GATEWAY TO THE FUTURE

EESAT 2017 | San Diego, California | October 11-13 | The Westin San Diego

EESAT 2017
EVOLUTION & REVOLUTION

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Welcome to EESAT 2017

The U.S. Department of Energy (DOE), Sandia National Laboratories, Pacific Northwest National Laboratory, Oak Ridge National Laboratory and Energy Storage Association have collaborated to present to you the 2017 Electrical Energy Storage Applications and Technologies (EESAT) conference.

EESAT is the premier energy storage technical meeting. The first EESAT conference took place in Chester, UK in 1998. For two decades the EESAT meetings have proven to be at the international forefront of advancing leading-edge research, development, and deployment of energy storage ideas, projects and challenges – bringing together energy storage end-users, system developers, manufacturers, researchers, etc.

The 2017 EESAT theme is "Energy Storage Evolution and Revolution". This year's meeting provides a format to revisit critical, turning point research coupled with new frontiers in technology development and emerging applications for the smarter modern electricity grid.

The conference features keynote speakers Maria Skyllas-Kazacos of the University of New South Wales, DOE's own Michael Pesin and Matt Roberts of the Energy Storage Association -- one of the original industry partners for the EESAT International Conference.

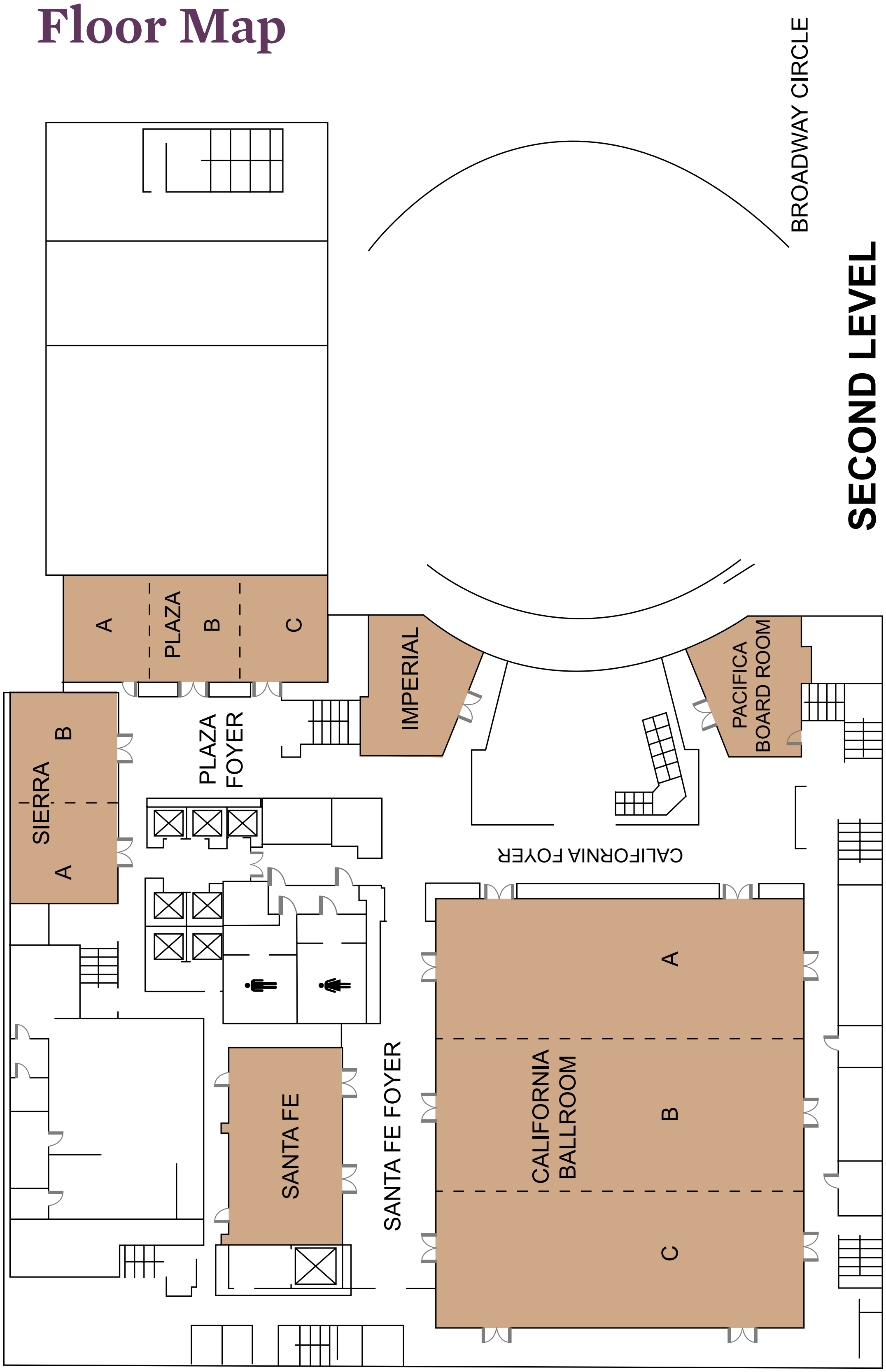
The conference will include innovative technical presentations, poster exhibits, ideas forums, tutorial workshops, and select topical panelists. The networking dinner cruise, a special luncheon, and an on-site tour. This is an excellent opportunity to share and listen to energy storage professionals from the national laboratories, academia, industry and government entities.

Thank you so much for joining us and we look forward to the next 20 years of Energy Storage Evolution and Revolution with you and our partners!

EVENT FACILITATOR:

NAATBatt
INTERNATIONAL

Conference Floor Map



ENERGY STORAGE TODAY

Since the discovery of electricity, we have sought effective methods to store that energy for use on demand. Over the last century, the energy storage industry has continued to evolve and adapt to changing energy requirements and advances in technology.

Energy storage systems provide a wide array of technological approaches to managing our power supply in order to create a more resilient energy infrastructure and bring cost savings to utilities and consumers.

The primary benefits are:

Risk of Power Outages: Today's electricity grid is increasingly vulnerable to threats from nature, terrorists, and accidents. Millions of American families and businesses are victimized by outages (both sustained and monentary) each year. Power outages cost as much as $130 billion annually, while hitting the job-creating commercial and industrial sectors the hardest.

Saving Consumers Money: Sixty million Americans in thirteen states plus Washington, DC are saving money because energy storage systems are providing frequency regulation in PJM territory (the power transmission operator in the mid-Atlantic region). PJM has projected that a 10-20% reduction in its frequency regulation capacity procurement could result in $25 million to $50 million savings to consumers. Energy storage can also let customers avoid premium pricing that utilities charge during times of peak demand. That's like getting a cheap airline flight on Thanksgiving or a rush-hour subway pass at an off-peak price.

Clean Energy Integration and Energy Independence: Energy storage supports the integration of renewable energy generation. Energy storage can also help cut emissions as it takes more of the load off fossil-fuel generation. Peaking generation is one of the most costly and wasteful aspects of the grid, so making existing generation go further and avoiding capital and resource-intensive new facilities would make a significant contribution to our environmental priorities. By supporting an all-of-the-above energy strategy, storage will also help accelerate our drive to energy independence.

Economy and Jobs: In addition to reducing economic losses from major and minor annual outages, experts say that energy storage will be a critical technology in the electricity grids of the future. They also predict that the long term-health of the U.S. economy, and tens of thousands of future U.S. jobs, depend in no small part on the ability of U.S. companies to at least remain competitive, if not to become leaders, in this critical technology.

The importance of keeping up with the rapid pace of technical innovation in the energy storage industry has never been so apparent. The energy sector is transforming, and it is more important than ever to engage directly with experienced engineers, system designers, and grid planners to understand the evolving technical considerations for advanced procurement, deployment, integration, and operation of successful energy storage projects.

Energy storage fundamentally improves the way we generate, deliver, and consume electricity.

Energy storage fundamentally improves the way we generate, deliver, and consume electricity. Energy storage helps during emergencies like power outages from storms, equipment failures, accidents or even terrorist attacks. But the game-changing nature of energy storage is its ability to balance power supply and demand instantaneously - within miliseconds - which makes power networks more resilient, efficient, and cleaner than ever before.

Energy storage is needed on an industrial or grid scale for three main reasons. The first is to "balance load" – to shift energy consumption into the future, often by several hours – so that more existing generating capacity is used efficiently. The second reason is to "bridge" power – in other words, to ensure there is no break in service during the seconds-to-minutes required to switch from one power generation source to another. Finally, power quality management – the control of voltage and frequency to avoid damaging sensitive equipment – is an increasing concern that storage can alleviate whenever needed, for a few seconds or less, many times each day.

