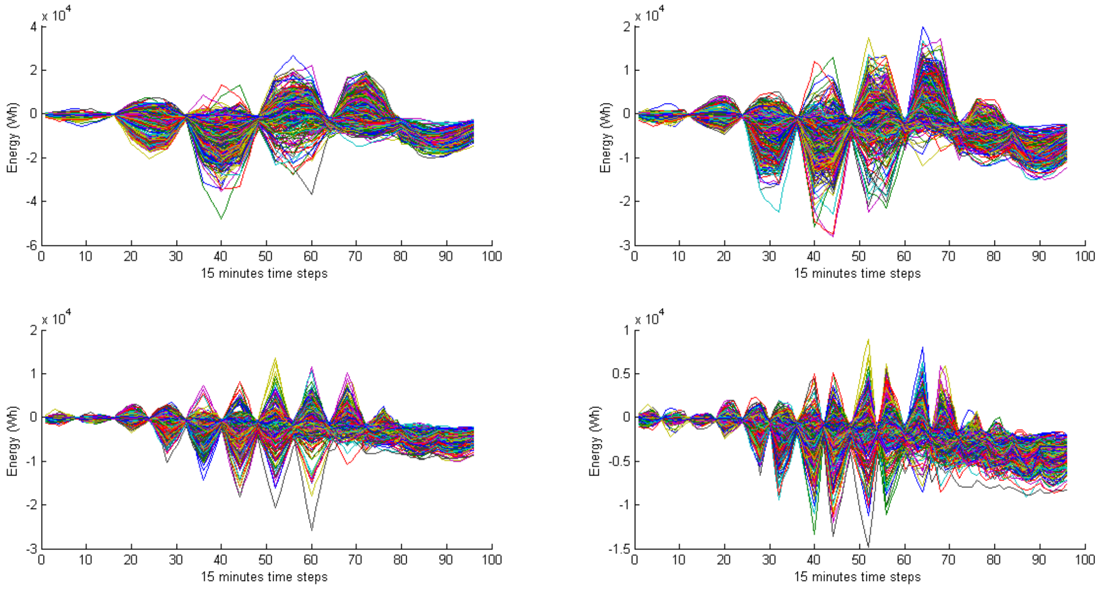
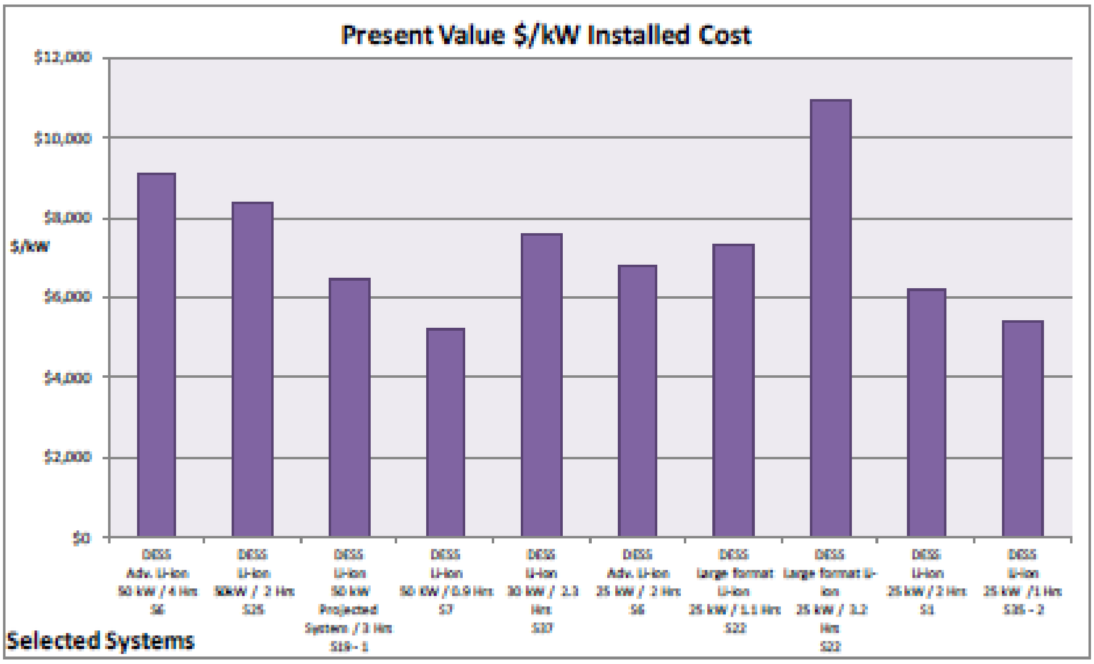


