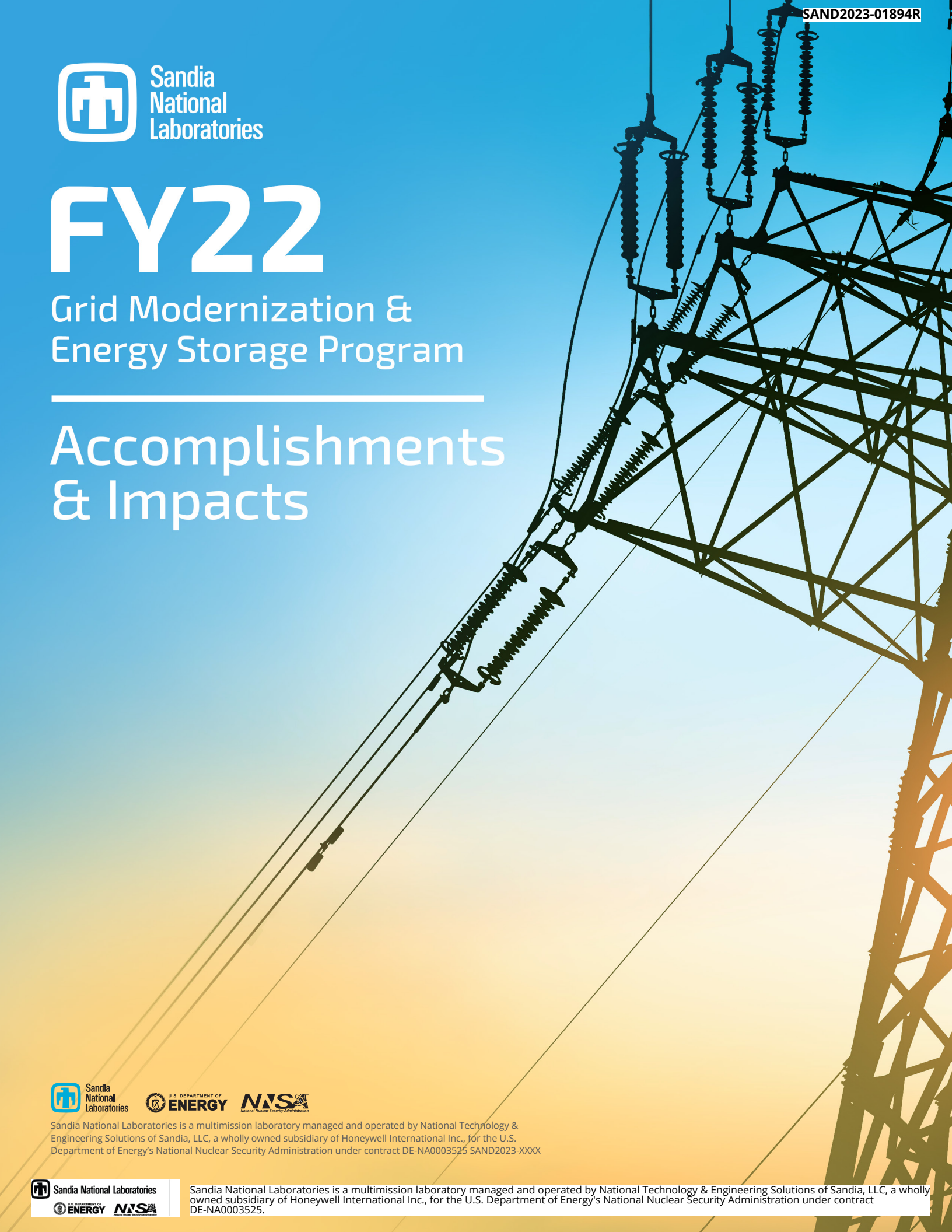
SAND2023-01894R

Sandia National Laboratories

FY22

Grid Modernization & Energy Storage Program

Accomplishments & Impacts



Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & 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 SAND2023-XXXX

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INTRODUCTION

Sandia's Grid Modernization and Energy Storage program works to advance a national vision of a secure, resilient, and sustainable electric system for all users. Our achievements reflect a strategic approach combining technology development; modeling, simulation, and data analytics; and partnered demonstrations and outreach to further the adoption of advanced grid and storage technologies. Our FY22 efforts leverage the strengths of our partnerships—spanning Sandia's core science and technology competencies as well as external technology leaders—to develop the solutions today which enable the grid of tomorrow.

Much of the material in this report comes from the separate 2022 Accomplishments Report compiled by our Energy Storage subprogram team, a cornerstone of our grid research and achievements. The Grid Energy Storage Program at Sandia is focused on making energy storage cost-effective through research and development (R&D) in new battery technologies, advanced power electronics and power conversion systems, improved safety and reliability for energy storage systems, analytical tools for the valuation of energy storage, and the validation of new energy storage technologies through demonstration projects. During the 2022 fiscal year, Sandia executed R&D work supported by the U.S. Department of Energy's (DOE) Office of Electricity – Energy Storage Program under the leadership of Dr. Imre Gyuk.

This report indicates key areas of research and engagement and summarizes the impact of Sandia's contributions through notable accomplishments, journal publications, patents, and technical conferences and presentations. It is provided with the hope that readers discover ways we can further team to create our modern grid and apply the outcomes of our efforts. The bulk of work described herein is funded by the DOE Office of Electricity and key programs within the DOE Office of Energy Efficiency and Renewable Energy.

As we indicated in our report from last year, the contributors to our successes are too numerous to name here, though our team wishes to express our deep gratitude to the numerous program and project sponsors at the US Department of Energy, who often function equally as technical collaborators; our many partners in industry, academia, utilities, and other national labs; and fellow researchers and business partners at Sandia whose leadership and creativity have enabled the accomplishments described herein.

Charles Hanley

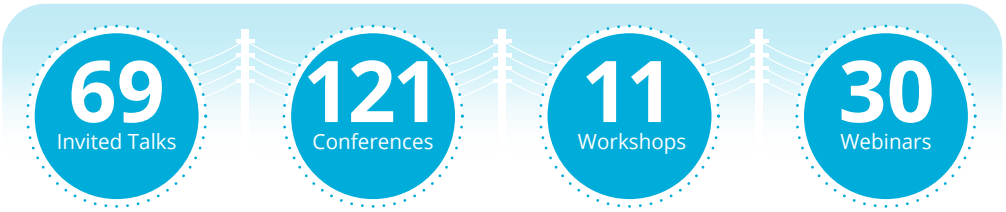
Charles Hanley

Grid Modernization and Energy Storage Program Manager
Sandia National Laboratories

Publications

Intellectual Property Advancements

Presentations



38 Notable Accomplishments

During this fiscal year, Sandia contributed to research and development to modernize the grid and advance grid technologies, received prestigious professional and technical recognitions and organized multiple technical symposia.