FULL SCHEDULE

11

WEDNESDAY

WEDNESDAY, OCTOBER 11		
8:00-8:05	Opening Remarks - Dave Schoenwald and Patrick Balducci, EESAT Technical Co-Chairs	
8:05-8:15	Welcome to EESAT - Imre Gyuk, US Department of Energy	
8:15-8:45	State of Energy Storage Industry - Matt Roberts Energy Storage Association	
8:45-9:40	Invited Speaker - Maria Skyllas-Kazacos, University of New South Wales	
9:40-10:00	**AM Break**	
10:00-12:00	1-Advanced/Applied Materials Presentations	2-Power Electronics Presentations
12:00-1:10	**Lunch**	
1:10-1:40	Invited Speaker - Joydeep Mitra, Michigan State University	
1:40-2:40	3-Power Electronics Ideas Forum	
2:40-3:00	Invited Speaker - Michael Pesin, U.S. Department of Energy	
3:00-3:20	**PM Break #1**	
3:20-5:00	4-Special Applications Presentations	5-Demonstrations and Deployment Project Presentations
5:00 - 5:30	**PM Break #2**	
5:30 - 7:00	Poster Session Reception	

FULL SCHEDULE

12 THURSDAY

THURSDAY, OCTOBER 12		
8:00-8:05	Opening Remarks - Dave Schoenwald and Patrick Balducci, EESAT Technical Co-Chairs	
8:05-8:45	Invited Speaker - Tom Bialek, San Diego Gas & Electric	
8:45-9:30	Invited Speaker - Giovanni Damato, Electric Power Research Institute	
9:30-9:50	**AM Break**	
9:50-11:50	6-Validated Safety & Reliability / Guidelines, Standards, and Protocols	7-Energy Storage Valuation, Modeling, and Financing Tutorial
11:50-1:00	**Lunch - Celebrating 20 Years of EESAT, Moderator - Abbas Akhil**	
1:00-2:40	8-Controls Presentations	
2:40-3:00	**PM Break**	
3:00-3:30	Invited Speaker, Ryan Franks, CSA Group	
3:30-5:00	9-Enhancing Regulatory Equity and Markets	10-Microgrid Presentations and Tutorial
5:00-5:05	**Closing Remarks - Imre Gyuk, US Department of Energy**	

WEDNESDAY SESSIONS:

Wei Wang, Pacific Northwest National Laboratory

Materials and Chemistry Development for Novel Redox Flow Batteries

Leo Small, Sandia National Laboratories
Chemically Mediated Redox Flow Batteries for Modular, High Power Energy Storage

Jonathon Duay, Sandia National Laboratories
Screening of Alkaline Zinc Battery Separators using Anodic Stripping Voltammetry

Sergil Tychina, Yunasko Limited
Hybrid Energy Storage: Charging a Battery within 3 Minutes

Erik Spoerke, Sandia National Laboratories
Sodium-Based Batteries: Toward Meeting Next Generation Challenges in Grid-Scale Energy Storage

Raj Jana, JRI, LLC
Electrostrictive Capacitors for High Energy and High Power Density Storage Applications

Mehdi Ferdowsi, InnoCit LLC
GaN based High Frequency Inverter for Energy Storage Applications

Bruce Pilvelait, Creare LLC
A Power Dense Advanced Power Inverter (API) for Grid Tied Energy Supplies

Robert Kaplar, Sandia National Laboratories
Reliability Characterization of Vertical GaN PiN Diodes

Reinaldo Tonkoski, South Dakota State University
Genitor Based Energy Management System for Remote Microgrids Considering Battery Lifetime

Gregory Nichols, Homeland Defense and Security Information Analysis Center
Integrated Energy Harvesting for Wearable Battery Charging

Zach Jones, Freshwater Energy
Zero-Emission Energy Storage for Electric Vehicles

Hengzhao Yang, California State University, Long Beach
Bounds of supercapacitor open-circuit voltage change after constant power experiments

Stephane Bilodeau, Novacab Inc. -- Hybrid Thermal and Electrical Energy Storage System

Rainer Vor Dem Esche, Stornetic GmbH
Fast Response Flywheel Energy Storge Technology for Virtual Power Plants and Microgrids

James Kersey, Czero
Hybrid Power Generation for Improved Fuel Efficiency and Performance

Patrick Balducci, Pacific Northwest National Laboratory
An Assessment of the Technical Performance and Economic Potential of the Salem Smart Power Center

CONFERENCE NOTES:

KEYNOTE SPEAKER

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Matt Roberts
Key Note Speaker
11:00am

Matt Roberts serves as the Executive Director of the Energy Storage Association (ESA), overseeing operations and strategic initiatives for the industry's trade association. Matt has over 15 years of experience in energy policy, communications, and association management with a recognized expertise in renewables, distributed energy, and sustainable infrastructure. Prior to joining ESA, Matt oversaw policy and operations for a global energy trade association focused on reforming the transportation infrastructure and expanding the use of renewable fuels. Mr. Roberts began his career as a House staffer and speech writer and has consulted in the energy industry with organizations and companies focused on solar, wind, and geothermal energy policy and deployment.

SEMINAR NOTES:

EESAT 2017
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KEYNOTE SPEAKER

Maria Skyllas-Kazacos
Key Note Speaker
11:00am

Maria Skyllas-Kazacos is a chemical engineer whose invention of the Vanadium Redox Battery (VRB) in the late 1980s may revolutionize how we store energy. The VRB is a unique type of flow battery that can repeatedly absorb and release huge amounts of electricity, making them possibly the best partner for renewable energy. Over the last twenty years, Maria has been improving the technology and finding commercial applications in various markets to reduce the cost and make the VRB a feasible solution to our energy storage challenges. Maria's VRB technology can already be found in action in Japan, USA, Europe, and Australia for storing wind and solar energy and balancing peak electricity demand. Maria recently joined the Advisory Board for Apella Resources Inc. to help grow their presence in the vanadium markets. She is Professor Emeritus for the University of New South Wales in Australia where she received her PhD in 1978. As a distinguished academic, Skyllas-Kazacos has won numerous awards for her research including the R.K. Murphy Medal from the Royal Australian Chemical Institute in 2000 and the Order of Australia in 1999.

SEMINAR NOTES:

ADVANCES IN MATERIAL SCIENCE, ABSTRACT 6

High-Temperature Thermal Storage for Dispatchable Renewable Power

David Baldwin

To penetrate the electric power market more than the 10-15% range, all renewable power generation sources require storage to match temporal supply with demand. In addition, as for nearly all high-power generation sources today, the issue of the competing demands for fresh water makes their cooling-water requirements a paramount issue.

SLPI has developed a patented new approach to high temperature thermal energy storage, deploying latent-heat principles in common NaCl, vapor heat transport, a coolingwater-free Brayton-cycle turbine, and a modular approach that can be flexibly applied to customer needs—all at attractive cost. The primary power source can be

Concentrated Solar Power (CSP), for which the SLPI system is described, or wind/PV, which are discussed in less detail. Our design is a timely, market-based systemsoptimization of existing and operating CSP plants. SLPI's unique design is based upon proven, technologically sound principles and is well suited for meeting the currently unmet market needs for efficient, utility- scale, grid quality CSP and storage.

ADVANCES IN MATERIAL SCIENCE, ABSTRACT 6

Chemically Mediated Redox Flow Batteries for Modular, High Power Energy Storage

Leo Small

The energy density of nonaqueous redox flow batteries is often limited by the concentration of redox active species soluble in solution. A possible route to increasing this energy density is through the use of common, energy-dense Li-ion battery components. These materials can be contained in cannisters through which an electrolyte with redox-active species is flowed in typical flow battery fashion. The redox potentials for the flowing species are chosen specifically such that they mediate the chemical reduction and oxidation of the Li-ion battery components contained in the cannisters. This strategy is advantegous in that it allows for independent optimization of the flowing electrolyte (e.g. for low viscosity, high charging rate) and the solid energy storing media (e.g. high enery density). By exchanging a discharged cannister of the energy storing media for a fully charged one, such batteries can be recharged nearly instaneously. Here we present recent results using a variety of redox-active organic and metallorganic species to mediate the oxidation and reduction of some common Li-ion battery chemistries in a redox flow battery system.

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ADVANCES IN MATERIAL SCIENCE, ABSTRACT 43

Screening of Alkaline Zinc Battery Separators using Anodic Stripping Voltammetry

Jonathon W. Duay

Zinc alkaline battery chemistries such as Zn/Ni, Zn/MnO2, and Zn/Air are currently attracting a lot of attention due to their potential as safe, low cost, high energy density rechargeable batteries. A main failure mechanism for these cells is the poisoning of the cathode material during cycling due to "zinc crossover". Advanced separators that successfully stop or limit this "zinc crossover" are crucial in order to increase the cycle lifetimes of these batteries. To be screened effectively, these membranes need to be evaluated for their ability to block zincate, the ionic form of zinc in strongly alkaline solutions (pH > 14). Existing complexometric titration and elemental analysis methods for zincate membrane transport characterization require large sample dilution factors and additional sample processing which can take days to weeks to process as well as require high initial concentrations of zincate. Here, an anodic stripping voltammetry (ASV) sensing assay will be presented which provides real time determination of zincate transport in alkaline electrolyte with total experimental times on the order of hours. Here, an H-cell is utilized consisting of two solutions (feed and draw) separated by the membrane of interest with the feed side containing a known concentration of zincate and the draw side containing an initial blank electrolyte where the ASV is performed. This method is performed in situ and thus eliminates the need for sample dilution and post experiment sample processing. This electrochemical assay significantly increases the throughput for the screening of these vital membranes. To evaluate the utility of this assay, zincate diffusion through commercial off-the-shelf (COTS) Celgard 3501 and Cellophane 350P00 membranes is monitored using both ASV and inductively coupled plasma – mass spectrometry (ICP-MS) methods. The obtained zincate diffusion coefficients for both techniques are shown to compare favorably.

This work was supported by Sandia National Laboratories and by the U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability. We thank Imre Gyuk, Manager of the Energy Storage Program for continued support. Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

CONFERENCE NOTES:

ADVANCES IN MATERIAL SCIENCE, ABSTRACT 48

Sodium-Based Batteries: Toward Meeting Next Generation Challenges in Grid-Scale Energy Storage

Erik Spoerke

Batteries able to provide safe, low-cost, robust grid-scale electrical energy storage remain a national priority, critical to agile, reliable energy distribution, integration of increasingly prevalent renewable energy, effective emergency response, and even successful national defense initiatives. Viable candidate energy storage systems must be able to reliably provide the high capacity and power needed to meet evolving electrical demands while remaining cost-effective and safe over the course of years of operation. With current large-scale battery technologies challenged by high cost, limited cyclability, and potentially hazardous runaway reaction behaviors, there is a clear need for innovation in large-scale battery design and development. Here, I will describe collaborative research between Sandia National Laboratories and Ceramatec, Inc., focused on the development of next generation sodium-based batteries, enabled by the solid state ceramic electrolyte NaSICON (Na Super Ion CONductor). NaSICON provides exceptional low-to-intermediate temperature sodium ion conductivity, serves as a chemically and structurally robust separator, and can be produced in a range of form factors on an industrial scale. In particular, I will describe a series of molten salt-based batteries that integrate molten sodium anodes, NaSICON solid state electrolytes, and AlCl3-based molten salt catholytes to create high performance battery constructs that operate below 200oC. These all-inorganic systems avoid hazards associated with runaway exothermic reactions, polymer separators, and organic electrolytes used in other batteries. I will describe the design and scalable performance (up to 250Wh) of several emerging intermediate temperature molten salt technologies including Na-NiCl2 and Na-I2. Recognizing the importance of long-term, stable performance, we apply a fundamental, materials-based approach to our research, aiming to optimize interfacial reactions, molten-salt electrolyte behaviors, and chemical stability in prototype battery systems. These promising, intermediate temperature technologies boast coulombic efficiencies near 100% and energy efficiencies >80% through months of stable electrochemical cycling. Moreover, accelerated rate calorimetry verifies the inherent safety of these molten salt chemistries, revealing neither the runaway exothermic reactions nor hazardous pressurized gas generation that plague other large-scale battery technologies. Finally, I will highlight promising early results utilizing NaSICON as a robust, low-temperature ionconducting separator in new aqueous-based battery chemistries. Coupling NaSICON's high ionic conductivity with promising chemical stability and zero-crossover separator performance allow us to explore the feasibility of a new generation of aqueous sodium-based battery chemistries.

