Large Scale Energy Storage with Thermal Matrix Energy Storage

G. Lynch, T. Pietsch, S. Sutherland

george.lynch@kelvinstorage.com, tony.pietsch@kelvinstorage.com
steve.sutherland@kelvinstorage.ca http://kelvinstorage.com

ABSTRACT

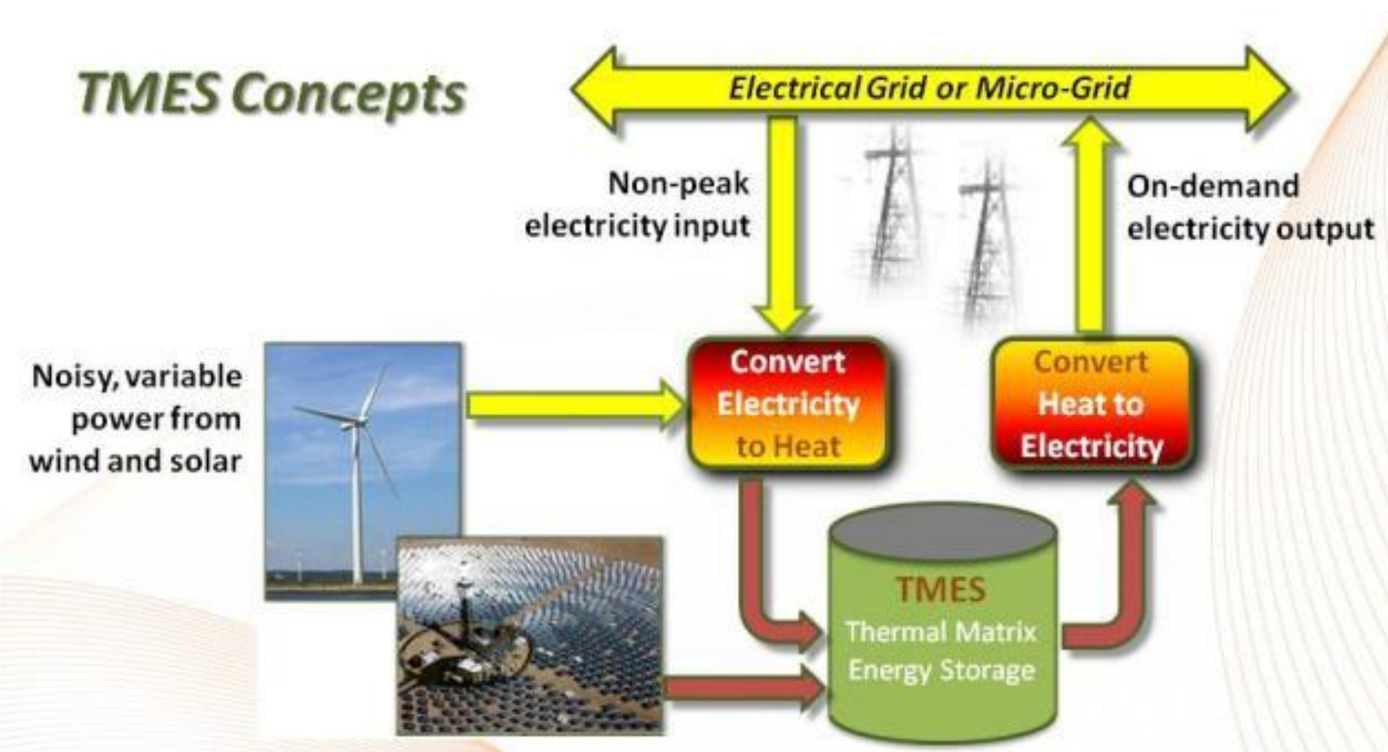
Utilities of the 21st century are transitioning towards a green world of wind and solar generated electricity, but the intermittency of wind and solar create voltage fluctuation problems for grid operators. Energy storage is required to fill in those periods when the wind does not blow or the sun does not shine, as well as shift nighttime wind energy to afternoon periods when it is valuable. Batteries are good for a few megawatts for a few hours[7], but far greater capacity is needed [4] to provide Giga-watts of power for days at a time such that utilities do not have to maintain idle backup fossil fuel power plants. Thermal Matrix Energy Storage (TMES) can store enormous amounts of energy in tanks filled with heated graphite which can be recovered by transferring that heat back to conventional turbine power plants. Technology is being developed to store heat at up to 2500K (4041F), making possible the storage of hundreds of Giga-watt-hours of energy using only environmentally friendly, non-toxic materials and easily obtained synthetic graphite.