145 Publications

Sandia researchers produced many grid modernization and energy storage-related publications, including over 50 journal articles.

18 Patents and Technical Advances

Sandia's efforts have produced a number of patents, technical advances, and patent applications on topics that include active damping control of inter-area oscillations, systems and methods for controlling electrical grid resources, and collaborative controls to maintain unintentional islanding standards.

231 Technical Conferences & Presentations

Sandia researchers were invited to talk at multiple conferences; contributed to numerous technical presentations; and participated in organizational workshops, symposia, and webinars.

ACRONYM LIST

Abbreviation	Definition
ADDSec	Artificial Diversity and Defense Security
AI	Artificial intelligence
AMI	Advanced metering infrastructure
ANL	Argonne National Laboratory
APS	American Physical Society
BES	Battery energy storage
BLC	Battery Lifecycle Framework
CAISO	California Independent System Operator
CAST	Cluster to Advance Cyber-Security and Testing
DER	Distributed energy resources
DETL	Distributed Energy Technologies Lab
DOE	Department of Energy
DPOLY	Division of Polymer Physics
Energy StorM	Energy Storage for Manufacturing and Industrial Decarbonization
EPRI	Electric Power Research Institute
ES4SE	Energy storage for social equity
ESS	Energy storage system
ESGC LCT	Energy Storage Grand Challenge National Laboratory Coordinating Team
FEMA	Federal Emergency Management Agency
GMLC	Grid Modernization Lab Consortium
I&EC	Industrial and Engineering Chemistry
ICC	Illinois Commerce Commission
IEEE	Institute of Electrical and Electronics Engineers
LANL	Los Alamos National Laboratory
MDT	Microgrid Design Toolkit
NAERM	North American Energy Resilience Model
NRECA	National Rural Electric Cooperative Association
OAJPE	Open Access Journal of Power and Energy
OMF	Open Modeling Framework
ORNL	Oak Ridge National Laboratory
PIDMS	proactive intrusion detection and mitigation system
PNNL	Pacific Northwest National Laboratory
PPL	Pulsed power loads
PRM	Performance Reliability Model
RONM	Resilient Operation of Network Microgrids
SPD	Sandia Postdoc Development
SWE	Society of Women Engineers
UL	Underwriters Laboratories
VVUQ	verification, validation, and uncertainty quantification
WIMRG	Western Interconnection Modes Review Group
WNTR	Water Network Tool for Resilience
WPT	Wireless-Power Transfer

NOTABLE ACCOMPLISHMENTS

Renewable & Distributed Systems Integration

Puerto Rico 400MW alternative generation resilience: Sandia completed an investigation of the feasibility of various generation options to support energy resilience in the north of Puerto Rico, an area struck heavily by Hurricane Maria in 2017. This effort delivered analysis results to electric grid operators in Puerto Rico and supported the impactful use of Federal Emergency Management Agency (FEMA) recovery funds. Feasibility considerations included electric adequacy to serve critical loads, cost constraints, land area requirements, energy storage needs, and the ability to continue operating during and after resilience events. This project resulted in key findings including confirmation that small increases in generation capacity could have a large impact by supporting resilience of critical loads, such as hospitals; that renewable energy microgrids can both enhance local resilience and combine well with various forms of utility-scale generation; and that renewables may have high up-front costs compared to other options but can eliminate fuel supply risks and cost uncertainties. Impactful results were achieved within an extremely short timeline through strong collaboration among Sandia's energy storage, electric systems, renewable energy, and grid integration departments; effective external collaboration with Pacific Northwest National Laboratory for transmission system risk analysis; and USDOE's Puerto Rico team, which orchestrated data collection from local stakeholders. The results are being used by the stakeholders to inform their recovery fund applications.

Robust DC Microgrids: This project evaluated interconnected DC microgrids on a proposed lunar base. Sandia utilized NASA toolboxes to build a software model of the lunar base and then developed bus-to-bus converter models that can operate up to 10kV in multiple topologies. The models were used to evaluate contingency scenarios with variable tie-line voltage and distances to show high-voltages needed to mitigate voltage sag over long distances. The NASA toolbox models linearize power electronics response, which can be unrealistic in certain situations. Sandia developed State Space models of in-situ resource utilization and Lunar Habitat to demonstrate power flow between grids in a variety of contingency scenarios including a top-level controller and autonomous voltage droop. Sandia also developed a grid-level controller that can oversee microgrid-to-microgrid power flow using integrated feedforward and feedback schemes.

Kirtland Air Force Base Microgrid: Sandia partnered with Emera Technologies to run a 250kW, load-serving DC microgrid on Kirtland Air Force Base. The microgrid has nine nodes connected into a common DC bus via power electronics interface. This connection allows for granular node-level control in contingency situations. Sandia simulated the system operation in contingency situations and evaluated dynamic node-controlled energy flow. The ability to change node criticality was demonstrated both in space and time to optimize node-by-node power flow. A variety of faults were evaluated on the system to understand the ability of the power electronics to ride through low voltage scenarios. Sandia carried out line-to-line, line-to-ground, and arc fault experiments on the DC main bus. The results show that the system can ride through faults with no interruption, even with low impedance faults.

HyGaiN DC Power Conversion: The HyGaiN project is developing a 600V to 10kV single-stage boost circuit for use in DC microgrids. Previous work demonstrated 600V to 10kV operation in an open-loop configuration. Sandia fabricated an updated prototype of the HyGaiN circuit and demonstrated 10kV and 10kW operation using a resistive load. Additionally, the circuit operated on a voltage bus utilizing closed loop operation at 1.2kV, which has not been demonstrated previously. Circuit-level simulations evaluated the parallel operation of the HyGaiN circuit with a buck leg and will be used as the basis of a bus-to-bus prototype during the second year of project research.

