

Energy Storage, DG, and System Stability



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Tim Corrigan
Instrumentation and
Controls Supervisor
Blenheim-Gilboa
Pump Hydro Energy
Storage Plant

Hurricane Sandy

- Most solar PV installs done in New York (as well as most small wind installs) are “grid-tied” and “net-metering”.
- These systems have no storage, and as a safety measure when the grid goes down they are required to turn themselves off and stay off until they see 5 minutes of good power
- During Sandy, the result of this was that some people with solar on their roofs actually had no power
- These systems could have been built to be more resilient, and provide rallying points during disasters and extreme weather events.

The New York Times

Business Day
Energy & Environment

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Solar Companies Seek Ways to Build an Oasis of Electricity

By DIANE CARDWELL

Published: November 19, 2012

When [Hurricane Sandy](#) wiped out the power in areas like coastal Long Island and the Jersey Shore, what should have been beacons of hope — hundreds of solar panels glinting from residential rooftops — became symbols of frustration.



Robert Stolarik for The New York Times
R. David Gibbs of the nonprofit group Solar One directed volunteers in an installation at the Rockaway Beach Surf Club.

Despite the popular perception that installing solar panels takes a home “off the grid,” most of those systems are actually part of it, sending excess power to the utility grid during the day and pulling electricity back to run the house at night. So when the storm took down power lines and substations across the Northeast, safety systems cut the power in solar homes just like everywhere else.

Multimedia



“Here’s a \$70,000 system sitting idle,” said Ed Antonio, who lives in the Rockaways in Queens and has watched his 42 panels as well as those on several other houses in the area go unused since the power went out Oct. 29. “That’s a lot of power sitting. Just sitting.”

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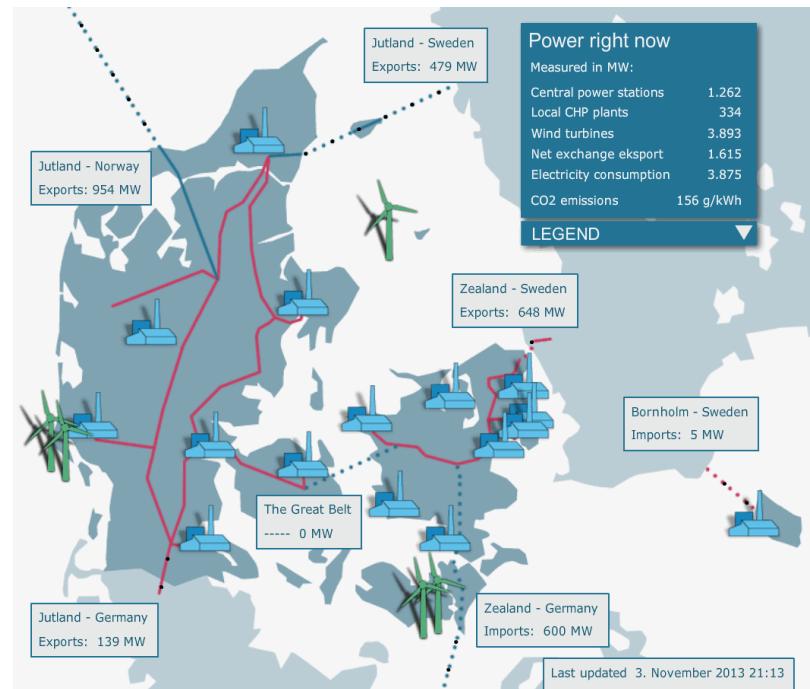
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New York Power Authority

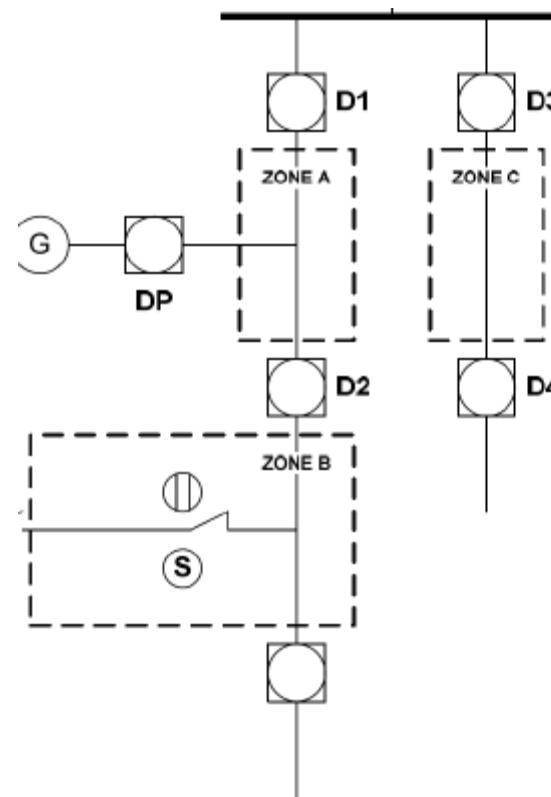
Wind Limitations

- Denmark regularly supplies more than 100% of its market from wind (on off-peak days), with 30% of its annual supply coming from wind, and is building more
- This is only possible with very robust interconnections with countries like Sweden and Norway, which can use this power by “holding back” their hydro power, effectively using it as storage