Keywords: energy storage, graphite, thermal storage, bulk storage, smart grid

1 "TMES"

Kelvin Storage Technologies, Inc, ("KST") is developing Thermal Matrix Energy Storage ("TMES", sounds like "Tim's") which converts electricity from renewable sources, the grid, or other generation sources to high temperature heat (up to 2,500K) stored in a graphite-based energy storage system with 2-10 times the energy density of batteries [1] and a lifetime of over 20 years. A turbine is used to convert the heat back to electrical energy. The graphite and a proprietary, environmentally-friendly gas mixture[3] is safely enclosed in a protective container that cost effectively stores the energy for extended periods with loss rates of as low as 1% per day in larger installations and with development under way to reach loss rates of < 7% per month. This economical, large scale energy storage will make wind and solar power reliable and manageable. Even with round trip conversion loses, the extreme high-density storage combined with the low cost, inexpensive materials, makes TMES a very economical storage solution for large scale projects with high energy to power ratios.

The concept of storing thermal heat in graphite is a



proven process in the public domain.[2] The key enabling innovation by KST is the use of an intermediate inert gas mixture to transfer heat out of the graphite to an application-specific heat exchanger. This key innovation allows the maximum temperature of the graphite heat storage to be far hotter, and therefore enabling the storage of far greater amounts of thermal energy in the same space and tonnage of graphite.

There is virtually no energy loss on conversion of electricity to heat. Depending on the turbine/generator set, total round-trip efficiencies vary from 30% to 60% with the best efficiencies achieved with larger-scale facilities using combined cycle gas and steam turbines. The Company's work will lead to future designs for more efficient turbines to take advantage of the high-heat configurations possible with TMES. Even with conversion losses, TMES's ability to store energy at low-peak prices and sell at high-peak prices is financially very attractive when utilities operate in open-transaction markets which experience high price variability. No other technology supplies the high efficiency, bulk energy storage capability of TMES.

1.1 Improving the Profitability and Growth of Wind Generation

Renewable energy resources are being added to the grid rapidly, particularly in California with the mandate of AB2514 which requires Utilities to generate 33% of their energy from renewable sources by 2020. Similar mandates also exist in at least 31 other states at this time.[5] The variability of solar and wind generation means that utilities would have to maintain fossil fuel power plant capacity to cover for calm or cloudy days, which, ironically, generates more green house gases as power plants ramp up and down than the renewable energy sources save.[8] Bulk energy storage can provide pollution free stabilization of the grid.

Wind in particular needs low-cost, bulk storage since it blows largely at night when electrical demand is reduced. As a result, the average selling prices per MW for wind generators is significantly discounted (for example, in Alberta a 34% discount to the annual average price for the province). Storage would allow wind operators to shift sales of electricity from non-peak to peak pricing. In Alberta, that price range can well exceed 50 times high to low. Making wind operators more profitable will fuel the growth of this sector. They will be able to manage their delivery of electricity, reducing or eliminating the need for peaker plants and the related Green House Gas emissions ("GHGs).

1.2 Extending the Useful Life of Coal Plant Facilities and Sites

Over 200 coal plant closures are planned over the next 10 years in North America; some because the plants have reached the end of their economic life. However, many plants are also being closed as a result of poor economics due to rising coal prices and new emissions standards in the US which leave coal operators faced with additional multi-hundred million dollar capital cost expenditures.

TMES offers an alternative business model: convert the coal plants into grid-size storage facilities, as illustrated

here:

At coal plants with many years of useful life left in the turbine "gen sets", coal burners could be replaced with TMES storage units while plants continue to use the existing steam turbines and transmission hookups. The utility would then store electricity taken from the grid or wind generation at non-peak periods and sell it in peak periods at substantially higher prices. The land is already available and zoned for utility use. Workers are already trained to maintain the turbines. Alternatively the plant may be closed prematurely in its economic life cycle with asset write-offs and jobs lost.

Worn out coal plants could be replaced with TMES storage and more efficient, new combined cycle turbine sets, with their thermal storage charged from wind and surplus energy at night to satisfy peak power demand with zero emissions, while utilizing existing utility zoned land and existing grid connections.