Alaska Resilience Planning: Sandia is carrying out a microgrid sizing study for the Port of Alaska that will enable critical operation of the port facilities under contingency situations. As a basis for this study, energy and power requirements for the port are needed. Sandia is developing power requirement

data through the metering of the port main electrical interconnection as well as large inductive loads, including cranes. Meters were installed on three cranes and the electrical point of interconnect at the Port of Alaska and high-frequency (3s) data was collected for 90 days before the meters were removed and sent back to Sandia. Relevant data—including power, voltage, current, and load information— was collected in three second intervals and sent to Launch Alaska, a key partner, for analysis.

Advanced Protection System for Microgrids: Sandia collaborated with several utilities on a holistic approach to address the challenges of distribution systems and microgrid protection design under high inverter-based distributed energy resources (DER) penetration. The Sandia team held an industry workshop with Quanta Technology and Electric Power Research Institute (EPRI) to better understand the holistic approach required to support distribution system and microgrid needs. As a result of these efforts, Sandia developed a research and development roadmap for protection of low-voltage secondary network systems with DER and microgrids.

Grid Modernization Lab Consortium (GMLC) – Citadels: The GMLC Citadels project is designing controls for networks of microgrids to support bulk system operations, the continuous operation of critical end-use loads when the bulk system fails, and bulk system restoration. Using Sandia's Distributed Energy Technologies Lab (DETL) facilities, grid-forming and grid-following inverters were investigated to identify grid disturbance response times. The results identified how the inertia time constant for grid-forming inverters and the frequency-watt curve for grid-following inverters can be adjusted to provide stability for microgrids and the bulk system. This work was conducted in partnership with PNNL.

Resilient Operation of Network Microgrids (RONM): Sandia is creating a capability called Resilient Operation of Networked Microgrids (RONM), which will allow utilities to operate microgrids to support rapid recovery during extreme events. The RONM software provides optimal dispatch, reconfiguration, and protection settings for multiple or networked microgrids and is available for use by researchers and industry through NRECA's Open Modeling Framework (OMF). Sandia designed an optimization algorithm that can determine the best protective settings for each device during the restoration process. The protection settings are determined in real-time based on the expected fault currents in that network configuration from each of the generators. The protection optimizer guarantees that all relays are coordinated through directional time-overcurrent protection settings sent to the relays. This work is a partnership with Los Alamos National Laboratory (LANL).

Protection of Low-Voltage Secondary Networked Systems: Due to protection issues, DER is not generally allowed to interconnect in low-voltage spot or meshed network systems. To promote adoption of distributed energy resources (DER) and microgrids in low-voltage networks, Sandia is developing new protection schemes to detect faults in the medium-voltage feeders. Using hardware-in-the-loop testing, Sandia has developed a digital twin model of network protector relays. By adding additional supervisory controls — such as negative sequence, voltage restrained, or rate-of-change-of-power — the network protectors can detect faults without false trips due to DER. Sandia is working with industry partners, Quanta Technology and EPRI, utilities such as ConEd and Oncor, and network protector vendors to develop new protection schemes and test them in hardware-in-the-loop which will eventually allow DER interconnect in low-voltage or meshed network systems.

Environmental Response Management Application: Sandia created the first functional water-power co-simulation feature in the Microgrid Design Toolkit (MDT). Coupling the capabilities of the Performance Reliability Model (PRM) and Sandia's Water Network Tool for Resilience (WNTR), users can now create co-simulation, connecting water systems to power systems. This new capability is the basis for several new place-based work to be done in Puerto Rico and other locales and data collection and model development efforts continue with Coast Guard Base Kodiak in Alaska. Significant interest from both Kodiak and Coast Guard headquarters will lead to additional applications.

New UL1699 Standard: Sandia was highly active in developing and revising the Underwriters Laboratories (UL) 1699B: Photovoltaic (PV) DC Arc-Fault Circuit Protection Outline of Investigation. Sandia investigated a number of open questions brought up by the UL 1699B Standards Technical Panel over several past years. These included arc-fault generation methods, signal injection testing, unwanted tripping tests, and acceptable array topologies. On May 18, 2021, the American National Standards Institute formally approved the UL Outline of Investigation as a U.S. Standard.

Market Disruptor receives two R&D 100 Awards: The market disruptor "Proactive Intrusion Detection and Mitigation System (PIDMS)" application package received two R&D 100 awards: one in the Software/Services category and a second place Silver award in the Special Recognition category for market disruptors. The proactive intrusion detection and mitigation system (PIDMS) secures grid-edge photovoltaic smart inverter and other equipment in distributed energy resource systems. It is a distributed, bump-in-the-wire solution; cyber and physical data are automatically processed using network inspection tools and custom machine learning algorithms to detect abnormal events and correlate cyber-physical events.
The PIDMS was funded by DOE SETO (Solar Energy Technology Office) and leveraged multi-disciplinary Sandia expertise and Distributed Energy Technologies Lab (DETL) capabilities. A key outcome of the PIDMS was the creation of a new cyber-physical emulation capability using open Real-Time Digital Simulators and Hardware-In-the-Loop testing equipment (OPAL-RT).

Advanced Grid Modeling

Physics-Based Data-Driven Modeling to Accelerate Accurate PV Integration: Sandia led two partnerships to facilitate demonstration and implementation of Sandia-developed distribution system phase identification algorithms. These algorithms help utilities and co-ops validate and update their electrical distribution system models by identifying customers with incorrect phase labeling within these models. Sandia partnered closely with the National Rural Electric Cooperative Association (NRECA) to integrate the phase identification tool into their Open Modeling Framework (OMF) tool. The OMF tool is publicly available and designed to enable co-ops in rural areas access to state-of-the-art analytics tools. Sandia also worked to ensure open-source code release of distribution system model calibration algorithms, hosted on the Sandia Labs GitHub. The algorithms were developed throughout a recent SETO project and leverage timeseries data from advanced metering infrastructure (AMI) meters to calibrate distribution system models.

Grid Uncertainty Visualization Project: Sandia developed code to generate tightly controlled stimuli for electric grid-based human subject research. The team completed the design of an experiment comparing the impact of eight different visualizations of uncertainty on decision making performance. Sixteen participants completed the task under each visualization condition, resulting in a total of 128 sets of experimental data. The results of the study informed the design of a second study planned for FY23 that will test fifteen uncertainty visualization conditions. The Sandia team also contributed to a publication on aspects of visualization design that influence trust in artificial intelligence (AI), which will be relevant to the implementation of AI tools in the electric grid domain. The team also partnered with two universities, the School of Interactive Computing at Georgia Tech and the Cognitive and Information Sciences Department at the University of California Merced to develop a software tool for creating experimenter-controlled grid visualizations that will support additional human-subject studies and test the impact of increasing numbers of visualizations on human performance in an information integration task.