The encouraging performance of these low-to-intermediate temperature sodium-based batteries promises opportunities to provide reliable, safe, and cost-effective solutions needed to meet evolving national challenges in grid-scale electrical energy storage.

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POWER ELECTRONIC, ABSTRACT 8

High Frequency Link Converters Using Advanced Magnetics

Todd C Monson

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Baolong Zheng, Yizhang Zhou, Enrique Lavernia, University of California, Irvine, CA 92697, USA

Siddharth Kulasekaran, Raja Ayyanar, Arizona State University, Tempe, AZ 85287, USA

High frequency DC links, leveraging advanced magnetic materials, would be an enabling technology for transportable energy storage and PCSs. Such compact and agile systems, able to fit inside a single semi-trailer, would significantly decrease the cost and time to install solar, wind, and geothermal energy systems in even the most remote locations. In order to accomplish this goal, new advanced magnetic core materials that can perform at high frequencies without active cooling need to be fabricated. The ’ phase of iron nitride, manufactured into magnetic components for the first time ever, will lead to lighter, smaller, more affordable, and higher efficiency transformers required for transportable energy storage systems and the widespread adoption of renewable energy. The fabrication of the first ’-Fe4N magnetic components using innovative manufacturing techniques and their characterization is reported here.

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POWER ELECTRONICS, ABSTRACT 18

GaN based High Frequency Inverter for Energy Storage Applications

Mehdi Ferdowsi

Energy storage systems are the backbone of the future grid They not only support the grid in meeting the future energy needs but also reduce concerns over reliability and voltage stability resulting from high penetration levels of renewables. According to IHS Markit Ltd., the energy storage market is estimated to have an annual installation size of 6GW in 2017 and is expected to exceed 40GW by 2022. This will be a huge jump from the initial installation size of 0.34GW observed in 2012 and 2013. In such systems, high-power bidirectional inverters play a key role. They not only impact the performance but also affect the economics of these systems.

Existing energy storage inverters suffer from many drawbacks due to the utilization of Silicon (Si) technology. Si-based devices suffer from higher conduction and switching losses leading to reduced efficiency of the system and increased real estate requirements with increased cooling needs. Also, low switching frequencies of Si-based inverters increases the need for large filtering inductors. This thereby increases the cost, weight, and volume of the inverter while reducing its efficiency due to increased losses in inductors. Recently commercialized Gallium Nitride (GaN) technology offers a new solution to the challenges observed with the Si technology. GaN devices offer lower conduction and switching losses thereby improving the efficiency of inverter and reducing the cooling requirements. Also, faster switching speeds enable the use of higher switching frequencies for the inverter. This allows for smaller filtering inductors to reduce the cost and volume of the converter. Furthermore, the reduced losses improve the inverter efficiency.

POWER ELECTRONICS, ABSTRACT 28

Electrostrictive Capacitors for High Energy and High Power Density Storage Applications

Raj Jana

High energy and high power density solid state capacitors are being actively pursued for efficient energy storage and delivery [1-2] in cutting-edge electronic systems (such as consumer, portable and flexible electronics etc.), automobile electric systems (such as automotive electric vehicles), and other energy-efficient, eco-friendly health & safety applications. Electrochemical batteries (e.g. Li-ion battery) [1-2] which provide high energy density but low power density are normally used for portable electronics. Due to relatively low power density in such batteries, they are not efficient for powering high-performance electronic systems and electric vehicles. In particular, solid state energy storage devices with high specific energy and power density are essential for automotive car industry such as electric vehicle and clean energy applications.

In this work, we propose a solid state electrostrictive capacitor using an active piezoelectric barrier that exploits a linear and non-linear electromechanical coupling of piezoelectricity and electrostriction in the piezoelectric barrier. Application of a voltage V across the piezoelectric barrier leads to an electromechanical pressure across the layer, which strains the barrier layer of the capacitor [3-5]. The electrostriction mechanism in the piezoelectric barrier of a capacitor sets up a positive feedback between strain and polarization-induced sheet charge and results in internal charge boost under the applied voltage [3-5]. The proposed solid-state piezoelectric capacitors are expected to provide a higher specific stored energy (electrostatic energy stored in internal polarization-induced electric fields) and a higher specific power density (quickly energy delivered to a load due to fast charging/discharging capabilities) as compared to conventional supercapacitors [1-2] and rechargeable battery cells [1-2]. Our modeling results based on the proposed mechanism predicted a higher range of specific energy density ~ 0 to 400 W.h/Kg and specific power density ~ 0 to 108 W/Kg at specific capacitance ~ 0 to 70 F/g at V = 0V to 7.5V prior to electrical breakdown of a piezoelectric barrier in the electrostrictive capacitor. In our calculation, we choose piezoelectric material properties such as layer thickness t ~ 20nm, elastic constant C33 ~ 108GPa, piezoelectric coefficient e33 ~ 27.1 C/m2, and dielectric constant Ed ~ 2700 E0 (E0 is the free-space dielectric constant) for the PMN-0.3PT [6] in charge-voltage (Q-V) and capacitance-voltage (C-V) characteristic equations in refs. [3-5].

In conclusion, the proposed solid state electrostrictive capacitors with enhanced device performance are expected to outperform conventional supercapacitors and rechargeable electrochemical battery cells. The proposed electrostriction mechanism, in general, can be exploited to flexible capacitors (for flexible storage and efficient power delivery) with any active piezoelectric/dielectric materials such as III-V nitride alloys, piezoelectric polymers, micro fiber composite (MFC), BST, PZT etc. The proposed solid state capacitor (acts as a flexible battery) might replace the electrochemical battery cell for futuristic portable, consumer, flexible electronics, automotive electric car industry, and other eco-friendly health, safety and clean energy applications.

References

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POWER ELECTRONICS, ABSTRACT 30

A Power Dense Advanced Power Inverter (API) for Grid Tied Energy Supplies

Bruce Pilvelait

Grid operators are increasingly incorporating containerized energy storage to improve power delivery reliability and resilience. Even with containerized battery systems, it is often not practical to incorporate the full power electronics system into a standard shipping container. The large 60 Hz transformer and complex liquid cooling are costly and undesirable features that provide opportunity for exciting market advances.

Creare is developing a power dense Advanced Power Inverter (API) which includes a transformerless, medium-voltage grid tied inverter, and thermal management which doesn't require liquid cooling. Reducing the total space required for a battery energy storage system and enabling more energy storage and generation capability in the same space will provide an improved value proposition and commercial viability of a containerized energy storage grid tied inverter.

This paper describes achievements in four key areas:

(1) Architecture Assessment -- The inverter delivers 500 kW per module with bidirectional power flow, where multiple modules can be combined for greater power levels. A high-frequency transformer converts between the 1 kV battery bus and the 12.47 kV AC utility bus, eliminating the much larger 60 Hz transformer. Thermal management uses convection cooling, eliminating liquid cooling and minimizing size and cost. Several power conversion topologies are evaluated and compared, with the bidirectional 3LNPC chosen as the most likely to achieve these goals.

(2) System Simulation -- Key simulation results include verifying that (a) voltages can be boosted from the 1 kV battery to achieve 12.47 kV AC interconnections, (b) voltage transients are less than 1% with power flowing to and from the utility interconnect at levels of ± 500 kW to ± 500 kVAR, (c) efficiency will be approximately 96%, (d) switching device losses can be tolerated while maintaining allowable junction temperatures, and (e) Total Harmonic Distortion meets IEEE 519 / IEEE 1547 limits.

(3) Component Selection and Design -- Using system simulation data, components were selected and preliminary circuits designed. SiC MOSFETs with ratings of 1.7 kV and 10 kV and isolated gate drive circuits were experimentally demonstrated with switching times of 100 to 400 ns, which will support a nominal API switching frequency of 20 kHz. SiC MOSFETs achieve the smallest size, highest efficiency, and best harmonic performance when compared with existing silicon Insulated Gate Bipolar Transistors (IGBTs) and MOSFETs. Analytically estimated efficiency is 96%, verifying that the liquid cooling system can be replaced with forced air convective cooling.

(4) Inverter Package Design -- A primary objective of this work was to quantify the power density benefit to be realized from SiC switching devices. Utilizing the SiC MOSFETs and high-frequency transformer and eliminating the liquid cooling is expected to result in a power density improvement of 4.3 times when compared with the existing silicon IGBT inverter.

POWER ELECTRONICS, ABSTRACT 32

Reliability Characterization of Vertical GaN PiN Diodes

Robert J Kaplar

Vertical gallium nitride (v-GaN) power semiconductor devices grown on native GaN substrates are emerging as the next frontier in power electronics, with a unipolar figure of merit (UFOM) surpassing that of SiC (Figure 1). This is due to the high critical electric field (EC) of GaN, which is believed to exceed 4 MV/cm. In the past several years, rapid progress in the growth and fabrication of v-GaN PiN diodes has been made (Figure 2). Such diodes exhibit high breakdown voltage, low on-resistance, negligible reverse-recovery loss, and avalanche ruggedness. While these properties hold promise to greatly improve the power density of switched-mode power conversion circuits for grid-level energy storage, little reliability characterization has been reported to date for such devices. Therefore, Sandia National Laboratories has teamed with Avogy to evaluate the static and dynamic reliability characteristics of v-GaN PiN diodes under a variety of temperature, voltage, and current conditions. The 1200-V-rated diodes were designed and fabricated at Avogy, and the stress and characterization were performed at Sandia.