1.3 Technical Roadmap

The R&D Plan is organized into 4 phases, with frequent progress milestones:

1. Proof of performance laboratory testing of selected ceramic materials prove that they withstand the peak

temperatures of operation of the storage modules, with the goal of reaching 2500 K and higher. Initial materials are currently being tested, with an expanded set proposed for a joint development effort with the faculty of the New York State College of Ceramics of Alfred University.
2. Construction of the first Demo System to demonstrate the design solutions to all the detailed technical issues and begin Proof of Performance cycle testing of the storage system.
3. Construction of a refined Demonstration System including turbine generated energy output
4. Extension of the technology to larger scale installations as described below.

1.4 KST Product Family Plan

A series of product families will be developed with progressively larger scale storage and power output:

1. 4 MWh storage unit driving a 250kW gas turbine for 4 hours from storage, operational 16 months after major funding, which will be (relatively) portable:

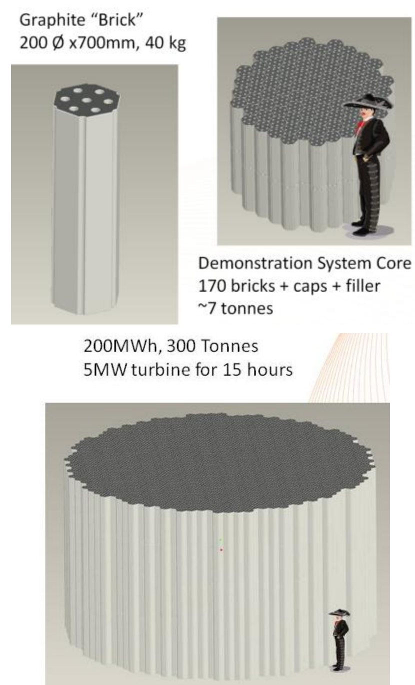
2. 200MWh storage module, capable of driving a 12MW gas turbine for 6 hours to meet the need for wind farm time shifting of night time wind production. Three storage modules and that same turbine could operate for 18 hours at full output.

3. 2GWh storage module, capable of driving a 50MW gas turbine for 16 hours. These modules enable scalable power plants, such as a cluster of 5 200MW gas turbines driven by an array of 36 2GWh storage modules resulting in nominal power generation of 1GW for 24 hours.

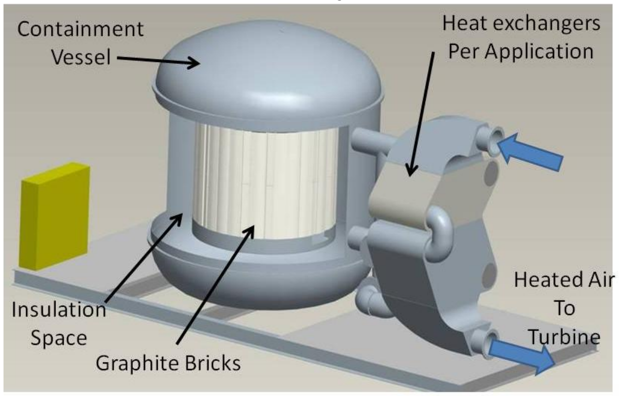
1.5 Why Use Graphite?

"Sensible" heat energy storage (as opposed to utilizing a phase change material) in graphite has been utilized with varying success over time [2] and remains attractive for bulk use. Graphite is an inexpensive, relatively high-energy-density thermal storage material due to its very high sublimation point in inert gas (3925 K ≈ 3650 °C) and high heat capacity that increases at elevated temperatures. Graphite's high thermal conductivity enables rapid heat absorption and deployment. Its relative abundance in nature, both as mineral graphite and as coal and coal and petroleum tars that can be converted into graphite make it both inexpensive and abundant for bulk utilization. TMES energy storage material is currently comprised of processed synthetic graphite that has the majority of its ash forming content removed by common industrial processes. The graphite does not need to have expensive highly aligned crystallographic structures, significantly reducing the cost of raw material.

Most graphite can be inexpensively processed into standard size bricks, as shown below, that can be joined together with simple mechanical alignment features. Assemblies of these bricks will be wrapped with additional graphite materials for structural support (graphite fiber composites, cloth, foil, foam, fabric, felts, etc.) to meet worst cast loading forces that may result from earthquakes and other natural or man-made disaster situations. The reinforced assemblies are then wrapped with layers of graphite insulation in the very high temperature zones, and ceramic fiber insulations in the cooler zones. This piecewise and layered construction will enable graphite cylinder size scaling to very large storage capacity – from a few mega-watt-hours up to hundreds of giga-watt-hours. TMES energy storage is the only geography agnostic energy storage technology capable of scaling to such large sizes.