North American Energy Resilience Model (NAERM): NAERM is a multi-lab project that focuses on developing the software infrastructure and underlying models required to assess the resilience of the U.S. electric power grid and associated natural gas infrastructure. Sandia coordinated uncertainty

quantification (VVUQ) education to foster consistent understanding of VVUQ and project goals. As a result of the training coordinated by Sandia, NAERM modelers have a uniform understanding of VVUQ and can begin to build out uncertainty quantification consistently. In addition to coordinated education, Sandia's team adapted a commercial application to be a plug-and-play part of the NAERM micro-service architecture. This adaptation addressed a long-standing manual configuration issue that limited the software. Finally, the Sandia team created a data access and control architecture for NAERM. This advancement allows users to have fine grained controls on system data, which is a necessary requirement for multiple users of the same system with different nondisclosure agreements. This effort is led by Lawrence Livermore National Laboratory (LLNL).

Small Signal Stability Analysis and Estimation: Sandia significantly revised and expanded the existing 2014 WECC report, "Modes of Inter-Area Power Oscillations in the Western Interconnection" to better reflect recent grid trends including synchronous generator retirements (21.8 GW since 2014), changes in demand patterns, and reductions in system inertia. To support this work, Sandia developed a next-generation mode-shape visualization tool in Matlab. The tool was released to project partners under a government-use copyright. Sandia also applied system identification techniques to determine the critical transmission paths for each mode. The project team then worked with WECC and its data providers to make the report publicly available. This ensures that it can be used not only by reliability coordinators and system planners, but also researchers at national labs and universities. The updated document was produced within the Western Interconnection Modes Review Group (WIMRG) and includes contributions from Sandia, Pacific Northwest National Laboratory, the University of Wyoming, Montana Tech, California Independent System Operator (CAISO), and Southwest Power Pool.

Probabilistic Impact Scenarios for Extreme Weather Event Resilience: This project develops data-driven methods and associated computational analysis tools for creating probabilistic scenarios for grid impacts as a function of extreme weather events. Sandia completed development of a machine learning-based model to estimate impacts on utility-scale solar PV energy generation from wildfire events. In completing this model, the team conducted exploratory data analysis of a nationwide dataset that couples county-level power outages, historical weather data, and 30 types of extreme weather events to inform historical ranges of key weather variables that will facilitate the development of realistic impact scenarios.

Machine Learning for Grid Stability: Grid operating security studies are typically used to establish operating boundaries to ensure secure and stable operation for a range of operations. However, if these boundaries are violated the existing system security margins will be largely unknown. Sandia developed complex transmission system models for use in machine learning, where system security margin values are included as additional outputs for specified grid dispatches and dispatches were sampled for normal failure and near-blackout conditions. As an alternative to the use of complex optimizations over dynamic conditions, this work uses reinforcement-based machine learning to identify a sequence of secure state transitions which place the grid in a higher degree of operating security with greater static and dynamic stability margins.

Energy Storage Technologies & Systems

The following achievements are summarized from the report, U.S. DOE Office of Electricity Energy Storage Program at Sandia National Laboratories: Summary of Accomplishments and Impacts for FY22. For more details and information, refer to the complete report.

Battery Materials Research R&D100: Sandia received *R&D Magazine's* prestigious R&D 100 Award for developing the world's first commercially available iron nitride (Fe_4N) soft magnetic component. Soft magnetic materials enable low loss inductive switching in high frequency power converters. Fe_4N

can be used as the magnetic core in both inductors and solid-state transformers – key components in next generation energy storage power conversion systems – potentially reducing system size and weight by up to an order of magnitude over existing state-of-the-art soft magnetic materials, while also realizing increases in efficiency. The revolutionary performance advantages of Fe_4N soft magnetics are expected to spur key innovations in utility-scale and transportation-based power electronics hardware and to increase the accessibility and use of distributed energy resources such as grid energy storage and carbon free mobility. This work was completed in partnership with University of California - Irvine. https://www.rdworldonline.com/rd-100-winners-for-2022-are-announced.

Energy Storage for Manufacturing and Industrial Decarbonization Workshop: Sandia hosted the Energy Storage for Manufacturing and Industrial Decarbonization (Energy StorM) Workshop with DOE and eight other National Laboratories. This virtual two-day workshop brought together industry, national labs, government agencies, utilities, academia, and others to discuss energy and energy storage needs for industrial decarbonization. Needs, challenges, and opportunities for energy storage technologies that could meet the needs of industry were also discussed. Speaker bios, presentations, and videos can be found on the Energy StorM website.

Energy Storage Grand Challenge Leadership: Sandia led the DOE Energy Storage Grand Challenge National Laboratory Coordinating Team (ESGC LCT) and co-chaired the Technology Transitions Track within ESGC. Activities culminated in several publications, the release of Energy Storage pages on the Lab Partnering Service and Visual Patent Search websites, and the execution of the 2nd Annual Energy Storage Grand Challenge Summit in September 2022. During the Summit, a new initiative called Storage Innovations 2030 was launched, in which Sandia is a key member. SI2030 will utilize extensive industry input to chart a path forward for lab-based research in long-duration energy storage. Through this activity, Sandia personnel continued a partnership with Pacific Northwest National Lab (PNNL), Argonne National Lab (ANL), and Oak Ridge National Lab (ORNL), as well as several DOE offices, to coordinate lab research activities and outreach with the energy storage industry and academia.

Power Electronics

Hybrid Battery Technologies Testing: Sandia successfully developed a platform for cycling and testing hybrid battery technologies. The integrated system includes a CAN communication library, battery modules that use two different battery technologies (Lead-Acid and Lithium-Iron-Phosphate), DC-DC bi-directional converters, and a modular open-source software for controlling the different constituents of the system and remote data acquisition. The system is a modular platform for research on energy storage system integration. Clones of the system will be supplied to academic and commercial partners to pursue research on new batteries, power converters, battery models, and cybersecurity research.