Static stress was applied to unpackaged die using a high-temperature (300°C), -voltage (3 kV), and -current (20 A DC) probe station. Experiments were conducted in a stress-measure sequence, with current-voltage (I-V) curves taken in between stress periods to characterize the change in diode performance as a result of electrical and thermal stress. Both forward (current) and reverse (voltage) stresses were applied at a variety of temperatures. In addition to the full I-V curves measured in between stress periods, operation-point parameters were monitored in-situ to characterize parametric drift during stress. In general, the diodes showed very good stability up to very high stress levels.

In complimentary experiments, dynamic switching stress was applied to the diodes using a double-pulse test circuit (DPTC, Figure 3). The DPTC utilizes a power switch in conjunction with the v-GaN diode. The switch was selected to be a SiC junction transistor (SJT, available from GeneSiC) due to the SJT's very low on-resistance and extremely fast switching time (~10 ns). Additionally, the first applications of v-GaN diodes will likely be in circuits containing SiC switches, so the DPTC was felt to be representative of plausible real-world scenarios. The evolution of the switching characteristics (e.g. switching time) under repeated switching stress was characterized as a function supply voltage and pulse duration. As with the static measurements, the v-GaN diodes showed very good robustness up to high stress levels. These results indicate that v-GaN diodes show promise as highly reliable devices for power conversion applications.

The characterization work at Sandia was supported by the Energy Storage Program managed by Imre Gyuk of the DOE Office of Electricity, and the fabrication work at Avogy was supported by the SWITCHES program managed by Tim Heidel of ARPA-E. Sandia National Laboratories is a multi-mission 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.

EESAT 2017
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Joydeep Mitra

Invited Speaker
Wednesday, October 11
1:30pm - 2:00pm

Joydeep Mitra is Associate Professor of Electrical Engineering at Michigan State University, East Lansing, Director of the Energy Reliability & Security (ERISE) Laboratory, and Senior Faculty Associate at the Institute of Public Utilities. He received a Ph.D. in Electrical Engineering from Texas A&M University, College Station, and a B.Tech.(Hons.) in Electrical Engineering from Indian Institute of Technology, Kharagpur. He has five years of industry and consulting experience ranging from power system hardware installation to modeling and simulation of energy markets, and seventeen years of academic experience. Prof. Mitra has conducted research in power system modeling, analysis, stability, control, planning and simulation, and is known for his contributions to power system reliability analysis and reliability-based planning. He has over 170 publications and patents in the power systems area, including an edited book, an IEEE Standard, book chapters, technical articles and research reports. Prof. Mitra's research has been funded by the U.S. National Science Foundation, the U.S. Department of Energy, U.S. National Laboratories, and several electric utilities. Prof. Mitra is a Senior Member of the IEEE. He serves as an Editor for the IEEE Transactions on Power Systems and Power Engineering Letters. In the past he has served as Chair of the IEEE-PES Analytic Methods for Power Systems Committee, Chair of several IEEE-PES Subcommittees, and as an Editor for the IEEE Transactions on Smart Grid. Prof. Mitra engages actively in several IEEE activities such as organizing conference tracks and contributing to the development of IEEE standards.

POWER ELECTRONICS IN ENERGY STORAGE

Energy storage (ES) have been used for decades in electric transmission and distribution grid for energy management and power quality control. ES can be instrumental for emergency preparedness and provide multiple applications — energy management, backup power, load leveling, frequency regulation, voltage support, price arbitrage and grid stabilization.

Power electronics (PE) plays a critical role in energy storage system design and integration by providing maximum energy transfer to and from the grid. PE enables the power source to connect to a specific load with a specific characteristic e.g. dc-ac (inverter), ac-dc (rectifier), dc-dc, ac-ac, change of voltage / current level, change of frequency etc. PE is naturally a cross-cutting technology that has a wide variety of applications. Significant advances have been made in semiconductor, magnetics, capacitors, controls, and packaging research and development (R&D) in the last several decades that provided new approaches to the conversion of energy. For example, wide band gap materials such as Silicon Carbide (SiC) and Gallium Nitride (GaN) have made significant improvements over the last few decades. They offer the potential for higher switching frequencies, higher breakdown voltages, lower switching losses, and higher junction temperature compared to silicon-base semiconductors. The higher voltage and switching frequencies has a significant impact on PCS by allowing much smaller passive components like inductors and capacitors to be utilized for the same power requirement. Current energy storage systems utilize water cooled thermal management systems. By using higher junction temperature semiconductors, smaller cooling apparatus could be used resulting in significant increase in power density. Current energy storage systems are housed in shipping containers where high power density designs and more reliable PCS is critical. Advanced material that offer significant increases in power density, efficiency, controllability, and reliability is needed. The recent advances in advanced materials and packaging has improved the current PCS designs.

In this forum, each panel member will briefly discuss their technologies, applications and their perspectives on on-going R&D. The follow-on discussion will be centered around future power electronics R&D opportunities that will assist in making energy storage systems more viable technically and economically.

WORKSHOP CHAIRS

Stan Atcitty, ***Sandia National Laboratories***
satcitt@sandia.gov

Stan Atcitty received his BS and MS degree in electrical engineering from the New Mexico State University in 1993 and 1995 respectively. He received his PhD from Virginia Tech University in 2006. He is presently a Distinguished Member of Technical Staff at Sandia National Laboratories in the Energy Storage Technology & Systems department. He has worked at Sandia for over 21 years. His interest in research is power electronics necessary for integrating energy storage and distributed generation with the electric utility grid. He leads the power electronics subprogram as part of the DOE Office of Electricity Energy Storage Program.

M A Moonem, ***Sandia National Laboratories***
mmoonem@sandia.gov

M A Moonem is a Postdoctoral Appointee at Sandia National Laboratories in the Power Electronics program in Energy Storage research group. He got his PhD in Electrical Engineering with Power Electronics major from the University of Texas at San Antonio in July 2016. He has more than 11 years' of experience in power electronics and power engineering research field. His recent research has been on the power electronic converter design and optimization for grid energy storage systems.

DEMONSTRATIONS AND DEPLOYMENT ABSTRACT 2

Hybrid Thermal and Electrical Energy Storage System

Stephane Bilodeau

Electric Energy Storage (EES) and Thermal Energy Storage (TES) have been integrated in a Hybrid approach in order to optimize energy efficiency and load leveling. This integration is allowing for significant improvement and stability in the operation in a critical application such as Hospital, Datacenters, Manufacturing Plants and other critical thermal/electric processes.

Using the extensive experience in the hybrid energy storage for vehicles, a special SPCM (Synthetic Phase Change Material) has been developed. The Hybrid Thermal and Electrical Storage System maximizes the flexibility and the overall performance of the equipment on the grid.

Developed to be operated on a 24/7 basis, the system act as a buffer to mitigate the fluctuations in the demand. Monitoring has shown that optimum results in building and industrial facilities are obtained when initial fluctuating conditions were observed.

The SPCM is acting as a shock absorber in the thermal process. Improved performance and stability were measured. Ramp up and Ramp down of the equipment are reduced and the Supply and Return process temperatures are stabilized. It allows for:

- *Performance improvement and stability in the operation;*
- *More reliability in the operation with Electrical + Thermal Backup (UPS+UTS).*

For the grid, the impact would also be substantial:

- *Smoothing the load profile and optimizing demand side management;*
- *Improved Redundancy and Predictability of the energy distribution.*

The integration and combined outcomes of the EES-TES systems will be highlighted in the presentation including on-site data on operating cost, return on investment, reliability, and performance.

DEMONSTRATIONS AND DEPLOYMENT, ABSTRACT 9

Fast Response Flywheel Energy Storage Technology for Virtual Power Plants and Microgrids

Rainer Vor Dem Esche

STORNETIC GmbH is a manufacturer of modular scalable and containerized flywheel energy storage technology with a power rating of 60 kW (80 kW peak) and 3,6 kWh capacity and typical charging discharging times in a range from seconds to a few minutes. A special strength of the technology is to deliver more than 1,000.000 full charging cycles without degradation. This feature allows continuous delivery or absorption of power for applications with a volatile demand.

Stornetic flywheels are being used in a virtual power plant and concept microgrid demonstrations projects in Europe, two used cases of these demonstrations in Germany and France will be presented.

Global warming and the efforts to reduce carbon emissions will lead to drastic changes for the electric power generation in Germany. The approximately 200 large power plants of the country will be replaced by millions of renewable generators, mainly wind and PV (today 1.5 million units).

As the electric grid architecture changes from a one way power flow with large base load generators to distributed renewable generators connected to the distribution grid, grid stability and power quality become a challenge for grid operators. How will these instable situations be managed? The project Quirinus was initiated by the German government to provide answers. It will focus on instable operating modes and how these situations can be mitigated, especially:

- Market driven voltage control of grids based on forecasts.
- Seamless transition of grid following to grid forming modes of operation.
- Management of renewables and loads to prevent a grid failure (beyond the means of the markets).

The seamless transition between the various generators will be ensured by a combination of flywheel energy storage and gas operated CHPs (combined heat and power units).

A consortium of five distribution grid operators, three technology companies and two academic institutions in the German state of North Rhein-West Phalia (NRW) will participate in this demonstration project.

Additionally the results of a concept microgrid with EDF in France will be presented. Fast response Flywheel Energy storage technology will be demonstrated to prove the following:

Power Peak Load Shaving & Energy Management in grid following mode (i.e. PV or Wind Firming), Grid forming and power quality mode (microgrid application),Voltage stabilization (fast active power response), Frequency control, Reactive power supply and Voltage ride through (microgrid application) Island mode(microgrid application).

DEMONSTRATIONS AND DEPLOYMENT, ABSTRACT 12

Hybrid Power Generation for Improved Fuel Efficiency and Performance

James E Kersey

This paper provides an overview of the analysis and design of the HPG hybrid power generation system, including the trade studies and analysis performed to define the system architecture, the control system developed to supervise and control the system, and the performance and fuel economy benefits (predicted and test results) of the system. This system is a new approach to containerized, deployable power generation that aims to overcome the weaknesses of conventional diesel power generation.