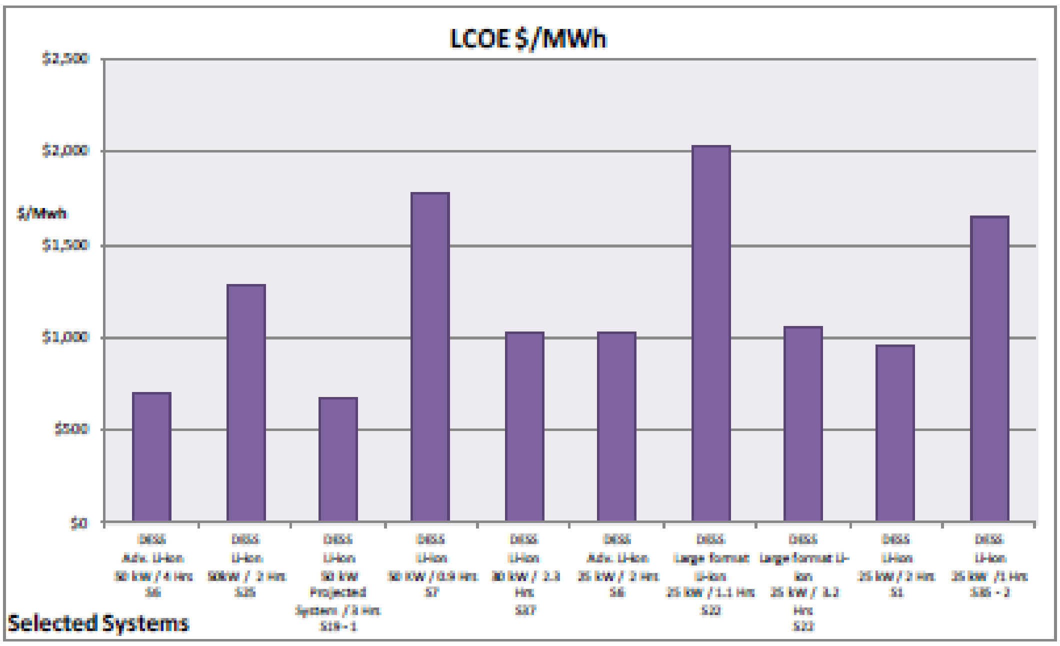
Figure 7.14: Storage Profiles with different Predictable Profile resolutions with 18 PV connected

Commercial Data used for storage system cost definition



Present Value Installed Cost in $/kW for Li-ion Batteries in Distribute Energy Storage System Applications

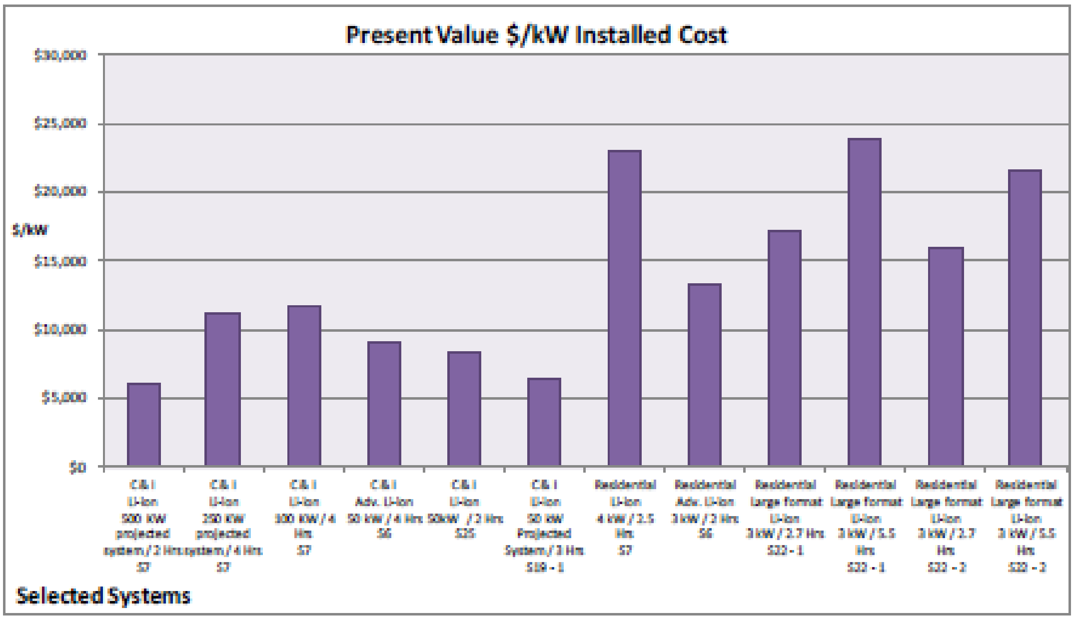
(The S designation under each bar is a vendor code that masks the identity of the vendor.)



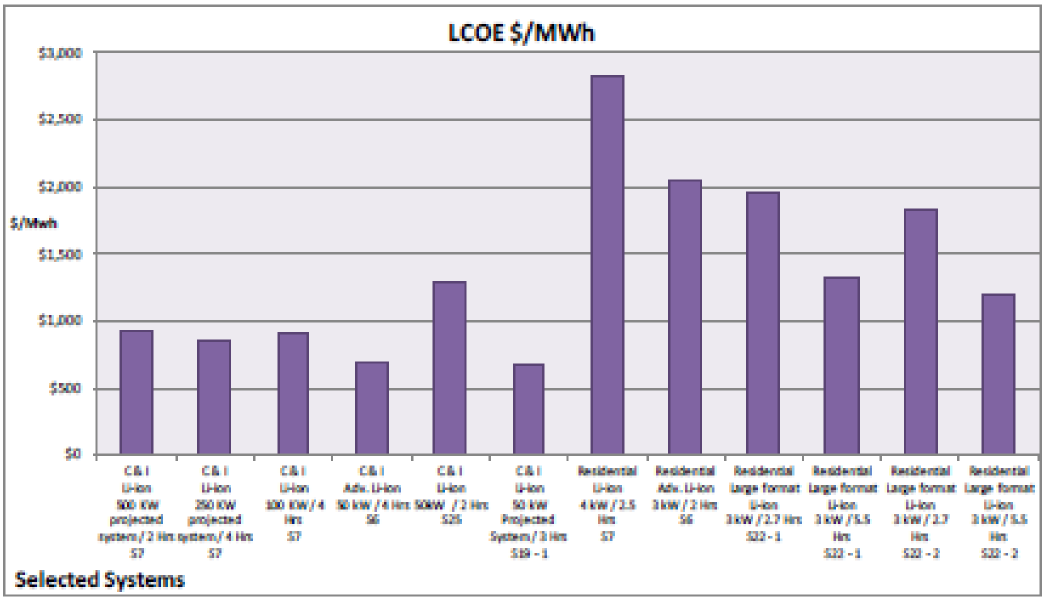
. **LCOE in $/MWh for Li-ion Batteries in Distribute Energy Storage System Applications**

(The S designation under each bar is a vendor code that masks the identity of the vendor.)