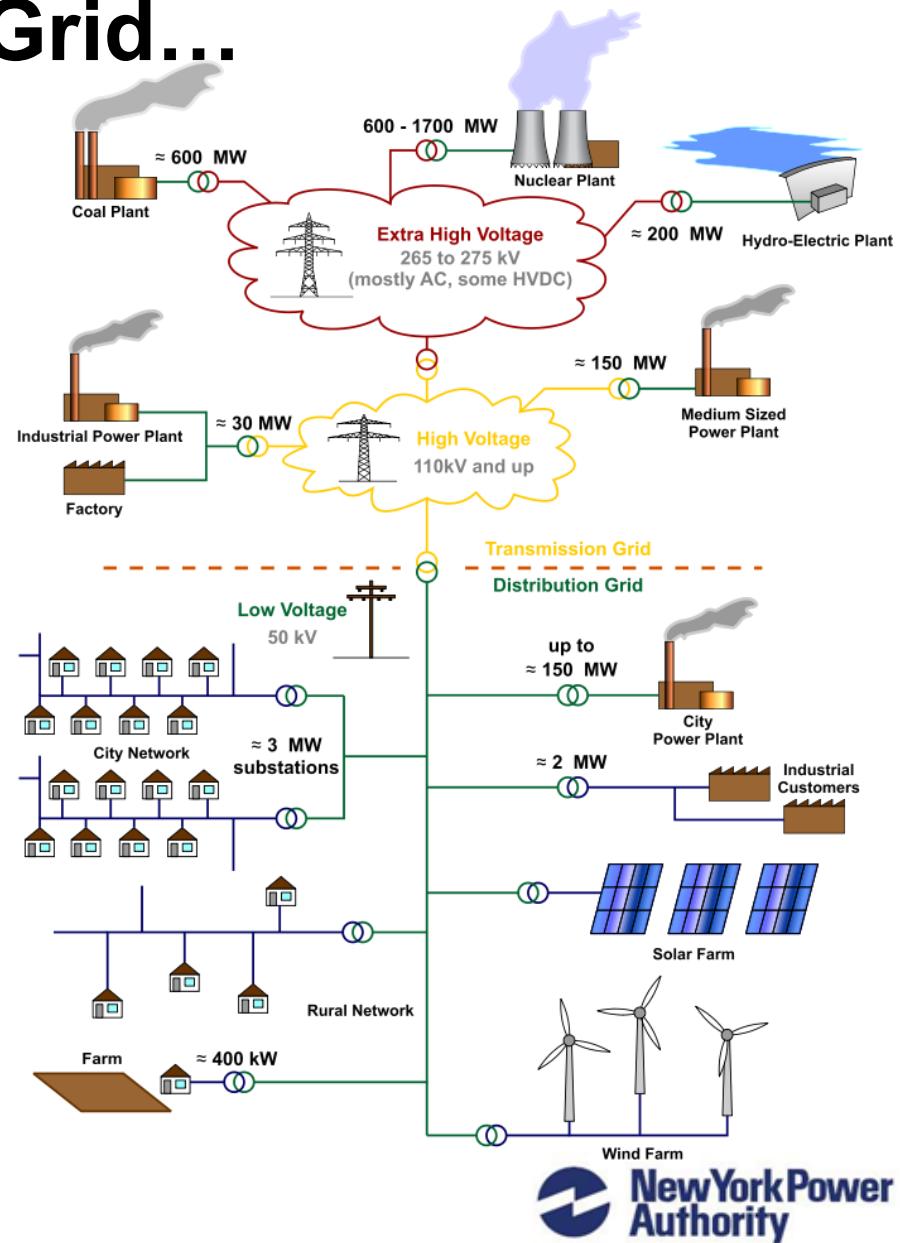
DG pushing current forms of protection to their limits

- Traditional power system protection used imperfect but complete enough information about a system with a hub and spokes to react
- DG adds unpredictable and sometimes unengineered power sources into the ends of a system where they can be invisible to current forms of protection and control
- A smarter grid could help... but the number of different scenarios that could be happening is huge



A Quick Look At the Grid...

- “The Grid” is really more than one system, and the issues of integrating DG (Distributed Generation) depend on what system it is connecting to
- The **transmission grid (or the bulk power system)** is higher voltage, goes long distances between nodes (connection points), and has far fewer connections.
- The **distribution grid** is the last mile of the power system, and is much more complex because there are many more connections. This is where most of the DG sources and solar photovoltaics (PV) live.



Why Energy Storage (1)?

- Virtually all of the electricity used in the grid is produced the second that it is used, which requires a continual balancing of loads to production over very long distances
- Most industrial sources of power are *dispatchable*, meaning we can
 - schedule power to start production at a certain time
 - at a specified power
 - run for a known amount of time, fuel providing
- *But*, older fossil steam plants (coal and oil) and nuclear
 - could take a long time to start
 - couldn't necessarily run at every power level
 - as a result, some were run at night in the past even if this wasn't economic.



Why Energy Storage (2)?

- Even with dispatchable sources we need to keep a certain amount of “spinning reserve” – power that can come online almost instantly in case another power source trips offline unexpectedly due to faults, because most fossil and nuclear sources come up to speed slowly
- Storage for the traditional grid is made up of sources that are fast enough that they can eliminate the need for some of this spinning reserve; they were also able to soak up power produced at night and use a differential in cost between day and night to make a profit.
- Storage allows some buffering of the system against unplanned events

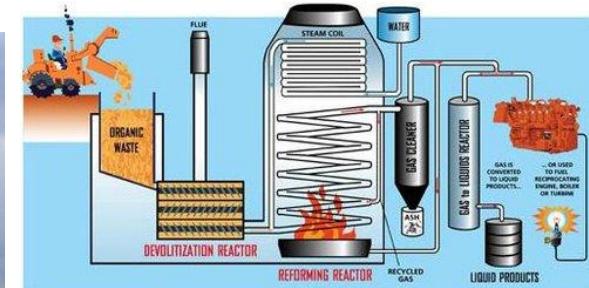
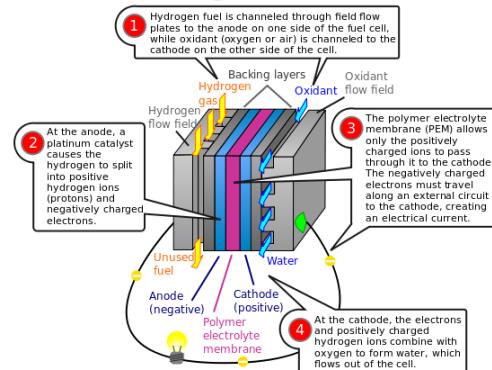


What is Distributed Generation?

- Distributed Generation (DG) can take many forms, and is basically a catch-all term for anything that produces electricity that isn't a traditional centralized power plant. Usually these sources are attached to the **distribution grid** (if they are not attached to the grid they are called off-grid)
- The energy sources for DG can include wind, solar, biomass, biogas, geothermal, diesel, natural gas, fuel cells, batteries, cogen and others.
- DG is enabled by modern power electronics that allow small systems to “synchronize” with the grid in a way that was much more difficult 20 years ago.

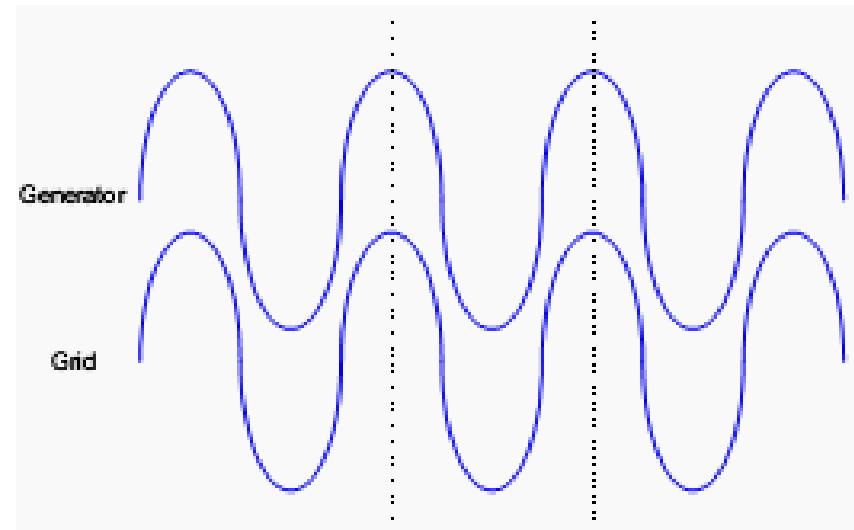
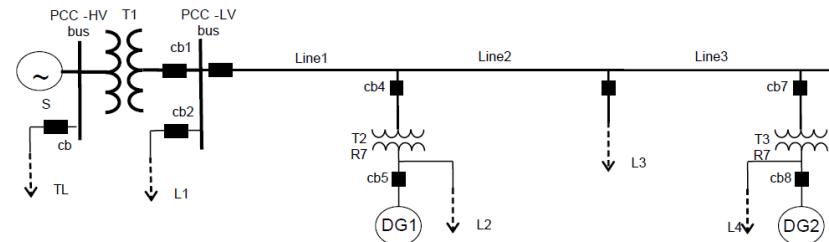


Proton exchange membrane fuel cell



How does DG work with the grid?

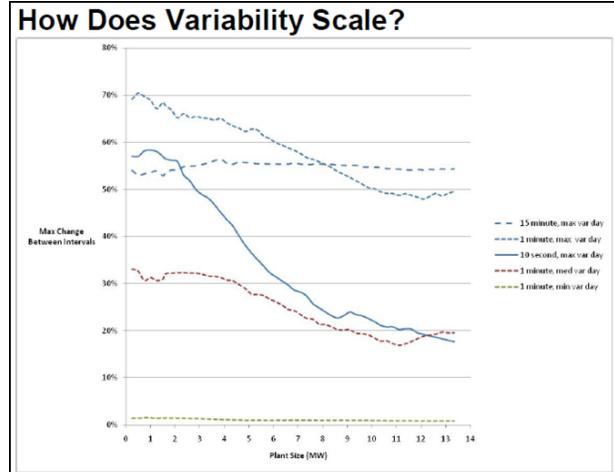
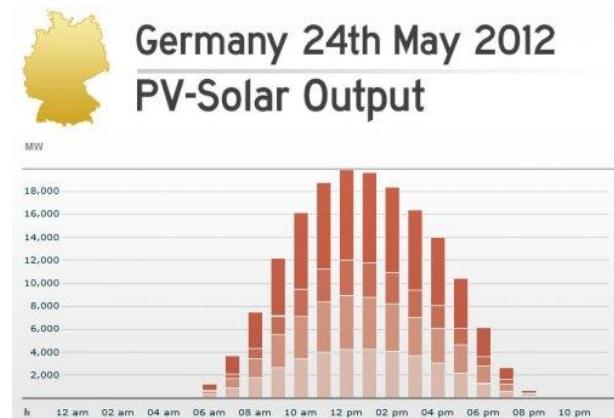
- DG is enabled by modern power electronics that allow small systems to “synchronize” with the grid in a way that was much more difficult 20 years ago.
- DG monitors the grid’s frequency and phase (in the US this is 60 Hz) and then gradually moves its peak to match the grid (to be “in phase”)
- When a DG is producing power and is not connected to the grid it is an “island”
- Some systems that lack storage, particularly wind and solar, aren’t designed to work when disconnected from the grid and shut down



Why do Renewables Need Storage (1)?

Solar PV

- Solar production varies (for fixed panels) with the position of the sun from sunrise to sunset, on the upper right
- This also means production varies seasonally from an equivalent of around 1.9 peak sun hours in December to almost 6 in the summer
- This chart (lower right) shows the % variation that can happen in solar in a given time interval in a day
- A medium variability day for solar can involve a 70% change in 15 minutes in power output for a 1 MW solar farm
- Issues like this are becoming an issue in markets like Germany with high rates of PV installs, which can produce 12% of that nation's power



Solar PV with Off-grid Capability

- Solar PV systems can be designed to be normally grid connected but with a battery backup; under normal circumstances batteries are fully charged and all surplus power goes into the grid like with a normal net-metering PV system
- Downside is lower efficiency
 - ~67% end-to-end compared with ~75% end-to-end for solar PV net-metering install
- Advantages can include automatic “islanding”, autostart of generators, and for the grid *dispatchable* solar power



Why do Renewables Need Storage (2)?

Wind

- Seasonal variation of wind is inverse to solar (higher in winter, lower in summer), which is helpful when integrating both
- The chart lower right shows the variation in absolute power production over a 24 hour period
- Wind generally is not this variable, but it is also not as predictable by season as solar, and variations can last longer
- Because of the larger power scale of wind and its wider adoption there are already draft rules for wind for “low voltage ride through” and further rules are proposed for storage on site to smooth short term variability
- Several industrial storage technologies (pump hydro, NaS batteries, flow batteries, compressed air storage) are focused on making wind farms more “dispatchable” over minutes to hours

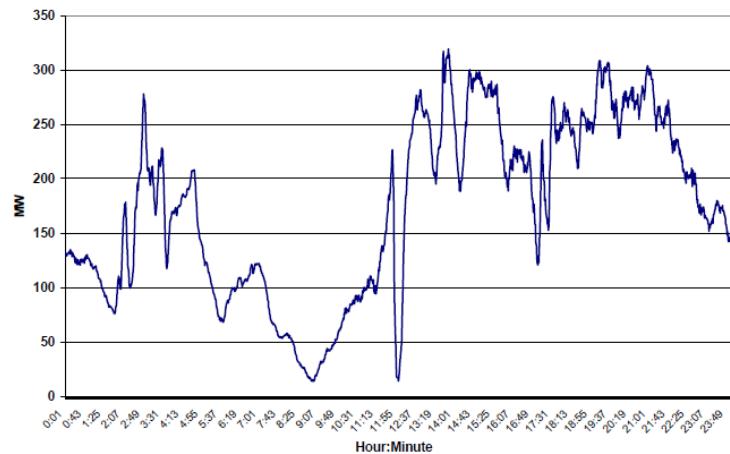
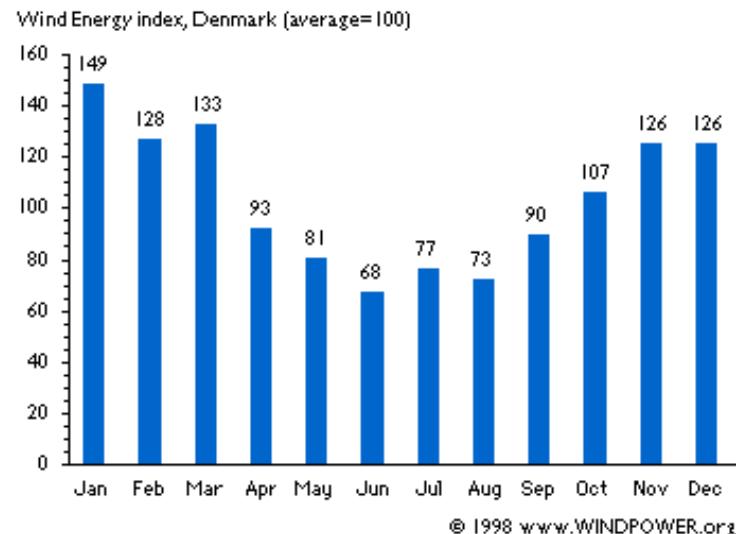
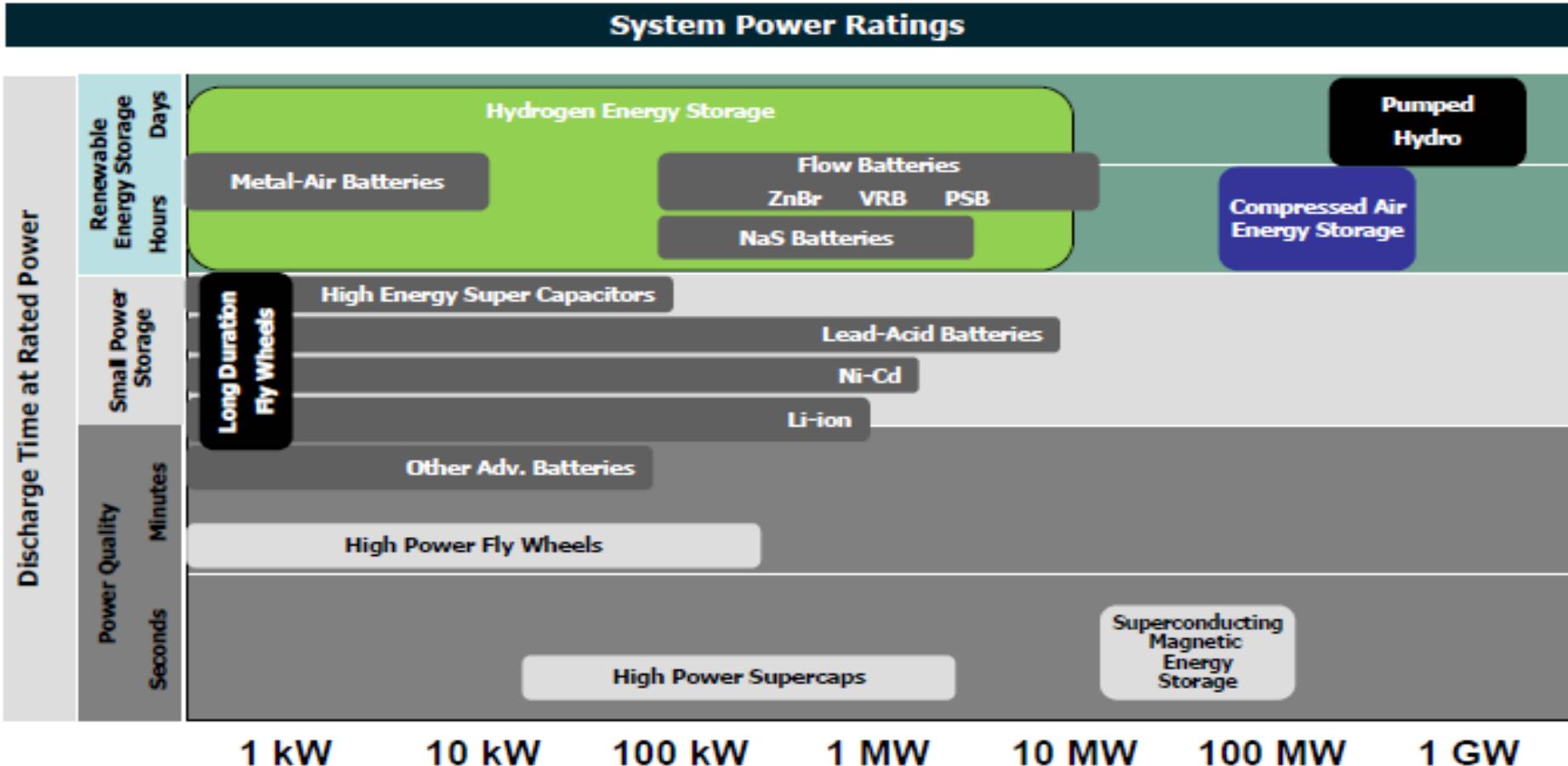


Figure 3-1: Aggregate Wind Output - Northern Zones (June 10, 2008)

Competitive Energy Storage Technologies



Source: Electricity Storage Association

Storage Types

- **Batteries** run the gamut from hours to days, and are the most common type of storage.
- Most have a fixed capacity, but a “**flow battery**” is an attempt to give batteries capacity limited only by external electrolyte storage tanks
- **Fuel cells** are not by themselves a form of storage; they are sometimes considered a storage system because hydrogen to fuel them can be created from water using electricity. However, current hydrolysis (separation technology to break water into hydrogen and oxygen) suffer from very, very low efficiencies compared to other storage systems.
- **Pump hydro, compressed air and flywheels** are all systems that store electricity in a readily convertible mechanical form