Traditionally in island power scenarios, the generators must be sized to meet the peak power demand. While conventional diesel generators are rather fuel efficient at higher loads, sizing for peak power demand results in generators that spend significant time at low loads (<40%) in smaller island grids comprised of one to three diesel generators. Furthermore, even in larger island grids, power reliability for critical facilities may require significant spinning reserve that also results in generators spending significant time at these low loads. At these lower loads, specific fuel consumption of conventional generators increases as the diesel engines are no longer operating in a region of high efficiency. Operating in this range can also cause wet stacking, a condition where the diesel fuel does not fully combust and begins to accumulate in the exhaust system components, in turn resulting in increased maintenance costs.

The HPG system architecture addresses these shortcomings of conventional generators while maintaining similar fuel efficiencies at higher loads via the following: multiple engine-generator units controlled by a single supervisory controller either individually or together based on load; variable speed engine operation with rectifier and inverter to decouple engine speed and load from power demand; and energy storage via high performance lithium iron phosphate batteries for peak shaving, step load changes, and very low load operation. The energy storage also allows for a "quiet mode" of operation where power can be delivered without engines running. Furthermore, the system architecture supports renewable energy inputs in the form of solar and wind that can further increase overall energy efficiency.

THURSDAY SESSIONS:

Giovanni Damato, Electric Power Research Institute

Storage VET Tutorial

David Conover, Pacific Northwest National Laboratory
Update on and Overview of Model Codes and Standards for Energy Storage System Safety

Frank Mier, New Mexico Tech
Determining the internal pressure in 18650 format lithium batteries under thermal abuse

Pam Cole, Pacific Northwest National Laboratory
An Overview of Tools to Facilitate Documenting and Validating the Safety of an Energy Storage System Installation

John Hewson, Sandia National Laboratories
Computer modeling to understand and prevent initial and cascading thermal runaway

Ray Byrne, Sandia National Laboratories
The Value Proposition for Energy Storage in CAISO

Di Wu, Pacific Northwest National Laboratory
Non-linear battery model

Richard Baxter, Mustaing Prairie Energy

Energy Storage Financing: A Roadmap for Accelerating Market Growth

Jing Zhang, Department of Systems Engineering, University of Arkansas at Little Rock
Single-Phase Battery-Buffered Smart Load Controller

Ian Gravagne, Baylor University
Timing Consideration for Networked Control of Energy Storage Services

Shijie Tong, University of California
Battery dispatching optimization in stacked energy storage applications for utility grid

David Copp, Sandia National Laboratories
Power System Damping Control via Current Injections from Distributed Energy Storage

Mchael Jacobs, Union of Concerned Scientists
How Storage Displaces and Replaces Conventional Generation - Trajectory of storage providing supplemental services, to essential services, to full replacement of generation

Xiaojin Zhang, Paul Scherrer Institute

Technology assessment of stationary electricity storage technologies for different system and time scales

Rebecca O'Neil, Pacific Northwest National Laboratory
The Regulatory Challenge with Resiliency: How Energy Storage's Resiliency Potential Fits Regulatory Structures

Marc Mueller-Stoffeis, Alaska Center for Energy and Power
Alaskan Microgrid

Hamidreza Nazaripouya, University of California, Los Angeles
Energy Storage in Microgrids: Challenges, Applications, and Research Needed

David Baldwin, SunLight Power, Inc.
High-Temperature Thermal Storage for Dispatchable Renewable Power

Jorge Mirez, National University of Engineering
Analysis of the change from centralized storage to distributed storage in micro-sources, loads and common coupling point in DC microgrids

Elaine Prause, Oregon Public Utilities Commission

Co-Author to The Regulatory Challenge with Resiliency: How Energy Storage's Resiliency Potential Fits Regulatory Structures

Avram Pearlman, Evolution Energy Storage
Arbitrage and the California Independent System Operator: A Feasibility Study for the Utilization of Energy Storage in the Marketplace

Andres Valdepena Delgado, Boise State University
Using Detail Feeder Modeling to Accurately Size a Battery Energy Storage System to Defer an Asset Upgrade

Sergil Tychina, Yunasko Limited
Hybrid Energy Storage: Charging a Battery within 3 Minutes

Srinivas Bhaskar, Cow and Calf Dairy Farms LTD
Flywheel Power Multiplication

Tyler Stevens, Sandia National Laboratories
Synthesis of γ'-Fe4N, a new soft magnetic material for inductors and transformers

Leo Small, Sandia National Laboratories
Molten Nal-AICI3 Catholytes for use in a sodium battery

EESAT 2017
EVOLUTION & REVOLUTION

Thomas Bialek

Invited Speaker
Thursday, October 12
8:05am - 8:40am

Thomas Owen Bialek (M'82) received a B.Sc. (EE) and M.Sc.(EE) from the University of Manitoba in 1982 and 1986 respectively. He also obtained a Ph.D. in Electrical Engineering from Mississippi State University in 2005. He is currently employed by San Diego Gas & Electric Company ("SDG&E") as a Chief Engineer on the Smart Grid Team. His present responsibilities involve smart grid strategy and policy for transmission and distribution issues including equipment, operations, planning, distributed generation and development of new technologies.

CONFERENCE NOTES:

EESAT 2017
EVOLUTION & REVOLUTION

Giovanni Damato

Invited Speaker
Thursday, October 12
8:05am - 8:40am

Giovanni Damato serves as Senior Project Manager in the Energy Storage and Distributed Energy Resource Program at the Electric Power Research Institute (EPRI).

Damato has over a decade of professional experience leading the exploration of distributed energy resources (DER), including grid-connected energy storage. Damato provides innovative grid storage and DER techno-economic analyses with strategic recommendations to energy industry stakeholders, while managing the program's integrated modeling frameworks for EPRI's grid storage practice areas. He leads the collaborative efforts in Grid Services and Analysis through the Energy Storage Integration Council (ESIC) and drives StorageVET™ (www.storagevet.com) development as its product manager.

At Strategen Consulting, Damato led the team's clean energy value proposition practice for over eight years. Stakeholders sought his expertise to identify use cases, construct evaluation frameworks, and conduct cost effectiveness analyses of various clean energy projects that included the integration of solar, fuel cells, energy storage, and electric vehicles. On the regulatory front, he guided the California Public Utilities Commission's stakeholder process for the cost effectiveness evaluation of energy storage during the Storage Rulemaking (AB2514) and inclusion of energy storage in California's Self-Generation Incentive Program.

As a licensed general contractor, Damato founded a custom homebuilding business.

Damato holds an MBA from the Stanford Graduate School of Business and a BS in Civil Engineering from California Polytechnic State University, San Luis Obispo. He enjoys trekking—including Mount Everest, Aconcagua, and Kilimanjaro.

Update on and Overview of Model Codes and Standards for Energy Storage System Safety

David R. Conover

There are a myriad of energy storage technologies (EST) being deployed in addition to those under development with the hope of future deployment. The successful design and construction of EST and their installation and use in the built environment must address a number of issues; the foremost of which is safety. The safety of any technology and its installation and use in the built environment is addressed through the development and adoption of and compliance with model codes and standards. Such documents, developed under the auspices of such organizations as ASME, CSA, ICC, IEEE, NEMA, NFPA and UL as well as the IEC, are updated on a regular basis or newly developed when appropriate. While they are developed on a regular basis, they typically lag technology development and its initial deployment. Until they are updated there can be gaps between the criteria in these documents that can help ensure an EST is safe and the specifics associated with the EST design, construction, installation and/or use. Those responsible for documenting or verifying the safety of an EST and its installation and use need updated criteria on which to communicate and base their decisions concerning EST safety. Until those gaps are filled these model codes and standards do provide for the evaluation of EST on the basis of its expected performance with respect to safety, however, there is an increased probability that a custom site specific documentation and validation will be required with each EST installation.

This paper will provide information on how the U.S. Department of Energy's Energy Storage Systems (ESS) Program, through the support of Pacific Northwest National Laboratory (PNNL) and Sandia National Laboratories (SNL), is supporting the updating of existing and development of new model codes and standards that can provide appropriate safety-related criteria for today's EST's and can continue to evolve over time to address future EST.

The specifics to be covered in the paper will include:

- An overview of the safety-related issues associated with EST
- Which model codes and standards provide criteria applicable to EST and its installation and use
- A summary of the criteria and their scope as it relates to an EST
- An overview of where these model codes and standards have been adopted and the scope of those adoptions
- Identification of ongoing opportunities to provide recommended changes to model codes and standards and become further involved in their development

Those in attendance will not only learn about the model codes and standards development process and how to become involved, but will learn about the provisions in the those documents, how they have been adopted and efforts underway to update them as EST evolves and more is learned about how to address EST safety.

VALIDATED SAFETY, GUIDELINES, STANDARDS PROTOCOL, ABSTRACT 10

Determining the internal pressure in 18650 format lithium batteries under thermal abuse

Frank A Mier

Lithium batteries have a well-known tendency to fail violently under abuse conditions which can result in venting of flammable material. Understanding these events can aid in evaluating safety associated with individual battery cells and battery packs when these fluids are vented. The external fluid dynamics of the venting process, including liquid droplets and gases, is directly related to internal pressure of the battery cell. In this work, battery case strain is measured on cells under thermal abuse which is then used to calculate the internal pressure via hoop and longitudinal stress relations. Strain measurement is a non-invasive approach which will have no bearing on the decomposition within batteries that leads to thermal runaway. Complementary tests are performed to confirm the strain-pressure relationship by pressurizing 18650 cell caps to failure with an inert fluid. A laboratory setup with a heated test chamber was designed and fabricated to remotely subject cells at heating rates up to 15 C/min. Additional measurements include cell temperature and the test chamber pressure, temperature, and heat flux. Variables explored in tests include cell chemistry, state of charge, and heating rate.