Journal of the Electrochemical Society Frequently Downloaded Paper: Two years after publication, the following paper on long-term cycling of Li-ion batteries continues to be in the top three most-read papers of the Journal of the Electrochemical Society (downloaded over 50K times). Y. Preger, H. Barkholtz, A. Fresquez, D. Campbell, B. Juba, J. Roman-Kustas, S. Ferreira, B. Chalamala "Degradation of Commercial Lithium-ion Cells as a Function of Chemistry and Cycling Conditions" https://iopscience.iop.org/article/10.1149/1945-7111/abae37.

Solid-State Battery Safety: Sandia initiated new research covering foundational work evaluating the safety of solid-state batteries. The early results were published in an impactful journal article and have attracted significant attention from industry and US Government agencies. – A.M. Bates, Y. Preger, L. Torre-Castro, K.L. Harrison, S.J. Harris, and J. Hewson "Safer, More Powerful Batteries for Electric Cars, Power Grid" Sandia Labs News Releases, March 7, 2022, https://newsreleases.sandia.gov/safer_batteries.

Rhine-Westphalia Technical University of Aachen Visiting Scholar: Sandia researcher, Yuliya Preger, was invited to be a visiting scholar for one month in Summer 2022 at Rhine-Westphalia Technical University of Aachen as part of their post graduate program, "Integrated Energy Supply Modules for Roadbound E-Mobility." The university has the premier battery testing and power electronics labs in Europe, including a new $100 million Center for Ageing, Reliability, and Lifetime Prediction of Electrochemical and Power Electronic Systems. This visiting scholar relationship has resulted in a long-term collaboration opportunity to share battery data publicly.

Symposium on Emerging Materials for Electrochemical Energy Storage Devices: Sandia was the lead organizer of "Symposium EN05: Emerging Materials for Electrochemical Energy Storage Devices—Degradation and Failure Characterization—From Composition, Structure and Interfaces to Deployed Systems" at the 2022 MRS Spring Meeting & Exhibit held in Honolulu, Hawaii. The focus was understanding the interfaces, intercalation, degradation, and failure associated with advanced electrochemical energy storage technologies. The symposium's main discussion topic was emerging materials for improved performance, safety, sustainability, and reliability of all types of rechargeable batteries and supercapacitor devices. The secondary focus was degradation and failure mechanisms under stressful operating conditions in various industrial applications. The symposium received over 400 abstracts for consideration, one of the highest responses in the conference overall.

Demonstration Projects

Energy Storage for Equity Initiative: The Sandia Energy Storage Demonstrations team is leading DOE's energy storage for social equity (ES4SE) initiative. Initial project for ES4SE Project Development and Deployment Assistance (PDDA) selected: Albuquerque Public Schools – Atrisco Heritage High School Project, 2,884 kWh / 4-hour Battery Energy Storage System and 850kW Roof Mounted Solar PV. The system is installed and opened October 13, 2022. Also, within the scope of the social equity, Sandia commissioned a microgrid with new Zn-MnO2 batteries in the Navajo Nation, in collaboration with Navajo Tribal Utility Authority.

Policy & Outreach

Educational Workshops for Public Utility Commissions: The Energy Storage Outreach team conducted a series of educational workshops for state public utility commissions. The workshops series included: Illinois Commerce Commission (ICC); Microgrids & ES for Emergency Grid Resilience, in collaboration with Iowa State University's Electric Power Research Center and FEMA Regions 5 & 7 and FEMA HQ; and a Southeast Energy Storage Workshop Series at the request of Southern Research Institute (focused on energy storage technology, economic and policy issues impacting the Southeastern U.S regulators).

Other Achievements & Recognitions

Battery Archive Website: Sandia researchers developed Battery Archive (www.batteryarchive.org), the first public site for easy visualization and comparison of battery data across institutions. The site has been used by thousands from academia and industry in over 50 countries, ranging from undergrads working on class projects to employees of Fortune 500 companies. Sandia asserted a copyright on the software underlying the public site, the Battery Lifecycle Framework (BLC), and it has been released as an open-source package. Battery Archive has become the data hub for a growing international ecosystem of open-source software initiatives for battery development and analysis.

DOE Energy Storage Handbook Contributions: The DOE Energy Storage Handbook has been significantly updated, with contributions from Sandia team members and partners in several chapters,

including: Chapter 7: Flywheels; Chapter 14: Integrating Energy Storage; and Chapter 19: Stability Analysis of Energy Storage Integration in Power Systems. These contributions showcase Sandia's substantial energy storage research and development expertise.

Energy & Water Systems Integration

Book Chapter Published: The Sandia Water-Energy team published Embracing Analytics in the Drinking Water Industry, Chapter 12 "Water Network Tool for Resilience." Analytics tools can support numerous aspects of water industry planning, management, and operations. Given the wide range of touchpoints and applications, it is becoming increasingly imperative that the championship and capability of broad-based analytics needs to be developed and practically integrated to address the current and transitional challenges facing the drinking water industry.

Grid Security

Ft. Belvoir ADDSec Demonstration: Sandia developed a novel capability, Artificial Diversity and Defense Security (ADDSec), that automatically detects and responds to threats within critical infrastructure environments in real-time. A demonstration at Fort Belvoir successfully deployed the ADDSec technologies within the Ft. Belvoir microgrid environment. Sandia successfully demonstrated machine learning algorithms detecting malware and automatically mitigated the malware using moving target defense strategies. These results improved microgrid security and showed the potential to integrate additional detection and response capabilities into the ADDSec technologies for future research and development.

Learning Algorithms to Detect Abnormal Physical Data: Sandia evaluated digital twin approaches using mod/sim environments, namely the IEEE 8500 model, that leverage reinforcement learning algorithms to detect abnormal behaviors from physical data such as voltage, active/reactive power, and frequency. This modeled environment can be compared against the actual environment and would serve as the "digital twin". Initial investigations focused on reinforcement algorithms, which successfully predicted voltage levels but had significant variance when fast convergence was desired or when noise (attack data) was introduced. To address the high variance, the team utilized genetic algorithms which did not experience the high variance levels. This low variance data development will help detect data breeches introduced by a stealthy adversary whose goal is to slowly impact the data so that attacks would eventually be viewed as "normal".

