14TH ANNUAL ELECTRIC POWER™ CONFERENCE & EXHIBITION

Energy Storage
at Near-Zero Capital Cost and Near-100% Efficiency - **Thermal Energy Storage** coupled with **Turbine Inlet Cooling**

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Outline

- Introduction
- Energy Storage Technologies
  - Types; Characteristics; Comparisons
- Turbine Inlet Cooling (TIC)
- Thermal Energy Storage (TES) with TIC
  - Examples; Economics; Efficiencies
  - U.S. Electric Power Market Potential
- Summary and Conclusions

Appendix: actual installation data comparisons

Introduction

- Storage is a useful part of many, if not most, man-made and natural systems:
  - Battery in your PC
  - Ice-cube in your cold drink
  - Fuel tank in your car
  - Storage tanks in a municipal potable water system
  - Hot water tank in your home hot water system

Storage would also be very useful in an electric power utility system. However, this poses technical and economic challenges.

Introduction

- The value of storage has only grown as:
  - air-conditioning drives demand growth and widens the gap between peak and baseload demand,
  - time-of-day differentials grow in marginal heat rates, emissions, and value of electricity, and
  - Power gen from renewable energy grows, but often with a significant intermittent, or even out-of-phase, nature relative to demand (e.g. wind).

Thus, practical and economical energy storage can play a key role in electric power systems.

Introduction

“Storage will be critical
for large scale implementation
of sustainable energy.”

– The November 2007 California ISO report “Integration of Renewable Resources”

Types of Energy Storage

- Traditional commercial utility-scale storage:
  - Pumped Hydro-electric (PH) Energy Storage
- Developing utility storage technologies:
  - Compressed Air Energy Storage (CAES)
  - Advanced Electro-Chemical Batteries
  - Mechanical Flywheel Energy Storage
  - Superconducting Magnetic ES (SMES)

Another available storage technology:

- ***Thermal Energy Storage (TES)****, specifically Cool TES coupled with Turbine Inlet Cooling (TIC)*

Key Storage Characteristics

- Technical development status; readiness for reliable & economical utility-scale applications
- Initial unit capital cost ($/kW and $/kWh)
- Life expectancy and life cycle costs
- Round-trip energy efficiency
- Practicality for rapid discharge (secs or mins)
- Practicality for extended discharge (hours)
- Ease of siting (practical & environm'l concerns)

But each individual storage technology differs.

Pumped Hydro (PH) Energy Storage

- Fully commercial, utility-scale history
- High unit capital costs (>$2,000/kW)
- Long life expectancy (30+ years)
- ~75 to 85% round-trip energy efficiency
- Not practical for rapid discharge (secs or mins)
- Practical for extended discharge (many hours)
- Very difficult to site (technically & environm'ly)
- Very long permitting & construction periods

Compressed Air Energy Storage (CAES)

- Two old “demos”; two “2nd gen” proposed
- Moderate “target” unit costs (~$1,000/kW)
- Long life expectancy (20+ years)
- moderate round-trip energy efficiency
- Not practical for rapid discharge
- Practical for extended discharge (many hours)
- Difficult to site (technically & environmentally)
- Long permitting & construction periods

Advanced Electro-Chemical Batteries

- “Pioneering” ~1 MW-scale demonstrations
- Very high multi-hour unit costs ($4 - 6,000/kW)
- Limited life expectancy (~15 years)
- ~70 to 75% round-trip energy efficiency
- Practical econ’ly for rapid discharge (minutes)
- Practical tech’ly for extended discharge (hours)
- Likely not difficult to site (tech’ly or environm’ly)
- Modest permitting & construction periods

Mechanical Flywheel Energy Storage

- 1 MW “demo”, 20 MW planned “pilot”
- Med-high unit capital costs (>$1,000/kW)
- Long life expectancy (perhaps 20+ years)
- moderate round-trip energy efficiency
- Practical for rapid discharge (secs to minutes)
- Perhaps practical up to ~15 minute discharge
- Perhaps not difficult to site (tech’ly or envir’ly)
- Modest permitting & construction periods

Superconducting Magnetic ES (SMES)

- Developmental; 10-100 MW sizes projected
- Very high unit capital costs
- Undetermined life expectancy
- moderate round-trip energy efficiency
- Practical for very rapid discharge (seconds)
- Not practical for extended discharge
- Perhaps not difficult to site (tech’ly or envir’ly)
- Modest permitting & construction periods

An Alternative Energy Storage Technology

- Fully commercial, demand-side history
- Very low unit capital costs ($100-400/kW)
- Long life expectancy (30+ years)
- Near 100% round-trip energy efficiency
- Not practical for rapid discharge
- Practical for extended discharge (many hours)
- Not difficult to site (technically or environm'ly)
- Modest permitting & construction periods

Thermal Energy Storage (TES)

Turbine Inlet Cooling (TIC)

- CT output highly sensitive to inlet air temp:
  - Warmer air = less density = less mass = less power
  - Frame CTs can lose 20-25% power at 100 F vs ISO
- Cooling the inlet air aids hot weather output:
  - Evap cooling can get near to wet bulb temp; not much help in humid climate; consumes water.
  - Chiller-based cooling typ'ly gets 45 to 50 F inlet air; gains 20 to 30% output <u>and</u> improves heat rate; but chiller plants are costly & consume parasitic power.