Figure 7.15: Cost and LCOE for Li-Ion Battery for Distributed Energy Storage Systems (DESS) applications "



Present Value Installed Cost in $/kW for Li-ion Batteries in Commercial and Industrial Applications
(The S designation under each bar is a vendor code that masks the identity of the vendor.)



LCOE in $/MWh for Li-ion Batteries in Commercial and Industrial Applications
(The S designation under each bar is a vendor code that masks the identity of the vendor.)

Figure 7.16: Cost and LCOE for Li-Ion Battery for Commercial and Industry applications

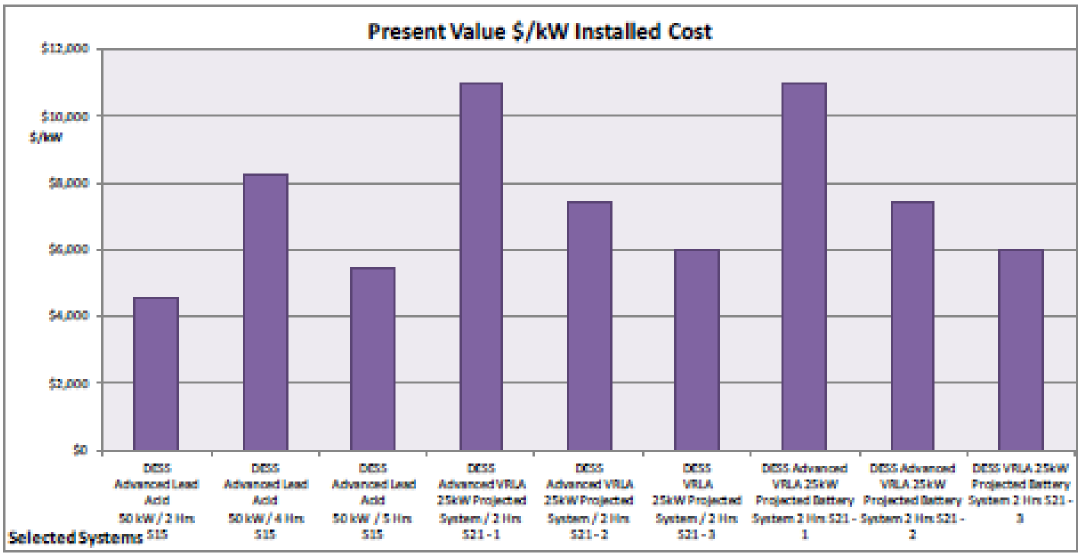


Figure 83. Present Value Installed Cost and Levelized Costs in $/MWh and $/kW-yr for Lead-acid Batteries in Distributed Energy Storage System Applications
(The S designation under each bar is a vendor code that masks the identity of the vendor.)