Defense Energy

Patent issued for "Energy Storage Systems for Electrical Microgrids with Pulsed Power Loads": Sandia developed medium-voltage DC (MVDC) and medium voltage AC (MVAC) 4-zone power system modeling capabilities for Naval ship performance evaluations. This increased ability to evaluate and influence MVDC power system architectures for future Naval ships. MVAC models enable advanced control development, demonstration, and cross validation with external efforts. Sanida also explored control aspects of Energy Storage System (ESS) integration to address pulsed power loads (PPLs), which are highly non-linear and can cause significant stability and power quality issues in an electrical microgrid. The ESS can maintain a constant bus voltage and decouple the generation sources from the PPL. For example, the ESS specifications can be obtained with an ideal, band-limited hybrid battery and flywheel system.

Additional Recognitions

Advanced Grid Modeling

Institute of Electrical and Electronics Engineers (IEEE) Editorial Board: David A Schoenwald joined the editorial board of the IEEE Open Access Journal of Power and Energy (OAJPE) as an associate editor. The editor-in-chief of OAJPE, Professor Fran Li (University of Tennessee, Knoxville), selected Dave to be one of six new associate editors for 2022. The volunteer position is an important professional service to maintain high quality published papers that reach the broader power systems community including academia, industry, and government.

Energy Storage Technologies & Systems

Society of Women Engineers Rising Technical Contributor: Yuliya Preger was selected as a recipient of the Society of Women Engineers (SWE) 2022 Rising Technical Contributor Award based on her work for the Office of Electricity Energy Storage Program. The Rising Technical Contributor Award honors a SWE member at the professional or graduate student level, who has been actively engaged in the fields of engineering or engineering technology and has individually contributed technical work resulting in significant breakthroughs or results.

Society Fellow Recognition: Babu Chalamala elected as a Fellow of the American Association for the Advancement of Science and the National Academy of Inventors. https://www.sandia.gov/labnews/2022/02/25/sandia-engineer-elected-fellow-of-two-prestigious-national-societies.

PUBLICATIONS

Journal Publications

Renewable & Distributed Systems Integration

Darbali-Zamora, R., S.T., F. Wilches-Bernal, J. C. Berg "Development of a Wind Turbine Generator Volt-Var Curve Control for Voltage Regulation in Grid Connected Systems" Energies, 2022. DOI: 10.3390/en13174303.

Fragkos, G., J. Johnson, E.E. Tsiropoulou "Dynamic Role Based Access Control Policy for Smart Grid Applications: An Offline Deep Reinforcement Learning Approach" IEEE Transactions on Human-Machine Systems, 2022, DOI: 10.1109/THMS.2022.3163185.

Johnson, J., B. Fox, K. Kaur, J. Anandan "Evaluation of Interoperable Distributed Energy Resources to IEEE 1547.1 Using SunSpec Modbus, IEEE 1815, and IEEE 2030.5" IEEE Access, vol. 9, pp. 142129-142146, 2021, DOI: 10.1109/ACCESS.2021.3120304.

Jones, C.B., C. J. Bresloff, R. Darbali-Zamora, M. Lave, E. E. Aponte Bezares "Geospatial Assessment Methodology to Estimate Power Line Restoration Access Vulnerabilities After a Hurricane in Puerto Rico" IEEE Open Access Journal of Power and Energy, 2022, DOI: 10.1109/SmartGridComm47815.2020.9303023.

Jones, C.B., W. Vining, M. Lave, T. Haines, C. Neuman, J. Bennett, D.R. Scoffield "Impact of Electric Vehicle customer response to Time-of-Use rates on distribution power grids" Energy Reports, Volume 8, 2022, Pages 8225-8235, ISSN 2352-4847, 2022, DOI: 10.1016/j.egyr.2022.06.048.

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Qatramez, A.E., A. Kurzawski, J. Hewson, M. Parker, A. Porter, D. Foti, A.J. Headley "Characterization of Vented Gas Predictions in Lithium-ion Modeling with 1-D Thermal Runaway (LIM1TR)" ASME 2022 Summer Heat Transfer Conference (SHTC), Philadelphia, PA, July 11-13, 2022, DOI: 10.1115/HT2022-79560.

Rathore, V., S.R.P. Reddy, K. Rajashekara "Modulation and Analysis of Current-Fed High Gain Multilevel DC-DC Converter in BESS Charging Mode" International Power Electronics Conference (IPEC-Himeji 2022-ECCE Asia), May 15-19, 2022, DOI: 10.23919/IPEC-Himeji2022-ECCE53331.2022.9807096.

Rauniyar, M.,N. Bhujel, T.M. Hansen, R. Fourney, H.M. Rekabdarkolaee, R. Tonkoski, P. Cicilio, M. Shirazi, U. Tamrakar "Diesel Generator Model Development and Validation using Moving Horizon Estimation" IECON 2021 – 47th Annual Conference of the IEEE Industrial Electronics Society, Toronto, ON, Canada, October 13-16, 2021, DOI: 10.1109/IECON48115.2021.9589981.

Sharma, A., K.J.P. Veeramraju, J.W. Kimball "Power Flow Control of a Single-Stage AC-AC Solid-State

Transformer for AC Distribution System" 2022 IEEE Power and Energy Conference at Illinois (PECI), March 10-11, 2022, DOI: 10.1109/PECI54197.2022.9744006.

Subedi, S., N. Guruwacharya, R. Fourney, H.M. Rekabdarkolaee, R. Tonkoski, T.M. Hansen, U. Tamrakar, P. Cicilio "Computationally Efficient Partitioned Modeling of Inverter Dynamics with Grid Support Functions" IECON 2021 – 47th Annual Conference of the IEEE Industrial Electronics Society, Toronto, ON, Canada, October 13-16, 2021, DOI: 10.1109/IECON48115.2021.9589066.

Trevizan, R.D., T. Nguyen, S. Atcitty, A.J. Headley "Valuation of Behind-the-Meter Energy Storage in Hybrid Energy Systems" (***received the "Outstanding Paper and Presentation" award***) 2022 IEEE PES Innovative Smart Grid Technologies Conference North America (ISGT N.A.), New Orleans, LA, April 24-28, 2022, DOI: 10.1109/ISGT50606.2022.9817528.

Trevizan, R.D., M. Reno "Detection of False Data Injection Attacks in Power System State Estimation Using Sensor Encoding" IEEE Kansas Power & Energy Conference (KPEC), Manhattan, KS, April 25-26, 2022, DOI: 10.1109/KPEC54747.2022.9814723.