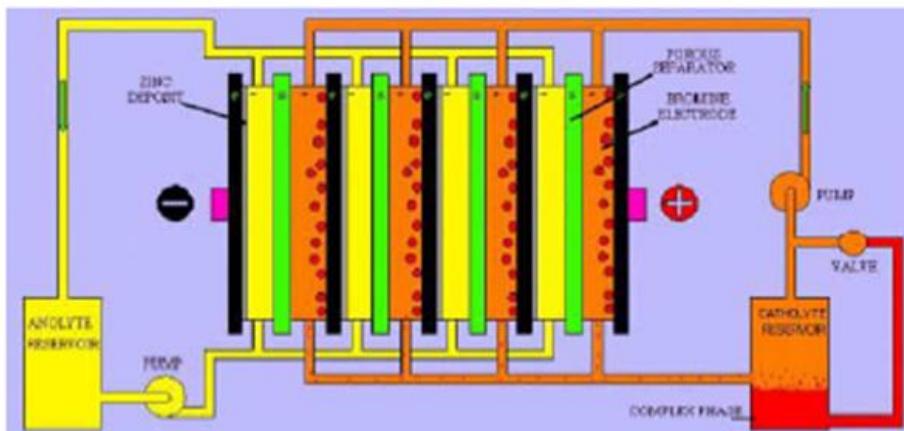


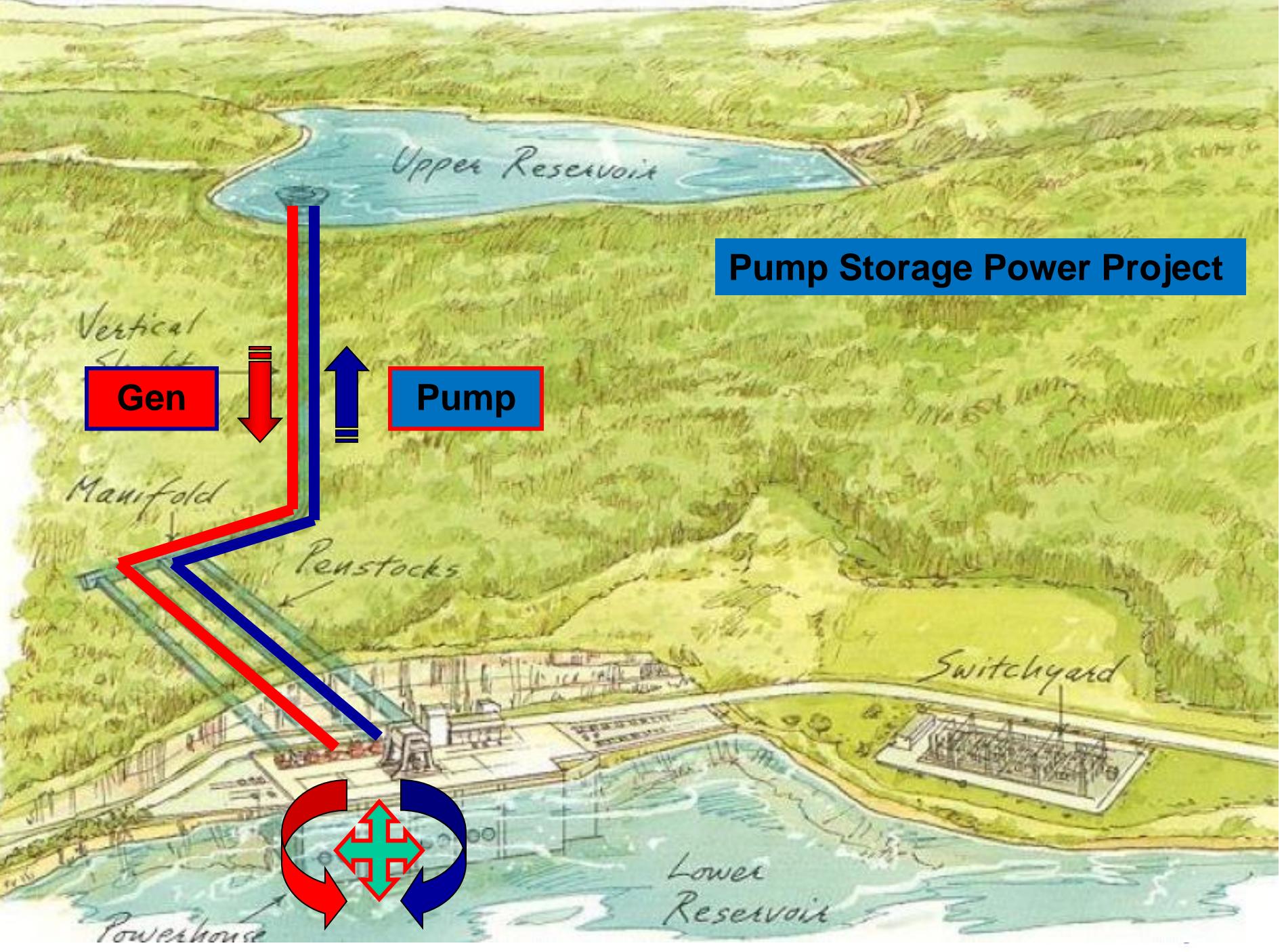
Figure 9-1
Zinc-Bromine Cell Configuration (Courtesy ZBB Energy Corporation)

What is Pump Hydro Storage?

- Pump hydro is a system that allows energy to be stored in the form of water pumped uphill
- Pump hydro plants buy power from the grid when demand and prices are low and use it to pump water into an upper reservoir
- When prices are high, water is run through the generators and sold back to the grid
- Unlike normal hydro-electric facilities, such as the St.Lawrence Project, pump hydro does not actually generate power
- Since no real system is ever 100% efficient, some power is actually lost in this process
- This is still worthwhile because of the high degree of control and speed of availability that this type of storage provides



Pump Storage Power Project



Advanced batteries

- The development of electric cars has driven many new battery types with more charge cycles
 - LiFePO₄, a lithium ion chemistry with thousands of charge cycles (not the same as the Boeing dreamliner battery)
 - Metal air is also a possible contender in the future, but is not out of the lab yet
- Other battery types have been driven by the need to store wind power
 - NaS (sodium sulfide) has been deployed in Japan, and has several thousand cycles and can store MWh of power, but also has a very high running temperature
 - Flow batteries like zinc bromide or vanadium redox would work for larger industrial sites, and have the capacity to charge large amounts of electrolyte, but are too complex at the moment for DG sites

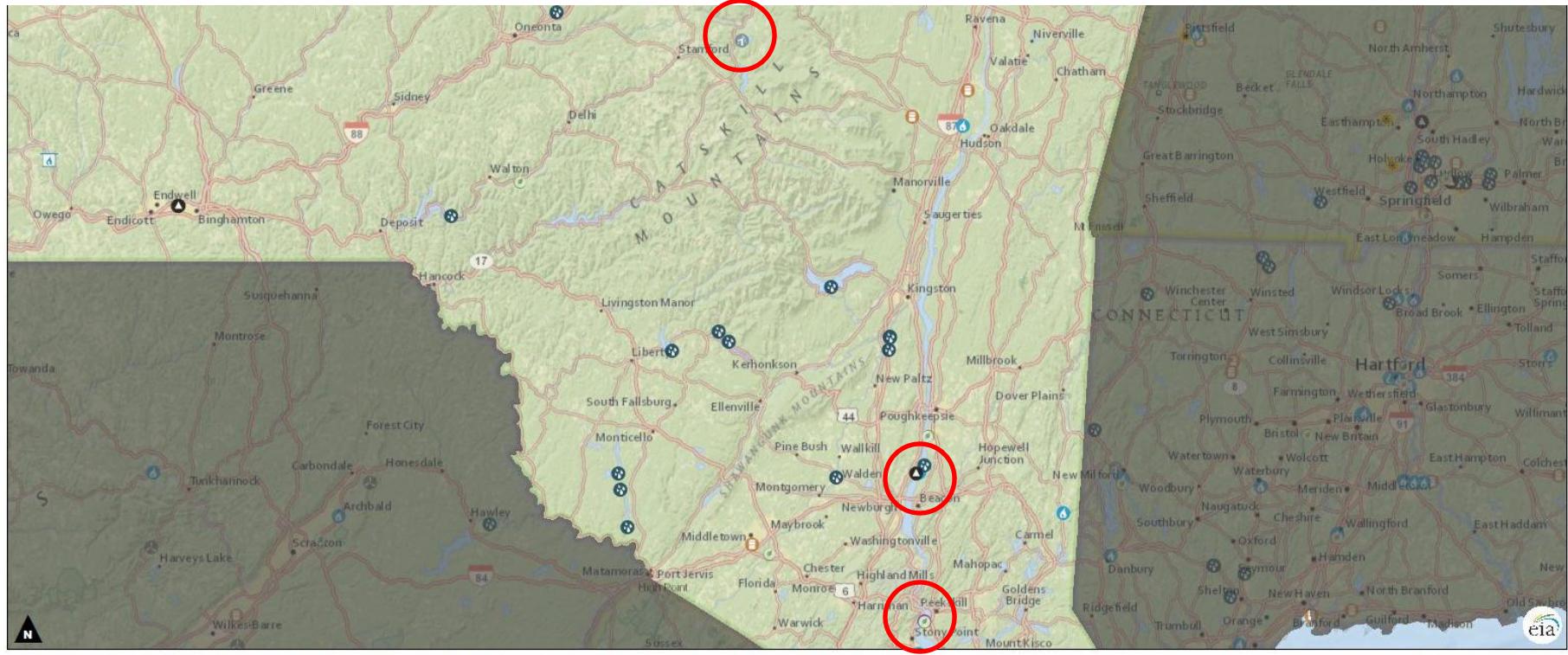


What is the role of Pump Hydro Storage?

- PHS was originally used to “time shift” nuclear and fossil power, but is now being looked at in Europe, Japan and China as a method for smoothing out **wind generation**
- It also can come online from a stop faster than any other type of industrial power (though gas turbines are now close to as fast)
- Pump hydro uses rotating machines, so it is more complex and less inherently reliable than batteries
- There’s a significant engineering and maintenance effort involved in setting up a PHS plant
- Traditionally these plants have been large scale, but work is being done on smaller, more automated systems for DG; systems are now being built to use areas near the ocean (Japan) or fjords (Norway)
- Somewhat limited by topology



Where is the HV's industrial fleet now?



