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TAILORABLE IONIC MATERIALS FOR HIGHER ENERGY DENSITY REDOX FLOW BATTERIES

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We present the synthesis and electrochemical cell testing of metal ionic liquids (MetILs) for redox flow batteries. Significant improvements in viscosity and electrochemical reversibility were recently achieved by systematically varying the charge-balancing anions as well as the complexing ligands. Static cell testing of the most promising copper- and iron-based compounds showed reasonable coulombic efficiencies. The results also showed that some of the compounds were stable in three different oxidation states, thus further increasing energy density by increasing the number of cyclable electrons in the cell.

Keywords: ionic liquids, redox flow batteries, energy density

INTRODUCTION

Worldwide energy demand is projected to significantly increase by 2050, and this increased need will be met, at least in part, through the use of renewable energy sources such as solar and wind [1]. However, the intermittent output of these sources requires the development of large-scale stationary energy storage systems. Among the most promising technologies are redox flow batteries (RFBs) that utilize the oxidation and reduction reactions of redox couples to perform reversible charging and discharging [2, 3]. RFBs can have long lifetimes due to the fact that their electrode reactions do not involve the mechanical stresses associated with the insertion or removal of the active species. In addition, because the energy-bearing complexes are stored externally rather than in the electrode compartment, the energy capacity can be tailored independently from the power output. Despite many compelling attributes, work is needed to increase energy density and decrease costs. As part of our own efforts to address energy density, we previously reported proof-of-concept work on the synthesis of a family of low-cost metal ionic liquids (MetILs) that contain a first-row transition metal coordination cation and weakly pairing monovalent anion(s) (Figure 1) [4,5]. The advantage is the higher concentrations of active metal that can be achieved relative to dissolution of a salt into a solution.

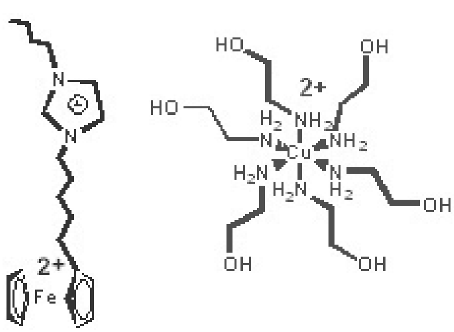

Figure 1: Illustrations of ferrocenium-based (left) and copper-alkanolamine-based (right) cations present in MetILs.

Recently we completed a systematic study on MetILs to determine how the physical and electrochemical properties of the compounds could be tuned to achieve lower viscosity and higher electrochemical reversibility and the results are presented herein [6]. We have also completed static cell testing of some promising compounds. The results showed a clear path forward to higher energy density RFBs.

PERFORMANCE DATA

A series of copper-based MetILs were prepared with varying ligands and anions in order to elucidate trends for lower viscosity (<1000 cP) and higher electrochemical reversibility (i.e. peak separations less than 200 mV), and the results are summarized in Table 1. The results showed the most promising compounds are those containing either EA or EN ligands and BF_4^- anions. In addition, several of the compounds have electrochemical reversibility values that were comparable or even better than ferrocene (~150 mV) under identical conditions (i.e. in an ionic liquid).

Table 1: Summary of cupric ionic liquids as a function of chemical constitution

Ligand[1]	Anion 1[2]	Anion 2[2]	State at 25 °C[3]	ΔE[4] [mV]
EA	EHN	EHN	Liquid	244
EA	OTf	OTf	Solid	158
EA	EHN	OTf	Solid	158
EA	BF_4	BF_4	**Liquid**	102
EA	BF_4	OTf	Solid	256
EA	BF_4	EHN	Liquid	187
EN	BF_4	BF_4	**Liquid**	112
DEA	EHN	EHN	Liquid	522
DEA	OTf	OTf	Liquid	566
DEA	EHN	OTf	Solid	507
DEA	BF_4	BF_4	**Liquid**	150
DEA	BF_4	OTf	Liquid	159
DEA	BF_4	EHN	Liquid	201

[1]EA = ethanolamine, EN = ethylenediamine DEA = diethanolamine; [2]BF_4 = tetrafluoroborate, EHN = 2-ethylhexanoate, OTf = triflate; [3]compounds with a viscosity less than 1000 cP at 25 °C are shown in bold; [4]0.1 M solutions in 1-butyl-3-methyl-imidazolium hexafluorophosphate (BMI-PF_6) with a glassy carbon (working) electrode (scan rate 50 mV s^{-1}).

Given the promising reversibility for some of these compounds, a non-flowing cell ("static cell") was constructed containing $Cu(EN)_6(BF_4)_2$ in a compartment that was partitioned from a ferrocene-based ionic liquid, $Fe(C_{20}H_{27}N_2)(PF_6)$ [7], by a microporous polyolefin separator. The coulombic efficiency of the cell was around 50% over 10 cycles. However, it is important to note that the small membrane area (1 cm^2) of the static cell and the large distance between the electrodes (2 cm) likely influenced efficiency. The key reason to initially perform testing with the static cell was that it provides significantly lower cost and faster screening of materials relative to laboratory-scale flow cell testing.

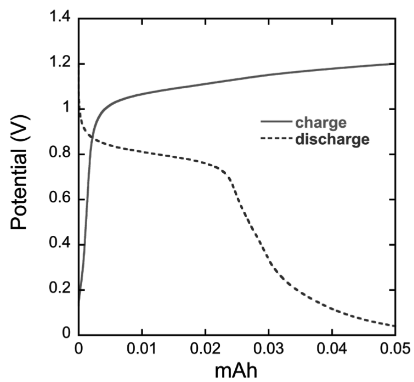

Figure 2: Voltage profiles for the charging (50 μA) and discharging (10 μA) of a static cell containing copper- and iron-based ionic liquids.

The voltage profile for the first cycle (charge and discharge) of this battery is shown in Figure 2. The results showed that charging was significantly more facile that the discharge. In addition, the discharge plateau continued to diminish with cycling (up to 10 cycles). Upon dissection of the cell, it was discovered that the cause was the irreversible plating of copper metal onto the electrode. This prompted us to perform additional cyclic voltammetry measurements on other copper MetILs to examine copper plating (and stripping) behavior. The ultimate goal was to identify MetILs with reversible plating and stripping since this would allow us to cycle between a two-electron process instead of the one-electron process we had originally envisioned.

The cyclic voltammograms (CVs) of $Cu(DEA)_6(CF_3SO_3)_2$, $Cu(EA)_6(BF_4)_2$, and $Cu(DEA)_6(BF4)_2$, performed at a 100 mV s^{-1} scan rate with a glassy carbon working electrode, are shown in Figure 3. The open circuit potential was around 3.0 V in all three compounds (i.e. the fully oxidized species was present at the start of the experiment). The CV for $Cu(EA)_6(BF4)_2$ indicated that electrodeposition and stripping of the bulk metal on the working electrode occurred at 0.5 V and 2.4 V, respectively, with the Cu(II)/Cu(I) redox pair centered at 2.5 V. The redox processes at 1.1 V, 1.4 V, and 2.0 V were attributed to the ethanolamine ligand, and this assignment was verified by comparing the CV with that of a pure sample. Compounds $Cu(DEA)_6(BF_4)_2$ and $Cu(DEA)_6$ $(CF_3SO_3)_2$ underwent Cu(II)/Cu(I) reductions at 2.3 V and 2.1 V, respectively, which was consistent with the differences in the ion pairing of BF_4^- and $CF_3SO_3^-$. In contrast to $Cu(EA)_6(BF_4)_2$, neither $Cu(DEA)_6(BF_4)_2$ nor $Cu(DEA)_6(CF_3SO_3)_2$ had any evidence of stripping although copper deposition was slightly more facile (i.e. a slightly higher potential) in $Cu(DEA)_6(BF_4)_2$. Given that DEA is a more strongly coordinating ligand, the results suggested that DEA hindered stripping. Finally, static cell testing of a cell containing $Cu(EA)_6(BF_4)_2$ and $Fe(C_{20}H_{27}N_2)(PF_6)$ in separated compartments showed significantly improved discharge profiles that were consistent with more reversible plating and stripping of copper. In addition, the coulombic efficiency increased from 50 to 65%. Additional efforts to further improve copper plating and stripping reversibility are currently underway, and flow cell testing of these compounds has commenced. The latter will be done with a specially designed cell that can accommodate higher viscosity fluids. These results will be reported in due course.

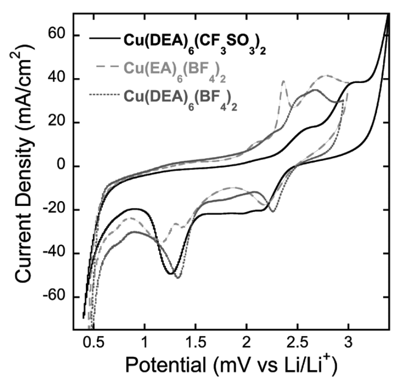

Figure 3: Cyclic voltammograms of $Cu(DEA)_6(CF_3SO_3)_2$, $Cu(EA)_6(BF_4)_2$, and $Cu(DEA)_6(BF_4)_2$ with a scan rate of 100 mV s^{-1} and a glassy carbon working electrode.

SUMMARY

A systematic variation of anion and ligand constituents of copper-based ionic liquids was performed in order to lower viscosity and increase electrochemical reversibility. The results indicated that the most promising compounds were those containing either EA or EN ligands and BF_4^- anions. A static cell containing $Cu(EN)_6(BF_4)_2$ in a compartment that was partitioned from a ferrocene-based ionic liquid, $Fe(C_{20}H_{27}N_2)(PF_6)$ was then constructed and tested. The results showed reasonable coulombic efficiency, but the discharge plateau was diminished in comparison with the charge plateau due to irreversible copper plating. In contrast, when $Cu(EA)_6(BF_4)_2$ was used instead of $Cu(EN)_6(BF_4)_2$, the discharge profile improved significantly and coulombic efficiency increased to 65%.

REFERENCES

[1] C. Wadia, P. Albertus, V. Srinivasan, “Resource constraints on the battery energy potential grid and transportation applications,” *J. Power Sources*, **2011**, 1593

[2] M. Skyllas-Kazacos, M. H. Chakrabarti, S. A. Hajimolana, F. S. Mjalli, and M. Saleem, “Progress in flow battery research and development,” *J. Electrochem. Soc.*, **2011**, R55

[3] A. Z. Weber, M. M. Mench, J. P. Meyers, P. N. Ross, J. T. Gostick, Q. Liu, “Redox flow batteries: a review,” *J. Appl. Electrochem.*, **2011**, 1137

[4] T. M. Anderson, D. Ingersoll, A. J. Rose, C. L. Staiger, and J. C. Leonard, “Synthesis of an ionic liquid with an iron coordination cation,” *Dalton Trans.*, **2010**, 8609

[5] H. D. Pratt III, A. J. Rose, C. L. Staiger, D. Ingersoll, and T. M. Anderson, “Synthesis and characterization of ionic liquids containing copper, manganese, or zinc coordination cations” Dalton Trans., 2011, 11329

[6] H. D. Pratt III, J. C. Leonard, L. A. M. Steele, C. L. Staiger, T. M. Anderson, “Copper ionic liquids: examining the role of the anion in determining physical and electrochemical properties” *Inorg. Chim. Acta*, **2013**, 78

[7] R. Balasubramanian, W. Wang, R. W. Murray, “Redox ionic liquid phases: ferrocenated imidazoliums” *J. Am. Chem. Soc.*, **2006**, 9994

BIOGRAPHICAL NOTE

Travis Anderson is a staff member in Sandia National Laboratories’ Advanced Power Sources Research and Development group. Travis obtained his PhD in inorganic chemistry from Emory University in 2002. He has over 10 years’ experience in advanced energy materials research and development. His research interests focus around the synthesis and characterization of redox-active coordination complexes, flow batteries, and thermal battery ageing.

DISPATCHABLE HYDRO-ELECTRICITY

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ABSTRACT:

The supply of electricity in Ontario is at a crossroads. The fortuity to have an entirely green electricity supply from completely renewable sources is both possible and affordable. The recent rapid proliferation of gas turbine plants in this Province is seen as a short-run expedient solution, necessary to quickly replace shuttered coal plants as well as cope with the equally rapid construction of unpredictable and unfirm wind and solar energy sources. Before the last coal plant is shut down next year, gas turbine output will greatly exceed the maximum capacity of coal that existed at its peak 10 years ago. This will soon result in overall lower air quality as the gas plants eventually exceed the peak air pollution and greenhouse gas emissions from coal. And, at that point, what will we have gained for the environment and for the people in Ontario who are breathing this polluted air? There needs to be a permanent, clean, and sustainable solution is needed.

The author's research will show how *all* the clean and renewable electric energy can be captured from a river network, and in a dispatchable form. In doing so, stability in the grid can be maintained though a 100% back-up of all the intermittent renewable sources. Then, through eliminating the gas turbine plants in time as age overtakes them, similar to the way that coal is being curtailed today – including the option of no new nuclear plants being required in the future – Ontario will arguably have the greenest large electricity system in the world. This Province can enjoy the least expensive non-subsidised green and sustainable electricity of any G8 country.

Since water behind a dam represents electric energy not yet produced, the proposed development method can be described as a distributed energy storage system with the same objective as other types of energy storage, designed to smooth out the supply of electricity by accommodating the erratic electricity output derived from wind and solar sources as well as meeting a fluctuating demand. The major advantages are: (a) it is all renewable energy with little environmental impact, (b) it can eliminate the surplus energy issue while supporting the backup of wind and solar 100%, (c) unlike most other storage methods, there are no losses resulting from energy conversions (converting electricity into another storage medium and back again), and (d) controlling the flow of these rivers can greatly reduce the risk of urban flooding. With proper maintenance, hydro-electric facilities can last for over a century -- far beyond the productive life of any other generating technology. There are also profound implications for an improved quality of life for residents; and better road access within the developed watersheds; and a large number of well-paid jobs in an area of the Province, which has a chronically depressed economy.

This document will show how a completely green electricity system can be established in Ontario and describes the research necessary to prove the case. In Ontario alone, this approach could unlock over $30 billion (US) annually in renewable and dispatchable electric energy. Most of this energy could be made available for export to the US to reduce energy derived from coal, which is ideal because about half of the air pollution in Ontario originates at coal plants in the American Mid-West.

BIOGRAPHICAL NOTE

John Banka has been researching how *all* of the energy in a river may be captured and converted into electric energy. What started off as a part-time curiosity is now a full-time passion.

John owned a motor manufacturing business for several years which sparked his interest in generating hydroelectricity. In particular, he noticed that not all of the energy was being attained – only high-head sites were being commercially exploited. During this time he invented an efficient low-head turbine which was immune to cavitation and could effectively get the energy which was being ignored. A demonstration site was built at a private lodge in Canada proving this turbine technology. The initial concept which he had has morphed into a system which allows dispatchable hydro-electricity to be efficiently attained, even during the spring freshet of northern rivers.

Earlier research results are published in two journals with a third pending.

John is now creating a sophisticated computer simulation model for his concept which integrates the energy storage and generation aspects of the research. He plans on selling energy, not the technology.

John holds a degree in engineering, a certificate in advanced digital geography and GIS, and is presently pursuing a certificate in project management.

THE ENERGETIC IMPLICATIONS OF CURTAILING OR STORING WIND AND SOLAR GENERATED ELECTRICITY

Charles J. Barnhart

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The steady increase of electricity supply from variable wind and solar resources is posing a challenge to reliable power grid operation. In response, technologies that provide grid flexibility are being proposed and developed. This abstract introduces a framework that quantifies how one such technology -storage- affects the system-level efficiency of power grids with solar PV and wind turbine generation sources. We identify renewable and storage technology pairings that deliver a net energy benefit to society. We also identify energetically costly pairings. This framework can be extended to explore other technologies besides storage.

BACKGROUND:

The field of net energy analysis (NEA) is a broad system of methodologies and tools for comparing the amount of energy delivered to society by a technology to the energy consumption over the full lifecycle of the technology. A frequently used metric in NEA is the EROI, which is the ratio of energy delivered to the lifecycle costs of energy production. We present our data and results in terms of EROI. An analogous ratio, the electrical energy stored on life-cyle electrical energy invested, ESOI, is used for storage technologies. EROI and ESOI values for technologies considered here are as follows: on shore wind (86), solar PV (8), CAES (797), PHS (704), Li-Ion (32), NaS (20), VRB (10), ZnBr (9), Pb-Acid (5) *cf. Dale and Benson 2013, Barnhart and Benson 2013.*

METHODS:

A forthcoming paper to be published in Energy and Environmental Sciences provides a thorough derivation of the following framework for calculating the EROI of renewable generation paired with storage. Here we present necessary terms and equations required to understand the results presented in this abstract. Curtailing renewable resources results in an immediate and obvious energy forfeiture, reducing the grid-scale EROI as a function of curtailment rate, φ: $EROI_{curtail}=EROI(1-\varphi)$. However, flexible grid technologies can consume significant amounts of energy in their manufacture and operation. The resultant EROI of a resource-storage pairing as a function of storage AC-AC efficiency, η, and the fraction of energy passing through storage, φ, is: $EROI_{grid}=(1-\varphi+\eta\varphi)/(1/EROI+\eta\varphi/ESOI)$. Setting $EROI_{curtail}=EROI_{grid}$ and rearranging, we established the following decision inequality: store if $(ESOI/EROI) > 1-\varphi$; otherwise, curtailing is more energetically favorable.

RESULTS:

Figure one tells a simple story. From a net energy perspective, electricity generated using solar PV technologies can be stored at energetic benefit over curtailment using all plotted storage technologies. Storing wind power, however, is only energetically more favorable than curtailment for geologic storage technologies CAES and PHS.

Research and Development Directives: The energetic performance of battery technologies can and should be improved. ESOI depends linearly on cycle-life, efficiency, depth-of-discharge and embodied energy. Given the realistic values for these variables, an increase in cycle life has the greatest potential to increase ESOI (Barnhart and Benson, 2013). Reducing the embodied energy and improving efficiency and depth-of-discharge will also increase ESOI. Figure two shows the number of cycles electrochemical storage technologies must achieve to outperform curtailment.

The Energetic Implications of Curtailing or Storing Wind and Solar Generated Electricity

Charles J. Barnhart

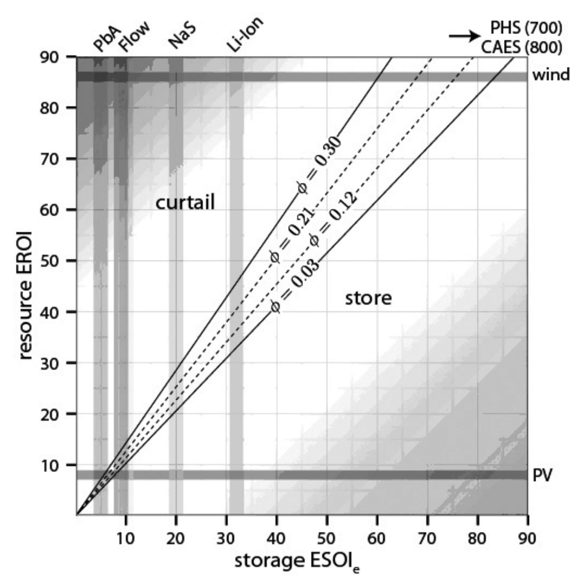

Figure one: The decision to install and operate equipment to store or curtail excess electrical energy depends on the energy resource, the storage technology, and the fraction of energy that is to be curtailed or pass through storage. Four curtailment rates or storage fractions, φ, bisect the plot into two regions. The blue region above and to the left of a φ line shows combinations of resource EROI (y-axis) and storage ESOI (x-axis) values that would reduce the grid EROI to values below reductions simply due to curtailment. The green region below and to the right of a φ line shows combinations of EROI and ESOI that yield grid EROI values that are better than curtailment EROI values. In this region the use of storage provides a net energy gain over curtailment.

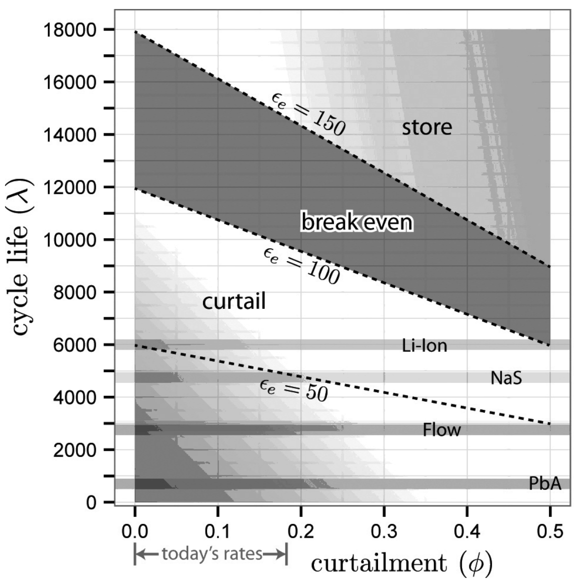

Figure two: The number of cycles electrochemical storage technologies must achieve to outperform curtailment (y-axis) when paired with wind generation (EROI=86) at curtailment rates or storage fractions φ (x-axis). The colored ribbons indicate present day cycle life values for commercially available electrochemical storage technologies. The embodied electrical energy per unit storage capacity, ε, for batteries today is about 150.

BIOGRAPHICAL NOTE

Charles Barnhart (Charlie) is a postdoctoral scholar at Stanford University's Global Climate and Energy Project (GCEP), where he performs energy systems analysis. His research focuses on identifying technology attributes that can reduce energy and materials use, as well as lower financial costs. He adopts net energy analysis and life cycle assessment methodologies. In a 2013 study published in the journal *Energy & Environmental Science*, he presented a novel way to calculate the material and energetic cost of building large-scale batteries and other storage technologies for the electrical grid. In 2010, prior to joining GCEP, Dr. Barnhart was a national postdoctoral fellow at NASA. He holds a PhD in planetary geophysics from the University of California, Santa Cruz, a BS in physics and a BS in astronomy from the University of Washington.

DEVELOPMENT OF SODIUM-IODINE BATTERY FOR LARGE-SCALE ENERGY STORAGE

Dr. Sai Bhavaraju

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Enhanced implementation of renewable energy requires development of large-scale stationary energy storage devices. Secondary batteries are considered attractive for this application due to their modularity and scalability. High temperature (> 300 °C) sodium batteries with ceramic electrolyte are currently being used for grid scale storage (e.g. NGK Sodium-Sulfur battery) and have the potential for widespread use on the grid provided their lifecycle costs can be reduced. Toward this end, we are developing an intermediate temperature (~ 120 °C) sodium-iodine secondary battery. This battery is constructed by combining a sodium metal anode with a non-aqueous iodide/iodine cathode. This battery utilizes NaSICON-based sodium-ion ceramic conductor that has been shown to have high sodium-ion conductivity (e.g. 6 x 10^{-2} S cm^{-1} at 120 °C) and stability with metallic sodium and iodine/iodide-based electrolytes. The battery is built using low cost materials engendering a practical battery solution for grid storage application. Figure 1. shows the charge/discharge voltage profile for a single cycle for the Na-I_2 cell. The depth of discharge for this test is 50%. The charge/discharge efficiency is ~ 100%. Practical aspects of the battery construction and cycling performance will be presented.

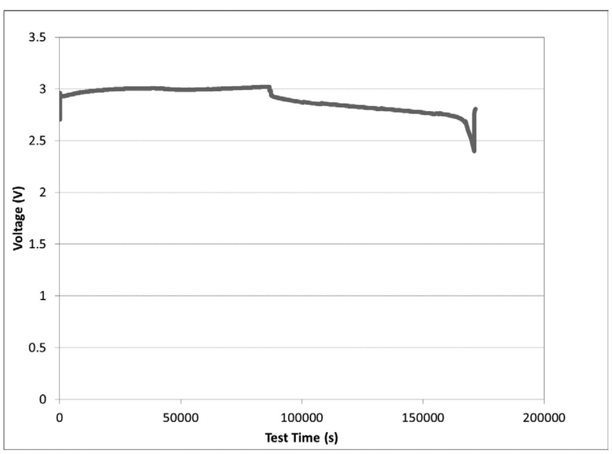
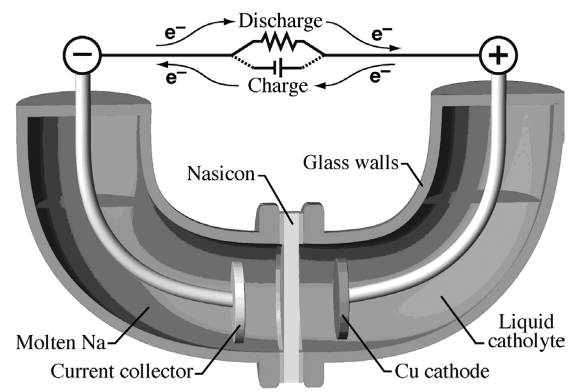


Figure 1: Charging/discharging characteristics for a cycle @DOD 50%

Title: **Computational Modeling of Sodium Copper-Iodide Secondary Batteries**

Contact author: **Robert J. Kee**



BIOGRAPHICAL NOTE

Dr. Bhavaraju received his M.Sc in general chemistry from the Indian Institute of Technology at Madras, India. He subsequently earned his Ph.D. in solid state electrochemistry in 1996, working with Prof. Allan Jacobson at the University of Houston. His Ph.D. dissertation was entitled "Electrochemical Variation of Oxygen Stoichiometry in Perovskite and related Oxides."

Dr. Bhavaraju's industrial experience is primarily in the field of batteries. Previously, he has worked as research scientist at SKC America, Inc. and RBC Technologies. Dr. Bhavaraju holds the title of Senior Scientist/Principal Investigator at Ceramatec. At Ceramatec, Dr. Bhavaraju has worked on many different types of batteries both at the R&D and commercial levels. Those technologies include: Cylindrical Li-Ion and prismatic Li-Ion polymer, Li-Thionyl chloride, Rechargeable Zinc-MnO2, Zn-air, Ni-Mh, all solid-state LiAl-FeS2 high temperature batteries, implantable batteries and PEM fuel cell technology. Other than batteries, he has been involved in R&D of Li+ and Na+ conducting electrolytes, power sources for new topical and implantable drug delivery devices, electrolytic ozone generator with lead-free anodes, oxygen reduction cathodes for the Chlor-Alkali process, ceramic electrodes for electrohydrodimerization and organic electrosynthesis.

ADVANCES IN ENERGY STORAGE RESEARCH, DEVELOPMENT, DEMONSTRATION AND DEPLOYMENT IN CALIFORNIA

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ABSTRACT

California has a long history of supporting energy storage research and development. Energy storage is expected to play a major role in successfully integrating renewables and achieving California's goal for 33 percent renewables by 2020. In 2010, the California Legislature enacted Assembly Bill 2514 (Skinner, Chapter 469, Statutes 2010), directing the California Public Utilities Commission (CPUC) to convene a proceeding to determine cost-effective energy storage procurement targets, if any, for the electric utilities in California. The AB 2514 proceedings are underway and the CPUC may announce its final decision on procurement targets in October 2013. Currently, there are over 30 different energy storage projects at different stages of research, development and demonstration funded by the California Energy Commission in collaboration with the utilities, the United States Department of Energy, and the energy storage industry. These projects are generating valuable information and experience to better understand the value of energy storage. Experience gained and lessons learned from these projects will help the utilities and the energy storage industry to cost-effectively and strategically deploy energy storage in California. The presentation provides an overview of the current status of these projects, lessons learned, and future efforts needed to advance the energy storage technology and systems in California.

BIOGRAPHICAL NOTE

Dr. Avtar Bining is currently Program Manager (Energy Storage) at the California Energy Commission. The Energy Storage Program is designed to advance the energy storage technology for various applications in California. In this role, Dr. Bining manages a portfolio of Energy Storage research, development and demonstration (RD&D) projects such as batteries, flywheels and compressed air, and their applications including Smart Grid and Renewables Integration in California. Previously, Dr. Bining has developed and managed RD&D programs and projects on advanced power generation technologies and their applications both in transportation and power generation including distributed generation and combined heat and power systems. Dr. Bining has over 30 years energy research related experience at various levels in India, Canada, and USA, and has organized and participated in many conferences and published his research extensively. He has worked and traveled in India, Canada, United States, Russia, and Europe. Dr. Bining holds a Ph.D. in Engineering (Energy Conversion Systems) from University of California, Davis, California.

CAPACITOR DEVELOPMENT FOR RELIABLE HIGH TEMPERATURE OPERATION IN INVERTER APPLICATIONS

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Advanced inverters based on wide band gap (WBG) semiconductors are attractive for increased efficiency and power handling capabilities over their Si-based counterparts. In addition, WBG materials can function at significantly elevated temperatures, which would allow the simplification or even elimination of bulky, costly, and complex cooling systems for associated inverters and other power electronics modules. Present inverter designs, however, are limited by the capacitors as much as (or in many cases, more than) the active semiconductor material. We have developed inverter-scale ceramic capacitors using scalable low-cost manufacturing techniques that can operate reliably at temperatures exceeding 300°C. This presentation will focus on the materials advances associated with this development and resulting performance of these capacitors as related to integration into inverters for high operating temperature power electronics applications.

This work was supported in part by the Energy Storage program managed by Dr. Imre Gyuk for the Department of Energy's Office of Electricity Delivery and Energy Reliability. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation - a wholly owned subsidiary of Lockheed Martin Corporation - for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

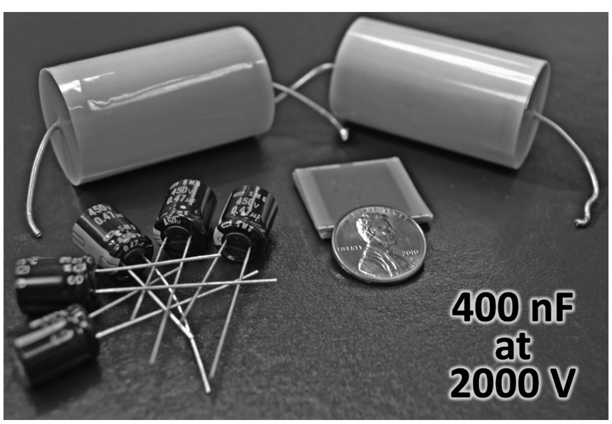

Figure 1: Newly developed multilayer ceramic capacitors (center) compared with commercial polymer (top) and electrolytic (left) capacitors. Each collection of capacitors in the image represents 400 nF for operation at 2000 V.

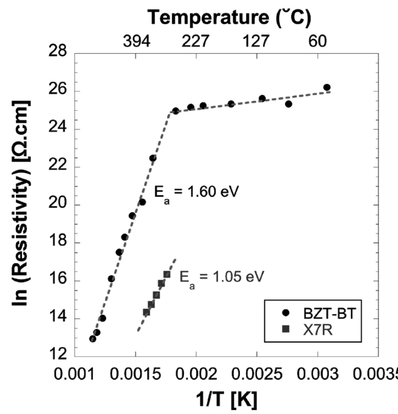

Figure 2: New BZT-BT dielectrics exhibit significantly higher resistivity and activation energy of conduction than commercial X7R dielectrics, a key to a more reliable high-temperature operation.

BIOGRAPHICAL NOTE

Geoff Brennecka is a Principal Member of the Technical Staff at Sandia National Laboratories in Albuquerque, NM, where the majority of his group's R&D work focuses on enabling new functionality through the clever integration and processing of ferroelectrics and other electronic oxides. Geoff has been investigating and developing materials for energy storage and related applications for 15 years, always with a focus on understanding fundamental mechanisms in order to improve performance and reliability.

Geoff is an author of 30 peer-reviewed articles and serves as an Associate Editor of the Journal of the American Ceramic Society. He has served in a number of leadership roles within the American Ceramic Society, including President of the National Institute of Ceramic Engineers, and has been honored with the Karl Schwartzwalder Professional Achievement in Ceramic Engineering award and the ACerS Emerging Leader award. Geoff is a member of the PES, DEIS, and NPSS societies of IEEE and is primarily active in UFFC, where he is a member of the Ferroelectrics committee and serves as a Technical Programming Chair.

Geoff received BS and MS degrees in Ceramic Engineering from the University of Missouri-Rolla and a Ph.D. in Materials Science and Engineering from the University of Illinois.

ISOTHERMAL CAES: FUEL-FREE, SITE-FLEXIBLE ENERGY STORAGE FOR RENEWABLES INTEGRATION AND T&D SUBSTITUTION

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SUMMARY

Renewable energy deployments are increasing around the world, adding degrees of supply variability and challenging grid stability. Grid operators are taking a close look at the impact of increasing penetration of highly variable resources, such as wind and solar, and how energy storage can play a role in stabilizing the electricity network. In many parts of the world, the issue is not *if* grid-stabilizing solutions will be needed, but *when*.

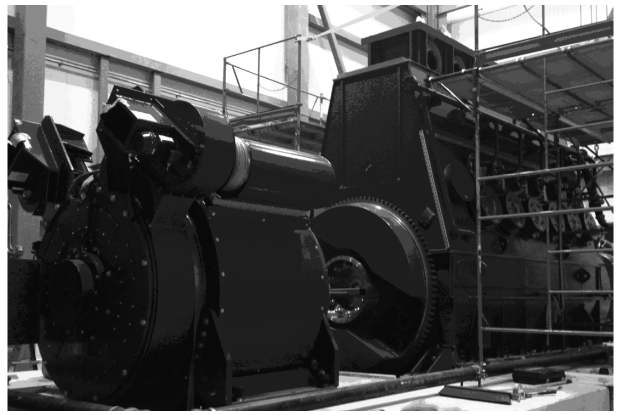
Despite advances in electrochemical solutions for stationary energy storage, new technology solutions have thus far been limited to short-duration, high-power applications. The only technologies that have proven technically and commercially viable for bulk energy storage are pumped hydro and compressed air (CAES). Pumped hydro is geographically limited and presents numerous environmental challenges. As for CAES, there are only two working installations in the world (Germany and U.S.), due to geological constraints, high costs and environmental concerns.

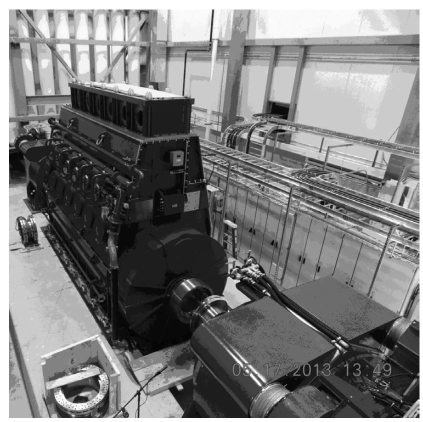
SustainX has solved the problems of conventional CAES, allowing the low-cost, large-scale, and long-lifetime benefits of compressed air energy storage to be applied to a site-anywhere, zero-emissions solution. The SustainX innovations include a patented isothermal cycle that enables fuel-free operation, unlike traditional CAES. Installations can be sited virtually anywhere using flexible pipe-type storage. SustainX's isothermal CAES (ICAES) has been demonstrated at 40 kW, and a 1.5 MW system is now being built and will be grid-connected in the fall of 2013. At a commercial scale, the SustainX ICAES system can provide multi-megawatt, long-duration power for renewable energy integration, as well as T&D substitution or deferral in congested, high-growth areas.

The presentation will provide an overview of the state-of-the-art, comparing conventional CAES and pumped hydro storage with newer isothermal-based developments. We will also review capabilities, applications, and economics, and provide a progress update for the world's first megawatt-scale ICAES system.

Isothermal CAES: **Fuel-Free, Site-Flexible Energy Storage for Renewables Integration and T&D Substitution**

Author: **Richard Brody, Ph.D.,** VP of Business Development, SustainX, Inc.





1.5 MW isothermal compressed air energy storage system under construction at SustainX facility in Seabrook, NH (May-June 2013)

BIOGRAPHICAL NOTE

Richard Brody is Vice President of Business Development at SustainX, and has more than 20 years of experience in technology-based international business development and government policy. At SustainX Richard is responsible for developing product strategy and global markets for the company's bulk energy storage solutions and, as an executive team member, driving the strategic direction of the company. Previously, he was VP of Business Development at PowerGenix, responsible for market and product strategy. Before PowerGenix, Richard held senior positions at United Technologies Corporation (UTC), including VP of International Business Development at UTC Power, where he established the company's clean and renewable power generation business in Asia and Europe. Prior to that, Richard was President of UTC's corporate office in Moscow and chairman of the American Chamber of Commerce in Russia. Before UTC, he served in the White House as Russia foreign policy advisor to Vice President Al Gore. Richard holds a Ph.D. and master's degree from the University of Michigan and a bachelor's degree from Columbia University.

SOLAR PV AND STORAGE COMBINE TO PROVIDE COST EFFECTIVE ENERGY, RESILIENCY AND SECURITY FOR CRITICAL LOADS

John R. Bryan

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Keywords: energy storage; photovoltaics; battery management system; solar; commercial & industrial

Solar PV power is commercially viable and available in nearly all regions of the world. Due to rapidly declining system prices and business model innovations, PV has achieved or is rapidly approaching grid parity. This has led to dramatic changes in our energy mix: in the first quarter of 2013, nearly half of all new U.S. electricity generation capacity came from solar.

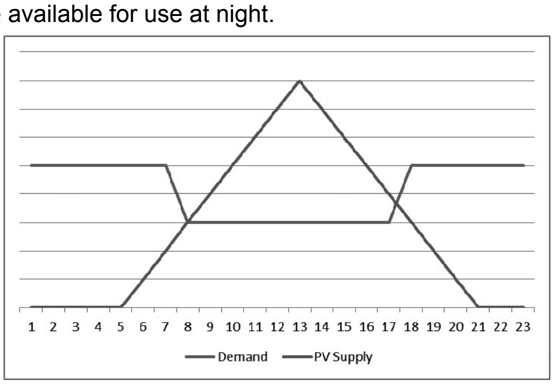
In addition to growth in the utility and residential markets, commercial & industrial (C&I) end-users are rapidly turning to PV to meet their unique power needs. These end-users generally require an uninterrupted supply of high quality, quickly dispatchable power. PV is unable to meet the complete power needs of these end-users, even when grid-connected.

In C&I applications, both behind-the-meter and off-grid, combining energy storage with PV is an efficient way to produce a stable, secure and resilient supply of electricity. By capturing low cost, distributed energy for use when it's needed, the addition of energy storage leads to a better return on investment in PV generation.

Following a quantitative analysis of 19 government owned facilities on the island of Maui with proposed PV installations, we have determined that there are distinct demand and energy usage profiles in which it is cost effective to add storage to PV.

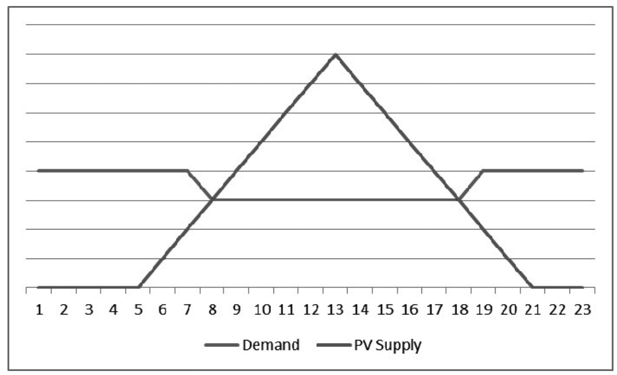
NIGHT TIME POWER USERS (e.g. police stations)

This site usage profile has utilization/demand that can be greater in the evening and night-time hours than normal. All PV generation occurs during daylight hours, so storage is essential to capture a greater than normal amount of excess PV energy during the day and shift it to be available for use at night.



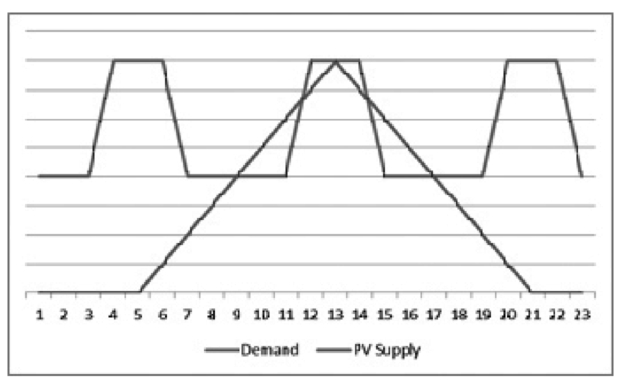
OPEN AIR FACILITIES WITH NO AC (e.g. community park)

This type of facility generally has flat utilization periods. PV generation accumulates during daylight hours in excess of demand, and storage is essential to capture PV and prevent discharge into the grid.



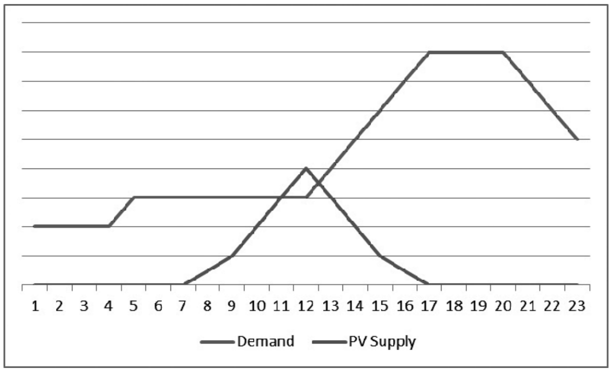
INDUSTRIAL (e.g. water treatment facility)

Power is required quickly in these facilities to match generation to demand with little or no notice or control from variable mechanical systems. Industrial machines operate at constant set points where demand is generally flat, but have unpredictable peaks and valleys throughout the day potentially allowing excess PV generation to feed back into the utility grid. Storage is necessary for fast/high ramp rates to provide energy quickly on demand.



THERMALLY SENSITIVE SITE
(e.g. forensics)

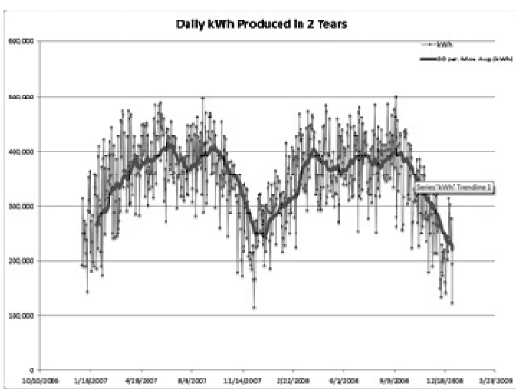
Temperature regulation is required throughout the day, and peak demand occurs later in the day due to afternoon heat loading and sensitive building operating thermal set points. Storage is needed to capture excess PV generation and can be used to meet late afternoon peak demand when PV has stopped.



EVENING PEAK POWER
(e.g. stadiums with large lighting loads)

Utilization periods at these facilities peak in the later evening and night-time. Storage is essential to capture PV during the day and make it available for use at night to mitigate demand charges.

PV HAWAIIAN DAILY PV PRODUCTION OVER 2 YEARS

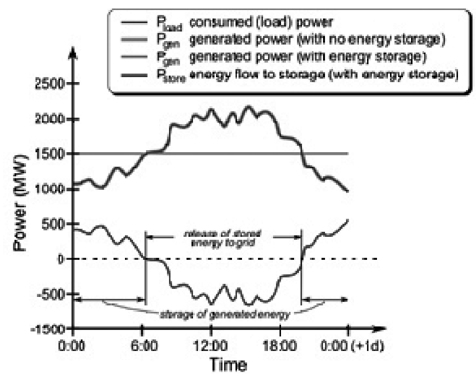


As demonstrated by the various load profiles above, energy storage is essential in cases where demand peaks do not match solar supply peaks. However, energy storage is not necessary for grid connected systems if the PV supply matches the demand curve and is highly reliable less than the demand at any time of utilization. The graphic above shows the daily variability of PV generation over a two-year period in Hawaii. Given this variability, storage is a useful addition for quickly responding to the intermittency of PV inputs (rapid generation due to cloud dispersal and return of high intensity sunshine). Storage can also contribute to smoothing and leveling to avoid minor micro peaks (due to sunshine or increased cloud cover) for improving utility bills by reducing demand charges. When PV and energy storage are combined, the synergy of the combined system allows the battery to control when and how the energy is used while preventing any PV discharge into the grid.

A properly designed PV + Energy Storage system provides 95% of the possible value that PV + Energy Storage can theoretically provide by reducing a site's reliance on average use profiles and other sources of generation. Average use profiles and average generation models only gain 50% to 68% of a possible reduction in utility bills.

PEAK POWER RATES

Storage systems level the load of energy demanded by providing PV energy supply to match it, regardless of when the energy is generated. Using stored PV energy to fill peak demand prevents drawing additional energy from the grid and further minimizes energy costs.



ADDITIONAL BENEFITS OF PV + STORAGE

In addition to providing a reliable, cost effective supply of energy, PV + Energy Storage provides critical power quality benefits by protecting critical loads from disruption. In the event of a power outage, the battery is capable of providing instant backup power, bridging the restoration or start-up time of longer term back-up generation. In the case of a sensitive site, such as a forensic facility or hospital, the battery would maintain critical processes or services that would otherwise be shut down at significant cost or worse.

Facility managers that desire stable, cost effective electricity sources, and security and resiliency for critical loads, are increasingly turning to PV + energy storage to meet their needs.

ABOUT CODA ENERGY

CODA Energy designs and builds scalable energy storage solutions that support a smarter, cleaner and more reliable grid. The CODA Core UDP tower combines advanced batteries with proven battery and thermal management systems (BMS and TMS), all managed through a sophisticated power source controller. CODA energy storage systems are optimized for generation, distribution and behind-the-meter applications for commercial and industrial end users. CODA Energy professionals have deployed a combined 140 MW and 50 MWh of energy storage in stationary and mobile applications throughout their careers.

BIOGRAPHICAL NOTE

John Bryan has more than 20 years of energy, utility, technology and automotive experience. He is currently the VP of Product & Marketing at CODA Energy, a manufacturer and distributor of scalable battery energy storage systems headquartered in Monrovia, CA. Prior to CODA, John was the CTO for Fleet Energy Company, a spinoff of the $2.1B Burt Fleet Services (BFS). John also worked at Xcel Energy in its Utility Innovations program, where he was responsible for overseeing vehicle-to-grid plug-in hybrid electric vehicle (V2G PHEV) projects, and served as program manager for the $100M SmartGrideCity program and 1MW/7.2 MWh wind integrated battery energy storage project. Earlier in his career, John also spent several years in the automotive industry as a manufacturing quality engineer working for a major Tier 1 supplier to Ford, GM, and Toyota, and managed telecommunications fiber backbone deployment programs for Qwest Communications, now known as CenturyLink. He earned an MBA from the University of Missouri and a B.S. in mechanical engineering from Vanderbilt University.

THE NEXT APPLICATION FOR ENERGY STORAGE RESOURCES ON THE GRID

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This paper makes the case for the use of energy storage to provide frequency response.

Ancillary services on the grid can be characterized into three temporal categories. The first category is primary response or frequency response. The primary response is autonomous; the resource is constantly evaluating the frequency of the grid and responds according to its own measurement as opposed to being dispatched remotely. The performance period for primary response is measured in cycles to seconds.

The second category is frequency regulation, which is dispatched by an automatic system controlled by the grid operator which constantly evaluates the frequency on the grid and determines the appropriate response from the available frequency regulation resources. A new signal is sent to the frequency regulation resource every four to six seconds depending on the grid operator. The performance period for regulation is measured in seconds to minutes.