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VALIDATED SAFETY, GUIDELINES, STANDARDS PROTOCOL, ABSTRACT 11

An Overview of Tools to Facilitate Documenting and Validating the Safety of an Energy Storage System Installation

Pam C Cole

Codes, standards and regulations (CSR) governing the design, construction, installation, commissioning and operation of the built environment are intended to protect the public health, safety and welfare. While these documents change over time to address new technology and new safety challenges there is generally some lag time between the introduction of a technology into the market and the time it is specifically covered in model codes and standards developed in the voluntary sector. After their development, there is also a time frame of at least a year or two until they are adopted. Until existing model codes and standards are updated or new ones developed and then adopted, one seeking to deploy energy storage technologies or needing to verify an installation's safety may be challenged in applying current CSRs to an energy storage system (ESS). Even when CSRs provide specific criteria those deploying ESS technology must document compliance with those CSR and those enforcing must be able to verify compliance with their CSR.

Under the Energy Storage Safety Strategic Plan, developed with the support of the Department of Energy's Office of Electricity Delivery and Energy Reliability Energy Storage Program by Pacific Northwest Laboratory and Sandia National Laboratories, an Energy Storage Safety initiative with collaboration and involvement from many stakeholders has been underway since July 2015. One of three key components of that initiative involves CSR impacting the timely deployment of safe energy storage systems (ESS). The timely deployment of safe ESS is focused on how to document and validate compliance with current CSR and in so doing validate that a proposed ESS installation is safe as intended pursuant to those CSR.

This paper will provide information on two tools to help address the acceptability of the design and construction of stationary ESSs, their component parts and the siting, installation commissioning, operations, maintenance and repair/renovation of ESS within the built environment. These tools assist with the tasks of documenting and validating compliance with CSR covering ESS safety, either the specific provisions that may address an ESS technology and its application or a situation where the codes and standards may not provide specific provisions.

A task force was formed under the ESS Safety working group to address documenting and verifying compliance with current CSR and through their efforts the Energy Storage System Guide for Compliance with Safety Codes and Standards was developed and published in June 2016. In late 2016, another task force was formed composed of all stakeholders that are involved with the ESS safety initiative, and through their efforts the Energy Storage System Safety – Plan Review and Inspection Checklist was developed in March 2017.

Attendees will learn what is needed to document that an energy storage system meets safety related CSR and how to validate the technology as installed meets adopted CSR. Though this they will also have an increased ability to recognize key safety related issues associated with an ESS technology installation that will help augment their future efforts to develop and deploy current and future ESS.

CONFERENCE NOTES:

SAFETY STANDARDS AND IEEE STANDARDS WITH ENERGY STORAGE

This presentation will focus on discussion of the establishment of safety protocols and guidelines for the emerging field of energy storage. These protocols begin with laboratory testing and analysis on individual battery cells all the way to 1 MW systems. In addition to the establishing a general set of guidelines for ES, discussion will be had concerning the active revision to IEEE 1547 which adds explicit new guidance for ES systems.

WORKSHOP CHAIRS

Summer Ferreira, Principal Member of Technical Staff, *Sandia National Laboratories, srferre@sandia.gov*

Ferreira spent two years at Sandia National Laboratories as a postdoctoral researcher in hybrid organic/inorganic photovoltaics before moving to stationary energy storage in 2011 in support of the DOE Office of Electricity program. Summer leads the Energy Storage Analysis Laboratory, which is dedicated to advancing energy storage through: involvement in energy storage standards; the development and understanding of testing profiles on the life of energy storage technologies; the relationship between energy storage device life under laboratory profiles to that in real world applications; and the third party characterization and life cycle testing of devices for academic, government laboratory, and commercial developers. Summer received her Ph.D. In Materials Science and Engineering from the University of Illinois Urbana-Champaign with Prof. Jennifer Lewis.

Charlie Vartanian
Senior Member of IEEE

Charlie Vartanian has over 25 years of power industry experience in electric utility planning, technical standards development, policy analysis, and the marketing and sales of advanced energy systems. Charlie is a licensed Professional Engineer in California, and is a senior member of the IEEE.

ENERGY STORAGE VALUATION, MODELING, AND FINANCING TUTORIAL

Driven by renewable portfolio standards in 29 U.S. states plus Washington D.C. and three U.S. territories, the total contribution of renewable resources to the electricity generation portfolio is expected to grow substantially over the next 30 years. States including Oregon, California, and Hawaii have set RPS targets at or above 50 percent by 2045. With the advent of smart grid technologies and the growing need for enhanced grid flexibility, a future with more distributed energy resources is increasingly becoming a necessary reality.

Energy storage includes a suite of technologies that have a number of attributes that provide tremendous flexibility to grid operators. Attributes such as the capacity to act as both generation load, ability to provide benefits at multiple points in the grid, and the capacity to be more effective than conventional generation in meeting ramping requirements and responding to regulation signals at the sub-second level distinguish storage from traditional forms of power generation.

Several energy storage technologies show promise but it remains difficult to quantify or capture the benefits that energy storage systems provide. There are varying rules, requirements, and capabilities tied to value capture. To monetize the value of energy storage, these services must be modeled and co-optimized in a manner that addresses the physical and performance-related limitations of the ESS. Because no ESS can meet the needs of all services simultaneously, valuation models are necessary to determine technically achievable returns on investment.

This tutorial will begin with a presentation covering the basic principles underlying the valuation of energy storage services. The Electric Power Research Institute will be presenting an overview of its Storage Value Estimation Tool. The tutorial will include two applied assessments of energy storage value. Finally, the fundamentals of energy storage financing will also be covered.

WORKSHOP CHAIRS

Patrick Balducci, Chief Economist
Pacific Northwest National Laboratory

Patrick Balducci is a Chief Economist at the Pacific Northwest National Laboratory (PNNL) where he has been employed since 2001. He has 20 years of professional experience as an economist and project manager, and is currently leading the industrial acceptance area of the PNNL Energy Storage Program. He has extensive experience in modeling the benefits of energy infrastructure and in leading research and development efforts supporting the U.S. Department of Energy (DOE) and the electric power industry, and has authored over 100 publications, including journal articles, conference proceedings, and technical reports. He currently serves as the President of the Pacific Northwest Regional Economic Conference. He holds a BS in Economics from Lewis and Clark College, where he graduated with honors, and an MSc in Applied Environmental Economics from the University of London, Imperial College of London.

CONTROLS AND GRID CONSIDERATION, ABSTRACT 21

Analysis of the change from centralized storage to distributed storage in micro-sources, loads and common coupling point in DC microgrids

Jorge L Mirez

The microgrids are the structural bricks of the smart grids, can be connected or disconnected from the external power grid and have a capacity to manipulate powers of up to 10 MW at the point of common coupling.

The smart grids will be formed among other things by hundreds or thousands of interconnected microgrids in very different ways between them and with the electrical networks of the electric companies.

Usually, microgrids have been designed with respect to storage with (i) one or several (but few) sources of energy storage which are centralized at a single location in the microgrid and (ii) some microgrids have been designed without energy storage. Additionally, the electric loads are elements that have a function of consuming energy which is requested of the microgrid and in some cases have self-generation.

In both scenarios, the micro-sources of microgrids have to constantly adjust their production in function of the charge/discharge processes of the storage source and the demand of electrical loads, which leads to complex systems of prediction, data management, optimization and of improvement of the electrical energy quality.

In view of this, it is proposed and analyzed that micro-sources and loads are those that have storage, which means that both production and consumption is defined at a fixed value for a certain time that we call "state", of sufficient duration for that the control systems can process the information and to optimize the next state, which simplifies the microgrids control and operation.

Has been assumed that the microgrids are of DC type and that each microgrid may have several points of common coupling both with the external electrical network and/or with neighboring microgrids. The energy exchange will be analyzed in a configuration of interconnection between microgrids and external power grid which will allow exporting the surplus of energy produced or stored in one of the microgrids or to import energy from the external power grid. Arrangements of two microgrids and external electric network and three microgrids and external electric network have been considered for our analysis.

By using mathematical models of microgrids and interconnections, the behavior of the variables (power, energy, voltage, storage capacity) has been determined, the advantages and disadvantages between microgrids that have a centralized storage and when the storage has been distributed in loads and micro-sources.

CONTROLS AND GRID CONSIDERATION, ABSTRACT 36

Timing Considerations for Networked Control of Energy Storage Services

Ian Gravagne

Energy storage elements are poised to provide increasingly important services that can enhance power grid stability including wide-area modal damping, frequency and voltage regulation, and others. Services like these are enabled by the presence of fast-response power electronic inverters, modulated by real-time controllers. The value of damping and regulation services may be increased when the storage system can respond to measurements at remote locations. For example, controllable inverters on a large PV array may provide ancillary frequency regulation service if the frequency measurement is non-local, located on a major transmission line some distance away. Additionally, it could be advantageous for a controller to receive measurements from multiple locations, and command energy storage inverters at yet another location altogether.

Remotely located sensors and/or controllers, however, present the problem of communications latency. Latency, in turn, limits the effective operational bandwidth of the controller and the service it provides. This paper presents an analysis of how latencies statistically accumulate through multiple network channels, including the potential effect of controller time-alignment as well as packet reversals and drop-outs.

