

# Battery Storage

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## Executive Summary

As the use of renewable energy sources increase, so does the need to both stabilize the grid, due to the inherent intermittency of the generated power, but also to provide means for storing the energy to use during peak demands or when the renewable sources aren't available.

A more thorough explanation on the importance of battery storage and the expected market situation is discussed in the beginning of this paper.

Battery Energy Storage Systems (BESS) play an important role in the renewable energy transition. However, these systems are considered relatively new technology and could in many ways be seen as prototypical. As with most developing technologies there are often some challenges to tackle before the technology can be seen as proven. As the technology is developing fast, this paper is intended to provide an overview of the current technologies and what their differences are.

The significant amount of energy stored in these systems could result in danger or loss if some of the challenges aren't managed in a correct way. This paper presents the main loss exposures and types of causations of fire loss as well as actual market loss examples.

The theory for BESS technology is explained, as well as what could go wrong and how errors can be prevented. The main standards and codes that should be applied when certifying the batteries and how to get more in depth information on loss prevention are also presented in the paper.

There are several considerations for the underwriter to make before insuring BESS's. Some of the main considerations to make are provided, as well as the reasoning behind. A check-list for battery projects is also provided.

The vocabulary and definitions associated with battery storage can be found in the appendix section where also the different battery types are explained in more detail.

The aim of this paper is to provide the reader with enough information to make informed decisions when it comes to insuring battery storage systems.

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## 1. Introduction

On 24 April 2019, the small German city of Bordesholm celebrated setting a 10 MW Battery Electrical Storage System (BESS) in service. This investment, coupled with a Bio Gas Plan, provides electricity to the 7,500 people inhabiting the community which has the target to meet 100% of its demand with renewable energy sources by 2020. The primary role of this BESS is to help stabilize the regional network (frequency containment reserve), and to provide back-up power. In case of a grid outage, it can help putting back the grid in operation (Black Start) and enable the operation of an independent local grid (Islanding). This investment saves 12,000 tons of CO<sub>2</sub> per year. For its contribution to the grid stability the municipality receives a remuneration from Tennet, one of the four grid owners.

Every week, new battery system developments are announced. They're either connected to solar plants, wind farms (onshore or offshore), or used as a regulating system to improve the stability of the electrical networks.

The combination of the falling price of Li-Ion batteries (-85% during the last 9 years) and the emergence of renewable energy lead Bloomberg to estimate that the global energy storage market\* will grow to a cumulative 942GW / 2,857GWh by 2040, attracting \$620 billion in investment over the next 22 years (as from 2018).

*\* Bloomberg NEF Blog 6/11/2018*

This does not consider the emergence of the 10-times-bigger storage capacity expected for electrical vehicles (EV). Tens of billions of USD are invested in the R&D for these EVs in the context of a "patent war", with China owning 83% of the patent rights, followed by Japan and South Korea.

But the emergence of these new technologies is also linked to new exposures. What are the new risks? What can trigger a fire in a battery? How does the charging mode influence the life potential of a battery? What are the current technologies, and are some safer than others? When indemnifying a claim, should we consider the lifetime of the battery. What are the revenue components to consider when assessing the DSU or BI exposure of a plant? These are the questions that we try to answer in the following chapters.

2. Importance of Battery Storage

Energy storage sources allow the management of power supplies that customers require when they need them the most. Developing technology to store electrical energy to meet power demands whenever it's needed will represent a breakthrough in peak load electricity distribution. Energy storage decouples supply and demand and introduces an unprecedented level of flexibility and control. Installed systems can complement intermittent sources of renewable energy such as wind, solar, wave and tidal in an attempt to balance energy production and consumption.

Forms of Energy Storage			
Mechanical	Thermal	Electrical	Electrochemical
Hydropower Pumped storage Compressed air Flywheel Energy Gravitational Potential	Sensible heat Latent heat	Super-capacitors	Battery Energy Storage

Energy comes in multiple forms including, electrical chemical, mechanical, electrical and kinetic to name a few. Many types of technologies can store this energy, including electrical, thermal, mechanical, and electrochemical technologies. Hydroelectric pumped storage, a form of mechanical energy storage, accounts for the greatest share

of large-scale energy storage power capacity in the United States. Other examples of these systems are flywheels, compressed air storage, super capacitors and battery energy storage systems (BESS). Anyone following electric utility trends knows that BESS tops the list of exciting and transformative technologies in the power industry today.

Source: <https://www.eia.gov/>

As the market share of renewables in power production increases, so does its intermittency. This leads to an increased need for flexible power providers on the electricity grid. Battery Energy Storage has a substantial technical advantage over conventional generation units in terms of load shifting capacities thanks to their fast ramping rate, which makes these systems a dominant choice. Batteries have unique abilities to both charge and discharge from the grid and ramp up and down at speeds that traditional generators can't match.

A BESS needs to suit a customer's electricity demand profile. Customer installations connected to network operator distribution systems are designed to export power into the grid, while remote area supplies are not. BESS in remote installations may have to be integrated with wind and / or diesel generators as well as solar PV panels. BESS prices are projected to continue a downward trend and future storage is now being seriously looked at for several different applications.

The important distinction for battery storage is the different ratings between power and energy capacity. Conventional generation technologies are often characterized in terms of power capacity, which is the maximum instantaneous amount of power output, and is measured in units such as megawatts (MW). However, batteries are limited by the time they can sustain power output before they need to recharge. The duration i.e. the length of time that a storage system can sustain power output at its maximum

discharge rate, typically expressed in hours. The energy capacity of the battery storage system is the total amount of energy that can be stored or discharged by the battery storage system and is measured in units such as megawatt hours (MWh). A “large scale” BESS system would be defined as a single installation >1MW capacity. Small-scale refers to systems that are less than 1 MW in power capacity and are typically connected to a distribution network.

A range of battery technologies are available, the most common being lithium-ion, lead acid, nickel-based, flow technologies and hybrid-ion technology. Different battery technologies and chemistries have different performance capabilities and different requirements for installation, operation and maintenance. Various battery types will have different probabilities of failure and varying consequences of that failure (i.e. a different risk profile). Those responsible for the specification and / or supply of the BESS must ensure that an appropriate risk assessment is undertaken for the specific customer circumstances, location, the equipment proposed and its installation.

Researchers at Bloomberg NEF (BNEF) predict that utility scale lithium-ion battery storage systems will transform the economic case for batteries in both the vehicle and the power sector. The battery boom has penetrated the Chinese market, US-California and will follow everywhere else. Projections for new installations have already been exceeded in some countries. The analysts at Bloomberg NEF predict that the global energy-storage market could reach a cumulative 942 gigawatts by 2040 and that this boom will be fueled by sharply falling battery costs. BNEF sees the capital cost of a utility-scale lithium-ion storage system falling another 52 percent by 2030. Governmental stimulus is likely to play a part in this. For example, South Korea took the top spot in 2018 with nearly 1.1 gigawatt-hours of energy storage deployed, compared to just under 700 megawatt-hours in the U.S. This was primarily the result of the Korean government’s policy to allow storage-backed wind and solar projects to earn renewable energy certificates worth five times their capacity value, which drove nearly \$400 million in energy storage investments and a pipeline of projects that had overshot a goal of 800 megawatt-hours by 2020. However, BESS costs are still fairly high and there is a lack of regulatory requirements and subsidies are not universally available. BESS’s still may not be cost-effective for any one application in any given region. Government policy uncertainties may restrain larger-scale battery installations, yet are imperative to direct grid operators to create mechanisms to accommodate supply bottlenecks and maintain grid stability.

Between 2003 and 2017, 734 MW of large-scale battery storage power capacity was installed in the United States, two-thirds of which was installed in the past three years. As of December 2017, project developers report to EIA that 239 MW of large-scale battery storage is expected to become operational in the United States between 2018 and 2021.



## U.S. Large-Scale BESS Installations by Region (2017)

Source: U.S. Energy Information Administration | US. Battery Storage Market

Trends

The next few years will continue to define the future market leaders in the BESS industry. The increased competition in this space is the key driver that is making storage more and more attractive to utilities and related companies. Energy storage installations result in a reduction in peak electrical system demand and system owners are often compensated through regional grid market programs. An increase in owner participation may be stimulated by regulator offered incentives. State policy, wholesale market rules, and retail rates will play a central role in where opportunities for battery storage exist. Installed capacity is expected to grow as costs decline and market rules are updated.

The costs for battery storage technologies depend on technical characteristics, such as the power and energy capacity of a system. Costs will be driven by technological and site-specific requirements and can be divided into three main categories, based on the nameplate duration of the battery storage system, which is the ratio of nameplate energy capacity to nameplate power capacity. Short-duration battery storage systems refer to systems with less than 0.5 hours of nameplate duration. The medium-duration battery storage category includes systems with nameplate durations ranging between 0.5 hours and 2.0 hours, while the long-duration category includes all systems with more than 2.0 hours of nameplate duration.

According to Clair Addison, AES Stakeholder Manager: “In the eight years that AES has been operating in the BESS sector, lithium-ion battery costs have fallen by 80%. Renewable energy penetration and peak demand combined with aging thermal plants, could see a peak demand of 16GW by the mid-2020s and BESS [facilities] could provide 50% of that.”

### **Total Installed Cost of Large-Scale Battery Storage Systems by Duration**

The large-scale energy storage capacity additions in the US since 2003 have been almost exclusively electrochemical battery energy storage systems. For this reason, this paper will focus on these storage technologies.

### 3. Usage / Purpose of Battery Storage

Among energy-intensive economies of the world, there is a shift occurring, from centralized, fossil-fueled power generation systems to more distributed and inherently variable renewable energy sources. In addition to this, the nature of electrical load is changing, such as that due to large-scale data centres, increased use of air-conditioning systems and the deployment of electric vehicle (EV) charging infrastructure. Changes in the architecture and controllability of the grid call for smart, efficient power transmission and distribution networks. BESS technology will not only facilitate the integration of more renewable energy but also, help create a smarter and more reliable grid. Revenue from spinning reserve (meaning ramping over a specified range within 10 minutes and running for at least two hours) as well as reactive and active power management of the grid are also revenue avenues. The challenge in adding battery storage to a grid run by generators serving load is that it doesn't work quite like those resources. Electrical storage systems that charge and discharge actual electrons, can go in both directions, and react much more quickly than many other resources. But it's also limited in duration, and of course is only as efficient or as clean as the electricity it stores, or the balance between its charging and discharging cycles over its lifespan.

The first large scale (i.e. commercial) peak-shaving system (2 MW / 4 MWh) was deployed by Chevron Energy Solutions. AES Energy Storage LLC has deployed more than 50 MW of systems as an independent power producer (IPP) for frequency regulation and spinning reserve services. Other utilities are also deploying megawatt-scale units for PV integration and distribution grid support.

In many locations the regulatory status and rules to operate a BESS are not fully defined. In the USA, The Federal Energy Regulatory Commission (FERC) issued its landmark Order 841 on February 15, 2018, in which it directed regional grid operators to remove barriers to the participation of electric storage in wholesale markets. By directing the regional grid operators to establish rules that open capacity, energy, and ancillary services markets to energy storage, the Order affirmed that storage resources must be compensated for all these services. Furthermore, Order 841 created a clear legal framework for storage resources to operate in all wholesale electric markets and expanded the universe of solutions that can now compete to meet electric system needs.

Battery Energy Storage Applications	
Type	Duration
Frequency Regulation	.5 to 1 h
Critical Power	up to 1 h
Generation Enhancement	up to 1 h
Renewable Integration	up to 4 h
T&D Enhancement	up to 4 h
Energy Cost Control	up to 4 h
Micro grids & Islands	up to 4 h
Capacity Peak Power	up to 6 h

Source:

Overview of the Energy Storage Market and Fluence, an AES and Siemens Joint Venture September 6, 2018

Batteries have physical and operational constraints such as power output and discharge duration. These constraints are often designed with the intent of optimizing the delivery of certain types of services or applications to the grid. It is also possible and sometimes necessary to combine applications to maximize the value of the system.

## Purpose Descriptions

Some uses for BES systems and their definitions include:

- Frequency regulation (ancillary services) – this helps balance momentary differences between demand and supply, often in response to deviations in the interconnection frequency from base frequency. Regulation involves managing interchange flows with other control areas to match closely the scheduled interchange flows and momentary variations in demand within the control area. The primary reasons for including regulation in the power system are to maintain the grid frequency and to comply with grid regulations such as the North American Electric Reliability Council's (NERC's) standards.
- Spinning reserve (SR) – generation capacity that is online but unloaded and that can respond within 10 minutes to compensate for generation or transmission outages. SR provides synchronized capacity for grid frequency management, which may be available to use during a significant frequency disturbance. This reserve ensures system operation and availability. Importantly for storage,

generation resources used as reserve capacity must be online and operational (i.e. at part load). Unlike generation, in almost all circumstances, storage used for reserve capacity does not discharge at all; it just has to be ready and available to discharge if needed.

- Voltage or reactive power support – this ensures the quality of power delivered by maintaining the local voltage within specified limits by serving as a source or sink of reactive power. To manage reactance at the grid level, system operators need voltage support resources to offset reactive effects so that the transmission system can be operated in a stable manner.
- Load following – the system supplies (discharges) or absorbs (charges) power - also known as a form of ramp rate control. Load following is characterized by power output that generally changes as frequently as every several minutes. The output changes in response to the changing balance between electric supply and load within a specific region or area. Most renewable applications with a need for storage will specify a maximum expected up- and down-ramp rate in MW /minute and the time duration of the ramp.
- System peak shaving – reduces or defers the need to build new central station generation capacity or purchase capacity in the wholesale electricity market, often in times of high (peak) demand. Depending on the circumstances in a given electric supply system, energy storage could be used to defer and / or to reduce the need to buy new central station generation capacity and / or purchasing capacity in the wholesale electricity marketplace. The marketplace for electric supply capacity is evolving. In some cases, generation capacity cost is included in wholesale energy prices (as an allocated cost per unit of energy). In other cases, market mechanisms may allow for capacity-related payments.
- Load management – provides a customer-related service, such as power quality, power reliability (grid-connected or micro-grid operation), retail electrical energy time-shift, demand charge management, or renewable power consumption maximization.
- Storing – excess wind and solar generation reduces the rate of change of the power output from non-dispatchable generators, like wind or solar, in order to comply with local grid codes for grid stability or prevent over production, which might incur penalties. High solar adoption will create a challenge for utilities to balance supply and demand on the grid. This is due to the increased need for electricity generators to quickly ramp up energy production when the sun sets and the contribution from PV falls. In 2013, the California electric grid operators (CAISO) published a graph nicknamed “The Duck Curve” that is now commonplace in conversations about large scale deployment of solar (PV) power. It shows the state’s demand for electricity over a single day, subtracting out the state’s growing supply of solar and wind power. The Duck Curve is a 24-hour period snapshot that illustrates where high solar adoption creates a challenge for utilities to balance supply and demand on the grid.

Solar capacity has reduced fossil fuel generation load during daylight hours. During the evening hours when residents return home from work, the state's aging natural gas plants then increasingly struggle to ramp up to meet the evening (6pm-8pm) demand.

Solar power coupled with BESS technologies could alleviate, and possibly eliminate, the risk of over-generation. Solar curtailment isn't necessary when excess energy can be stored for use during peak electricity demand. In short, battery storage could make it easier for utilities to rely on solar energy to meet customer needs around the clock and eliminate the "ramp up" from fossil fuel generation during evening hours, when solar power is low. According to the Energy Information Administration (EIA), the installed amount of PV is expected to triple by 2030—potentially migrating the duck curve outside of California.

- Electric energy time (Arbitrage) – 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.
- Black Start – storage systems provide an active reserve of power and energy within the grid and can be used to energize transmission and distribution lines and provide station power to bring power plants online after a catastrophic failure of the grid.

- Transmission and distribution deferral – keeps the loading of the transmission or distribution system equipment lower than a specified maximum. This allows for delays or completely avoids the need to upgrade a transmission system or avoids congestion-related costs and charges.
- Co-located generator firming – provides constant output power over a certain period of time of a combined generator and energy storage system. For example, BES systems have found useful application in smoothing wind power output. Batteries are charged when wind turbines are operating but then provide supplemental power when the turbines are idle.

## Noteworthy BESS Storage Project Uses

### Puerto Rico Electric Power Authority (PREPA)

Grid Services: Frequency control and spinning reserve

Project Location: Sabana Llana substation, San Juan, Puerto Rico

Commissioned: 1994

Power/Energy: 20 MW/14 MWh

Battery Type: Lead-acid, flooded cell, by C&D Battery

The PREPA BESS also provides frequency regulation and spinning reserve services to the island grid of Puerto Rico. This battery system demonstrated that the faster response of a battery system could be an invaluable resource for grid stability, superior to CTs for frequency regulation and spinning reserve duty. However, operational issues that surfaced soon after the battery was commissioned showed that frequency regulation duty requires far more cycling of the battery than originally estimated in the design and engineering phase of the project. The battery was decommissioned in 1999.

### Southern California Edison

Grid Services: Demonstrate load-levelling, transmission line stability, T&D deferral, local VAR control, and local area black start

Project Location: Chino, CA

Commissioned: 1988

Power/Energy: 10 MW/40 MWh

Battery Type: Lead-acid, flooded cell, by Exide

The Chino project was an early demonstration of a large battery for multiple applications in the U.S. grid. The project was jointly sponsored by EPRI, DOE, and the International Lead Zinc Research Organization (ILZRO), supported by SCE as the host utility. This landmark project provided valuable experience with maintaining large

banks of flooded lead-acid batteries and high-voltage battery strings. The lessons learned in this project influenced later battery projects and also spurred the development of smaller modular storage systems versus large field-assembled battery systems. The Chino project was also the largest utility battery system in the world until the PREPA BESS and later the Fairbanks battery projects were commissioned in 1994 and 2003, respectively. The Chino battery was decommissioned in 1997.

### **Golden Valley Electric Association (GVEA)**

Application: VAR Support, spinning reserve, power system stabilization

Project Location: Fairbanks, AK

Commissioned: 2003

Power/Energy: 27 MW/14.6 MWh

Battery Type: Nickel/cadmium, by SAFT

NOTE: At the time of writing this paper, the Fairbanks battery storage system is the largest in the United States and the only one using NiCd batteries. It also provides a real-world example of the successful stacking of several grid services, including voltage support, spinning reserve, and reserve power for Fairbanks in the event of an outage on the transmission line connecting Fairbanks to Anchorage.

### **Batwind (Hywind Scotland floating offshore wind farm)**

Application: the world's first BESS for a floating wind farm

Project location: Peterhead, Scotland

Capacity: 1MW

Commissioned: 2018

Electricity produced at the world's first floating offshore wind farm, Hywind Scotland, located 25 kilometres off the coast of Peterhead, will be transported via cables to an onshore substation where the 1 MW batteries are placed and connected to the grid.



## 4. The main types of battery technologies used for energy storage

### 4.1 Storage battery technology

Various technologies can be harnessed for battery energy storage, but these come with certain advantages and disadvantages. Currently most of the battery energy storage systems that are installed use Lithium-ion technology followed by lead-acid, sodium salt and flow batteries.

Specification	Lead-acid	Nickel based	Lithium-ion	Flow	Sodium-sulfur (NaS)
Specific energy [Wh/kg]	30 – 50	up to 120	up to 250	up to 150	up to 150
Life cycles [80% DoD]	200 – 300	up to 500	up to 10.000	up to 1.000	up to 4.000
Safety requirements	Thermally stable, can emit H <sub>2</sub>	Thermally stable, fuse protection	Protection circuit mandatory	Thermally stable	Has to be heated possibility of short circuits when cooling down
Cost	Low	Moderate	high	high	high
Self-discharge [per month]	5%	20 – 30%	5 – 10%		

Source: Swiss RE BESS leaflet

## 4.2 Lead-acid batteries

Lead-acid batteries, are the oldest type of rechargeable battery systems, are relatively rugged and forgiving if abused, and can be economically priced. However, they have low specific energy, making them bulky, and limited cycle count compared to other types. In general they have a depth of discharge of approx. 60%, meaning that 40% of their capacity cannot be used if the cell should not be damaged for the rest of their lifetime.

Lead-acid systems perform best around 20°C and operation above this temperature will result in reduction of lifetime and capacity. These batteries are thermally stable and do not need any internal safety measures, but they can emit hydrogen gas so the storage area should be well ventilated to prevent the emergence of an explosive atmosphere.

Lead-acid batteries are most often used as uninterruptible power supplies (UPS).

## 4.3 Nickel-based batteries

Mature and well understood nickel-based batteries are used where long service life, high discharge current and extreme temperature tolerance are required. Nickel Cadmium “NiCd” batteries in particular are one of the most rugged and enduring battery types and are the only ones with a chemistry that allows ultra-fast charging with minimal stress.

Nickel based batteries are mainly used in medical devices, power tools and industrial application (like UPS). The main types are:

- Nickel Cadmium (NiCd)
- Nickel-metal-hydride (NiMH)
- Nickel-iron (NiFe)
- Nickel-zinc (NiZn)
- Nickel-hydrogen (NiH)

#### 4.4 Lithium-ion (Li-ion) batteries

Li-ion battery technology is replacing many applications that were previously served by lead-acid and nickel-based batteries. They do not suffer significantly from the memory effect, unlike their NiMH and NiCd counterparts. Due to safety concerns they require special handling and protection circuits. Li-ion batteries are more expensive than most other batteries, but high cycle count and low maintenance reduce the cost per cycle over many other chemistries.

This type of battery is mainly used for portable appliance, automotive (e-mobility) and also large-scale battery storage.

Several types of Li-ion batteries exist:

- Lithium Cobalt Oxide (LiCoO<sub>2</sub>)
- Lithium Manganese Oxide (LiMnO<sub>2</sub>)
- Lithium Manganese Oxide (LiMnO<sub>2</sub>)
- Lithium Iron Phosphate (LFP - LiFePO<sub>4</sub>)
- Lithium Nickel Cobalt Aluminum Oxide (LiNiCoAlO<sub>2</sub>, NCA)
- Lithium Titanate

One of the most catastrophic failures of a lithium-ion battery system is a cascading thermal runaway event, where multiple cells in a battery fail due to a failure starting at one individual cell. Thermal runaway can occur due to exposure to excessive temperatures, external short circuits due to faulty wiring, or internal shorts due to cell defects. Thermal runaway events result in the venting of toxic and highly flammable gases and the release of significant energy in the form of heat. If ignited, these gases can cause enclosed areas to over-pressurize, and if unmitigated, this over-pressure can result in an explosion and severe damage to the battery and surrounding equipment or people. An explosion scenario can be even more severe for a large battery pack, where the heat generated by one failed cell can heat up neighbouring cells and lead to a thermal cascade throughout the battery pack.

Source:

Thermal Runaway and Safety of Large Lithium-Ion Battery Systems; Nicolas Ponchaut

## 4.5 Flow batteries

Flow batteries are accumulators that store electrical energy in two chemical liquid components. A typical element for a flow battery is currently vanadium. The voltage is generated on a membrane (similar to traditional fuel cells). The liquids are stored in two separate tanks and pumped into the membrane. The size of the membrane determines the power (kW) of the battery, while the size of the tanks determines the capacity (kWh) of the battery. This makes this kind of battery easily scalable by increasing the size of the tanks.

Due to its size and high possible capacity, this technology is well suited for large scale energy storage.

<b>Advantages</b>	Energy and power can be scaled independently.
	No “thermal runaway” unlike traditional lithium cells.
<b>Disadvantages</b>	Still under development
	Size of the battery (tanks)
	Complex system of pumps, sensors and vessels are required for operation

## 5. Underwriting: Material Damage

The scope of this section is to provide the reader with an overview of the main causes of material damage (physical loss) in a BESS, with a special focus on insurance related matters.

The driving force in a catastrophic failure of a BESS (as in all energy storage systems) resides in the technical need to retain the highest amount of energy in the smallest possible volume, using physical and chemical properties of materials, maintaining at the same time the ability to upload and recall power/energy from the storage system at a rate which is optimal for the kind of load fed by the device.

In the specific case of BESS, the feature of energy storage is achieved by means of electrochemical reactions taking place in the so called “cell”, that is the smallest modular element of the storage system.

Cells are organized in larger modules that can be in turn connected to optimize the specific operative conditions for which the whole BESS device is designed. Almost as important as the electrochemical elements where energy is finally stored, the balancing, equalizing and control electronics give a fundamental contribution not only to the operational efficiency, but also to the safety and resilience of the whole device to defects or to unexpected external stresses [1,2,3,4]

The exposure to physical losses (electromechanical, electrochemical, fire, explosion) and the failure modes of BESS strongly depend on the BESS technology, not only at the level of the single cell, but including all the technical setup of the device: circuit topology, balancing, equalization and control electronics, environmental/temperature/ventilation control, etc. Guidelines exist to assist the design, installation and operation of BESS within acceptable safety limits [5].

Due to the extremely high concentration of energy, oxygen and combustibles present in a cell when charged, in case of off-spec conditions or stresses, an unfavorable combination of effects may lead to a self-amplifying reaction loop, leading to catastrophic damage (fire, explosion), called Thermal Runaway.

Although thermal runaway is observed and theoretically possible in almost all currently available cell technologies [6], it is a priority concern for Li-ion based technologies.

A typical example of a thermal runaway event may start with a point source of heat inside of or attached to a single cell, for example an internal short circuit or a hot object in contact with the cell, leading to the damaging of cathode/anode separator, producing a fast discharge of energy and therefore more heating, causing electrolyte degradation and formation and release of flammable/explosive gases, producing flames or explosions and so forth a self-sustaining loop of reaction/energy release.

Given the very high number of parameters involved, it is impossible to establish “a-priori” if a combination of inputs/events will produce for sure a catastrophic event [7-9].

Some authors have tried to propose methodologies to study “a-posteriori” thermal runaway accidents by breaking them down to a series of partial reactions/events [7,8], but it is evident that lab-based tests with simplified set-ups can only provide hints and very broad guidelines to help understanding triggers and aggravating factors for this kind of catastrophic failure.

A very partial list of parameters that may trigger and drive a thermal runaway event include:

Cell technology and materials, electrolytes, overcharge, external heat, cell geometry, circuit topology, mechanical stress /deformation, gas emission, nature of the emitted gases, ventilation of the installation, etc.



In their papers / proceedings [8, 9] Döring, Wörz and Scharner, give a number of examples of possible thermal runaway initiation triggers, including: overcharge, crush, thermal exposition, high current/voltage exposition, external short circuit, internal short circuit (e.g. nail penetration, particle inclusion).

All these triggers simulate the real-world occurrence of material / design / manufacturing defects, accidents, mechanical impacts (e.g crushing / bending / piercing), wrong operation (short circuit, wrong charging) or exposure to off-spec temperature. Again, although they reach the conclusion that no general statement or model can be reached, they provide an empirical estimate for the likelihood that certain thermal, mechanical and electrical off-spec stresses may or may not trigger a thermal runaway. Several research works were carried out to understand the contribution to

the thermal runaway phenomenon by the various constructive or technological elements of BESS: anode, cathode, separator, electrolytes, casing, etc. These works show a large variability in thermodynamics and kinetics for reaction' required conditions, energy release rates, temperature evolution and propagation/extinguishing times for gaseous and solid components involved or released during the event. [9, 10]

It is interesting to note that if the interpretation of single triggers proves to be difficult, the combination or concatenation of their effects (real world case) is extremely challenging to comprehend, to model and to control with guidelines or with protection measures or devices.

Although catastrophic events are for sure a topic of great concern for both the industry and the insurance sectors, the topic of the evaluation of residual life of BESS is also extremely interesting and potentially of very high impact for what concerns economic aspects, especially after an insured loss.

As a matter of fact, due to their typically long payback period, it is of fundamental importance to estimate the residual life of a BESS after an event damaging or obliterating part or all of the storage system. A fair quantification of the financial loss due to the physical loss of an asset of this kind cannot leave aside the consideration that these systems have an intrinsic but difficult to assess rate of performance decay, connected with their operational pattern, maintenance and environmental conditions. [11, 12]

It may not be of secondary importance, for insurance matters, to consider the possibility of cyber-attacks aimed at sabotaging the complex control logic that manages the correct operation of a BESS. Malicious software could be designed and installed to produce a range of damages, from less easily visible (but economically costly) accelerated decay of performance or health of the whole storage system to a more spectacular thermal runaway event.

Finally, it is worth mentioning that catastrophic events like fires and explosions, with release of potentially toxic and flammable gases and fumes, and with shock waves able to produce mechanical damage at a fairly long distance. This may also be the trigger for third party liability claims, both for bodily injury, accidental death and for third party property damage and interruption of business. [13]

## 5.1 Electrical Breakdown

Regardless of the battery technology used, the electrical systems supporting large-scale energy storage are the same consisting of grid-tied power conversion systems with a controller to maintain an electrical balance of system

### Inverters

Utility scale storage projects use either large central inverters or rely on many smaller inverters. Typically, large storage inverters range from 500 to 2500 kW, are mounted on a concrete pad or skid, and are rated for the outdoors. Smaller storage inverters range from 50 to 250 kW, are rated for the indoors, and are installed on the floor or a rack. The power inverter is critical to provide the direct interface with the batteries. The inverter charges and discharges the batteries and also provides the expected grid regulation functions, complying with appropriate power quality requirements and supporting the grid during abnormal conditions with high, low and frequency ride-through functions.

### Switching and Metering

The electrical solutions supporting energy storage include everything from AC and DC switching and protection, to medium-voltage step up transformers for grid distribution. Typically, the utility dictates the requirements for switchgear and metering.

### Monitoring and Control

An energy storage system controller is the interface between the battery management system (BMS) and the utility or building control system and supports specific application requirements like frequency regulation, renewable firming, load shifting, or demands made to the system. Best practices for energy storage control systems dictate that they are modular and scalable when designed for large-scale, utility applications. The controller for the energy storage system typically needs the ability to operate in both grid-connected and islanded modes. Control systems should allow for monitoring of process variables from a continuously manned location and as a minimum allow for higher level actions to be carried out. Remote actions should as a minimum include isolation from the system by tripping the main breaker and/or placing the system into a standby mode.

Online condition monitoring systems are designed with self-diagnostic capability and as a minimum, the following parameters at the battery module and/or cell level:

- Charging and discharging voltage and current
- Resistance
- Module and room temperature
- Capacity
- State of charge (SOC)
- State of health (SOH)
- Alarm or fault log

The monitoring systems are designed with the ability to transmit data to a continuously supervised station and signal alarms when unusual conditions are detected. OEM personnel most likely will be able to remotely log into the BESS system and analyse alarm data. Operators have the ability to analyse monitored parameters and generate a summary of the condition of the battery system. Operator security to prevent unauthorized changes of critical parameter limits, such as voltage, temperature, and current need to be properly managed.

## Electrical System Protection

- A system short circuit and protection coordination study needs to be completed to confirm the adequacy of rating and relay settings for existing circuit breakers.
- Provide automatic isolation of affected modules when the battery management system (BMS) fails to operate (i.e., a fail-safe design for BMS). BMS failure to operate can be caused by BMS electronic components failure or loss of its power supply
- Provide temperature monitoring with high alarm for battery room/container. Have alarms routed to a continuously supervised station

## 5.2 Mechanical Breakdown (MB)

The failure of the majority of the BESS components will result in a loss of output/storage capacity, rather than a total loss of generation. The main components of the BESS are based on solid state systems, therefore mechanical breakdown failures will usually result in a requirement to replace the entire component affected. Currently components are sized in 1-2MW capacity and connected in parallel to provide the required output. Most plants are likely to have a single point of failure associated with the generator step up transformer and/or within the HV systems.

Lead times of 3-6 months are typical for inverters, charging systems, battery management systems etc. Mitigation will involve critical spares which need to be correctly stored in climate controlled areas and subject to OEM guidance for regular viability testing, as required.

Inverter costs (1MW capacity) may average \$100,000 to \$200,000 plus depending on configuration and design. As with most “new build” projects, caution on replacement pricing should be exercised as the initial project costs for equipment may not be representative of the market value of one off spares.

### **Risk Assessment Loss Control Measures**

- Staff Training by the OEM to comprehensively cover Operations and Maintenance practices with refresher sessions.
- Weekly on site visits for remote installations are considered appropriate or when an issue is suspected.
- The on-site inspection should be fully documented per OEM instruction and include:
  1. Visual inspection of all areas
  2. Review of any standing alarms
  3. Review of security
  4. Review of building/container condition (for environmental damage)
  5. Inspection for rodent activity
  6. Review of site storage conditions
  7. Other normal loss keeping inspections
- Electrical preventive/predictive programs should include thermographic inspections at peak load and be carried 1 month after initial energization of the system and thereafter, annually on all connections/systems under operation. Electrical inspections should be performed in accordance with NETA guidelines or equivalent (grounding and bonding, relays and breakers). Electronic parts such as boards, sensors, relays, and fuses, may require replacement as necessary. Solid state components are easily replaced and critical ones should be held in an inventory of spares.
- Inspect HVAC system inspection every six months.
- Float check and calibration of battery charger annually.
- Test operator annunciations to the central control room for operator response annually.
- Fire protection and detection system maintenance and testing (NFPA reference).

## Life Cycle Management

The OEM will establish an expected service life for a BESS. This will be the number of years that the system is expected to perform adequately. This establishes budget and replacement or refurbishment timelines for critical components. The life cycle program should include a trend of operational abnormalities that may influence or decrease the replacement intervals. Unexpected component malfunctions or failures and operating outside design parameters can age batteries faster than when operating within design. Consultation with the OEM for engineering disposition is preferred and prudent to assess warranted interval adjustments. Replacement timeline adjustments due to accelerated ageing could be indicated by the following:

- Significant step changes or trends in condition monitoring data.
- Serial cell failure during operation.
- Exposure to severe environment conditions. An extreme environment is one that could allow cell-level temperatures to rise or fall outside the normal operating temperature range of 32°F (0°C) to 212°F (100°C) despite BMS control. Thermal management components, such as a common condensing unit (cooling tower), are designed to shut down in the event of a component failure.

## 5.3 BESS Fire

Fire is a major risk for a BESS installation, especially for those using Lithium based technology.

### Susceptibility to fire

The intensity and speed of development of a lithium-ion fire depends on the lithium-ion cell chemistry. Two of the most common chemistries are the lithium nickel manganese cobalt (Li-NMC) and lithium iron phosphate (LiFePO<sub>4</sub>). The LiFePO<sub>4</sub> chemistry is more robust and is better suited for high temperature operations above 40°C. The Li-NMC chemistry is however better at storing energy with comparably better power and energy densities. The thermal runaway temperatures are however very similar between the chemistries with 180-220°C (Li-NMC) and 270°C (LiFePO<sub>4</sub>).

### Causes of fire

Fires can occur in many ways, but the predominant causes of fire are listed below:

- Thermal runaway: There are several known causes for an energy storage system to reach thermal runaway. Thermal runaway originates from a damaged cell that can, for instance, be the result of manufacturing defects, mechanical failures, overheating, overvoltage charging or BMS failure. During a thermal runaway event, the electrolyte starts to boil and this can happen at temperatures

as low as 80°C. When the electrolyte does this, the fluid expands at a drastic rate, which causes the cell to expand. Rupture of the cell enclosure causes a release of combustible gasses. The solid electrolyte interface (SEI) starts to deteriorate at around 120°C and 200°C is the point of no return, at which point the temperature will start to increase faster. An exothermic reaction commences at this stage, generating even more heat that can initiate a fire. Other cells rupturing could ultimately cause a domino effect and lead to catastrophic failure of the entire facility.

- Manufacturing defects: If there isn't enough space for the electrodes and the separators. During charging the battery expands due to the heat which could cause the electrodes to bend and short circuit.
- Mechanical failures: Li-ion batteries are very sensitive to mechanical damage, i.e. external forces, which result in short circuit. A certain level of robustness to the product must therefore be provided.
- Overheating: Extreme heat is very likely to cause a failure. If batteries are located close to a heat source or caught in a fire this has been known to cause adverse effects like explosions. If generated heat is higher than the heat dissipation this leads to thermal runaway.
- Electrical fire: overcharge can cause a large increase in temperature due to the exothermic (release of energy) reaction. Over discharge has a similarly damaging effect on lithium cells.
- Failure of control system (BMS): The battery management system (BMS) monitors and protects the lithium-ion battery packs. If the system fails there is nothing that ensures safe operations and will eventually lead to thermal runaway.
- Low quality cells will not perform as intended and will eventually fail.
- Operational error: Careless operations allowing over-charge and/or over-discharge, using the system at elevated temperatures, charging allowed to take place below minimum temperature, using the cells above specified maximum currents or prolonged use at maximum currents.
- Human error during installation.

### **Issues when extinguishing fires - *History of losses & why it happens?***

If a lithium-ion battery fire occurs, it is in some cases possible to cool it, have it contained and suppressed. One can however not be fully certain that the fire has been extinguished due to the issue of thermal runaway. A lithium-ion fire does not require oxygen to “burn” in the ordinary sense of the word, and may therefore be referred to as a “chemical” fire.

## Loss prevention

- Construction
- Spatial separation
- Passive protection
- Fixed protection

The only way to stop the exothermic chemical reaction is to cool the battery. To achieve this very large amounts of water are needed. Unlike lithium metal, lithium ions do not react to water and are therefore considered a safe application. Special protection systems like gaseous extinguishing can temporarily put out the fire but since these don't provide any cooling the exothermic reaction can still continue.

### 5.4 Fire protection standards and codes

As shown above, there are various reasons for fire or explosion in lithium ion battery systems but the following are the widely accepted scenarios of possible causes.

Electrolytes are sensitive to heat. When electrons move in a state where strong current flows or a high temperature environment such as a midday vehicle is moved, a chemical reaction occurs and gas or heat is generated. If heat is generated and chemical reactions occur violently, the lithium ion battery will be in a congested state and in the worst case, explosion or fire may occur. Therefore, battery temperature management is very important.

Also, overcharging is dangerous if the energy stored in the battery exceeds the rated capacity. The lithium ion battery is overcharged if too many lithium ions move to the anode. This will be prevented by the Battery Management System (BMS) which will incorporate a safety device (Circuit Protection System) to automatically stop charging when the battery is saturated.

According to the National Fire Protection Association (NFPA), fires are classified into five different kinds (Classes A, B, C, D, and K).



The classification of a Li-ion battery fire can vary, but generally fits into classes A, B, or C. In some cases, a Li-ion battery is used as the power source, and the fire involves electrical devices. In other cases, a fire caused by a Li-ion battery can spread and ignite nearby materials. Fire extinguishers for Li-ion batteries vary based on the extinguishing agent, such as dry chemicals, carbon dioxide, foam, water, halons, and dry powders. However, it is not easy to decide which agents should be used to suppress the fire as the proprietary information is confidential on battery technologies used between manufacturers. Battery chemistries for ESS have been developed for over a decade and new battery technologies will continue to be developed for the foreseeable future. Manufacturers are not incentivized to share proprietary information on their latest battery chemistry or technology, which makes the application of codes and standards, as well as the identification of a proper emergency response plan, more difficult. Information on the chemical makeup or physical and health hazards presented in the form of MSDS needs to be carefully reviewed and verified. Systems are mostly categorized based on energy capacity (kilowatt-hours) only, which is not very helpful in assessing their fire risks. For hazard assessment purposes, it would be better to categorize ESS batteries by technology and chemistry, as hazards differ significantly among those. Many of the current battery technologies can be categorized into Lead Acid (vented, VRLA), Nickel Cadmium, Li-ion, Sodium Sulfur (NAS), and Flow Batteries (tank based energy storage). There are other types of batteries, sometimes in the form of a hybrid between these battery types or the materials used. Therefore, this categorization can simplify the differences and may change in the future as new technologies emerge.

Battery chemistries differ among ESS installations, so specific extinguishing agent(s) need to be matched to the hazard(s). A single agent may not provide optimum protection characteristics depending on the specific ESS application they are protecting. Regardless of whether active fire protection systems (water sprinkler systems, gaseous suppression systems, etc.) and/or passive fire protection systems (separation, location, etc.) are employed, they are all dependent on how ESS battery types and chemistries perform in fire situations. Often different battery technologies perform differently under the same conditions.

Among various kinds of extinguishing agents, carbon dioxide can be used to suppress fire, but it does not cool the battery down. Putting out a Li-ion battery fire requires both extinguishment of the open flame but also reduction of battery temperature. If battery temperature is high enough after the open flame is extinguished, there is still a possibility that the battery will reignite. In one test, a battery fire reignited 22h after the open flame had been extinguished. In the event of a fire where a sprinkler system is activated, there is the risk of damaging the surrounding batteries that are not involved in the fire and substantial cleanup will be required. Water is efficient at extracting heat from a battery fire but often the batteries are located on shelves, on racks and inside

cabinets, which can make it difficult for a sprinkler system to apply water directly to the battery itself. However, testing has shown water and sprinkler systems can be effective for extinguishing a lithium battery fire. Additional verification is still needed to determine the appropriate water application rate for an ESS. In general, large amounts of water have been shown to be effective, yet chemical suppressants need to be considered for batteries that are water-reactive.

NFPA's Fire Protection Research Foundation sponsored an ESS safety workshop in November 2015. NFPA also set up a technical committee to develop new standard for the installation of stationary energy storage systems NFPA 855 which address the design, construction, installation, and commissioning of ESS. The new standard is expected to be released in late 2019.

The International Code Council, publisher of the International Fire Code, has already developed a code language that addresses design, installation, and deployment for a successful emergency response in the event of a fire. This code was included in the 2018 edition of the International Fire Code.

FM Global has been working on a new Property Loss Prevention Data Sheet for Energy Storage Systems, DS 5-33. It was released in February 2017. This new data sheet addresses many aspects of energy storage systems including protection, operation and maintenance, emergency response and contingency planning.

From these various workshops and discussions a level of consensus was reached that allows the code practitioner to address fire and life safety issues originating from the installation and deployment of energy storage systems. You can compare the difference from the following table but the main recommendations on fire prevention are almost in common.

### ESS Safety standards/code comparison

<https://www.nfpa.org/News-and-Research/Publications-and-media/NFPA-Journal/2019/May-June-2019/Features/Energy-Storage-Systems>

	NFPA 855 draft	FM 05-33	IFC 2018
Registration	Late 2019	Feb 2017	August 2017
Min Capacity to be applied	20kWh	20kWh	20kWh
Max allowable quantities	600kWh	600kWh	600kWh
Over 600kWh	To be installed in the dedicated building	-	-
Ventilation	25 % the lower flammable limit (LFL), or where the level of toxic or highly toxic gas exceeds 1/2 the IDLH <sup>(3)</sup>	-	25 % the lower flammable limit (LFL), or where the level of toxic or highly toxic gas exceeds 1/2 the IDLH
Separation between groups and walls	Min 0.9m for every 50 kWh	Min 0.9m (If UL certified 250kWh)	Min 0.9m (If UL certified 250kWh)
Separation between ESS enclosure	-	6 m separation or minimum 1 hour thermal barrier	-
Sprinkler	0.30 gpm/ft <sup>2</sup> (Min 12.2 L/min/m <sup>2</sup> )	0.30 gpm/ft <sup>2</sup> (Min 12.2 L/min/m <sup>2</sup> )	Based on NFPA 13
Max. sprinkler room area	230 m <sup>2</sup>	230 m <sup>2</sup>	Based on NFPA 13
Alternative fire suppression	If testing shows they are effective	-	If sprinkler cannot be used
Construction (Fire rate)	1 hr	1 hr	1 hr

(3) IDLH: Immediately dangerous to life or health

UL also developed the UL 9540A Test Method to help manufacturers have a means of proving compliance to the new regulations. Leveraging the long practice of developing standards with vast experience in similar industries and deliver a viable test method to accelerate adoption of innovative technology. UL9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems, was developed by request of industry members and authorities to address fire characteristics of battery energy storage systems that undergo thermal runaway. The data generated, as a result of this analysis and evaluation, was used to determine the fire and explosion protection required for an installation of a battery energy storage system and support installation according to local codes and regulations.

The current ICC International Fire Code (2018 IFC) allows an individual battery energy storage system (BESS) unit not exceeding 50 kWh and having a maximum quantity of systems totalling 600 kWh of energy per indoor fire area (battery room). The 2018 IFC and the draft NFPA 855 standard for installation of energy storage systems currently limits the individual BESS unit size for UL 9540 listed units to 250 kWh. These BESS units are to be installed with separation distances of 3 ft (1 m) between units and between units and any wall. The latest IFC and NFPA 855 drafts allow the code official to approve larger individual BESS units, and separation distances less than 3 ft. based on large scale fire testing conducted in accordance with the UL 9540A Test Method.

Results from the UL 9540A Test Method address the following key issues identified by building codes and the fire service:

- BESS Installation Instructions
- Installation Ventilation Requirements
- Effectiveness of Fire Protection (integral or external)
- Fire Service Strategy and Tactics

Overall, we can summarize International codes and standards relating to Lithium batteries. UL Certifications are already in use before 2017 but with the increase concerns on Lithium ion batteries, UL9540A was additionally adapted in 2018.

Classification	Standards & Codes	
Manufacturing of batteries, ESS	<ul style="list-style-type: none"> <li>▪ UL 1642: Lithium batteries</li> <li>▪ UL 1973: batteries for use in stationary, vehicle auxiliary power and light rail</li> <li>▪ UL 9540: Energy storage system and equipment</li> </ul>	
Construction, installation of ESS	<ul style="list-style-type: none"> <li>▪ NFPA 70</li> <li>▪ NFPA 855: standards for the installation of stationary energy storage systems</li> <li>▪ IFC: the international fire code</li> </ul>	
Additional testing for BESS	<ul style="list-style-type: none"> <li>▪ UL 9540A: test method for evaluating thermal runaway fire propagation in battery energy storage systems</li> </ul>	<i>Introduced in 2018</i>

## 5.5 Life Potential of battery storage systems, wear and tear and performance decrease over time

Whilst battery storage concepts have been around for many years, the rapid growth associated with the deployment of large scale renewable energy power systems means that the performance of new technologies (and older ones that are being scaled up), can provide limited time for them to be evaluated for the purposes of insurance underwriting.

In the first instance, there is the need to monitor and measure. How many losses, what were the causes, how much did they cost? All these and other questions are

prerequisites for the risk to be modelled and for the coverage to be tailored to the risk. Then, there is the process of adjustment. How to measure the loss, can it be mitigated? Overarching this are the fundamental questions of underwriting. Is there an alignment of interests, especially where batteries are used to supplement a more complex system? Following a major incident, would radiated heat cause degradation to the facility that might increase the risk of a future BESS failure? Have extinguishment water and/or corrosive products of combustion found their way in to the BESS, perhaps via the air conditioning equipment?

The underwriter will want to consider what clauses should be included and how ambiguity is to be avoided where standard exclusions for wear and tear, gradual deterioration and corrosion are involved? Are there any market norms that need to be taken into consideration or, have any legal precedents been set via settled claims that might impact on the underwriting process? Are the long term risks associated with degradation of battery systems fully understood? If the premium for a BESS project is benchmarked to current market conditions but a loss event occurs several years later, perhaps in the maintenance period, to what extent might the premium adequately reflect the future cost of reinstatement? If BESS technology has made significant progress in the meantime, will betterment be an issue?

One of the basic questions concerning the insurance of a BESS must surely be the need to know whether the cover is to be on a "new for old" or alternatively, an "indemnity" basis. The latter being where deductions are made for lifetime degradation or for "fair wear and tear", as it is often referred to. There clearly needs to be a price differential between the two but the problem might be more complicated than first appears. Questions about betterment, the application of restrictions on cover for prototypical technology, series loss adjustments or the application of a "local authorities" clause, which may require reinstatement in a particular way and that carry with them certain cost implications.

This naturally leads to considerations about life potential, performance decrease and how these impact the final settlement of a claim, if at all. It should also be at the forefront of an underwriter's mind when first evaluating and negotiating the terms for a risk.

In most systems, cyclic loading patterns, which may be factors in both the short and long term, tend to decrease the overall performance of the systems, and in the end, are a cause of failure. However, in the case of batteries, some exercising of the system can be positive, rather like turning over an engine to prevent it from seizing. A properly configured BESS control system will incorporate software to maximize the benefit of this whilst minimizing the negative effects, for example, of rapid charging. From an underwriting point of view, it may be assumed that a commercial scale system will be thus configured. However, the cycle management and overall usage pattern remains an issue for consideration. If the degradation of the system is linked to the type and

extent of cyclic loading, then the underwriter might wish to build a formula into the cover to assist the adjuster in the adjustment of a claim. Such mechanisms are sometimes seen within engineering covers for contractor's plant and equipment. For example, for indemnity to be based on new for old up to a certain age limitation and thereafter for a percentage decrease to be applied according to number of years but subject to an agreed maximum. An alternative approach might be to agree a fixed value prior to inception, subject to a long-term maintenance agreement with a recognized third party company.

Another consideration is whether there might be salvage value after a loss. This could be in the form of re-sale of partially or slightly degraded units, or the scrap value of condemned units. In respect of the latter, a fire might cause direct physical damage but there is also the possibility of units being considered a "Constructive Total Loss" (often referred to as a "CTL"). In such instances, a judgement will be needed as to whether the cost of repair exceeds the cost of replacement. Whereas this might present clear-cut alternatives, it is nevertheless possible that in marginal cases, discussions will take place around the possible performance attenuation and/or lifetime degradation of the system. Scrap value, in terms of metal price multiplied by tonnage may be another mechanism to consider. This could be especially appropriate for lead acid units, where the lead plates constitute the bulk of the weight and can be easily referred to scrap metal pricing. More complicated, perhaps, would be the valuation of rarer metals although it might be expected that such materials would also be of interest from a recycling point of view. Another thing to take into account is the possible use of published references such as indices and price listings for equipment sold at auction, for example. In this respect, it might be possible to source equipment from second-hand dealers and/or manufacturers selling re-conditioned equipment. Typically, companies specializing in used electrical transformers, which could be useful to mitigate business interruption where long lead times are in play.

New equipment supplied to a project, will be subject to certain statutory and contractual obligations. The enforceability of these will either be prescribed in the purchase agreement or written into the relevant statutory instruments and regulations. (Questions might arise around "merchantable quality" or "fitness for purpose", for example). Consequently, it may be assumed that even for operational BESS equipment that has been running for some time, there is the potential for discussions around lifetime degradation and the associated expectations of both the supplier and purchaser (or insurer) concerning the longevity of the system. In particular, it should also be held in mind that a manufacturer's warranty and product performance guarantees, will come with obligations around operations and maintenance. The underwriter should consider these at the outset and in the event of loss, the adjuster should investigate and report on their application, accordingly.



## 6. Underwriting: Third Party Liability

The BESS stores a very significant amount of energy in a relatively small volume and the restitution happens via a chemical process.

Batteries are used to power various types of machinery in an industrial setting and commonly used to provide backup power to critical train systems during a power cut or in case of an emergency. To maintain large banks of energy, facilities often have charging areas where multiple batteries are recharged at the same time. Gases released or produced by batteries while being charged could be a significant safety concern, especially when located in a poorly ventilated or an enclosed environment.

Studies have identified three common third party hazards related to batteries, namely:

### Fire and Explosion

Overcharging or malfunctioning of lead acid batteries could produce great amounts of hydrogen, oxygen and sulfur – this usually happens when batteries are old, damaged or heavily corroded. Typically, hydrogen is not toxic, however at high concentrations it becomes a highly explosive gas. LEL concentration for hydrogen is 4% at which a source of ignition could lead to an explosion. Sparking from a connected battery charging terminal could be a root source of ignition and hence it is always recommended for batteries to be charged in a well-ventilated area (that could maintain the hydrogen concentration levels).

Bulk storage of multiple batteries in close proximity adds potential threat due to risk of contagious overheating.

Deteriorated, damaged and old batteries are likely to be associated with leakages (release of  $\text{SO}_2$ ) and deformed or over pressurized batteries are associated with explosions (release of  $\text{H}_2\text{S}$ ).

Lithium-ion batteries and accumulators will react differently in the event of a fire in comparison to lead batteries or NiCD or NiMH batteries where the electrolytes are water-based. Lithium-ion batteries usually contain flammable components (including polymer separators, electrolytes, and having various adhesive agents like graphite in electrodes and anodes). Despite technological and standards advancement, most accidents and fires occur due to uncontrolled release of battery's chemically stored energy due to structural defects, technical defects, mechanical damage, thermal stain, or overloading.

Normally thermal runaway is a typical fire scenario for Li-ion batteries and accumulators. The interior of the battery heats to around  $80^\circ\text{C}$ , causing steam and gas to appear in the cell – a chain reaction is triggered during this process and at the



temperature of 120° C the anode and cathode separator melt. This would lead to a short circuit and thermal decomposition of the cathode, post which oxygen and heat energy would ignite the materials in the anode, electrolyte and cathode where the temperatures could rise up to 1000° C. The potential danger of this varies on the output of the battery and product design itself. In case of a low output battery the risk is relatively smaller, however this could be catastrophic for high output batteries or for batteries stored near or in an industrial setting.

As a safety measure it is imperative to monitor controls for the charging and discharging process, including regular maintenance of batteries or monitoring of hydrogen levels, excessive temperatures and obsolescence as this would assist in mitigating risks in the event of red flags being raised.

Many explosion and fire events are known to all, however the threats posed by toxic gas emissions and source of these emissions are not well understood.

## **Leakage**

Leaks are mainly a concern for lead acid battery systems. The envelope containing the battery can deform when subject to overheating and cause leakage of sulphuric acid which is harmful to human health and is also corrosive.

## **Environmental Impacts**

Accidents affecting battery storage can also have a very significant impact on the properties or health of third parties.

Fire tests carried out by NFPA on lithium ion batteries have shown that significant amounts of hydrogen fluoride can be released. This gas, when in contact with water (for example used to extinguish the fire), becomes hydrofluoric acid, one of the most corrosive types of acid, which can even dissolve glass. Hence, if such a gas reaches surrounding properties, decontamination measures will need to be implemented. These gases also have a very detrimental effect on the respiratory system, and some precautionary measures like of evacuation of the population may also be needed.

## **Additional considerations**

Due to the nature of battery energy storage systems, it is important that the underwriter clarifies what or who is a third party. For instance, the installations can be installed in third party properties with a specific lease contract. Such documents usually define the TPL insurance requirements and can be of help to the underwriter when assessing the exposure.

## 7. Underwriting: DSU and BI

Up until recently, most battery storage systems were in the range of up to 20MWh and revenues were rather moderate. We are now seeing the construction of battery storage systems of 100's of MW and some utilities proposing projects in the range of 1200MWh.

The increasing size of these projects will pose a complex question about how to assess the Delay in Start-up and Business interruption exposure. Underwriters typically understand well the nature of the PD risk for most risk types within the Power Generation/Transmission sector but it is often difficult to understand the mechanisms through which clients are generating revenue in complex markets. Battery storage will be a new subject for Underwriters to cope with. Furthermore, it will be necessary to adapt some policy wordings for Business interruption to match the exposure.

A significant number of battery storage projects will be built purely for grid stability and could be generating revenue on a fairly simple availability based but the possibility of opening up the energy market to large scale battery storage for pure arbitrage will pose a very complex business interruption scenario when huge variations in costs and charging/discharging strategies come into play.

### Assessing the Sum Insured for DSU/BI

For many battery storage projects it is very difficult to estimate the DSU/BI sums insured because clients may not know in advance how many services and to what extent the project will be used for. For Battery projects which are planned to operate as pure energy arbitrage or also peak shaving type functions, it is almost impossible to determine what the potential revenues will be. Other battery storage projects such as those in the UK are also subject to auction tenders and these results may not be as expected.

Both costs and revenue are potentially extremely volatile in markets which huge variations. For these reasons underwriters may give consideration to monthly caps on DSU/BI in order to avoid extremely high losses.

Battery storage systems operating as pure energy arbitrage will make money purely from the differences between charging at low cost and discharging when the \$/MWh is highest. Considering the possible differences in market pricing with some markets having extreme spikes it would be wise for underwriters to consider on a cap on discharge \$/MWh in order to avoid potentially large DSU/BI claims. However, not all

energy markets are configured to use energy storage systems currently but this may change in the near future.

Some large industrial facilities may decide to build large battery storage facilities for "behind the meter" storage to avoid peak demand charges. These charges are levied based on the maximum amount of energy used over a very short time during a given term which could be a year. These charges can make up around half of the energy bill for some clients and the economics may well dictate the need for large batteries, especially in some US states such as California and New York.

### **Battery Storage systems integrated with Renewables**

Due to the intermittent nature of renewables, there is a greater need for grid stability technology and battery storage can play a major role in stabilising the grid due to the fast reaction time of batteries compared to other previous technology types used for this role. Considering a project where batteries are built alongside a windfarm or solar plant, be aware that the ability of the batteries to store long term energy from the wind or solar plant will be negligible. Take for example a 250MW windfarm with a 20MW battery storage facility. If the grid does not take the power, then the batteries would not be able to absorb the energy for more than several minutes before they are fully charged. Therefore, the primary role of batteries is in grid stabilization rather than to absorb excess renewables production. Battery storage projects may be built next to renewable facilities in order to use common facilities such as grid tie such as transformers, switch yard etc.

Source: 22MW energy storage scheme co-located with the 228MW Pen y Cymoedd wind farm in Wales  
<https://renews.biz/31667/vattenfall-battery-charge-at-pyc/>

## Loss Adjusting for DSU/BI

Loss adjusting for DSU/BI could be a very complex for forensic accountants especially for projects that foresee a place in energy arbitrage. It will be unreasonable to suggest post loss that the operator of a plant would have had in place the optimal bidding strategy for the market. Loss adjusters will have to try to calculate the lost opportunity considering a reasonable capacity bidding strategy. For business interruption there may be some trending of the business that can be considered when arising to a reserve. This should be taken into consideration when arriving at a reserve in case of loss.

As battery storage projects will be operating often with "stacked revenues" as a result of several contracts and possibly energy arbitrage, the Loss adjuster will need to assess which of those revenue streams would have been given priority.

An additional complication for some projects is that they may operate in a market which requires a tender process and during the loss adjustment process the adjuster will have to determine how successful the project would have been during the bidding process had the project not suffered a loss. Some markets offer more certainty by offering longer term contracts of several years duration. What if the project is delayed and misses the auction for capacity?

For some Battery storage systems the charging may at many times of the year be free or the system could even be paid to charge. This would occur when the \$/MWh pricing is negative which is often the case when there is an excess generation typically arising from renewables.

Some systems maybe rather simple in the case that they are being paid on an availability basis or paid a fee for providing a frequency regulation service or spinning reserve.

## **Deductibles**

Several energy storage systems have been brought to the insurance market and typically have a DSU/BI deductible not dissimilar to other types of power generation risk types such as Combined Cycle Power Plants (CCPP). However, these systems are designed to operate for very short times and therefore clients involved especially in energy arbitrage may possibly find themselves missing a large income in a timescale of a matter of hours/days in the case of a minor failure. The insurance industry may need to adapt how deductibles are specified in order to consider the short-term nature of the operation of such plants.

## **Extra Expense**

Extra Expense coverage in the case of battery storage systems should be carefully considered and costs of replacement generation could, if not excluded, be potentially a large exposure.

## **Lead times**

Currently battery lead times are typically 7 months and therefore the indemnity period required by clients will of course sensibly be longer than this. The demand for battery storage is increasing but so is the development of new manufacturing facilities. It will be interesting to see if manufacturing capacity can keep up with demand in the next few years.

## Betterment in the case of future Improved efficiencies and performance

As existing battery storage systems age and performance deteriorates at the same time that newer batteries become more efficient (and cheaper) then there will no doubt be a potential betterment in the case of replacing say 20MWh of an old battery system with that of a new one. Both the round trip efficiency and battery capacity deteriorate significantly over time and this should also be considered in the case of any loss adjustment process.

Underwriters should consider development of battery specific wording in order to address the betterment issue especially as older battery systems age. Any short term BI loss maybe partly or completely compensated by the installation of a newer more efficient battery.

In the case of a loss incurring significant down time, the expected deterioration in lifetime of the project should be considered in the adjustment process due to the relatively short lifetime of battery storage devices.

## DSU/BI SUM Insured breakdown

### Typical Cost element

- Variable - Cost of charging (maybe in some cases free if based on strategy of charging at zero or negative pricing or when integrated with owned renewable (or even non-renewable) generation.
- Fixed - O&M Costs – possibly in range of \$6'000-\$14'000 per installed MW per year
- Fixed - Debt servicing if covered
- Fixed - Land rental (if applicable)
- Fixed – Insurance
- Possible Penalties in case of unavailability in times when System is required
- Depreciation of Battery Assets

### Revenue

- Multiple revenue streams from energy arbitrage, frequency regulation, peak shaving etc
- Payments maybe in the form of capacity payments (payments for making the service available, also called availability fee) and performance payments made when performing the service.

- Revenue of all types maybe difficult to estimate if the project is planned to operate in a market in which battery storage compete in an auction based system such as the UK Firm Frequency Response (FFR) bidding market.

### Probable Maximum Loss

## 8. Underwriting: Check lists and clauses

The purpose of this chapter is to support the Underwriter in the risk assessment and underwriting of BESS facilities. We have restricted the questionnaire and classes to lithium ion.

### Checklist for Lithium-Ion Battery Storage Projects

#### Project/Plant Overview

- Location of BESS
- What is the primary purpose of the BESS? (Frequency response/Peak shaving/Energy Arbitrage/ etc)
- PD value (breakdown as per subsystems: Batteries, SCADA and BMS, Inverters, Transformer, Power switches)
- DSU/BI Sum insured – breakdown of fixed and variable costs, Revenue for Availability, Any penalties for lack of availability
- Rating in MWh, Max Power Output, expected mode of operation, expected Depth of Discharge
- Project Duration
- Key Suppliers
- Is the BESS built into an existing Generation project? Will the BESS make use of existing facilities such as Substation/Control room, Switchyard etc.?
- Who is controlling the dispatch of the BESS system? Onsite or automatically from grid?

#### DSU/BI

- Understand how the battery storage system is making its revenue
- Breakdown of the assumed revenue by service provided. Fixed costs such as Debt servicing
- What assumptions/strategies are assumed in the operation of the BESS system

- Will the BESS provide only one service or multiple services
- How volatile are electricity prices in the market in which the BESS is operating and how does it impact the DSU/BI amount
- Is there a monthly cap on the DSU/BI figures
- Is there any seasonality in the revenue?
- What degree of redundancy is designed into the system?
- Is the Substation included in the project? If yes, then consider full DSU/BI for MPL considerations
- What are the lead times for replacement parts? Batteries, inverters, transformers

### Layout

- Will the BESS be a containerised system?
- How many containers/inverters/transformers? Does each container have its own Inverters/Transformer or are several containers connected to one inverter etc. What equipment is critical to overall capacity?
- Spacing between containers
- Is the site secured? Fenced, guarded?
- Cyber security measures?
- Are there any third party exposures nearby? Schools, housing etc.? At what distance?

### Fire Protection

- Details of fire detection and suppression systems. Type, capacity?
- Are they in accordance with latest NFPA 855 Standards?
- What is the procedure following fire within the facility? Will total flooding of the container be foreseen? Or simply watch and cool down?
- Has the local fire service been consulted on the project?
- Is an emergency response plan in place?
- Are all disconnects easily marked? Is there a nominated person to help deal with an emergency?

### NATCAT



- EQ, Flood exposure etc. and relevant design codes and mitigation measures (e.g. elevation)?
- History of flooding?

### Maintenance/Monitoring

- Who will provide maintenance of BESS? OEM/Third Party/Own staff?
- What maintenance is required and how often will it be performed?
- What are the testing requirements of the fire detection/Suppression systems
- Is the BESS system remotely monitored or on site?
- CCTV Monitoring inside the container?

### Others

- Any known issues with this battery type?
- How is the warranty for the components such as batteries? When do they start? At time of leaving factory or after commissioning?
- What is the battery anticipated lifetime for the said service/operation.
- Expected Performance degradation per year.
- Fixed costs such as Debt servicing
- What assumptions /Strategies are assumed in the operation of the BESS system

## Clauses :

### Battery Energy Storage Systems: Battery Depreciation Clause:

In the event of an occurrence to a component or components of electrical battery which have a life expectancy appreciably shorter than that of the energy storage system, the amount indemnifiable in respect of the items thus affected shall be depreciated.

The amount payable shall be calculated by taking into account:

- 1- the expired life (EL) in service hours of the component at the time of occurrence, and
- 2- the normal life expectancy (NLE) in hours of the component according to the plant specification

and then applying them in the relationship  $(1 - EL/NLE)$  to the total replacement costs (installed within the plant) of the component.

Should the normal life expectancy for any component or components indicated by the manufacturer be found to be in conflict with the operational and/or claims experience, an agreement on more realistic component life expectancies shall be reached between the insured and the insurer and shall supersede such advices of the manufacturer.

### **MPL (Maximum Probable Loss):**

Each company has its own methodology to determine the MPL and the following indications have just to be considered as directions.

The typical battery storage system is laid out in a containerised system which currently has a size of around 1-2MWh per container. Many containers make up the overall capacity of the project. This has several benefits such as ease of transport, design of fire suppression systems for enclosed space, minimum on-site work and so on. This is fortunately advantageous to the extent that the loss as a result of fire will be minimized to one container. This will limit also the DSU/BI to a single container.

Underwriters should also consider the possibility of transformer losses within the battery facility compound which may lead to higher BI/DSU loss in the case of single transformers servicing a number of battery storage containers.

Source : <https://www.windpowerengineering.com/business-news-projects/parker-hannifin-aes-deploy-large-scale-energy-storage-system-chile/>

A single building with all batteries contained within will pose an extreme DSU/BI risk and prove difficult to design fire protection systems which limit damage to restricted area.

Material Damage (MD) MPL scenario : Fire affecting the most expensive BESS unit/block as well as other battery units/blocks located within 100 feet. We can consider that these battery units will in turn catch fire due to an induced thermal run away.

In addition to the MD loss amount, the underwriter will have to consider the cover extension (removal of debris, etc...), the TPL amount as well as the DSU. The latter can be relatively complex and must reflect the plant architecture as well as the PPA. It must be reminded that numerous BESS are used as ramp up support, spinning reserve or power factor improvement units. Hence specific PPAs might have been concluded and the loss of profit or revenue is not necessarily proportional to the available electrical capacity.

## **9. Losses and repairs**

### **9.1 Loss exposures and types of causations of fire loss**

Whilst new technology is helping to drive both existing and renewable energy developments, several Li-ion battery-related fire and explosion incidents have been reported in recent years. However, the root causes for these are not always easy to identify. As BESS usage grows, it is becoming increasingly important to establish the possible reasons for these losses and the loss cases below provide some insights in this respect.

From Tokyo Sodium Sulphur battery fire incident (2011) and numerous fires in BESS in Korea (2019) and elsewhere, the following inferences can be made.

## **The defect of BMS (Battery Management System)**

As shown above, BMS controls the state of the battery. It monitors the voltage and charge status of the battery and protects the battery from overcharging as well as cell balancing to adjust the degree of charge. As Li-ion batteries have a risk of fire or explosion when exposed to heat, moisture, BMS plays a very important role in the system. However, if BMS is not working properly, they cannot monitor the abnormal conditions of batteries and can cause the fire or explosion on batteries. In most of the cases, this is related to manufacturer's defects and it's difficult to trace correctly.

## **Faulty workmanship and poor installation**

In some instances, BESS facilities are in remote locations where accessibility is not good. These can be small scale and the contractors are not specialized in working with battery systems or might not follow all the appropriate procedures or have the necessary experience. A typical case occurred due to incorrect connection of an anode/cathode without knowing the difference.

In other cases, the battery can be subject to rough handling, incorrectly packed in transit or badly handled by workers during installation. External shock is easily transmitted through the battery casing, resulting in damage to the separator and fire can easily result, particularly, when the battery cell membranes are damaged, which is difficult to identify from the external appearance.

## **No surge arrester installation**

Also, fire caused by lightning or ground fault is frequent. Some of the plants operate without installing surge arresters, which protect the facility from sudden inflow of high voltage electricity. Therefore, the batteries run over the designed current rating causing fires.

## **High temperature and humidity**

Li-ion batteries are vulnerable to heat. Therefore, the temperature of the BESS room should be climate-controlled with an ambient temperature maintained around 23 ° C and humidity at 80% or less. If the indoor air conditioner fails and the room temperature rises, the electrolyte is vaporised, and the anode and cathode materials are oxidized. Therefore, the separator can melt causing thermal runaway. In some cases, it is advisable to install back up air conditioning equipment.

## 9.2 Loss Experience

### Toyko Sodium Sulphur battery 'Fire Incident' – 2011

On September 21, 2011 a fire occurred in NaS batteries used for storing power from The Tokyo Electric Power Company. These were installed at the Tsukuba Plant (Joso City) of Mitsubishi Materials Corporation. Although the manufacturer had been shipping this type of battery from 2002 and they had been installed in 174 locations in 6 countries around the world, the company ordered a temporary halt in production pending a safety review.

The cause of the fire is set out in a diagram below, from which it can be seen that molten material leaked from a battery cell causing a short between battery cells in an adjoining block. As there was no fuse between the cells, the current continued to flow, catching fire to the whole battery module. Hot molten material continued to spill over battery cell casings elsewhere inside the battery modules causing the fire to spread.

### **First Wind at Kahuku, Hawaii wind farm battery fires - 2012**

This incident resulted in the \$30million battery loss that closed First Wind's 30MW Kahuku project in Hawaii in 2012.

The first fire broke on Kahuku, west of Kahuku town on Oahu's North Shore, Hawaii, in March 2011. The project, which consists of 12 2.5MW Clipper Liberty turbines, included a battery storage system from Xtreme Power. It was also notable as being the first utility-scale project on the island.

On August 3, 2012 a second fire started at the project's storage facility. As the fire was so fierce, firefighters could not enter the building for several hours. They used dry chemicals to try to extinguish the fire, but this approach failed. Firefighters faced thick smoke, toxic fumes and other hazards.





## **Flagstaff, Arizona ESS fire – 2012**

An electrical fire atop McMillan Mesa in 26 November 2012 caused significant damage to a \$3 million installation. The incident occurred at two twinned energy storage systems of 2MW / 2MWh at the McMicken substation. Arizona Public Service (APS) began testing in February a new 1.5 megawatt system. The fire did not affect the nearby substation, as APS installed the equipment for the energy storage system away from the existing infrastructure.

## **Lithium – Ion Battery fires onboard Boeing Dreamliner - 2013**

An inflight lithium-ion battery fire broke out on an All Nippon Airways 787 over Japan, forcing an emergency landing. Another battery fire occurred aboard a Japan Airlines 787 at Boston's Logan International Airport. Both battery failures resulted in the release of flammable electrolytes, heat damage and smoke on the aircraft. At least four aircraft suffered from electrical system problems stemming from these issues.

### **Franklin, Wisconsin ESS – 2016**

A fire broke out at around 11:00 on 10th August 2016 at the facility on Franklin Drive and involved a bank of lithium ion batteries. Damage estimates were between \$3 and \$4 million. The fire began in a utility-scale energy storage system that was in a partially assembled state, which contained lithium-ion batteries. They were not in operation at the time, that is, they were not connected to a power source or load. The fire occurred when a technician from the battery manufacturer was working on the energy storage system and started in one of the manufacturer's DC power and control compartments adjacent to a battery rack. Once, the fire had taken hold it spread to the other batteries.

### **ENGIE, Belgium ESS fire – 2017**

The fire occurred on November 11, 2017 during the commissioning phase the Engie Ineo battery container test site in Drogenbos, near Brussels. The 6MW project was the first time a BESS was to be used for grid Frequency Containment Reserve services in Belgium. The facility was set to use the BESS for grid balancing via the primary reserve managed by Elia, the Belgian transmission system operator. The 1MW container was heavily damaged, despite rapid emergency response, the installation was damaged seriously enough to represent a "total loss" and two neighbouring containers by GE and Alfen also suffered light, but repairable damage.

The cause of a fire at Belgium's first grid-connected lithium ion battery energy storage park was still unknown months after the incident.

## **Various ESS fires in Korea – 2017 to 2019**

Between August 2017 and Jan 2019, there were 21 cases of BESS fire loss in Korea. As part of its policy to save electricity and expand renewable energy use, the government had given attractive levels of subsidies to stimulate the use of BESS technology. This led many entities to use the technology without enough verification of its safety and stability.

After the 21 fire cases, the government recommended individuals, companies and other organizations to stop using 584 uninspected BESS installations across the country. The move was aggravated by an energy storage system failure at a cement plant in Jecheon, North Chungcheong Province, which caught fire, causing \$3.63 million worth of damage.

At the time of writing, the results of the Korean government's probe into the incidents are expected to be released around second quarter of 2019.

Estimates of the fire loss amount vary from USD 1 million to over USD 10 million. The largest fire loss reported was the 47MWh facility at Daesung Industrial Gas Plant, Ulsan with a value of about USD 18.0 million.

**Addenda :**

The South Korea authorities have released in June 2019 a document summarizing the findings of the investigation: A translation of this document is available in Appendix 3

The four main fire causes are the following:

1. Temperature control
2. Negligence during construction
3. Operation negligence
4. PCS system and batteries not separated.

The points 1 and 4 are connected since the PCS system generates a lot of heat during charging which made it difficult to manage a constant temperature in the ESS storage. So now these are built separately. Point 2, relates to people dropping the units and still installing them. This has led to battery manufacturers sending a supervisor on site to be present during all handling as well as installing CCTV's for covering all handling. Point 3 is related to an operation outside of the battery specifications and more specifically overcharging.

## **10. Conclusion**

Battery storage systems are becoming more and more popular. This is caused by the growing importance of renewable energy and its inherent intermittency as well as by the falling price of Lithium Ion batteries which are now manufactured on a large scale. Though several types of battery coexist, the market clearly favors Li-Ion technology. Unfortunately, for such technology recent accidents have shown that an internal failure can trigger a so-called "thermal run-away" which can expand into a severe fire. Different authorities like NFPA or UL have issued standards to define the necessary fire protection. The most common is the NFPA 855.

BESS are not only used as a pure energy reservoir but can also have different roles like, spinning reserve, ramp up support, power factor improvement, peak shaving or peak shifting, black start etc. Because of this variety of applications, the underwriter needs to be cautious when underwriting Delay in Start-up covers.

## 11. Appendix 1: Battery basic vocabulary and definitions

### Units of Battery Capacity: Ampere-Hours

The energy stored in a battery, called the battery capacity, is measured in either watt-hours (Wh), kilowatt-hours (kWh), or ampere-hours (Ah). The most common measure of battery capacity is Ah, defined as the number of hours for which a battery can provide a current equal to the discharge rate at the nominal voltage of the battery. The unit of Ah is commonly used when working with battery systems as the battery voltage will vary throughout the charging or discharging cycle. The Wh capacity can be approximated from the Ah capacity by multiplying the Ah capacity by the nominal (or, if known, time average) battery voltage. A more accurate approach takes into account the variation of voltage by integrating the Ah capacity  $\times V(t)$  over the time of the charging cycle. However, because of the large impact from charging rates or temperatures, for practical or accurate analysis, additional information about the variation of battery capacity is provided by battery manufacturers.

### Battery State of Charge (BSOC)

A key parameter of a battery in use in a PV system is the battery state of charge (BSOC). The BSOC is defined as the fraction of the total energy or battery capacity that has been used over the total available from the battery.

Battery state of charge (BSOC or SOC) gives the ratio of the amount of energy presently stored in the battery to the nominal rated capacity. For example, for a battery at 80% SOC and with a 500 Ah capacity, the energy stored in the battery is 400 Ah. A common way to measure the BSOC is to measure the voltage of the battery and compare this to the voltage of a fully charged battery. However, as the battery voltage depends on temperature as well as the state of charge of the battery, this measurement provides only a rough idea of battery state of charge.

### Depth of Discharge

In many types of batteries, the full energy stored in the battery cannot be withdrawn (in other words, the battery cannot be fully discharged) without causing serious, and often irreparable damage to the battery. The Depth of Discharge (DOD) of a battery determines the fraction of power that can be withdrawn from the battery. For example, if the DOD of a battery is given by the manufacturer as 25%, then only 25% of the battery capacity can be used by the load.

Nearly all batteries, particularly for renewable energy applications, are rated in terms of their capacity. However, the actual energy that can be extracted from the battery is

often (particularly for lead acid batteries) significantly less than the rated capacity. This occurs since, particularly for lead acid batteries, extracting the full battery capacity from the battery dramatically reduced battery lifetime. The depth of discharge (DOD) is the fraction of battery capacity that can be used from the battery and will be specified by the manufacturer. For example, a battery 500 Ah with a DOD of 20% can only provide  $500\text{Ah} \times .2 = 100\text{ Ah}$ .

### Daily Depth of Discharge

In addition to specifying the overall depth of discharge, a battery manufacturer will also typically specify a daily depth of discharge. The daily depth of discharge determined the maximum amount of energy that can be extracted from the battery in a 24 hour period. Typically, in a larger scale PV system (such as that for a remote house), the battery bank is inherently sized such that the daily depth of discharge is not an additional constraint. However, in smaller systems that have a relatively few days storage, the daily depth of discharge may need to be calculated.

### Charging and Discharging Rates

A common way of specifying battery capacity is to provide the battery capacity as a function of the time in which it takes to fully discharge the battery (note that in practice the battery often cannot be fully discharged). The notation to specify battery capacity in this way is written as  $C_x$ , where  $x$  is the time in hours that it takes to discharge the battery.  $C_{10} = Z$  (also written as  $C_{10} = xxx$ ) means that the battery capacity is  $Z$  when the battery is discharged in 10 hours. When the discharging rate is halved (and the time it takes to discharge the battery is doubled to 20 hours), the battery capacity rises to  $Y$ . The discharge rate when discharging the battery in 10 hours is found by dividing the capacity by the time. Therefore,  $C/10$  is the charge rate. This may also be written as  $0.1C$ . Consequently, a specification of  $C_{20}/10$  (also written as  $0.1C_{20}$ ) is the charge rate obtained when the battery capacity (measured when the battery is discharged in 20 hours) is discharged in 10 hours. Such relatively complicated notations may result when higher or lower charging rates are used for short periods of time.

The charging rate, in Amps, is given in the amount of charge added the battery per unit time (i.e., Coulombs/sec, which is the unit of Amps). The charging/discharge rate may be specified directly by giving the current - for example, a battery may be charged/discharged at 10 A. However, it is more common to specify the charging/discharging rate by determining the amount of time it takes to fully discharge the battery. In this case, the discharge rate is given by the battery capacity (in Ah) divided by the number of hours it takes to charge/discharge the battery. For example, a battery capacity of 500 Ah that is theoretically discharged to its cut-off voltage in 20 hours will have a discharge rate of  $500\text{ Ah}/20\text{ h} = 25\text{ A}$ . Furthermore, if the battery is a 12V battery, then the power being delivered to the load is  $25\text{ A} \times 12\text{ V} = 300\text{ W}$ . Note

that the battery is only "theoretically" discharged to its maximum level as most practical batteries cannot be fully discharged without either damaging the battery or reducing its lifetime.

### Charging and Discharging Regimes

Each battery type has a set of constraints and conditions related to its charging and discharging regime, and many types of batteries require specific charging regimes or charge controllers. For example, nickel cadmium batteries should be nearly completely discharged before charging, while lead acid batteries should never be fully discharged. Furthermore, the voltage and current during the charge cycle will be different for each type of battery. Typically, a battery charger or charge controller designed for one type of battery cannot be used with another type.

## 12. Appendix 2: Battery types: Additional information (

### Sodium Sulphur (NaS) batteries

This type of accumulator has a solid state (sodium) electrolyte and a liquid state (sulphur) electrode. NaS batteries operate at high temperatures, typically  $>300^{\circ}\text{C}$ .

This type of accumulator is currently used in large scale battery storage systems for voltage or frequency stabilization of the public grid (mainly in Japan).

The requirement of an external heater to generate the necessary temperature for the cell to operate is also the main disadvantage of this type of accumulators.

As batteries serve a wide range of functions (from stationary to mobile applications and from powering consumer electronics to large industrial facilities), there is a wide variety of electrochemical energy storage technologies, each with different characteristics. Below we provide an overview of the different technology.

### Lithium-ion (Li-ion) batteries

Li-ion Batteries make use of a cathode (positive electrode) which is metal oxide, an anode (negative electrode) which is porous carbon, and an electrolyte. When the circuit is closed, the ions flow from the anode to the cathode during discharge, generating electricity. Charging reverses the direction of the ion flow.



Several types of Li-ion batteries exist:

**Lithium Cobalt Oxide ( $\text{LiCoO}_2$ ) batteries** use a cobalt oxide cathode, and a graphite carbon anode. Its high specific energy makes it the popular choice for mobile applications such as phones, laptops and digital cameras. The typical operating range of Li-cobalt cells is between 3 - 4.2V. Specific energy density varies between 150 and 200 Wh/kg and can go up to 240 Wh/kg for specialty cells. These systems can typically reach up to 1,000 charge/discharge cycles before performance is significantly reduced. The main disadvantages of Li-cobalt cells are their relatively short life-span, limited specific power capabilities, and low thermal stability, which causes overheating when the cell is charged at a current higher than its capacity,

**Lithium Manganese Oxide ( $\text{LiMnO}_2$ ) batteries** make use of lithium manganese oxide as the cathode material. The design of the batteries creates a 3-dimensional spinel structure that enables better flow of ions on the electrode. This provides higher thermal stability, as well as better safety, which makes Li-manganese batteries highly suitable for applications with high loads, such as electric vehicles and power tools. Main disadvantages are their relatively low calendar and cycle life, as they can typically reach up to 700 cycles. Li-manganese batteries can provide between 3 - 4.2V, while their specific energy density varies between 100 and 150 Wh/kg.

**Lithium Nickel Manganese Cobalt Oxide (NMC) batteries** are one of the most successful systems as the combination of nickel-manganese-cobalt at the cathode gives them the flexibility to be tailored for energy (higher capacity, lower current) or power (lower capacity, higher current) applications. This flexibility makes the battery ideal for a variety of applications, from electric vehicles (EVs) to medical devices and industrial applications. Another advantage is the reduced cost (compared to other Li-ion technologies) due to the (partial) replacement of cobalt with nickel at the cathode, which is cheaper. Like other Li-ion technologies, NMC have a typical operating range between 3 and 4.2V. Specific energy density varies between 150 and 220 Wh/kg, and batteries can reach up to 2,000 cycles.

**Lithium Iron Phosphate (LFP -  $\text{LiFePO}_4$ ) batteries** make use of iron phosphate in the cathode, which provides good electrochemical performance, and low resistance. The main advantages of the technology are long cycle life, good thermal stability, high tolerance to full charge conditions, lower stress if kept at high voltage for long periods, and high current rating. This makes them useful in applications that need high load currents and endurance, e.g. as a starter battery in vehicles, replacing lead-acid batteries.

As a trade-off, the Li-phosphate batteries have a higher self-discharge compared to other Li technologies, and lower nominal voltage around 3.2V, which reduces their specific energy density to 90-120 kWh/kg. Li-phosphate batteries can reach up to 2,000 cycles.

**Lithium Nickel Cobalt Aluminium Oxide ( $\text{LiNiCoAlO}_2$ , NCA) batteries** are similar to NMC ones. They have a high energy density of 200 - 260Wh/kg, operating range of 3 - 4.2V, and reach up to 500 cycles. They are typically costlier than the average Li technology, and are usually used in industrial applications, and electric powertrains.

**Lithium Titanate batteries** make use of titanate in the anode, instead of graphite in typical Li-ion batteries. Cathodes can be Li-manganese oxide, or NMC. Li-titanate has good performance at extreme temperatures and does not form a solid electrolyte interface (SEI) film or lithium plating when charging in low temperatures, or fast charging. Typical applications are electric powertrains and Uninterruptible Power Supplies (UPS). The main disadvantage of the technology is its high cost, as well as its low specific energy density of 50 Wh/kg. Typical operating range is 1.8 - 2.85V. Li-titanate batteries can reach up to 7,000 cycles.

## Flow batteries

Flow batteries are a type of electrochemical cell which is a cross between a conventional battery and a fuel cell. The energy is provided when two liquid electrolytes (metallic salts dissolved in liquids) are circulated through a common core (with the help of a pump) that consists of a negative and a positive electrode and separated by a membrane. This circulation generates an ion exchange between the catholyte and anolyte, which generates a flow current, and hence, electricity. Similarly, the reverse process is used to charge the battery. The biggest difference between conventional and flow batteries is that the energy is stored in the electrolyte (compared to the electrodes in conventional batteries). Hence, the volume of the battery dictates the battery's capacity.

There are several types of flow batteries:

**Redox flow batteries** (*reduction-oxidation*) are the most commonly used flow batteries, where electricity is generated due to the difference in potential of the two tanks. When discharged, both tanks hold the same electrolyte solution – a mixture of positively and negatively charged ions. Materials commonly used in redox flow batteries are Vanadium-Polyhalide, Vanadium- Vanadium, Bromine-Polysulfide, Iron-Chromium, and Hydrogen-Bromine<sup>4</sup>.

In **hybrid flow batteries**, one or more electro-active components are stored as a solid layer. The electrochemical cell contains one battery electrode and one fuel cell electrode. Typical materials used are Zinc-Bromine, Zinc-Cerium, and Lead-Acid.

Membrane-less flow batteries make use of a laminar flow to ensure separation of the two electrolytes in the common core, eliminating the need for a membrane.

Cell voltage for flow batteries ranges between 0.5V and 2.4V, depending on the specific technology, and materials used. Power density can vary from some 800 W/m<sup>3</sup> for vanadium-vanadium to >1,000 W/m<sup>3</sup> for zinc-bromine and lead-acid systems and can go up to 15,000 W/m<sup>3</sup> for hydrogen-lithium systems. Energy density for flow systems is typically around 50 Wh/L for vanadium-vanadium systems, but can go up to ~1,400 Wh/kg for hydrogen-lithium chlorate systems.

One key advantage of flow batteries is the separation of power and energy requirements. As the electrodes are not part of the electrochemical “fuel”, they can be designed for optimal power acceptance without the need to maximise the energy storage density. In addition, the fact that electrodes do not contain active material, leads to more durable and stable performance, and longer lifetimes. The separation of active materials ensures increased safety of the whole system. In addition, flow

batteries can reach deep discharges without any impact on cycle life, and can reach near unlimited charging cycles, with little to no impact on nominal capacity. The main disadvantage of flow systems is their size, which limits their applications to large stationary industrial applications, as well as the complex system of pumps, sensors, vessels etc. required, even though the mechanics of each individual component are relatively simple.

### Nickel-based batteries

Ni-based batteries make use of a porous nickel electrode for the deposit of active materials. Since their invention at the end of the 19th century, several enhancements have been introduced.

**Nickel Cadmium (NiCd)** was the first type of Ni-based battery. It is highly durable and can reach more than 1,000 cycles with proper maintenance. In addition, it can be charged fast, performs well in low temperatures and has among the lowest costs per cycle. This has made it the technology of choice for many years in the aviation industry, and it has also been used for stabilising wind energy systems.

The most important downside is that Cadmium is a toxic material which cannot be disposed in landfills due to soil pollution, so it is gradually being replaced by other technologies. NiCd also has a relatively low specific energy density of 45 – 80 Wh/kg and has a memory effect (so needs periodic full discharge and charge cycles).

**Nickel-metal-hydride (NiMH)** is a newer Ni-based technology and provides ~40% higher energy density than typical NiCd systems. It is mainly used as rechargeable batteries (typically in AA and AAA sizes) for consumer electronics. Main advantages are good performance in a wide range of temperatures, and ease of recycling. On the downsides, NiMH has a high discharge rate (20% in the first 24 hours, 10% each subsequent month), and is sensitive to overcharge, requiring complex charging algorithms. Specific energy density is typically between 60 to 120 Wh/kg and cells can reach up to 500 cycles.

**Nickel-iron (NiFe)** makes use of an iron anode, an oxide-hydroxide cathode, and potassium hydroxide electrolyte. It is resilient to over-discharge and overcharge, and resistant to vibrations and high temperatures. For this reason, it is mainly used in mines, rail signalling systems and trucks/forklifts. Disadvantages include high discharge rates (up to 40% per month), poor performance in low temperatures, and relatively low energy density, of up to 50 Wh/kg. The cost of the system is not low either at about four times the cost of lead acid systems and comparable to Li-ion.

**Nickel-zinc (NiZn)** are similar to NiCd, as it uses an alkaline electrolyte, but has a higher cell voltage (1.65V compared to 1.2V for NiCd), but does not include highly toxic materials. Energy density can go up to 100 Wh/kg and can reach up to 300 cycles.

**Nickel-hydrogen (NiH)** batteries were developed to address the issues with metal instabilities in NiMH batteries. NiH has solid nickel and hydrogen electrodes, and the electrolyte, electrodes and screen are encapsulated in a high-pressure steel canister (8270 kPa). It has a long service life, low self-discharge and good performance in a wide range of temperatures (-28 °C to +54 °C). NiH batteries are mainly used in satellites. Specific energy density is 40 – 75 Wh/kg.

### Metal-air batteries

Metal-Air batteries comprise a pure metal anode, an air cathode, a separator, and the electrolyte. The separator is an insulator which only allows the transformation of ions. During the discharge process, oxidation reactions occur to the metal anode with metal dissolved in the liquid electrolyte and an oxygen reduction reaction is induced in the air cathode. Due to the open battery configuration that uses air as the reactant, metal-air batteries have much higher energy capacity (up to ~12,000 Wh/kg, which is comparable to that of petrol), which has made it very attractive to the automotive industry. Nevertheless, metal-air batteries have not yet been put into commercial use, as there are still some technical challenges to be overcome.

Several alternative metal-air technologies exist, with that of *Li-air* being one of the most promising. Other technologies include *Al-air*, *Iron-air*, *Zinc-air*, *Mg-air*, *Sodium-air*, *Na-air*, and *K-air* among others.

### Lead-acid batteries

Lead-Acid batteries consist of flat lead plates which are immersed in a pool of electrolyte. One of the plates is covered with a paste of lead dioxide, serving as the positive, and the other is made of sponge lead, serving as the negative. A separator is placed between the two plates. A key difference for lead-acid systems compared to other batteries is their very long charging times, compared to discharge, which is connected to the formation of lead sulphate on the negative electrode. Lead-acid batteries also often require addition of water to the electrolyte, as excess electrons lead to hydrogen generation and hence, water loss.

Apart from this, lead-acid batteries require low maintenance. Typically, they are used for emergency / back-up power, automotive and traction applications. Energy density varies between 30 to 50 Wh/kg, cell voltage is 2V and systems can go up to 300 cycles.

# 13. Appendix 3 : Investigation Result on ESS Fire Accident Korea Ministry of Trade Industry Energy June 19.

## Investigation Result on ESS Fire Accident [Ministry of Trade, Industry & Energy, Investigation Commissions]

June, 2019

### 1. Current State of Fire Accident from ESS

No.	Capacity [MWh]	Usage	Topography	Type of ESS	Date of Loss
1	1.5	Wind Power	Shoreline	Container	2017.08.02
2	8.6	Amplitude Modulation	Hill	Container	2018.05.02
3	14.0	Wind Power	Hill	Prefabricated Building	2018.06.02
4	19.0	Solar Power	Shoreline	Prefabricated Building	2018.06.15
5	3.0	Solar Power	Shoreline	Prefabricated Building	2018.07.12
6	9.7	Wind Power	Hill	Prefabricated Building	2018.07.21
7	18.0	Demand Management	Industrial Area	Prefabricated Building	2018.07.28
8	6.0	Solar Power	Hill	Prefabricated Building	2018.09.01
9	6.0	Solar Power	Shoreline	Prefabricated Building	2018.09.07
10	0.2	Solar Power	Industrial Area	Concrete	2018.09.14

11	17.7	Amplitude Modulation	Industrial Area	Container	2018.10.18
12	3.7	Solar Power	Hill	Prefabricated Building	2018.11.12
13	1.2	Solar Power	Hill	Prefabricated Building	2018.11.12
14	4.2	Solar Power	Hill	Prefabricated Building	2018.11.21
15	1.3	Solar Power	Hill	Prefabricated Building	2018.11.21
16	9.3	Demand Management	Hill	Prefabricated Building	2018.12.17
17	2.7	Solar Power	Hill	Concrete	2018.12.22
18	3.3	Demand Management	Industrial Area	Concrete	2019.01.14
19	5.2	Solar Power	Hill	Prefabricated Building	2019.01.14
20	4.5	Solar Power	Hill	Container	2019.01.15
21	46.8	Demand Management	Industrial Area	Concrete	2019.01.21
22	3.7	Solar Power	Hill	Prefabricated Building	2019.05.04
23	1.0	Solar Power	Hill	Prefabricated Building	2019.05.26

\* 14 Cases were occurred after charging of battery.

\* 6 Cases were occurred during charging or discharging time

\* 3 Cases were occurred whilst construction period

## 2. An Investigation Commission

- A. We set up a committee of inquiry for ESS Fire Accident on December 27<sup>th</sup> 2018 and requested user of ESS especially who installed the ESS within the Multi-Purposed Facility.
- B. The Investigation Commission consists of Professionals, Research Institutes, Test Certificate Issuers, Fire-Fighting Professionals, Government.
- C. We had been doing a regular meeting at least once a month, Site Survey and Interview with various companies for the recent 5 months.
- D. We set up 76 Types of Hypothesis and did the test for the Parts of ESS by System unit.



1) Defect of Battery System

- We found that there were some types of defect of battery system as below;

	d
Separation of Cell	Folding of Negative Plate
Defect of Cutting (Negative Plate)	Defect of Cutting & Coating (Positive Plate)

- We made a similar model with above cases and conducted the test 180 times.
- However, there have been any circumstances which it may lead to a fire accident

2) Defect of PCS (Power Conversion System)

- As a result of the test regarding earth fault, there was a possibility of fire accident in case that Insulation Performance would be decreased in a direct current contactor.

3) Short-Circuit of PCS Parts

- Since the Circuit Break would work well, there was no possibility of Fire Accident.

4) Electro-Magnetic Susceptibility

- Most Products has sufficient Electro-Magnetic Susceptibility

5) Management of Operating Environment

- Moisture & Dust Test
  - As a result of the test, One Company's Product show that Insulation Performance was decreased in case of exposures to Moisture & Dust and lead to a fire accident.
  - Such Product includes a Cooling Pan and it could be a pathway of Dust & Moisture.
- Malpractice in Installation
- Management & Operations System
  - Unitary Integrated System could help users to prevent a fire accident
- Defect of Battery Cell
  - There would no reasons that the battery would ignite itself in natural environment

## Strengthen Safety Measures

[Ministry of Trade, Industry & Energy, Investigation  
Commission]

June, 2019

### 1. Improve Safety Regulation for ESS

#### A. Manufacturing Standards

- A Impose on ESS Safety Standard (Korean Standard, May 2019)
  - Electricity, Machine, Explosion, EMF, Fire, Temperature, Chemical, Malfunction, Environment
- KC Certificate for Major Parts of ESS such as Battery, PCS and etc (Based on the IEC Standard)
  - Battery: Quality Test, Inspection prior to shipment
  - Battery System: Quality Test
  - PCS: Expanded a range of application from 100 kW to 2 MW

#### B. Installation / Erection Standard

- Limited Capacity of 600kW in case of indoor installation.
- Separated & Exclusive Building (Structure) would be necessary for Outdoor Installation
  - Distance between each ESS: more than 1.5m
- Mandatory of Safety Device
  - Safety Device for over current
  - Safety Device for over voltage
  - Safety Device for Short-Circuit
- Monitoring System
  - Emergency Shutdown and notify to the PIC
  - Save & Management of Operating information

#### C. Operation & Management

- Prohibit to additional charge after charge of batter completely.
- Environmental Management in accordance with Manufacturer's guide.
- Period reduction of compulsory inspection from 4 years to 1 or 2 years.
- Limited to repair discretionally.

#### D. Fire-Fighting Standard

- Mandatory of Fire-Fighting System
  - Relevant Act would be revised within year of 2019.
- Set up the Fire-Fighting Standard specialized in ESS.
- Set up the Procedure Standard or ESS Fire Accident.

**2. Safety Measures & Re-Operation for existing Facilities****A. General Corrective Measure (1,490 Locations)**

- Safety Device for Electrical Abnormality
- Installation of Emergency Shutdown System
- Prevention of over-charging
- Management of Operating Environment

**B. Additional Measures**

- Construction of Fire-Wall
- Secure of separation distance between other facilities and ESS

**C. Special Investigation of Fire-Fighting**

- Prohibit of installation of ESS in outdoor if the facilities are located in Multi-purpose facility
- Request user to operate ESS if the facilities are located in Multi-purpose facility

**D. Check on whether New Standards & Regulation would be followed**

- Do investigation after the request

**E. Government's support**

- Particular Instance of Costs
- Support costs for construction of safety facilities such as Fire-wall.

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