The third category involves the manual dispatch of generation or load in order to provide a balance caused by scheduled or unscheduled changes in the supply and consumption of energy. The performance period for the third category is measured in minutes to hours.

Energy Storage resources have made great strides in supplying regulation services (the second category) and are now well positioned to be used for frequency response due to a favorable confluence of technical, regulatory and reliability factors.

NERC (North American Energy Reliability Committee) recently completed a several year process to define new requirements for frequency response. This new standard was submitted to FERC for approval in RM13–11. The standard would require each balancing authority to maintain a minimum performance for frequency response. This response is generally provided now by droop response from the generators operating on the grid (and not at maximum output). In some cases such as ERCOT, providing frequency response is a condition of the generator interconnection agreement. In no case is there compensation for the delivery of this service. The generators would prefer to either be paid or not be required to provide frequency response.

As this new standard goes through the process of review at FERC, there is an opportunity to evaluate the potential of providing energy storage resources instead of relying on generation. FERC has indicated an interest in evaluating this as a transmission resource, allowing the capital cost to be added to the utility rate base, eliminating the issue of market uncertainty.

This paper describes in detail the technical requirements for the service and the commercial/regulatory opportunity, as well as steps required to make this an attractive new application for storage.

BIOGRAPHICAL NOTE

Bill Capp founded Grid Storage Consulting, LLC in 2012. GSC provides expertise to utilities, grid operators and equipment manufacturers interested in improving the operation of electrical systems with advanced energy storage systems.

Before founding GSC, he served Beacon Power as President and CEO for 10 years. He led the evolution of Beacon's flywheel technology while simultaneously working with the Federal Energy Regulatory Commission (FERC), grid operators, and public service commissions to create the market for energy storage based frequency regulation. Beacon initiated commercial service in New England in 2008 and inaugurated the first-of-its-kind 20 megawatt facility connected to the New York grid in 2011, ahead of schedule and under budget.

In response to a price reduction created by low natural gas prices, Bill led the effort to establish an order from FERC mandating higher payment for better performance. FERC Order 755 was issued in October 2011 and is currently being implemented.

Bill's career includes leadership roles in general management and technology in diverse companies including Ford Motor Company, Torrington, York International, and Ingersoll-Rand. He has a BS in Aeronautical Engineering from Purdue University and a Masters in Mechanical Engineering from the University of Michigan, where he also earned his MBA degree.

MODEL PREDICTIVE CONTROL APPLICATION IN PV AND STORAGE SYSTEM

Feng Cheng

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Currently, renewable energy is used broadly. A major concern is the intergradation of the renewable energy into power grid. A lot of research has been done regarding how to integrate a single type of renewable energy into power grid. However, co-optimization of different types of renewable energy to work effectively and reliably is also very important. It is very possible that several different renewable resources exist in a same area with different operation characteristics. Even for the same types of renewable resources, the different capacity size, output power and other parameters could be a control problem, which should be addressed. At the same time, optimization usually runs with some uncertainties. Under these requirements, model predictive controller (MPC) is chosen to optimize the dispatch of the renewable energy resources.

Earlier than 1980, the chemical plants and oil refineries began to use MPC for process control. It became the most popular advanced control method in the industry. MPC involves the prediction of state, and is good for a system with a lot of uncertainties. Future control inputs and future plant responses are predicted using a system model and are optimized at regular intervals[1]. It pursues the optimization solution for the next short period to reach the optimization for the long term. Though it never actually operates optically over any period of time[2].

In this project, MPC was used in a micro-grid, which includes a PV plant, battery energy storage system, and a gas engine. Fig.1. shows the system diagram. The MPC gets the data of PV production and load forecast, and then calculates the optimal output of battery storage system and gas generator. Meanwhile, the state of charge (SoC) of both storage resources should be considered.

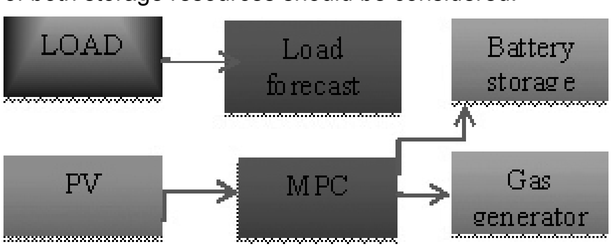

Figure 1: MPC System structure diagram

The MPC runs well for this project. The optimization calculates with the load forecast based on most new data. It successfully makes two resources dispatch energy in a safe SoC range. Also the cost function tends to decrease the SoC range. The prediction has a very important meaning for this optimization problem. The weather forecast helps plan the usage of storage. It is better than the ordinary optimization method due to the consideration of load uncertainty.

Wes Greenwood will be presenting in F. Cheng's stead.

BIOGRAPHICAL NOTE

Wes Greenwood is a graduate student research assistant for the Prosperity Energy Storage Project investigating various challenges in utility-scale solar power production with battery energy storage. While pursuing his Masters in Mechanical Engineering at the University of New Mexico, he has participated in several research topics such as thermal energy storage and numerical analysis of sustainable energy systems with an emphasis on solar energy. In addition to providing modeling support for colleagues and performing a number of unique analyses, his research goals include increasing the reliability and reducing the levelized cost of energy of solar power and energy storage.

MEASURING AND EXPRESSING THE PERFORMANCE OF ENERGY STORAGE SYSTEMS

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ABSTRACT:

Currently, there is no uniform set of criteria to measure and express the performance of energy storage systems (ESS). This lack of criteria can affect the acceptance of ESS in the market because, among others, different systems cannot be equitably compared and any assessment of system cost-benefit may be challenging due to the lack of verified and relevant ESS performance. In addition, the lack of such criteria increases the probability that each ESS customer will make up their own assessment, necessitating "custom validation" each time an ESS is to be installed.

This paper will provide information on how the U.S. Department of Energy's Energy Storage Systems (ESS) Program, with the support of Pacific Northwest National Laboratory (PNNL) and Sandia National Laboratories (SNL), facilitated the development of a protocol to measure and express ESS performance in early 2012 and how that work continues and is finding its way into the marketplace. While the paper will provide the details of what has been and is being done, it will also focus on the very unique way in which the activity was conducted which saved considerable time and involved any interested collaborator.

The specifics to be covered in the paper will include:

- The unique, open and transparent process to develop a protocol (pre-standard) to address ESS performance measurement and expression that resulted in over 100 individuals from over 60 organizations participating and the release of a protocol covering peak shaving and frequency regulation applications in just nine months;
- The purpose, scope and format of the protocol that provide a firm foundation for addressing all ESS technology and all ESS technology applications over time, building on prior work;
- The interaction with standards developers in the U.S. and internationally fostering their application and use of the protocol and relevant project documentation as they develop formal standards to cover the ESS performance measurement;
- The initiation of a Protocol User's Group comprised of over 20 entities who have test driven the protocol on actual ESS installations and have reported back their experiences for the purpose of refining the protocol, informing standards developers using the protocol as a basis for formal standards and most importantly documenting the time and cost associated with determining ESS performance; and
- How stakeholders have come together to develop enhancements to the protocol that will cover thermal storage systems for peak shaving applications and the application of ESS for micro-grids and frequency smoothing associated with PV systems.

Those in attendance will not only learn about the process and how to become involved, but will also learn about the provisions in the protocol and experiences to date with their application and use. This can lead to ESS proponents measuring and reporting system performance per the protocol and ESS customers readily accepting the performance reported for a particular ESS.

BIOGRAPHICAL NOTE

David Conover (Dave) is a Senior Technical Advisor for the Pacific Northwest National Laboratory. Dave brings 40 plus years of experience in the building technology and energy sector to PNNL. Dave's work at PNNL is focused on market acceptance of technology in relation to codes, standards, regulations and criteria governing technology and its installation in the built environment in addition to conformity assessment activities that relate to documentation and verification of compliance with those criteria.

Dave was a Senior Advisor to the International Code Council (ICC) focusing on the development, adoption and compliance with building construction regulations. Dave joined the ICC having been the CEO of the National Evaluation Service (NES), a subsidiary of the three organizations that merged in 2003 to form the ICC.

Prior to joining PNNL in 1991 Dave held positions with the National Conference of States on Building Codes and Standards (NCSBCS) and the American Gas Association (AGA), both focused on codes and standards and their impact on building technology acceptance.

Dave holds degrees in Mechanical Engineering.

FOUR STEP MODELING FRAMEWORK FOR ENERGY STORAGE

Eric Cutter

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ABSTRACT

The grand hope for energy storage is that it will enable the transition to a cleaner and more resilient energy network. However, California remains stuck in the clouds discussing the potential benefits of energy storage. For energy storage to have a full seat at the table in utility resource planning, cost-effectiveness analysis needs to expand beyond current approaches. “Is storage cost-effective” is not the right question; and traditional analysis does not address key issues such as: 1) what is the probability, size and duration of flexible capacity needs, 2) what are viable alternatives to meet those needs, and 3) how much should utility ratepayers pay for those alternatives. A four step framework with multiple models appropriate to each service is needed to address important policy issues. The four steps are: 1) Define the services needed for the grid, 2) Identify and characterize feasible solutions, 3) Quantify the societal benefits of viable alternatives and 4) Develop the business case. The complexity of the first and third steps is underappreciated and requires stochastic modeling, production simulation and/or distribution system modeling. All benefits relevant for energy storage can be included, but only with judicious prioritization to match available time and budget in a tractable approach. Such a comprehensive framework is needed to answer such questions as:

- How much flexible capacity is needed to meet renewable, GHG and distributed generation goals?
- How much new fossil generation or distribution investment can be avoided with fast, accurate and flexible storage?
- What is the role of storage in least-cost portfolio planning?
- What incentives, if any, are justified and necessary to attract investment in storage?

Regulators currently have two unappealing options: approve storage procurement with limited justification or leave storage to compete in a market with known gaps and shortfalls. The four step-modeling framework provides a third option, combing different models appropriate to each task in one integrated approach. It is a big job requiring leadership and budget, but it is the only way to move storage beyond niche applications into utility resource planning.

Four Step Modeling Framework for Energy Storage - Eric Cutter

Figure 1: Model Matrix by Segment, Type and Time-step

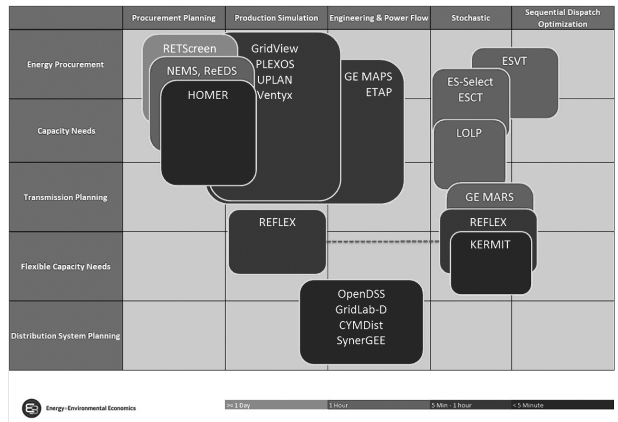
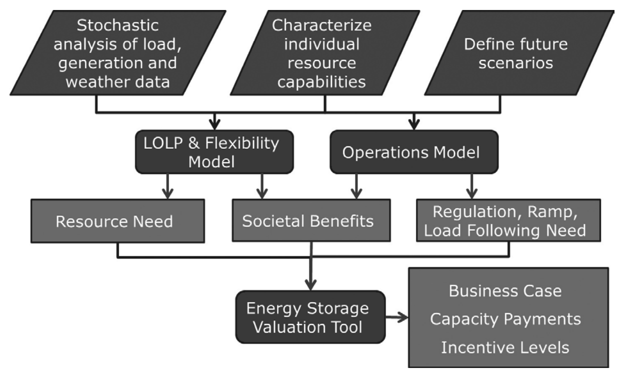


Figure 2: High Level Flow Chart



BIOGRAPHICAL NOTE

Eric Cutter is a lead analyst at E3 on the costs and benefits of energy storage, distributed generation, and responsive load, working with the Electric Power Research Institute (EPRI), utilities, regulators and technology companies to assess their value for the integration of renewable and distributed generation. Mr. Cutter managed E3’s work for the recently completed UCSD-Viridity Innovative Business Model CSI RD&D Round 2 project. Mr. Cutter leads the development of the Energy Storage Valuation Tool for EPRI and member utilities, leading and supporting the California Public Utilities Commission (CPUC) on Demand Response (DR) cost-effectiveness. He is also leading the 2013 California Solar Initiative (CSI) impact analysis with metered and simulated generation data for over 160,000 systems. He has led the development of numerous financial and economic models for planning and regulatory policy in energy and water resources for the State of California and electric utilities nationwide. Prior to joining E3, Mr. Cutter worked as an independent consultant in water resources for seven years and at PG&E for 10 years.

A SECOND LIFE FOR USED MINI E BATTERY PACKS IN AN ELECTRICAL ENERGY STORAGE SYSTEM

Peter Dempster; Rene Eckstein

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Tom Gage; Dave Sivertsen

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Battery packs that are removed from electric vehicles (EV) by an auto original equipment manufacturer (OEM) - after they have lost capacity and no longer meet customer mobility needs - may be used in a variety of grid-tied electrical energy storage devices. EVs operate in harsh environments; even with faded capacity, automotive-grade lithium-ion batteries are safe, durable and designed to operate at high and low temperatures. In the absence of healthy lithium-ion battery recycling markets, re-use markets present a near-term opportunity to reduce the total cost of ownership and lifecycle emissions of an EV.

EV battery packs' module form factor, interconnection topology and communications interfaces vary across and within plug-in electric vehicle segments. This creates a challenge for both auto OEMs who desire to create and foster battery second use (B2U) markets and system integrators who desire to purchase and install into their energy storage products used EV battery packs and modules. The use of standard communication protocols and the definition of system integration requirements for used vehicle batteries in electricity grid-tied storage applications may be critical for creating a market for B2U.

This paper discusses the design and development of a grid-tied stationary energy storage system which integrates six used MINI E high-voltage Li-ion battery packs. First, the design and development of a battery management system (BMS), including hardware and software for modified vehicle management systems (VMS), input and output (I/O) board, voltage, current and temperature measurement devices, contactors, fuses, wiring, and an enclosure is described. Next, an interface system – a "super" BMS - including software and hardware needed for communication between BMS and inverter controller is discussed. Finally, the design and development of a MINI E B2U battery system – which includes 6 separate battery packs, an enclosure, interconnects and related hardware is addressed as it relates to a standardized B2U approach.

The standardization of controls and software interfaces and the hardware definition for B2U may impact the design of EV battery packs and modules, as well as financing models for EVs. It is believed that assessment of the EV battery value chain and its complex interactions is required to identify the current and future state of the value proposition of B2U. Once this critical step is achieved, auto OEMs can develop vehicle battery systems that are cost optimized for their entire life cycle, which may lead to multiple huge gains for both smart grid and EV technologies.

Tom Gage is presenting in Peter Dempster's stead.

BIOGRAPHICAL NOTE

Tom Gage is CEO and founder of EV Grid, Inc., a company that develops and supplies technology for integrating electric vehicles, batteries, and the power grid.

Prior to founding EV Grid, Mr. Gage was CEO of AC Propulsion, Inc., a leading supplier of electric vehicle technology based in the US and China. During his tenure, AC Propulsion pioneered vehicle-to-grid charging systems, established ongoing supplier relationships with automotive OEMs worldwide, set up manufacturing and marketing operations in China, and achieved profitability and positive cash flow.

Mr. Gage's professional specialties include the energetics of automobiles and the effects of public policy on automotive technology and market trends. He has held executive positions at Chrysler in the Regulatory Strategy Office, and at SRI Consulting, Global Automotive Practice, in Menlo Park, CA. He holds a mechanical engineering degree from Stanford University, and an MBA from Carnegie Mellon University. He is a 30-year member of the Society of Automotive Engineers. He has driven electric cars since 1995

VALUATION OF ENERGY STORAGE – QUANTIFICATION AND ONGOING POLICY CHALLENGES

Paul Denholm* *(presenting author)*, Jennie Jorgenson, Marissa Hummon, Thomas Jenkin, David Palchak, Brendan Kirby, Ookie Ma, and Mark O'Malley

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An ongoing issue regarding deployment of energy storage for grid applications is appropriate valuation. Despite the introduction of restructured markets, it is still a challenge for energy storage developers to receive compensation for the multiple services storage can provide.

This work demonstrates several of the challenges faced by energy storage developers both in regions with wholesale energy markets and with vertically integrated utilities. It uses a production cost model to simulate the operation and value of energy storage when providing load leveling, spinning contingency reserves, and regulation reserves. Storage devices were added to a utility system in the western United States, and the operational costs of generation was compared to the same system without the added storage. This operational value of storage was estimated for devices of various sizes, providing different services, and with several sensitivities to fuel price and other factors. Overall, the results followed previous analyses that demonstrate relatively low value for load-leveling but greater value for provision of reserve services. However, an important component of value for devices providing both energy and reserves is capacity value, which can be significant and is often not included when considering only the results of production simulations.

In addition, we estimated the potential revenues derived from a merchant storage plant in a restructured market, based on marginal system prices. Due to suppression of on-/off-peak price differentials and incomplete capture of system benefits (such as the cost of power plant starts), the revenue obtained by storage in a market setting appears to be substantially less than the net benefit provided to the system. Storage plants may also be unable to recover their capacity benefits in markets where scarcity pricing is insufficient for appropriately compensating new generators.

While some changes to current market designs (such as FERC 755 and the development of new ramping reserve products) are targeted towards compensating flexible resources, there may be additional sources of value that go uncompensated in the evolving grid. In particular, the ability of energy storage to incentivize and enable renewable resources remains unquantified. Additional effort by the energy storage community to value these technologies, multiple services these technologies can provide insight into deficiencies in current market designs and regulation regarding energy storage and other flexible energy resources.

BIOGRAPHICAL NOTE

Paul Denholm is a Senior Energy Analyst in the Strategic Energy Analysis Center at the National Renewable Energy Laboratory. His research interests include examining the technical, economic, and environmental benefits and impacts of large-scale deployment of renewable electricity generation, including the role of enabling technologies such as energy storage, plug-in hybrid electric vehicles and long distance transmission. His analysis focuses on modeling electric power systems using grid simulation tools with an emphasis on bulk storage technologies including compressed air, pumped hydro, long duration batteries and thermal storage. He holds a B.S. in physics from James Madison University, an M.S. in instrumentation physics from the University of Utah, and a Ph.D. in environmental studies and energy analysis from the University of Wisconsin-Madison.

SECOND-LIFE APPLICATIONS FOR PEV BATTERY SYSTEMS: EARLY TESTING TO EARLY-COMMERCIALIZATION

Contact Author: Mike Ferry

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Electrical Energy Storage Applications and Technologies (EESAT) 2013 Conference

ABSTRACT

More than 100,000 plug-in electric vehicles (PEVs) were sold in the United States between January 2011 and July 2013, heralding a new automotive segment dependent on large-format battery storage systems. Cumulatively, the lithium-ion battery systems in U.S. vehicles today represent over 2,000 megawatt-hours (MWh) of electrical energy storage. Moreover, with moderate projected growth in the PEV market, this number could exceed 50,000 MWh by 2023. Due to the high performance requirements (power and energy capacity) of PEV batteries in automotive use, lithium-ion battery cells, modules, and even entire battery packs will likely have residual power and energy capacities upon retirement from vehicle use. As a result, potential "second-life" applications for used PEV battery systems are currently being investigated in order to (1) increase the total lifetime value of PEV battery systems, (2) provide potential low-cost stationary energy storage resources for utility, balancing authority, generation, and customer end-use applications, and (3) lower the risks and costs associated with the commercialization of PEVs. Since April 2010, with funding provided by the California Energy Commission (CEC), the National Renewable Energy Laboratory (NREL), and private investments from industry and academia, a project team led by the California Center for Sustainable Energy (CCSE) has conducted the most in-depth and single longest continuous research effort focused on second-life applications for PEV batteries. CCSE's research and industry partners have included, among others, NREL, San Diego Gas & Electric (SDG&E), AeroVironment, BMW Motors, UC Davis, and UC San Diego.

This paper will describe the testing of PEV batteries over the past three years as well as the six primary research tasks and deployment efforts that the project team has accomplished to date, specifically: (1) assessment of potential second-life applications for used batteries and development of real-world duty-cycles for these battery storage systems, (2) techno-economic analysis of potential markets for repurposed PEV batteries, (3) acquisition of used PEV battery packs and modules of multiple lithium chemistries for initial benchmark and laboratory testing, (4) down-selection and deployment of 68 kWh of used PEV battery packs and modules in long-term field testing within the UC San Diego microgrid, and (5) deployment of a 100 kW/160 kWh energy storage system using retired battery packs from BMW MINI E vehicles, due for commissioning in October 2013. Additionally, the paper will describe a new research initiative funded by the CEC and led by Electricore, Ricardo, CCSE, BMW, and SDG&E to investigate the benefits and feasibility of standardizing PEV battery systems, including packaging, form factors, battery management systems, and communications.

Based on research to date, PEV batteries are capable of operating within acceptable temperature, voltage, round-trip efficiency, and state-of-charge limits when tested in applications including area regulation, load following, customer-side demand charge management, back-up power supply, and solar generation firming. Additionally, second-life PEV batteries hold the potential to out-compete new lithium and lead-acid battery technology in terms of system payback.

BIOGRAPHICAL NOTE

Mike Ferry is Senior Manager for Transportation at the California Center for Sustainable Energy where he manages a diverse portfolio of local, state, and federal clean transportation programs including regional and statewide alternative fuel vehicle rebate programs, state and federally funded advanced vehicle battery research, management of the San Diego Regional Clean Cities Coalition, and coordination of CCSE's public outreach and education efforts regarding sustainable transportation initiatives. In 2010, Mike finalized and implemented California's Clean Vehicle Rebate Project, a five-year, $65 million program to incentivize the deployment of zero-emission vehicles in California. Mike also led CCSE's role in a collaborative partnership with Nissan, GM, U.S. DOE, SDG&E, and others to plan for the deployment of 2,450 EVSEs within the San Diego region. In early 2012, Mike developed and successfully implemented a $1 million alternative fuel vehicle program at the San Diego International Airport, successfully placing 181 alternative fuel and clean vehicles with the Airport's ground transportation service fleet. Since March 2011, Mike has led multiple research teams from academia, industry, and government laboratories investigating advanced second-life application for used EV batteries. Mike holds a Master of Science degree from the Energy and Resources Group at the University of California, Berkeley.

RIGHT-SIZING ENERGY STORAGE SYSTEMS FOR RENEWABLES INTEGRATION

By Rhys Foster

Senior Business Development Manager, A123 Energy Solutions, 155 Flanders Road, Westborough, MA 01581, USA.

As renewable energy generation capacity increases, the power grid is experiencing a shift from predictable, dispatchable generation to ever more variable, non-dispatchable generation. Since generation from renewable sources can be difficult to predict, it becomes challenging to schedule and manage traditional generation assets to compensate. Renewable sources also tend to be geographically concentrated and are often isolated, creating potential transmission constraints.

Grid and renewable operators are developing strategies to respond to these changes, including deploying grid scale energy storage systems as an efficient solution for smoothing the output of renewable generation and controlling the fluctuations in the amount of energy flowing onto the grid. By tapping excess reserves when the wind dies down and recharging when it picks back up, energy storage systems can help control the rate at which renewable power is distributed to the power grid.

Before moving forward with a battery energy storage project, however, it is important that utilities and project developers work with technology providers to determine the optimal size of a battery system to meet their specific application requirements.

This paper presents a structured approach to determining the optimal size for an energy storage system and presents some of the key data required to inform such a sizing. A case study for ramp management of a wind farm is used to illustrate the method.

BIOGRAPHICAL NOTE

Rhys Foster has spent more than 15 years working with systems built around electrochemical devices and currently works in business development for A123 Solutions. Prior to his business development role, Rhys was a member of the applications engineering team, with responsibilities including the analysis of energy storage applications to determine optimal system configurations and projecting the lifetime performance and costs of such systems. He has previously worked in fuel cell development and power electronics design and manufacturing. Rhys received his BSc, MSc, and PhD degrees from the University of Waikato in New Zealand, with dissertations in Solid Oxide Fuel Cell Modeling.

AMBRI'S FIRST DEPLOYMENT: ELECTRICITY STORAGE AT THE MASSACHUSETTS MILITARY RESERVATION

Author: Phil Giudice, Chief Executive Officer

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BACKGROUND

In May 2013, Ambri was awarded funds by the Massachusetts Clean Energy Center to study the engineering requirements and economic potential of an Ambri system deployed at the Massachusetts Military Reservation. The funding will conclude with the deployment of Ambri's first prototype system in 2014.

The Massachusetts Military Reservation (MMR) is a joint-use base, home to multiple military commands and government agencies including Otis Air National Guard Base, Camp Edwards, Cape Cod Air Force Station and the United States Coast Guard's Air Station Cape Cod. MMR is one of the largest electricity users in the Commonwealth of Massachusetts and has one of the largest and fastest growing portfolios of variable renewable generation in the region.

Ambri is currently conducting a functional feasibility study to evaluate the engineering requirements and economic potential of an Ambri system at MMR. The functional feasibility study will inform all on key decisions regarding how best to deploy a full-scale Ambri system at MMR, considering:

1) The most valuable use(s),
2) Potential location(s) based on the most valuable uses,
3) The optimal size of the battery (MW / MWh)
4) The most attractive capacity (MW) to energy (MWh) ration, as Ambri can adjust this ratio within a range as needed based on MMR's most valuable uses of the system, and
5) The product requirements required to maximize value (e.g. response time).

Ambri's presentation at EESAT will cover this analysis.

ABOUT AMBRI

Ambri is commercializing the innovative 'Liquid Metal Battery' (LMB) technology for use in grid-scale electricity storage applications. The LMB technology was invented at the Massachusetts Institute of Technology (MIT) in the lab of Professor Donald Sadoway and was inspired by the concept of reversing large-scale electrometallurgical processes that consume huge quantities of electricity (i.e., aluminum smelting). Applying the principles of large-scale electrometallurgy has enabled Ambri to create a **unique, low-cost, flexible, reliable, long-lifespan and safe** electricity storage technology.

Ambri was incorporated in 2010 and has its offices in Cambridge, MA. Investors include Khosla Ventures, Bill Gates and the energy company Total. In May 2012, Ambri raised a Series B round of financing for $15 million.

Michael Kearney will be presenting in Phil Giudice's stead.

BIOGRAPHICAL NOTE

Michael Kearney is a Principal on the Corporate Development team at Ambri. As its first full-time employee in April 2011, he has helped build Ambri's corporate infrastructure, managing finance, human resources, marketing and business development. Michael's primary role at Ambri today is establishing and executing Ambri's go-to-market strategy.

Prior to Ambri, Michael received a Master's of Science from MIT where he studied energy economics in the Technology and Policy Program. He also holds a Bachelor's of Arts from Williams College in Mathematics and Political Science.

CAPACITIVE PERFORMANCE OF TITANIUM CARBIDE BASED MXENES

Maria R. Lukatskaya[1,2], Chang E. Ren[1,2], Olha Mashtalir[1,2], Yohan Dall'Agnese[1,2,3,4], Michael Naguib[1,2], Patrice Simon[3,4], Michel W. Barsoum[1] & Yury Gogotsi[1]*

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We recently produced a new 2-D material, viz. Ti_3C_2, by selectively etching Al from a MAX phase Ti_3AlC_2 and labelled it MXene, to emphasize its similarity to graphene. MXenes represent a large family of transition metal carbides and carbonitrides, not just one phase. Unlike graphene, whose chemistry is restricted to carbon, MXenes allow a variety of chemical compositions and are establishing themselves as a new class of two-dimensional materials. MXenes possess good in-plane conductivity, which in combination with the rich surface chemistry makes them attractive for electrical energy storage. However, while potential of MXenes as anode materials for Li-ion batteries has already been shown, their use in electrochemical capacitors has not been explored.

Here, we report on our latest findings regarding the capacitive properties of Ti-containing MXenes. Electrodes were fabricated by vacuum filtration of MXene sheets or by conventional film rolling with binder and conductive additives. In some cases prior to electrode fabrication, MXene was delaminated in order to achieve better separation of the 2D sheets. Several different electrochemical techniques were employed to understand the mechanism of charge storage in both aqueous and organic electrolytes. Electrochemical impedance spectroscopy confirmed the low resistivity of the tested materials showing characteristics for capacitors close to a 90° angle on the Nyquist plot. Cyclic voltammetry measurements showed a high rate handling ability along with impressive volumetric capacitance values for the electrodes from the delaminated MXene. Galvanostatic cycling showed no degradation of the capacitive properties after more than 10'000 cycles.

Maria Lukatskaya will be presenting in Yuri Gogotsi's stead.

BIOGRAPHICAL NOTE

Maria Lukatskaya got her BS in Materials Science and MS in Chemistry at Moscow State University, graduating with honors. Now Maria is pursuing her PhD in Materials Science at Drexel University in Professor Gogotsi's group. Her professional area of interest is development and testing of new materials for energy storage. She won the American Ceramic Society Ceramographic Competition Award (2010) and the Best Presentation Award at the International Conference on Advanced Capacitors (ICAC) in 2013.

HOW ENERGY STORAGE PROVIDES SOLUTIONS TO RENEWABLE INTEGRATION CHALLENGES

Alexandra Goodson

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ABSTRACT

Renewable energy integration is consistently increasing in island locations. While there are many benefits to generating energy through renewable sources, the characteristics associated with solar and wind generation lead to many challenges for local utilities. The stability and reliability of an island's power system can be compromised and the existing generation assets may be utilized inefficiently. This presentation will review the challenges of renewable integration and how quick responding energy storage can provide a solution. In addition, optimizing a system's assets, including storage, through an intelligent control system allows maximum renewable energy consumption. A case study reviewing this kind of system will be explained in addition to other renewable generation projects coupled with energy storage.

BIOGRAPHICAL NOTE

Alexandra "Alex" Goodson earned a bachelor's degree in Industrial Engineering and is completing her masters in Power Systems Management. She has supported the development of the ABB Energy Storage Modules portfolio working with customers and R&D to optimize the design of these solutions. She has also supported the development of microgrid projects on remote and island locations. She is currently the Business Development Manager for ABB's Energy Storage Modules' portfolio.

K.SPHERE …IS A KINETIC BATTERY.

Mario Gottfried

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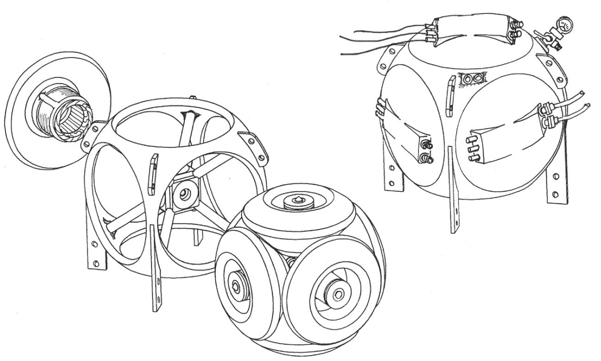
The Three Dimensional Counter Rotating Kinetic Electro-Mechanical Energy Accumulator (3D CR KEMEA), KEMEA or “K.Sphere” is a 37+ year engineering quest charged with optimizing safe fast sets of 6 double-cone flywheels, each with its own fast electric motor, in an optimized sphere vacuum frame, which is gyro neutral, and high strength. The secret is mass at speed, increasing kinetic capacity as a battery, with powerful fast loading, and sustain overloads. It is lighter, smaller and far longer life than chemical batteries. Consider that unit weight to lead/acid is equal at medium speeds (approx. 53,000 RPM); Lithium batteries are matched at higher speeds. The inherent quick recharging capability accomplished by “forcing” is a new battery breakthrough, useful for powering-up quickly and safely.

Regarding Mobil, re-cycled energy, +/-60% is absorbed off regenerative braking recovery of EV/HEV’s to +/-32% net free energy. 15” rotors in stationary uses (single or banks) boast ~10 kWh ea. at +/-60K RPM, a bank of 100 K.Spheres, 600 flywheels, add up to 1 MWhr. With commercial materials, 13”rotors can spin over 100,000 RPM; 15” is limited to 80,000 RPM. Stronger materials are used by the military.



BIOGRAPHICAL NOTE

Mario Gottfried became professionally involved with energy since joining and later becoming senior mftg. management, in Mexico with Grupo Fuerza, S.A., a traditional NEMA and SAE motor and generator in line production + new design engineering to 15 MW/13KW volts. Plus the engineering of other line products such as 60 Hz. flywheel UPS to 1.25 MW, wind machines, 10 KW to 1 MW, special motors and m-g sets.

Today, Mario self funds full time flywheel research and development of fast rotors, using material technology to increase density and strong fibers to leap into high speed, and remarkable new flywheel performance, to compete with chemical batteries.

President of several companies, and a local business owner’s council, he has excelled in energy consulting for gov’t, mines and mills, selections include steam or engines, and remote power solutions with solar, wind for mainly refrigeration and desalinizing seawater and success at topographical opportunities for hydro.

He obtained grants from the Mexican government to re-engineer prototype as per a new design for multiple very fast flywheel rotors over 80,000 RPM.

Ongoing research efforts are financed by income generated by mining properties, real estate and other investments.

IMPACT STUDY OF VALUE-ADDED FUNCTIONALITY ON INVERTER RELIABILITY IN STATIONARY ENERGY STORAGE SYSTEMS

Eric Green

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The electric utility grid is being challenged by increased penetration of distributed energy resources (DER) in addition to greater loads. To this end, power conversion systems (PCS) developers are incorporating value-added functions for utility grid support and to realize smart grid economic advantages in stationary energy storage systems (ESS) applications. However, as existing PCS are tasked with additional grid-support functions such as voltage-support and frequency-support, the stress on individual components and impact on overall PCS reliability is not well studied. Investigation into the reliability of ESS and PCS devices employed in these support roles presents an opportunity to characterize the risk to device lifetime, which will be critical for future PCS and control designs.

Electrical and thermal simulations are developed using MATLAB/Simulink and PLECS software to model grid-connected battery energy storage system (BESS); a high-level system diagram is displayed in Figure 1 (attached). The BESS consists of a battery bank connected to a dual-active bridge (DAB), which serves as the DC supply for a 3-phase inverter. Electrical and thermal losses are modeled for system and individual components in order to calculate component mean time to failure (MTTF). Lifetime of the capacitor and IGBT switches are identified as the main considerations for system reliability. The MTTF for the IGBT is primarily determined by the junction temperature, using a chi-squared distribution model, while the mean time to failure of the DC-link capacitor is estimated from component temperature and ripple current using the Arrhenius equation.

At the present time, the initial simulations of the voltage-support case have been completed. It can be concluded from the preliminary simulation data that the effect of voltage-support on the MTTF of the key components is nuanced. Generally speaking, the IGBT switches experience a greater degradation while supplying reactive power, while the capacitors experience greater degradation while supplying real power. Further refinement of the simulation is necessary in order to make definitive statements about methods of control that may minimize total system wear and whether alternate component selection may alleviate the burden placed on the key inverter components by the voltage support value-added functionality.

There are a few areas in which the simulated system is to be either improved or expanded in order to build upon the work presented in this digest. Thermal and electrical models for capacitors are to be expanded through the use of impedance spectroscopy to match parameters to component models with increased complexity and accuracy. Using the voltage-support model as a baseline case, frequency-support can now be investigated. Simulation construction is under way for the frequency support value-added function, which shall utilize detailed generator and governor-exciter models developed from the characterization of the Caterpillar C9 250 kW Diesel Generator available from the Distributed Energy Test Laboratory (DETL) at Sandia National Laboratories.

This work was supported in part by the Energy Storage program managed by Dr. Imre Gyuk for the Department of Energy's Office of Electricity Delivery and Energy Reliability. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

"Impact Study of Value-Added Functionality on Inverter Reliability in Stationary Energy Storage Systems"

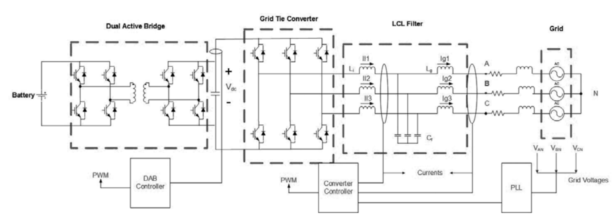

Figure 1: BESS and Inverter Grid-Tied System

BIOGRAPHICAL NOTE

Eric Green is a Ph.D. candidate in Electrical Engineering at North Carolina State University concentrating in Power Electronics. Eric is currently working at NC State's Future Renewable Electric Energy Delivery and Management (FREEDM) Systems Center under the direction of Dr. Subhashish Bhattacharya.

Through his graduate academic career, Eric has served as the Student Leadership Council's Outreach Coordinator, served as Teaching Assistant for Embedded Systems and Power Electronics Courses, has co-authored four papers presented at ECCE and EESAT conferences, and has interned at Eaton and Sandia National Laboratories.

Eric's current project "Impact Study of Value-Added Functionality on Inverter Reliability in Stationary Energy

Storage Systems” is in partnership with Sandia National Laboratories and the Department of Energy, under the guidance of Dr. Stan Atcitty and Dr. Imre Gyuk.

OPTIMIZATION OF SOLAR PV SMOOTHING ALGORITHMS FOR REDUCED STRESS ON A UTILITY-SCALE BATTERY ENERGY STORAGE SYSTEM

Wesley Greenwood

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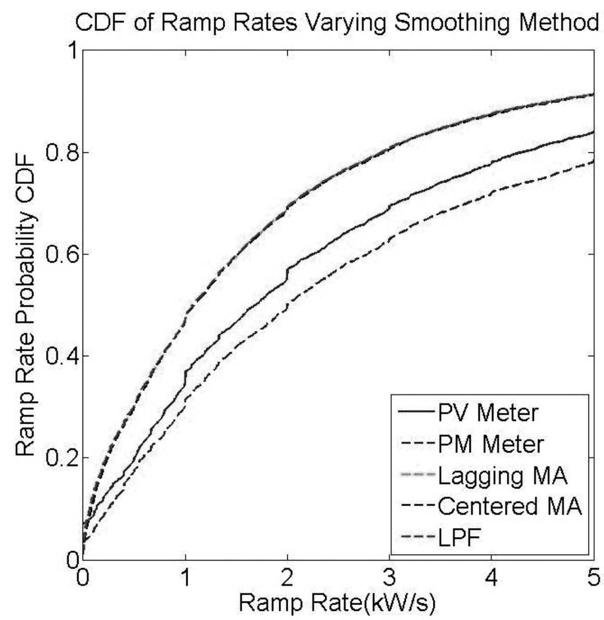
With the increase in grid-tied utility-scale solar PV energy production, there is a growing concern for distributed power variability due to high-frequency intermittencies caused by clouds and other weather phenomenon. Using battery energy storage, unaltered PV power can be “smoothed” before being dispatched to the grid. This is done by calculating the smoothed profile of the raw PV power, then charging or discharging storage appropriately to achieve all or part of this difference in profile. There are many algorithms for calculating this smoothed profile and they provide varying quality of smoothing in terms of ramp rate (change in power) reduction, stress on the batteries, and system requirements for making the calculation. With respect to the batteries, increased stress shortens the lifespan leading to increased system O&M costs.

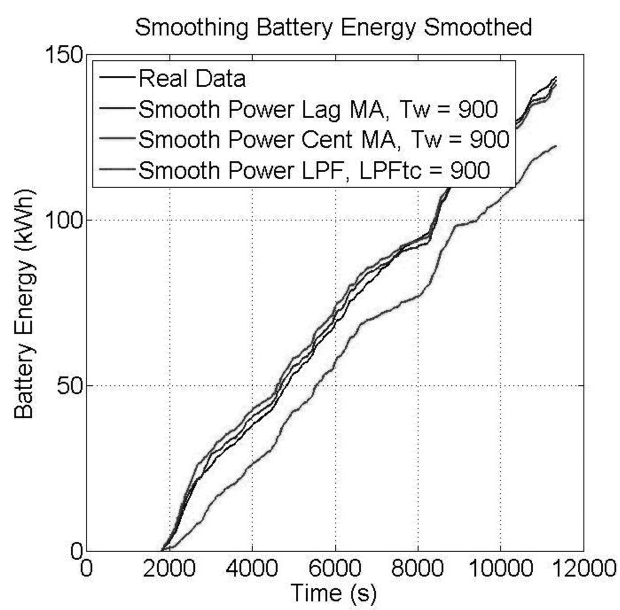
The goal of this analysis is to determine which of three different smoothing algorithms best provides satisfactory smoothing while minimizing total displaced battery energy, thus maintaining the batteries’ longevity. This is achieved using performance data from the Prosperity Energy Storage Project in Albuquerque, New Mexico. This DOE/ARRA funded SMART Grid Storage Project is investigating large-scale grid-tied PV energy production with utility-scale battery storage. Running each algorithm for the project’s one-second PV power data, theoretical ramp rate distributions and battery energy usages are compared side by side for algorithms using a lagging moving average, a centered moving average simulating a solar forecast, and a low pass filter. Prior to algorithm comparison, parameters such as deadband and system response delays are calibrated to adequately reproduce historical output data from the Prosperity Site for days using either lagging moving average or low pass filter real-time.

Current results suggest that algorithms utilizing short-term solar forecasts provide an advantage over a conventional lagging moving average or low-pass filter due to significantly reduced stress on the batteries for roughly equivalent reduction in ramp rates. Modern solar forecasting methods, however, are still under development and require added system investments. Between conventional methods, lagging moving average is proving to be slightly less battery-intensive for, again, comparable smoothing quality. We will present results of such optimizations together with cost-benefit analysis of the utility-scale storage system operation at PNM’s Prosperity Site.

Optimization of Solar PV Smoothing Algorithms for Reduced Stress on a Utility-Scale Battery Energy Storage System

Wesley Greenwood





BIOGRAPHICAL NOTE

Wes Greenwood is a graduate student research assistant for the Prosperity Energy Storage Project investigating various challenges in utility-scale solar power production with battery energy storage. While pursuing his Masters in Mechanical Engineering at the University of New Mexico, he has participated in several research topics such as thermal energy storage and numerical analysis of sustainable energy systems with an emphasis on solar energy. In addition to providing modeling support for colleagues and performing a number of unique analyses, his research goals include increasing the reliability and reducing the levelized cost of energy of solar power and energy storage.

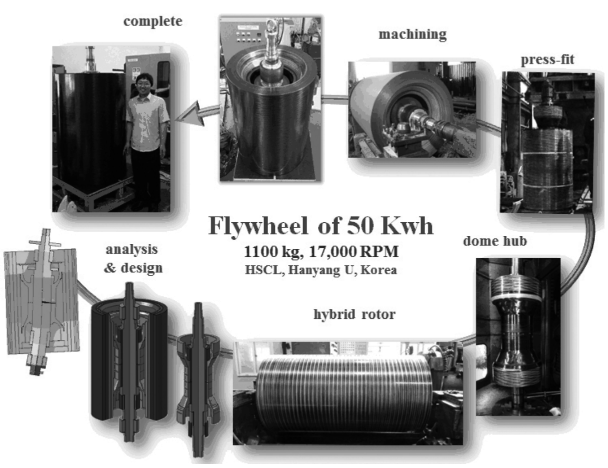
INNOVATIVE DESIGN AND FABRICATION OF HIGH ENERGY AND POWER KINETIC FLYWHEEL ENERGY STORAGE SYSTEM

Sung K. Ha and Seong J. Kim

Hanyang Structures and Composites Lab., Dept. of Mech. Eng., Hanyang University, sungha@hanyang.ac.kr

To increase effectively stored energy of the kinetic flywheel energy storage system, the rotor needs to be thick and large, especially in the radial direction. But the thick rotor expands in the radial direction, causing material failure or delamination of the filament wound rotor. To reduce radial stresses, the rotor should be designed so that the inner surface expands more than the outer surface, reducing the radial stress. This was achieved mostly with hybrid rotors with press-fit. However, to be compatible with this type of rotor, the hub, connecting the rotor to the shaft, should be flexible enough in the radial direction to be with the inner rotor surface. At the same time, this hub needs to be stiff yet in the conical deformation mode to increase the vibration frequency for high rotational speed. This has been very challenging in the flywheel rotors and hubs.

We have now overcome these technical problems by developing dome hubs and rotors of hybrid composites. This revolutionary flywheel rotor system enables significant increases in the storage of energy. It also improves the stability of the shaft, hub and the rotor system, enabling quick rotor release of the energy, increasing the power. Based on this technology, an unprecedented flywheel rotor system of 50 kWh has been designed and fabricated with a rotor that is 1250 mm high with a 900 mm outer diameter. A surrogate rotor system with the same diameter has been successfully spin-tested reaching 17,000 RPM, exceeding the design speed of 15,000 RPM.



BIOGRAPHICAL NOTE

Dr. Sung K. Ha is a Professor in the department of mechanical engineering at Hanyang University, South Korea, directing Hanyang Structures and Composites Laboratory (HSCL). He received his PhD in the area of composite materials from Stanford University, in 1988. He has been a visiting and consulting Professor at Stanford for the last five years. His major research areas include flywheel kinetic energy storage system and innovative design of wind turbine blades, and multi-scale strength and life prediction of composites.

He has been working on developing flywheel energy storage system since 1996 which is funded by Korea Electric Power Research Institute, Korea Institute of Energy Research, Hyundai Motor and the US Air Force. He is developing multi-rim hybrid rotors and composite hub for the flywheel system. He has also developed design tools for composite structures including flywheel rotors and wind turbine blades.

He has authored more than 80 peer-reviewed articles in journals, four book chapters, twenty patents, and more than 100 conference and seminar presentations. He is currently an active member of Stanford Global Composites Design Team.

UTILITY SCALE ENERGY STORAGE AND THE NEED FOR FLEXIBLE CAPACITY METRICS

Ben Haley

Energy and Environmental Economics, San Francisco, CA

ABSTRACT

The planning paradigm for system capacity, which has traditionally been procured to meet peak load, is changing to also focus on the flexible resources needed to integrate variable renewable resources. We argue that this new reality challenges the efficacy of traditional cost of new entry (CONE) capacity planning metrics and requires a more careful analysis of the role of energy storage. Least-cost procurement of flexible capacity resources from a portfolio of options requires (a) a more precise definition of system need, (b) rigorous characterization of operating the characteristics for each resource, and (c) cost metrics for direct CONE comparisons across flexible resources. We demonstrate that even without premium payments for flexibility in energy and ancillary services markets, these measures significantly improve energy storage cost-effectiveness compared to traditional planning metrics. Specifically, by using a mixed linear program to optimize dispatch of CTs and storage technologies against historic prices in both day-ahead and real time markets in California, we show that bulk energy storage could already be cost competitive with CTs using a flexible capacity cost metric.

A number of studies have evaluated the value of energy storage participating in wholesale energy and as markets [11,15,17,19–21] and combined with renewable generation [9,10,22]. We contribute to this body of research in three ways. First, we optimize the dispatch for three bulk energy storage technologies and a CT in the same model, including both day-ahead and real-time markets in the optimization. We find that the performance characteristics of the storage technologies lead to higher net market revenues even without premium payments for performance. Second, unlike prior studies that focus on the value of energy storage, we estimate the capacity payment necessary to encourage new investment based on the CONE for each technology. Finally, we show how energy storage could be cost competitive with a CT in today's market, using a capacity payment that is based on flexibility rather than nameplate generating capacity.