TIC capital $/kW is less than even simple CTs.

Thermal Energy Storage (TES)

- Cool TES can be Ice, Chilled Water (CHW), or Low Temp Fluid (LTF) TES; shifts chiller load to off-peak
- CHW TES is increasingly used with TIC:
  - Shifts parasitic load to off-peak, maximizes net kW;
  - Reduces chiller plant capacity and capital cost, which can save <u>more</u> than the cost of the TES:

Thus, by incorporating CHW TES with TIC:

- ***Net capital cost is down; net kW is up; and***
- ***Net $/kW is <u>way</u> down, even <u>negative</u> vs non-TES TIC;***
- ***I.e. adding TES to TIC can have zero or negative cost.***

CHW TES Round-trip Energy Efficiency

- There are inherent <u>in</u>efficiencies in CHW TES:
  - Pumping energy to/from TES (typically 3-6%)
  - Heat gain into TES (typically 1-2% per day)
- But there are also inherent <u>e</u>fficiencies:
  - Avoid low part load equip oper (typical gain 3-6%)
  - Cooler off-peak condensing temp (typ. gain 5-10%)

Net round-trip energy efficiency for CHW TES is typically ~100%, or even up to ~110% (compared to the same cooling without TES)

Some CHW TES-TIC – 1999-2011

Application	CT No. x Type	Ton-hrs	Boost
Elec Utility - TX	1 x SW 501F	28,989	15%
Elec Utility - CA	2 x GE 7FA	39,000	
IPP - NM	2 x MHI 501FD2	55,500	10%
Elec Utility - VA	2 x GE 7FA	78,710	14%
IPP - TX	3 x W 501 D5	107,000	21%
Elec Utility - TX	4 x GE 7FA	110,016	11%
Elec Utility - PA	4 x GE 7FA	129,000	13%
Util - Saudi Arab.	10 x GE 7EA	193,000	30%
Util - Saudi Arab.	40 x GE 7EA	710,000	31%

Analysis of CHW TES-TIC Data

- 9 examples, over 13 years (more planned)
- 68 CTs; new & retrofits; simple CTs & CTCCs
- 1.5 million Ton-hrs total; 160,000 Ton-hrs avg.
- TIC for avg. of 6 hrs/day; range: 4-13 hrs/day
- Hot weather power augmentation:
  - range: 10 to 31% net increase

Total peaking power from TIC = ~1,200 MW

Total storage as TES = ~325 MW x 6 hrs/day

TES-TIC Example - Riyadh, KSA

Electric utility power generation facility (2005):
10 existing simple cycle CTs, each 75 MW ISO;
at the design ambient air temp of 50 °C (122 °F),
power output is only 75-80% of nominal rating.

Saudi Electricity Co. (national electric utility):

- Needed to meet rapidly increasing demand.
- They could add 3 more CTs for 30% more power.
- Instead, they chose Turbine Inlet Cooling (TIC).
- TIC has much lower capital $/kW than new CTs.

TES Solution / Results

- Added TIC (at 3,100 Tons per CT x 10 CTs).
- Did not install 31,000 T (non-TES) chiller plant.
- Added only 11,000 T plant, to run 17-hrs/night.
- Added 193,000 T-hr (31,000 T x 6 hr) CHW TES.

TES-TIC adds a net increase of 180 MW (30%),

at only $250/kW, ~half the cost of a new CT plant!

TES adds net 48 MW x 6 hrs/day on-peak power;

+ over $10 million in net capital cost savings!

And TES round-trip energy efficiency = ~100%.

Chilled Water (CHW) TES for TIC

- Saudi Electricity Company - Riyadh, Kingdom of Saudi Arabia (2005)
- 193,000 ton-hrs CHW TES, with CHW supply / return temps of 45.5 / 86.1 °F
- 140 ft diameter x 70 ft high (8 million gallon) CHW TES tank
- Provides Turbine Inlet Cooling for 30% net power increase in hot weather
- TES-TIC produces 180 MW at $250/kW; TES contributes 48 MW x 6 hrs/day

Turbine Inlet Cooling with CHW TES

	Entire Installation **(TIC w/ CHW TES)**	**Storage Portion Only** **(CHW TES sub-sys)**
Location	Saudi Arabia	Saudi Arabia
Year in operation	2005	2005
Peak power	180 MW	48 MW
Energy storage	288 MWh	288 MWh
Projected life	30+ years	30+ years
Round-trip efficiency	near 100%	near 100%
Classification	commercial	commercial
Unit capital cost	$250/kW	$83/kW (or <$0/kW*)
Dispatch period	6 hours/day	6 hours/day

** After credit for smaller CHW plant, over $10M net capital savings!*

TES-TIC Potential in the U.S.

Assume:

- ~300 GW of total installed CT capacity
- ~50% is to be retrofit with TES-TIC
- ~20% output enhancement from TES-TIC

Then TES-TIC could provide:

1. ~30,000 MW of hot weather peaking power, at a typical capital cost of only $200-400/kW, plus
2. ~8,000 MW x 6 hrs of Storage each hot day (at near-zero add'l capital cost (or net savings) vs TIC w/o TES; and near-100% round-trip energy efficiency of TES)

Summary

- Energy Storage is useful for most systems.
- ES will aid electric systems & renewable power.
- Many ES technologies; but with different traits.
- Pumped Hydro – well proven; but costly, inefficient, and difficult to site and permit.
- CAES, Batteries, Flywheels, SMES – promising; but developmental, inefficient, and costly for multi-hour ES applications.
- TES – Wide demand-side use & growing TIC-TES use, with an order-of-mag less $/kW than other multi-hour ES, & much higher energy efficiency.

Conclusions

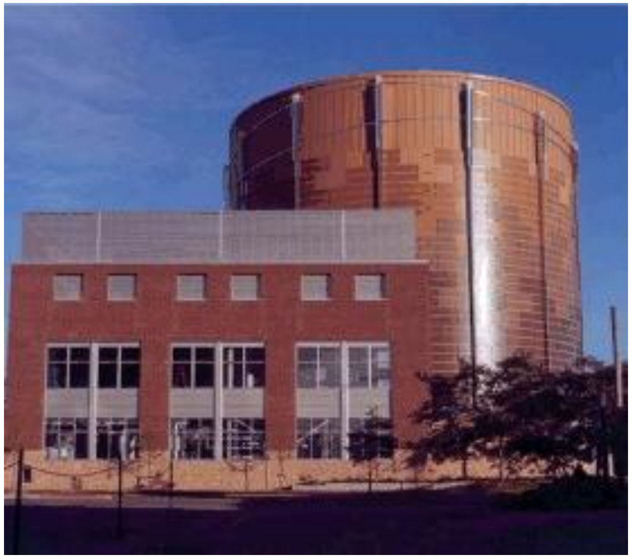
No one storage technology is the "silver bullet" to provide a comprehensive solution to all the energy storage needs of the electric power grid.

*But **Thermal Energy Storage (TES)**, coupled with **Turbine Inlet Cooling (TIC)**, can provide an immediately effective and substantial contribution to Energy Storage power grid needs*

- ***often at Near-Zero capital cost and***
- ***at Near-100% round-trip energy efficiency.***

Questions / Discussion ?

Or for a copy of this presentation, contact:



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Appendices

- Side-by-side Comparisons of Data from Actual Energy Storage Installations: Chilled Water Thermal Energy Storage (TES) coupled with Turbine Inlet Cooling (TIC) versus:
  - Pumped Hydro-electric (PH) Energy Storage
  - Compressed Air Energy Storage (CAES)
  - Advanced Electro-Chemical Battery Storage
  - Mechanical Flywheel Energy Storage

Pumped Hydro ES vs TES-TIC

	Pumped Hydro Energy Storage	**Turbine Inlet Cooling with CHW TES**
Location	Michigan	Saudi Arabia
Year in operation	circa 1990	2005
Peak power	1,200 MW	48 MW
Energy storage	9,600 MWh	288 MWh
Projected life	30+ years	30+ years
Round-trip efficiency	~70-80%	near 100%
Classification	commercial	commercial
Unit capital cost	$2,000+/kW	$83/kW
Dispatch period	8 hours/day	6 hours/day

Compressed Air ES vs TES-TIC

	Compressed Air Energy Storage	Turbine Inlet Cooling with CHW TES
Location	Iowa	Saudi Arabia
Year in operation	201X (planned)	2005
Peak power	268 MW	48 MW
Energy storage	1,608 MWh	288 MWh
Projected life	20+ years	30+ years
Round-trip efficiency	~70%	near 100%
Classification	developmental	commercial
Unit capital cost	$900/kW (target)	$83/kW
Dispatch period	6 hours/day	6 hours/day

Advanced Battery ES vs TES-TIC

	"Utility-scale" Na-S Advanced Batteries	Turbine Inlet Cooling with CHW TES
Location	West Virginia	Saudi Arabia
Year in operation	2006	2005
Peak power	1.2 MW	48 MW
Energy storage	7.2 MWh	288 MWh
Projected life	15 years	30+ years
Round-trip efficiency	~70%	near 100%
Classification	"pioneering"	commercial
Unit capital cost	$4,500/kW	$83/kW
Dispatch period	6 hours/day	6 hours/day

Flywheel ES vs TES-TIC

	Flywheel Energy Storage	**Turbine Inlet Cooling with CHW TES**
Location	New York	Saudi Arabia
Year in operation	2011 (1st 20%)	2005
Peak power	20 MW	48 MW
Energy storage	5 MWh	288 MWh
Projected life	20 years	30+ years
Round-trip efficiency	~80-90%	near 100%
Classification	demonstration	commercial
Unit capital cost	$3,440/kW	$83/kW
Dispatch period	15 minutes	6 hours/day