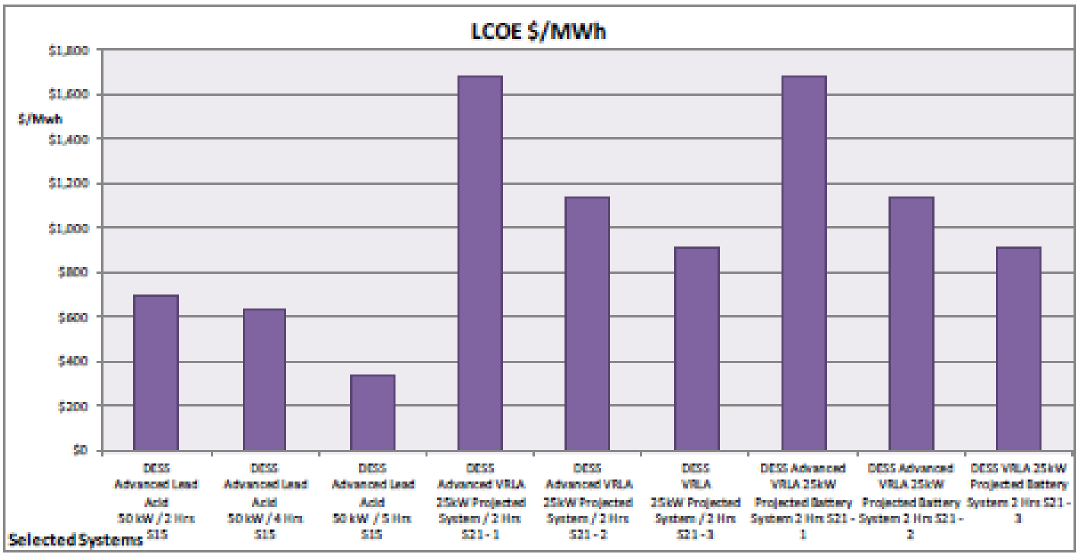
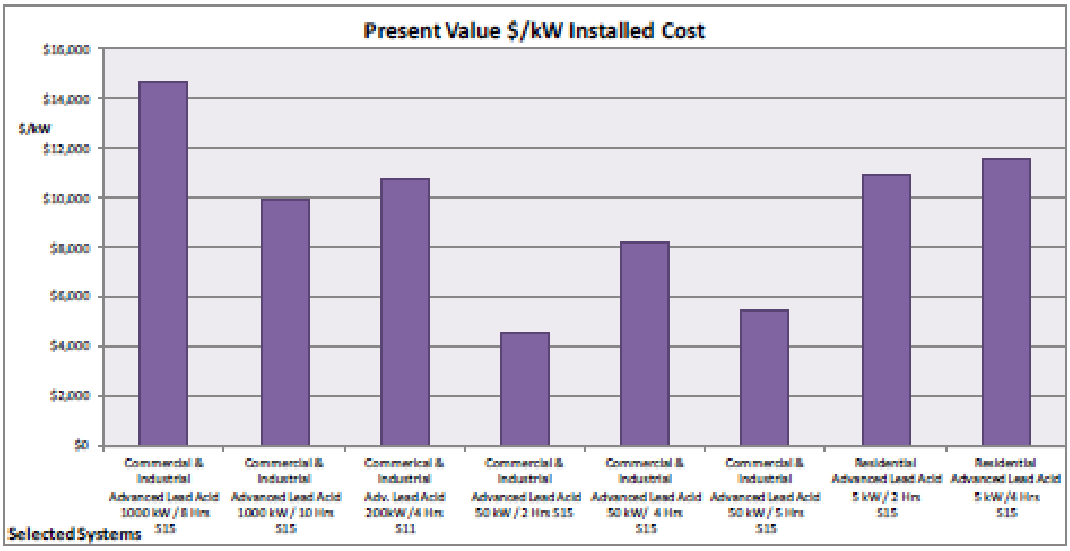
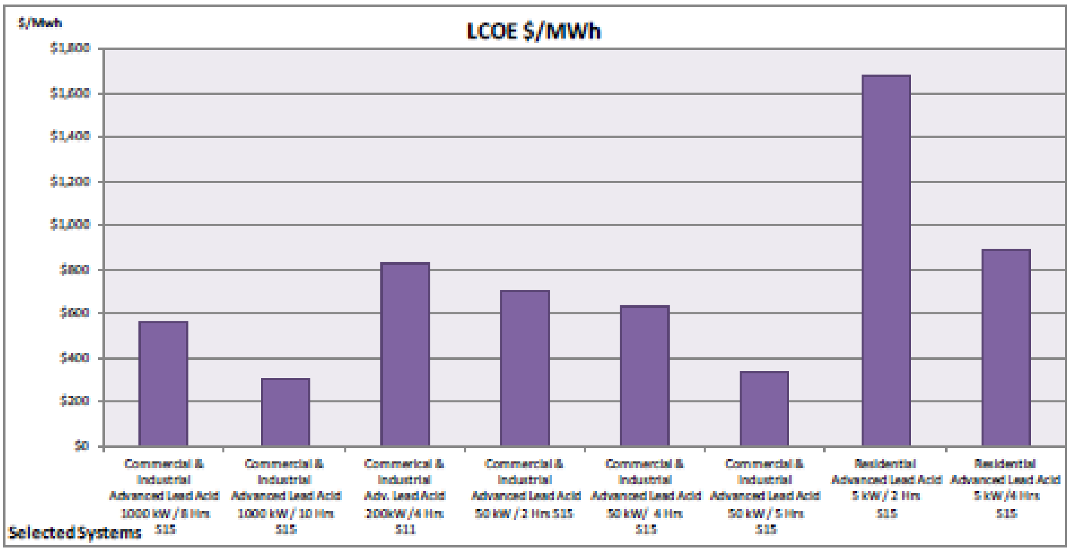


Figure 84. Present Value Installed Cost and Levelized Costs in $/MWh and $/kW-yr for Lead-acid Batteries in Distributed Energy Storage System Applications
(The S designation under each bar is a vendor code that masks the identity of the vendor.)

Figure 7.17: Costs of Lead Acid Battery for Distributed Energy Storage Systems



Present Value Installed Cost and Levelized Costs
in $/MWh and $/kW-yr for Lead-acid Batteries in Commercial and Industrial Applications
(The S designation under each bar is a vendor code that masks the identity of the vendor.)



Present Value Installed Cost and Levelized Costs
in $/MWh and $/kW-yr for Lead-acid Batteries in Commercial and Industrial Applications
(The S designation under each bar is a vendor code that masks the identity of the vendor.)

Figure 7.18: Costs of Lead Acid Battery for Commercial and Industrial Sector

Table B-30. Li-ion Battery Systems for Distributed Energy Storage

(Parameters noted in black are vendor inputs.)

Application	DESS	DESS	DESS	DESS	DESS	DESS	DESS	DESS
Technology Type	Adv. Li-ion	Adv. Li-ion	Li-ion	Li-ion	Large format Li-ion	Large format Li-ion	Large format Li-ion	Large format Li-ion
Supplier	S6	S6	S25	S19 - 1	S22	S22	S22	S22
Survey Year	2010	2010	2010	2010	2010	2010	2010	2010
DESIGN BASIS - General								
System Capacity - Net kW	25	50	50	50	25	25	25	25
Hours of Energy storage at rated Capacity - hrs	2	4	2	3	1.1	3	1.2	3.2
Depth of Discharge (DOD) per cycle - %	85%	85%	80%	80%	85%	85%	85%	85%
Energy Capacity - kWh @ rated DOD	50	200	100	150	28	75	30	80
Energy Capacity - kWh @ 100% DOD	59	235	125	188	32	88	35	94
Auxiliaries - kW								
Unit Size - Net kW	25	50		50				
Number of Units - #	1	6	Pad mounted	1				
Physical Size - SF/Unit	15	24		1	43" x 25" x 23"	27" x 61" x "26	43" x 25" x 23"	27" x 61" x "26
System Foot Print - SF	15	26.4		4X4				
System Weight - lbs	880.88	654.368		5,000				
Round Trip AC / AC Efficiency - %	89%	89%	93%	80%	85%	85%	90%	90%
Number of cycles / year	365	365	365	365	365	365	365	365
GENERAL - Timing								
Commercial Order Date								
Plant Life, yrs	15	15	15	15	15	15	15	15
TOTAL PLANT COST								
$/kW	$3,685	$4,789	$4,570	$3,523	$4,064	$6,594	$4,064	$5,904
$/kWh @ rated DOD	$1,843	$1,197	$2,285	$1,174	$3,695	$2,198	$3,387	$1,845
$/kWh @ 100% DOD	$1,566	$1,018	$1,828	$939	$3,140	$1,868	$2,879	$1,568
PLANT CAPITAL COST								
Power - $/kW	$1,994	$1,407	$1,407	$1,896	$1,994	$1,994	$1,994	$1,994
Storage - $/kWh @ rated DOD	$846	$846	$1,581	$542	$1,882	$1,533	$1,725	$1,222
SYSTEM COSTS - Equipment & Install	Actual Cost	Actual Cost	Actual Cost	Actual Cost	Actual Cost	Actual Cost	Actual Cost	Actual Cost
ES System								
ES Equipment	$36,765	$147,059	$137,500	$57,750	$45,000	$100,000	$45,000	$85,000
ES Installation	$1,838	$7,353	$6,875	Included	$2,250	$5,000	$2,250	$4,250
Enclosures	$2,350	$2,350	$2,350	Included	$2,350	$2,350	$2,350	$2,350
Owner Interconnection								
Equipment	$31,000	$44,500	$44,500	$44,500	$31,000	$31,000	$31,000	$31,000
Installation	$15,500	$22,500	$22,500	$22,500	$15,500	$15,500	$15,500	$15,500
Enclosures	Included	Included	Included	included	included	included	included	included
System Packing	$0	$0	$0	$9,000	$0	$0	$0	$0
System Shipping to US Port	$0	$0	$0	$17,813	$0	$0	$0	$0
Utility Interconnection								
Equipment	$250	$250	$250	$250	$250	$250	$250	$250
Installation	$250	$250	$250	$250	$250	$250	$250	$250
Site BOP Installation (Civil Only)	$500	$500	$500	$18,313	$500	$500	$500	$500
Total Cost Equipment	$70,365	$194,159	$184,600	$129,313	$78,600	$133,600	$78,600	$118,600
Total Cost Installation	$18,088	$30,603	$30,125	$41,063	$18,500	$21,250	$18,500	$20,500
General Contractor Facilities at 15% install	$0	$0	$0	$0	$0	$0	$0	$0
Engineering Fees @ 5% Install	$0	$0	$0	$0	$0	$0	$0	$0
Project Contingency Application @ 0-15% install	$0	$0	$0	$0	$0	$0	$0	$0
Process Contingency Application @ 0-15% of battery	$3,676	$14,706	$13,750	$5,775	$4,500	$10,000	$4,500	$8,500
Total Plant Cost (TPC)	$92,129	$239,468	$228,475	$176,150	$101,600	$164,850	$101,600	$147,600

DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA

Appendix B: Storage System Cost Details

Table B-31. Li-ion Battery Systems for Commercial and Residential Applications

(Parameters noted in black are vendor inputs.)

Application	Commercial & Industrial	Commercial & Industrial	Commercial & Industrial	Commerical & Industrial	Commerical & Industrial	Commerical & Industrial	Commerical & Industrial
Technology Type	Adv. Li-ion	Li-ion	Li-ion	Li-ion	Li-ion	Li-ion	Li-ion
Supplier	S6	S25	S19 - 1	S7	S7	S7	S7
Survey Year	2010	2010	2010	2011	2011	2011	2011
DESIGN BASIS - General							
System Capacity - Net kW	50	50	50	100	200	250	500
Hours of Energy storage at rated Capacity - hrs	4	2	3	4	4	4	2
Depth of Discharge (DOD) per cycle - %	85%	80%	80%	100%	100%	100%	100%
Energy Capacity - kWh @ rated DOD	200	100	150	400	800	1,000	1,000
Energy Capacity - kWh @ 100% DOD	235	125	188	400	800	1,000	1,000
Auxiliaries - kW							
Unit Size - Net kW	50		50	100	200 kW	250	500
Number of Units - #	6	Pad mounted	1	1	1	1	1
Physical Size - SF/Unit	24		1				
System Foot Print - SF	26.4		4X4	336	693	693	693
System Weight - lbs	654.368		5,000		44,000		
Round Trip AC / AC Efficiency - %	89%	93%	80%	90%	90%	90%	90%
Number of cycles / year	365	365	365	365	365	365	365
GENERAL - Timing							
Commercial Order Date				2010.12			
Plant Life, yrs	15	15	15	15	15	15	15
TOTAL PLANT COST							
$/kW	$4,789	$4,570	$3,523	$5,804	$5,924	$5,464	$3,034
$/kWh @ rated DOD	$1,197	$2,285	$1,174	$1,451	$1,481	$1,366	$1,517
$/kWh @ 100% DOD	$1,018	$1,828	$939	$1,451	$1,481	$1,366	$1,517
PLANT CAPITAL COST							
Power - $/kW	$1,407	$1,407	$1,896	$2,173	$2,314	$1,859	$1,231
Storage - $/kWh @ rated DOD	$846	$1,581	$542	$906	$902	$901	$901
SYSTEM COSTS - Equipment & Install	Actual Cost	Actual Cost	Actual Cost	Projected Cost	Actual Cost	$/kWh	$/kWh
ES System							
ES Equipment	$147,059	$137,500	$57,750	$312,000	$624,000	$780,000	$780,000
ES Installation	$7,353	$6,875	Included	$15,600	$31,200	$39,000	$39,000
Enclosures	$2,350	$2,350	Included	$30,048	$50,080	$50,080	$50,080
Owner Interconnection							
Equipment	$44,500	$44,500	$44,500	$79,000	$131,500	$131,500	$233,500
Installation	$22,500	$22,500	$22,500	$39,500	$33,000	$33,000	$58,500
Enclosures	Included	Included	Included	Included	Included	Included	Included
System Packing	$0	$0	$9,000	$0	$0	$0	$0
System Shipping to US Port	$0	$0	$17,813	$4,322	$4,322	$4,322	$4,322
Utility Interconnection							
Equipment	$250	$250	$250	$250	$62,900	$62,900	$70,400
Installation	$250	$250	$250	$250	$62,900	$62,900	$70,400
Site BOP Installation (Civil Only)	$500	$500	$18,313	$43,500	$72,500	$72,500	$72,500
Total Cost Equipment	$194,159	$184,600	$129,313	$425,620	$872,802	$1,028,802	$1,138,302
Total Cost Installation	$30,603	$30,125	$41,063	$96,850	$199,600	$207,400	$240,400
General Contractor Facilities at 15% Install	$0	$0	$0	$14,828	$29,940	$31,110	$36,060
Engineering Fees @ 5% Install	$0	$0	$0	$4,943	$9,980	$10,370	$12,020
Project Contingency Application @ 0-15% Install	$0	$0	$0	$4,943	$9,980	$10,370	$12,020
Process Contingency Application @ 0-15% of battery	$14,706	$13,750	$5,775	$31,200	$62,400	$78,000	$78,000
Total Plant Cost (TPC)	$239,468	$228,475	$176,150	$580,383	$1,184,702	$1,366,052	$1,516,802
OPERATING EXPENSES							
FIXED O&M - $/kW-yr	$26.8	$26.8	$26.8	$23.7	$16.5	$13.2	$11.7
Replacement Battery Costs - $/kW	$1,471	$1,375	$578	$1,560	$1,560	$1,560	$780
Battery replacement - yrs	8	8	8	5	5	5	5
Variable O&M - $/kWh (Charging or Discharging)	0.0014	0.0027	0.0018	0.0014	0.0014	0.0014	0.0027

Table B-25. Cost and Performance Data of Advanced Lead-acid Batteries
(Parameters noted in black are vendor inputs.)

Application	DESS	DESS	DESS	DESS	DESS	DESS
Technology Type	Advanced Lead Acid	Advanced Lead Acid	Advanced Lead Acid	Advanced VRLA	Advanced VRLA	VRLA
Supplier	S15	S15	S15	S21 - 1	S21 - 2	S21 - 3
Survey Year	2010	2010	2010	2011	2011	2011
DESIGN BASIS - General						
System Capacity - Net kW	50	50	50	25	25	25
Hours of Energy storage at rated Capacity - hrs	2	4	5	2	2	2
Depth of Discharge (DOD) per cycle - %	80%	50%	80%	70%	70%	70%
Energy Capacity - kWh @ rated DOD	100	200	250	50	50	50
Energy Capacity - kWh @ 100% DOD	125	400	313	65	71	65
Auxiliaries - kW						
Unit Size - Net kW						
Number of Units - #				234 Units of	48 Units of battery	34 Units of battery
Physical Size - SF/Unit				84(H) x 25(W) x	56(H) x 46(W) x	84(H) x 25(W) x
System Foot Print - SF	20' container	20' container	20' container	2.45	7.6	3.65
System Weight - lbs				1,470lbs/stand	4,100 lbs/stand	2,147 lbs/ stand
Round Trip AC / AC Efficiency - %	90%	90%	90%	85%	85%	85%
Number of cycles / year	365	365	365	365	365	365
GENERAL - Timing						
Commercial Order Date						
Plant Life, yrs	15	15	15	15	15	15
TOTAL PLANT COST						
$/kW	$2,499	$4,505	$2,782	$5,526	$3,789	$2,609
$/kWh @ rated DOD	$1,249	$1,126	$556	$2,763	$1,894	$1,304
$/kWh @ 100% DOD	$1,000	$563	$445	$2,125	$1,326	$1,003
PLANT CAPITAL COST						
Power - $/kW	$1,407	$1,407	$1,407	$1,994	$1,994	$1,994
Storage - $/kWh @ rated DOD	$546	$774	$275	$1,766	$897	$307
SYSTEM COSTS - Equipment & Install	Actual Cost	Actual Cost	Actual Cost	Actual Cost	Actual Cost	Actual Cost
ES System						
ES Equipment	$49,625	$140,800	$62,500	$80,275	$40,786	$13,975
ES Installation	$2,481	$7,040	$3,125	$4,014	$2,039	$699
Enclosures	$2,350	$2,350	$2,350	$2,350	$2,350	$2,350
Owner Interconnection						
Equipment	$44,500	$44,500	$44,500	$31,000	$31,000	$31,000
Installation	$22,500	$22,500	$22,500	$15,500	$15,500	$15,500
Enclosures	included	included	included	Included	Included	Included
System Packing	$0	$0	$0	$0	$0	$0
System Shipping to US Port	$0	$0	$0	$0	$0	$0
Utility Interconnection						
Equipment	$250	$250	$250	$250	$250	$250
Installation	$250	$250	$250	$250	$250	$250
Site BOP Installation (Civil Only)	$500	$500	$500	$500	$500	$500
Total Cost Equipment	$96,725	$187,900	$109,600	$113,875	$74,386	$47,575
Total Cost Installation	$25,731	$30,290	$26,375	$20,264	$18,289	$16,949
General Contractor Facilities at 15% install	$0	$0	$0	$0	$0	$0
Engineering Fees @ 5% Install	$0	$0	$0	$0	$0	$0
Project Contingency Application @ 0-15% install	$0	$0	$0	$0	$0	$0
Process Contingency Application @ 0-15% of battery	$2,481	$7,040	$3,125	$4,014	$2,039	$699
Total Plant Cost (TPC)	$124,938	$225,230	$139,100	$138,153	$94,714	$65,223
OPERATING EXPENSES						
FIXED O&M - $/kW-yr	$26.8	$26.8	$26.8	$37.2	$37.2	$37.2
Replacement Battery Costs - $/kW	$298	$845	$375	$2,902	$1,468	$480
Battery replacement - yrs	8	8	8	8	8	3
Variable O&M - $/kWh (Charging or Discharging)	0.0027	0.0014	0.0011	0.0027	0.0027	0.0027

Table B-26. Cost and Performance of Advanced Lead-acid Batteries for Commercial and Industrial Applications
(Parameters noted in black are vendor inputs.)

Application	Commercial & Industrial	Commercial & Industrial	Commercial & Industrial	Commercial & Industrial	Commercial & Industrial	Commerical & Industrial	Residential	Residential
Technology Type	Advanced Lead Acid	Advanced Lead Acid	Advanced Lead Acid	Advanced Lead Acid	Advanced Lead Acid	Adv. Lead Acid	Advanced Lead Acid	Advanced Lead Acid
Supplier	S15	S15	S15	S15	S15	S11	S15	S15
Survey Year	2010	2010	2010	2010	2010	2011	2010	2010
DESIGN BASIS - General								
System Capacity - Net kW	50	50	50	1000	1000	200	5	5
Hours of Energy storage at rated Capacity - hrs	2	4	5	8	10	4	2	4
Depth of Discharge (DOD) per cycle - %	80%	50%	80%	33%	80%	60%	33%	50%
Energy Capacity - kWh @ rated DOD	100	200	250	8,000	10,000	800	10	20
Energy Capacity - kWh @ 100% DOD	125	400	313	24,242	12,500	1,333	30	40
Auxiliaries - kW								
Unit Size - Net kW						200		
Number of Units - #				44	29		1	1
Physical Size - SF/Unit				110X197	60X141			
System Foot Print - SF	pad mtd cabinet	20' container	20' container	21670	8460	154		
System Weight - lbs						152,000		
Round Trip AC / AC Efficiency - %	90%	90%	90%	90%	90%	75%	90%	90%
Number of cycles / year	365	365	365	365	365	365	365	365
GENERAL - Timing								
Commercial Order Date						Q4/2010		
Plant Life, yrs	15	15	15	15	15	15	15	15
TOTAL PLANT COST								
$/kW	$2,499	$4,505	$2,782	$8,090	$5,023	$5,995	$6,323	$6,509
$/kWh @ rated DOD	$1,249	$1,126	$556	$1,011	$502	$1,499	$3,162	$1,627
$/kWh @ 100% DOD	$1,000	$563	$445	$334	$402	$899	$1,043	$814
PLANT CAPITAL COST								
Power - $/kW	$1,407	$1,407	$1,407	$1,573	$1,036	$1,795	$3,570	$3,570
Storage - $/kWh @ rated DOD	$546	$774	$275	$815	$399	$1,050	$1,377	$735
SYSTEM COSTS - Equipment & Install	Actual Cost	Actual Cost	Actual Cost	Actual Cost	Actual Cost	Actual Cost	Actual Cost	Actual Cost
ES System								
ES Equipment	$49,625	$140,800	$62,500	$5,924,160	$3,625,000	$800,000	$12,515	$13,360
ES Installation	$2,481	$7,040	$3,125	$296,208	$181,250	Included	$626	$668
Enclosures	$2,350	$2,350	$2,350	$782,120	$306,560	$26,560	$2,350	$2,350
Owner Interconnection								
Equipment	$44,500	$44,500	$44,500	$367,000	$367,000	$131,500	$9,500	$9,500
Installation	$22,500	$22,500	$22,500	$92,000	$92,000	$33,000	$5,000	$5,000
Enclosures	Included	Included	Included	Included	Included	Included	Included	Included
System Packing	$0	$0	$0	$0	$0	Included	Included	Included
System Shipping to US Port	$0	$0	$0	$0	$0	Included	$0	$0
Utility Interconnection								
Equipment	$250	$250	$250	$80,400	$80,400	$62,900	$250	$250
Installation	$250	$250	$250	$80,400	$80,400	$62,900	$250	$250
Site BOP Installation (Civil Only)	$500	$500	$500	$43,340	$16,920	$14,500	$500	$500
Total Cost Equipment	$96,725	$187,900	$109,600	$7,153,680	$4,378,960	$1,020,960	$24,615	$25,460
Total Cost Installation	$25,731	$30,290	$26,375	$511,948	$370,570	$110,400	$6,376	$6,418
General Contractor Facilities at 15% Instal	$0	$0	$0	$76,792	$55,586	$16,560	$0	$0
Engineering Fees @ 5% Instal	$0	$0	$0	$25,597	$18,529	$5,520	$0	$0
Project Contingency Application @ 0-15% Instal	$0	$0	$0	$25,597	$18,529	$5,520	$0	$0
Process Contingency Application @ 0-15% of battery	$2,481	$7,040	$3,125	$296,208	$181,250	$40,000	$626	$668
Total Plant Cost (TPC)	$124,938	$225,230	$139,100	$8,089,823	$5,023,423	$1,198,960	$31,617	$32,546
OPERATING EXPENSES								
FIXED O&M - $/kW-yr	$26.8	$26.8	$26.8	$9.2	$9.2	$16.5	$58.0	$58.0
Replacement Battery Costs - $/kW	$298	$845	$375	$1,777	$1,088	$1,200	$751	$802
Battery replacement - yrs	8	8	8	8	8	8	8	8
Variable O&M - $/kWh (Charging or Discharging)	0.0027	0.0014	0.0011	0.0007	0.0005	0.0014	0.0027	0.0014

Utility Interconnection (UI) Costs

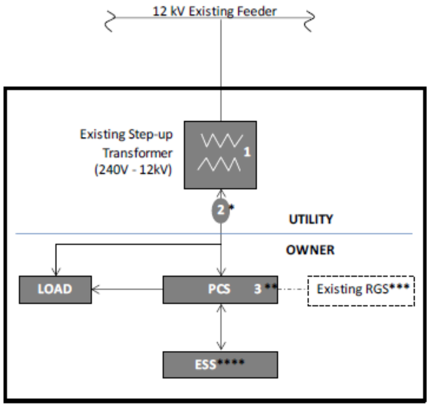
		5kW	15kW	25kW	50kW	100kw
1	Step-up	Existing	Existing	Existing	Existing	Existing
2	Smart Metering:	$500	$500	$500	$500	$500
	Equipment	incl.	incl.	incl.	incl.	incl.
	Subtotal	**$500**	**$500**	**$500**	**$500**	**$500**
	$/kW	$100	$33	$20	$10	$5

Owner Interconnection (OI) Costs

		5kW	15kW	25kW	50kW	100kw
3	PCS Equipment:	$9,500	$24,500	$31,000	$44,500	$79,000
	PCS Installation:	$5,000	$12,500	$15,500	$22,500	$39,500
	Subtotal	**$14,500**	**$37,000**	**$46,500**	**$67,000**	**$118,500**
	$/kW	$2,900	$2,467	$1,860	$1,340	$1,185
	Total (UI and OI)	**$15,000**	**$37,500**	**$47,000**	**$67,500**	**$119,000**
	$/kW	$3,000	$2,500	$1,880	$1,350	$1,190

System Inverter Scope (kW)

	5kW	15kW	25kW	50kW	100kw
Size (LxWxH):	74"x45" x26.875"	74"x45" x26.875"	74"x45" x26.875"	74"x45" x26.875"	67"x86" x23"
Outdoor Enclosure	y	y	y	y	y
Weight:	1732 lbs	1732 lbs	1732 lbs	1732 lbs	2605 lbs
Efficiency:	96	96	96	96	98



NOTES:

* Supplier to provide metering connections at 240V

** UL 1741 Listed

*** Should a new ESS be installed to support an existing Renewable Generation System (RGS) then no additional Utility and Owner Interconnection equipment or cost is required. This assumes that the DC voltage output for the ESS is similar to the RGS.

**** Battery Capacity does not exceed peak load. Therefore existing transformer does not need upgrades

PCS Power Conditioning System

Figure 7.19: Electrical Energy Storage 5-100 kW scheme

Utility Interconnection (UI) Costs

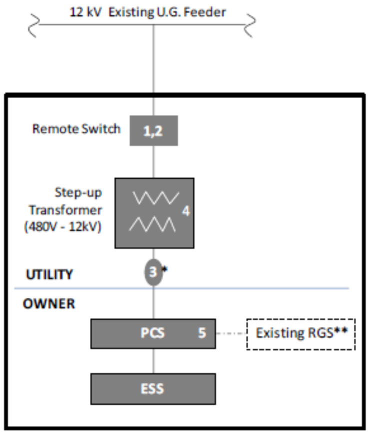
		250kW	500kW	1MW
1	*** Remote Switch:	$100,000	$100,000	$100,000
2	Communication (Radio):	Incl.	Incl.	Incl.
3	Smart Metering:	$800	$800	$800
4	Transformer Equipment:	$12,500	$20,000	$30,000
	Transformer Installation:	$12,500	$20,000	$30,000
	Subtotal	**$125,800**	**$140,800**	**$160,800**
	$/kW	$503	$282	$161

Owner Interconnection (OI) Costs

		250kW	500kW	1MW
5	PCS Equipment:	$131,500	$233,500	$367,000
	PCS Installation:	$33,000	$58,500	$92,000
	Subtotal	**$164,500**	**$292,000**	**$459,000**
	$/kW	$658	$584	$459
	Total (UI and OI) Cost	**$290,300**	**$432,800**	**$619,800**
	$/kW	$1,161	$866	$620

System Inverter Scope (kW)

	250kW	500kW	1MW
Size (LxWxH):	22'x8'5" x8'7"	83"x159" x31"	83"x115" x38"
Outdoor Enclosure Y or N:	y	y	y
Weight:	28000.00	7700.00	4500.00
Efficiency:	97	97	97



NOTES:

* Supplier to provide metering connections at 480V

** Should a new ESS be installed to support an existing Renewable Generation System (RGS) then no additional Utility and Owner Interconnection equipment or cost is required. This assumes that the DC voltage output for the ESS is similar to the RGS.

*** U.G. Distribution System with Pad Mounted Equipment

PCS Power Conditioning System

U.G. UnderGround

Figure 7.20: Electrical Energy Storage 5-100 kW scheme

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