TABLE I
NET MARKET REVENUES ($/KW-YR.)

CT	Battery	Pumped Storage	CAES
$37	$143	$73	$56

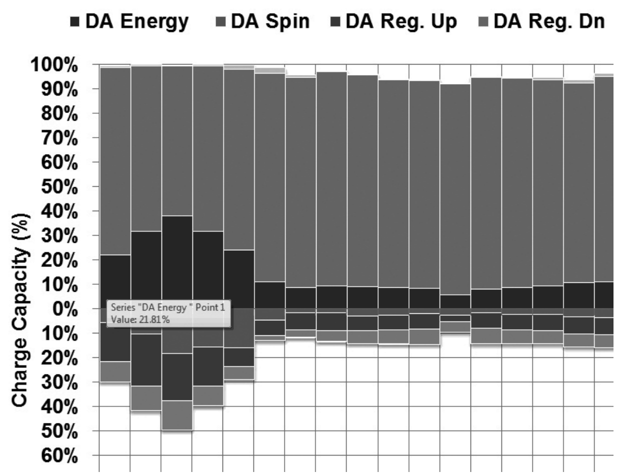


Figure 1: Average Annual Battery Discharge Dispatch by Market and Hour. Without start-up costs or a minimum operating load, Battery market participation is much higher than CT. Most of the discharge capacity is dedicated to regulation up and spinning reserves, with only limited energy arbitrage. Negative bars are regulation down and decremental energy bids in the real-time market.

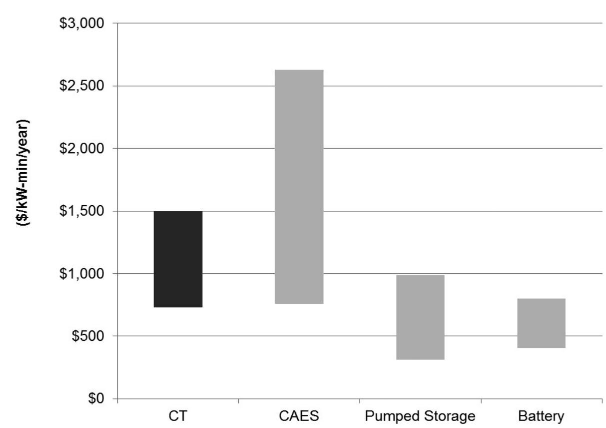


Figure 2: Flexible Capacity Cost of New Entry (CONE). Total costs minus net market revenues

Eric Cutter is presenting in Ben Haley's stead.

BIOGRAPHICAL NOTE

Eric Cutter is a lead analyst at E3 on the costs and benefits of energy storage, distributed generation, and responsive load, working with the Electric Power Research Institute (EPRI), utilities, regulators and technology companies to assess their value for the integration of renewable and distributed generation. Mr. Cutter managed E3's work for the recently completed UCSD-Viridity Innovative Business Model CSI RD&D Round 2 project. Mr. Cutter leads the development of the Energy Storage Valuation Tool for EPRI and member utilities, leading and supporting the California Public Utilities Commission (CPUC) on Demand Response (DR) cost-effectiveness. He is also leading the 2013 California Solar Initiative (CSI) impact analysis with metered and simulated generation data for over 160,000 systems. He has led the development of numerous financial and economic models for planning and regulatory policy in energy and water resources for the State of California and electric utilities nationwide. Prior to joining E3, Mr. Cutter worked as an independent consultant in water resources for seven years and at PG&E for 10 years.

HIGH PERFORMANCE FLOWING ELECTROLYTE BATTERY FOR GRID SCALE ENERGY STORAGE

Jonathan Hall, VP Engineering

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Flow batteries promise low cost, easy-to-operate, long-duration, utility-scale energy storage. Today, a number of companies are seeking to turn that promise into reality with demonstration and commercial deployment at utility scale. Primus Power, with its energy and power dense, low-cost, zinc bromide grid scale storage system, is one such company.

The core of the Primus technology and product innovation is the 20kW-rated EnergyCell battery module with multi-hour duration. Primus is currently transitioning from an EnergyCell design verification phase to field deployments of strings of multiple EnergyCells within EnergyPods (250kW, multi hour duration) in order to demonstrate real world performance of the complete system.

This session will focus on the chemistry and design innovations of the EnergyCell that have enabled its high power/energy density and low total cost of ownership, as well as the results from internal verification testing. Sandia National Labs was recently invited to independently measure and certify the performance of the EnergyCell; the conclusions from that testing will also be discussed.

BIOGRAPHICAL NOTE

Jonathan Hall is the Vice President of Engineering for Primus Power, where he leads R&D and Product Engineering of the EnergyCell battery module and EnergyPod grid scale storage systems. Jonathan brings 14 years of diverse experience in the design and development of electromechanical products. He moved into the grid storage space from the electric vehicle industry in order to develop technology that will have an even greater global energy impact in terms of increased energy efficiency and shifting electricity production to renewables.

Prior to joining Primus Power, Jonathan was an engineering manager in powertrain engineering at Tesla Motors. His most recent role at Tesla was as the engineering manager for the Roadster Lithium Ion battery pack system, and he also engineered aspects of the vehicle's induction motor and electro mechanical transmission.

Jonathan also gained expertise in the design of advanced mechatronic systems at Moog CSA, where he was a principle investigator and developer of advanced motion and active vibration control systems.

Prior to that Jonathan did a short stint with an early clean energy company, Solo Energy Corp, where he developed subsystems of a catalytic combustion micro turbine for clean distributed power generation.

MODULAR ADSORPTION-ENHANCED COMPRESSED AIR ENERGY STORAGE SYSTEM

Timothy F. Havel

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Adsorption-Enhanced Compressed Air Energy Storage (AE-CAES) is a novel, yet surprisingly low-tech form of stationary, long-duration energy storage. It is based on the well-known fact that certain micro-porous materials, most notably zeolites, can adsorb very large quantities of air. At pressures of order a mere 10 bar and deep-freeze temperatures (ca. –30°C), common zeolites such as 13X and 5A hold more than ten times as much air per unit volume as an ordinary tank would at the same pressure. About 85% of this air is released on heating the zeolite to near-boiling tempera¬tures, without dropping the pressure. Such a "temperature-swing" storage cycle offers the following distinct advantages over other forms of CAES:

- It is extraordinarily safe, since even if the vessel holding the zeolite were ruptured, the large amount of heat needed to raise its temperature ensures the air would only slowly be released.
- It is environmentally benign, as zeolites are nonflammable, nontoxic, highly inert minerals.
- The nonmoving parts of the system, and in particular the zeolite, will last tens of thousands of cycles without degradation, so the system's life-cycle costs will be very low.
- The overnight cost promises to be quite low as well, because the tanks cost a fraction of those needed at high pressures, zeolites can be produced cheaply, and a low-and-constant pressure makes efficient compression/expansion straightforward with off-the-shelf hardware.

The only significant challenge lies in the large quantities of heat that must be moved around in order to implement the temperature swing. There are two approaches to this challenge. One is to use a "thermally open" system that provides thermal energy storage in parallel with mechanical. An AE-CAES system installed at a cold-storage facility, for example, could be charged with cold and with air at night, then used to offset cooling and other electrical loads during the day. A more general approach is to include a thermal energy storage subsystem within the AE-CAES system. Such a "thermally closed" system would recycle most of the heat and cold needed to implement the temperature swing over successive cycles, thus keeping the parasitic loads required to "top off" the system each cycle within acceptable bounds.

A more detailed introduction to the principles of AE-CAES may be found in our paper from the 2009 EESAT Conference proceedings. Here we will present a practical new approach to building a thermally closed AE-CAES system, along with supporting engineering analyses. The proposed system consists of multiple independent modules, one which is shown in Figure 1. Each module includes a vertical tank filled with a zeolite particulate and a second vertical tank filled with gravel or another nonporous, high heat capacity particulate. The tops and bottoms of the tanks are connected by pipes so that air can be made to circulate in either direction. In accord with the principles of regenerative heat exchangers, such a circulation will exchange the temperatures of the zeolite and the gravel, with efficient countercurrent exchange being attained by reversing the circulation direction between charging and discharging.

To minimize the system's footprint and ensure complete safety, the modules are built on-site by drilling caissons in the ground and lining them with prestressed concrete pipe, which is cheaper and more durable than steel. Horizontal drilling is used to connect pairs of caissons, and these tunnels are fitted with radiators to make up for heat or cold lost over each cycle. Horizontal drilling is also used to connect each module to a central equipment facility, as shown in Figure 2. This houses the compressors and all other machinery requiring regular maintenance. Additional regen¬erators are included to store and allow recovery of the heat of compression, as indicated.

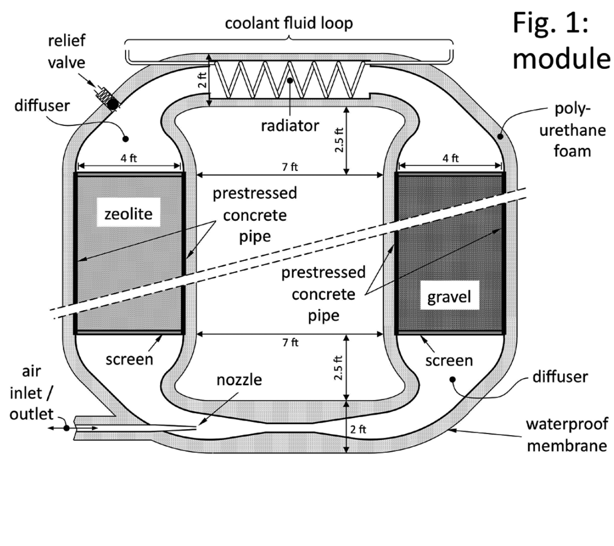

Fig. 1: module

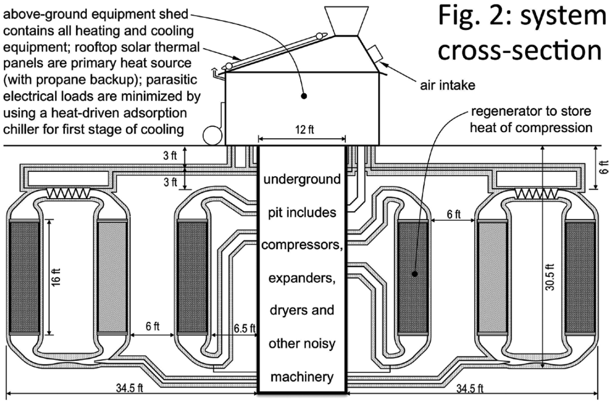

Fig. 2: system cross-section

BIOGRAPHICAL NOTE

Timothy F. Havel is the Founder and CTO of Energy Compression Inc., an early-stage startup focused on commercializing the use of the adsorption of air in porous media as a means of improving the economics of CAES. Over the last five years he has been developing the intellectual property and identifying the market opportunities for this technology, which is called Adsorption-Enhanced CAES or AE-CAES.

Immediately prior to founding Energy Compression Inc., Tim worked in the Center for Technology, Policy and Industrial Development, and in the Dept. of Nuclear Science and Engineering, both at MIT. His academic career covers over two decades of research in diverse topics in computational chemical physics, beginning at the ETH in Zürich and including the Scripps Research Foundation, the Univ. of Michigan and Harvard.

Tim holds a Bachelor degree in Chemistry from Reed College in Portland OR, a Ph.D. in Biophysics from the Univ. of California Berkeley, and a S.M. in the Management of Technology from the MIT Sloan School.

EESAT 2013 “ENERGY STORAGE - A KEY TO A RESILIENT GRID”

RedFlow ZBM USA Operational Experience

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RedFlow developed the R510 (Residential, 5kW, 10kWh) Energy Storage System (ESS) to meet the requirements of a utility smart-grid distributed storage project in Australia. The R510 includes one Zinc Bromine Module (ZBM) and an SMA Sunny Island 5kW inverter in a weatherproof enclosure. In May 2012 several variants modified for the USA (R510US) were commissioned. This paper reviews the operational experience gained and some analysis of the results.

Installations to be reviewed include Florida Gulf Coast University (FGCU), Sandia National Laboratories (SNL), and Sprint Tucson (BTS demonstration site). All of these sites employed cellular data links for remote control and data logging via host server in Brisbane, Australia. Data logging at 15-second resolution for more than 100 points of ZBM and SMA operation provided a rich and accurate resource for system analysis. The R510US control software allows the operator to conduct a wide range of energy storage experiments including conventional peak-shifting and renewable firming. All sites are grid connected and the FGCU and Sprint sites have load-side AC coupled PV supplies. The SNL device was subjected to a wide range of characterization tests including the emerging ESS protocol.

BIOGRAPHICAL NOTE

Steven Hickey began working with RedFlow in 2008. Under Alex Winter’s tutelage developed control and testing systems and methodologies since the first ZBMs were constructed. His initial focus was in the R&D test laboratory where he gained experience with the electrochemistry of the zinc-bromine system, hydrodynamics, failure analysis, performance analysis, and modelling techniques. He has read and collected an extensive library of papers from the literature and written scores of reports on many aspects of the technology.

Steve developed the first PLC-based battery management system, and latter designs based on the RedFlow (microprocessor) Battery Controller. He designed and developed the innovative hybrid ZBM-Lead Acid Remote Area Power System for the successful ESV project.

Intimate knowledge of the battery and systems has enabled Steve to commission ZBMs, conduct training, and specify test programs in Australia, UK, and USA.

Prior to joining RedFlow, Steve was a founding director of Blastronics, a leading instrumentation and consulting company in the global mining industry. There he designed and developed systems for vibration, acoustics, structural monitoring, and explosive testing, with 15 years’ experience in North and South America, and Australasia. He was awarded a Bachelor of Engineering (Electrical) from University of Queensland in 1981.

OFF GAS MONITORING FOR LI-ION BATTERIES: IMPLICATIONS FOR CONTROL AND LIFE EXTENSION

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Off gas from Li-ion batteries is becoming a growing concern because the volatile organics emitted are flammable and their unpredictable release represents a safety risk. Recent safety incidents involving Li-based battery chemistries have occurred across automotive, marine, electric grid, and aviation sectors and indicate a need to understand battery failure and the implications for control of the thermal event and the off gas hazard. The work presented summarizes ongoing results of an ARPA-e AMPED funded study (2012-2015) to qualify a novel sensor for off gas detection. It has already been demonstrated that with enough prior warning from the sensor, thermal runaway failure can be prevented and the residual capacity of the battery can be salvaged. Data to this effect will be presented, and the implications for off gas monitoring is investigated in several contexts including life extension, second life batteries, and the use of batteries in new environments with varying safety considerations. The second life topic, or the use of discarded or reclaimed batteries from an automotive application for energy storage, implicitly requires enhanced safety monitoring. While much testing is underway, the value proposition is dependent on the application, and there is a risk in unknowns about the prior history and whether there is an increased probability of failure as a result. The assumption is that the remaining life in partially consumed batteries is available at a discounted capital value, and the operationalized monetization of that value has a positive result. This investigation will test second life batteries with the off gas sensor to determine if there are any differences in off gas behavior in partially used or partially consumed batteries. This issue also ties into the general discussion of life extension and methods to extract more value (energy) from battery systems over their lifetime, as is the major objective of the ARPA-E Advanced Management and Protection of Energy Storage Devices (AMPED) program, under which this project is funded.

BIOGRAPHICAL NOTE

Davion Hill, Ph.D., is an applied physicist with over 7 years of project management and testing expertise. He obtained his Ph.D. in Physics in 2006. His technical expertise is in the areas of materials testing and techno-economic analysis. Dr. Hill presently manages projects for battery testing for the US Department of Energy Advanced Research Projects Agency - Energy (ARPA-E) and in the past has been principal investigator on projects for the US Department of Transportation and the California Energy Commission. His areas of specialization include energy storage, composite materials, transportation, and energy harvesting.

In 2006 Dr. Hill graduated from The Ohio State University while doing research in titanium metal matrix composites with the Center for the Accelerated Maturation of Materials. He then joined Honda for a 6 month post-doc where he worked on applications for carbon nanotubes, before joining CC Technologies as a project engineer in their client research department. In his work with CCT, he performed a number of projects investigating new materials for oil & gas systems, and then after DNV acquired CC Technologies, Dr. Hill joined their strategic research program. There he built a business on testing and qualification of composite materials and also built a techno-economic evaluation tool for processes that utilize and recycle carbon dioxide. In 2008 he was given an internal budget to build expertise in batteries, which he then leveraged into an ARPA-e project and the development of a novel testing method to assess the off gas hazard from Li-ion batteries. During that time DNV merged with KEMA and GL and Dr. Hill now manages multiple energy storage testing projects across the organization.

SIC JFETS REDUCE THE BALANCE OF SYSTEM FOR STATIONARY ENERGY STORAGE POWER CONVERSION SYSTEM

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The widespread adoption of energy storage applications for both renewable resources and power conditioning can be greatly facilitated if the cost for the power conversion stages, which can be 30% or higher of a total storage system, is significantly reduced. The balance-of-system costs for inverters are driven largely by the performance limitations of existing Si-IGBTs when increasing the DC-link voltage above 1 kV, which reduces the effective device switching speed and results in a severe impact on system component size and cooling. The excellent material properties of silicon carbide (SiC) semiconductors offer great promise for increasing the DC link voltage to well over 1 kV, while maintaining high efficiency and also achieving smaller more cost effective power conversion[1]. The ability to increase the DC-link voltage up to 4 kV, is especially attractive for SiC unipolar devices, for example, a JFET or MOSFET rated at 6.5 kV, could easily accommodate such operational voltages, while maintaining high switching speeds of 20 kHz. Such a platform could enable small, lightweight, transformerless topologies for industrial medium voltage grid applications operating in the 3.3 kV or 4.16 kV regimes.

The recent emergence of reliable 1200 V SiC devices has solidified the process and supply chains, where Schottky diodes have now demonstrated commercial success and clearly show efficiency benefits for hybrid systems, such as PFC applications, micro-inverters and motor drives, running in tandem with Si-MOSFETs and Si-IGBTs. Furthermore, demonstrations of inverters utilizing 1200V SiC-JFETs and SiC-MOSFETs are emerging, where the efficiencies are reaching >99% and operating at a 1 kV DC link voltage [2, 3]. This report will outline the current state-of-the-art for 1200 V SiC JFETs as a commercially proven technology device platform, demonstrating the benefits of the JFET through operational comparisons with SiC-MOSFETs, and Si-IGBTs of similar rating. Switch losses and device reliability are discussed as well as the impact on power inversion systems.

The second topic of the report will outline the progress and challenges of commercializing a 6.5 kV JFET device. One key challenge is obtaining high yield epitaxial wafers requiring a 70 μm low doped drift layer. For <2 kV rated devices, the presence of stacking faults from basal plane dislocations (BPDs) and other origins, has shown not to be so critical, however, for 6.5 kV and above rated devices, it is unknown if such defects create leakage paths in unipolar devices. USCi addresses this issue and will present the latest epitaxial results where BPD reduction methods [4] have been performed to achieve high yielding epitaxial wafers grown in a multi-wafer planetary reactor. Other critical issues, such as edge termination and gate driving will be discussed for module level components aimed at 3 phase power inversion in the medium voltage regime using 6.5 kV rated SiC-JFET transistors.

[1] A. Elasser and T.P. Chow, Proceedings of the IEEE, Vol. 90, No.6, pp.969-986, 2002.

[2] C. Wilhelm et al. Proc. of the Conf. Int. Power Elec., p8.3, 2010.

[3] http://www.cree.com/news-and-events/cree-news/press-releases/2013/april/delta-pv-inverters

[4] S. Chung et al., J. Appl. Phys. 109, 094906, 2011

BIOGRAPHICAL NOTE

Dr. John Hostetler received his Ph.D. from the University of Virginia in 2000 in Mechanical and Aerospace Engineering. His graduate research focused on microscale heat & energy transfer in semiconductors and metals. In 1999, Dr. Hostetler received the Alan-Talbot Gwathmey Memorial Award from UVa. He received his BS in Physics from Virginia Commonwealth University in 1990.

At United Silicon Carbide, Dr. Hostetler is focusing on building a new epitaxy department, demonstrating reliability of SiC devices and modules, and introducing new robust packaging techniques aimed at high power devices. Before joining United Silicon Carbide, Inc. in 2010, Dr. Hostetler was the Head of Semiconductor Development at TRUMPF Photonics, where he was responsible for realizing next generation AlGaAs laser diode products from epitaxy to packaging and seeing them through to high volume production.

DEMONSTRATION OF A UTILITY SCALE LITHIUM-ION BATTERY SYSTEM WITH A WIND TURBINE

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Two lithium-ion batteries with a total power output of 400 kW and an energy storage capacity of 740 kWh have been connected to the grid adjacent to an 800 kW wind turbine at a site four km east of Regina, Saskatchewan. This is one of the first utility scale turbine and battery installations in North America. Data from the wind-battery system is being monitored continuously to evaluate the performance and the economic value of the wind-storage system.

The focus of the paper is to quantify the effectiveness of the battery's smoothing and dispatching capabilities, and to assess the value of energy storage. Preliminary data show that the smoothing algorithm appears to reduce ramp rates by more than a factor of twenty, and that the system is capable of dispatching 400 kW for 90 minutes, three times per day. The reliability and durability of the wind-storage system are also being assessed.

BIOGRAPHICAL NOTE

Ryan Jansen is an Associate Research Engineer with the Alternative Energy business unit of the Saskatchewan Research Council (SRC) in Canada. He received a B. Sc. in Engineering Physics, and is currently pursuing his M. Sc. in Electrical Engineering from the University of Saskatchewan with a focus on Grid Reliability and Microgrids. His current work at SRC focuses on the role of energy storage and its effect on the performance, reliability, and financial viability of renewable energy systems.

Mr. Jansen joined SRC in 2009 and has developed, participated, and managed a variety of projects including the development of Saskatchewan's first hydrogen-fuelling station, the design and implementation of dual-fuelled hydrogen, ammonia, and natural gas vehicles, and the modeling and analysis of an intelligent remote microgrid system with energy storage and renewable integration. He is currently the technical lead for the Cowessess Wind-Battery project which consists of one of North America's first utility-scale wind-battery installations.

On a personal side, he and his wife have designed and built their own home which is one of Canada's first net-zero homes. It employs methods such as passive-solar design, super-insulated walls, a ground source heat pump, and an 8.19 kW photovoltaic array on a single axis solar tracker.

MESA: MODULAR ENERGY STORAGE ARCHITECTURE

David Kaplan – CEO

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PROBLEM STATEMENT

Broad deployment of grid-connected energy storage systems (ESS) is limited by lack of physical, electrical and communication standards. Current ESS implementations are project-specific, with proprietary hardware and software that is not modular or interoperable. This has several negative consequences: 1) increased time, complexity and cost for all ESS deployment phases (design, engineering and construction); 2) ESS designs are not easily scaled (for example, replicated across substations); 3) customers cannot easily combine best-of-breed components (batteries, power converters and software); 4) customers are dependent upon a single ESS supplier, with few options to upgrade or expand their investment.

MESA

An industry consortium of utilities and technology suppliers has developed Modular Energy Storage Architecture *(MESA), an open, non-proprietary, technology-neutral* specification, to address these limitations and increase customer choice.

INTERNALS

MESA-compliant batteries are typically organized as shown in Fig. 1 (other organizations are also supported). *Bank* is a top-level unit of energy storage, with typical total capacity of 250 kWh or more, comprising one or more strings and managed by ESS executive software. Banks within an ESS may be supplied by different manufacturers (shading), a key MESA capability. *String* comprises multiple series-connected modules, with typical total capacity of 25-100 kWh, managed by manufacturer's technology-specific battery management system (BMS). *Module* comprises battery cells, with typical total capacity of 1-10 kWh.

EXTERNALS

Externally, MESA standardizes connections between grid-connected ESS(s) and utility IT software such as SCADA, DMS, historian, power scheduling, etc. – see Fig. 2. An optional MESA-compliant Fleet Executive can manage groups of ESS or other assets, delivering an aggregated energy resource to the utility or grid operator.

MESA-1 PROJECT

In the MESA-1 Project, Snohomish County PUD, 1Energy Systems, and battery and PCS partners are deploying a 1 MW / 1 MWh ESS built from MESA-standard battery, PCS and software components at a utility distribution substation.

ECOSYSTEM

MESA technology partners deliver plug-compatible products built to open, industry-standard specifications. In the MESA ecosystem, utilities procure batteries and PCS as they procure other standardized electrical equipment (e.g., transformers, reclosers, etc.).

EESAT PAPER

This EESAT paper will discuss MESA technologies and the MESA-1 Project:

1. Deploying a 1 MW / 1 MWh MESA-standard ESS at a utility distribution substation.

. Developing standard physical, electrical and communication interfaces among battery, PCS and software components within an ESS. These *MESA standards* will be described.

3. Integrating ESS with utility SCADA, DMS, historian and power scheduling platforms.

4. Analyzing and quantifying business cases for grid-connected ESS.

Title: MESA: Modular Energy Storage Architecture

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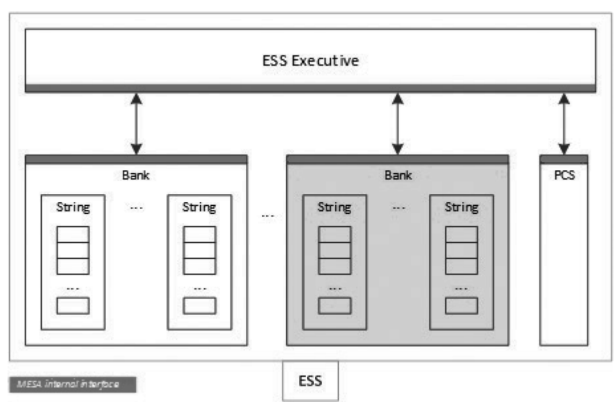

Figure 1: MESA Internal Interfaces

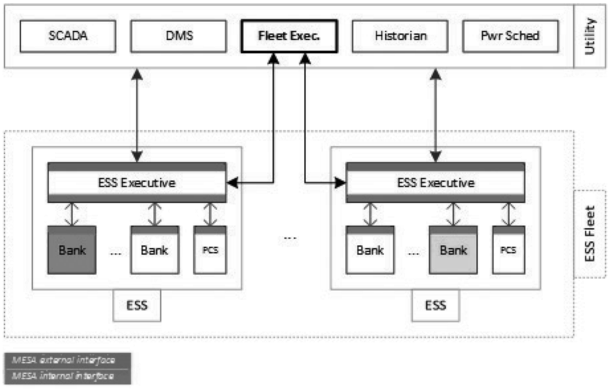

Figure 2: MESA External Interfaces

BIOGRAPHICAL NOTE

David Kaplan is CEO and founder of 1Energy Systems. The company delivers advanced control software for grid-connected energy storage and other electric assets, and enables scalable, modular energy storage systems (ESS) built from industry-standard batteries and power converters.

In 2006, David founded V2Green to deliver the first technology platform connecting electric vehicles with the power grid. V2Green achieved national recognition as a leading clean tech company and was acquired by Gridpoint in 2008. Subsequently, David served as Grid Technologist for Snohomish County PUD, advising the General Manager and staff on new technology initiatives.

David has over 30 years of technology experience in fields such as database management, web services, and radio-frequency identification (RFID). At Microsoft, he helped to create SQL Server, Access, and the company's internet services platform.

EVALUATION OF SIC POWER MOSFET RELIABILITY UNDER DC AND AC GATE BIAS STRESS

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Keywords: Silicon Carbide, MOSFET, Gate Oxide, Reliability

The superior material properties of the wide-bandgap semiconductor Silicon Carbide (SiC), such as low intrinsic carrier concentration, high thermal conductivity, and high breakdown electric field, make it a strong candidate for power switching applications. In particular, the SiC power Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) is attractive due to the ability to thermally grow a Silicon Dioxide (SiO_2) gate oxide on SiC, similar to what is done for established Silicon (Si) technology. However, the small band offset between SiC and SiO_2, coupled with a high density of electrically active bulk and interface defect states, results in large threshold voltage instability (ΔV_T) and hence unreliable device operation, particularly at high temperature. In this work, we have characterized commercially available, 1200 V SiC MOSFETs to evaluate ΔV_T under DC and AC gate bias stress conditions as a function of temperature. 1st and 2nd generation MOSFETs from the same manufacturer were evaluated. For all devices tested, the magnitude of ΔV_T was shown to increase monotonically with both temperature and DC gate voltage magnitude. Significantly, temperatures exceeding those rated for the device had to be used before significant degradation was observed, indicating good overall reliability if the device is used within the recommended limits. Further, negative gate voltage (device off-state) was observed to cause larger magnitude ΔV_T than equal magnitude positive gate voltage (device on-state). The sign of ΔV_T is opposite in the two cases: positive under positive gate bias stress (likely due to electron injection into bulk and interface traps), and negative under negative gate bias stress (likely due to hole injection into bulk and interface traps). This is significant because the device manufacturer recommends that a negative gate signal be applied to the MOSFET to reduce drain leakage current in the off-state. Our results also suggest that injected holes play an important role in SiC MOS reliability, similar to what has been reported for Si technology. Significant improvement in ΔV_T was observed for the 2nd generation device compared to the 1st generation device (Figure 1), particularly under large negative gate bias. This indicates that process and/or design improvements are capable of significantly improving SiC MOSFET reliability. AC gate bias stress experiments, intended to more closely approximate real-world switching conditions, were performed on the 2nd generation MOSFET (+20V/-5V, 50% and 90% duty cycle, 150˚C), and showed complex results (Figure 2). A clear two-phase behavior was observed (V_T showed a very fast initial shift, followed by a much slower degradation), and even for 90% duty cycle the net shift was negative, indicating that hole injection dominates electron injection. More study is needed to understand the complex injection, capture, and emission properties of electrons and holes into bulk and interface states to understand SiC MOS reliability under realistic AC switching conditions. These experiments, along with experiments on SiC MOSFETs from other manufacturers as well as on gate-oxide-free SiC Junction FETs, are currently being performed.

Figure 1: Change in threshold voltage (ΔV_T) of 1st and 2nd generation SiC MOSFETs as a function of temperature for various DC gate bias stress conditions. Note the much-reduced ΔV_T for the 2nd generation device under the -20 V stress condition.

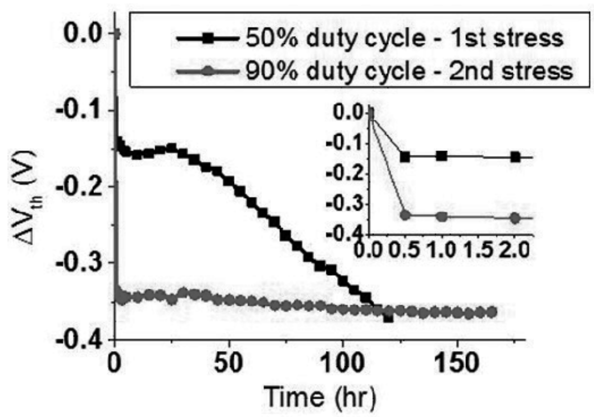
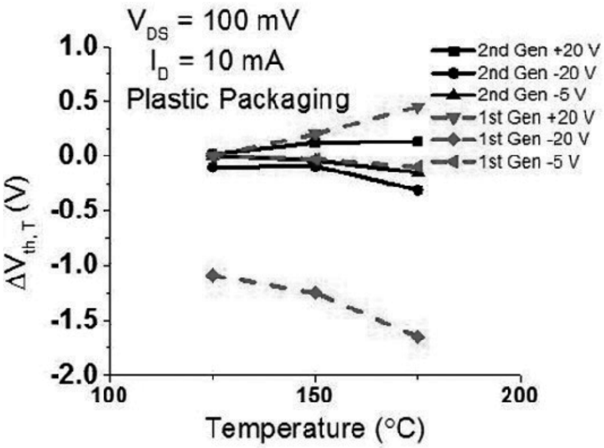


Figure 2: ΔV_T for 2nd generation SiC MOSFET stressed at 150˚C using 50% and 90% duty cycle AC gate bias conditions (+20V/-5V). Note that the net shift in V_T is negative for both cases, and that the shift displays a clear two-phase behavior. Inset shows expanded view of early-time behavior.



BIOGRAPHICAL NOTE

Robert Kaplar received a B.S. degree in Physics from Case Western Reserve University, Cleveland, OH, and M.S. and Ph.D. degrees in Electrical Engineering from Ohio State University, Columbus, OH. Following his Ph.D., he joined Sandia National Laboratories, Albuquerque, NM, where he first worked as a Post-Doctoral Researcher and where he is now a Principal Member of the Technical Staff. His current work focuses on wide-bandgap power semiconductor device characterization, modeling, and reliability physics, primarily for energy applications.

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly-owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. This work was performed under funding from the DOE Office of Electricity's Energy Storage Program managed by Dr. Imre Gyuk.

PEAK SHAVING CONTROL METHOD FOR ENERGY STORAGE

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ABSTRACT:

Peak shaving is one of the Energy Storage applications whose large potential has become important in the future's smart grid. The goal is to avoid the installation of capacity to supply the peaks of a highly variable load. It can be used by electricity end-users (households, industries etc.) to bring down the cost of electricity by shaving their power peaks. It can also be used for grid upgrade deferral and for managing power peaks generated by renewable and electric vehicle fast chargers. This paper addresses the challenge of utilizing a finite energy storage reserve in an optimal way. The owner of energy storage would like to bring down the maximum power peak as low as possible but at the same time ensure that the energy storage is not discharged too quickly (rendering in an undesired power peak). This paper proposes a method for calculation - an optimal shave level based on recorded historical load data. It uses optimization methods to calculate the shave levels for discrete days, or sub-days and statistical methods to provide an optimal shave level for the coming day(s).

First, an overview of existing methods in the literature will be presented. Next, the developed algorithm will be explained. The developed method uses an optimization routine to find the lowest possible shave level where the energy storage will shave everything that exceeds the minimum level. The changing variable in the optimization is the shave level and the objective function is the energy in the storage device (here a battery system was chosen). The optimization routine aims to utilize as much of the battery capacity chosen by the user. It works by integrating the difference between load and shave level with the limit that the battery during charge or discharge will not exceed the maximum or minimum SOC levels respectively. The objective function, which is minimized, is the error between the available battery capacity and actual capacity used. The optimization scheme is general and can be utilized in both charge and discharge. Also, it can be applied to a set of data, statistical or not, regardless of its time span. The results of this algorithm can be either used in specific time windows, separate days or they can be statistically processed to provide an optimal shave level for future days. The statistical analysis is the following:

1. Calculation of the shave levels using the optimization scheme.
2. Definition of the probability of not having a misfire (i.e. 95% means 5% chance of having a misfire).
3. Application of distribution fitting to track which distribution fits best in the calculated shave levels.
4. Calculation of discrete/continuous probability density function, cumulative probability function or survival function to provide the best estimation to satisfy step 2.

The proposed method has been tested with real load data, provided by a utility company in Sweden. The available energy in the battery is 75kWh. Fig.1 depicts results for peak shaving and optimized charging for one day. Fig.2 depicts the cumulative distribution function for several shave level data. If shave levels with 85% chance of not running low on battery should be found, then this level should be 373 kW for peak shaving.

Peak Shaving Control Method for Energy Storage
Contacts: Tomas Tengnér, Georgios Karmiris

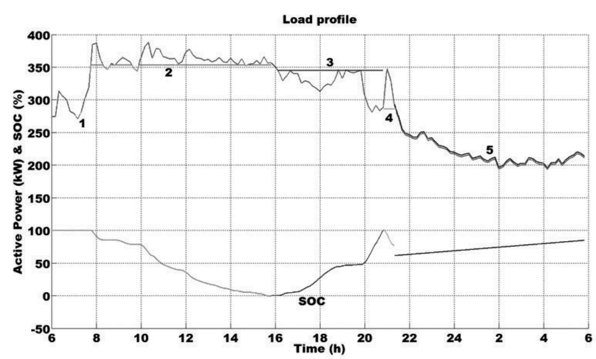


Figure 1: Results for a specific day. Standby mode (1), Peak shaving without charging (2), optimal charging (3), peak shaving without charging (4), charging with constant power (5). The red curve is the original load.

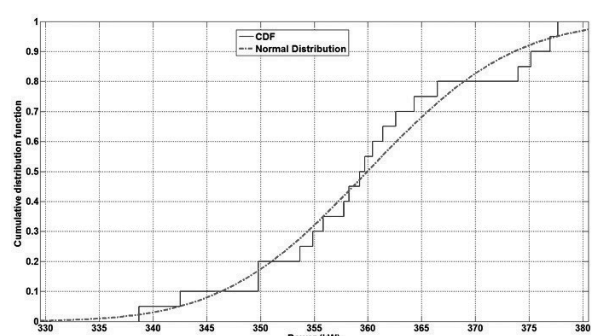


Figure 2: Cumulative distribution function for the selected shave level data of operation (2), peak shaving without charging.

Tomas Tegnér will present in Georgios Karmiris' stead.

BIOGRAPHICAL NOTE

Tomas Tengnér is a scientist in the Electrical Power Systems group at ABB Corporate Research in Sweden. He has been with ABB since 2009, starting with his thesis work on wireless power transfer. His main research interest is battery energy storage systems (BESS) and the use of such in the grid. Other areas of interest are Renewable Energy Systems, e-Mobility and Wireless Power Transfer. He is working with battery testing and evaluation, power electronics and converters for BESS and BESS application control.

Before joining ABB Tomas has been working with hydro power generation at the power utility Fortum, and at the steam power station of the Grycksbo paper mill.

Tomas earned his M.Sc. degree in Energy System Technology from Umeå University in Sweden in 2009.

CONTAINED VACUUM ENERGY STORAGE[1]

Samuel T. Kelly

[1] NOTE: This concept is protected by US pat # 8,072,086 "ELECTRIC ENERGY STORAGE AND RETRIEVAL SYSTEM" issued to Samuel T Kelly.

ABSTRACT

Searches for cost-effective, broadly applicable, grid-scale electrical energy storage have yet to produce a wholly acceptable proposal. The value of such storage has long been recognized but the staggering amount of power involved presents an enormous challenge. Lately, the problem of widely varying electrical power demand has been exacerbated by the increasing inclusion of the renewable energy sources of wind and solar power generation, which are intermittent and generally fail to meet demand. Some success has been achieved for providing large-scale energy storage with pumped hydro where water is vertically displaced for energy storage, but the paucity of suitable sites has limited its implementation. Small-scale energy storage devices such as batteries, flywheels, and various exotics, have been advanced, but costs accrue from periodic replacements and problems arise when attempts are made to scale these smaller devices up to megawatt-hour storage levels. Using compressed air for energy storage has been proposed, but the problem is that the heat (energy) from compressing air will be lost over time. Also, there may be high costs and safety issues involved in containing substantial volumes of compressed air. This concept has failed to gain support since it was first applied eighty years ago.

Conversely, it is my contention that it is cost-effective to store bulk electricity with a vacuum by displacing air from relatively low-cost, pressure-proof concrete domes, to be recovered in a timely manner. Concrete is ideal for such vacuum domes because it is cheap, easily formable, and possesses high strength in compression. This process produces no heat and utilizes atmospheric pressure of 100,000+ Pa to provide a working pressure differential with the vacuum.

EXAMPLE:

An 80 meter diameter hemisphere encloses 134,041 cubic meters. Drawing air from the dome to produce a pressure of negative 60kPa will provide energy storage, thusly; - (60kPa (newtons / square meter) x 134,041 cubic meters) / (3600 sec/hr x 1000 W/kW) = 2234 kWh. An off-the-cuff estimate is that the noted concrete dome will cost approximately $1.1 million by constructing the dome as described in US Pat # 2,270,229 and similar US Patents. This comes to $492/kWh. The ancillary components (multistage centrifugal exhauster (available) and low pressure air turbine generator (new)) will add approximately $90k, resulting in a total estimated cost of about $582/kWh. While the larger dome provides a better cost vs. kWh ratio, various sized vacuum domes may be specified to suit space and energy capacity requirements.

These power storage domes offer advantages in addition to providing controlled dispatching for wind and solar power. With a footprint of approximately one acre and with just 60% dome air evacuation, expect high round-trip efficiencies and only occasional servicing of ancillary components required. Concrete domes are constructed on the sites where energy storage is sought and they will endure for centuries. Concrete structures built by the Romans still remain structurally sound after two thousand years. Today, concrete is plentiful and modern construction practice will permit the dispersed placement of gigawatt-hours of electrical energy storage throughout the grid. These concrete domes are not environmentally threatening, aesthetically displeasing, nor hazardous. Even catastrophic failure only results in implosion, minimizing the risk of injuring people nearby. This system for bulk electricity provides fast response times, yet it retains 100% of stored energy, indefinitely. This is an energy banking system that operates on alternating current for both storage and recovery, thus bettering efficiency and cost by eliminating rectifier and power inverter networks to match up with grid electrical parameters. By utilizing state-of-the-art manufacturing, no technical breakthroughs are sought, thereby requiring only conventional design and development to integrate this power storage system into the grid. Other applications include microgrids, load leveling, and the improvement of grid stability.

BIOGRAPHICAL NOTE

Samuel Kelly retired as a project engineer with Robertshaw Controls Company. Sam brings more than thirty years experience as a design engineer and project engineer. Sam has designed, tested, and managed all aspects involved, from conception to production of several successful gas heating controls. Sam holds title to more than a dozen US patents with Robertshaw, and several more since retiring.

Sam has been married for fifty years. He is a graduate from Los Angeles City College and a veteran of the US Navy (Sea Bees).

NANO-ENCAPSULATED MATERIALS FOR HIGHLY-TUNABLE HIGH TEMPERATURE CAPACITORS

David M. King, PneumatiCoat Technologies Stoughton, MA

ABSTRACT

This poster presentation will detail the ongoing efforts of an SBIR project that focuses on producing novel, tunable dielectric materials that are expected to produce significantly improved high temperature capacitors for a number of DC-link, hybrid vehicle, and pulse and power electronic applications. There are a number of important new advantages in these new materials such as higher reliability, positive voltage dependence, higher permittivity, higher resistivity, and maybe the most attractive of all for commercialization is the ability to co-process with nickel or copper electrodes, and avoid the very high cost of silver, gold or platinum.

The overall objective of this work is to significantly improve the performance, cost and lifetime of ceramic capacitors available today. This team is producing its own dielectric materials, applying nanoscale coatings onto a wide array of materials, developing novel ceramic processing steps to form dielectric layers from nanocomposite materials, fabricating complete capacitor devices, and carrying out testing before and after accelerated aging steps. Novel niobate-based ceramic dielectric materials have recently been discovered, which yield much higher performance and can be used at higher temperatures than conventional dielectrics. These new dielectrics will be paired with passivated Ni- and Cu- base metal electrode powders nanocoated with oxidation barrier films to allow these low cost conductors to supplant silver, gold and platinum used today and significantly reduce advanced capacitor costs. TGA results will be shown that demonstrate how film thickness controls oxidation onset temperatures, and how these can be aligned with desired processing conditions, including binder burn-out temperatures and dwell times. Results from device-level coatings will be reported, and a roadmap showing how integrated coating strategies can improve the long-term corrosion resistance of the components, thus significantly extending product lifetimes even in harsh environments.

Future power distribution and energy storage systems, medical devices and other novel electronic devices will depend on advances in dielectric materials with high energy and power densities. Since capacitors occupy > 30% of the overall volume in conventional power converters and pulse power systems, capacitor performance, size, and reliability must be dramatically improved to meet the requirements of current and future systems. This project addresses these issues.

Paul Lichty will present in David M. King's stead.

BIOGRAPHICAL NOTE

Dr. Paul R. Lichty is a Founder and CEO for PneumatiCoat Technologies LLC (PCT) and is a co-inventor of PCT's high-throughput nanocoating technology. Paul is an avid inventor and entrepreneur. He has helped to found several high tech companies in the energy and surface coating fields (Boulder Surface Dynamics, Copernican Energy) that have raised as much as $20M. As a researcher, consultant, manager, and founder, Paul has developed business experience across the spectrum including leadership, team building, financing, logistics, and execution. Paul has managed several research and development groups and has extensive experience leading these teams from idea conception to commercial production. Prior to founding PCT, Paul was a Senior Engineer at Sundrop Fuels, where he oversaw R&D efforts and chaired several project taskforces focused on biomass to fuels processes and materials. He received a B.S. in Mechanical Engineering and a Ph.D. in Chemical Engineering from the University of Colorado at Boulder.

Paul is currently overseeing the construction of PCT's pilot-scale nanocoated materials production facility located in Broomfield, Colorado. PCT has received two SBIR awards focused on nanocoated materials for energy storage applications, one focused on high-temperature and high-voltage DC Link capacitors, and one focused on high energy and power density Li-ion battery materials.

COMPRESSED AIR ENERGY STORAGE: MATCHING THE EARTH TO THE TURBO-MACHINERY- NO SMALL TASK

Michael King, R.G., C.E.G., C.HG., The *Hydrodynamics* Group, LLC, Edmonds, WA,
George Moridis, PhD., and John Apps, PhD.

Compressed Air Energy Storage (CAES) is a process for storing and delivering energy as electricity. A CAES facility consists of an electric generation system and an energy storage system. Only earth-based geological structure can currently store adequate potential energy in the form of a pressurized air mass required by commercial electric turbine. Earth-based structures suitable for service as air storage vessels include 1) solution-mined salt cavities, 2) excavated mine cavities, 3) aquifer-water bearing geologic structures, and 4) depleted natural gas reservoirs. *Hydrodynamics* has found that the greatest limitation on developing CAES is to locate an underground storage vessel that can support the turbo-machinery equipment. This is a universal global issue that includes CAES development in Canada, China, Europe, South Africa, and the United States.

The technical barrier to CAES is that air has only been successful in solution-mined salt cavities in Huntorf, Germany and McIntosh, Alabama, and has never been stored in a solution-mined salt bed, excavated mines, aquifers, or depleted gas reservoirs for use in an energy storage system (proof of concept). This paper presents *Hydrodynamics* research on technical barriers to the development of solution-mined salt beds, aquifers, and depleted gas fields for CAES service.

The development of a solution-mined cavity in a bedded salt may be constrained by limits on the physical size of the cavity (multiple storage cavities to operate one CAES power plant), removal of non-soluble impurities in the salt formation, disposal of the solution mined salt, and potential collapse of the cavity because of plasticity of salt. *Hydrodynamics* evaluated options for resolving these constraints.

CAES in aquifer storage media is problematic in constraint of air storage pressure around the hydrostatic pressure of the aquifer, limitations on well productivity, the potential for oxygen depletion, and the potential of water production with the air. Mitigation of these issues is dependent on the selection of an anticline structure at the proper depth, and highly permeable porous media. The technical feasibility of developing the Dallas Center aquifer structure as a CAES air storage vessel was analyzed using the TOUGH+H2OGas simulator code. The results of this study are used to illustrate the issues with CAES aquifer storage systems.

Air has never been stored in a depleted natural gas field for use as an energy storage system. It is unknown if chemical reactions between air and natural gas in a depleted field will create an explosive environment, or whether the stored air would be oxidized to the point that it can not support combustion of natural gas in the turbine. It is also unknown if it is possible to create an air bubble in a depleted gas field that can store and deliver the required air mass flow rate at a pressure to operate CAES turbo-machinery. The results of *Hydrodynamics* analysis of potential chemical reactions between air-methane, air-groundwater, and air-rock storage reservoirs are presented. The merits of CAES in a depleted natural gas field are also presented.

BIOGRAPHICAL NOTE

Michael King is a Principal Partner of The *Hydrodynamics* Group and a Registered Geologist in six states and Alberta, Canada. Mr. King received his Masters Degree in Geological Engineering from the Rolla School of Mines, and has over 36 years of experience in the field of gas storage and geological engineering. Mr. King started his career as a natural gas storage engineer responsible for gas storage operations at a number of gas storage fields. Mr. King was a principal researcher on the hydrogeology of the Yucca Mountain high-level nuclear waste repository. Michael has recently conducted over 14 CAES studies that include the Norton Mine, and in aquifer and depleted natural gas fields since 1978. Michael was on the Electric Power Research Institute's Technical Review Committee for CAES at the Pittsfield Illinois aquifer test facility. Mr. King is currently assisting the Sacramento Municipal Utility District, Nebraska Public Power District, and Gaelectric with their CAES development projects.

DEMONSTRATIONS OF MODULAR ENERGY STORAGE IN THE NORTHWEST WITH CONSIDERATIONS OF RESILIENCE IMPROVEMENTS OF POWER SUPPLY

Michael Kintner-Meyer and Chunlian Jin, of PNNL, Richland, WA

With significant wind energy penetration in the Pacific Northwest, transmission operators are facing operating challenges such as fast ramps caused by wind variability, oversupply during low load/high wind period, and voltage fluctuations on buses close to wind farms. Furthermore, Northwestern utilities have been coping with long recovery time for outages on remote feeders and transformer overloading in old substations or supply disruptions due to snow storms. Energy storage can be an effective solution to all the above technical supply issues. This paper presents two battery storage demonstration projects that use a 120 kW/500 kWh lithium-ion battery module and two 250 kW/1 MWh Zinc Bromide flow battery Energy-Pods, respectively. One is focusing on the field testing of the developed control scheme and evaluating the performance of energy storage; the other on co-optimizing the multiple value streams to maximize the value of energy storage including outage management to improve resilience of rural distribution feeders.

The lithium-ion battery storage as shown in Figure 1 has been co-located with Nine Canyon wind farm at Energy Northwest in southeast Washington, and will be co-located with photovoltaic at end-users' side and at a substation of the City of Richland to investigate the potential barriers of implementing the designed control scheme including confidential data transfer and crossing firewalls of different entities, and evaluate the performance of providing different grid services at different locations. In order to simulate the total impact of utility-scale energy storage, a model has been developed for the lithium-ion battery storage with the field test data collected from the energy storage including ramping capability and charge and discharge efficiencies.

Figure 1: Lithium-ion battery module for a 120 kW/500 kWh battery bank, its battery management system and grid interface

After the model has been validated with the actual performance of the real storage unit, field tests will be carried out to control hundreds of the battery modules with the real unit as one of them. The control scheme needs to wisely distribute the required total output to every battery module with consideration of round-trip efficiency for each application duty cycle, the state of charge of every battery unit, and the lifetime degradation of them. The storage system has been tested successfully with respect to the peak shaving and frequency regulation protocol developed by a PNNL-Sandia led team. The control strategy being developed for this project will investigate wind curtailment and wind schedule deviation management. The test results will serve as an indicator for the ability of the energy storage system to respond to various duty cycle signals, which is critical to grid reliability.

For the flow battery storage, two high value locations have been selected after screening all the potential sites in Puget Sound Energy system. One of the locations is a remote feeder in heavily forested mountains. One of the main expected benefits of the energy storage is to increase the resilience of the distribution system during snow storms through outage management. In contrast to the lithium-ion demonstration, the flow storage demonstration is mainly focusing on co-optimizing multiple value streams to maximize the benefits of the energy storage. The value streams considered are capacity value, energy arbitrage, balancing service, distribution upgrade deferral, outage management and power factor correction. The values of different individual and bundled services are estimated either based on market prices of the services or costs avoided by the energy storage. The presentation will show under what conditions and what services have to be provided to achieve cost-effectiveness from a life-cycle perspective.

BIOGRAPHICAL NOTE

Dr. Michael Kintner-Meyer is Staff Scientist at the Pacific Northwest National Laboratory in Richland, Washington. He is the Laboratory's lead for energy storage grid analysis and electrification of transportation.

Michael received a Ph.D. in Mechanical Engineering from the University of Washington and a MS from the University of Aachen, Germany.

SOLAR POWER RAMP RATE MITIGATION UTILIZING BATTERY STORAGE AND SKY IMAGER SOLAR POWER FORECASTS

Contact Author: Dr. Jan Kleissl

University of California, San Diego, Department of Mechanical and Aerospace Engineering, 9500 Gilman Dr – EBU2, La Jolla, CA 92093-0411, Tel.: (858) 534-8087, Fax: (858) 534-7599, Email: jkleissl@ucsd.edu

The variability of solar power presents challenges to its integration into the electric grid. Recently, the Puerto Rico Electric Power Authority (PREPA) issued a new ramp-rate (RR) minimum technical requirement. Now, interconnecting generators must commit to limiting changes in power output to 10% of the rated power plant capacity, per minute. In order to mitigate ramps in PV power output, plant operators can curtail power output or charge/discharge a battery energy storage system (BESS). However, curtailing power output can only mitigate up-ramps and incorporating a BESS is expensive.

Using sky imagery-based forecast technology, upcoming ramp events can be forecast up to 15 minutes. When coupled with a battery control scheme that can buffer forecast errors and capture curtailed energy, the forecast can reduce the required BESS size for RR mitigation. To determine the relative advantages of solar forecasts and BESS, three scenarios are simulated: (i) PV plant with large BESS; (ii) PV plant without BESS, but with a perfect 10 minute solar irradiance forecast; and (iii) PV plant with small BESS and a perfect 10 minute solar irradiance forecast.

BESS specifications were based on Sanyo DCB-102 Lithium-ion batteries with a nominal storage capacity of 1.59 kWh, and maximum charging power of $P_S^{min} = -340$ W and a maximum discharge rate of $P_S^{max} = 720$ W. 750 of these units were simulated for the plant. In order to characterize solar variability, a pyranometer was deployed at the University of Puerto Rico at Mayagüez, Puerto Rico (18.21°N, 67.14°W). Solar irradiance and cloud speed were used to estimate power output every five seconds for a 54 MW power plant from September through November in 2013. To account for geographic smoothing of irradiance, which is required when scaling from a point sensor to a power plant, the wavelet variability model was used. During this period, ramp violations at the simulated 54 MW plant occurred 3.84% of the time (power data was simulated at five second intervals). Figure 1. provides an example of a period with frequent ramp events.

For the PV system with BESS, ramp violations occurred 1.64% of the time, over the three month period, representing a 57% reduction from the 3.84% ramp violations occurring in the case with no BESS installed (Fig. 1). The effects of a perfect short-term forecast on ramp mitigation and BESS capacity reduction will also be quantified through (i) energy losses, (ii) number of RR violations, and (iii) BESS cycling and expected life.

Photovoltaic (PV) Facilities' Power Ramp Rate Mitigation Utilizing Battery Storage and Short-term Solar Power Forecasts

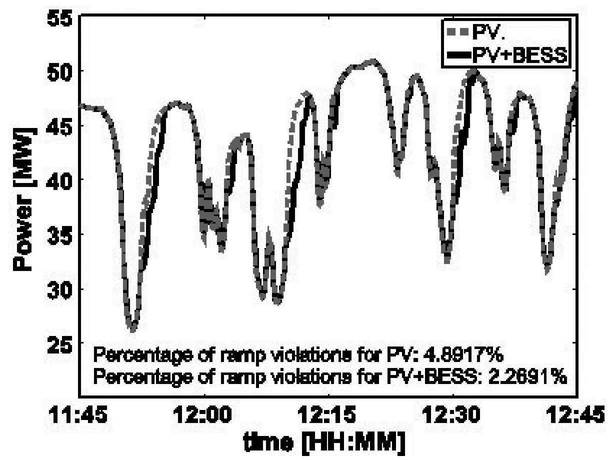


Figure 1: Simulated power output from a 54 MW PV plant without storage (red line) and a PV plant with a BESS controlled to mitigate ramps (blue line). Two hours of data on 09/09/2012 are shown. Ramp violations are reported for the entire day.

BIOGRAPHICAL NOTE

Jan Kleissl is an Associate Professor at the Department of Mechanical and Aerospace Engineering at the University of California, San Diego, and Associate Director of the Center for Energy Research. Kleissl received a PhD from the Johns Hopkins University in Environmental Engineering and joined UC San Diego in 2006. Kleissl supervises 16 PhD students who work on solar power forecasting and solar grid integration work funded by CPUC, CEC, NREL, and DOE. Kleissl teaches classes in Renewable Energy Meteorology, Fluid Mechanics, and Laboratory Techniques. Kleissl received the 2009 National Science Foundation CAREER award and the 2008 UC San Diego Sustainability Award.

ENERGY DISPATCH SCHEDULE OPTIMIZATION FOR DEMAND CHARGE REDUCTION USING A PHOTOVOLTAIC-BATTERY STORAGE SYSTEM WITH SOLAR FORECASTING

Contact Author: Dr. Jan Kleissl

University of California, San Diego, Department of Mechanical and Aerospace Engineering, 9500 Gilman Dr – EBU2, La Jolla, CA 92093-0411, Tel.: (858) 534-8087, Fax: (858) 534-7599, Email: jkleissl@ucsd.edu

Battery storage operation in a grid-connected, combined photovoltaic-battery storage system (PV+ system) was simulated to optimize utility demand charge costs in real time. Commercial and industrial building loads typically peak around midday or in the early afternoon (Fig. 1.). Daily peaks can often be reduced significantly with a PV system, but temporary cloud cover can reduce PV output causing substantial peaks in net demand. Energy storage is needed to reliably reduce metered load over a month (Fig. 2.).

Daily minimization of peak demand is sought to evaluate the peak reduction and robustness of the algorithm. The problem is formulated as a linear program (or linear optimization) considering solar power forecasts and building load forecasts. The battery dispatch algorithm then minimizes peak net loads subject to the dynamical and electrical constraints of the PV+ system. Solar power forecasts are generated using solar irradiance forecasts from a numerical weather model and load forecasts are based on historical data. Forecast errors cause the load demand target (i.e., the minimum threshold to which demand can be reduced) to be adjusted throughout the day to prevent complete battery discharge as unmitigated load spikes can occur immediately following battery failure. Because demand charges are assessed on the maximum monthly demand averaged over a 15 min interval, battery discharge is managed within 15 min intervals to maintain the demand target. The operational discharge algorithm responds to 1 min fluctuations in measured load and PV to mitigate or maintain net load within the interval.

Discharge was simulated for a summer month (July) and a winter month (November). During these two months, various degrees of cloud cover (and therefore PV energy penetration) and forecast error occurred. PV penetration and forecast error notwithstanding, the PV+ system consistently reduced demand for a metered load with a strong diurnal peak. Excluding weekends and holidays (i.e., days when the load is flat), the average reduction in peak demand was 21.1% in July and 20.8% in November. By itself, the PV array (excluding the battery array) reduced the peak demand on average 12% in July and 11.8% in November. The inclusion of a storage device thus reduced the peak demand another 9.1% and 9.0%. The mean maximum depth of discharge (DOD) was 37% and 46% of total capacity in July and November, respectively, where 80% DOD is the maximum usable capacity. The average number of charge cycles was 0.67 and 0.84 for July and November, where a charge cycle is defined as one complete discharge and charge event. The battery discharged completely on three days in July (13.6% of weekdays) and two days in November (10% of weekdays) due to large forecast error, which caused the demand target to be too aggressive. Economic indicators for demand charge reduction, battery life, and net present value will also be presented.

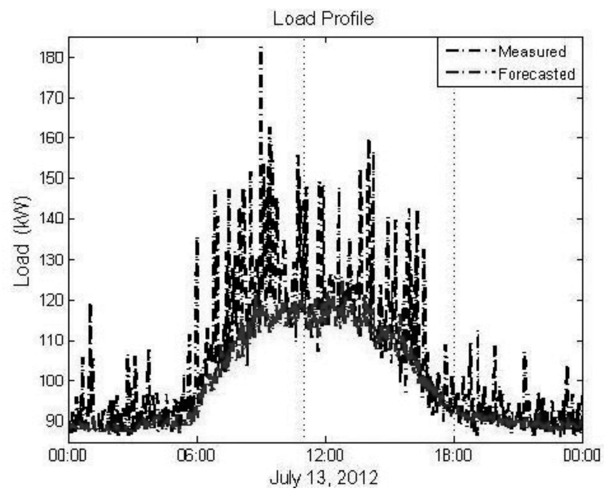


Figure 1: Forecasted load (blue) and measured load (black) with 1 min temporal resolution for a weekday. The metered load is part of the San Diego Supercomputer Center at the University of California, San Diego and is connected downstream of typical office electronics and some HVAC components. The forecasted load is based on averaged historical data and thus fluctuations in the forecast are damped. The load peaks diurnally around midday.

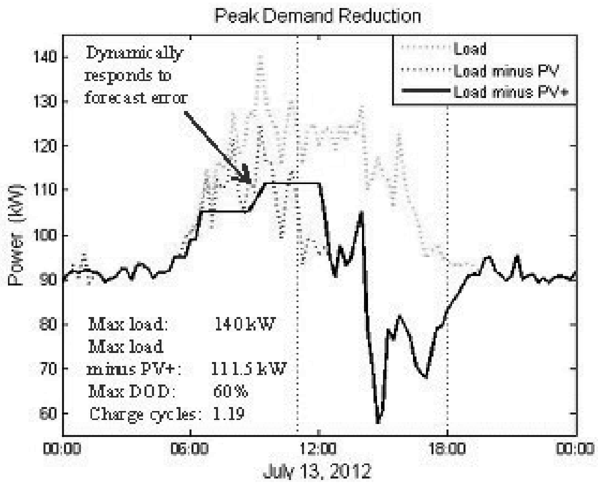


Figure 2: Sample time series of the 15 min model output illustrating the performance of the battery dispatch algorithm. The load (dotted cyan), the load after power from the PV array is considered (dotted red), and the load after power from both the PV array and battery array (PV+) is considered (solid black) are shown. The PV array reduces the net load on the grid, but smaller spikes remain; the battery is discharged to plateau the remaining load spikes. The demand target is increased around 09:00 in response to forecast error. The demand charge price point was reduced from the maximum unmitigated load peak (cyan) to the maximum attenuated load plateau (black).

Ryan Hanna will be presenting in Dr. Kleissl's stead.

BIOGRAPHICAL NOTE

Ryan Hanna is a graduate student in the Department of Mechanical and Aerospace Engineering at the University of California, San Diego (UCSD). In his recent work, he has studied and programmed dispatch schedules for combined photovoltaic-battery storage systems to mitigate metered load for demand charge management. He works under the guidance of Dr. Jan Kleissl, co-Director of the California Solar Energy Directive and the Associate Director of the Center for Energy Research at UCSD.

Ryan has undergraduate degrees in mechanical engineering, from Washington University in St. Louis, and in physics, from Pacific Lutheran University.

SECRET FOR A LASTING STORAGE AND GRID MARRIAGE? THE RIGHT CHEMISTRY!

Vinayak Walimbe, Judith Judson and Pramod Kulkarni

ABSTRACT

Recent opening of the ISO/RTOs regulation markets to non-generating resources has prompted many storage technology vendors to explore this lucrative opportunity, and many battery systems are among the aspiring technologies. Based on the modeling of storage technologies for its clients by a team at the Customized Energy Solutions, it is clear that all storage assets may not have what it takes to profitably participate in the market. The paper will discuss the unique requirement of each ISO/RTO market and how their characteristics could have varied impact on the participating storage technologies. It will explain how ISO/RTOs area generation control signal, its latency and frequency could have a different impact on each battery type. The presentation will explain how project economics for the same battery could vary from one ISO to another. The presentation will focus on how a battery's characteristics could determine its optimal operation and possibly turn an otherwise discouraging financial return into a profitable proposition. The presenter will share information on current ISO/RTO operating practices so that a technology developer/vendor can better assess whether his/her battery chemistry is suitable for the duty cycles dictated by dynamic and fast changing ancillary services markets.

The presentation will briefly address about different ancillary services purchased by ISO/RTOs to maintain grid's reliability and resiliency. Each service is priced differently depending on the characteristics of the need met and the performance of competing assets. The presentation will present a range of breakeven costs (price point) below which a vendor must price his battery system to compete in that market.

BIOGRAPHICAL NOTE

Pramod Kulkarni, Sr. Consultant: Emerging Technologies, works as a Senior Advisor at the Customized Energy Solutions- a Philadelphia, PA based international company. Customized Energy Solutions helps clients sell ancillary services, demand response and congestions rights in various ISO/RTO markets. Pramod and his co-authors work with energy storage project developers, technology developers and system integrators on assessing the economic and technical feasibility of energy storage for ancillary and other services for grid operation.

Prior to joining Customized, he worked at the California Energy Commission for 23 years and has been actively involved with renewable energy, energy storage, RD&D financing, technology assessment and commercialization programs. Pramod started and then managed the Energy Storage program at the California Energy Commission. The program has funded several landmark storage projects over years. Pramod has also been a US DOE Energy Storage Program reviewer since 1998.

Prior to joining the Commission Mr. Kulkarni worked in the field of energy technology development, project finance; and in the finance department of a Fortune 100 company. His educational background includes an MBA, a MS and a BS.

ADVANCED MULTILAYER CERAMIC CAPACITORS FOR HIGH ENERGY DENSITY AND HIGH TEMPERATURE APPLICATIONS

Seongtae Kwon, TRS Technologies, State College PA 16801
Co-authors: Wesley Hackenberger (TRS) and David Cann (Oregon State University)

ABSTRACT

Advanced ceramic materials have unique characteristics and have significant potential for dielectric and capacitor applications. Ceramic multilayer capacitors have advantages in thermal stability and high energy storage which can be exploited for a wide range of applications including energy storage devices for transportation and alternative energy systems, portable electronic devices, energy weapons systems for defense applications, and even in-vivo biomedical applications. These materials can also be developed for inverter capacitors for SiC-based high power electronics packages. In this paper, several ceramic compositions with high energy density and thermal stability will be introduced. The important performance characteristics of the material will be discussed including the dielectric and thermal properties as well as the breakdown strength and reliability of the multilayer component.

David Cann will present in Seongtae Kwon's stead.

BIOGRAPHICAL NOTE

David P. Cann received a B.S. degree in Materials Engineering from the Virginia Polytechnic and State University in Blacksburg, VA in 1991. He received M.S. and Ph.D. degrees in Materials from the Pennsylvania State University in 1993 and 1997, respectively. In 1997, he joined the Materials Science and Engineering faculty at Iowa State University, in Ames, IA. In 2005, he joined Oregon State University, where he is now Professor of Materials Science. His research is focused on the area of ferroelectric, dielectric, piezoelectric and semiconducting ceramic materials with funding from the National Science Foundation, the Office of Naval Research, NASA, the Department of Energy, and industrial sources.

Dr. Cann is a recipient of the CAREER award from the National Science Foundation (2001). Dr. Cann is the author or co-author of over 85 publications in peer-reviewed journals. He is also an Editor for the *Journal of Materials Science*, overseeing the electronic ceramics technical area. He is a Senior Member of IEEE and serves as the VP for Ferroelectrics within the IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society.

SURVEY AND ANALYSIS OF ENERGY STORAGE TOOLS

Colette Lamontagne, Navigant Consulting, Inc., Burlington, MA

ABSTRACT

Stakeholders in the energy storage industry include electric system operators (ISO/RTOs), generators and independent power providers (IPPs), integrated and transmission and distribution (T&D) utilities, state and federal regulators, electricity consumers, energy storage technology providers, research and development (R&D) and consulting organizations, project developers, and the finance community. Modeling and analysis tools can be used by each of these stakeholders to:

- demonstrate the potential value of energy storage systems prior to financing and construction,
- size energy storage systems for specific applications,
- dispatch the energy storage systems,
- operate the energy storage system to ensure reliability and stability of the grid, and
- track the revenue of operating systems.

Under contract to the Electricity Storage Association, Navigant Consulting, Inc. will conduct a survey and analysis of available tools to:

- Identify and confirm stakeholder modeling and analysis needs;
- Map the current landscape of existing utility-scale system planning models and other relevant tools; and
- Identify the gaps and opportunities.

This presentation and paper will summarize the results of the study.

BIOGRAPHICAL NOTE

Colette Lamontagne is a Director in the Emerging Technologies group of Navigant's Energy Practice. Her work involves energy technology R&D including energy storage and smart grid. She is currently serving as Vice Chair on the Electricity Storage Association Board of Directors. Ms. Lamontagne has over twenty years of consulting experience focusing primarily on emerging technology demonstrations, industrial energy efficiency, and environmental engineering. Ms. Lamontagne has conducted and provided oversight for numerous lab-, bench-, and pilot-scale technology R&D programs. She managed the DOE project to estimate the value of energy storage in the U.S. over 20 years. She also managed a study of energy storage business opportunities for a multinational utility, a feasibility study of energy storage for a Canadian utility, and a global market study and strategic plan for a leading battery manufacturer. She is a primary contributor to the U.S. Dept. of Energy Smart Grid Demonstration program which includes 16 energy storage demonstrations. She holds a B.S. in Biology/Environmental Studies and a M.S. in Environmental Engineering from Tufts University.

A COMPACT MODULAR DISTRIBUTED ENERGY STORAGE SYSTEM

Edward Liang, Ph.D.

MCV Energy, San Diego, CA

A compact 35kW/35kWh distributed energy storage system (DESS) employing UL1642 and UN38.3 certified battery cells with an active cell balancing battery management system (BMS) and ETL certified power converter system (PCS) has been presented. The PCS features full 4-quadrant power operation, anti-islanding, low voltage ride through and 400 Hz or custom order variable frequency.

INTRODUCTION

A compact distributed energy storage system is developed to reduce the intermittent and stochastic nature of renewables and stabilize the power flow between local generation and the utility grid. Flexible control provides auxiliary functions to support operation of distribution systems aggregated into a cluster effect for the utility grid. The main structure and its control logistic are presented. This presentation focuses on five elements: system structure, battery cell testing, applications in a distribution power system, a case study approach, and conclusions. Each of these topics is briefly described with one illustration of the compact modular system.

SYSTEM STRUCTURE

The system structure consists of a Battery Module, Bi-directional Power Converter Systems (PCS), and Top Level Controller (TLC), (see Fig.1). DESS is integrated with selective control strategies in TLC which monitors the facility power and then commands the PCS to either charge or discharge the battery as needed to achieve the target “Power Set point” for the facility.

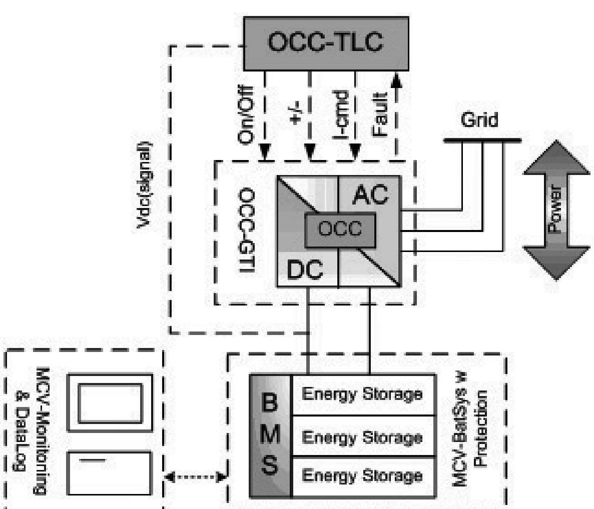


Figure1: MCV Distributed Energy Storage System

BATTERY CELL TESTING

Lithium iron phosphate batteries are extensively tested with evaluations for capacity check, open circuit voltage (OCV) hysteresis, slow discharge/charge, rate capacity, thermal analysis, slow charge/discharge and life cycle.

APPLICATIONS IN DISTRIBUTION POWER SYSTEM

The energy storage applications provide peak load management, frequency regulation, PV voltage transient support, PV intermittency smoothing, power quality improvement, etc. The module can adjust active/reactive power output or input and improve the power quality of distribution power system as presented.

CASE STUDY

For the case study, the application focus is achievement of peak load shaving and PV smoothing. During the presentation, the technical feasibility, economic issues and market position will be discussed. The final paper will demonstrate different control methods used in different applications.

CONCLUSION

A compact DESS demonstrates effectiveness in peak load shaving, PV voltage transient support and PV intermittency smoothing. This system can be used to improve power quality, adjust active/reactive power output or input. It is most suitable for use in pairing with distributed solar PV and serves versatile functions for the electric utilities and “behind-the-meter” customers technically and economically.

BIOGRAPHICAL NOTE

Edward Liang, Ph.D. (Ed) is founder and President of MCV Energy, Inc., an affiliate of MCV Technologies, Inc. in San Diego, California. Ed brings 30 years of experience in the RF/Microwave and materials sector to MCV Energy. Ed is responsible for leading a select team of scientists, engineers, technicians and analysts assembled to rapidly scale up and commercialize an advanced utility-scale electric storage system, in concert with utility and industrial partners.

Prior to founding MCV Technologies, Ed was Director of Engineering and Business Development of American Technical Ceramics, Heraeus, Inc. and TRW, Inc., in RF/Microwave components and microelectronics industries.

Since its founding in 2009, MCV Energy has shipped over 20MW of solar panels to Germany. In 2012, MCV installed an 80kW solar PV system at the Marine Exchange of Southern California in San Pedro. MCV is developing a 20kW solar project at TACC in San Diego in 2013 which it will own and operate.

Under Ed's leadership, MCV Energy has developed a modular distributed energy storage system scalable from 35kW/35kWh to multi-MW. The system is extremely compact. The 35kW system is only 2' x 3' x 5', and the 250kW system is 12' x 3' x 5.' Each system has full 4-quadrant operations with a round trip speed of 200 micro seconds.

Ed has several patent disclosures and patent applications. Prior to entering the energy sector, in 1995 Ed founded MCV-Microwave, a successful RF/Microwave filter manufacturer specializing in 4G LTE, GPS, satellite receiver and digital TV frequency bands.

Ed holds his Ph.D. in Ceramic Science from Penn State University.

ENERGY STORAGE SIZING AND PLACEMENT ON AN ISLANDED GRID WITH HIGH PENETRATION OF WIND

Michelle Lim and Frank Barnes

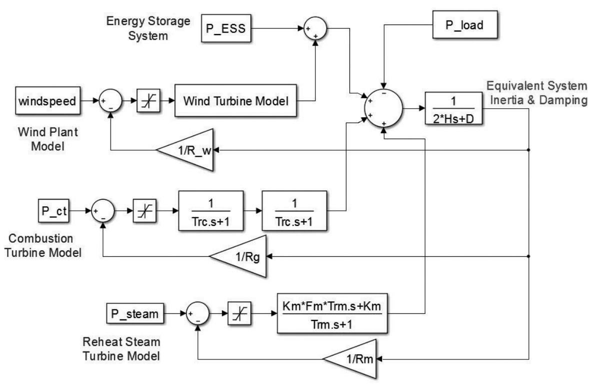
ECEE Department, University of Colorado-Boulder, Boulder CO

ABSTRACT

Utilizing energy storage systems (ESS) to reduce rapid power fluctuations from renewable sources of energy like wind has been discussed widely in recent years. However, energy storage systems are still a cost-prohibitive solution and so, this study aims to find a cost-effective selection of energy storage systems with optimal capacity (MWh), rated power (MW) and bus placement on an islanded grid system. This study will only take into account active power compensation by short-term ESS, i.e. systems with less than four hours of storage time.

A low-order system load-frequency model of an islanded grid as shown in Figure 1 is used to model the islanded grid.

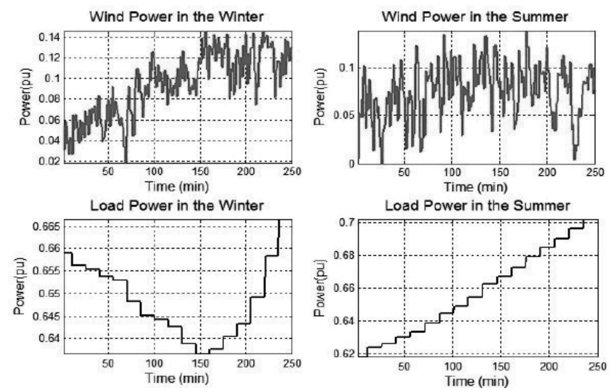
Figure 1:



By ignoring inter-machine oscillations within the island and assuming the majority of generation is from reheat steam turbines, the system's combined steam turbines can be averaged into a single reduced model [1]. So, the grid's overall frequency response is an indicator of wind power volatility. The ESS uses a simple proportional-integral-derivative (PID) controller to regulate the grid's frequency.

The wind data consists of a 250-minute time slice of the 2011 winter and summer seasons, with 1-minute intervals (Figure 2).

Figure 2: Winter and Summer Wind Data.



The average wind penetration is 15%. The 250-minute corresponding load data has approximately 1.65GWh of consumption. For this study, line congestion (defined as percentage of rated line MVA used) was the metric used to find the ESS bus placement. Preliminary results, using an 8-bus power flow model representation of the islanded grid, indicated that the ESS is best placed close to the wind source and away from load centers. Assuming a full four hour operation to regulate frequency, a flooded lead-acid battery at 70% the size of the wind farm (E_{wind} = 340 MWh & P_{rated} = 200 MW) is the most cost-effective system. A cost comparison ($million) of ESS and a non-ESS alternative (a gas-fired plant) with varying storage time at rated power output, is shown in table below [2].

Type of System	C_p ($/kW)	C_e ($/kWh)	$Cost_{10min}$	$Cost_{1hr}$	$Cost_{full}$
Nickel Cadmium	125	750	56	188	301
Zinc Bromine	400	150	118	144	167
Flooded Lead-Acid	300	125	83	105	124
Sodium Sulfur	350	350	102	163	216
VRLA Lead-Acid	400	350	108	170	223
Lithium Ion	400	600	108	214	304
Flywheel	500	1600	143	425	665
Supercapacitors	500	10,000	339	2105	3605
Gas-Fired Plant	650	-		130	130

REFERENCES

[1] P. M. Anderson and M. Mirheydar, "A low-order system frequency response model," *IEEE Trans. on Power Systems*, vol. 5, no. 3, 1990.

[2] S.M. Schoenung, "Energy storage systems cost update: A study for the DOE energy storage system program," Tech. Rep. SAND2011-2730

BIOGRAPHICAL NOTES

Michelle Lim received the B.Sc. degree in aerospace engineering ('06) and M.Sc. in electrical engineering ('09) from Wichita State University, KS. She worked on the economic feasibility of integrating wind energy in the state of Kansas with a Department of Energy grant in 2009. She has also worked in the aviation industry in the past and most recently at the Mid-Continent Independent System Operator (MISO) as a summer intern. She is currently working towards her PhD degree at the University of Colorado-Boulder in the electrical engineering department. Her main research interest is in the economic and efficient utilization of energy storage systems on the electric grid.

Barnes received his B.S. from Princeton University in electrical engineering in 1954 and his M.S. Engineer and PhD from Stanford University in 1955, 1956, and 1958. He joined the University of Colorado-Boulder in 1959. He was appointed a Distinguished Professor in 1997. He was elected to the National Academy of Engineering in 2001 and received the Gordon Prize 2004 for innovations in Engineering Education from the National Academy. He is a fellow of IEEE, AAAS, and ICA and served as Vice President of IEEE for publication and as Chairman of the Electron Device Society. In the last six years, he has been working on energy storage and the integration of wind and solar energy into the grid and the effects of electric and magnetic fields on biological systems.

ULTRACAPACITOR SOLAR SMOOTHING FOR GRID STABILITY

R. Shaw Lynds[1], William Torre[2], Byron Washom[3]

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[2]William Torre, Director of Energy Storage and Systems at UCSD, Email: wtorre@ucsd.edu
[3]Byron Washom, Director of Strategic Energy Initiatives at UCSD, Email: bwashom@ucsd.edu

ABSTRACT

The impact of energy variability associated with the use of renewable power sources such as solar and wind is significantly increasing in places such as California, where renewables currently represent about 20% of the total portfolio and are expected to continue to rise to 33% by 2020 in support of California's Renewables Portfolio Standard. The short term variability and intermittency of renewables is a concern to the grid for two major reasons. The first is that when a variable power source is not producing, some other power source must be brought online to take its place. This leads to a larger total operating generation capacity than would be needed with less variable power sources like large hydro or fossil fuels. The second concern is grid stability while transitioning generation from one power source to another. If the loss of output from the variable source is slow enough, or known about ahead of time, then grid dispatchers can dispatch other generation and manage the transition smoothly without concern of frequency excursions or brownouts to their customers. However, if the loss of output is rapid, typically considered anything less than five to ten minutes, then the power output must be compensated for by the automatic generation control of the other power sources on the grid, requiring large amounts of costly spinning reserve generation. Solar and wind power are the most variable forms of renewable power, and do not have automatic generation control of their output power. Therefore, not only do they add variability to the grid, but they also make the grid less stable to the effects of variability.

This paper describes a project supported by the California Energy Commission to demonstrate the technical and economic benefits of combining solar power with Ultracapacitor energy storage and solar forecasting to reduce variability and increase grid stability. The first subscale demonstration will take advantage of a 28kW Concentrated Photovoltaic (CPV) array built by Soitec and located at the University of California San Diego Center for Energy Research. An Ultracapacitor system developed by Maxwell Technologies will provide five minutes of energy storage at 28 kW and will be integrated with UCSD's solar forecasting technology. The system will provide power smoothing to increase grid stability and bridge power firming of short duration cloud cover to reduce total variability.

BIOGRAPHICAL NOTE

R. Shaw Lynds has over seven years of experience design and modeling of engineering systems. In his current role as Sr. R&D Systems Engineer at Maxwell Technologies, Inc. Shaw leads the design and development of numerous next- generation ultracapacitor energy storage modules and systems. He holds a B.S. in Mechanical Engineering from the University of California at Santa Barbara, and an M.S. in Mechatronics from California Polytechnic in San Luis Obispo.

ROBUST DEVICES AND COMPACT POWER ELECTRONICS FOR NEXT GENERATION ENERGY-STORAGE AND POWER SYSTEMS

Sudip K. Mazumder[1]

[1]Professor, University of Illinois, Chicago, Illinois, USA
President, NextWatt LLC, Hoffman Estates, USA

In this brief overview, we have provided an outline on new power-electronics and device technologies that can have profound impact on the next-generation energy storage and power systems. The first technology refers to a novel patented optically-controlled power semiconductor wide-bandgap device technology for very-high-voltage power applications. The second technology refers to patented capacitor-less high-frequency-link inverter technology and its control.

Keywords: optical power semiconductor, high voltage, capacitor-less inverter, high frequency link, power electronics

INTRODUCTION

With the rapid advancements of power-electronics devices and control technologies, the emerging scenarios for energy storage and power systems with regard to dynamic power-flow controllability and power quality may evolve to be radically different. For instance, currently distribution-level solid-state controllability of power is dependent on Si-based multi-switch and multi-level power conversion technologies to work around the limitations of the reduced breakdown voltage capability of even the state-of-the Si power semiconductor devices. While the costs of Si devices are relatively low and the Si technology is relatively mature, the system-level adverse impact of such Si-based often cumbersome power conversion systems cannot be always ignored. Further, switching frequency limitations of the high-voltage and high-current devices such as Si IGCT may also have an impact on the control response of the power conversion system which attains importance in the presence of harmonic loads and need for disturbance-rejection capability.

To address these limitations, currently, significant and groundbreaking work is being done in the area of silicon carbide (SiC) controllable devices for high-voltage (HV) as well as very high-voltage (VHV) devices including SiC DMOSFET, SiC IGBT, and SiC switched thyristor. The focus of these next-generation SiC VHV/HV device technologies is on electrical triggering-based device technologies. In contrast, the author's focus has been on addressing the HV/VHV device challenge using an all-optical approach. Optically-switched and optically-controlled device technology yield some major advantages including immunity from electromagnetic interference, preclusion of back-propagation wave from power stage, relatively easy solution to ground bouncing, relatively easy extension to series and parallel connection of the HV/VHV devices for distribution-level and potentially transmission/sub-transmission voltages, and fast actuation due to direct photogeneration to name only a few. In this presentation, the author will provide a background and overview of some of his recent work and outline its remarkable suitability and advantages for energy storage and power systems.

Another focus of the presentation will be capacitor-less high-frequency-link power-conversion systems. The author has developed novel switching methodologies that yield power-conversion systems operating without dc-link electrolytic capacitors and yet providing low total harmonic distortion. Additionally, these smart switching techniques yield a significant reduction in switching losses of the power conversion system due to novel modulation methodology. The high-frequency-link power-conversion systems, which can be used for energy-storage inverter systems or for other applications in power systems encompassing inverter or even cycloconversion (ac-to-ac) applications significantly reduce the size, weight, and cost of the magnetics as well.

Finally, in the context of the above device and power conversion technologies, radically different control technologies that aim to control a system at device level will be outlined. Such a technology encompasses control of the time evolution of the switching states of the power semiconductor devices of the power conversion systems as well as control of the switching transition of the devices. This has the potential to enable a fundamentally different multi-scale and multi-objective control of the power-conversion systems yielding plurality of system benefits.

BIOGRAPHICAL NOTE

Dr. Sudip K. Mazumder received his Ph.D. degree from the Department of Electrical and Computer Engineering of Virginia Tech in 2001. He received his M.S. degree from the Department of Electrical Power Engineering of the Rensselaer Polytechnic Institute (RPI) in 1993.

Dr. Mazumder is the President of NextWatt LLC, a small business organization that he set up in 2008. He is also the Director of Laboratory for Energy and Switching-Electronics Systems and a Professor in the Department of Electrical and Computer Engineering at University of Illinois, Chicago (UIC). He has over 20 years of professional experience and has held R&D and design positions in leading industrial organizations and has served as Technical Consultant for several industries.

His current areas of interests are a) Interactive power-electronics/power networks, smart grid, and energy storage; b) Renewable and alternative energy based power electronics systems for distributed generation and microgrid; SiC and GaN based high-frequency, high-temperature, and high-voltage power electronics; and c) Optically-triggered wide-bandgap power-electronics device and control technologies.

He has been awarded about 40 sponsored projects by NSF, DOE, ONR, ARPA-E, CEC, EPA, AFRL, NASA, NAVSEA, and multiple leading industries in above-referenced areas. He has published over 160 refereed papers in prestigious journals and conferences and has published 1 book and 6 book chapters. 50% of his journal papers are published in IEEE transactions with a current impact factor close to 5. Dr. Mazumder has presented 46 invited/plenary/keynote presentations and currently, he also holds 7 issued and 2 pending patents.

Dr. Mazumder received in 2013 the prestigious University Scholar Award from the University of Illinois. In 2008 and 2006, he received the prestigious Faculty Research Award from UIC for outstanding research performance and excellent scholarly activities. He also received the ONR Young Investigator Award and NSF CAREER Awards in 2005 and 2003, respectively, and prestigious IEEE Prize Paper Awards in 2002, 2007, and 2013 respectively. In 2005, he and his team received an IEEE sponsored International Future Energy Challenge Award.

Dr. Mazumder served as the first Editor-in-Chief for International Journal of Power Management Electronics (currently known as Advances in Power Electronics) between 2006 and 2009. Currently, he is also serving as the Guest Editor-in-Chief for IEEE Transactions on Power Electronics Special Issue on High-Frequency-Link Power-Conversion Systems (2013-2014) and the Guest Editor-in-Chief for IEEE Transactions on Industrial Electronics Special Issue on Control Strategies for Spatially Distributed Interactive Power Networks (2013-2014). Currently, Dr. Mazumder also serves as an Editorial Board Member for the following transactions: IEEE Transactions on Power Electronics (since 2009), IEEE Transactions on Industrial Electronics (since 2003), and IEEE Transactions on Aerospace and Electronics Systems (since 2008). He is currently serving as the Vice Chair of IEEE Power Electronics Society Subcommittee on Distributed Generation and Renewable Energy.

BASELOAD POWER FROM WIND FARMS USING MAGNESIUM HYDRIDE SLURRY FOR HYDROGEN STORAGE

Andrew W. McClaine, Kenneth Brown, and David D. G. Bowen

Safe Hydrogen, LLC, Lexington, Massachusetts, USA

ABSTRACT

Renewable energy farms, such as wind and solar farms, have the potential to supply all the energy that is needed by the United States. The issue is to use the energy when it is available or to store it until it is needed.

We are all quite familiar with stored energy. Our economy relies on the energy stored in fossil fuels. The use of stored energy allows us to use energy when we need it to produce light, heat, and motion.

Hydrogen provides an alternative to fossil fuels for energy storage. Electricity, from wind or solar farms, can be stored by electrolyzing water to produce hydrogen and oxygen. This hydrogen can be stored until it is needed and then burned with air in a gas turbine to turn a generator and produce electricity again. The byproducts of these reactions, besides electricity, are water and some nitrogen oxides. Alternatively, the hydrogen can be used in a fuel cell to produce electricity directly with byproducts of only water.

Safe Hydrogen, LLC has been developing a hydrogen storage medium using magnesium hydride in a slurry with light mineral oil. This slurry promises to be an inexpensive large-scale storage medium for hydrogen. Once stored in the metal hydride, the slurry can be stored very safely at ambient temperature and pressure. It can be pumped between tanks like a liquid fuel and transported and stored inexpensively using the existing liquid fuels infrastructure. When charging or discharging, the slurry is pumped into a reactor where conditions are provided to enable rapid hydrogen absorption or desorption. The slurry can be cycled repeatedly. Safe Hydrogen has demonstrated 50 cycles with the slurry to show that the slurry can be cycled enough times to be economical. At the conclusion of the cycling test, the performance of the metal hydride was the same as at the beginning of the test. Others have demonstrated cycling of dry magnesium hydride up to 1,000 times.

In this paper, we present the results of a study evaluating the cost of electricity using magnesium hydride slurry for hydrogen storage to make a wind farm, producing intermittent energy, into a dispatchable or baseload electrical energy system. For the study, we use 10 min. wind data, from the National Renewable Energy Laboratory, and hourly load data, recorded by ISO New England, to model the performance of dispatchable and baseload wind systems. The computer model calculation uses an entire year of data to determine the amount of wind power sold directly, the amount of energy stored and recovered, and the amount of electrical power sold to make up for when the wind is not blowing sufficiently. Costs for all the major components of the systems are used to estimate the capital cost of the systems. Maintenance and operating costs estimates are included. Costs for the hydrogen storage system are scaled from the costs incurred for our experimental systems. The hydrogen storage system includes electrolysis machines, magnesium hydride slurry, reactors for hydriding and dehydriding the slurry, compressors, and gas turbine generators. From this analysis, we conclude that a renewable energy farm system using a wind farm, electrolysis machines, hydrogen storage, and hydrogen fueled gas turbine generators can operate as a baseload power plant for an electricity cost of $88/MWh providing a return of 10% to its investors. When the system is operated to provide dispatchable electricity, a 10% internal rate of return (IRR) can be achieved with $110/MWh.

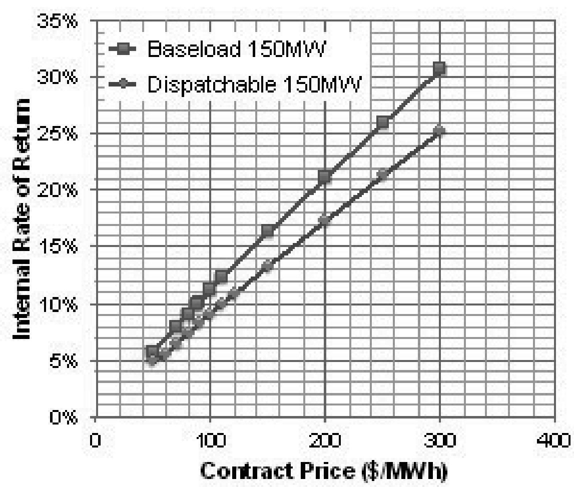

Figure 1: Contract Price versus Internal Rate of Return

Figure 1 displays the results of the study for a range of contract prices. The higher prices might be found on an island system. The lower prices are typical of large metropolitan areas.

The analysis assumes an investment tax credit of 30% and the sale of electrical energy, above that contracted, up to the full capacity of the grid connection (250MW) when the price of electrical energy is higher than the contract price with the utility. The contract power production is assumed to be 150 MW. The wind farm is scaled to provide the energy required to supply the needs of the baseload or dispatchable systems.

The storage system is sized to meet the demand of the system throughout the year. This requires about 21 days of storage for the dispatchable case and 30 days of storage for the baseload case. The data used for this analysis showed more wind energy in the winter than in the summer. This required storage to carry some of the winter wind energy to the summer demand. If the renewable energy system were made up of wind farms and solar farms (which supply more energy in the summer than in the winter), then the storage system could be smaller and the costs would be reduced.

BIOGRAPHICAL NOTE

Andrew W. McClaine, PE, is a founder and Chief Technology Officer of Safe Hydrogen, LLC. He is a Research Mechanical Engineer with 41 years of experience in the research and development of energy production and storage systems. Andy has been developing metal hydride slurries for hydrogen storage for the past 15 years, first for Thermo Power Corporation, a Thermo Electron Company and then for Safe Hydrogen, LLC. Safe Hydrogen was formed to carry on the development of metal hydride slurry after Thermo Electron's decision to divest from energy products. From 2004 to 2008, Andy was the program manager on a DOE sponsored project to evaluate metal hydride slurry for hydrogen storage in automobiles. This project laid the foundations for the current slurry products that are used in a cyclical manner to store and return hydrogen.

Prior to his work at Thermo Power Corporation, Andy held several positions at the Avco Everett Research Laboratory developing magneto-hydrodynamic power generators and an advanced glass melter.

Andy earned a Master of Science in Mechanical Engineering degree from Stanford University and is a Registered Professional Engineer. He has authored over 50 technical papers and holds 7 patents.

ENERGY STORAGE CAN ENABLE WIDER DEPLOYMENT OF DISTRIBUTED GENERATION

Troy Miller

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This presentation will focus on how the adoption of distributed energy storage can enable the wider deployment of Distributed Generation such as roof-top photovoltaic and small wind generation.

As utilities strive to meet the 20% by 2020, (renewable energy mandates many central governments have enacted), there will be a wider deployment of both Grid-Scale and Distributed Renewable Energy Sources. In addition, governments have also offered attractive subsidies to spur these types of deployments. Renewable sources, while carbon neutral, are by their nature intermittent. This intermittency can cause problems on the distribution networks if the renewables comprise a significant portion of the overall generation. The problem is amplified on “weak networks” – those with low X/R ratios because of low fault levels.

Solar generator output varies, producing local voltage swings and contributing to feeder level voltage swings that happen on the order of seconds - too fast for traditional distribution voltage regulation equipment to react. Loads on distribution secondaries are already highly variable due to large loads switching on and off. Impact of variable distribution loads is minimal at the feeder level because they are generally random. Solar generators are largely coincidental, however, as iridescence varies. This varying output causes perceptible swings in voltage at the feeder level. The excursions can temporarily exceed allowable limits or have other noticeable customer impacts such as imbalance because DG is typically single-phase connected.

The fundamental objectives of co-locating Distributed Energy Storage with Distributed Generation are:

- Improvement of load factor
- Improvement of voltage profile
- Stabilization of voltage
- Minimization of losses
- Mitigation of reverse current flow.

One of the newest, most innovative storage systems is Community Energy Storage (CES), lithium-ion battery-based storage, which enables utilities to provide reliable local backup power and multi-faceted grid support at the outermost edges of distribution system networks. CES systems are small pad-mounted units, which can be strategically distributed along residential feeders. They are ideally suited to serve neighbourhoods and small commercial buildings. One 25-kVA CES unit supplies one to three hours of battery storage for multiple residential or light commercial loads.

CES units can be easily co-located with renewable energy resources, including grid-tied rooftop PV panels and small wind turbines. With the growing adoption of small-scale renewable resources and plug-in electric vehicles (EVs), utilities require a more effective way to control voltage on local feeders to sustain service quality. CES offers a unique solution. Utilities can aggregate up to 1,000 grid-tied CES units using a distributed energy management (DEM).

BIOGRAPHICAL NOTE

Troy Miller is a Business Development and Marketing Manager in the Power Quality Products Division of the S&C Electric Company. He has over 23 years of experience in the Power Engineering industry. Mr. Miller has a vast history in the application and implementation of all aspects of power electronics and power quality. Mr. Miller is a speaker at industry events around the world covering market trends and economic benefit analysis. He has published numerous papers and articles in technical journals and media outlets. He is currently responsible for all Power Quality activities at S&C Electric. These activities include Energy Storage, VAR Compensation and Uninterruptible Power Systems (UPS).

STATUS AND OPPORTUNITIES FOR BREAKTHROUGH REDOX FLOW BATTERY SYSTEMS

Ronald J. Mosso

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Most deployed advanced energy storage systems have high power-to-energy ratios (i.e. short duration) to service applications such as area regulation, renewable energy grid integration, and power quality. The rising cost of fossil fuels in most regions, increased penetration of renewables on the grid, and transition to time-of-use and/or real-time pricing create a need for shifting markets for energy storage systems with high energy-to-power ratio (i.e. long duration) that some analysts predict will be an order of magnitude higher than that for short duration systems. Meeting the requirements for longer duration systems becomes costly and more difficult to engineer with conventional batteries but are ideally suited for Redox Flow Batteries.

The intrinsic advantages of Redox Flow Batteries include megawatt-hour energy capacity easily configured to application requirements as energy is decoupled from power, thousands of cycles service life regardless of depth-of-discharge history, a high degree of safety by virtue of electrically connecting only a small fraction of total stored energy at any point in time, dilute aqueous electrolytes that eliminate thermal runaway, and the potential for low cost.

EnerVault's Redox Flow Battery systems are based on the patented Engineered Cascade™ design that enables the use of abundant iron-chromium reactants, low-cost micro-porous separators, greater electrolyte utilization, and steady-state operation to deliver highly economic and reliable, customizable storage solutions. The environmentally benign and non-volatile iron and chromium chemistry make EnerVault's Redox Flow Battery one of the safest and most environmentally friendly energy storage systems for megawatt-hour scale storage.

This presentation will present the status of an ARRA-funded U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability, and California Energy Commission project demonstrating EnerVault's novel Engineered Cascade™ architecture and low cost iron-chromium chemistry. The demonstration is comprised of a field-deployed system dispatchable at 250 kW_{AC} for 4 hours to deliver the full energy rating of 1 megawatt-hour that is sited with a tracking solar photovoltaic system. The implications for future opportunities will also be discussed.

BIOGRAPHICAL NOTE

Mr. Ronald Mosso leads the development and scale-up of EnerVault's novel flow battery technology, applying his 30 years of product engineering, operations, and business development experience in materials-technology-driven companies. During 15 years at Raychem Corporation, he led several product development programs from R&D through full-scale commercialization. As Raychem's Division Technical Director for the above-ground power electrical products business, he managed operations and world-wide product development for over-voltage and insulation products. After Raychem, Mr. Mosso held executive management positions at NeoPhotonics and NanoGram Corporations where his responsibilities included operations, business development, and product engineering. As COO of NanoGram in 2004, he and a colleague launched NanoGram's thick-film silicon solar cell development program, leading internal R&D and developing customer and supplier partners for scale-up. Mr. Mosso has a degree in Chemical Engineering from Carnegie-Mellon University and is a Professional Engineer in California.

PHOTO-THERMALLY REDUCED GRAPHENE: HIGH PERFORMANCE LI-ION BATTERIES

Rahul Mukherjee*, Eklavya Singh, Dr. Nikhil Koratkar

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In analyzing the performance of any energy storage device, the two key metrics include 'energy density' and 'power density'. Li-ion batteries provide energy densities of ~150 Wh/Kg which is about two orders of magnitude higher than capacitors but as much as eight times lower than hydrogen fuel cells. On the other hand, they offer power densities of ~100 W/Kg which is an order of magnitude lower than capacitors and three orders of magnitude lower than combustion engines. While the low energy densities that can be availed from Li-ion batteries have limited its use in fields such as grid storage, its low power densities have impeded its large scale incorporation in next generation electric vehicles. However, the key to successful implementation of Li-ion batteries in a wide variety of fields including portable electronics, EVs/HEVs and grid storage lies in the development of a cost efficient, versatile battery that is capable of delivering both high energy density as well as high power density.

In this study, we focus on improving the performance characteristics of the anode material. We replace commercial graphitic anodes with a free-standing graphene paper, fabricated by photo-thermal reduction of graphene oxide. Photo-thermal reduction was carried out by (a) laser scanning the graphene oxide paper and (b) exposing the graphene oxide paper to the flash of a digital camera or a stand-alone flash unit. A unique 'open-pore' and expanded structural morphology was obtained due to a rapid deoxygenation reaction. Photo-thermally reduced graphene was capable of providing energy densities in excess of 500 Wh/kg and power densities as much as 30 kW/kg, far surpassing the performance characteristics of commercial graphitic anodes. At a charge/discharge rate of 1C (a rate of *n*C implies charge or discharge in 1/*n* hours), the capacity was as high as 900 mAh/g. Further, the anodes demonstrated excellent rate capability. In this regard, the phenomenon aiding rapid and extensive lithiation/delithiation has primarily been attributed to the structural morphology. The presence of wide cracks and pores ensure that the liquid electrolyte can penetrate through the bulk of the electrode, providing the Li-ions with an additional electrolytic pathway to reach the underlying sheets of graphene. This not only provided high rate capability but further ensured significant intercalation over a wide range of charge/discharge rates. For instance, at a rate of 5C, the capacity obtained was as high as ~370 mAh/g.

In addition to impressive capacities, superior electrochemical stability and mechanical integrity of photo-thermally reduced graphene was also obtained, as the cells exhibited excellent cycling ability with less than 5% drop in capacities even after 10,000 cycles.

Finally, photo-thermally reduced graphene is highly scalable and can be scaled up to achieve commercial standards for electrode mass loading (~5 mg/cm^2). Scalability of the anode material has been achieved through a novel electro-deposition approach to synthesize large area (> 50 cm^2) free-standing graphene oxide papers that are several hundred microns thick in as little as 6-8 hours. In comparison, the conventional vacuum filtration technique for production of graphene papers is lengthy (taking up to 4 days) and non-scalable (achievable thickness is generally limited to 5-10 microns while the total area is typically < 15 cm^2). A combination of the rapid and scalable synthesis technique along with photo-thermal reduction will therefore facilitate these next-generation anodes comprised of nano-scale building blocks to be integrated in larger industrial sized cylindrical or prismatic cells in order to pave the way towards next generation, high performance Li-ion batteries.

BIOGRAPHICAL NOTE

Rahul Mukherjee received his Bachelor of Technology in Mechanical Engineering from the National Institute of Technology, India in 2010. He joined Rensselaer Polytechnic Institute in the same year and is currently pursuing his Ph.D. in the Department of Mechanical, Aerospace and Nuclear Engineering under Professor Nikhil Koratkar. In his 3 years, he has authored and co-authored 7 papers and 1 book chapter in energy storage, electrochemistry and nanomaterial depositions and has a patent application in the field of synthesis and application of graphene-based electrodes in lithium ion batteries. His research focuses on lithium ion batteries and his interests lie in the fields of alternate energy systems, including batteries, capacitors and fuel cells as well as physical vapor deposition systems including e-beam evaporation and sputter deposition.

THE BENEFITS OF ENERGY STORAGE COMBINED WITH HIGH VOLTAGE DC LINK POWER MODULATION FOR MITIGATING POWER SYSTEM INTER-AREA OSCILLATIONS

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Damping of inter-area oscillations in the western North American power system (wNAPS) has been the subject of research and development for over three decades. Several approaches have been considered, including tuning of power system stabilizers using a local frequency measurement, modulation of static VAR compensators for damping control, thyristor braking and series impedance modulation.

Most recently, there has been increased attention on the use of Pacific DC Intertie (PDCI) modulation and/or energy storage-based damping controllers that modulate power at two locations. The PDCI modulates power flow between the Celilo plant in northern Oregon and Sylmar in Southern California. There is strong evidence that this system will be effective at damping inter-area oscillations if a component of power modulation is a function of the difference in measured frequencies at the two locations. Unfortunately, this transmission system is static, and aside from electrical losses, the power sourced/synced at Celilo is roughly equal to that synced/sourced at Sylmar. In contrast, the location of energy storage-based damping controllers is flexible; however, thus far, investigations have focused on pairs of nodes with equal and opposite power modulation.

In this research, we generalize an energy storage-based damping control system with N nodes, wherein N>2 nodes may be desired to improve mode observability, controllability, and redundancy for a robust system implementation. In addition, we revisit the premise that power modulation between damping control nodes needs to be symmetric. In particular, straight forward linear quadratic regulator control designs have been formulated to optimize damping against normalized control effort, and the results of this study reveal that symmetrical power modulations, and thus symmetrical gains, are in fact not indicated unless the corresponding inertias of the areas are identical. Thus, even for a PDCI-based damping control approach, energy storage nodes may be added to break the symmetry in the flow of power and accomplish better damping.

BIOGRAPHICAL NOTE

Jason Neely began at Sandia National Laboratories in 2001 in the Intelligent Systems and Robotics Center. Currently, he is a senior member of technical staff in the Energy Sciences and Experiments organization. Jason has Bachelors, Masters and PhD in Electrical Engineering with a focus on Power Systems and Automatic Controls. His interests include system optimization, distributed and networked power systems and grid-connected power electronic systems. Jason has 20 technical publications.

ANALYZING THE EFFECTS OF CLIMATE AND THERMAL CONFIGURATION ON COMMUNITY ENERGY STORAGE SYSTEMS

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ABSTRACT

Community Energy Storage (CES) has been proposed to mitigate the high variation in output from renewable sources and reduce peak load on the electrical grid. Thousands of these systems may be distributed around the grid to provide benefits to both local distribution circuits and to the grid as a whole when aggregated. Because of their wide geographical distribution, CES must therefore be low-cost to purchase and install, and also be largely maintenance free through more than10 years of service life to be acceptable to most utilities.

Achieving the required system life time is a major uncertainty for lithium-ion (Li-ion) batteries installed in this application. Both the life time and the immediate system performance of batteries can change drastically with battery temperature, which is a strong function of system packaging, local climate, electrical duty cycle, and other factors. In other Li-ion applications, this problem is solved via air or liquid heating and cooling systems which may need occasional maintenance throughout its service life. CES, however, requires a maintenance free thermal management system that can provide protection from environmental conditions while rejecting heat from a moderate electrical duty cycle. Thus, the development of an effective, low-cost, zero-maintenance thermal management system poses a challenge that is critical to the success of CES.

The National Renewable Energy Laboratory (NREL) and Southern California Edison (SCE) have collaborated to evaluate the long-term effectiveness of various CES thermal configurations in multiple climates. This has been approached by building a detailed electrical and thermal model of CES based on collected test data, integrating it with an NREL-developed Li-ion degradation model, and applying CES electrical duty cycles and historic location-specific meteorological data to forecast battery thermal response and degradation through a 10 year service life. Herein the authors shall present the methodology behind this approach in detail, as well as share preliminary results that quantify the sensitivity of Li-ion performance to climate and CES thermal configuration.

BIOGRAPHICAL NOTE

Dr. Jeremy Neubauer is a Senior Engineer with NREL's Center for Transportation Technologies and Systems, where his primary responsibility lies in researching the reuse of retired automotive traction batteries and modeling the total cost of ownership of advanced vehicle types. Prior to coming to NREL, Dr. Neubauer was Chief Engineer at ABSL Space Products, a leading manufacturer of Li-Ion batteries for the space industry. Dr. Neubauer has a Bachelors, Masters, and Doctorate in Mechanical Engineering from Washington University in St. Louis.

OPTIMAL SIZING OF ENERGY STORAGE AND PHOTOVOLTAIC POWER SYSTEMS FOR DEMAND CHARGE MITIGATION

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ABSTRACT

Commercial facility utility bills are often a strong function of demand charges – a fee proportional to peak power demand rather than total energy consumed. In some instances, demand charges can constitute more than 50% of a commercial customer's monthly electricity cost. While installation of behind-the-meter solar power generation decreases energy costs, its variability makes it likely to leave the peak load – and thereby demand charges – unaffected. This then makes demand charges an even larger fraction of remaining electricity costs.

Adding controllable behind-the-meter energy storage, however, can more predictably affect building peak demand, in turn reducing electricity costs. Due to the high cost of energy storage technology, though, the size and operation of an energy storage system providing demand charge management (DCM) service must be optimized to yield a positive return on investment (ROI). The peak demand reduction achievable with an energy storage system depends heavily on the shape of a facility's load profile, so the optimal configuration will be specific to both the customer and the amount of installed solar power capacity.

In this paper we explore the sensitivity of DCM value to the power and energy levels of installed solar power and energy storage systems for multiple customer types and load profiles. An optimal peak load reduction control algorithm for energy storage systems is introduced and applied to historic solar power and meter load data for a broad range of energy storage system configurations. For each scenario, the peak load reduction and electricity cost savings is computed. From this we identify favorable energy storage system configurations that maximize ROI.

BIOGRAPHICAL NOTE

Dr. Jeremy Neubauer is a Senior Engineer with NREL's Center for Transportation Technologies and Systems, where his primary responsibility lies in researching the reuse of retired automotive traction batteries and modeling the total cost of ownership of advanced vehicle types. Prior to coming to NREL, Dr. Neubauer was Chief Engineer at ABSL Space Products, a leading manufacturer of Li-Ion batteries for the space industry. Dr. Neubauer has a Bachelors, Masters, and Doctorate in Mechanical Engineering from Washington University in St. Louis.

PRICING ENERGY STORAGE FOR A BALANCED MARKET PENETRATION

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ABSTRACT

With all the efforts put into reducing the storage cost and increasing its value in bundled applications, it is only a matter of time before the phrase "storage is too expensive" will be replaced with the question "what is the right price for energy storage?" The purpose of this paper is to apply approaches for estimating market penetration with the sales of energy storage for grid applications in order to find a price that would balance profit against market penetration to benefit both vendors and end users of energy storage. It may appear to be premature to talk about an optimum sales price that is lower than the current market price at a time when most storage vendors are struggling to survive. However, looking over the horizon would benefit all stake holders in the energy storage community and help prepare a better roadmap into this evolving market.

Keywords: Energy Storage Pricing, Market Penetration, S-Curve, Payback, Optimum Price, Maximum Sales Potential, Cost, Value, Grid Applications

MARKET PENETRATION FOR ENERGY STORAGE

Market Penetration forecasting can be used to estimate market growth when there is little history or data on the market performance of a new product [1]. While the use of energy storage for grid applications is an established concept, storage technologies and application concepts have evolved significantly over the last decade. Therefore, there is little historical information available today about the market successes of new storage options.

NREL's report on the market penetration of new energy technologies offers a very comprehensive overview of different market penetration models focused on energy technologies [2]. Figure 1, borrowed from this report, identifies different market penetration potentials from projection to theoretical potentials. Market projection (the smallest section) is the focus of the market penetration analysis used in this paper.

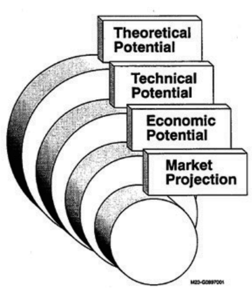

Figure 1: Different market penetration potentials for new technologies (picture from NREL report [2])

The NREL report explains different forecasting methods and diffusion models for market penetration ranging from the Bass model (1969) that is the most general approach to Kalish and Lilien model (1986) that treats adoption or market penetration as a function of price.

The market penetration model presented in this paper can be shown as a non-linear S-Curve that is also referred to as the sigmoid cumulative adoption function. It shows market penetration as a function of the technology payback. As shown in Figure 2, the longer the payback of a storage project, the smaller the market penetration or amount (MWh) of storage sold. Some models use S-curves which are symmetric about its inflection point, and others use non-symmetric S-Curves. Here, we illustrate our approach using a symmetric S-Curve.

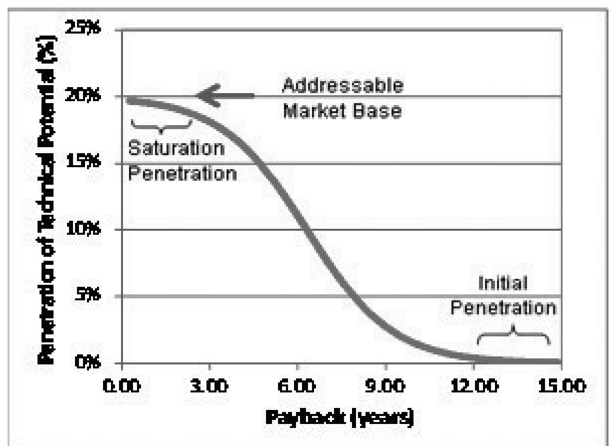

Figure 2: Example of an S-Curve for a developing market

Depending on the type of product and the readiness of the market for it, the addressable part of a market (maximum penetration with payback less than one year) is often 10%-40% of its potential.

For any given application and its realizeable value, payback itself is a nonlinear function of the storage price and would not exist above certain price point (no payback). Figure 3 shows an example of a storage payback as a function of its price ($/kW) for a given grid application with an estimated value of $ 360 / kW per year. Approximately 38% has been added to the storage price to cover installation and present value of annual operation and maintenance expenses. This chart would vary with application types and their storage requirements.

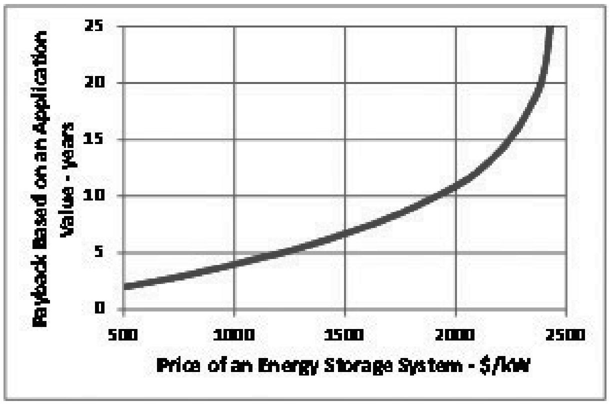

Figure 3: Payback vs. the price of an energy storage

Now if the above two nonlinear relationships (curves) are combined, we find the market penetration as a function of the price of a storage system for the grid application considered in this example. Figure 4 shows this relationship with the market penetration converted from percentage into actual MW assuming that the targeted grid application has a 10-year market potential of 2,500 MW.

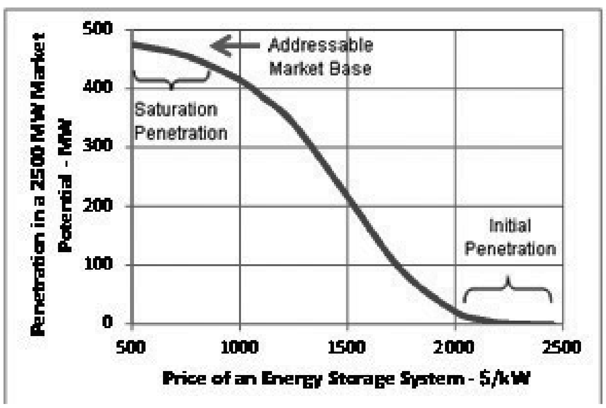

Figure 4: Example of market penetration vs. price

PRICING FOR THE MAXIMUM SALES AND PROFIT POTENTIALS

The total sales potential (product of the storage price by the market potential) may be expressed as a function of the storage price. As shown in Figure 5, the total sales potential goes through a maximum at a certain storage price point. Selling storage above or below this price point would reduce the total sales potential.

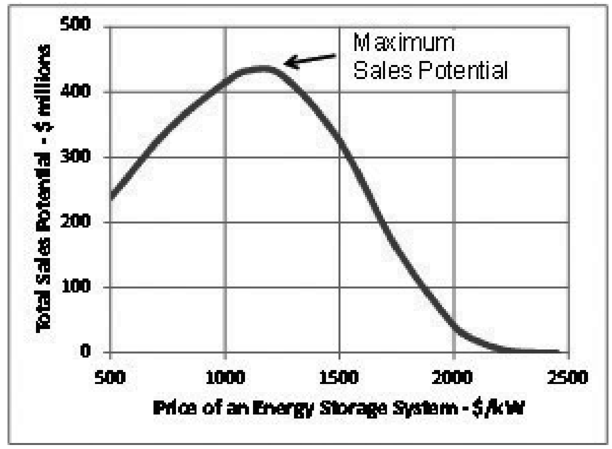

Figure 5: Example of pricing for the maximum sales potential

It should be noted that the storage price which brings the highest sales potential does not maximize vendors' profit potential. To obtain the price for maximum profit, a vendor has to subtract the cost of making his product. This manufacturing cost varies widely for different energy storage technologies. Figure 6 shows the adjustment for a manufacturing cost of $1,000 / kW.

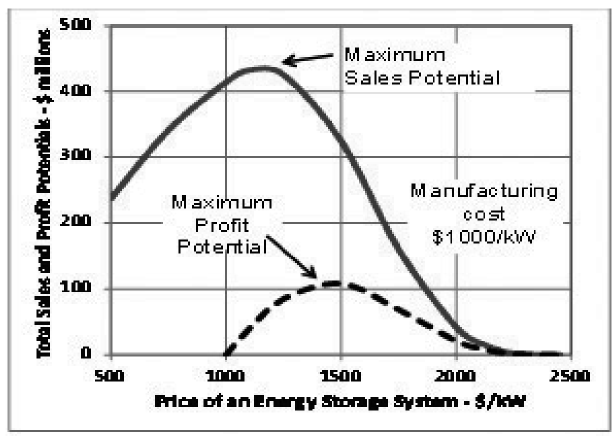

Figure 6: Storage price for maximum sales and profit potentials

IMPLEMENTATION OF ENERGY STORAGE PRICING

Optimum storage pricing for maximum sales and profit potential is influenced by many parameters including:

- Market readiness or penetration models that may be simplified in the following three scenarios,
  - ✧ sluggish market (about 10% of its potential is addressable)
  - ✧ evolving market (about 20% of its potential is addressable)
  - ✧ already started market (about 40% of its potential is addressable)

- Reasonable or expected payback for any particular application (impacts the shape of the S-Curve),
- Market price sensitivity that defines the slope of S-Curve,
- Storage deployment cost including installation, maintenance and operational costs, and
- Actual cost of operating a storage system or offering a storage service.

In order to study the optimum storage pricing for different grid applications, energy storage devices, market penetration scenarios and other factors that impact it., DNV KEMA used its ES-Select tool as a platform since it already has extensive databases on the benefits and markets of grid applications as well as cost components for a wide range of energy storage technologies. Another reason for trying this on ES-Select is that a public version of that tool is currently available from DOE through SANDIA website (www.sandia.gov/ess) and it could, at some point, also be put on the public version of the tool for public use.

The mathematical model for the S-Curve representing the market penetration has been expressed in many forms and equations to fit different products and markets [2]. This paper offers a simplification of these equations that appears to make more sense to the users and other stakeholders of energy storage technologies and applications. Below is the simplified equation:

$$Penetration = \frac{Pmax}{1 - e^{S(\frac{X}{H}-1)}} \quad (1)$$

Where:

Penetration is in per units (less than 1 or 100%)

X is the payback time in years (variable of the equation)

Pmax is the maximum penetration when payback is less than a year. This is also referred to as addressable market base. In most cases, Pmax ranges from 0.1 (sluggish market) to 0.4 (already established market)

H is the market's half-value payback time beyond which more than half the addressable market will be lost (this is expected to in the 7-14 year range). This at the S-Curve's point of inflection.

S is the sensitivity to payback or slope of the S-Curve and is dimensionless with a numerical value between 5 (not sensitive) to 10 (price sensitive). At S=10, the difference between the paybacks for no market penetration and full market penetration is about 5 years. At S=5 this difference expands to about 10 years.

Figure 7 shows impacts of these parameters on the S-Curve shape.

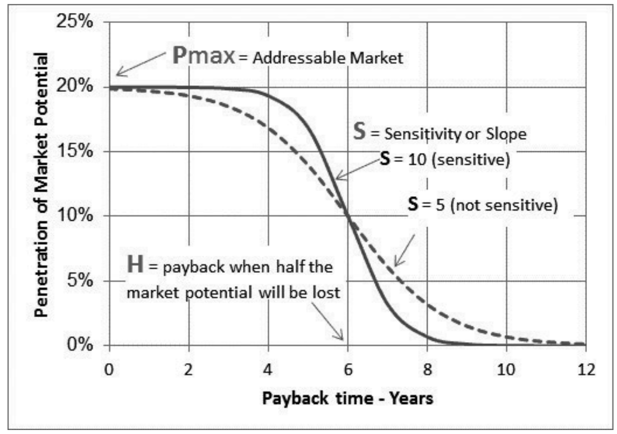

Figure 7: Simplified parameters of a market penetration S-Curve

Figure 8 shows implementation of the market penetration S-Curve and study of the optimum pricing for a bundled application of distribution and transmission deferrals. The key parameters selected for this chart, as shown on the screenshot are:

- Market Readiness (Addressable base) = "Evolving" = 20%
- Market Sensitivity to storage price = "Low", S=5
- Reasonable Payback = 7 years
- Application average annual value = \$556.7/kW per year
- Market potential over the next 10 years = 5670 MW
- Cost or producing a storage solution = \$1000/kW

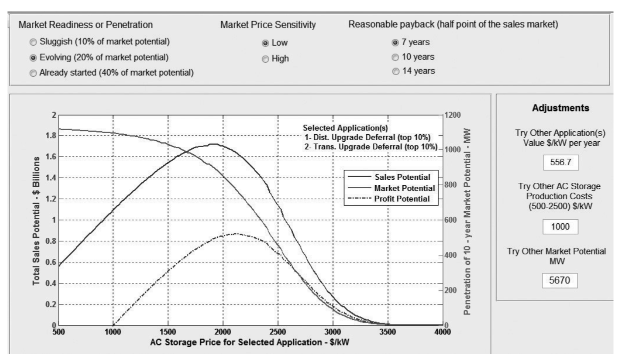

Figure 8: Screenshot of ES-Select showing implementation of the market penetration model to obtain the optimum storage pricing.

It should be noted that storage price is the purchase price of storage and, in order to calculate the payback correctly, installation and operational cost as well as its maintenance cost need to be considered. ES-Select uses the average of these extra costs for different storage technologies and adds that to the storage price before calculating the payback and market penetration.

SENSITIVITY ANALYSES

The optimum price of storage for maximum potential profit on storage for any given application is sensitive to a few parameters including application(s) value, market's half-value payback time and the storage manufacturing cost.

IMPACT OF APPLICATION(S) VALUE

Figure 9 shows the impact of the application(s) value on the optimum price for maximum profit potential. The approximate location of different applications is shown on this chart.

It is noted that, for every $100/kW (per year) increase in the annual value of a storage application, the optimum sales price would increase about $300/kW.

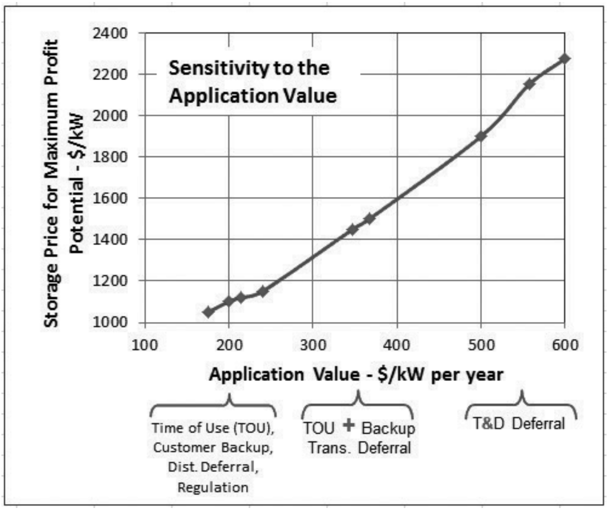

Figure 9: Sensitivity of the optimum storage price to the applications' value.

IMPACT OF THE MARKET'S HALF-VALUE PAYBACK TIME

To gauge this sensitivity, the half-value payback time has been changed between 7 and 14 years. Figure 10 shows the sensitivity of the optimum storage pricing to this payback time.

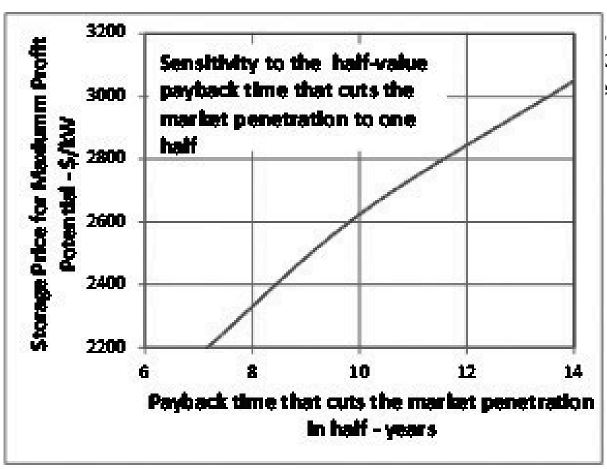

Figure 10: Sensitivity of the optimum storage price to the half-value payback time.

IMPACT OF THE STORAGE MANUFACTURING COST

While the price for maximum sales potential is mainly a function of the application value and almost independent of the storage type, the price for maximum profitability does depend on the storage as it is strongly affected by the manufacturing cost of the storage. Figure 11 shows the sensitivity of the optimum storage price for maximum profitability to the storage manufacturing cost.

It is noted that, for the case used in this example, a $100/kW reduction in the manufacturing cost would only allow reducing the sales price by about $25/ kW while staying at the optimum pricing point.

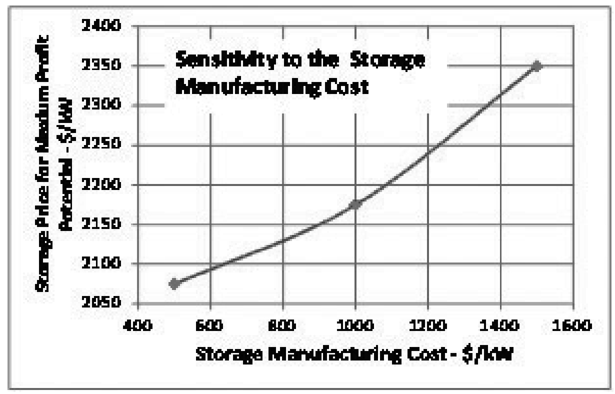

Figure 11: Sensitivity of the optimum storage price to the manufacturing cost of energy storage

SENSITIVITY OF THE OPTIMUM PRICE TO OTHER FACTORS

In the case used for the example shown in this paper, following factors had negligible impact on the optimum price for maximum profitability potential:

- Market Sensitivity - S factor in equation (1)
- Market Potential
- Addressable Market

Market potential and its addressable amount would directly impact the total sales and profit potential but have no impact on the optimum pricing.

REMARKS

Pricing a product for an evolving market that has little precedence or historical data is a complicated challenge. This is particularly true for energy storage devices that offer multiple services and the values of those services is still evolving and under investigation. The optimum pricing guidelines discussed in this paper are only a starting point and need to be revisited and further developed. Following are just a few of the gaps in this study that need to be addressed in the next iteration on the concept of optimum pricing:

- Competitive pricing

- Innovators starting a fresh market vs. imitators benefiting from established markets
- Development of storage technologies with time and its impact on market adoption

Diffusion models typically consider the technology not to improve over time or react to the market reactions. This certainly is not valid for energy storage

CONCLUSIONS

Application of the market penetration S-Curve to energy storage allows us to investigate the optimum pricing for maximum total sales or profit from sales of the energy storage systems.

The value of knowing where the optimum storage price is for any grid application is very clear to vendors. Buyers and other stakeholders would also benefit from this information. The sale of a storage product at or near its optimum price would maximize the sales and installation of storage on the grid. Besides the benefits to the grid, the increased sales would also accelerate further price reduction and standardization of the storage solutions that would benefit everyone. The following observations were made or confirmed in this study:

1. Optimum storage price for maximum sales potential is unique for each application or bundle of multiple applications. This is almost independent of the storage technology except that different storage technologies have different installation and operation costs that need to be considered in calculating paybacks.
2. Optimum storage price for maximum profit potential is a function of the energy storage technology because each storage technology has a different manufacturing cost.
3. While the sales and profit potentials are directly dependent on the market potential of each application and its addressable amount (the sales when payback is less than 1 year), optimum storage price for maximum profit potential is very sensitive to the value of each application.

REFERENCES

[1] Electric Power Research Institute (EPRI). 1991. *Market Penetration of New Technologies, Programs and Services*, EPRI CU-7011, Project 2864-1. Palo Alto: Electric Power Research Institute.

[2] Daniel J. Packey , “Market Penetration of New Energy Technologies”, NREL/TP-462-4860, Feb 1993

BIOGRAPHICAL NOTE

Dr. Ali Nourai joined DNV KEMA as an Executive Consultant in 2010 after a 30-year utility career with American Electric Power (AEP) where he launched AEP’s successful sodium sulfur (NaS) battery program and introduced the concept of the Community Energy Storage (CES).

As an executive consultant in DNV KEMA, he is helping all stake holders in energy storage to make informed decisions on energy storage applications and options. He has been advocating bundled storage applications and developed the publicly available ES-Select tool to quantify their benefits and identify the best storage options to serve them.

Dr. Nourai is an IEEE Fellow, a board member and former chairman of the Electricity Storage Association (ESA) dedicated to promoting development and commercial application of energy storage technologies as solutions to power and energy problems

APPROACHES TO EVALUATING AND IMPROVING LITHIUM-ION BATTERY SAFETY

Dr. Christopher J. Orendorff

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As lithium-ion battery technologies mature, the size and energy of these systems continues to increase for emerging applications in transportation, grid storage, military use and aerospace. In fact, broadening the application space for lithium-ion batteries from the consumer electronics industries to these emerging markets increases their size from 1-50 Wh batteries for smart phones and laptops to >10 kWh for electric vehicles (EVs) and MWh scale for utility storage systems. As these energy storage systems grow, safety and reliability issues will become increasingly important. Moreover, as the application space changes for these energy storage devices, the failure modes and mitigations for hazards associated with these failures will also change and evolve. While system or use controls are often designed into large batteries to mitigate more predictable problem scenarios (overcharge, cell imbalance, high voltage short circuit, etc.), it is a significant challenge to design for unpredictable field failure safety incidents (internal short, failure propagation, etc.). Moreover, there are fundamental materials chemistry improvements that can be made in order to improve the overall inherent safety of a large battery (and therefore, the system), without the need for relying solely on ancillary external system control electronics.

This presentation highlights our work to better understand safety issues and abuse response of large-scale lithium-ion battery systems and development efforts to improve inherent lithium-ion battery safety.

BIOGRAPHICAL NOTE

Christopher J. Orendorff is the Principal Investigator of the Battery Safety R&D Program and Battery Abuse Testing Laboratory (BATLab) at Sandia National Laboratories. This program at Sandia is focused on developing inherently safe lithium-ion technologies for the transportation market through materials development, mechanistic understanding of battery abuse and failure, and full spectrum testing of cells and battery systems. Before joining Sandia in 2006, Chris earned B.S. degrees in Chemistry and Biochemistry from Purdue University in 1999, his Ph.D. in Analytical Chemistry from the University of Arizona in 2003, and was a post-doc at the University of South Carolina. Currently, he lives in Albuquerque with his wife, Judi, and their three children.

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RECONFIGURABLE SOLAR CONVERTER (RSC): SINGLE-STAGE POWER CONVERSION PV/BATTERY SYSTEM

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Solar photovoltaic (PV) electricity generation varies depending on the time of the day and weather conditions. From an energy source standpoint, a stable energy source that can be dispatched and utilized at the request is desired. As a consequence, deployments of energy storage devices that can firm-up the PV source output have drawn significant attention. With energy storage systems, a solar PV system becomes a stable energy source which results in improving the performance and the value of solar PV systems.

There are different options for integrating energy storage to a utility-scale solar PV system which is either in DC or AC side of the main (grid) inverter. Different integration solutions can be compared with regards to the number of power conversion stages, efficiency, storage system flexibility, and control complexity. Nonetheless, at present, to maintain the Maximum Power Point Tracking (MPPT) capability at large installations (>250KW), extra conversion stages are considered for the integration of energy storage to the PV system. Therefore, it adds extra costs associated with the hardware and installation, with efficiency losses at each stage.

This paper presents a family of single-stage converters called Reconfigurable Solar Converter (RSC) for integration of energy storage to the PV system where peak-shifting is desired. The RSC concept arose from the fact that energy storage deployment for solar PV systems has the highest value if there is enough of a gap or a minimal overlap between the PV power generation and release time. Therefore, one power conversion system with multi-mode capability may be realized and used at different time of the day. In other words, the RSC is using a single power conversion system that performs different operation modes such as PV to grid, PV to battery, battery to grid, and battery/PV to grid for solar PV systems with energy storage. The proposed solution potentially requires minimal complexity and modifications to the solar PV converter for PV-battery systems. In addition, it is shown that the RSC will provide new architectures and utilization methods for achieving more efficient <u>(3-5% efficiency) gains</u> and more controllable PV farms. These architectures will potentially create flexible, retrofit and expandable platforms for current and future PV power plants that can accommodate efficient PV arrays and economical battery systems. In this paper, a combination of analysis and experimental tests are used to demonstrate the attractive performance characteristics of the proposed RSC.

RECONFIGURABLE SOLAR CONVERTER (RSC): SINGLE-STAGE POWER CONVERSION PV/BATTERY SYSTEM

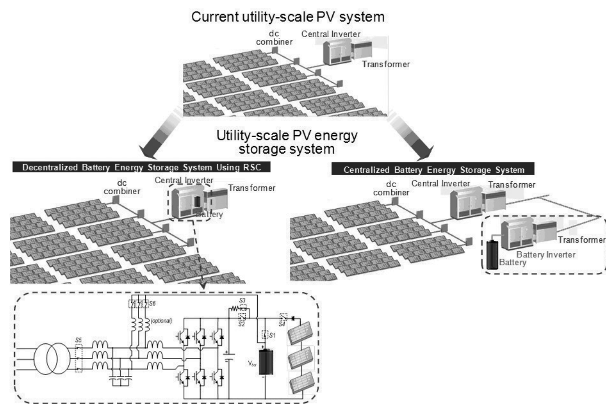

Figure 1: Utility-scale PV-energy storage systems with the RSC and the current state-of-the-art solution (product-level).

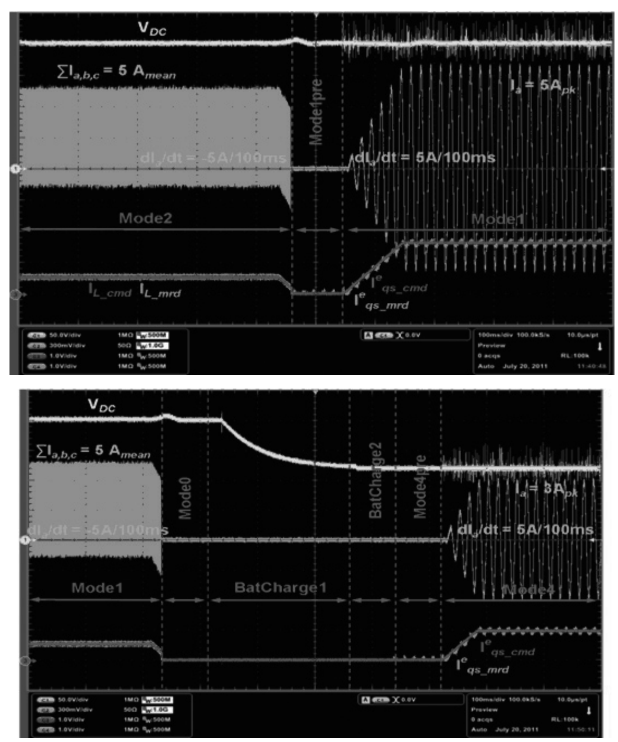

Figure 2: Examples of RSC modes' transient and steady-state lab-scale experimental results with PV/Li-ion

battery system.

BIOGRAPHICAL NOTE

Babak Parkhideh received the B.Sc.(Hons.), M.Sc. and PhD degrees in Electrical Engineering from the University of Tehran, Tehran, Iran in 2003, the Institute of Power Electronics and Electrical Drives of RWTH-Aachen University, Aachen, Germany in 2006, and, Electrical and Computer Engineering Department, NSF FREEDM Systems Engineering Research Center (ERC) of North Carolina State University, Raleigh, NC in 2012, respectively. During his PhD study, he worked for Siemens mining industries and ABB corporate research center as a visiting researcher. There, he was responsible for several energy storage projects for mining and grid applications.

He joined the Electrical and Computer Engineering Department at the University of North Carolina-Charlotte in August 2012. He is also a faculty member of Energy Production and Infrastructure Center (EPIC) at UNC-Charlotte. His research interests are utility and industrial applications of power electronics.

FROM CONCEPT TO COMMERCIALIZATION – CHINA AS A DESIGN AND ENGINEERING BASE FOR LOW COST FLOW BATTERY PRODUCTS

Author: Robert Parry

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With unprecedented market interest and a rapidly expanding recognition of the commercial potential for Energy Storage Systems, worldwide, the rush is now on to bring truly commercialized ESS products to the forefront. The challenges that this rush presents are no longer purely of a scientific and R&D nature, nor are they of the intrinsic "one off' prototype field testing nature. The challenges today are very much about cost, scale and durability. They are also about seamless integration on both sides of the energy storage product, with the power producer and with the power consumer.

This paper will introduce a new approach to commercializing flow battery products based on proprietary designs and concepts from recognized leaders in the field of zinc/bromine flow battery technology. The zinc/bromine flow battery science is well-known and documented from as far back as the late 1800s. Today, the R&D challenges of materials and chemistry have all been largely resolved. Despite the efforts of many groups around the world, the major unresolved challenge has been to transition from science into product.

The Hong Kong-based Smart Energy group, in conjunction with partners in industrial manufacturing, power electronics, materials design and supply in China and with ongoing research at Australia's Murdoch University, is undertaking an exciting short-term commercialization program in China. Based in the Shanghai region, Smart Energy has established a purpose built facility for manufacturing the first of its designed products over the next 24 months.

Smart Energy is now working with a team of tool and machine designers, plastics component manufacturers and membrane and electrolyte suppliers to establish commercial manufacturing based on a fully automated "in-machine" assembly concept for cell stack production and the establishment of a locally sourced supply chain for all key material and chemical supplies. This initiative is a direct approach to lowest manufactured cost for a zinc/bromine flow battery product and is expected to achieve at least a 30% reduction against today's current market. This approach is also designed for a rapid scaling in manufacturing output through the active participation of all key industry participants.

Similarly, Smart Energy is addressing the development of its proprietary power electronics products through collaboration between its own power electronics engineering group and appropriately focused Chinese Universities and other consultancy groups. Manufacturing of both the on-board battery power electronics and the interfacing power conditioning systems is also a collaborative effort between the company and China based manufacturers.

Smart Energy, with significant financial backing from its Hong Kong-based private equity group, has a deep understanding of the China power markets, and by focusing the design, engineering, manufacturing and marketing of its products in China the company is now unveiling this unique business model to achieve a fast track to commercial success.

BIOGRAPHICAL NOTE

Robert Parry is a 30-year veteran of the Energy Storage Industry. Over that period of time he has raised in excess of $80 million for research, development and commercialization of flow battery technologies. He was a director of ZBB Technologies Ltd when founded in 1982 by a group of eleven Australian investors to finance the electrochemistry research project being conducted at Murdoch University (Perth, Australia).

Through the 1980's and 90's Rob assumed full time responsibility for the daily operation of all aspects of the company's business. In 1994 Rob successfully negotiated for the acquisition of Johnson Controls Inc. zinc/bromine battery research group in the United States and merged both Australian and US operations into ZBB Energy Corp. He retired from the ZBB group at the end of 2009.

In 2011 Rob and a group of business colleagues formed a new flow battery initiative, to capitalize on new designs, materials and manufacturing techniques for commercializing large-scale energy storage systems. In 2013 with the introduction of significant private equity partners, the Smart Energy group was formed to establish a testing and manufacturing base in the Shanghai Jinqiao development zone. Rob is a Director and COO for the group that is now undertaking a fast-track expansion program in China to commercialize the first generation of these energy storage systems.

Rob graduated from WA Institute of Technology (Curtin University) and is a Fellow of CPA Australia.

A HIGH VOLTAGE (15 KV) SIC MULTI-CHIP POWER MODULE (MCPM) FOR GRID-TIED APPLICATIONS

Zach Cole, Brad Reese, and Brandon Passmore*

Arkansas Power Electronics International, Inc., Fayetteville, AR (USA), Phone: (479) 443-5759 Fax: (866) 515-6604 Email: bpassmo@apei.net

ABSTRACT

The advancement of power converters for energy storage systems has the potential to aid in the emergence of smarter, seamless powered grids with less dependence on inefficient peak power plants. A major issue with high power converters is that they tend to have higher current requirements due to low DC-link voltages. These high currents create an increase in losses, resulting in heat generation and reduced efficiency, making HV SiC-based power electronics systems an ideal fit for next generation HV converters. Moreover, multi-level power topologies are typically used in high voltage conversion increasing the size and complexity due to the increase in the number of switches of the system. To this end, a high voltage (15 kV) SiC multi-chip power module will be presented. Some of the key characteristics include ease of manufacturing; reworkable, wire bond free, low junction-to-case thermal resistance; low profile, and low parasitic inductance. In addition, this advanced packaging method will utilize high temperature materials eliminating the need for bulky thermal management systems. Detailed mechanical, thermal, and electrical characteristics of the high voltage SiC MCPM will be modeled. Specifically, the junction-to-case thermal resistance, maximum power loss for various cooling systems, parasitic impedances for the power and gate loop, and electric isolation profile will be presented.

BIOGRAPHICAL NOTE

Brandon Passmore is a Sr. Electronics Packaging Engineer at APEI, Inc. where he is responsible for leading a team of electronics packaging engineers and scientists to develop and commercialize discrete packages, multi-chip power modules, and systems utilizing wide bandgap based power electronics.

Prior to joining APEI, Inc., he was a postdoc at Sandia National Laboratories where he worked on developing novel plasmonic- and metamaterial-based photonic devices for mid-IR applications. He has accumulated over thirty refereed conference and journal publications. At APEI, Inc., he is heavily involved in a number of projects, which include developing new wire bondless technologies, a high frequency, high temperature wide bandgap MCPM for electric vehicles, high voltage SiC power packages, and high frequency discrete packages for a GaN power HEMTs.

He has a B.S. degree in electrical engineering as well as M.S. and Ph.D. degrees in microelectronics and photonics.

REDOX FLOW BATTERIES WITH HIGH POWER DENSITY CELLS

Mike L. Perry

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ABSTRACT

A Redox Flow Battery (RFB) possesses several key advantages that make this technology potentially well-suited for large scale energy storage applications. This is especially true of applications that require high energy-to-power requirements (*i.e.*, multiple-hour discharge times at rated power), since the power and energy of an RFB system are independent variables. However, the initial capital cost of flow batteries has been the major barrier to commercialization of RFB technology. One attractive path to cost reduction is the development of RFB cells with substantially higher power densities than conventional RFB cells. The cost of the cell components comprises a significant portion of the total RFB system cost, especially at low production volumes, since cell parts are custom-built components made of relatively expensive materials.

United Technologies Research Center (UTRC) has developed vanadium-redox battery (VRB) cells with order-of-magnitude higher power densities than conventional RFB cells, utilizing the same material set as is used in conventional RFB cells. This advanced cell-design technology can theoretically be applied to other RFB chemistries as well. UTRC's high power density RFB cells take full advantage of the inherent power and energy independence of the RFB architecture in a manner that had not been previously exploited; namely, flow-battery cells can be designed for high power, independent of the quantity of reactants stored in the tanks of an RFB system, and this power density is much higher than can be achieved with conventional batteries due to the forced-convective flow of the RFB reactants. Some of the key concepts utilized to enable these high performance RFB cells will be described, as well as the multiple key benefits of high power density RFB cells.

With the support of DOE's ARPA-E Office, UTRC has successfully demonstrated this technology in a complete advanced RFB system and the current maturity level of the technology will be highlighted. UTRC's path to commercialization of this technology will also be briefly discussed. Additionally, some potential research opportunities to further improve RFB technology will be presented, including advanced cell materials (*e.g.*, electrodes, membranes) that are optimized for high performance RFB cells.

ACKNOWLEDGEMENTS

The author would like to thank the multiple colleagues at UTRC who have been an essential part of UTRC's advanced flow-battery team. The work to be presented herein was funded, in part, by the Advanced Research Projects Agency - Energy (ARPA-E), U.S. Department of Energy (DOE) under Award Number DE-AR0000149.

BIOGRAPHICAL NOTE

Mike Perry joined the fuel-cell business unit at *United Technologies Corporation* in 1999, where he worked on Polymer Electrolyte Fuel Cells (PEFC). Mike and five of his UTC colleagues were the 2012 recipients of the *New Electrochemical Technology Award* from the *Electrochemical Society* for developing durable PEFC technologies, which has enabled a fleet of transit buses in commercial service to operate with cell stacks that have exceeded 13,000 operating hours. In 2008, Mike transferred to UTRC, where he initiated a new project on flow-battery technology. UTRC's primary focus has been the development of high power density flow-battery cells and, with support from DOE's *ARPA-E Program Office*, this technology has been successfully scale-up and demonstrated in a complete Prototype System. This flow-battery technology was recently selected for a *2013 R&D 100 Award by R&D Magazine*. Mike has over 50 unique patents or patent applications related to fuel cells and flow batteries. Mike holds a M.S. degree from U. C. Berkeley (1996) and a B.S. degree from U. C. Santa Barbara (1985), both in Chemical Engineering. Mike also served as a Naval Aviator in the U.S. Navy, where he flew EA-6B aircraft, prior to returning to graduate school to study electrochemical systems.

THE ROLE OF LOCAL ENERGY MARKETS AS A MEANS TO INCREASE THE PARTICIPATION OF ELECTRICITY STORAGE

Anthony PRICE

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ABSTRACT

Increasing renewable generation embedded in the distribution networks may cause effects such as local voltage rise, reverse power flows and overloading of network resources. There has been considerable discussion of the management of these issues, and techniques such as active network management, demand response and demand management have been proposed and trialled.

A local energy market offers an alternative approach –by encouraging trades between participants, local demand can be increased to match local production or vice versa. Furthermore, local energy storage, whether individually or communally owned can be used to improve the economic benefit to the participants in the local market as well as providing a range of technical benefits to the local network .

A local market differs from the other approaches in that prices are agreed upon locally between buyers and sellers; prices vary with time and prices are set locally and so they may or may not be the same as a national price. Developing local trading defers or avoids the local network reinforcement, reduces network losses and importantly encourages the increased uptake of renewable energy and the use of local energy storage.

This paper reviews a feasibility study on local energy markets, supported by the UK's Technology Strategy Board. The paper describes the benefits, challenges and progress in implementing this new business model, and provides illustrations of the value of local energy storage to the trading patterns within a local energy market. Additional work undertaken to develop an embodiment of the trading platform will also be described. (See Figure 1.).

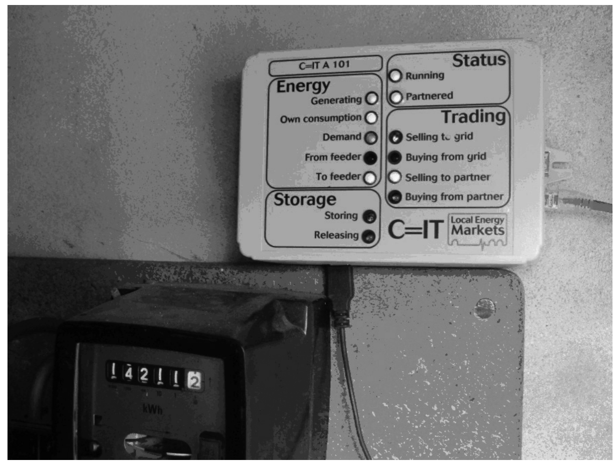

Figure 1: An Example of a LEMMA trading box for a domestic installation.

BIOGRAPHICAL NOTE

Anthony Price is actively involved in the commercial development of electrical energy storage with experience gained from project work, marketing, and commercialisation of technologies and projects. He is the Director of the Electricity Storage Network, the industry group committed to creating a UK market for electrical energy storage, comprising manufacturers, developers, researchers and users of large scale, network connected electricity storage.

Anthony Price is also a Director and Principal Consultant for Swanbarton, a consultancy company specialising in electrical energy storage. Over the past ten years he has worked with clients, in manufacturing, research, project development as well as potential users of large scale storage to provide support for projects in large scale electricity storage both in the UK and abroad.

Prior to the formation of Swanbarton, Anthony worked on design and construction of several infrastructure projects before joining the Electricity Supply Industry. He was the commercial manager for a large scale electricity storage development project undertaken by National Power. He was an elected director of the Electricity Storage Association for six years. He is a chartered engineer and is the author of several papers and journals on energy policy and electrical energy storage.

THE CELLCUBE VANADIUM REDOX FLOW BATTERY – A CRITICAL ROLE IN GRID RESILIENCY

Bill Radvak

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The interest and concern surrounding grid resiliency has risen dramatically since Superstorm Sandy, which highlighted the fragility of America's ability to reliably deliver electrical energy. The vulnerability of the 100-year old transmission and distribution system was hyper-accentuated when Sandy left industry, hospitals, businesses and millions of people without power for days, weeks and months. This serious lack of grid resiliency then shone a bright spotlight on the vulnerability of the grid as a target for terrorist attacks. Military bases and critical infrastructure sites now fully realize they are openly vulnerable to either direct attacks or cyber attacks which could be perpetrated from anywhere in the world and would leave them completely powerless.

With extreme weather now accepted as an ongoing, common occurrence and the military understanding their energy supply is under a continual threat, grid resiliency is a national priority. Energy storage will play a leading role in the third of three areas of improvement defined by EPRI: prevention, recovery and **survivability**. Multi-hour, multi-megawatt energy storage systems are absolutely essential to the resiliency of mission critical facilities such as hospitals, police, military, emergency response and a variety of government services that are required to maintain a minimum level of service and communication at all times.

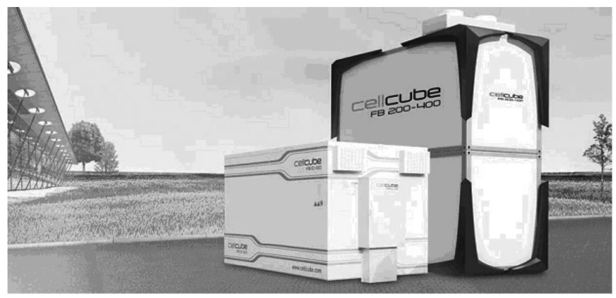
Additionally, microgrids offer the ultimate resiliency from climatic and terrorist events. And the key to microgrids, particularly those relying on renewable energy for their generation, is energy storage. With proper energy storage, microgrids offer the ability to dramatically lessen the reliance on the grid, and even enable the option of going completely off-grid.

The Vanadium Flow Battery (VFB) is the only battery technology today ca¬pable of powering everything from a single home right up to the storage demands of a pow¬er grid or microgrid. The VFB operational window is a perfect fit for grid resiliency requirements, having a rated power of 10kw to 10 MW and a bridging time of 1 hour to 10 hours. Not only do they maintain 99% of a charge over a year-long period, they supply uninterruptible power with a response time of less than 20 milliseconds.

American Vanadium's CellCube vanadium redox flow battery is now in full-scale production with more than 50 systems commercially installed globally. Constructed and fabricated to German engineering standards by Gildemeister, the CellCube is a proven, reliable and safe energy storage solution with over three years of field testing. With unlimited deep cycling over a twenty year battery life, low maintenance cost, and modularity of separate power and energy units, the CellCube will provide amongst the lowest Levelized Cost of Energy. Additionally, the CellCube energy storage system is weatherproof without the need for a building, operational in all climate zones and plug & play with a short commissioning period.

The CellCube Vanadium Redox Flow Battery – A Critical Role in Grid Resiliency

Bill Radvak



BIOGRAPHICAL NOTE

Bill Radvak joined American Vanadium as President and CEO in January, 2010. He spearheaded the company's transition from a mineral exploration company into a vertically integrated energy storage company with the execution of the Master Sales Agreement for North America with Gildemeister to market the world's leading CellCube vanadium redox flow energy storage system. At American Vanadium, he guided the Gibellini Project in Nevada through a positive bankable feasibility study and into the environmental permitting process.

Bill Radvak received a Mining and Mineral Process Engineering Degree (1986) from the University of British Columbia. Previously, he was a Founder and CEO of Response Biomedical, a publicly listed medical device company. Mr. Radvak led Response Biomedical from its evolution to a 90-employee, sales and manufacturing company.

CONTROLS FRAMEWORK FOR GRID STORAGE

Satish Rajagopalan and Haresh Kamath

EPRI in Knoxville, TN

ABSTRACT

As more and more grid storage systems come online, the need for well-defined control architectures has never been more important. Recent deployments have focused on system integration more so than on actual controls. This has resulted in several open questions as to what controls need to be developed, who owns it, and where they should reside. This paper makes a first attempt to answer these questions by proposing a framework for a multi-layer control architecture for grid storage systems. The objective of this work is to set in motion a thought process on how energy storage controls and communications can be defined and standardized in the long run.

A four-layer framework is proposed, focusing on 1) subsystem (battery, PCs, etc) controls, 2) integrated system controls, 3) application control, and 4) asset management (multi-system control and dispatch). This paper will lay out the control definitions, layer ownership/authorship (where does each layer reside and who owns it), define the parameters (input, output, and control parameters) describing each layer, and describe the interdependencies between them. It is expected that this first step would eventually lead to a well-defined industry-agreed energy storage control protocol that would enable cost-effective and reliable energy storage through concepts such as plug-and-play.

BIOGRAPHICAL NOTE

Dr. Satish Rajagopalan is a Project Manager in the Power Delivery & Utilization Sector at EPRI. He is responsible for power conversion and energy storage research, testing, and development. In this role Satish manages projects that address: 1) electric transportation – investigating impact of PHEVs on distribution systems, and testing/demonstration of emerging PHEV related technologies, 2) energy efficiency – investigation the energy savings and grid impact to new emerging technologies such as DC-powered datacenters, 3) energy storage – performing in-depth technical, economic, and market assessment of new battery technologies for transport, transmission, and utility applications and, 4) power quality – Conducting research in support of power quality standards SEMI F47-0706 and the IEC 61000-4-11/34.

Prior to joining EPRI, Satish worked as a Researcher for General Motors Corporation, where he was responsible for the development of diagnostic and prognostic techniques for vehicle subsystems. He also worked as a Power Electronics Engineer at Baldor Motors and Drives where he had responsibility for the design of power circuitry and control circuitry for industrial variable speed motor drives.

Satish received his PhD in Electrical Engineering from Georgia Institute of Technology (2006), a MS in Electrical Engineering from Iowa State University (2000), and a BE in Electrical and Electronics Engineering from the University of Madras (India-1997).

FABRICATION AND CHARACTERIZATION OF HIGH TEMPERATURE CAPACITORS USING NOVEL THERMAL SPRAY PROCESSING ROUTES

Clive Randall[1], Other Authors: Eugene Furman[2], Rashmi Dixit[3], Satish Dixit[3]

[1]Director of the Center for Dielectric Studies Professor, Materials Science and Engineering Penn State University, University Park, PA
[2]Penn State University
[3]DRS Research

ABSTRACT

Future technological advances in power electronics modules for renewable energy interfaces, hybrid/electric vehicles, and power distribution systems will depend on advances in dielectric materials with high power and energy densities, resistivities, material RC time constants, and minimized power dissipation densities.

This paper discusses the design, development, and evaluation of high temperature capacitors fabricated with novel thermal spray coating processes, which will allow the devices to meet the performance requirements. The overall capacitor architecture is designed based on multilayer coating structure, and the form factor is realized using a novel shadow mask technology to provide unique microstructures and processing routes that permit low ESR and ESL, and high temperature reliability. The thermal spray method allows low temperature deposition of both the dielectric and the electrode materials in a sequential and rapid processing route that avoids the complexities of binder removal, sintering etc. The electrodes and dielectric material selections will be screened to examine material compatibility and high temperature performance. We have screened likely candidates for high temperature capacitors and identified possible candidates based on the key operating requirements and compatibility with the fabrication techniques.

BIOGRAPHICAL NOTE

Dr. Eugene Furman will present in Clive Randall's stead.

Dr. Eugene Furman is a Research Associate at the Pennsylvania State University and also a Consultant. He consulted with Raytheon, NASA, TRS, Sabic, SPS Corporations and other organizations.

His research interests include electroceramics, composites, glasses, polymers for capacitors and electrocaloric applications, high temperature capacitors, microwave materials and devices, materials for energy storage and cooling, finite element, finite difference and Monte Carlo Modeling of the single phase materials and composites. He is on editorial board of Dataset Papers in Materials Science and was on the organizing committee and session co-chair for the 2010 SAE Power Systems Conference. He has presented about 10 invited talks and more than 70 publications. Prior to Penn State, he worked at Oak Ridge National Laboratory, University of Illinois, Clemson University, and Allied-Signal, Inc. pursuing research in electroceramics and electrochemical devices. He obtained Ph.D. in Solid State Science and M.S. Electrical Engineering both from Pennsylvania State University as well as B.S. in Computer Engineering from Lehigh University.

ADVANCES IN PNNL'S MIXED ACID REDOX FLOW BATTERY STACK

Contact Author: David Reed[1]

Vincent Sprenkle, Edwin Thomsen, Wei Wang, Bin Lu, Brian Koeppel, Kurt Recknagle,
Xiaoliang Wei, Zimin Nie, Qingtao Luo, and David Reed

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This presentation will report the recent advances in PNNL's redox flow battery research and development utilizing mixed acid electrolytes. Stacks contain up to 15 cells with active areas of 780 cm2. The developed stack is capable of delivering more than 2kW in the operation range of 15~85% state of charge at 160 mA/cm2 with an energy efficiency of 77% and energy content of 1 kWh. Operation at higher current densities and the influence on capacity fade and efficiencies will be presented. In addition, Bismuth nanoparticles deposited on the graphite felt for enhanced electrode performance, lower cost Nafion membranes, and an inter-digitated design for lower pressure drop in cells will be presented. Potential methods to separate and enhance electrode performance and processes will also be addressed.

Dr. Vincent Sprenkle will present in David Reed's stead.

BIOGRAPHICAL NOTE

Dr. Vincent Sprenkle joined PNNL in January 2001 and is currently Chief Engineer for Energy Storage and Conversion within the Energy Materials Group. He is currently project manager for the Department of Energy – Office of Electricity Energy Storage Program at PNNL. This project is focused on the development of electrochemical energy storage technologies to enable renewable integration and improve grid reliability. He previously led the Delphi/Battelle solid oxide fuel cell (SOFC) effort at PNNL and the ARPA-e planar Na battery development projects focused on the demonstration and deployment of these technologies. Prior to his arrival at PNNL, he was a senior ceramic engineer at Litton Life Support and was responsible for the development of prototype advanced electrochemical oxygen generating system. Dr. Sprenkle currently holds 14 US patents on fuel cells and high temperature electrochemical devices with 17 current patent applications.

USE OF A FAST RESPONSE BATTERY SYSTEM FOR FREQUENCY REGULATION

Richard Rocheleau

Hawaii Natural Energy Institute, University of Hawaii; Honolulu, HI, 1680 East West Road, POST 109, Honolulu HI 96822; Phone: 808-956-8890; Fax: 808-956-2336; email: rochelea@hawaii.edu

Electricity costs in Hawaii are some of the highest in the nation due to our small isolated grids, difficult transmission issues, and use of oil for over 70% of our generation. As a result, several islands are experiencing high penetrations of wind and photovoltaics (PV). On the Hawaii Electric Light Company (HELCO) grid on the Island of Hawaii, wind and distributed PV systems account for approximately 15% and 3% respectively of total electricity generation. It is well documented that the variability of this wind and PV power can cause imbalances between generation and load that are manifested as a variability in grid frequency.

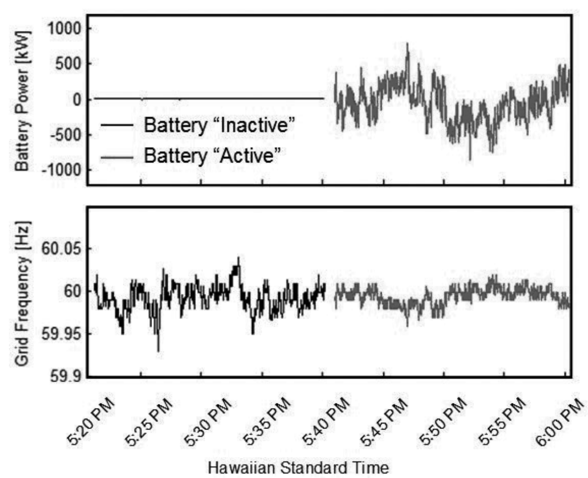
In 2007, models of the Hawaii Island grid indicated that a relatively small (1 MW) fast acting Battery Energy Storage System (BESS) could significantly reduce grid frequency variability on the Hawaii Island grid. In 2010, the Hawaii Natural Energy Institute at the University of Hawaii initiated a joint project with HELCO to experimentally validate the impact of a fast acting BESS on the HELCO grid.

In 2012, with funding from the Office of Naval Research and cost share from HELCO, a 1 MW BESS was installed at the point of interconnection between the Haw'i Renewable Development wind farm and the HELCO grid. This system includes a 1 MW, 250 kW-Hr battery power module from Altairnano Inc. comprised of 2,688 50A-hr Lithium-ion Titanate cells and a 1.2 MVAr inverter developed by Parker Hannifin Corporation. In partnership with HELCO and Altairnano, two real-time algorithms were developed allowing the BESS to respond to either system frequency (frequency regulation) or wind power (wind smoothing). The frequency regulation algorithm is capable of responding to changes in grid frequency within 100 ms while the wind-smoothing algorithm is capable of responding to wind power within 200 ms.

Initial testing to assess the performance of the frequency regulation algorithm has been conducted by comparing grid frequency over repetitive periods of time, with the BESS alternatively turned off (inactive), then turned on (active). Results from one such experiment with the battery inactive for 20 min, and then active for 20 min is shown in the attached figure. During this period of time, total demand on the HELCO system was approximately 150 MW; total power supplied by the two wind farms was approximately 23 MW; and there was little contribution from PV due to the time of day. The top section of the figure shows the battery power, off during the inactive period, then cycling in response to frequency changes reaching charge/discharge power of up to 750 kW. The lower section of the figure shows grid frequency. The reduction in frequency variability with the battery active is clearly observed. Analysis of data to date, over a range of grid operating conditions, shows a typical reduction in the standard deviation of the frequency variability of 30 to 50%. Preliminary data also shows significant reduction in frequency drop during larger wind drop events, e.g. > 1 MW. This paper will describe the BESS system, the control system, results under a variety of grid operating conditions, and the statistical significance of the results.

Use of a Fast Response Battery System for Frequency Regulation

Richard Rocheleau



Impact of BESS on HELCO Grid Frequency

Top: Battery Power during an inactive and active period

Bottom: Frequency variability test results. Standard deviation for active state reduced 35% compared to inactive period. This data was taken during March 2013.

FORWARD OPERATING BASE MICROGRID, EVALUATION AND TESTING OF ENERGY STORAGE SYSTEMS

David Rose

Sandia National Laboratories, Albuquerque, NM (USA)

ABSTRACT MAILTO:

In times of war, the cost of fossil fuel is high and the costs of lives are at stake. Insurgents know that if they can cut off the fuel and water supply to a Forward Operating Base (FOB), it will be rendered useless since the tactical operation can no longer function. The Department of Energy Office of Electricity (DOE/OE), Sandia National Laboratory (SNL) and the Base Camp Integration Lab (BCIL) partnered together to incorporate an energy storage system into a microgrid configured forward operating base to reduce the fossil fuel consumption and ultimately, to save lives. Energy storage systems have undergone functional testing for microgrid operation at the SNL Energy Storage Test Pad (ESTP). The technologies that have been tested are electro-chemical energy storage systems comprised of lead acid, lithium-ion and zinc-bromide. SNL has created a program in Matlab to predict the possible fuel savings that might be achieved when these systems are incorporated into an FOB. Load profiles from the BCIL forward operating base test bed are used in the SNL program along with ESTP test data to produce a more accurate model

BIOGRAPHICAL NOTE

David Rose spent three years working with the Idaho National Laboratory developing advanced spectral impedance measurement techniques for hybrid vehicles cells before moving to the stationary energy storage sector in 2011. He now uses the Energy Storage Test Pad (ESTP) to characterize AC integrated energy storage systems up to 1MW in size. He obtained his master’s degrees in electrical engineering from Montana Tech.

SOLVING THE RENEWABLE+BATTERY BUSINESS CASE IN A ROBUST WAY: USE OF OPERATIONAL DATA AND DEDICATED MODELING TOOL

Michael Salomon

Clean Horizon, Paris, France, Michael.salomon@cleanhorizon.com

In this paper, Clean Horizon will use real data based on operational experience of batteries, actual weather conditions, regulation and economics, to size battery systems added to a renewable plant and to compute its Internal Rate of Return (IRR).

Clean Horizon, the research and consultancy firm dedicated to energy storage, will present results for photovoltaic and wind project developers. These results are based on work performed with the Laboratory for Electrical Energy Storage at CEA INES using their M2C simulation platform.

Renewable project developers are often not aware of technical issues linked to electrochemical electricity storage, therefore they are unable to independently size storage assets they might want to add to the renewable plant, nor can they estimate the lifespan of batteries placed in real conditions. Then, they are forced to rely on manufacturers' data, which by construction are not independent.

This paper will first present a regulatory analysis of storage assets installed on renewable power plants in three different areas (to be confirmed: California, France, Germany). Economics applicable to storage (i.e. Feed in Tariffs, net metering, spot prices) will also be presented.

The paper will then present the technical and financial results of a business case computed by applying a similar battery management scenario based on the regulatory analysis to a 10 MW solar field in the selected areas.

The business case will be quantified in terms of IRR using:

- the optimal sizing of the batteries depending on the climate conditions and using operational battery data for the project sizing,
- the lifespan of the batteries, and
- the regulation and electricity tariffs in each sector

Thus, the presented business cases will be as robust as possible as they will be grounded on technical, regulatory and financial considerations.

BIOGRAPHICAL NOTE

Michael Salomon obtained his engineer's degree at Mines ParisTech in France and his Ph.D. at Stanford in the USA. He witnessed the booming of Cleantech venture capital and entrepreneurship while an academic in the Silicon Valley, and then went on to become a management consultant at McKinsey in Paris. Since 2009, Michael has believed that a high penetration of renewable energy can only be possible if a strong energy storage sector is formed. He thus founded Clean Horizon to provide technological, regulatory and business expert information to stakeholders of this emerging industry.

LESSONS LEARNED FROM A DISTRIBUTED ENERGY STORAGE DEMONSTRATION

Ed Sanchez

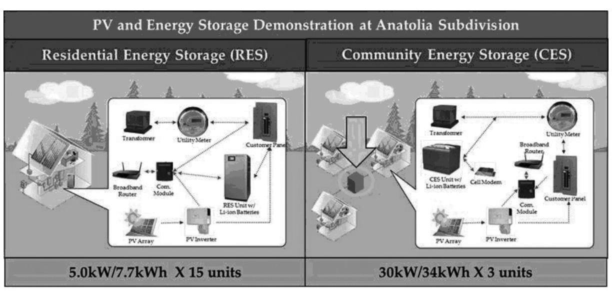
Sacramento Municipal Utility District (SMUD), Sacramento, CA, Phone: 916-732-5572, Fax: 916-732-6423
Email: esanche@smud.org

SMUD is wrapping up a demonstration of distributed energy storage at homes and transformers in a Sacramento neighborhood with a high penetration of solar. The work was partially funded by DOE's Office of EERE. SMUD has aggressive renewable procurement and greenhouse gas reduction goals that will drive a high penetration of solar. SMUD is testing the value using storage to manage the solar intermittency and the mismatch between peak demand and solar output. Our project has high fidelity monitoring through the neighborhood and we have developed a detailed picture of the neighborhood's electrical system.

Our project is ending in September of 2013 and by the time of the EESAT Conference, we will have completed all of our analysis. We will present the following:

- Lessons learned in billing, customer interaction, communications, integration, and data management and analysis;
- The impact of energy storage on the community and electrical distribution system based upon real measurements;
- The value of energy storage to SMUD and its customers; and
- Strategic implications to utilities.

Below is a figure of our experimental set up that we will be discussing.



BIOGRAPHICAL NOTE

Ed Sanchez is a Project Manager at SMUD. He leads the Anatolia PV and Storage Demonstration Project and works to provide technology support, planning and integration for the Energy Research and Development efforts. Ed has worked in the Energy Efficiency Research and Development group developing business cases analysis for Combined Heat and Power, District Energy and Data Center initiatives.

PROFESSIONAL EXPERIENCE

- Twenty-five years experience in Information Technology including programming, project management, and infrastructure deployment and consulting.
- Business technology solutions through process design, application development, integration, and implementation.
- Project lead for several technology initiatives to include web applications, remote access, call center technology, computer/voice integration, network redesign, data center infrastructure and financial management systems.
- Administrator in the USAF Reserves. Plan, direct and execute medical exercises and operations providing medical care to armed services members transiting the Aeromedical Evacuation System.
- Former Educator, teaching graduate coursework at USC.
- Systems Analyst, developed system requirements and processes to support design and construction business technology solutions.

EDUCATION

- AS in Math in Science, Victor Valley Junior College
- BS in Business Administration, Operations Research and Information Systems, California Polytechnic University Pomona
- MBA in Management, Golden Gate University
- MHA University of Southern California

A REVIEW OF CURRENT AND IN-PROCESS STANDARDS FOR ELECTRICITY STORAGE

Chet Sandberg P.E.

EnerVault in Palo Alto, CA

ABSTRACT

Electricity storage has been classified as "the silver bullet" for the smart grid. It is also increasingly being seen as an ancillary service and the key to integrating renewables into the power grid. Electricity storage is also a key to implementation of micro grids and energy efficient buildings. With all this deserved attention, the engineering community has embarked on development of a number of Standards and Recommended Practices that will provide the technical background and basis for installation, design and commissioning of electricity storage systems. This paper will review a number of these standards. Some of the important characteristics of the following standards are examined:

1. IEEE P2030.2™ *Guide for the Interoperability of Energy Storage Systems Integrated with the Electric Power Infrastructure*
2. IEEE P2030.3™ *Standard for Test Procedures for Electric Energy Storage Equipment and Systems for Electric Power Systems Applications*
3. DOE/EPRI 2013 *Electricity Storage Handbook in Collaboration with NRECA*
4. NIST *Framework and Roadmap for Smart Grid Interoperability Standards*
5. DOE PNNL *Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems*
6. IEEE SCC21 1547 Series of Interconnection Standards
7. US TAG to IEC TC120 *Electrical Energy Storage Systems*
8. NFPA National Electrical Code (NEC NFPA 70)

This paper will present a cursory look at the important aspects and status of each these standards.

The Electricity Storage Association has taken on the role of a "Librarian of Electricity Storage Technical Information" through the work of its "Technical Working Group". A short review of the public accessible content of their website will also be included.

BIOGRAPHICAL NOTE

Chet Sandberg received a BS degree from Massachusetts Institute of Technology in Mechanical Engineering, and an MS in Electrical Engineering from Stanford University. He then joined the Chemelex Division of Raychem Corporation where he managed technology projects for 30 years. After working for Shell Oil for 6 years, Chet started a consulting business with emphasis on energy and electricity storage in particular. He has consulted for Altairnano and is currently consulting for EnerVault. Chet is the Chair of the Technical Working Group of the Electricity Storage Association. Chet is an invited speaker at battery conferences and has a number of patents in this area. Chet also currently consults on other various electrical and mechanical engineering due diligence projects for various venture capital firms. He is also involved with Silicon Valley startups and is an angel investor in some. He has served as an expert witness on numerous cases.

NO FUEL COMPRESSED AIR ENERGY STORAGE PLANTS APPLIED TO ENHANCING THE UTILIZATION OF RENEWABLE GENERATION RESOURCES

Contact Author: [1]Dr. Robert B. Schainker, EPRI
Other Co-Author: [2]Sebastian Freund, General Electric

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[2]Freisinger Landstasse 50, Garching b. Muenchen, D-85748, Germany, freunds@ge.com

ABSTRACT

A new type of Compressed Air Energy Storage plant which uses no fuel (i.e., an Advanced Adiabatic CAES plant) is described (See Figure 1.), highlighting thermodynamic engineering trade-off analyses used to finalize a plant design that has low capital cost and high performance metrics when applied to better utilizing and enhancing the use of renewable generation resources. In this type of plant, low cost (e.g., off-peak kWh) electricity is used to compress air into an above or below ground air storage system, which produces heat that is stored and later used to generate on-peak electricity. This paper also describes the ISO/RTO economic benefits (See Page 2, Figure 2.) of an adiabatic CAES plant to smooth out the intermittency and fluctuating power from renewable generation resources. The paper concludes with a brief description of ongoing efforts of Canada's HydroOne and Germany's RWE utilities to build utility scale pilot plants demonstrating the operating and capital costs of adiabatic CAES plants.

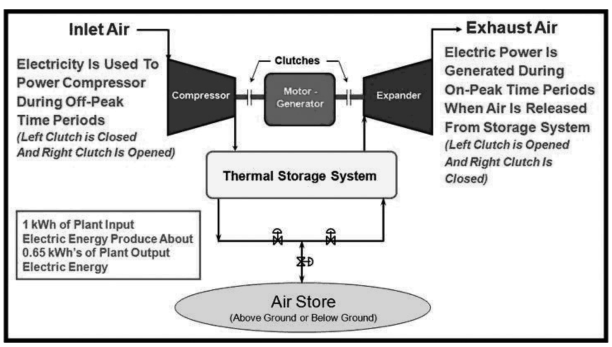

Figure 1: Simplified Schematic of No-Fuel Adiabatic CAES Plant

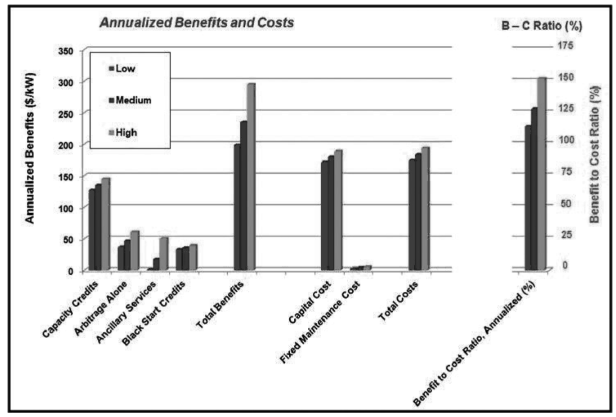

Figure 2: Benefits and Costs for Deploying Adiabatic CAES Plant: Preliminary Results

BIOGRAPHICAL NOTE

Dr. Robert Schainker is Senior Technical Executive at the Electric Power Research Institute (EPRI). He was a key contributor designing, building and testing the first US solid state high voltage converter, the first U.S. grid connected battery plant at Southern California Edison, the first compressed air energy storage plant (110M - 26 hours) at Alabama Electric Cooperative, the first 600 MVA bank of HV Recovery Transformers at CenterPoint, and assisted in the design, construction, and testing of two battery energy storage plants. Schainker has given expert testimony to the U.S. Congress and to the U.S. Federal Energy Regulatory Commission on strategic planning and ways to improve the efficiency and reliability of the U.S. grid. He was also a guest editor for the IEEE Power and Energy Journal (March-April, 2006) which published a landmark set of papers on US grid security. He holds three patents (two on energy storage systems and one on an improvement to the design of simple cycle and combined cycle combustion turbine plants). He also has written chapters in two encyclopedias on energy storage technologies. He has a BS in Mechanical Engineering, a MS in Electrical Engineering and a PhD in Mathematics.

COMBINING LARGE-SCALE PUMPED HYDRO STORAGE AND WIND FOR 1200 MEGAWATTS OF 100% RENEWABLE, HIGH CAPACITY FACTOR, FULLY-DISPATCHABLE ELECTRIC GENERATION IN THE UPPER MIDWEST

Robert H. Schulte, Principal, Schulte Associates LLC

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ABSTRACT

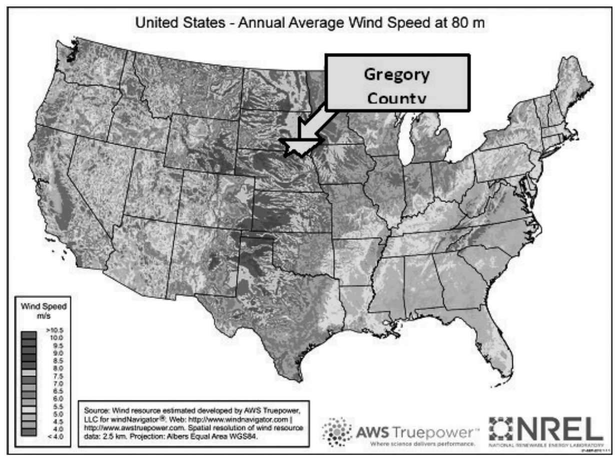
Gregory County in south central South Dakota has been identified by the U.S. Army Corps of Engineers as the best potential pumped hydro site on the Missouri River. Using the existing Lake Francis Case, the 5.7 million acre-feet impoundment behind the existing Fort Randall dam as a lower reservoir, the site offers 700 feet of hydraulic head, and potential upper reservoir capability to provide up to 2400 MW of pumped hydro capacity.

The site is located in some of the best wind speed resources in the country (Figure 1.). No existing pumped hydro facility in the U.S. is so favorably located with regard to wind resources. Wind farm annual capacity factors of greater than 40% are common here. Combined with the pumped hydro site, the opportunity exists to create a 100% renewable storage/wind combination resource of unequalled capabilities. Such a combo could conceivably replace existing or future fossil-fired generation sources for intermediate or baseload duty. It could provide a resource for connection to regional markets in the Midcontinent Independent System Operator (MISO), Southwest Power Pool (SPP) or Western Electricity Coordinating Council (WECC) whose boundaries are all located nearby, or transfer by ultra-high voltage lines to markets elsewhere.

This paper will summarize a Schulte Associates LLC (SA) analysis of combining the pumped storage and regional wind resource into a combo resource of 1200 Megawatts (MW) of fully-dispatchable generation capacity at a high (60% to 80%) annual capacity factor. In contrast to traditional pumped storage operations that pump (store) during off-peak electric load hours, the study will evaluate the combo resource by dispatching the pumping phase in accordance with wind speed/output. This will enable a 1200 MW pumped hydro unit, with only 1200 MW of outlet transmission, to accommodate more than 2000 MW of installed wind capacity.

The study will be performed using actual hourly wind data from large wind farms within transmission distance from Gregory County. It will also include consideration of hourly diversity of actual wind farm outputs from farms hundreds of miles apart; thereby assessing the potential benefit of using widely-dispersed wind farms rather than a single, local farm. Results of the study will include lifetime cost comparisons of the storage/wind combo resource with natural gas-fired combined cycle and combined cycle/wind combinations to provide the same amount of annual dependable capacity and energy. The effect of regional wind patterns on the required size of the upper reservoir will be examined. Relative amounts of renewables made possible by each alternative and resulting greenhouse gas emissions will also be addressed.

Figure 1: Gregory County Pumped Hydro Site on Wind Speed Map of the United States



BIOGRAPHICAL NOTE

Robert "Bob" Schulte is a Principal in Schulte Associates LLC, an executive management consulting firm with offices in Raleigh North Carolina. He has 35 years of experience in the utility industry.

Bob spent 16 years at Northern States Power Company (NSP), now a unit of Xcel Energy. While at NSP, he performed resource planning, developed and managed large-scale customer demand response programs, and led planning, construction and operations for distribution facilities. He served as VP of Rates and Corporate Strategy, and VP of Marketing and Customer Service.

In the past 18 years with Schulte Associates, Bob has provided client consulting services in organizational and project development and permitting for generation and transmission projects, as well as interim CEO and COO services. He is the primary author of "Lessons from Iowa", the DOE/Sandia report on lessons learned from the planned 270 Megawatt Iowa Stored Energy Park project, available for download at www.lessonsfromiowa.org.

Bob is a native of South Dakota, the location of the project addressed in his paper. He holds Bachelors and Masters degrees in Electrical Engineering. In addition to his energy work, Bob is also COO of MLB.com Digital Academy, the new on-line youth instructional portal for Major League Baseball at mlb.com/digitalacademy.

UTILITY ENERGY STORAGE USING LARGE FORMAT LIFEPO4 BATTERIES

Paul B. Scott, Michael Simon – TransPower

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Fast-response energy storage provides a new choice in utility ancillary services for utilities and municipalities. A competitive marketplace and notable improvements in commercially available technologies are making convenient battery options affordable. TransPower uses large format lithium ion batteries in transportation applications, and is[1] developing similar batteries for stationary applications. The 80 volt module pictured has rated storage of 14kWh and can be assembled and qualified in a day with component cost of well under $1/Wh. The modules include quick disconnect couplings to enable safe and fast assembly of high voltage strings of cells. With multiple strings in parallel batteries of a megawatt hour or more it can be conveniently assembled.

In a parallel effort, a compact high power inverter has been developed for the vehicle application with a similar 250kW bi-directional inverter for the stationary applications. Multiple units of this inverter can be operated in parallel, such that transfer of megawatts DC to AC line (both battery discharging and charging) is enabled. With appropriate software provisions, energy storage over extended periods or ancillary services, including phase and/or voltage control, can be implemented.

Testing of these modules has progressed to qualification of an 870 volt string of 150kWh energy storage which with the inverter connects to a 480V three phase line. The paper will discuss the system design and evaluation of the inverter-battery system, which is to include multiple parallel strings. Applications will include voltage stabilization of a large city subway rail system.

BIOGRAPHICAL NOTE

Dr. Paul B. Scott, TransPower VP for Advanced Development, has played key roles in the development of a series of hydrogen fueled buses, a fuel cell APU for class 8 trucks, and solar and wind hydrogen generation stations. He now focuses on advanced development programs, including batteries and Zero Emission HD vehicles. It is his mission to provide clean transportation which uses locally sourced fuel.

Dr. Scott has contributed to the patent literature related to solar energy, x-ray imaging and isotope separation, and has published on diverse topics. In recent years he has frequently presented papers on solar energy and hydrogen related matters. He has consulted with over twenty corporations and technical institutes and in the mid-1990s was the on-site engineer for the Xerox/Clean Air Now Solar Hydrogen Project which included hydrogen–powered trucks and solar generated fuel.

Dr. Scott received degrees through D. Sc. from Massachusetts Institute of Technology and served on the professorial staffs of MIT and University of Southern California.

[1]Supported by the California Energy Commission, Agreement 500-10-058

OPTIMIZING ENERGY STORAGE TO MITIGATE VARIABILITY OF RENEWABLE ENERGY AND IMPROVE RESILIENCY OF THE ELECTRICITY

Mohammad B. Shadmand[1] and Robert S. Balog[2]

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ABSTRACT

Interest in renewable energy-generated electricity continues to gain popularity. However, two fundamental limitations exist that prevent widespread adoption: variability of generation and the cost of equipment. Distributed grid-tied photovoltaic (PV) systems with centralized battery back-up have been proposed for community-scale microgrids. In addition to improving electricity reliability for the microgrid, this concept also mitigates the variability of the renewable resources as seen by the utility. Thus, a neighborhood designed with distributed PV and centralized battery storage is an attractive technology solution for communities to “go green” without compromising reliability of the electric utility. The downside is the cost of the equipment needed for the PV and battery grid interface. Optimization of generation, storage, and mitigation of variability is imperative to the financial feasibility of such microgrid systems.

The focus of this project was to develop design methodology that minimized the variability of a high-penetration PV scenario in a residential community application. The case study was a 27.6 kW PV system installed on Texas A&M campus, a system configured as five residential-scale arrays. Electricity generation data is sampled every 10 seconds which provides a dataset with far greater temporal resolution than that used in most PV sizing and economic studies. The result shows that the variability of high penetration PV is not as large as if the PV was centrally located and that only a small amount of community energy storage is needed to arbitrarily mitigate this variability as well as reduce energy intensity through demand reduction including peak shaving and demand shifting. The presentation will explore these concepts by examining the optimization methodology and discuss the dataset and results of the study.

The campus PV array was a Department of Energy sponsored collaboration between the PI and the TAMU Athletics Department. The location of the array, adjacent to Kyle Football Stadium and visible to 83,000 game day spectators, is a strategic effort to support the community outreach mission of the project to educate the public about the science behind renewable energy. The presentation will also showcase how the PV array is incorporated in the classroom to teach interdisciplinary students about renewable energy technology.

Keywords: photovoltaic energy, storage system, solar energy, optimization, community outreach, smart grid

POWER-TO-GAS: A HYDROGEN ENERGY STORAGE SOLUTION

Ryan Sookhoo

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ABSTRACT

As the penetration of renewable sources of generation in a region grows, integration challenges emerge. One is energy balancing in the local distribution network. Another is absorbing surplus output at night when it is not needed and shifting it to the following day's peak. However, the combination of a high proportion of renewables in the generation mixed with seasonal variations in load demand has presented another challenge in several jurisdictions—extended periods of surplus generation. The need to load-follow renewables and absorb the surplus power on consecutive days, and even consecutive weeks, without the opportunity to discharge the stored energy requires storage in TWh range. In other words, seasonal storage. Power-to-Gas is an innovative solution using electrolysis. It converts surplus renewable generation when it is not needed into renewable transport, low carbon heat or dispatchable renewable generation where and when it is needed. It provides a link to capitalize on the vast potential of alternate generation sources by using hydrogen for running clean fuel cell electric vehicles or injecting hydrogen into the existing natural gas system. Numerous Power-to-Gas demonstration projects have been launched to date.

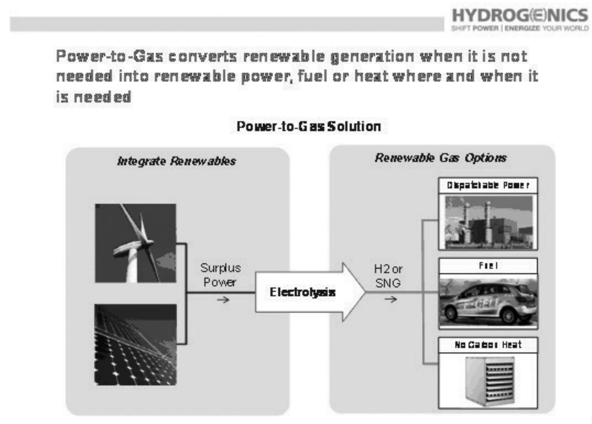
Power-to-Gas is a highly effective way of integrating renewables. It can provide a rapid, dynamic response to the independent grid operator's signals to adjust to the variations in renewable generation output. A Power-to-Gas facility can provide ancillary services such asload-following and can be deployed at locations on the power grid where there is congestion.

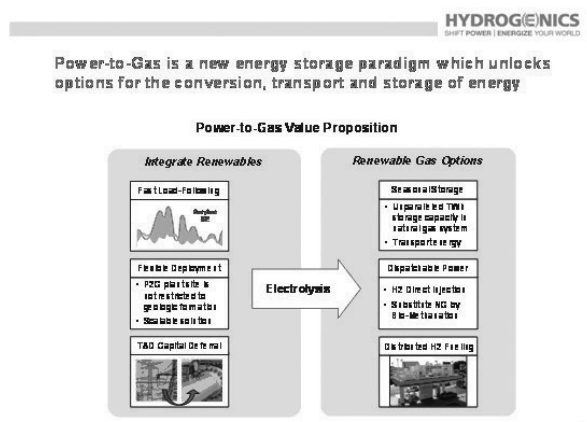
Other large-scale energy storage technologies such as pumped hydro or compressed air energy storage are limited to specific reservoir or cavern sites. Traditional energy storage technologies such as batteries capture, store and discharge electricity at a single location, but

Power-to-Gas represents an entirely new energy storage paradigm. It is a scalable technology which provides virtually unparalleled energy storage capacity.

The heart of the Power-to-Gas solution is the electrolyzer. It converts surplus energy to hydrogen by electrolysis—the splitting of water (H2O) molecules into its constituent elements of hydrogen (H2) and oxygen (O2) using electricity. The hydrogen and oxygen are evolved as gases from the electrolyzer without any carbon emissions. The hydrogen is then compressed, metered and injected into the existing natural gas system.

Alternatively, the hydrogen can supply a hydrogen fueling station for Fuel Cell ElectricVehicles (FCEVs). The purity of the hydrogen produced by an electrolyzer is very high and well-suited to this application. Another option is to produce substitute natural gas through a methanation process. For example, hydrogen can be used to enhance the energy content and utility of existing biogas plants by converting the carbon dioxide content (typically 35—40%) to biomethane.





BIOGRAPHICAL NOTE

Ryan Sookhoo, currently a Director of New Initiatives at Hydrogenics Corporation, has been a dedicated member of the research and development program since joining the organization in 2006 as project manager for PEM fuel cell development and commercialization. He holds BE in Electrical Engineering. As a leader in hydrogen generation and fuel cell industries, Hydrogenics has given Ryan the opportunities to work with various industries in helping define many of “tomorrow’s energy & power solutions”.

Throughout his time at Hydrogenics, Ryan has been committed to innovation; his involvement has spanned the PEM fuel cell development and commercialization from conceptual assessment, design, manufacture, test, certification, operations, marketing and customer adoption of new technologies. Leveraging his many years of experience working in Hydrogenics, he focuses on bridging the energy gaps through the use of PEM fuel cells in advancing technology sectors.

THE INFLUENCE OF EXCESS SODIUM ON NASICON MATERIALS CHEMISTRY

Erik D. Spoerke[1], Nelson Bell, Cynthia Edney, Jill Wheeler, and David Ingersoll

[1]Sandia National Laboratories, Albuquerque, NM USA

ABSTRACT

Sodium ion chemistries offer tremendous opportunities for next generation battery technologies. Realizing the effective utility of these new battery systems, however, depends on the development of a robust, efficient solid state electrolyte, capable of physically separating molten sodium from incompatible catholytes, while providing high sodium ion conductivity for effective battery performance. The solid state electrolyte NaSICON (Sodium Super Ion Conductor) with the composition $Na_{1+x}Zr2P_{3-x}Si_xO_{12}$ ($0 \le x \le 2$) is a promising candidate electrolyte that has demonstrated excellent sodium ion conductivity[1] and stability against molten sodium, but it is prone to the formation of deleterious secondary phases such as ZrO_2 or amorphous, glassy materials, particularly when formed at high temperatures (>1200°C).[2]

We explore here a lower temperature (<1100°C) sol-gel route to NaSICON synthesis, using this process as a platform to evaluate the influences of introducing excess sodium to the ceramic composition. In particular, we explore the relationships between processing temperature and NaSICON composition as they affect the ceramic phase chemistry and stability against aqueous electrolytes. Our research identifies an optimal window for NaSICON formation using this particular sol-gel approach, balancing phase conversion and reagent volatility. In addition, we provide new evidence that small amounts of excess sodium can dramatically affect the formation and transformation of ZrO_2 secondary phases, likely through influences on the liquid phase sintering processes involved in NaSICON synthesis. Sodium phosphate and sodium silicate glasses formed during this process, however, can lead to significant instability against aqueous electrolytes. Insights from these studies may lead to new approaches for low temperature syntheses of phase-pure NaSICON electrolytes for emerging sodium battery systems.

The author gratefully acknowledges support from Energy Storage Program, managed by Dr. Imre Gyuk for the Department of Energy Office of Electricity Delivery and Energy Reliability. Sandia National Laboratories is a multi-program laboratory operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Company, for the US Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

[1] a) J. B. Goodenough, et al., *Mater Res Bull* **1976**, *11*, 203-220; b) H. Y. P. Hong, *Mater Res Bull* **1976**, *11*, 173-182; c) H.-B. Kang, *et al. J Mater Sci* **1999**, *34*, 5005-5013; d)D. M. Zhu, *et al. Key Eng Mater* **2007**, *334-335*, 149-152.

[2] a) A. Ahmad, *et al. Solid State Ionics* **1987**, *24*, 89-97; b) R. S. Gordon, *et al., Sol St Ionics* **1981**, *3/4*, 243-248; c) U. Warhus, *et al. J Sol St Chem* **1988**, *72*, 113-125.

BIOGRAPHICAL NOTE

Erik D. Spoerke, Ph.D. is currently a Principal Research and Development Materials Scientist in the Electronic, Optical, and Nano Materials Department at Sandia National Laboratories in Albuquerque, NM. Erik's research efforts span a diverse materials portfolio, with an emphasis on combining elements of chemistry, biology, and materials science to study and develop functional materials ranging from novel electrochemical materials to synthetic biological analogs and supramolecular thin film photovoltaics. Recently, he has focused efforts around ion-conducting materials aimed at the development of solid state electrolytes, functional separators, and even ionic filters for next generation ion-mediated technologies.

Prior to joining Sandia in 2003, Erik earned a B.S. (1998) and a Ph.D. (2003) in Materials Science and Engineering at Northwestern University in Evanston, IL. In his doctoral research, working with Professor Samuel I. Stupp, Erik applied a multidisciplinary approach to develop artificial bone replacement materials, utilizing combinations of porous titanium metallurgy, engineered synthetic peptides, and nanoscale calcium phosphate crystal growth.

He continues to employ this multidisciplinary strategy to materials development in his current research, working with a creative, dynamic group of technicians, postdocs, and students exploring materials challenges across a wide range of energy-relevant technologies.

INTEGRATION OF DISTRIBUTED SOLAR AND STORAGE TO SUPPORT DISTRIBUTION SYSTEM STABILITY

Doug Staker

Demand Energy Networks, Inc., Liberty Lake, WA

ABSTRACT

Many utilities throughout the United States are facing distribution system stability issues due to a number of factors. These factors range from increased saturation of solar power at the end of the feeder from both residential and commercial customers to increased EV adoption in large metro areas that already have peak distribution system loading issues. These factors and others present an opportunity for both utilities and customers to leverage existing and new solar installations in conjunction with distributed storage to solve the growing distribution system stability problem. There is a common misconception that storage must be deployed centrally at the substation or within the transmission system infrastructure. Leveraging the power of Demand Energy's software platform, multiple, smaller distributed storage systems can be aggregated in conjunction with distributed PV systems as a virtualized multi-megawatt generation system to increase stability for the distribution system. Additional benefits to the utility such as line loss reduction can be achieved in these scenarios as well.

This presentation is targeted to both commercial customers and utilities. The attendees of this session will walk away with an understanding of how distributed commercial solar directly coupled with energy storage can be managed and operated in a manner that offers daily benefits to both the solar customers as well as the utilities. The knowledge that the attendees of this session will gain is:

- How the PV systems and distributed storage systems can be managed as logical entities and the operational models/modes that can be implemented.
- How this type of infrastructure benefits the distribution system by providing relief at the "edge" of the grid.
- A detailed understanding of the benefits available to both the utility and the commercial customer and the resulting LCOE.

This session will be presented by: Doug Staker Vice President of Business Development for Demand Energy Networks

Doug Staker is the vice president of business development at Demand Energy, a distributed energy storage company with global activity. Staker has been involved in the energy business worldwide for 30 years. He started his career as an engineer in developing independent hydropower project in the 1980s. Prior to joining Demand Energy, he held a variety of executive positions at Itron, a global leader in smart meter technology.

UTILIZING EV/PHEV BATTERIES FOR COMMUNITY ENERGY STORAGE SYSTEM APPLICATIONS

Michael Starke

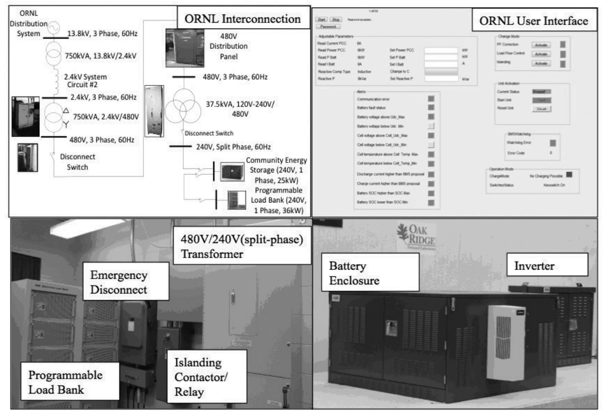
Oak Ridge National Laboratory, Oak Ridge, TN

ABSTRACT

This paper presents a study on the integration of a community energy (CES) storage system composed of repurposed used electric or plug-in hybrid electric vehicle (EV/PHEV) battery packs into the distribution system at Oak Ridge National Laboratory. The expectation is that the batteries from vehicles will be replaced with a fresh battery pack by the original equipment manufacturers (OEMs) once their performance (storage capacity and peak power capability) decreases to 80% of the initial performance. CES systems can be a feasible “secondary-use” of these after-vehicle batteries due to economic and environmental reasons. These batteries, if their power electronic interfaces are controlled properly, can perform many grid support applications or provide grid ancillary services as will be detailed in this study.

Applications of energy storage systems in power systems have always drawn significant interest from energy storage manufacturers and power system experts. A key issue for mass-market acceptance has been capturing the applications that have benefit to cost ratios exceeding 1.0. In a recent study, single and synergistic benefits were examined for secondary-use battery applications and a number of applications where energy storage will most likely fill a role were proposed.

This paper will focus on the testing and results of initial grid integration of secondary-use CES batteries. The specific applications discussed are: delivering peak shaving or increased load factor delivery at the residential level, providing potential regulation and spinning services via a signal received from a central control system (i.e., aggregator, utility, or ISO), providing voltage support through reactive power when required, and providing uninterrupted service. Besides analysis of actual batteries on the ORNL system, this work utilizes data captured from occupied residential homes for simulation of the load and a lithium-ion battery model to capture generation and charging characteristics. Future work and analysis will also be discussed.



BIOGRAPHICAL NOTE

Michael Starke is a Power System Research Engineer at the Oak Ridge National Laboratory. Michael currently leads a team of scientists, engineers, and technicians in research efforts at ORNL in areas of demand response, energy storage, and renewable energy integration in partnership with industry.

Prior to energy storage research, Michael was the chair of the Wind and Solar Plant Collector Design working in moving forward with standards in wind and solar plant design.

Michael received his B.S, M.S. and Ph.D. in electrical and computer engineering at The University of Tennessee in 2004, 2006, and 2009 respectively. He is a member of IEEE and of the Power and Energy Society with a number of publications in power systems and power electronics.

ADVANCED THERMAL ENERGY STORAGE FOR DIRECT LOAD CONTROL IN A LOW LOAD GROWTH -- HIGH DG FUTURE

Designated Contact Author: Paul Steffes, PE, CEO

Steffes Corporation, 3050 North Dakota 22, Dickinson, ND 58601

According to the 2011 FERC report "Assessment of Demand Response and Advanced Metering", direct load control programs are the most commonly used type of incentive-based demand response program, and represent 7% of total peak load across all ISOs and RTOs.

Sandia National Laboratory's ES-Select software model ranks thermal storage as the lowest cost of any energy storage, and the only one with a payback.

In June 2012, the American Council for An Energy-Efficient Economy (ACEEE) issued a report detailing a networked and systems based approach and in it they said: "Intelligent efficiency" is a systems-based approach ... that it is adaptive, anticipatory, and networked. "Intelligent efficiency is a systems-based approach to efficiency that can help to meet this need. ACEEE's report went on to say: "If the United States were to take advantage of currently available information and communications technologies that enable system efficiencies, we could reduce energy use by about 12–22% and realize tens or hundreds of billions of dollars in energy savings and productivity gains."

Cost-effect – Advanced - thermal storage combines the proven value of DLC with the leverage of a networked systems approach labeled by ACEEE as "intelligent efficiency".

Over 5 years ago, the Steffes Corporation, a leader in Electric Thermal Storage (ETS) began development of a 2-way communications controller which allowed electric space heaters to become grid-interactive electric thermal storage (GETS). Since that time, Steffes has had nearly 2 dozen demonstrations and trials, each responding to various utility or power provider signals in order to test this 2-way communication on both electric space heaters and electric storage water heaters.

Those trials indicate that GETS can adjust its charge rate and change as fast as wind and other renewable generation and so is able to respond as fast and as accurately, if not more so, than many other advanced storage technologies coming to market today, all while providing continuous hot water or space heating to the customer with no interruption. That means that utilities can integrate one tool that can peak shave, load shift, take advantage of low (or in some parts of the country, negative) LMP's, stabilize the grid with regulation, neutralize fast ramp challenges of unexpected shifts in variable energy resources (especially when baseload is at minimum run rate), and help accommodate greater penetration of renewable energy.

Utilities are looking for answers in a sluggish low-load environment and they are feeling increasingly challenged with the additional outlook of high penetration DG. Adding 2-way communication, high speed telemetry, monitoring, and verification creates "Intelligent Efficiency" systems effects that add a string of new values to that well known utility DLC tool.

BIOGRAPHICAL NOTE

Paul Steffes is the CEO for Steffes Corporation, an American manufacturer of residential, commercial, and industrial electric thermal storage (ETS) space and water heating systems. Paul's work focuses on transforming ETS into aggregated grid-interactive and dispatchable assets supporting renewable energy that assist utilities with balancing supply and demand in real-time.

MARKET EVALUATION FOR ENERGY STORAGE IN THE UNITED STATES

Prepared For The Copper Development Association by DNV KEMA

Contact: Zolaikha Strong - Director Sustainable Energy, Copper Development Association PMB 311 450 Massachusetts Ave, Washington DC 20001 202-558-7625, zolaikha.strong@copperalliance.us

Commissioned by the Copper Development Association Inc. (CDA), this paper evaluates the near-term market for grid energy storage in the United States (U.S.) and the copper content associated with this market. The CDA is a trade association chartered to enhance and expand markets for copper and its alloys in North America. To determine the energy storage market KEMA focused on four core points:

1. Defining the current market for energy storage in the U.S.
2. Assessing initiatives that are shaping the U.S. energy storage market.
3. Forecasting the near-future U.S. market for energy storage from 2011 to 2016.
4. Projecting copper demand associated with the U.S. energy storage market.

To forecast an annual market size of grid storage in the U.S., KEMA used its energy storage market penetration model. The analysis incorporated information on current and planned U.S. grid-storage activities, known grid-storage market trends, and proposed energy-storage incentives. KEMA supplemented analysis of the current market and five-year market potential with information on longer term market drivers to provide further insight into the U.S. market potential. The study considers technologies including electrochemical, mechanical and thermal storage, and grid applications ranging from distributed community energy storage (CES) to centralized, bulk storage. The study focuses on the four applications of ancillary services, transmission services, community energy storage, and other distributed storage.

The study found that industry analysts forecast that the global market for energy storage over the next 10 to 20 years could be upward of 300 GW in size and \$200–\$600 billion in value. The study found that the future U.S. grid energy storage market value is forecasted to reach between two to four gigawatts in size by 2016 in some of the most promising grid energy storage applications – ancillary services, renewable energy integration, transmission support, and community energy services. Near-term growth is expected in part due to past investments as well as the emergence of new policies that will likely promote the market. The long-term market for storage will depend on the ability of suppliers to reduce costs and policies to help formalize application markets. Copper will potentially play a significant role in the U.S. energy storage market, due largely to the electrical equipment used to integrate these technologies and also due in part to the copper intensity of the devices themselves. Though the technologies and configurations for energy storage applications have yet to standardize, and though many new applications may emerge, initial trends indicate that the copper intensity of grid storage applications can range from zero to more than 4 tons per MW.

Francie Israeli will present in Zolaikha Strong's stead.

BIOGRAPHICAL NOTE

Francie Israeli is Senior Vice President of Kellen Adams Public Affairs, and is responsible for development and implementation of public affairs and issue-driven campaigns on behalf of a number of clients, particularly on environmental and energy issues. Ms. Israeli is representing the Copper Development Association (CDA) at the EESAT 2013 Conference to discuss the CDA commissioned study on the Market Evaluation for Energy Storage in the United States (conducted by DNV KEMA).

In her role with Kellen Adams Associates she is responsible for spearheading strategic client programs focused on reaching policymakers and influencers. She has also organized client exhibits at major scientific conferences in Europe as well as the U.S. Francie has more than a decade of experience in corporate and non-profit PR in both New York and Washington. She serves on the global Board of Directors of the WORLDCOM Public Relations Group, the world's leading partnership of independently owned public relations counseling firms.

Francie holds a B.A. in journalism from the University of Maryland.

SMART GRID CLOUD PLATFORM OF DISTRIBUTED ENERGY STORAGE FOR FREQUENCY REGULATION SERVICE TO COMMUNITY ENERGY STORAGE APPLICATION

Kenji Taima[1], Bryant Eastham[2], Byron Gudmundson[2], Byron Washom[3], Joseph Romero[3]

[1]Panasonic Corporation, ECO Solutions Company; Kadoma, Osaka Japan;
[2]Panasonic Energy Solution Development Center America
[3]University of California San Diego

ABSTRACT

Panasonic launched mass production of high-capacity and high-voltage lithium-ion battery in 2010, and has conducted several demonstration projects. The 1.6 MWh demonstration system installed at Panasonic battery factory in Japan consists of 800 battery packs, and has been utilized as a test-bed.

This demonstration system has been upgraded to be a cloud-based energy storage platform. The target platform is flexible enough to build an energy storage system with minimum customization for the wide range of applications including grid-level Frequency Regulation (FR) service to mass deployment of distributed Community Energy Storage service.

Generally, each ISO FR market has its own mechanism, rule and interconnection interface. The interface software and battery operation algorithm to maximize economical benefits needs to be customized for each ISO market, even if the installed energy storage power system is the same. We implemented this software on a cloud to minimize the individual development to different flavored hardware of the energy storage power system for different ISO markets. This cloud-based architecture has another benefit to be able to update the algorithm of all installed energy storage power system at the same time, to easily maintain and control software versions.

Typically, a FR system is a megawatt-scale battery system, but several tens of kW stationary battery systems and EV batteries are expected to be aggregated as a fleet soon. The developed platform is designed for handling easily such aggregation by the cloud and is suitable for such aggregation business model.

The platform is also integrated with a cloud-based battery monitoring system to ensure the system reliability. Every one second all battery status information is temporarily stored locally in a site controller of the energy storage power system. In the case of a10 Megawatt scale site, 270,000 times internet transaction per second would be generated. To reduce this network load, the site controller calculates only the average, minimum and maximum values of all data collected within one minute, and sends out to the cloud-based battery database. On the other hand, when system errors occur, the site controller sends out automatically the stored original one second interval data for three minutes before and after the system errors, for finding the causes.

Finally, the results of experiments at University of California San Diego using this platform are also discussed, especially in response to PJM four second interval FR signals for fast resources.

BIOGRAPHICAL NOTE

Kenji Taima is a directing manager of a new business development at Panasonic Corporation. Kenji is responsible for leading a team of the Ancillary Power project, and works on the smart grid cloud solution platform of distributed energy storage to be applied for Frequency Regulation (FR) service to Community Energy Storage (CES).

Kenji joined SANYO Electric Co., Ltd. and has been working on various projects including the world first music distribution service over mobile phone network with unique PKI infrastructure in 1999, and served as a board member of the international MultiMediaCard Association to release Secure MultiMedia card.

He was also working on international standardization of a “digital” storage, a versatile removable secure hard disk drive for both broadcasting HD TV programs and digital data such as PC and digital camera under unique security framework in 2001 and served as a secretary general of the iVDR Consortium.

He began his career in energy storage in 2009, primarily specialized in the new business development including business model development, strategy planning and partnering.

DEVELOPMENT OF A CONTAINERIZED 200 KW NAS BATTERY UNIT

Tomio Tamakoshi

NGK INSULATORS, LTD. Nagoya Japan

A new NAS Battery Unit (NBU) rated at 200kW and configured for 20-ft cargo containers is under development at NGK. The container will function as the battery enclosure and its use will expedite exporting, installing and relocating multi-MW-scale NAS installations. The NBU will incorporate six 36 kW, 180 kWh modules and their battery management system, along with thermal management to accommodate a broad range of ambient site conditions. NGK plans to start taking orders soon and plans to deploy the 200 kW NBU in 2015.

Keywords: sodium sulfur battery

1. INTRODUCTION

Over 300 of NGK's 1 MW, 6 MWh NAS Battery units based on 50 kW modules have been deployed worldwide. That design is essentially unchanged since it was conceived in the mid-1990s. As demand for NAS has grown beyond the domestic market, deployment efficiency has become a more important cost element in growth markets, as has the need to accommodate a broader range of ambient site conditions. Design studies led to the selection of 1) the 20-ft container envelope, 2) battery modules maximum at 36 kW, and 3) thermal management by way of internal heaters combined with forced air cooling to maintain the internal NAS operating temperature regime of 300 to 350C.

2. DEVELOPMENT OF THE 36KW NAS MODULE

2.1 Specification

A 36kW NAS module containing 192 cells connected in series and parallel is under development. Thermal management is accomplished by temperature controlled forced air cooling and variable power resistance heaters within the modules. This design will maintain the normal cell temperature regime up to discharge at 120% of module rated power. Specifications are summarized in Table 1.

Table 1. Specifications for the 36kW Module

	Spec.	Note
Cell Number	192	
Cell Arrangement	(8s x 12p) x 2s	
Rated power, DC	37.9kW	Max.3hrs
Rated Energy, DC	189.6kWh	
Continuous Power, DC	31.6kW	
Heating Power	900W/module	w/o cooling
	1900W/module	w/ cooling
Weight, kg	2,500	

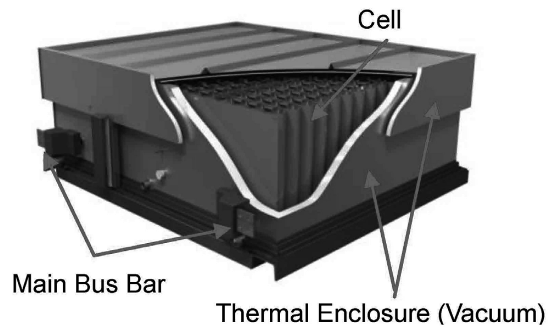


Figure 1: Isometric – 36kW NAS Module

2.2 THERMAL MANAGEMENT SYSTEM

During standby, internal temperatures are maintained with minimal heating power, i.e., about 900 W/module. When the module is operated, forced air cooling prevents over-temperature conditions. With this thermal management system, round trip efficiency (full discharge to full charge, AC) remains about 75% regardless of discharge duration. System performance is illustrated in Figure 2 during a discharge at 120% rated power, followed by charging. Even under these conditions, the peak temperature is reduced by 8C and the internal temperature returns to the normal standby condition of 305C within 16 hours.

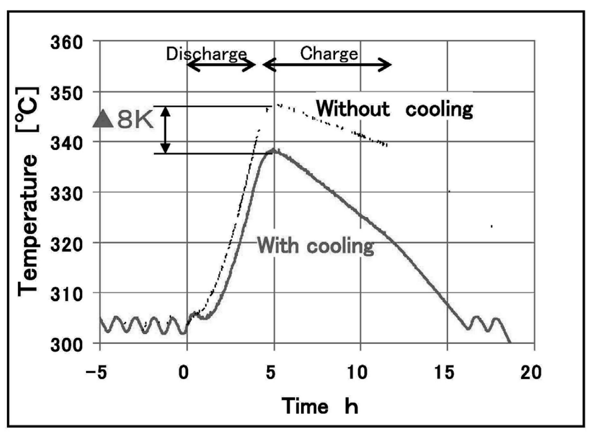


Figure 2: Temperature with/without Cooling

2.3 SAFETY FEATURES

The enhanced safety features incorporated in NGK's 50 kW module over the past two years are incorporated into the 36kW module design. The serial arrangement of cell blocks in the 36 kW module design intrinsically eliminates potential short circuits between cell blocks as illustrated in Fig. 3. As before, thermal insulation and a thermal resistance sheet capable of 2000 C temperatures are set around each cell. A thermal protection sheet is also applied to the top and bottom of the module. This thermal protection system prevents fire due to the ignition of one cell from propagating to adjacent cells. The cell arrangement and the results from a test of this configuration are shown in Fig. 4. Such tests confirm that fire propagation is prevented.

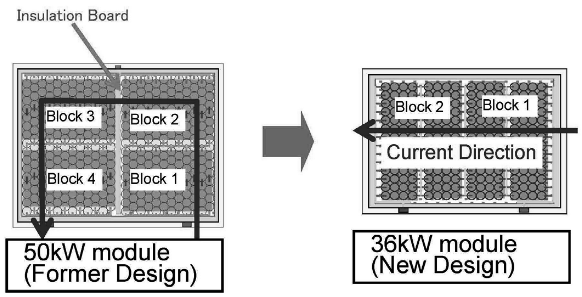


Figure 3: Improved Cell Arrangement

Figure 4: Cell Ignition Test Arrangement and Results

3. DEVELOPMENT OF THE 200 KW NBU

The 200 kW NBU consists of six 36 kW modules and the module controller, integrated in a 20-ft container as shown in Figure 5. The container is divided into two compartments: a compartment for modules and a separate compartment for the controller. The temperature within the module compartment is maintained at less than 80C for ambient site temperatures up to 50C, while the temperature within the controller compartment is maintained at less than 40 C by forced air ventilation or air conditioning as needed. This design approach minimizes the need for auxiliary power to cool controller components even in very hot ambient environments. NBU specifications are summarized in Table 2.

Up to four 200 kW NBU can be connected in series within the low voltage class. Fig.6 is a one-line diagram of 1,200kW NAS installation with six 200 kW NBU.

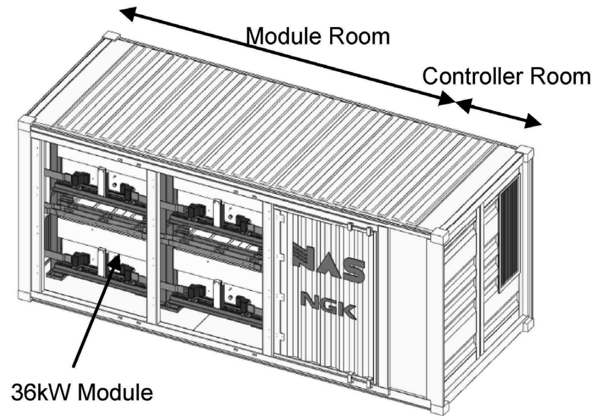


Figure 5: Isometric – 200kW NBU

Table 2 Specification for 200 kW NBU

Content	Specification	Note
Number of Modules	Six	36kW Module
AC Power / duration /round trip eff. At initial	180 kW/7.2hrs/78%	AC/DC conversion Eff.: 95%
	200 kW/4hrs/76%	
	220 kW/3hrs/76%	
Energy, AC	1,080 kWh	
Voltage Range	140 to 230V	
Current Range	-760 to 1380A	
Series Connection	Up to 4 unit	Low Voltage Class
Size	6.0mW x 2.4mD x 2.6mH	
Weight	Approx. 20t	
Ambient Temp.	Up to 50 degree C	

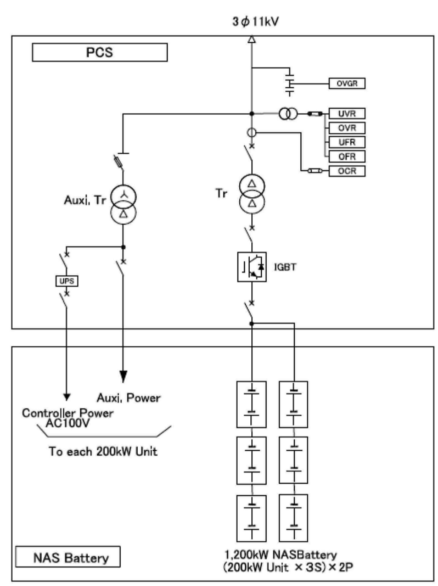


Figure 6: One- Line Diagram of 1200 kW NAS Installation with Six 200 kW NBU

BIOGRAPHICAL NOTE

Tomio Tamakoshi is General Manager of the Design Department, NAS Battery Division, NGK Insulators, LTD. He joined the NAS Battery Division in 1988, where he has contributed to development of the battery module, controller, and the system design. He was project manager for the integration of the 34MW NAS battery system with the 51 MW wind farm at Rokkasho-Futamata. He received B.Sc. and M.Sc. degrees in electrical engineering from Nagoya University in 1986 and 1988.

ABSTRACT: BREAKTHROUGH ENERGY STORAGE USING SURGE CURRENT TURN-OFF SOLID STATE SWITCHING

Dr. V Temple

Silicon Power Corporation, Clifton Park, NY

ABSTRACT

It is well-known that inductive energy storage has a many order of magnitude advantage over capacitive energy storage (Eq. 1), and that the missing link is a reliable (solid state) opening switch that can handle and turn off very high currents and block high voltages. We believe that the technology in both silicon and SiC has reached the point where this is possible utilizing resonant turn-off, and will present device, package and test data that support this claim, both for silicon and SiC-based switching.

$$\eta_E = \frac{energy}{volume} = \frac{1}{2}\epsilon E^2 \quad \eta_B = \frac{energy}{volume} = \frac{B^2}{2\mu} \qquad [1]$$

$$\eta_B/\eta_E = (B/E)^2/(\varepsilon\mu) = (Bc/E)^2 = 6.5x10^5$$

Where c is medium speed of light, B=7T and E=2.6MV/m

During the past 5 years, ARL has funded an ambitious program [1] at Silicon Power and at CREE aimed at providing closing switches operating at >10kA/us that provide, in one example, a 400kA, 150us pulse in a switch of about the size of a gallon of milk, utilizing 6 parallel, 4 series 8-die modules. These 8-die modules depend on SuperGTO's', fabricated initially in silicon and then in silicon carbide, both for their enhanced performance accruing from the IC-foundry design and for their thinPak lid which optimally handles ultra-high device currents. But they also have ideal characteristics for both the main and auxiliary switches (Figure 1.) of a resonant current turn-off switch block - low forward drop and fast recovery for the main switch, and extremely high I2t "action" and di/dt capability for the resonant switch. Capabilities that allow >2kA/cm2 to be turned off in the main switch with a very short current reversal time tCR, and a very compact and easily gated auxiliary switch that reliably provides short pulses at >20kA/cm2 current densities. The result is a switch with a resonant capacitor that is gallon-sized, not room sized.

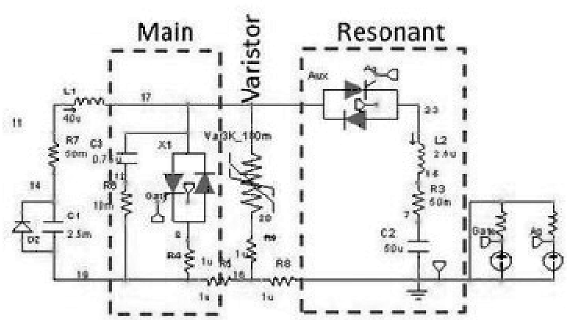


Fig 1 32kA current interrupt test circuit

Table 1 shows what we could achieve in a 30kA turn-off rated block, modeled first using standard thyristors or GTO's, then using our present 6.5 kV ARL gen2 SGTO-Off device, and then (see Figure 2.) using our 10 kV ARL SiC SGTO's, soon to be 15kV [1]. Particularly note the 100-fold reduction in capacitor value and energy, the first factor of ten from the SGTO, the second factor of ten from the switching speed advantage of SiC. Finally, attached Figure 3. shows present device, package and module hardware readiness.

Table 1. Resonant turn-off sub-circuit energies for different material and device technologies.

Semicon-ductor	Switch	Package	I-Off (kA)	I-res,pk (kA)	recovery period(us)	Cres (uF)	E-Cres (J)	V-Cres init.	V-Cres final	Lres (uH)	Rres (m?)
Silicon	std. GTO	pressPak™	37	50	83	1000	8000	-4000	5000	1.5	20
Silicon	SGTO	thinPak	33.5	50.2	17	80	640	-4000	5000	0.3	20
SiC	SGTO	thinPak	33.5	45.2	1.8	12	150	-5000	7000	0.1	20
SiC	SGTO	thinPak	33.5	48	1.25	8	100	-5000	6800	0.07	20

[1] AW911NF-12-2-0026, Production of Silicon and Silicon Carbide High-Action .. Switches ….

ADDITIONAL CLARIFYING FIGURES:

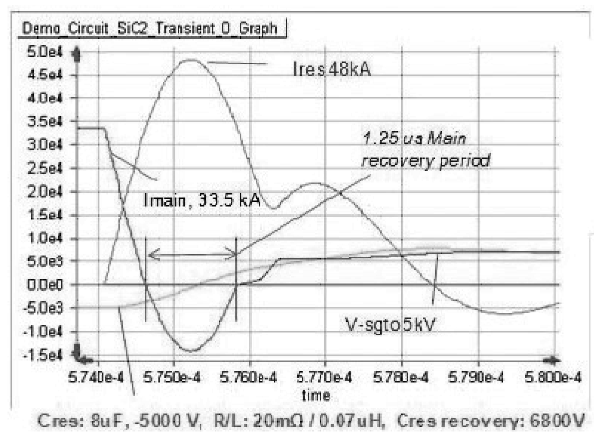


Figure 2: Resonant turn-off (see Figure 1.) with a main module containing 16cm2 of SiC active area and a resonant module with 2 cm² of SiC active area and a resonant RLC and capacitor voltage that reverses the 33.5 kA main current for 1.25us. Even with only 2cm² AA for the SiC die, resonant SiC case dissipation is only 6.8J, temperature rise 94C and cycles to failure about 2.3 e8.

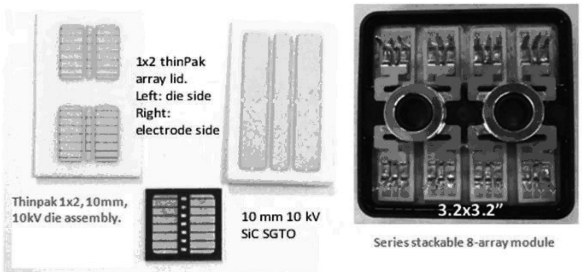


Figure 3: Left: Two 10mm 10-12 kV SiC SGTO's are mated to a thinpak lid that provides the necessary low parasitic inductance and resistance to handle the currents and di/dt's necessary.

Right: 8 pairs are combined into a stackable, compact module. Current flows through the stacked modules and returns down the two module holes, cancelling most of the stack inductance.

J. Waldron will present in Dr. Vic Temple's stead.

BIOGRAPHICAL NOTE

John Waldron is a Senior Device Technologist at Silicon Power Corporation. John has over a decade of experience in the power semiconductor business ranging from discrete power devices to power modules encompassing the design, fabrication and testing of both. John is responsible for capturing new applications for Silicon Power's silicon and silicon carbide thyristors, as well as optimizing the next generation of power electronics to be marketed by Silicon Power.

John has overseen the development, fabrication and delivery of several high frequency power module designs utilizing silicon and silicon carbide thyristors, JFETs and JBS diodes, successfully operating silicon thyristors in a resonant switching mode up to 500kHz!

John holds an MS in Electrical Engineering and a BS in Physics.

NEW NANOPARTICULATE MEMBRANES AND ELECTRODES FOR ADVANCING RECHARGEABLE BATTERIES

Robert Winkelman[1], John Wincelman[1], Z. Ryan Tian[2,3,4]

[1]Winkelman Storage Battery, Fayetteville, AR 72701
[2]Chemistry / Biochemistry
[3]Institute of Nanoscience / Engineering
[4]Microelectronics / Photonics, University of Arkansas (UARK), Fayetteville, AR

ABSTRACT

Developing new membranes/electrodes with versatile electrochemical and physical properties in both nm- and μm-scales has been a longstanding battle in advancing rechargeable batteries. To this end, our team formed to combine decades of battery manufacturing/consulting experiences in domestic/international settings with the world-leading expertise in developing nanocomposite membranes for solar-cells and rechargeable Li-ion and Na-S batteries. Targeting battery manufacturers (e.g. Eagle Picher, Johnson Controls) and battery consumers (e.g. Wal-Mart, J.B. Hunt, Tyson Foods) nearby, we have been developing (i) new nanoparticulate electrodes that can retain their high surface-area and size/shape after charging/discharging over many cycles and are suitable for being printed into flexible thin-films, and (ii) new paper-like freestanding membranes out of inorganic nanomaterials that are nontoxic, inexpensive, durable and environmental benign. Our preliminary data showed that (a) one new battery made of the new electrode after running over 6 years still performs far better than any of the same type in the market, and (b) the new nanocomposite membrane shows the never-seen-before ionic conductivity and corrosion-resistance that are long-sought in advancing rechargeable batteries. Next, we will move toward optimizing/commercializing the new battery technologies, in which we will soon seek potential investors and partners.

SHORT BIOS

Robert C. Winkelman: (CEO, Winkelman Storage Battery, 2009) Bob leads Exide's R&D in developing Sebring City Car (an EV, successfully marketed in U.S), and earned national awards from developing the Diehard battery for Sears. He then formed Winkelman Battery Company (the largest American importer of Global Y batteries from S. Korea), and advanced the AGM battery for Palma (the leading battery company in China) before forming the Good Earth Energy Conservation, Inc. (an EV manufacturer) and then LGWI. As a leader in battery technology, energy management and EV development, Bob received nonstop international consulting assignments in China, Russia, Bulgaria, Hungary, Zanzibar and South Africa.

John Winkelman: (VP, Winkelman Storage Battery) John currently serves as the Vice President of Winkelman Storage Battery in R&D and logistics. With trainings in Computer Systems Engineering (B.S., 1992, U. of Arkansas), he has performed in IT and management roles for many industries such as software development for energy efficiency controls, and got extensive hands-on experience in the manufacturing of rechargeable lead-acid batteries.

Z. Ryan Tian: (Associate Prof, UARK) Ryan's labs in SCIENCE and NANO Buildings have been developing world-unique membranes out of low-cost, environment-benign inorganic nanomaterials for advancing electrodes/separators in rechargeable Li-ion and Na-S batteries, fuel-cells, supercapacitors, solar-cells, etc. He worked at UC-Davis, industry in California and Sandia National Labs before joining the UARK. He has been consulted by energy companies (e.g. GE Energy, Duracell, Excide, etc.) since 2004. His labs house SEM, TEM, XRD, battery tester, glove-box, ICP-MS, electrochemical workstation, optical nanoimaging system, BET, UV-vis, microwave reactor, autoclaves, vacuum/regular ovens, furnaces, centrifuges, etc.

ENERGY STORAGE FOR RENEWABLE INTEGRATION AT THE UNIVERSITY OF CALIFORNIA – SAN DIEGO

William V. Torre, University of California – San Diego, La Jolla CA
Co-Author: Dan Borneo, Sandia National Labs, Albuquerque NM

Electrical Energy Storage Applications and Technologies (EESAT) 2013 Conference

ABSTRACT

The integration of energy storage into a microgrid that has renewables and distributed energy sources is very important to ensure that the full operational benefits are realized. This presentation will describe the ongoing work at the University of California, San Diego (UCSD) to integrate energy storage with renewable generation and other distributed energy sources into its 42 MW microgrid.

Due to the multiple building layout, various loads, and differing energy requirements, university campuses offer a perfect setting for establishment of a microgrid and allow for the ability to maximize operational benefits by using energy storage in a microgrid operation. UCSD has developed a state of the art self-sustaining microgrid by enhancing the existing utility infrastructure and incorporating energy storage with renewable generation. The University has a 42 MW microgrid with a master controller and optimization system that self generates 92% of its own annual electricity load and 95% of its heating and cooling load. UCSD now saves more than $800,000 per month through use of its microgrid generation when compared to the alternative of being a direct access customer importing from the grid.

This presentation will cover the University's aggressive plan to install additional renewable generation and energy storage to reduce the campus' overall carbon footprint, and create a self-sustaining campus. Highlights of the presentation will include the overview and operations of the system at UCSD.

Current PV installations of 2.3 MW, and the planned PV installation of 0.8MW. Integration of a planned SGIP funded Energy Storage system that will consist of seven systems at a total capacity of 2.7 MW/ 5 MWh that will increase the utilization of the distributed PV generation. Also UCSD has or will be installing vendor funded energy storage demonstrations that will consist of 108kW/180 kWh of Lithium-ion batteries, used EV batteries, a 125 kW/300 kWh flow battery energy storage system, and a 30 kW/30 kWh Lithium-ion battery energy storage system, 28 kW supercapacitor energy storage system, all of which will be integrated with existing rooftop PV, or CPV generation.

BIOGRAPHICAL NOTE

William V. "Bill" Torre is Program Director of Energy Storage at the Center for Energy Research, University of California – San Diego. He directs research for the UCSD microgrid, energy storage, and renewable resource integration. He recently retired as Manager of Research and Development and Chief Engineer at San Diego Gas and Electric Co. (SDG&E), in charge of implementation and testing of new technology and developing smart grid projects. Bill has worked at various management and engineering positions at SDG&E for 30 years.

He earned his Bachelor's Degree in Electrical Engineering at the University of Missouri – Rolla, and holds a Master's Degree in Electrical Engineering from California Polytechnic University. He is a senior member of IEEE, and is a registered professional engineer in California. He has authored numerous technical publications, and has spoken at many technical conferences, holds one patent and has several pending on new smart power system technology. Bill also helped to establish a power engineering program in electrical engineering at San Diego State University where he taught electrical engineering classes for 7 years. He has also worked at General Atomics on various power system research projects, and at Pacific Gas and Electric Co. as a field engineer in the construction group.

THE TRANSMISSION PLANNING PROCESS: A KEY TO ENERGY STORAGE'S USE FOR TRANSMISSION RELIABILITY PROJECTS

Charles Vartanian P.E.

UniEnergy Technologies, Huntington Beach, CA

The transmission capacity expansion planning process in North America is well-defined, and can be turned into a major opportunity for introducing the evaluation and consideration of grid storage as an additional reliability-support asset, versus the transmission planning process being a 'barrier' to storage projects. To support using the transmission planning process as a productive tool for grid storage project development, this paper outlines the underlying North American Electric Reliability Corporation's (NERC) transmission reliability standards, and the resulting regional transmission planning processes that are used to identify need, and then evaluate and select project options to meet NERC reliability standards.

Two recent positive regulatory decisions gave clear guidance that energy storage can be used, and classified for cost-recovery where appropriate, to meet transmission reliability requirements:

1) Federal Regulatory Energy Commission (FERC's) conditional approval for Western Grid Development's proposed storage-based transmission reliability projects, and
2) California Public Utility Commission's decision designating a 50 MW storage procurement target to meet a Local Capacity Requirement (LCR) resource need. LCR needs are established *based on transmission simulation studies* that identify grid constraints to the delivery of generation output into load pockets.

However, lack of supporting transmission studies is a barrier to converting these very positive regulatory rulings into actual energy storage projects. The first noted approved projects have not been developed despite FERC approval, in part because the proposed transmission reliability projects have not been evaluated through a transmission planning process, "… we (FERC) find that … the Projects are wholesale transmission facilities … **conditioned on, among other things, the California Independent System Operator Corporation's (CAISO) approval of the Projects in its transmission planning process.**[1] The second noted decision has a similar constraint that is critical-path for moving this decision/opportunity to an actual project. Per CAISO's comments to the CPUC's decision, "…the ISO has not identified any energy storage projects in its transmission planning process."[2]

Clearly, energy storage needs to be included in the CAISO's and wider North American transmission planning processes to 1) be evaluated and considered as a grid-reliability solution, and then 2) be deployed as a transmission-reliability asset that also brings increased grid resiliency and operational flexibility. To increase the Storage community's ability to engage this process, questions addressed in this paper will include, "what is NERC?", "what is Transmission?", "what technical criteria are used to justify transmission reliability projects?", "what is the study based process that is used to determine if criteria are met?", and "how can storage-based reliability projects enter this planning process for consideration and approval?".

BIOGRAPHICAL NOTE

Charles "Charlie" Vartanian is Marketing Director for UniEnergy Technologies (UET), a manufacturer of vanadium flow battery systems for grid-scale applications. Charlie has over 25 years of power industry experience including marketing advanced energy systems, leading and performing electric system planning studies, and contributing to technical standards development. At UET, Charlie focuses on matching client goals and market requirements with UET solutions. His previous employers have included DNV KEMA, A123 Systems, Southern California Edison, the California Energy Commission, Enron Energy Services, and the U.S. Navy Civil Engineer Corps. Charlie received his MSEE from USC, and his BSEE from Cal Poly Pomona. Charlie is a licensed Professional Engineer in California, and is a senior member of the IEEE.

[1]FERC Order, Docket No. EL-10-19-000, January 21, 2010, p.1

[2]CPUC Decision 13-02-015, February 13, 2013 p.60

OPTIMAL SIZING OF RESIDENTIAL BATTERY ENERGY STORAGE SYSTEMS USING HISTORICAL DEMAND

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ABSTRACT

Battery energy storage systems for residential use are now commercially available in some jurisdictions. These systems can provide a number of services to the home-owner and/or to utilities that may wish to use their storage capacity to better manage their network operations. For the home-owner, one of the benefits would be the ability to reduce peak demand charges by time-shifting loads from on-peak to off-peak, for example.

In some jurisdictions in Australia, time-off-use (ToU) tariffs are widely applied, and in many cases, peak usage charges can be up to 4 times off-peak charges. This provides a financial incentive to some home-owners to consider the use of local energy storage to minimize their electricity charges. However the financial attractiveness of a home energy storage system is highly dependent on a number of factors such as:

1. The demand profile over a full year
2. The cost of the storage system
3. The time-of-use tariff
4. The round trip efficiency and lifetime of the battery

The aim of this study has been to determine the break-even pricing in $/kWh of a storage system using historical half-hour load data for 9 homes spread across the Sydney region, for a number of tariffs. These homes cover a very wide variety of load profiles and total annual electricity consumption. The approach is to use linear programming to determine the optimum battery size that provides the lowest annual cost to the household, taking into account battery lifetime, efficiency, and tariffs, as applied to their historical load profile. It is necessary to use a full annual load profile for a city such as Sydney, to capture seasonal variations in demand with many houses using air-conditioning for both heating and cooling.

Using the historical load data and current time-of-use tariffs, it is evident that for some homes, storage systems with an installed cost of ~$1000/kWh and a 10 year lifetime are economically advantageous, using only savings provided by time-shifting load. If combined with additional revenue from a utility for example, then higher storage costs are feasible.

The presentation will show the effects of load profile, ToU tariffs, storage cost and efficiency on the optimal sizing of the battery.

BIOGRAPHICAL NOTE

Professor Anthony "Tony" Vassallo holds the Delta Electricity Chair in Sustainable Energy Development at the University of Sydney. He took up this position in October 2008. Prior to this, he held the position of Senior Principal Research Scientist with the Commonwealth Scientific & Industrial Research Organisation and has worked as a consultant to industry and government. Tony has over 80 fully refereed papers in international journals and 8 patents in the field of energy storage devices. He is the immediate past President of the Australian Institute of Energy, and leader of the Clean Energy Research Cluster in the Faculty of Engineering at the University of Sydney. His area of research is energy storage and its use in future electricity networks. He leads two major research projects on energy storage; use of energy storage in future grids, and novel materials for zinc bromine batteries. Tony has a PhD in chemistry.

ESTIMATION OF CAPITAL AND LEVELIZED COST FOR VANADIUM REDOX FLOW BATTERY

Vilayanur V Viswanathan[1], Alasdair Crawford, David Stephenson, Michael Kintner-Meyer, Bin Lu, Wei Wang, Ed Thomsen, Dave Reed, Kurt Recknagle, Brian Koppel, Patrick Balducci, Vincent Sprenkle

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ABSTRACT

Redox flow batteries (RFB) are one of the leading candidates for stationary energy storage to enable increased use of intermittent renewable energy resources and provide load-balancing services. Their quick response time, long life, deep discharge capability and independent sizing for power and energy allow significant degrees of freedom to design batteries for a range of stationary applications such as regulation, load following and load leveling/peak shaving. Each of these applications requires appropriate design of the battery system to optimize performance while keeping costs viable.

A cost model has been developed to estimate system cost for various energy to power ratios. The model development involved getting estimates for stack components in bulk from vendors and estimating energy costs from vanadium price trends along with large scale processing cost to synthesize the vanadium compounds used in the battery.

The cost model incorporates performances of cells/stacks using in-house testing. Pressure drop and shunt current losses were also incorporated to determine actual energy output. The state of charge (SOC) range of operation, current density, flow rate, flow channel dimensions and flow patterns were optimized to determine minimum system costs for various energy/power ratios. Applicability for the flow batteries to various grid applications were summarized, taking into account levelized cost for electricity storage/production. The synergistic effects of improved kinetics, lower electrode thickness, interdigitated flow and thermal management were analyzed to yield the best choice for each application.

A comparison of the levelized cost with currently deployed technologies such as combustion turbines will be made. The feedback to a PNNL-developed, DOE-OE sponsored interactive tool, which will be released to the community by the end of July 2013, will be discussed.

BIOGRAPHICAL NOTE

Vilayanur V. “Vish” Viswanathan has over 20 years’ experience in energy storage and fuel cell systems R&D. Energy storage work includes state of health (SOH) determination, battery sizing, electrode design to optimize power vs. energy, safety analysis, and design/development of Li-Ion, Na-S and redox flow batteries for stationary use. At PNNL, he is responsible for battery selection, cost estimation and sizing of energy storage systems for Transportation and Stationary applications.

Vish is actively involved in standards development for grid-connected energy storage, and was elected Head of the US Technical Advisory Group to the IEC TC120 grid-connected ESS standards development effort. He is co-managing an ESS grid integration project, where the pre-standard developed has been tested. Additional tasks will be integration with a wind farm, substation and a PV farm.

Vish holds a Ph.D. in Chemical Engineering.

STATIONERY ENERGY STORAGE SYSTEM USING REPURPOSED ELECTRIC VEHICLE BATTERIES

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ABSTRACT

Electric Vehicles (EV) battery systems are no longer suitable for vehicle application after the amount of energy that is able to be stored has degraded to approximately 80% SOC. This means the battery is now capable of only storing 80% of the energy stored for a new battery. The used batteries can have significant number of charge/discharge cycles remaining prior to the battery requiring fundamental recycling. A multi-partner project [1] sponsored by the Clean Energy Fund of Canada (CEF) investigated methodology for extending the useful life and thereby repurposing used electric vehicles battery systems into a stationery energy storage system. This energy storage system is implemented for use in the electrical power system.

The requirements for an effective repurposed EV battery program have the following challenges. EV battery technology will continue to change and develop as time proceeds. Different battery chemistry, DC voltage configurations, energy storage capacity (kW/hr), and maximum current (short term current ratings) will change from battery vendor, vehicle vendor and from year to year. Battery systems become available either due to degradation of energy storage capability or removal of the vehicle from service for other reasons have little or no historical usage information.

The CEF project developed and demonstrated a stationery energy system using batteries that effectively come from the vehicles in an “as is” state. Each vehicle battery system (consisting of the vehicle battery and its battery management system (BMS)) is used as a battery module. The project designed and implemented a dc-dc converter(s) that serves as interface and isolation for each battery module. The battery dc voltage is determined and controlled to the value as required by the battery. The battery voltage can be in the range of 300 to 700 VDC.

In order to allow parallel connection of many dc-dc converters, the collection side dc voltage is common to all. For the demonstration project, 950 VDC was selected to allow the next stage of dc-ac conversion for 600 Vac. The introduction of a dc-dc converter allows each re-proposed battery module to be operated to the particular ratings independently of the other parallel battery modules within the entire system. A master control co-ordinator monitors and determines how each of the battery modules will be dispatched and maintained within their rating and capability. Finally a dc-ac inverter system connects the batteries to the ac system. The overall configuration is shown in Figure 1. System description and test results are presented in the paper.

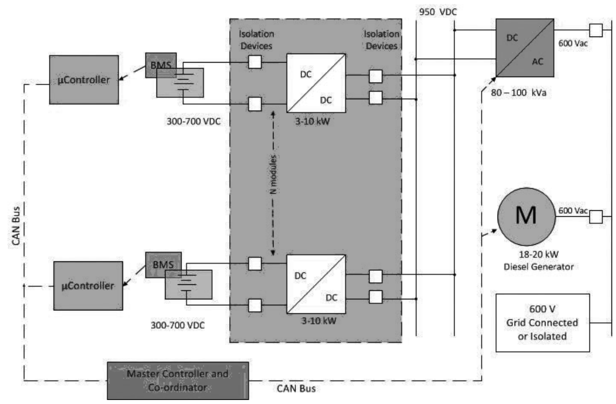

Figure 1: Repurpose Battery System

[1] Financial support from NRCan (CEF), Hydro One, Manitoba Hydro, Toronto Hydro, Ontario Power Authority and Ontario Centres of Excellence (“Sponsors”). Research services are being provided by Manitoba HVDC Research Centre (a division of Manitoba Hydro International Ltd.) and Electrovaya Corp.

BIOGRAPHICAL NOTE

Randy Wachal graduated from the University of Manitoba with BSc EE in 1981. Randy joined Manitoba Hydro where he worked for 13 years on the Nelson River HVDC System as a Control Design and Commissioning Engineer. In 1995 Randy joined the Manitoba HVDC Research Centre (MHRC) where he is currently the Engineering Systems Manager.

Randy has lead the development teams for a number of projects including power electronic convertor system for kinetic turbine energy, a vision based ice accumulation systems, HVDC Line Fault locators, and power electronic conversion system for electric vehicle battery project.

Randy has been involved in a large number of HVDC and SVC projects, including specifications and procurement, PSCAD simulation, commissioning and lifetime investigation studies. Randy is a professional engineer registered in Manitoba, a senior member of IEEE, a member of Cigre, currently Cigre WG Conveyor of B4-57 on DC Grid HVDC VSC Modeling.

HIGHER CONDUCTIVITY NASICON ELECTROLYTE FOR ROOM TEMPERATURE SOLID-STATE SODIUM ION BATTERIES

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ABSTRACT

Affordable grid-level energy storage is critical to the deployment of renewable solar and wind energy resources. Sodium ion batteries are among the most promising technologies for this application, but require high temperature (~300°C) to achieve sufficient electrolyte conductivity. We report, herein, the development of a highly conductive NASICON (Na^+ SuperIonic CONductor)-type electrolyte. Significant improvement of the conductivity was achieved due to a synergistic effect of enhanced Na^+ transport through an increase in carrier density and stabilization of the more conductive rhombohedral phase to lower temperature. The smallest trivalent ion likely to be stable in the octahedral site, aluminum, led to the largest stabilization and the highest conductivity at all temperatures. $Na_4ZrAlSi_2PO_{12}$ exhibited a high total Na^+ conductivity of 1.9 ×10^{-3} S-cm^{-1} at room temperature, matching that of liquid organic electrolytes.

BIOGRAPHICAL NOTE

Eric Wachsman, Director of the University of Maryland Energy Research Center, is the

Crentz Centennial Chair in Energy Research with appointments in both Materials Science & Engineering, and Chemical Engineering. He received his Ph.D. in Materials Science & Engineering from Stanford University, and his B.S. in Chemical Engineering from the University of California at Berkeley. He is a Fellow of The Electrochemical Society and The American Ceramic Society, Editor-in-Chief of *Ionics*, Editor of *Energy Technology, Scientific Reports,* and *Energy Systems*, Chair of the New Technology Subcommittee and the National Capital Section of The Electrochemical Society. He has more than 220 publications and 8 patents on energy related technologies.

Dr. Wachsman is a frequent invited panelist ranging from the US DOE “Fuel Cell Report

to Congress” and “Basic Research Needs Related to High Temperature Electrochemical

Devices for Hydrogen Production, Storage and Use,” to the NSF “Workshop on Fundamental Research Needs in Ceramics,” NATO “Mixed Ionic-Electronic Conducting (MIEC) Perovskites for Advanced Energy Systems,” and the National Academies “Global Dialogues on Emerging Science and Technologies.” He also serves on numerous boards and was appointed by the Governor to the Board of Directors of the Maryland Clean Energy Center.

ENERGY STORAGE EMULATIONS USING RECONFIGURABLE HARDWARE TEST-BED OF POWER CONVERTERS

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The University of Tennessee at Knoxville, Knoxville, TN

The intermittent feature of renewable energy sources such as wind and solar has limited their deployments for grid connection. However, the energy storage systems, such as compressed air storage, batteries, super-capacitors, and flywheels, can compensate for renewables' inherent disadvantages by leveling their peaks and valleys in their power generation curves.

A power electronic converter can be controlled to emulate various kinds of dynamics in flexible ways [1-3] as shown in Fig. 1. It can behave like the model described in its controller whose time scale is much longer than the controller reacting time. Energy storage systems, for example, have a typical time scale of most power system component dynamics, and can be emulated using a hardware test-bed consisting of power electronics converters.

The idea is to develop a power electronic converter-based scaled hardware test-bed (HTB) (shown in Figure 2.), which conceptually emulates a power system by a small number of interconnected generation sources and loads. Modular and reconfigurable converters for sources and loads enable flexible network and scenario emulation. With power system components emulated by power electronics-based programmable sources and loads, the dynamics of the power system could be matched to real generators and loads [4-7]. Also, energy storage system models are being developed in order to hold and supply reserve power to meet load requirements.

Compressed Air Energy Storage has many advantages such as high capacity for a long duration, good dynamics, high efficiency, small losses, low maintenance costs. As discussed in [8,9], compressed air energy system is widely researched for providing stable power backup for wind turbines. In addition, it can be used in load leveling and peak load shaving.

Batteries and ultra-capacitors have high energy, power density and reliable cost. They respond to fast power and energy demands. In papers [8-9, 11], battery and super capacitors are combined in an energy storage system to sustain the consistency of power supply in micro-grids, PV systems, and hybrid transportation system.

Flywheels are sometimes referred to as mechanical batteries and are good candidates in applications that require short duration energy storage. They are one of the best options for wind turbine or electrical vehicle system due to their short time in charge and discharge process and good dynamics [9, 12-13].

By extracting and programming their mathematical model relationships between input and output power according to their electrical behaviors, vivid emulators representing their dynamics could be implemented in the hardware test-bed system.

The final paper will provide the models used to emulate the aforementioned energy storage options and show different scenarios of how energy storage can benefit the electric grid when there are high penetration levels of intermittent renewable energy sources.

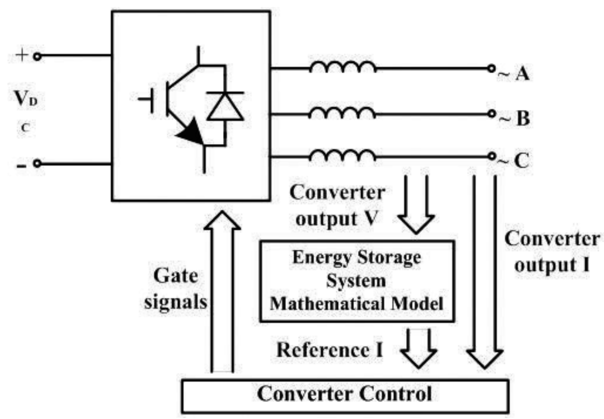

Figure 1: Power converter emulator structure.

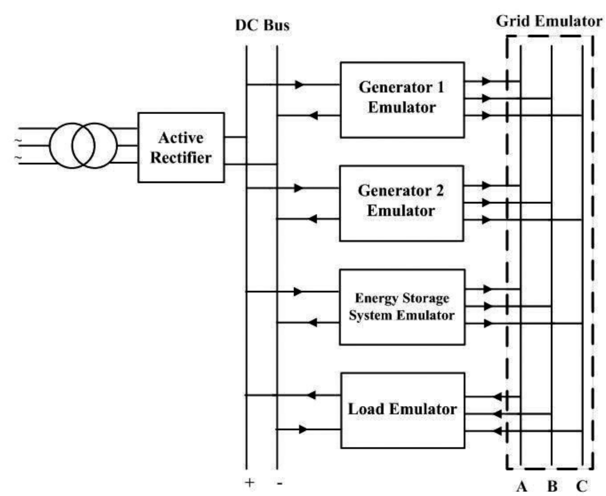

Figure 2: Proposed one-area grid emulation system. structure.

REFERENCES:

[1] H. Slater, D. Atkinson, and A. Jack, "Real-time emulation for power equipment development. Part II: The virtual machine," Proc. Inst. Elect. Eng., vol. 145, no. 3, pp. 153–158, May 1998.

[2] M. Armstrong, D. J. Atkinson, A. G. Jack, and S. Turner, "Power system emulation using a real time, 145 kW, virtual power system," in Proc. Eur. Conf. Power Electron. Appl., 2005, 10 pp. - P.10.

[3] A. Emadi and M. Ehsani, "Multi-converter power electronic systems: definition and applications," in Proc. IEEE 32nd Power Electron. Spec. Conf., Vancouver, BC, Canada, Jun. 2001, pp. 1230–1236.

[4] J. Wang, L. Yang, Y. Ma, X. Shi, et al, "Regenerative Power Converters Representation of Grid Control and Actuation Emulator." IEEE Energy Conversion Congress and Exposition, Sep. 15-20, 2012, pp. 2460-2465.

[5] L. Yang, X. Zhang, Y. Ma, et al, "Hardware Implementation and Control Design of Generator Emulator in Multi-Converter System. " The Applied Power Electronics Conference and Exposition, Mar 17-21, 2013.

[6] W. Cao, Y. Ma, J. Wang. et al, " Two-Stage PV Inverter System Emulator in Converter Based Power Grid Emulation System" IEEE Energy Conversion Congress and Exposition, Sep 15-19, 2013.

[7] J. Wang, Y. Ma, L. Yang, et al, "Power converter based three-phase induction motor load emulator." IEEE Applied Power Electronics Conference and Exposition , Mar. 17-21, 2013.

[8] J. M. Carrasco, L. G. Franquelo, and J. T. Bialasiewicz, "PowerElectronic Systems for the Grid Integration of Renewable Energy Sources: A Survey," IEEE Transactions. Power Electronics, vol. 53, No. 4,pp. l002-1016,2006.

[9] Daoud, M.I., Abdel-Khalik, A.S. "On the development of flywheel storage systems for power system applications: a survey", International Conference on Electrical Machines (ICEM), Sept. 2-5, 2012

[10] Varin Vongmanee, "The Renewable Energy Applications for Uninterruptible Power Supply Based on Compressed Air Energy Storage System", 2009 IEEE Symposium on Industrial Electronics and Applications (ISIEA 2009), October 4-6, 2009, Kuala Lumpur, Malaysia.

[11] Dai Haifeng, Chang Xueyu, "A Study on Lead Acid Battery and Ultra-capacitor Hybrid Energy Storage System for Hybrid City Bus", Conference on Optoelectronics and Image Processing, 2010, 154-159.

[12] Sathishkumar, R., "Dynamic energy management of microgrids using battery super capacitor combined storage", India Conference (INDICON), Dec. 7-9, 2012.

[13] T.D. Nguyen, K.-J. Tseng, S. Zhang, and H.T. Nguyen, "On the Modeling and Control of a Novel Flywheel Energy Storage System," IEEE International Symposium on Industrial Electronics, Bari, Italy, July, 2010.

BIOGRAPHICAL NOTE:

Jing Wang is a PhD candidate in the Center for Ultra-wide-area Resilient Electric Energy Transmission Network (CURENT) in the department of Electrical Engineering and Computer Science at the University of Tennessee at Knoxville. Her research advisor is Dr. Leon Tolbert.

She received her Bachelor's degree in Electrical Engineering from Huazhong University of Science and Technology, Wuhan, China in 2009; followed by a Master of Science degree in Electrical Engineering from University of Tennessee in 2011 with research focus on SiC high voltage power electronics switches characterization.

After graduation, she interned in Texas Instruments located in Manchester, New Hampshire from May to August 2011 with the project of optimizing gate drive for synchronous rectifier application for LLC resonant converter.

She is currently a third year PhD student with research concentration on emulating power system components using power electronic converters and stability optimization associated with paralleled multiple converters.

DEVELOPMENT OF NONAQUEOUS REDOX FLOW BATTERY

Wei Wang, Xiaoliang Wei, Wu Xu, Lelia Cosimbescu, Daiwon Choi, Vince Sprenkle

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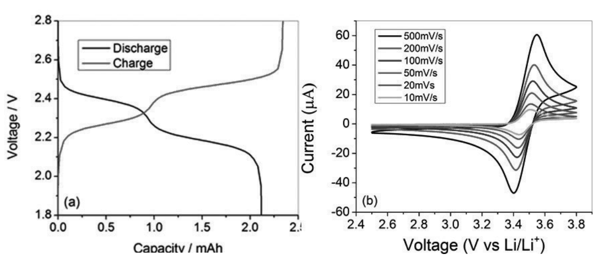
ABSTRACT

Redox flow batteries (RFBs) have attracted considerable research interests primarily due to their ability to store a large amount of power and energy, up to multi-MW and –MWh, respectively.[1] Traditional aqueous RFBs however, are generally low energy density systems limited by water electrolysis potential window and active materials' concentrations. In this regard, a nonaqueous RFB system is attractive because it offers the expansion of the operating potential window, which has a direct impact on the system energy and power densities.

Here we report the development of nonaqueous Li-organic redox flow battery (LORFB) based on a modified redox active organic molecule as the positive electrolyte and lithium metal as the negative electrode.[2] Molecular modification of quinone-based and ferrocene-based organic materials have demonstrated significantly improved solubility in common organic solvent, enabling the organic molecules to function as energy bearing active materials in the positive electrolyte. The synthesis and the electrochemical study of the two organic materials and the performance of the nonaqeuous flow cell using the modified organic redox couple as positive electrolyte will be reported.



REFERENCE

1. W. Wang, Q. Luo, B. Li, X. Wei, L. Li and Z. Yang, *Advanced Functional Materials*, 2013, **23**, 970-986.
2. W. Wang, W. Xu, L. Cosimbescu, D. Choi, L. Li and Z. Yang, *Chem Commun*, 2012, **48**, 6669-6671.

BIOGRAPHICAL NOTE

Dr. Wei Wang is a senior scientist at Pacific Northwest National Laboratory, where he is the lead scientist on the redox flow battery component research and development. He also is interested in materials design and synthesis for various energy-storage systems such as Li-ion and Na-ion batteries. Dr. Wang has authored/coauthored over 30 publications that have been published in peer-reviewed journals and two book chapters. He also holds one patent and has submitted 13 patent applications. Dr. Wang received his Ph.D. in Materials Science and Engineering from Carnegie Mellon University.

HYDROGEN/BROMINE FLOW BATTERIES

Adam Z. Weber, Kyu Taek Cho, Michael Tucker,
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ABSTRACT

Demand for large-scale energy storage is increasing, especially as renewable energy resources, such as solar and wind, become more prevalent. These variable energy generators require that large-scale energy storage is used to arbitrage and minimize fluctuations into the grid. As a promising candidate for energy storage and load leveling, redox flow cells (RFCs) or batteries (RFBs) have been considered.[1] However, due to the challenging issues such as low cell performance, durability, and high electrolyte cost, their wide-spread adoption has not occurred.

An electrochemical RFB system capable of meeting these demands is the hydrogen-bromine system. It has highly reversible and kinetically favored electrochemical reactions, soluble chemical species, high current-density operation, and a relatively inexpensive electrolyte.[2,3] The cell design uses traditional polymer-electrolyte-fuel-cell components: Nafion membrane coated with a Pt/C catalyst layer for the hydrogen electrode, carbon porous media for the bromine electrode, and graphite flow-field plates. We have shown that the optimization and understanding of the primary losses can result in power densities of 1.5 W/cm^2 and limiting current densities over 4 A/cm^2 for discharge at ambient conditions. Using a detailed cost model, we will also demonstrate that the interplay between tank size, reactant concentration, and area-specific resistance results in nonintuitive operating conditions.

However, a key attribute of any RFB system is robust and durable performance, especially upon cycling. In this talk, we will report on the cyclic performance of the RFB, and especially the effect of operating conditions such as electrolyte concentration, cut-off potential, and current on the cycling performance. Various diagnostic methods such as measurement of over-potential with open-circuit-voltage (OCV) monitoring cell, analysis of exit gas from cell with a real-time gas analyzer (RTGA), and characterization of species crossover by capillary electrophoresis (or bromide-selective electrode) were utilized to find the proper operating conditions to minimize performance loss and side reactions and understand degradation mechanisms.

ACKNOWLEDGEMENT

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REFERENCES

1. A. Z. Weber, M. Mench, J. P. Meyers, P. N. Ross, J. Gostick and Q. Liu, J. Appl. Electrochem., 41, 1137 (2011).
2. V. Livshits, A. Ulus, and E. Peled, Electrochem Comm., **8**, 1358 (2006).
3. K. T. Cho, P. Ridgway, A. Z. Weber, S. Haussener, V. Battaglia, V. Srinivasan, K. J. Electrochem Soc., **159**, A1806 (2012).

BIOGRAPHICAL NOTE

Adam Z. Weber holds B.S. and M.S. degrees from Tufts University, and a Ph.D. at University of California, Berkeley in chemical engineering. His dissertation work focused on modeling polymer-electrolyte fuel cells, which he continued at Lawrence Berkeley National Laboratory, where he is now a staff scientist. He has authored over 50 peer-reviewed articles and 9 book chapters on fuel cells, flow batteries, and related electrochemical devices and has been invited to present his work at various international and national meetings including the Gordon Research Conference on Fuel Cells, the Special Invitation Session at FC Expo 2007, and 6 keynote lectures at national society meetings. He has also been the recipient of a number of awards including the 2008 Oronzio and Niccolò De Nora Foundation Prize on Applied Electrochemistry of the ISE and the 2012 Supramaniam Srinivasan Young Investigator Award of the Energy Technology Division of the Electrochemical Society. Dr. Weber is on the Editorial Board of the Journal of Applied Electrochemistry and is current chair of the Energy Technology Division of the Electrochemical Society. His current research involves understanding and optimizing fuel-cell performance and lifetime; understanding flow batteries for grid-scale energy storage; and analysis of solar-fuel generators.

ENERGY STORAGE MONITORING AND CONTROL FOR A MICROGRID

Chuck Wells[1]

Co-Authors: Kevin Meagher (Power Analytics), William Torre (University of California – San Diego), Byron Washom (University of California – San Diego)

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ABSTRACT

Integrated monitoring and control of energy storage and other generating sources and loads in microgrids are important to ensure full realization of the benefits of energy storage. This presentation describes ongoing projects at the University of California, San Diego (UCSD) – the 42 MW microgrid that integrates energy storage and associated monitoring and control.

UCSD, using Power Analytics software, developed a microgrid master controller for real time operations of the microgrid. The software is also used to conduct power system analysis to verify reliability constraints for planning and operation of the microgrid. Energy storage on the microgid also requires optimization of generation resources for storage and energy stability both behind the generation source as well as microgrid connected storage.

The UCSD microgrid power system and building facilities are highly instrumented. The system monitors approximately 84,000 data streams per second and is designed for expeditious integration of distributed energy resources (DER). The microgrid controller is integrated with OSIsoft's PI data server on campus. Data collection and data analysis techniques are centrally managed by the on campus PI servers which are interfaced with the Power Analytics microgrid controller.

The UCSD microgrid also has one of the largest US academia installations of synchrophasors (Phasor Measurement Units [PMUs]) for data collection and data processing capability which includes the San Diego Supercomputer Center's (SDSC) high density flash drive machines. Six PMU synchophasors have been installed at the interconnection point of the microgrid with the local utility, in addition, six additional PMUs are planned to be installed on a distribution circuit to provide a detailed understanding of the performance of high PV penetration, EV charging, and energy storage on a distribution circuit. The microgrid controller is also expected to utilize these data providing the capability to operate the UCSD microgrid in a islanded condition, if necessary. The CAISO, DOE, CEC and SDG&E are also collaboratively engaged to utilize the UCSD microgrid to improve management and efficiencies of the utilities and statewide grid operations such as demand response, excess generation, renewable supply, load balancing and power outages.

BIOGRAPHICAL NOTE

Chuck Wells is OSIsoft's visiting scholar at UCSD. He has over thirty years of experience in real-time control and monitoring, published over fifty technical papers, awarded US Patents, and co-authored two textbooks. At UCSD he is involved in microgrid research involving Phasor measurement units (PMUs) as applied to control and monitoring. Working with UCSD faculty members, he applied innovative new methods for real time event detection and on-line parameter identification. He led a new data mining project that include anomaly detection algorithms developed using Big Data Analytic (BDA) tools taught at university (550 Gbytes of historical data). This work was done on the San Diego Super Computer Hadoop cluster. The software tools used included methods published by UCSD faulty. He is also working with multiple energy storage systems on campus providing peak shifting and regulation functions. He as worked in steel, paper, power systems, waste water, food processing and transportation systems. He has a PhD in Electrical Engineering, Masters and Bachelor's degrees in Chemical Engineering and is a registered Professional Engineer in Chemical and Control Systems Engineering.

PRUSSIAN BLUE BATTERIES FOR LONG CYCLE LIFE, HIGH POWER STATIONARY ENERGY STORAGE

Dr. Colin D. Wessells

Alveo Energy, Palo Alto, CA

ABSTRACT

The widespread deployment of batteries on the electric grid is critical for the integration of volatile solar and wind power with the electric grid. Conventional batteries cannot offer the long cycle life, high power, or high energy efficiency needed to mitigate the effects that the short term volatility of these renewable energy sources have on the rest of the grid.[1]

We previously demonstrated that a copper hexacyanoferrate cathode material, which has the open framework Prussian Blue structure, can survive over 40,000 high rate, deep discharge cycles. This long cycle life and high power are unmatched by conventional intercalation electrodes.[2]

In this presentation, we discuss a new cell chemistry in development by Alveo Energy that will result in inexpensive batteries having very long cycle life, high power, and high energy efficiency. This new cell contains both an anode and a cathode based on Prussian Blue, a common and inexpensive pigment, and a sodium-ion electrolyte. The unique open framework crystal structure of these Prussian Blue analogue electrodes contains large channels and interstices, which allows these electrodes to withstand tens of thousands of deep discharge cycles at very high rates.[2]

During this presentation, we review the fundamental materials' properties of Prussian Blue analogue cathodes and anodes, discuss the effects of these properties on cell performance, and examine future opportunities and applications for energy storage systems based on cells containing Prussian Blue analogues.

REFERENCES:

1. Rastler, D. "Electricity Energy Storage Technology Options: A White Paper Primer on Applications, Costs, and Benefits." *Electric Power Research Institute*, Report 1020676 (December, 2010).
2. Wessells, C. D., et al. "Copper hexacyanoferrate battery electrodes with long cycle life and high power." *Nat. Commun.* **2**:550 doi: 10.1038/ncomms1563 (2011).

ACKNOWLEDGMENTS:

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BIOGRAPHICAL NOTE

Dr. Colin Wessells is the CEO and cofounder of Alveo Energy, a startup company that is developing a new battery technology based on Prussian Blue analogues and intended for stationary applications. Colin leads Alveo's team of scientists and engineers in their efforts to rapidly finish development of Alveo's cell chemistry and scale up its cell engineering. He is also the principal investigator of Alveo's R&D program in the Molecular Foundry and Lawrence Berkeley Lab and for Alveo's ARPA-E award.

Prior to cofounding Alveo, Colin was a graduate student at Stanford University in the Department of Materials Science and Engineering, where he worked with Robert Huggins and Yi Cui. He has six years' experience developing novel battery electrode materials with a focus on those compatible with aqueous electrolytes.

UPDATE ON THE AQUEOUS HYBRID ION BATTERY A LARGE FORMAT STATIONARY ENERGY STORAGE DEVICE

J.F. Whitacre[1,2]

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This presentation will cover the scaled production and implementation of large-scale energy storage electrochemical batteries. The core devices, which we are calling Aqueous Hybrid Ion (AHI) batteries, use a configuration wherein the anode consists of a composite system of activated carbon and $NaTi_2(PO_4)_3$, and the cathode is an MnO_2 – based alkali intercalation compound (either Na4Mn9O18 or cubic spinel λ-MnO).[1] Data will be presented showing that large-scale industrially packaged individual batteries with over 200 Wh in capacity (in a voltage range of 7.6 V to 3.8 V) have been produced, qualified, and inserted into large format systems. Lifetime performance data show that the chemistry is completely stable even when exposed to elevated temperatures; many thousands of application specific cycles have been logged without loss of system capacity or function.

Further data will show that packs of these batteries in the multi-kWh range have been effectively implemented in field-testing. This will include support for both smaller off-grid applications with bus voltages in the in the 20 to 100 V range, as well as, grid compatible systems with bus voltages in excess of 800 V as controlled by several different off-the-shelf inverter systems using custom battery management firmware. These data are especially compelling because no cell-level battery management system was used to maintain string integrity. The recombinant nature of the battery chemistry provides for a self-regulating overcharge condition that allows for even very high voltage battery strings to have long-term stability.

Key topics to be addressed include: (1) a description of the manufacturing of these devices, (2) lifetime performance of this system in a range of environmental conditions, (3) data from third party field tests in relevant applications showing the performance of our batteries under application specific load profiles, and (3) our vision for future implementation of this technology on a large scale.

BIOGRAPHICAL NOTE

Dr. Jay Whitacre received a BA in Physics from Oberlin and a Ph.D. in Materials Science from the University of Michigan. Early in his career, he held various positions at Caltech (as a Postdoctoral Scholar at JPL) and The Jet Propulsion Laboratory, studying energy-related topics ranging from fundamental materials function to systems engineering, and worked on two most recent Mars rover missions. In 2007 he accepted a professorship at Carnegie Mellon, where his work has been focused on studying functional materials systems and performing economic / environmental impact assessment for energy technologies. His work resulted in the conception of a novel sodium-ion battery based on low cost materials and related manufacturing techniques. In 2008 he founded Aquion Energy, a company that has since garnered over $90 M in funding and has grown to over 120 employees since spinning out of CMU in 2009. While maintaining his professor post, he also serves as the CTO for Aquion as it builds its first full-scale manufacturing plant outside of Pittsburgh, which is on track to ship first pre-product devices in late 2013.

DESIGN AND PERFORMANCE DETAILS OF UET'S COMPACT FLOW BATTERY PRODUCT

Rick Winter

COO, UET Technologies, Mukilteo WA

ABSTRACT

UET has successfully leveraged a DOE-funded breakthrough in Vanadium chemistry at PNNL to create a compact, efficient, and thermally tolerant flow battery product. In combination with sophisticated containerization and volume production, the resulting product is highly suitable for wide-ranging MW-class utility and microgrid applications.

The leap forward in electrolyte performance has been achieved in two areas: energy density and thermal tolerance. The doubling of the electrolyte energy density has made containerization of vanadium batteries a practical reality. This in turn has led to a five-fold reduction in system footprint, a vital requirement in reducing site preparation costs and permitting, as well as accelerating deployment time and improving deployed build quality.

Furthermore, wide thermal tolerance has removed one of the remaining key hurdles to widespread adoption of vanadium flow batteries. By opening the thermal operating window to 50°C with no irreversible side reactions, significantly higher reaction kinetics can be utilized as well as passive thermal management to improve system efficiency.

This presentation will discuss the top four requirements that are vital for commercializing an energy storage product. In this context, specific design features and performance characteristics of UET's newly launched and fully operational flow battery will be described. The top four requirements are:

1. **Safety** at performance and operational extremes with inherently safe failure modes,
2. **Performance** and durability over 10,000 full cycles and at elevated temperatures,
3. **Cost-effectiveness** including capital cost, transportation, assembly, operation and service, and
4. **MW-scale field deployment** experience.

Image: 100kW/400kW Compact Flow Battery from UniEnergy Technologies

BIOGRAPHICAL NOTE

Rick Winter is a former ESA Chairman and recent winner of the Phil Symons award with 25 years of utility, entrepreneurial, and product development experience. He has participated directly in the transition of the grid storage industry from its early stages to a strategic imperative for grid stability.

By way of background, Rick has managed the storage technologies program at Pacific Gas & Electric; deployed remote area hybrid power systems in Australia's Torres Strait; and founded an advanced battery company. He has led product development teams at four battery companies, whose accomplishments include creating the world's first flow battery product.

Rick holds 14 US patents and numerous abroad. He invented the single loop flow battery in his garage (Pat#8039161) and founded Primus Power, going on to raise $30M in capital.

He has hands-on experience evaluating grid impacts of distributed generation systems including batteries, flywheels, microturbines, photovoltaics and diesel generators.

Rick is now Chief Operating Officer at UniEnergy Technologies (UET), a compact vanadium flow battery company bringing together a multinational supply chain of raw materials; mass production; and next generation electrochemistry invented at PNNL. UET's focus is to package an SOC agnostic and temperature tolerant containerized storage solution. Field deployment begins in 2014.

ULTRABATTERY® ENERGY STORAGE: LESSONS LEARNED, PRESENT STATUS, AND THE FUTURE

Name: John Wood, CEO Ecoult

For energy storage to be a key to a resilient grid, storage technologies themselves need to be resilient, and in order to make its greatest potential contribution, energy storage needs to operate highly efficiently and effectively in a continuous Partial State of Charge. Storage technologies also need to be long-lived, safe and recyclable to support grid variability and the sustainable, large-scale integration of renewable energy sources into the grid – at the same time as offering business cases with a positive Return on Investment.

UltraBattery®, invented by the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO), is a lead-acid based energy storage device that combines the fast charging rates of an Ultracapacitor with the energy storage potential of a lead-acid battery. The combination of these two technologies in a single electrolyte creates a hybrid device with unique capabilities: UltraBattery® operates most efficiently in a Partial State of Charge operation, provides more energy over its lifetime, can run longer between refresh charges, and can also be charged and discharged much faster.

Figure 1 depicts a schematic of the UltraBattery techonology.

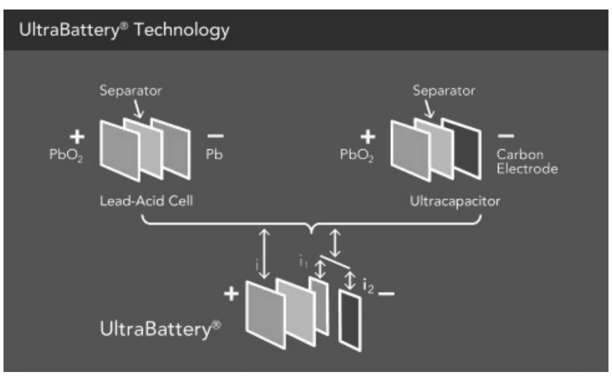

Figure 1: UltraBattery® Technology

UltraBattery® has been successfully deployed by East Penn Manufacturing, Ecoult and Furukawa Battery in multiple demonstration and commercial projects around the world. It has proven its outperformance across applications such as:

- Smoothing the intermittency of renewable energy
- Controlling ramp rates of renewable energy output
- Providing frequency regulation services
- Shifting energy for later time of use

The presentation will share the latest key insights into the UltraBattery® technology itself, gained through continued research and testing as well as through on the ground deployment of this hybrid storage technology. Topics discussed include:

- Lessons learned from 5 years of deploying and operating UltraBattery® storage
- Latest storage applications for UltraBattery® that deliver profitable storage models for grid variability management and support of renewable energy systems
- Where the currently deployed systems sit in the scope of the full potential for UltraBattery® and how our own understanding of the technology has advanced.

BIOGRAPHICAL NOTE

John Wood is the Chief Executive Officer of Ecoult. He joined the energy storage community in 2008 having previously launched technologies globally in Security, Identity, Payment Technology, and Telecommunications.

As a technology CEO for more than 20 years, John has had the good fortune to have worked with excellent individuals and led excellent teams that have created businesses and numerous successful products and solutions from the ground up that are used and trusted by many of the world's largest enterprises and governments, either directly or under license by many of the largest global technology enterprises.

John is now leading the Ecoult effort to commercialize the UltraBattery® storage solutions.

EFFECT OF MOISTURE CONTENT IN IONIC LIQUID GEL ELECTROLYTE FOR PRINTABLE ZINC/MNO2 BATTERY

Rich Winslow[1], Chun-Hsing Wu[2], Zuoqian Wang[1], Bernard Kim[3], Paul Wright[1], James Evans[3]

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[2]Green Energy and Environmental Laboratories, Industrial Technology Research Institute, Hsinchu, Taiwan
[3]Department of Material Science and Engineering, University of California, Berkeley

Keywords: Energy storage, Ionic liquid, Gel electrolyte, Printable Zinc Manganese Oxide battery

Energy generation is one of the most pressing global issues this century, and reliability is of paramount importance to renewable, intermittent, distributed generation systems. Although much research is focused on improving these technologies, there is no clear path to reliable integration without energy storage. Renewable energy usage statistics from developed countries show that distributed energy systems with grid-scale energy storage increase grid stability and allow for more renewable generation technologies to be integrated. However, no energy storage technology can fulfill all grid scale applications. Pumped hydro and compressed air energy storage technologies are cheap but space limited. Conversely flywheels, lithium ion batteries, and super capacitors are too expensive. Sodium sulfur batteries are an improvement but are simultaneously very dangerous. Thus there is still a large opportunity to develop advanced energy storage technologies.

Zinc is often utilized in primary batteries because it is atmospherically stable, cheap, and environmentally- benign. Yet for grid-scale applications, the batteries must be rechargeable, a characteristic that traditional zinc-based battery chemistries lack. Research shows that this phenomenon is predominately caused by the development of zinc-based dendrites on the surface of the electrode. Along with causing electrode passivation, these structures can grow long enough to contact the opposite electrode and electrically short the cell. Ho (2006) proved that by utilizing an ionic liquid-based gel polymer electrolyte, the cell rechargeability issue could be overcome [1]. They used a pneumatic dispenser printer to print layers of electrode (Zn anode and MnO_2 cathode) and electrolyte (1-Butyl-3-methylimidazoium trifluoromethanesulfonate and zinc trifluoromethanesulfonate salt in PVDF-HFP) material in order to create rechargeable battery cells. These cells produce nominal voltages ranging between 1.2-1.5 V, have been shown to operate from 0.9-1.8 V, and exhibit discharge capacities on the order of 1 mAh/cm^2. Properties unique to the gel polymer electrolyte used in this system have enabled the realization of a completely printable zinc battery that does not require rigorous hermetic packaging, therefore greatly simplifying processing considerations and reducing overall costs. Although the discharge capacity of the cells is lower than that of commercial batteries, there is still room for improvement in terms of manufacturing consistency and reliability.

This work presents a preliminary study on water as an impurity in the ionic liquid-based electrolyte and its effects on cell discharge capacity. In this research, commercial zinc foil was used as the anode. The cathode was composed of an MnO_2-based slurry developed specifically for flexographic printing. Acetylene black was added to slurry to increase the electrode conductivity and PSBR was used as binder. A flexographic printer was used to print cathodes on stainless steel foil at California Polytechnic State University, San Luis Obispo. [Zn][Otf] and [BMIM][Otf] were pre-mixed to form the electrolyte solution. Then the solution was added to a mixture of PVDF-HFP and NMP to form the gel polymer electrolyte. The ionic conductivity was determined experimentally with a Gamry Reference 600™. A Karl Fischer coulombic titrator was used to determine the amount of water present in electrolyte samples. Tested cells were manufactured in ambient laboratory conditions (20°C and relative humidity 25-55%) or in a dry, argon-filled glove box. Cells were cycled with a Maccor Series 4000 tester to determine cell performance parameters including discharge capacity and cycle efficiency.

Preliminary results show that the discharge capacities of cells with the same electrolyte composition (ZnOtf:[BMIM][Otf] of 1:15 parts by mass) vary by the amount of water present as follows. Neat [BMIM][Otf] ionic liquid with [Zn][Otf] salt was found to have 86 ppm of H_2O. The above electrolyte composition, when produced in ambient conditions, was found to have 12,483 ppm of H_2O. Wet and dry electrolyte solutions were mixed in order to produce solutions with 3338 ppm of H_2O, 6433 ppm of H_2O, and 9640 ppm of H_2O. Cells were produced for each electrolyte and their discharge capacities are shown in Figures 3 and 4. The results of this research suggest that water plays an important role in improving the performance of the cells produced in these experiments. Additional experiments are required to further investigate this phenomenon and the benefits therein.

REFERENCES

[1] Ho, C. C. et al. (2010, December 14). *Dispenser Printed Zinc Microbattery with an Ionic Liquid Gel Electrolyte*; University of California, Berkeley.

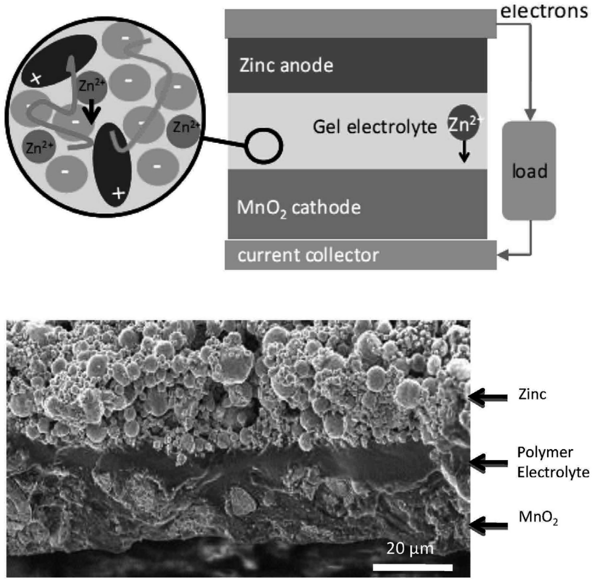

Figure 1: The structure and SEM picture of printed Zn-MnO2 battery and gel electrolyte.

Figure 2: The picture of continuing printed electrodes.

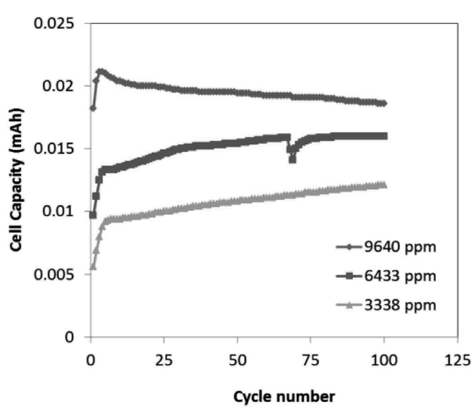

Figure 3: Discharge capacity curves of ionic liquid-based electrolyte solutions with different amounts of H_2O

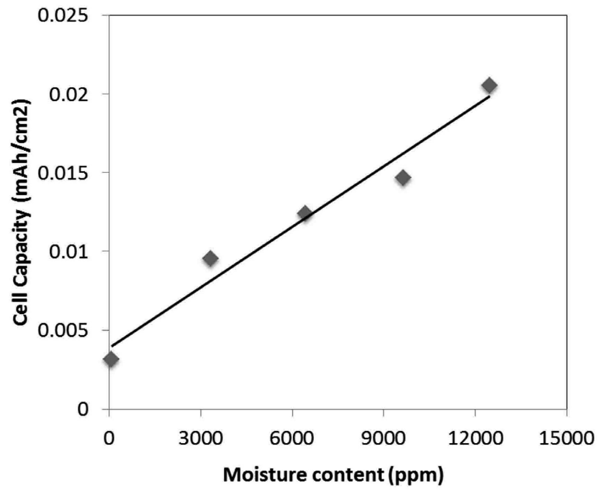

Figure 4: Discharge capacity of zinc/MnO_2 batteries as a function of moisture content in ionic liquid-based electrolyte solution.

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BIOGRAPHICAL NOTE

Conference presenter: Dr. Chun-Hsing Wu is a senior researcher of the (GEL) Green Energy and Environmental Lab in ITRI (Industrial Technology Research Institute). His graduate research was focus on the complex reaction kinetic study on organic wastewater decomposition by titanium dioxide. After he obtained his Ph.D. in 2006, he joined the hydrogen and fuel cell research team of GEL and worked on catalytic reforming of natural gas, fabrication of electrode, and development of metal bipolar plate. Since 2009, he was in charge as the project coordinator of large scale energy storage, including metal-air battery and redox flow battery for grid scale energy storage. Now, he is a visiting scholar in CITRIS center in UC Berkeley from Jan. 2103 and working with Prof. Paul Wright and Prof. James Evans in printed gel electrolyte rechargeable Zinc-MnO_2 battery technology. Dr. Wu has 13 patents and 43 papers published in conference and journal.

DC-LINK CAPACITORS FOR GRID BASED INVERTER APPLICATIONS

A.Yializis Ph.D, C. Hohmann, M. Engquist and P. B. Roop

Sigma Technologies International, Tucson, AZ

Transportable energy storage systems for grid applications serve several functions including integration and intermittency mitigation of renewables, improving grid stability and reliability by providing new capacity that can be deployed quickly and they offer a cost effective way to balance the load. Each energy storage unit includes a high power inverter that is used to convert DC voltage to three-phase AC.

A key component of the inverter circuit is the DC- link capacitor, used to minimize ripple current due to the inverter switching, voltage fluctuation and transient suppression. The DC-link capacitor is one of the largest, costliest and most failure-prone components in today's inverter systems. This holds true for all inverters used in applications that range from automotive (hybrid and electric vehicles) to grid-based high voltage systems. Metallized polypropylene capacitors that are commonly used for DC-link applications have <1J/cc energy density and limited thermal performance.

The latter manifests itself as a limit in operating temperature, but also more importantly as a limit in the ability of metallized capacitors to handle high frequency/amplitude ripple currents and high dV/dt transients. These limitations are addressed by developing "hybrid" metallized films that comprise a commercially available base film that has been modified for higher breakdown strength, higher temperature, higher current carrying capability and superior self-healing properties. Base films such as polypropylene and PVDF are converted into hybrid films in the vacuum, in-line with the metallization process by coating one or both sides of the film with a high temperature acrylate polymer dielectric. The acrylate coatings are deposited using a non–contact radiation curing process that results in highly cross linked, amorphous, pinhole free coatings, similar to those used to produce Polymer Multi-Layer (PML) surface mount capacitor chips. They have dielectric constants in the range of 3<k<6.2, dissipation factors as low as 0.002, low dielectric absorption, can withstand temperatures >260oC, breakdown strength of 1000V/µm and have excellent self-healing properties. Several hybrid film structures are evaluated including Acrylate/PP, Acrylate/PP/Acrylate, Acrylate/PVDF and Acrylate/PVDF/Acrylate, using different thickness base films and coatings.

The results show that a hybrid metallized PVDF film retains the high energy density of PVDF, excellent self-healing properties, lower dissipation factor and higher operating temperature. A hybrid metallized PP film retains its low dissipation factor and acquires higher energy density, higher operating temperature and higher ripple and transient current capability. Considering that current capacitor films are produced by a handful of suppliers worldwide and that there are significant technical and economic challenges in producing new capacitor films, the hybrid film technology presents an attractive alternative, which allows capacitor OEMs to innovate and create new products with superior application-specific properties.

BIOGRAPHICAL NOTE

Dr. Angelo Yializis (Ulysses) is the founder and CEO of Sigma Technologies. In the early-80s, Dr. Yializis while working at GE, developed a series of new capacitor products, including the two-layer metallized electrode for AC capacitors (now used throughout the industry) and the Polymer Multi-Layer PML technology, the only commercial capacitor technology with thousands of nano-thick polymer layers. The PML technology was spun off from GE and Sigma Technologies was founded in 1992. The PML technology was licensed to Rubycon and Panasonic for use in consumer electronic applications. Sigma has commercialized several pioneering non-capacitor products and is also pursuing the development of higher voltage PML capacitors. Dr. Yializis received his B.Sc. in Applied Physics, at the Royal Melbourne Institute of Technology, A M.Sc. in Solid State Physics at the University of Windsor, and a Ph.D. in HV Electrical Engineering at the University of Windsor. He is the recipient of several technical and managerial awards. He has 41 U.S. patents and more than 50 journal and conference publications.