For example, consider the system of Figure 1, which illustrates a wide-area damping configuration with two remotely located phasor measurement units (PMUs), a controller and an energy storage system, all communicating over the public internet. Figure 2 illustrates the computed latency PDF for commands arriving at the inverter (blue), assuming that all three network channels exhibit a given latency PDF (red). The paper will illustrate the assumptions and computations required to estimate network performance in several configuration scenarios. While it is not within the scope of the paper to examine controller design, designers will need a grasp of both accumulated latency and inter-packet communications spacing (known as "graininess") to understand the bandwidth and performance limits of a particular control design.

figures:

CONTROLS AND GRID CONSIDERATION, ABSTRACT 41

Battery dispatching optimization in stacked energy storage applications for utility grid

Shijie Tong

With the progression of the utility grid and battery technologies, an energy storage system needs to find better value proposition in the energy markets by delivering multiple applications to the grid. A genetic algorithm (GA) optimization routine was implemented to design battery dispatch schedules at real time to participate in stacked energy storage applications. Six potential energy storage applications were identified for stacking: demand charge management (DCM), day ahead energy time shifting (DA-ETS), real time energy time shifting (RT-ETS), flexible ramping (FR), and frequency regulation (FQR). A battery system was modeled to be able to dispatch in all five applications, constrained by its power, energy and state-of-charge limits. The GA leverages forecasting of energy market prices, flexible ramping demands, frequency regulation capacity demands and behind the meter energy demands using recurrent neural network (RNN). The cost function for the optimization task is constructed based on the estimated revenues from DA-ETS, FR-ETS, FR, FQR applications following the California independent system operator (CAISO)'s energy products design and from DCM application following the regional utility pricing. By adjusting the optimization constraints, four different stacking approaches were investigated, i.e. exclusive approach, combined approach, concurrent approach and progressive approach. The exclusive approach identifies the DA-ETS as the primary application, which is optimized and dispatched day-ahead, and then identifies the RT-ETS as the secondary application, which is dispatched at real time filling the idle gaps of the primary application. The combined approach divides a battery into two subsystems and participates in the RT-ETS and FR applications independently, to hedge the biddings. The concurrent approach examines four applications, RT-ETS, FR, FQR, and dispatches the battery for one of the applications in each optimization interval based on economic incentives. The progressive approach examines five applications, RT-ETS, FR, FQR, DCM, and dispatches the battery for a combination of the applications in each optimization interval based on economic incentives. This work unveiled revenues of an energy storage system in multiple applications through different stacking approaches. In addition, this work examined possible revenue improvements by relaxing some of the energy market rules, such as allowing self-dispatching in the regulation market and reducing the bidding lead-time in the real-time market.

CONTROLS AND GRID CONSIDERATION, ABSTRACT 45

Power System Damping Control via Current Injections from Distributed Energy Storage

David A Copp

A power system consists of a complex interconnection of nonlinear components distributed across wide geographic regions. In these systems, an event, such as a fault at one of the buses, results in swings in the power transfer between regions. These power swings are called inter-area oscillations. Damping inter-area oscillations is crucial for maintaining a secure and reliable power grid, and failing to do so can have severe consequences, such as a blackout. Traditionally, Power System Stabilizers (PSSs), utilizing

local measurements, have been used to implement damping control that mitigates the effects of inter-area oscillations. More recently, the use of remote signals with PSSs has been shown to be advantageous. The availability of system-wide information via remote signals has enabled the use of system components such as Energy Storage (ES) and renewable resources for damping control. Previous work concludes that the optimal location for an ES device to provide damping is in the area of the power system with lower inertia. In this work, we extend this result by investigating the performance of damping control implemented with several ES devices distributed throughout the system.

We analyze an example power system, which contains two areas, with two synchronous generators and one load in each area, as well as ES devices distributed throughout the system. The ES devices are capable of injecting current into the system in order to damp inter-area oscillations. We excite the system by applying a ground bus fault at bus 7, which causes inter-area oscillations, and investigate the damping performance when different combinations of ES devices provide current injections. For example, we quantify the differences in control effort (current injected) and transient system response when all six of the ES devices provide current injections versus when only ES devices 1 and 6 provide current injections. The damping control input for each ES device is determined by multiplying the difference between the average machine speed in area 1 and the average machine speed in area 2 by a control gain that is scaled by the number of injections in each area.

Naturally, injections from ES devices in different locations throughout the system produce different transient responses. Therefore, there may be scenarios in which it is advantageous to use smaller current injections from more ES devices distributed throughout the system rather than using larger current injections from fewer ES devices. We quantify performance for these types of scenarios and provide insights for how best to utilize ES devices for damping control in this example system.

ENHANCING REGULATORY EQUITY AND MARKETS, ABSTRACT 1

Arbitrage and the California Independent System Operator: A Feasibility Study for the Utilization of Energy Storage in the Marketplace

Avram L Pearlman

As the California grid mix becomes inundated with renewables (33% by 2020, and increasing to 50% by 2030 because of policy like SB 350 (a California bill including a renewable energy mandate), energy storage will play a significant role in balancing the grid. With increased renewables and the cyclic nature of the price of energy each day comes an opportunity for energy storage to generate revenue.

This study outlines the feasibility of an energy storage system optimized based on the California Independent System Operator (CAISO) average market price in California. The average price in the day ahead market within the CAISO is variable. Using data analysis and optimization, the ideal daily charge and discharge schedule was determined using 12 months of existing data. The analysis includes published data on storage cost and wholesale energy price data evaluated in five-minute intervals to justify the investment in an energy storage system.

Logic is used to determine a set of simple criteria for battery status: charge, discharge, and hold. Internal Rate of Return (IRR), Modified Rate of Return (MIRR) and payback is also included. The calculations are based on storage capacity, round-trip efficiency, and historical market price. The model includes daily optimization for maximum revenue and compares various scenarios using bidding schemes.

ENHANCING REGULATORY EQUITY AND MARKETS, ABSTRACT 17

How Storage Displaces and Replaces Conventional Generation - Trajectory of storage providing supplemental services, to essential services, to full replacement of generation

Michael B Jacobs

The trajectory of energy storage substituting for conventional generation can be traced from actual practices, and projected further from demonstrated capabilities. The implications of this on system planning, expansion, operations, and on energy markets have not been defined. Initial assessment of this trajectory suggests that retiring old generation and replacement with storage-backed variable renewable generation is a viable technical option.

Storage paired with generation began in isolated grids in Hawaii and Chile where ancillary services from very small generator fleets were unavailable or constraining the grid operations. Recent energy storage deployments on large grids of the U.S. demonstrate a turning point. Present state-of-art technology adoption includes manufacturer General Electric (GE) hybridization of storage with LM aeroderivative generators to improve the performance of peaking plants. Contemporary step is utility-scale peaking generation built entirely from energy storage. The end-stage is planning for long-duration storage paired with variable renewable generation for full satisfaction of market, reliability and regulatory requirements.

How did this happen and what does this mean?

As industry demonstrates the increased functions of inverters and long-duration energy storage, decision-makers face the reality of storage replacing conventional power plant capacity with storage.

Record shows energy storage making incremental replacement of the features, functions and roles of conventional generation. Initial commercial storage deployments provided operational flexibility to manage forecast errors and output variability. In Hawaii, limits set on windfarm variability led to high power, low energy storage systems to smooth short-term output. In Chile, AES substituted storage to provide spinning reserves for

contingency response previously provided by unloaded generator capacity.

With short duration storage now understood as providing ancillary and essential services, GE is delivering hybrid plants with storage and a gas turbine integrated in a system with a single set of controls. The GE hybrid system uses the storage to provide the reliability capabilities of the gas generator with instantaneous response, regardless of whether the unit is started and burning fuel when response is needed.

How to confirm storage facilities' reliability contributions equivalent to that of conventional plant?

Reliability expectations can be inferred from industry guidance documents. NERC Essential Reliability Services Task Force proposed measures to guide change in the generation mix. PJM added performance requirements to its capacity market rules for resource adequacy. Energy storage is quickly meeting critical milestones to satisfying these expectations. Paper will note field testing of utility-scale commercial deployment of inverters and long-duration storage installations demonstrating operating characteristics of such as replacement resources.

What are prospects for repowering old generation facilities in critical locations?

UCS and students at the University of Wisconsin-Madison examined the question, "can storage and renewables replace a major water-front fossil generator?" Multiple feasible combinations of storage with renewable generation are capable of providing capacity, energy, and ancillary services, as well as unpaid "essential services" in satisfaction of power system performance expectations. Analysis of options for the Waukegan Generation Station in northern Illinois illustrates the suggested end-stage for long-duration storage paired with variable renewable generation for full satisfaction of reliability and capacity market requirements.

ENHANCING REGULATORY EQUITY AND MARKETS, ABSTRACT 29

Continuous-time Scheduling and Pricing of Energy Storage in Electricity Markets Operation

Masood Parvania

Energy storage (ES) represents the lossy temporal shift of electricity that is fundamentally different from energy generation and consumption, and requires new models and market rules for integration in power systems scheduling and pricing practices. In this presentation, we will introduce a new method for continuous-time scheduling and pricing of generating units and ES devices in power systems operation. We first formulate the problem of joint commitment and scheduling of generating units and ES devices as a continuous-time optimal control problem, which schedules for optimal continuous-time power and ramping trajectories of generating units and ES devices to supply the net-load trajectory over the scheduling horizon, e.g., day-ahead. The continuous-time pricing counterpart problem is formed by fixing the commitment variables of generating units to their optimal values obtained from the scheduling problem.

We prove that the Lagrange multiplier associated with the continuous-time power balance constraint is the continuous-time marginal price of energy generation and storage, which corresponds a single marginal price at which both generating units and ES devices are priced. The proposed continuous-time marginal price is then calculated in closed-from, which shows that the marginal price not only depends on the incremental cost rate of generating units, but also to terms that embed the financial ES charging and discharging bids and are defined as incremental charging utility rate and incremental discharging cost rate. The proposed marginal price provides a price signal for ES devices, that reflects the impacts of continuous-time variations of net-load (load minus renewable energy) on the operating condition of the system, and enables the ES devices to gain additional profits by providing services at the times that is most needed in the system.

This presentation will also define a new index, called net incremental surplus of stored energy (NISSE), which quantifies the net surplus of incremental change in the energy stored at the ES devices over the charge-discharge cycle. NISSE establishes a temporal dependence between the incremental discharging cost and incremental charging utility rates of ES devices, thereby causing a temporal dependence between marginal prices during the ES charging and discharging states.

ENHANCING REGULATORY EQUITY AND MARKETS, ABSTRACT 39

The Value Proposition for Energy Storage in CAISO

Ray Byrne

Energy storage can provide a number of grid services. In the California electricity markets, the options include arbitrage, frequency regulation, and ramping products. Arbitrage refers to buying (charging) when electricity prices are low, and selling (discharging) when electricity prices are high. There are arbitrage opportunities in the day ahead market (DAM), the real-time market (RTM), as well as between the DAM and RTM. For frequency regulation, there is a regulation up (source energy) product and regulation down (sink energy) product. In 2013, the California Independent System Operator (CAISO) implemented “pay-for-performance”, which incorporated a mileage payment and tied remuneration to accuracy in following the automatic generation control (AGC) signal. Ramping products have recently been added to help mitigate the late afternoon ramping requirements caused by increasing penetrations of photovoltaic generation. This paper reviews the opportunities for energy storage based on an analysis of historical market data. Heat maps are used to indicate the relative opportunities across CAISO for the different products. The paper also identifies trends in market prices over the last few years.

