Enhancing Microgrid Performance and Economics with Energy Storage

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Outline

- Introduction
  - Intermittent Renewable (Wind and Solar) Power Resources
  - Need for Energy Storage (ES)
- Batteries for ES (if the microgrid is purely electric)
- Thermal Energy Storage (if the microgrid is electric <u>and</u> thermal)
- Case Studies – Performance & Economics of TES vs. Batteries
- Conclusions and Recommendations

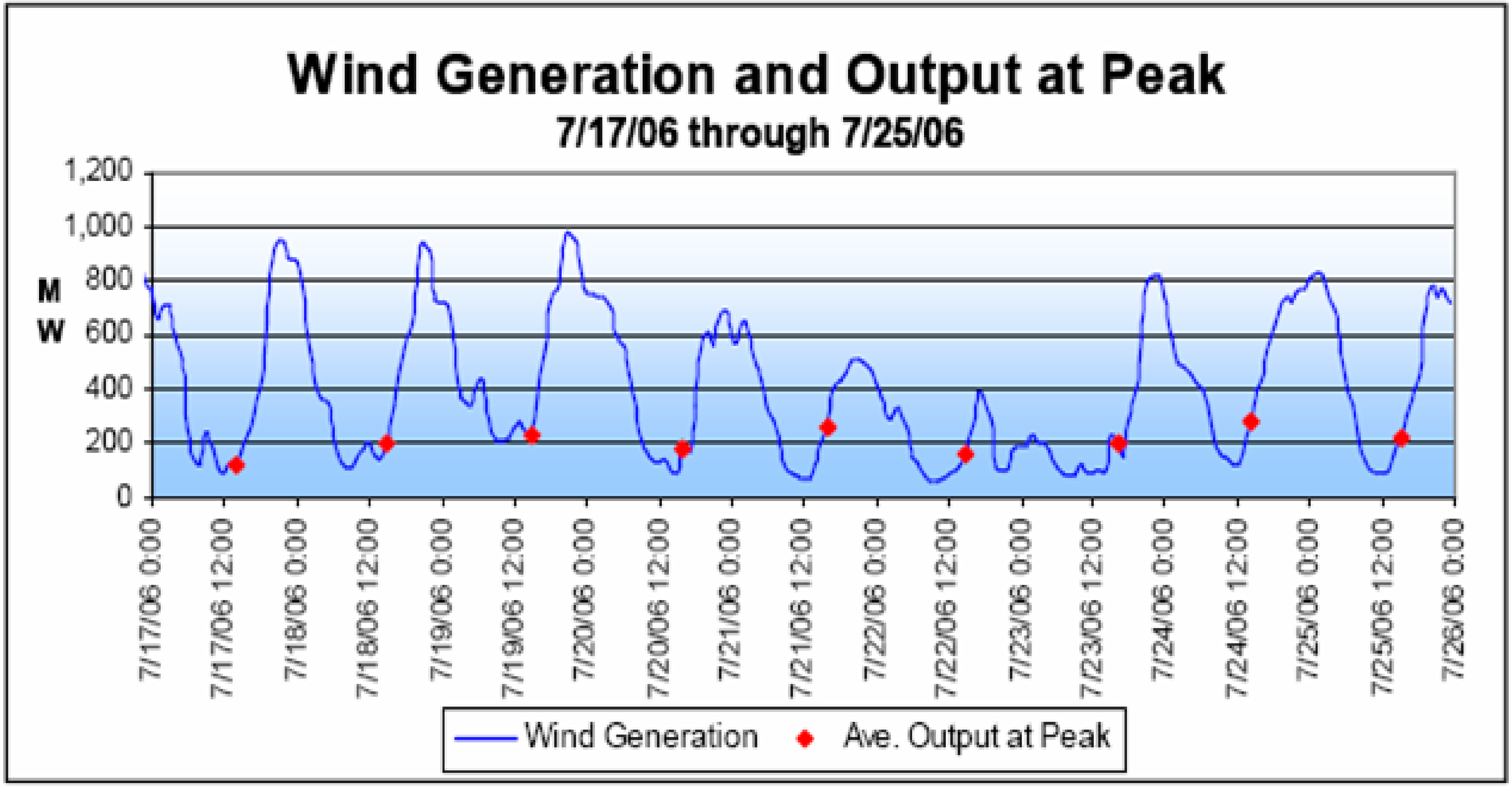
Impact of Renewable Power

- Renewable Portfolio Standards => increased Wind & Solar power
  - But they are intermittent and often out-of-phase with demand.
  - Coal + Nuclear + Wind power often exceeds nighttime demand.
  - Nighttime power trades <u>negative</u> at times, e.g.:
    - In Texas, as low as negative $0.10/kWh !
    - In Nebraska, as low as negative $0.20/kWh !!
- Energy Storage is increasingly critical; one can consider:
  - Batteries, Pumped Hydro, Compressed Air, Flywheels, SMES, Fuel Cells . . .

But large CHW TES often excels over other storage in terms of:

maturity, safety, siting, permitting, schedule, lifetime, efficiency, cap$

Wind Power Output Only ~20% at Peak Demand Times



Texas Grid (ERCOT) Historical Peak Demand

- 2017 summer peak demand: ~**70,000 MW**
- Installed wind generation: ~**23,000 MW**
- But wind output during that peak was **<600 MW**,
  i.e. **only ~2.5%** of the installed rated wind capacity!
- Thus:
  1. All this expensive, subsidized wind generation has not effectively reduced the need for conventional generation, at all.
  2. Only **Energy Storage** can make fuller use of the wind power investment.

Types of Energy Storage

- Mature storage technologies:
  - Pumped Hydro-electric (PH) Energy Storage
  - Traditional Batteries (Lead-Acid, Sodium-Sulfur)
- Developing storage technologies:
  - Advanced Electro-Chemical Batteries (Li-Ion, others)
  - Compressed Air Energy Storage (CAES)
  - Flywheels; Superconducting Magnetic Energy Storage; Fuel Cells
- An often overlooked option – Thermal Energy Storage (TES):
  - Hot TES (as Hot Water, Hot Oil, Molten Salt, Rock, or Concrete)
  - Cool TES (**Ice**, **Phase Change Material**, **Chilled Water**, **Low Temp Fluid**)

Key Characteristics to Consider for Energy Storage

- Technical development status; readiness for reliable & economical implementation
- Safety issues or concerns
- Ease of siting (considering both technical & environmental concerns)
- Schedule for permitting & installation
- Life expectancy and life cycle costs
- Round-trip energy efficiency
- Initial unit capital cost ($/kWh)

But characteristics differ for each individual storage technology.

Comparison of Energy Storage Options

Typical Characteristics	(Units)	Pump Hydro	Trad'l Batt's	Adv'd Batt's	Fly-wheel	Comp Air	Chilled Water (CHW) TES
Maturity Status		excell	excell	dev'l	dev'l	dev'l	excellent
Safety Issues		med	low	yes	yes	med	low
Flexibility of Siting		v. low	v. high	v. high	v. high	v. low	high
Ease of Permitting		diffic	simple	simple	med	diffic	simple
Implement Schedule	(years)	10+	1-2	1-2	1-2	3-5+	1-2
Expected Lifetime	(years)	40+	7-15	7-10	20	40+	40+
Round-trip Efficiency	(%)	70-85	80-90	80-90	90	70-80	near 100
Unit Capital Cost							
- Low	($/kWh)	310	500	350	7800	200	80
- High	($/kWh)	380	750	500	13760	???	200

Issues with Battery Storage

An electric-only microgrid will necessarily use batteries for storage;
but batteries (even today's leading choice, Lithium-Ion) are <u>not</u> ideal:

- Material Sourcing (exotic, costly materials; from unreliable locales)
- Safety (explosions & fires; + environmental issues extracting mat'l)
- Round-trip Energy Efficiency (typically only 80-90%)
  - Tesla's Li-Ion in S. Australia, Dec 2017: 2.42 GWh out/3.06 GWh in = 79%
- Life Expectancy (typically only 7-10 yrs, and with reducing capacity)
- Capital Cost (typical installed project costs of $500-800/kWh)
  - AEP's Li-Ion proposal in Texas: $2.3M / 3.0 MWh = $767/kWh

But a microgrid which incorporates electric <u>and</u> thermal networks can consider <u>Thermal</u> Energy Storage (TES).

Thermal Energy Storage

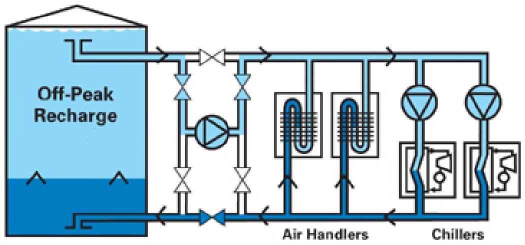
"Although battery technologies are continuing to evolve and improve, their costs are high. . . . ASHRAE's recently completed research project, RP-1607, found that thermal energy storage is currently the most cost-effective means to enable greater renewable energy generation deployment."

– *Douglas Reindl*, Ph.D, P.E., Professor of Mechanical Engineering and Chair of Dept of Engineering Professional Development at Univ. of Wisconsin-Madison (ASHRAE Journal, February 2018, p.20)

"Chilled water and hot water stratified thermal storage is the world's most viable storage technology."

– *George Berbari*, founder and CEO of DC PRO Engineering, Sharjah, UAE (speaking at the District Cooling and Trigeneration Summit 2016, Riyadh, KSA)

Chilled Water (CHW) Thermal Energy Storage (TES)



- An insulated tank, full of water at all times.
- Cool, dense CHW Supply in lower zone, at ~40 °F;
- Warm, less dense CHW Return in upper zone, typically at 50 to 60 °F;
- Narrow "thermocline" (temperature gradient) in between the zones.
- TES is charged off-peak (nighttime): CHWR pumped from top of tank, cooled in chillers, returned to bottom of tank; thermocline rises in tank, until tank is 100% cool water.
- TES is discharged on-peak (daytime): CHWS pumped from bottom of tank, meets cooling loads, returned to top of tank; thermocline falls in tank, until tank is 100% warm water.

No moving parts or heat exchange in tank; just pumps & valves outside.

Energy Efficiency of CHW TES

- TES inefficiencies: 1) heat gain, and 2) pumping.
- TES efficiencies: 1) cooler nighttime condensing temperatures, and 2) avoided low-load operation of chillers & auxiliaries.
- **CHW TES** annual round-trip energy efficiency is near 100%.
- Some examples even show net energy savings with TES:
  - **State Farm data processing campus in Illinois**
    - 89,600 ton-hrs **CHW TES**
    - annual kWh/ton-hr reduced by 3% (by modeling)
  - **Texas Instruments manufacturing facility in Texas**
    - 24,500 ton-hrs **CHW TES**
    - annual kWh/ton-hr reduced by 12% (by measurement)

Massachusetts ESI (Energy Storage Initiative)

In December 2017, the State of Massachusetts announced:

- 26 Energy Storage projects
- $20 million in state grants
- $32 million in private "matching funds"
- Average installed capital costs (grants + matching funds):
  - Flywheel Storage @ $948/kWh
  - Battery Storage @ $656/kWh
  - **Thermal Energy Storage @ $240/kWh**

Batteries may need grants or tax credits to be economic.

TES does not.

TES at Harvard University – Allston Campus

TES project currently underway, to be on-line in 2018/19

- Chilled Water TES Capacity: **13,392 Ton-hours**
- Equivalent electrical storage: **9 MWh**
- Estimated cost: **<$300/kWh** (~half the $/kWh of batteries); plus **TES avoids millions of $** in future chiller plant capacity
- Estimated summer round-trip energy efficiency: **100-103%** (vs. ~80-90% for Li-Ion batteries)
- TES extends winter use of **“free cooling”**
- TES life a minimum of **40-50 yrs** (vs. 7-10 yrs for Li-Ion batt’s)

TES fully justified with no grants, tax credits, or utility rebates.

CHW TES at University of Nebraska-Lincoln (UNL)

Two **CHW TES** at UNL, each providing:

1) energy storage, plus
2) peaking capacity for the campus CHW network

UNL East Campus

Storing 16,326 ton-hrs (12 MWh elec) and shifting up to 4,000 tons (3 MW)

UNL City Campus

Storing 52,000 ton-hrs (39 MWh elec) and shifting up to 8,333 tons (6.25 MW)

Example: 39 MWh at U of Nebraska-Lincoln

Storage Element	Lithium-Ion Advanced Batteries (hypothetical)	Chilled Water (CHW) Thermal Energy Storage (TES) (actual, 2017-18)
Peak cooling discharge	not applicable	8,333 tons
Peak electric discharge	6.25 MW	6.25 MW equivalent
Duration at peak disch.	6.24 hrs	6.24 hrs
Net storage (thermal)	not applicable	52,000 ton-hrs
Net storage (electric)	39.0 MWh	39.0 MWh equivalent
Storage unit cap cost	$350/kWh	$100/ton-hr
Storage capital cost	**$13.65 million**	**$5.20 million (38% of batteries)**
Full system cap cost	**$27.3 million**	**$11.7 million (43% of batteries)**
Full system unit cap cost	**$700/kWh**	**$225/kWh (43% of batteries)**

Example: 39 MWh at U of Nebraska-Lincoln

Storage System	Lithium-Ion Advanced Batteries (hypothetical)	Chilled Water (CHW) Thermal Energy Storage (TES) (actual, 2017-18)
Full system capital cost	$27.3 million	$11.7 million (43% of batteries)
Full system unit capital cost	$700/kWh	$225/kWh (43% of batteries)
Additional Chiller Plant		
Necessary new capacity	4,016 tons	none, as TES provides 8,333 tons
Unit capital cost	$2,900/ton	not applicable
Installed capital cost	$11.6 million	zero
Total capital cost	**$38.9 million**	**$11.7 million (30% of batteries)**
Storage life expectancy	**7-10 years**	**40+ years**
Round-trip energy efficiency	**80-90%**	**near 100%**

30+ years of CHW TES – Including Repeat Owners

From many hundreds of CHW TES, here are just a few Owners, each with Multiple TES Installations	# of TES	On-Peak Thermal Storage (ton-hrs)	On-Peak Thermal Peak Shift (tons)	On-Peak Electrical Storage (MWh)	On-Peak Electrical Peak Shift (MW)
California State University campuses	18	309,000	52,000	216	36
University of California campuses	9	281,000	47,000	197	33
University of Nebraska campuses	2	68,000	12,000	51	8
University of Texas campuses	7	152,000	25,000	106	18
U.S. (FDA, NASA, Nat'l Labs, NIH, VA)	12	269,000	45,000	202	34
U.S. DOD (Air Force, Army)	9	203,000	34,000	152	25
Airports(DFW, LAX, Love, Reagan, SanAnton)	5	152,000	40.000	106	28
Boeing / Lockheed Martin	5	230,000	38,000	172	29
Ford / GM / Toyota	13	381,000	63,000	263	44
Halliburton / Saudi Aramco	4	62,000	10,000	48	8
Honeywell / IBM / Texas Instruments	8	186,000	31,000	139	23
3M / State Farm / UPS	10	188,000	31,000	143	24
Distr St. Paul/ Qatar Cool/ Tabreed/ Trigen	16	517,000	86,000	346	58
Totals (from just these few)	**118**	**3 million**	**514,000**	**2,141**	**368**

Operating and Capital Savings with CHW TES

TES Project Type	Owner	CHW TES Capacity (ton-hrs)	Savings vs. Non-TES Chiller Plants: Annual Operating Savings	Savings vs. Non-TES Chiller Plants: Initial Capital Savings
retro	Washington St U	17,750	$ 260,000/yr	$1 to 2 million
new	Lisbon Distr Energy	39,800	$1,160,000/yr	$2.5 million
retro	U of Alberta	60,000	$ 600,000/yr	$4 million
new	Chrysler R&D	68,000	>$1,000,000/yr	$3.6 million
retro	DFW Airport	90,000	~$2,000,000/yr	$6 million
retro	OUCooling district	160,000	>$ 500,000/yr	>$5 million

***Net Capital Savings** accrued from downsizing chiller plants.*

TES Cap$ is less than that of equivalent chiller plant capacity.

Additional Benefits of TES

- **Mission Critical Facility** back-up (e.g. Princeton U data center)
- **Better CHP Economics** from flat cooling & electric profiles (TECO)

- **Turbine Inlet Cooling** maximizes hot weather CT output (SEC)

- **Fire Protection** dual-use (3M)

Conclusions and Recommendations

- The need for Energy Storage grows along with wind & solar power.
- Many storage options; but large-scale **CHW TES** offers advantages.
- In 39 MWh example, **CHW TES** (vs Li-Ion batt's) is 50-70% lower $/kWh; plus it has higher efficiency (near 100%), and longer life (40+ yrs).
- 30+ yrs of successful applications; many owners with multiple **CHW TES**.
- **CHW TES** has additional benefits for MCFs, CHP, TIC, and fire protection.

Grids and microgrids with large cooling needs
(e.g. air-conditioning, process cooling, or Turbine Inlet Cooling)
should consider incorporating CHW TES, as it likely offers
the lowest $/kWh for storage and the lowest $/ton for cooling.

District Energy's aggregated thermal loads present
prime opportunities to employ TES, rather than batteries or other ES.

Questions / Discussion ?

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