Electricity Transmission Lines - Ventyx, Velocity Suite, National Geographic, Esri, DeLorme, NAVTEQ, UNEP-WCMC, USGS, NASA,

- Mask
- Other Power Plant
- Oil/Gas Active Platform in Federal Waters
- Biomass Power Plant
- Other Fossil Gases Power Plant
- Natural Gas Underground Storage (z)
- Coal Power Plant
- Petroleum Power Plant
- NGL Market Hub (z)
- Geothermal Power Plant
- Pumped Storage Power Plant
- Natural Gas Market Hub (z)
- Hydroelectric Power Plant
- Solar Power Plant
- Wind Power Plant
- Natural Gas Power Plant
- Wood Power Plant
- Nuclear Power Plant

0 5 10 20 Miles

<http://www.eia.gov/state/>

Battery Types

Type	Technology Maturity	\$/Wh stored	Lifetime \$/MWh stored	Typical Charge Cycles	Applications
Plate batteries					
Sodium sulfide (NaS)	Widely deployed developing product	\$0.48/Wh	0.19	2500	MTA bus station battery, widely used in Japan for wind
Lithium iron phosphate (LiFePO4)	Used widely in vehicles; commercial prototype constructed for grid tie	\$1.00/Wh	0.14	2-7000	Tesla, Boeing 787
Lead Acid	Widely deployed mature product	\$0.16/Wh	0.27	1-600	Station batteries, most home storage batteries, your car
Advanced Lead Acid	Research	\$0.16/Wh	0.08	2000	
Flow batteries					
Vanadium Redox	Commercial prototype constructed	?		14,000	Wind farms
Zinc bromine	Commercial prototype constructed	\$0.83/Wh	0.42	2000	Wind farms

...So we're not certain of the eventual winning technology as these all mature – and it's also possible fuel cells will beat them all, or another battery not listed here (metal air or nanowire), but we have a way of comparing them, which are capacity per charge and total energy stored

What's the current state of system stability?

- **Ice storm of 1998** – 4 million without power in Canada for weeks, but more importantly destroyed 770 power towers, some of which served New York. With the Adirondack Express 500kV DC line replacing Indian Point, an increasing amount of the NY State power supply would travel this same very long supply line
- **The northeast blackout of 2003** – 55 million people affected - exposed some flaws in relaying and fault protection of the grid, which have resulted in major changes in the power industry to increase reliability
- **Queens blackout, July 2006 – 174,000** – smaller event, but indicative of problems coming from modern power electronics, and trying to manage a very complex grid; failure of traditional brownout strategy leads to major systemic damage
- **“Tropical Storm” Irene, August 2011** – Several million people without power initially, many for extended periods of time since so much infrastructure is lost
- **Hurricane Sandy, October 2012** – More than 2.5 million - exposes vulnerabilities of power systems to severe weather events. Indian Point offline; most “small in city” NYPA gas plants offline; transformers lost at Con Ed 14 St plant; state in “power emergency”

Tying Ourselves Together Tighter Might Not Be the Answer.

- In *Deep Survival* by Lawrence Gonzales, he discusses how people tied together can make a system less safe and less stable
- The ice axes allow these climbers to arrest a fall at low speeds and energies, and in these cases the ropes are a safety
- However, if that top person falls and doesn't stop themselves, they will quickly reach a speed and energy that the next person below can't possibly stop without a fixed anchor
- An accident on an "easy" mountain killed several people when their "safety" system made the incident more dangerous



“Tightly coupled”, complex systems lack resilience

- In *Normal Accidents* Perrow looks at the Challenger accident and Three Mile Island as examples of systems where complexity and tight coupling of many parts make a major accident less frequent but far more consequential when it happens
- An example of this is the inability to get gasoline because of an inability to get electricity to gas pumps during Hurricane Sandy
- A small number of micro-grid islanding systems can become rallying points during major weather or other disasters



Questions?

Storage “Figures of Merit”

When engineers compare technologies, they need benchmarks like “miles per gallon” to judge which is better for an application.

Unfortunately, as far as storage is concerned you've got lots to choose from.

Capacity Cost - \$/kWh (dollars per kilowatt hours stored)

- \$/kWh stored/cycle will be more important where the usage is occasional and the determining factor is sheer capacity for use in rare events
- You know this as how many hours your phone can make it without a charge

Lifetime Cost - \$/MWh stored (dollars per million watt hours stored)

- Lifetime is defined as the point where battery still retains 80% of its original capacity
- For most grid-connected batteries the total lifetime figure will be the most important

Storage “Figures of Merit” (Continued)

Specific Power - kW/Kg

- Measurement of how much instantaneous power can be delivered (can also be measured as a percentage of overall capacity)
- Important in applications with a fast discharge time

Energy density - kWh/Kg

- Measures total energy stored per unit mass
- Important in vehicle applications, but not very important in grid-tied applications... to a point.

Efficiency

- Generally measured as DC/DC input to output cycle
- Important for high power applications
- Critical for time shifting/"shaving" applications where the main motivation is economic

The choice of “figure of merit” depends on the application, and some types of storage do well in one measure but not another... as yet there is no single type that handles all situations well.