ENHANCING REGULATORY EQUITY AND MARKETS, ABSTRACT 51

The Regulatory Challenge with Resiliency: How Energy Storage’s Resiliency Potential Fits Regulatory Structures

Rebecca O’Neil

Energy storage technologies could potentially provide many energy service benefits to utility customers. Behind-the-meter or co-sited storage solutions could enable customers to avoid longer outages and support continuous public and emergency services. But these “resiliency” benefits come with regulatory challenges when utilities consider investing in resiliency assets.

This presentation will describe how utility regulators view resiliency investments. Is it distinct from reliability? What challenges, such as assuring equity and cost-effectiveness in meeting regulatory tests, do they face when considering utility engagement in resiliency assets? What is the proper role of electric utilities in customer resiliency investments? How can utilities integrate their interests with customer interests, and do so equitably among all customer classes?

Then, the presentation will review programs and proposed utility resiliency investments nationally to discuss the current state of practice. What is the regulatory basis for utility-run customer programs that support storage? Why are certain utilities unable to attain regulatory approval for proposals to invest in resiliency, and what is their business case or public interest case for doing so?

Finally, the presentation will discuss approaches to resolving the challenges identified in additional research and analysis, responding to regulatory questions, or taking lessons learned from the national outlook.

UNSORTED ABSTRACT 5

Genitor Based Energy Management System for Remote Microgrids Considering Battery Lifetime

Reinaldo Tonkoski

With the increase in the use of distributed generation (DG) in microgrids, it becomes increasingly challenging to coordinate the available energy resources for operation and control of the system. Though photovoltaic (PV) system utilization is increasing rapidly in remote microgrids, diesel generators are still the primary source of energy. The addition of PV to the microgrid reduces the load on the generator and also reduces fuel efficiency. Moreover, the PV power does not correlate with load demand, and the full potential of PV cannot be utilized. To overcome this issue, energy storage system (ESS) is used. ESS can act as a load to store excess energy and as a source to dispatch the stored energy. Batteries are typically used as an ESS in a microgrid. These have a limited energy throughput during its useful life. Therefore, the battery degradation needs to be considered to fully utilize the battery or to ensure that degradation does not reduce the lifetime considerably. A balance between fuel consumption and battery throughput is required to minimize the cost of microgrid operation. This can be achieved by scheduling the resources appropriately.

An energy management system (EMS) can be implemented to decrease the operational cost of the microgrids by obtaining schedule for using the available DG. Reducing the fuel consumption in a diesel-based remote microgrid is one of the main concerns to reduce the operational cost. Since the fuel consumption of a diesel generator is a quadratic function of its power output, it cannot be optimized by using linear techniques. Further, inclusion of battery characteristics results in high non-linearity. Optimization techniques such as linear, quadratic, gradient search may not generate a possible solution for such highly non-linear problems. This paper proposes the use of the Genitor algorithm for the scheduling of the energy resources in a remote microgrid to achieve minimum operational cost. Genitor is a heuristic search technique, a steady state genetic algorithm (GA) and is found to achieve more accurate optimization, especially on large problems. The steps involved in the algorithm are presented as a flowchart and included as an attachment.

The Genitor algorithm was implemented to generate a schedule of the energy resources in a remote microgrid consisting of two different diesel generators, a PV system, and a lead acid battery. This approach minimizes the fuel consumption and considers charging and discharging cycles of the battery. Further, the battery degradation has been included using weighted Ah throughput model of a battery bank which accounts for the differences in actual operating conditions and those used for standard tests. The minimization of generator fuel consumption and battery degradation was included in an objective function with specific weights assigned to each of these objectives. When the battery operating conditions were considered, the increment in the fuel consumption by 1.7% resulted in decrement in the battery wear cost by 68.7% for the day considered for analysis. Also, the algorithm successfully generated a schedule to fully charge the battery based on the operating conditions to minimize the battery degradation.

UNSORTED ABSTRACT 23

Integrated Energy Harvesting for Wearable Battery Charging

Gregory P Nichols

The amount of available energy generated by heat, electromagnetic radiation, and human motion is able to meet the modern world's increasing electrical power demand. This recognition led to the recent proliferation of novel energy harvesting technologies for small and large-scale applications. Advancements in e-textiles and flexible circuitry, coupled with modern batteries, allow for the prototypical design of a suit that harnesses available energy to maximize warfighter performance for an indeterminate period of time. The design consists of piezoelectric, triboelectric, solar, thermoelectric, and radio frequency (RF) energy harvesting systems connected using inkjet-printed circuitry and silver nanowires, which send the harnessed power to be stored in a flexible battery.

The average surface area of the human body is 1.9m2 for men and 1.6m2 for women, providing a large area to implement energy harvesting systems. Proper placement will ensure the most economical route for power generation (i.e., arms and legs for the piezo-triboelectric system, top of the shoulders and back for solar cells, etc.). The estimate of the total energy production of the suit assumes all systems are producing energy simultaneously at their maximum power generation potential. Approximately 80% of the body's surface area is available for harvester placement. Each system's efficiencies were estimated from data collected from various peer reviewed articles. This system generates a substantial amount of energy, as seen in the provided tables.

Several engineering obstacles must be overcome in order to make this design feasible for field use. Historically, flexible electronics have had low durability; typically failing at soldering junctions. Creating inkjet-printed copper electroplated traces would allow conventional soldering to connect electrical components onto flexible substrates, which mitigates wear and tear due to material flexion. Another engineering hurdle is managing the variable power input and the integration of multiple energy harvesting technologies. The energy generated from the above systems is small (on the level of W to mW power production per harvester) and highly variable with regard to user movement, solar intensity, temperature, and distance from RF sources. This variability has hindered implementation, as input voltage characteristics are typically uniform in most electronic systems. When these systems are coupled with devices like the Texas Instruments Ultra Low-Power Boost Charger With Battery Management and Autonomous Power Multiplexer, the low power and variability can be overcome, allowing for power storage in a battery.

Future research avenues include energy production under various environmental conditions, such as during nighttime, in isolated and urban areas, at different temperatures, and under various estimations of user movement. Research will also be conducted on the weight-to-energy production balance to ensure the energy harvesting systems will not disrupt mobility. Discerning the best ratio of energy production to weight addition will allow for system development that maximizes warfighter performance.

UNSORTED ABSTRACT 33

Zero-Emission Energy Storage for Electric Vehicles

Zach Jones

Vehicles with electric powertrains (EVs) have numerous advantages over vehicles with internal combustion engine powertrains, and recent advances in electrical energy storage technologies have accelerated their adoption. Lithium- ion batteries (LIBs) have achieved impressive cost reductions in recent years, but hydrogen fuel cells (HFCs) - which also store electrical energy - have made equally impressive gains over the same time period. While both technologies offer zero-emissions at the point of use, HFC systems provide the following benefits with respect to today's best LIBs:

- 15X Faster refueling
- 10X Cheaper electrical energy storage
- 5X Lighter

Critics point out that hydrogen is difficult to work with, has limited fueling infrastructure in place, and is cheapest when produced from natural gas via a process that emits CO2 . All of these criticisms are valid. However, for certain EV applications - particularly those requiring a high ratio of energy storage to power consumption - HFCs easily beat LIBs. And with enough hydrogen produced annually in the United States to fuel over 45 million of the light-duty HFC EVs available today from manufacturers like Toyota, Honda and Hyundai, both the supply and demand sides of theequation are ready to scale.

CONFERENCE NOTES:

WORKFORCE DEVELOPMENT FOR THE FUTURE GRID – ENERGY STORAGE "TECHNICIANS"

The US Dept. of Labor projects that there will be an increase of about 14,000 jobs in employment of electrical power-line installers and repairers from 2014 to 2024. Growth will be largely due to the growing population and expansion of cities and upgrading the interstate power grid that will continue to grow in complexity to ensure reliability. Energy storage is not considered an occupational field by the DOL and the job description of Storage Battery Tester has not been updated since 2001. Global battery-making capacity is set to more than double by 2021, topping 278 GWh/year from the current 103 GWh/year. It has been reported that the creation of a 15 GWh/year plant could create 7,000 jobs during construction and require 300 full-time jobs after start up. The energy storage industry is growing rapidly, but the line workers and technicians of today do not possess the skill sets for these new jobs and as an aging workforce are unlikely to undertake the training required. In order to avoid a skilled labor shortage in the emerging energy storage field this workshop will define the skill sets needed for technicians, operators and maintenance personnel for the Future Grid and work on the curriculum needed to train them.

WORKSHOP CHAIRS

Stephen Gómez, Ph.D., Chair – Trades, Technology and Sustainability Department,
Assistant Professor, Santa Fe Community College, stephen.gomez@sfcc.edu

Gómez is a native New Mexican. He started his career in the biomedical field with appointments at the Dept. of Molecular Biotechnology, U. of Washington; Dept. of Oncology, Children's Hospital of Los Angeles; Pasarow Mass Spectrometry Laboratory, UCLA and the Respiratory Immunology and Asthma Program, Lovelace Respiratory Research Institute.

Since returning to New Mexico, Gómez' interests have shifted to sustainable agriculture and biofuels. He has served as a consultant to Sandia National Laboratories in Renewable Energy and managed the research program in low-water greenhouse agriculture at the Indio-Hispano Academy of Agricultural Arts and Sciences.

Gómez joined the faculty at SFCC in 2014. Previously, he taught biology at UCLA, U. of Washington, U. of Wyoming, UNM and CNM Community College. While at CNM he developed a curriculum in Green Energy as part of the engineering program. In addition to his duties as chair, Gómez also teaches biology courses in the School of Science, Health, Engineering and Mathematics.

CONFERENCE NOTES: