Research on batteries used on large scale power dispatch

Chunsheng Jason Qiu

This research activity focuses on the current technology of using batteries to store the extra generated large scale power and as a backup when outage happens. Also included is a discussion of the regulation of this technology as part of the utility. Four real-world cases are introduced and a battery degradation model is plotted.

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Contents

Introduction

As we all known, unlike banking accounts, where you can save money in it and have it in there for as long as you want. Electricity must be used as exactly when it is being generated. Energy storage is a relatively complicated application. Most of the time we are not referring to “saving” the electricity”, but rather how energy could be saved when economic dispatch such as smartgrid technologies is utilized in order to serve the public with a robust and cost-effective manner. However, as the technology evolves and the electricity demands continue to increase, crunching the numbers at operator side won’t effectively save a lot of money. For example, for many places in the world, there are small villages or remote areas with small demand(small load). They need electricity but the amount they need might not justify routing the power from the substations that are far away. As previously mentioned, in short, generation and load should be balanced. The cost is not effective to provide electricity to those areas as compared to big cities to which substations are strategically placed. What is a better cost effective way? It will be using the battery that is designed for utility scale operation. As a matter of fact, some of the small towns in the U.S. is indeed power by the battery operated by the utility. One of the major advantage of using battery for power generation is meeting the increasing renewable energy profile. Due to the unpredictable characteristic of the renewable energy such as wind energy, it will cause a lot of trouble for the dispatch. However, batteries can be used to store and energy when wind profile is rich and feed the load when the wind generation is not optimal. Not only for the small loads, a lot of utilities use large battery for various reasons such as backup when severe, not fast recoverable outages happens, such as NYISO, New York Independent System Operator and so on. These battery applications have advantages such as fast response and their ability to operate “both ways”—consuming and providing, which is certainly to the advantage of economic dispatch. In short, with the future trends and dramatic change of load charateristics all over the world, application of using batteries to provide bulk of power to the load will become more popular and a new set of regulating rules will emerging. The utility profile—how they operate and regulate will be very different than what it is today.

The following section lists 4 most popular types being used in the current real world applications or being seen as the most feasible ones for large scale power application.

Battery Types

1. Lead Acid Batteries:

Lead-acid batteries have a significant history in providing energy storage for a variety of applications, either small(portable device), medium(cars) or even large scale. Because they have liquid electrolyte in it,they can only store small volumes of energy(of course—in terms of typical power business), but they are really reliable and most importantly—they are cheap. In an existing system for power application, multiple deep-cycle lead-acid batteries can provide a steady current over a long time period. They are connected together to form a battery bank. They can provide up to 1MW power to backup wind farm power generation.

Disadvantages: One disadvantage of lead acid batter, though, is that during discharge, the acid will react with electrodes to form lead sulfate, and when the chemical process is reversed during recharging, some of the lead sulfate do not re-dissolve. This will weaken the battery. The greater the depth of discharge, the more the battery is weakened.

Example: Trojan Battery Company's deep-cycle lead acid batteries.

Efficiency: around 80%

2. Li-ion Batteries:

Li-ion battery is a type of rechargeable battery in which lithium ions move from anode to the cathode during discharging process and vice versa in the charging process. Although Li-ion batteries are most common in consumer electronics, now more and more large scale power storage systems are using them thanks to their technical potentials. They are able to store more power in a more compact space, as well as promising a longer lifespan and higher efficiency. They are capable of completing 7,000 full cycles of charge and discharge cycles before they can experience loss

Disadvantages: A notorious disadvantage of Li-ion battery will be the cost. They are more expensive than the lead-acid batteries. Another big issue is safety—providing protection needs to be well considered when using Li-ion battery .

Example: Mitsubishi Heavy Industries is beginning tests of a 40-foot long container unit housing more than 2,000 li-ion rechargeable batteries. According to the company, the system has a capacity of 408 kWh. As well as grid power stabilization, the system will be tested for micro-grid use in areas where regular grid connections are difficult, providing a stable supply of electricity from renewable sources.

Efficiency: around 90%

3. Flow Battery:

Flow batteries are emerging energy storage devices that can serve many purposes in energy delivery systems. They can respond within milliseconds and deliver significant quantities of power. They operate much like a conventional battery, storing and releasing energy through a reversible electrochemical reaction with an almost unlimited number of cycles. The active chemicals are stored in external tanks, and when in use are continuously pumped in a circuit between the reactor and tanks. The great advantage is that electrical storage capacity is limited only by the capacity of the tanks. Also, it has a safety advantage that comes from storing the active materials separately from the reactive point source

Disadvantages: The main disadvantages of Flow batteries are their more complicated system requirements of pumps, sensors, flow and power management.

Example: currently GE is pushing the limit by developing a flow battery than can provide up to 240 miles within a single discharge for an electric car.

Efficiency: unknown

4. Sodium Sulfur Batteries

A sodium–sulfur battery is a type of molten-salt battery constructed from liquid sodium and sulfur . This type of battery has a high energy density, high efficiency of charge/discharge and long cycle life, and is fabricated from inexpensive materials, making it ideal for large scale power storage. They are usually installed at generations and substations where they are charged during off-peak hours and discharged during peak hours.

Other advantages include: long calendar lifetime, environmentally friendly

Disadvantages: They need to be operated above 300 C; The material used to make them contains metallic sodium, which is very hazardous and combustable when exposed into water. It takes extra money to make the preventive structure of the enclose to keep it from leaking . Stringent operation and maintenance requirements are also some of the drawbacks.

Example: The largest sodium sulfur battery in America, nicknamed 'BOB,' can provide enough electricity to power all of Presidio, Texas. The house-sized battery can deliver four megawatts of power for up to eight hours. Utilities are looking into similar batteries to store power from solar and wind so that renewables can come online before the country implements a smart grid system."

Efficiency: 89%--92%

Quick Overview:

Battery Type	Main Advantages	Disadvantages	Power Application
Lead-Acid	Low Capital Cost and reliable	Limited life cycle when deeply discharged	resonablely capable
Li-ion	High Power& energy densities, High efficiency	High Production cost;require special charging circuits	resonablely capable
Flow	High Capacity, independent power and energy ratings	Low energy density	resonablely capable
Sodium Sulfur	High Power& energy densities, High efficiency	Production cost	Fully capable

Table 1: Quick Overview for 4 types of batteries

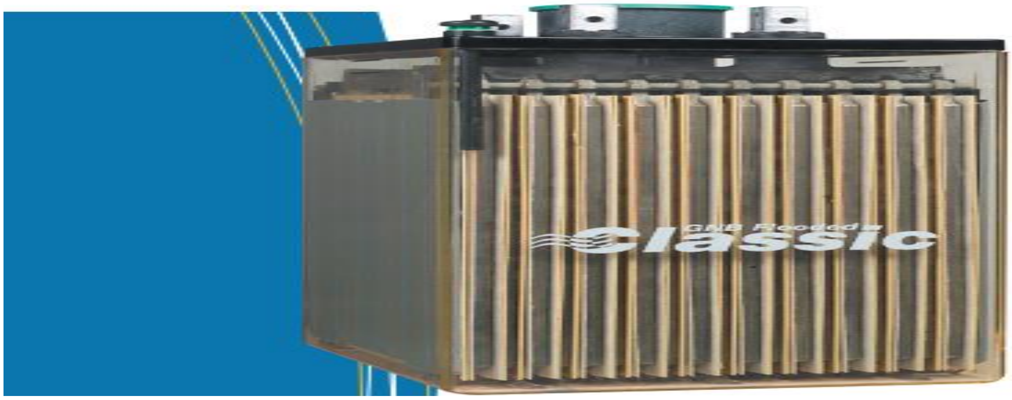

Figure1: Lead acid batteries

Figure 2: Stationary NaS batteries

Real World Cases

Below are the 4 applications around the world that use those 4 types of batteries to generate or store powers for utility use.

(Due to the limited source from the pertinent company/utility website, few portions of data are extrapolated by the relevant battery data provided by the battery manufacturer.)

Lead-Acid Battery:

Example:

Taking example application from Southern California Edison Chino Battery Storage Project, CA, USA:

The provided power and energy rating is : 14MW 40MWh

Estimated efficiency for lead-acid battery is 80%

Size: 8,256 cells in 8 parallel strings of 1032 cells each ; Cell size: 2,600 Ah This application is using Exide Gl-35 cell: 0.025m2

Total area of the battery=0.025*1032*8=210m2

Those lead to 210/40000k-=0.00525m2/kw

Energy per cycle: 24kw/h

Cost: use levelized cost for fuel cell generation: $140/MWh

Environmental concern and recycling

Lead-acid batteries contain sulphuric acid and large amounts of lead. They are highly corrosive and can produce a range of adverse health effects particularly in children.

With the size of this lead-acid type this big, the harmful substances can permeate into the soil,ground water and surface water through landfills.

The importance of recycling the used lead acid battery is big, and the process is among the most complicated.

Sodium Sulfur Battery:

Example

Taking example application from Long Island, New York Bus Terminal Energy Storage

System, NY, USA

The provided power and energy rating is : 1.2MW   6.5MWh

Estimated efficiency for lead-acid battery is 92%

Size: 20 NAS battery of 50kw each

One single battery is 2.3*1.7=3.91m2

Total area of the battery=78.2m2

Those lead to 0.065m2/kw

Energy per cycle: 44kw/h

Cost: use levelized cost for fuel cell generation: $140/MWh

Environmental concern and recycle

A disposal rate of 200 NAS batteries per year would result in an annual hazardous waste generation of about 20,000 kg of polysulfides, or approximately 1670 kg per month month, which might or might not exceed some state’s legal limits. Again, the recycling of this type of battery also should be cautious.

Li-ion Battery:

Example:

Taking example application from Panasonic's Kasai Green Energy Park (Japan)

The provided power and energy rating is : 288kW   1.5MWh

Estimated efficiency for lead-acid battery is 90%

Size: Instead of laying them flat, this Japanese company store all the Li-ion battery modules in one single building. There are more than 800 standard modules inside the building.

Total area of the battery=522m2

Those lead to 1.81m2/kw

Energy per cycle: 5kw/h

Cost: use levelized cost for fuel cell generation: $140/MWh

Environmental concern and recycle

Considering the number of lithium-ion batteries used on the market, this energy storage system has caused little harm in terms of damage and personal injury.

While lithion is 100% recyclable, currently economics do not add up to recycle it.

Flow Battery:

Example:

Taking example application from Vanadium-Redox Battery at the Sumitomo Densetsu Office, Osaka, Japan

The provided power and energy rating is : 3MW 800kWh

Estimated efficiency for lead-acid battery is “unknown”.

Size: 60 units of 50 kW Sumitomo battery modules

Total area of the battery=360m2

Those lead to 0.12m2/kw

Energy per cycle: 11kw/h

Cost: $1,500 kwh

Environmental concern and recycle

Compared to the first three types of battery, flow type battery has little environmental concerns as it requires stringent operating condition which separates them from the general environment at the first place. And it is fully recycle-capable due to its solution alike property.

Regulation:

Newer technologies like battery power storage devices have entered the technology maturity stage. Batteries for power supply will one day fundamentally change the current operation of the delivery of electricity. Hence, it is imperative to have a comprehensive regulation rules so that this newer technology won't adversely affect our current power transmitting business, such as monopoly. The basic principle will be that any energy extracting from or injecting to the market should follow the market rules.

Here are some of the specific rules that might be necessary:

1. Electricity storage should be paid in line with its contributions to the system peak
2. No discrimination regarding different plants
3. Adequate assessment of the real power availability
4. Pay the market price of the upward need for balancing
5. Allow generation&consumption balancing
6. Participation in capacity mechanisms, availability payments, upward needs
7. Increase upper limit in the electric market price

Example of battery energy storage regulations:

<u>California's Energy Storage Mandate:</u>

California Public Utilities Commission requires utilities to begin buying a combined 200megawatts of nergy storage technology by 2014 and reaching 1.3 gigawatts by the end of 2020. Some of their regulation protocals include:

1. Energy storage systems can be deployed in only three domains:transmission-interconnected, distribution-interconnected and behind the meter interconnected
2. Utility ownership of storage projects should not exceed 50% of all storage acrfoss all three grid domains
3. The Commission can hold a workshop to further explore the operational characteristics and uses for pumped storage projects

New York Independent System Operator (NYISO)

In 2009, NYISO filed tariff revisions to accommodate the unique charatersitics of energy storage devices, consistent with all applicable reliability criteria.

They defined a new type of regulation service provider: a limited energy storage resource(LESR). LESR is to provide continuous six-second changes in output coupled with its inability to sustain continuous operation at maximum energy withdrawal or maximum energy injection for an hour. Some of their regulation include:

1. Five-mins for LESR to sustain withdrawals and injections before another resources being dispatched
2. Purchase replacement regulation service when LESR limitation recharged
3. Always dispatch LESR first because of its extremely fast response

ISO New England

ISO new England has their own regulating program called Ancillary Service Pilot Programs, which includes Alternative technology regulation piolot program and demand response reserves pilot program. Some of their energy storage regulation include

1. Limited to 13MW total to ensure no threat to reliability
2. Continuously conducting marketing survey and electricity reliability survey until permenet market change is deemed ok to be implemented
3. Limit state-of-charge for storage resrouces with limited energy source(i.e. less than 2 hours)
4. Deploy cost-effecitve metering and communications for geographically dispersed resources

Degradation Analysis:

After extensive research on some articles about batteries degradation model, at this moment I am not able to find a comprehensive, accurate and detailed degradation model for four of the batteries discussed above. However, one of the article on IEEE(included in Resources) provides useful approximation method:

Using one-exponential decay approximation method to model the degradation model of

Lead-Acid, NaS and Li-on. Due to insufficient data, flow battery’s model is not analyzed an thus obtained. All degradation model is analyzed at assuming 100% Depth of charge.

$$Q(k) = a\cdot\exp(b\cdot k) + c\cdot\exp(d\cdot k)$$

Q is the capacity at Cycle k

a, b,c,d are model parameter pertinent to one battery type and they are estimated according to the material type of the battery.

a, b are related to the initial capacity

c and d represent the degradation rate.

1 Lead-Acid

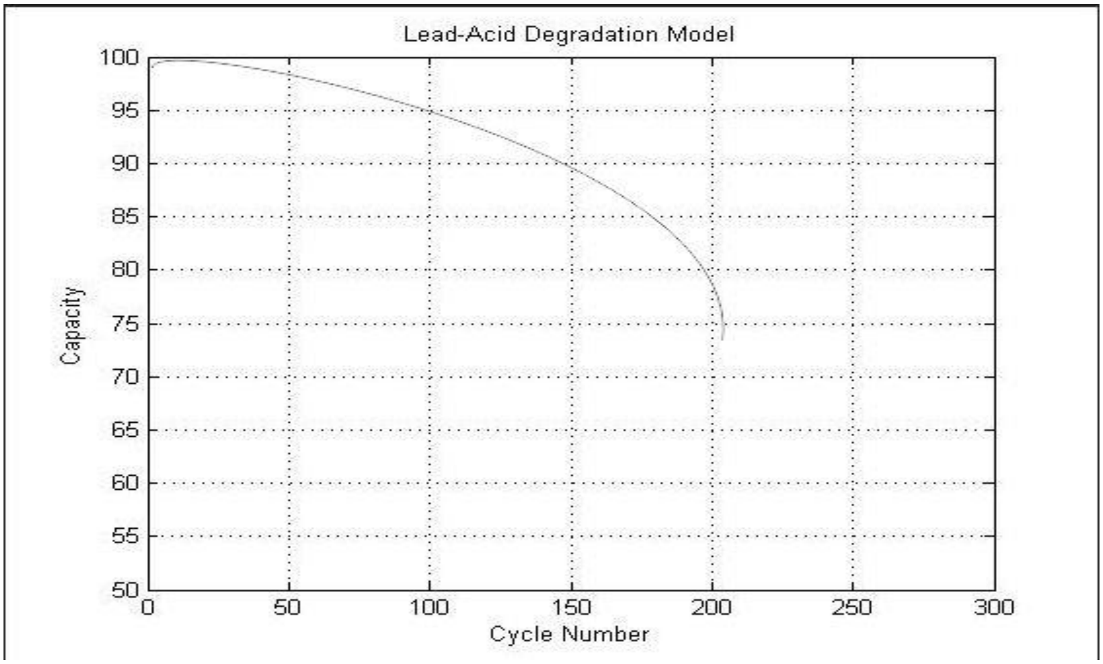

Figure 3

2.

Sodium Sulfur Battery

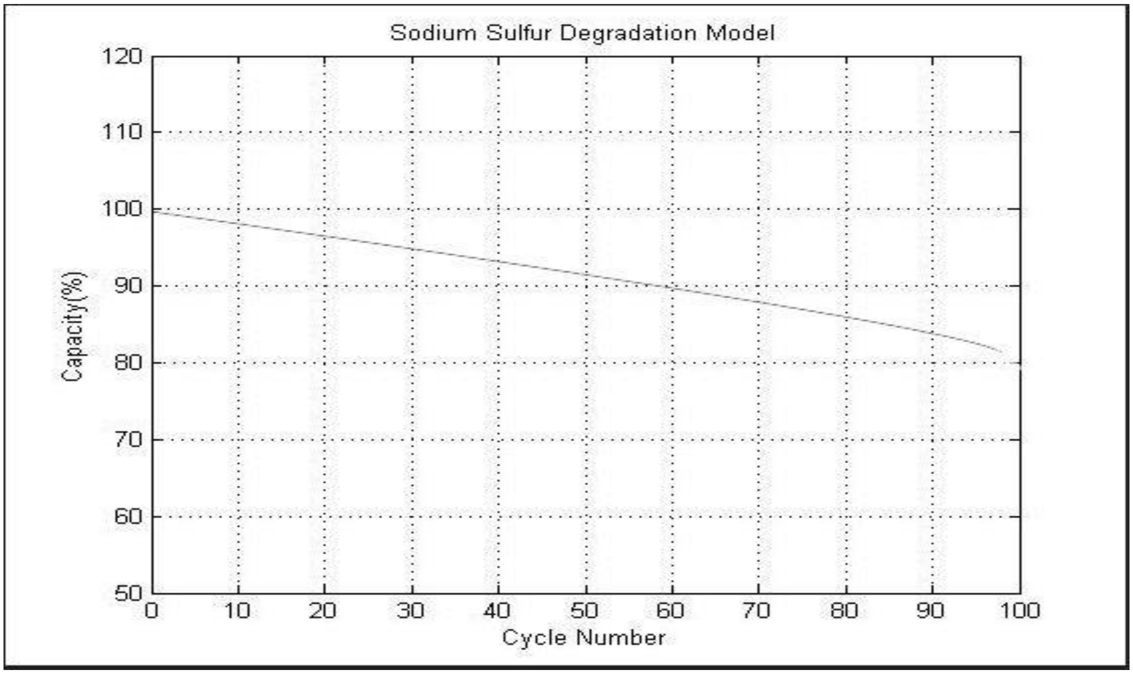

Figure 4

3 Lithium-ion

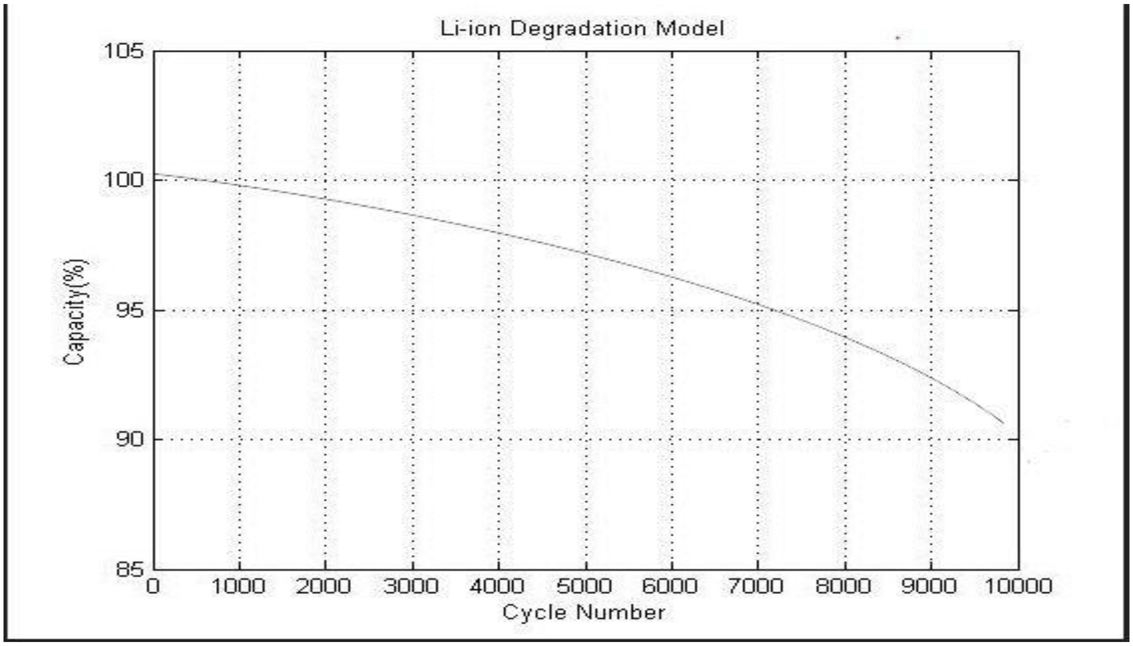

Figure 5

Degradation model suggests, under the same condition of DOD, the Lithium-ion performs the best, and sodium sulfur has a slightly edge over the lead-acid in large scale application. However, due to the situations of various utilities—how they implement the battery storage system, each battery will has its own advantages. Another disclaimer is that those are only the estimates based on the characteristic of the battery material. Other factors such as size and how single cells are assembled are not taken into the consideration.

Resources:

Department of Physics, Texas A&M University, College Station, Texas 77843-4242, HOW BATTERY DISCHARGES—A SIMPLE MODEL, W.M.SASLOW

Xcel energy development fund: SODIUM SULFUR BATTERY ENERGY STORAGE, HIMLIC NOVACHICK

New Independent System Operator: MEMOREDUM, NEW YORK INDEPENDENT SYSTEM OPERATOR

IEEE paper: A SIMPLE EFFECTIVE LEAD-ACID MODELING PROCESS, ROYBN JACKY