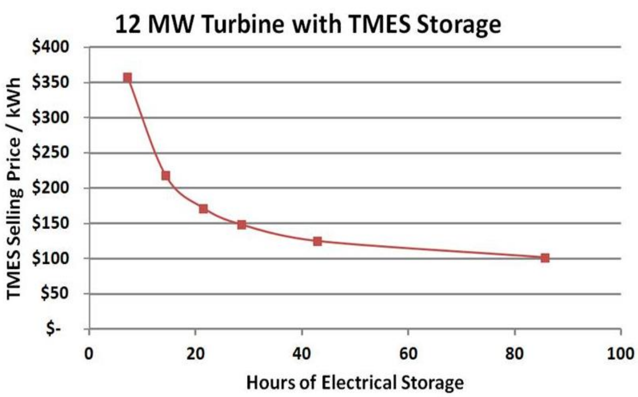


The 4 MWh Demonstration System will look like this:



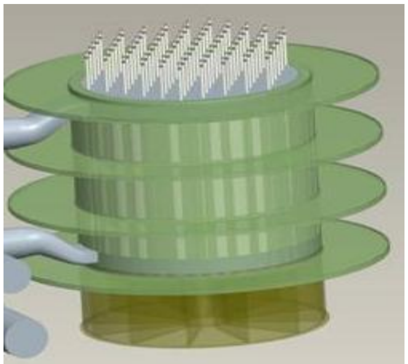
1.6 The High Temperature Advantage

Energy storage solutions from KST will utilize peak temperatures as high as 2500 Kelvin (4041°F) in order to take advantage of the very high energy density achieved by that high temperature, resulting in much smaller volumes of graphite to obtain a given amount of stored energy, and lower system costs. In comparison, this is 2x-4x the energy density of lithium batteries, and 10X that of lead acid batteries. TMES facilities will include the cost of the turbine generator set, so is an expensive alternative for short storage duration. But as the length of time of available power increases, the total capital cost of TMES, expressed in $/kWh of electrical energy output, decreases dramatically to become the lowest cost solution, by far, for long duration energy storage.[1][5][6].



Other graphite based energy storage systems currently on the market which utilize alloy steel tubing inside the graphite storage core for boiling high pressure steam, are limited to about 1250K as the maximum graphite temperature and require significantly larger amounts of graphite compared to the KST high temperature technology. Such lower temperature graphite storage solutions are limited to low temperature phase change Rankine cycle turbines, such as steam or Organic Rankine Cycle turbines using an organic liquid that boils at a temperature lower than water. These low temperature solutions will not be able to utilize higher temperature gas-turbines that are in common use today, nor take advantage of high temperature ceramic turbine technology and the higher thermal efficiencies that they promise for the future.

Storing energy at 2500K requires precise control over the transfer of heat throughout the system and the conduction of heat out of the hottest zones of the TMES. KST solutions achieve these high peak temperatures by removing all steels and other metals from the hot zone. This is an illustration of the ceramic structures designed



to support the weight of the graphite and provide space for the necessary insulation.

References

[1] D. Rastler, "Electricity Energy Storage Technology Options", EPRI report 1020676, December 2010.

[2] http://www.rapsystems.com.au/energy_storage.html, March 2013

[3] A. Pietsch, G. Lynch, S. B. Sutherland, and T. W. Goodwin III, "Enabling High-Density Energy Storage: Design Characteristics of Thermal Matrix Energy Storage and a Highly Conductive Gas Mixture", (Unpublished) *IEEE International Conference on Smart Grid Engineering*, Ontario, Canada, August 28, 2012.

[4]"Electrical Energy Storage", IEC Whitepaper, Dec 2011, "iecWP-energystorage-LR-en.pdf"

[5]http://www.sandia.gov/ess/docs/conferences/Dec_19_RPS_and_Energy_Storage_Combined_Slides.pdf, 3/2013, p14

[6]http://disgen.epri.com/downloads/EPRI%20CAES%20Demo%20Proj.Exec%20Overview.Deep%20Dive%20Slides.by%20R.%20Schainker.Auguat%202010.pdf

[7]J. Dodge, Smartplanet,(Blog) Aug 28, 2009 http://www.smartplanet.com/blog/thinking-tech/lithium-the-new-oil/1228

[8] Bentek Energy, LLC, "How Less Became More: Wind, Power, and Unintended Consequences in the Colorado Energy Market", prepared for Independent Petroleum Assoc'n of Mountain States, p.1,April 16, 2010

CTSI-Cleantech 2013, www.ct-si.org, ISBN 978-1-4822-0594-7