Vartanian, B., C. Koplin, T. Kudrna, W. Clark, D. Borneo, J. Kolln, D. Huang, F. Tuffner, M. Panwar, E. Stewart, L. Khair "Applying Utility's Advanced Grid Technologies to Improve Resiliency of a Critical Load" Resilience Week 2021, October 18-21, 2021, DOI: 10.1109/RWS52686.2021.9611785.

Veeramraju, K.J.P., A. Sharma, J.W. Kimball "A Comprehensive Analysis on Complex Power Flow Mechanism in an AC-AC Dual Active Bridge" 2022 IEEE Power and Energy Conference at Illinois (PECI), March 10-11, 2022, DOI: 10.1109/PECI54197.2022.9744009.

Veeramraju, K.J.P., J.W. Kimball "Multidimensional Extensions to Generalized Averaged Models for Multi-Frequency-Excited Dynamic Systems" 2021 IEEE 22nd Workshop on Control and Modelling of Power Electronics (COMPEL), November 2-5, 2021, DOI: 10.1109/COMPEL52922.2021.9645972.

Xing, Y. Zhang, A. Agarwal, R. Guenther Q. Cheng, B. Hu, J. Wang "Design of Medium-Voltage and Medium-Frequency Transformer for Solid State Transformers" 2022 IEEE Workshop on Wide Bandgap Power Devices and Applications in Europe (WiPDA Europe), September 18-20, 2022, DOI: 10.1109/WiPDAEurope55971.2022.9936139.

Yadav, G.G., M. Weiner, A. Upreti, J. Huang, X. Wei, T.N. Lambert, N.B. Schorr, N. Bell, S. Banerjee "The Advent of Aqueous >2.85 V Zn-MnO2 Batteries: Uncovering Novel Mechanisms in This New High Voltage Chemistry" 2022 ECS Annual Meeting, MA2022-01 22, 2022, DOI: 10.1149/MA2022-01122mtgabs.

Yan, D., A. Marellapudi, R.P. Kandula, D. Divan "Oversampling Multi-Variable Control for Soft-Switching Solid-State Transformer" 2021 IEEE Energy Conversion Congress and Exposition (ECCE), October 10-14, 2021, DOI: 10.1109/ECCE47101.2021.9595134.

Yip, J., M. Garcia, B. Pierre, E. Kutanoglu, S. Santoso "Optimal Black-Start Restoration Assisted by Mobile Energy Storage" IEEE Power & Energy Society (PES) General Meeting, Denver, CO, July 17-21, 2022, DOI: 10.1109/PESGM48719.2022.9916822.

Zhang, Z., B. Hu, Y. Zhang, J. Wang, J. Mueller, L. Garcia Rodriguez, A. Ray, S. Atcitty "An Isolated Bidirectional DC-DC Converter with High Voltage Conversion Ratio and Reduced Output Current Ripple" IEEE 8th Workshop on Wide Bandgap Power Devices and Applications (WiPDA), Redondo Beach, CA, November 7-11, 2021, DOI: 10.1109/WiPDA49284.2021.9645131.

Grid Security

Hossain-McKenzie, S., E. Vugrin, K. Davis, ""Enabling Online, Dynamic Remedial Action Schemes by Reducing the Corrective Control Search Space" 2020 IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids (SmartGridComm), 2022, DOI: https://DOI.org/10.1109/SmartGridComm47815.2020.9303023.

Other Publications

Energy Storage Technologies & Systems

Ellison, J.F., C.J. Newlun, A.G. Benson "An Analysis of PNM's Renewable Reserve Requirements to Meet New Mexico's Decarbonization Goals" May 2022, SAND2022-6704.

Ho, C.K., E.L. Roesler, T.A. Nguyen, J. Ellison "Probabilistic Modeling of Climate Change Impacts on Renewable Energy and Storage Requirements for NM's Energy Transition Act" January 2022, SAND2022-0583.

Kim, M. "Low-Cost MnO_2 Intercalation Cathodes Enabled by Using Bismuth as a Pillaring Agent" PhD Dissertation, Department of Chemical Engineering, Northeastern University, May 2020.

Lamb, J., J. Kim, A. Kurzawski, C. Yang, J. Hewson, A. Mallarapu, L. Torres-Castro, S. Santhanagopalan, B. Boudouris "Propagation Mitigation Testing Procedures, Modeling, and Analysis" U.S. Department of Transportation, National Highway Traffic Safety Administration, March 2022, Report No. DOT HS 813 230.

Preger, Y., R. Fioravanti, K. Kumar, S. Nakata, B. Chalamala were invited to write "Adopting Predictive Maintenance Practices for Battery Energy Storage System Safety" for T&D World magazine. This three-part series advocates for the use of predictive maintenance of grid-scale operational battery energy storage systems as the next step in safely managing energy storage systems.

The Sandia Energy Storage program wrote, edited, managed, and published the following chapters for the DOE Energy Storage Handbook:

- Chapter 7: Flywheels – Don Bender
- Chapter 14: Integrating Energy Storage - Grid Interconnection Process and Policy – Howard Passell, Charlie Vartanian, Will McNamara, Jeremy Twitchell, Sam Ojetola, Pramod Kulkarni
- Chapter 19: Stability Analysis of Energy Storage Integration in Power Systems – Ujjwol Tamrakar, Hyungjin Choi, Reinaldo Tonkoski

Sandia contributed extensive writing for the Cambridge University Press "Elements in Grid Energy Storage" series. Sandia's contributions included:

- "Beyond Li-ion Batteries for Grid-Scale Energy Storage" G.P. Wheeler, L. Wang, A.C. Marschilok (funded by Sandia through our partnership with Brookhaven University)
- "Energy Storage Applications in Transmission and Distribution Grids" H. Othman (funded by Sandia through our partnership with Quanta Technologies)
- "Li-ion Batteries" L. Torres-Castro, Y. Preger, A.M. Bates, J. McDowall, M. Abreu-Sepulveda

Energy & Water Systems Integration

Klise, K. "Embracing Analytics in the Drinking Water Industry" International Water Association, Dec. 2021.
Klise, K., K. Ruehl "Improving adoption of scientific software best practices through the development of a software Impact Factor" The Advanced Scientific Computing Research, Dec. 2021.

INTELLECTUAL PROPERTY ADVANCEMENTS

Patents

Renewable & Distributed Systems Integration

Hernandez-Alvidrez, J., N. Gurule, A. Summers, M. Reno, J. Flicker, A. Ellis "Systems and Methods for interfacing a Grid Forming Inverter to a Power Hardware-in-the-loop Testbed" Application no. 17/736,728. Filed May 4, 2022.

Reno, M., A. Summers "Zonal Machine Learning-based Protection for Distribution Systems" Filed July 22, 2022.

Energy Storage Technologies & Systems

Atcitty, S., B.R. Chalamala, J. Mueller, M.A. Moonem "Distributed Energy Storage for Photovoltaic Systems" Application No. 17/702,963. Filed March 24, 2022.

Bock, J.A., E.D. Spoerke, H.J. Brown-Shaklee, L.J. Small "Solution-Assisted Densification of NaSICON Ceramics" Application No. 2021/0320321 A1. Filed October 14, 2021.

De Angelis, V., J. Mueller, O. Dutta "Integrated Power Converters for Optimal Operation of Hybrid Battery Packs" Application No. 63/392,359. Filed July 26, 2022.

Fujimoto, C.,"Poly(Phenylene) with High Ion Selectivity for Use in Anion Exchange Membranes" Application No. 2022/0127450 A1. Filed April 28, 2022.

Fujimoto,C., E. Baca "Ion-Selective Membrane for Redox Flow Batteries" Application No. 2022/0059861 A1. Filed February 24, 2022.

Gill, L., L.A. Garcia Rodriguez, J. Mueller, J. Neely "High Voltage Switch with Cascaded Transistor Topology" Application No. 17/737,593. Filed May 5, 2022.

Lambert, T.N., "Zinc Battery with Improved Cycling from an Ion-Selective Separator" Application No. SD15848.1/003319.00007. Filed August 3, 2022.

Nguyen, T.A., R.H. Byrne, B.R. Chalamala, D.G. Wilson "Energy-Storage Based Packetized Delivery of Electricity" Application No. 63/239,489 (2021)

Spoerke, E.D., S.J. Percival, L.J. Small "Molten Inorganic Electrolytes for Low Temperature Sodium Batteries" US Patent No. 11,258,096 B2. Non-provisional patent issued February 22, 2022.

Spoerke, E.D., S.J. Percival, M.M. Gross, R.Y. Lee, L.J. Small "Low Temperature Sodium Battery Comprising and Electrochemically Active Molten Inorganic Catholyte" Application No. 17/505,413. Filed October 19, 2021.

Defense Energy

Weaver, W. "Energy Storage Systems for Electrical Microgrids with Pulsed Power Loads" US 11,316,363 B2, April 26, 2022.

Copyrights

Renewable & Distributed Systems Integration

Jones, C.B., W. Vining, M. Lave, T. Haines, C. Neuman, J. Bennett, D.R. Scoffield “Impact of Electric Vehicle customer response to Time-of-Use rates on distribution power grids” Copyright 2022 National Technology & Engineering Solutions of Sandia, LLC (NTESS). Under the terms of Contract DE-NA0003525 with NTESS, the U.S. Government retains certain rights in this software.

Johnson, J. “DER Cybersecurity Detection and Response Suite” Copyright 2022 National Technology & Engineering Solutions of Sandia, LLC (NTESS). Under the terms of Contract DE-NA0003525 with NTESS, the U.S. Government retains certain rights in this software.

Energy Storage Technologies & Systems

Elliott, R.T., D.A. Schoenwald “Visualizing the Inter-Area Modes of the Western Interconnection” Copyright 2022 National Technology & Engineering Solutions of Sandia, LLC (NTESS). Under the terms of Contract DE-NA0003525 with NTESS, the U.S. Government retains certain rights in this software.

PRESENTATIONS

Invited Talks

Renewable & Distributed Systems Integration

Ferreira, S. "Perspectives on Future Power Grids" International Solar Energy Society ISES Solar World Congress, December 9, 2021.

Johnson, J. "Solar Inverter Risks and Defenses from Power Electronics Hardware Attacks" Sunspec & Sandia DER Cybersecurity Webinar, February 24, 2022.

Minot, J.R., M.Z. Trujillo, S.F. Rosenblatt, G. de Anda-Jáuregui, E. Moog, A.M. Roth, B.P. Samson, L. Hébert-Dufresne "Distinguishing In-Groups and Onlookers by Language Use" 12th Workshop on Computational Approaches to Subjectivity, Sentiment & Social Media Analysis (WASSA) at ACL 2022, Hybrid, May 26, 2022.

Quiroz, J. "Preliminary Microgrid Resilience Design Tradeoffs", KAFB, Albuquerque, NM, March 2022.

Advanced Grid Modeling

Garcia, M. "New Reserve Products to Improve Primary Frequency Response" Informs Annual Meeting, Anaheim, CA, October 24-27, 2021.

Gilletly, S."Using Machine Learning for Predictive Modeling of Weather Impacts on Utility-scale Photovoltaic Systems" Sandia Machine Learning/Deep Learning Workshop, July 2022.

Jackson, N.D. "Let's Talk Risk" podcast interview, March 2022.

Jackson, N.D. "Characterization of extreme weather events during large scale power outages", Society for Risk Analysis Annual Meeting, December 2021.

Ojetola, S., M. Reno, J. Flicker, D. Bauer, D. Stoltzfuz "Testing Machine Learned Fault Detection and Classification on a DC Microgrid," 2022 Innovative Smart Grid Technologies, pp. 1-5, 2022.

Olis, W. "Battery Energy Storage System Modeling for Extreme Climates" Department of Energy Office of Electricity Energy Storage Program Peer Review virtual presentation, Oct 2021.

Olis, W. "Modeling Energy Storage Systems in Extreme Climates" U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), November 18, 2021.

Pierre, B. "Optimizing Electric Grid Resilience while Considering Critical Nodes and Cascading Outages" presented at an invited seminar for an hour and a half to the University of Texas (UT) Operation Research and Industrial Engineering, UT Energy Institute, and UT Engineering Departments, Jan. 28th, 2022.

Villa, D., J.P. Carvallo, S.H Lee "Probabilistic Modeling for Extreme Events and Concurrent Outages: Energy Resilience for Mission Assurance," IEEE PES Meeting Denver Panel Session, July 21, 2022.

Energy Storage Technologies & Systems

Atcitty, S. "Energy Storage, Power Electronics, and Tribal Energy Sovereignty", The 31st IEEE International Symposium on Industrial Electronics, Anchorage, AK, June 1-3, 2022.

Atcitty, S. “Energy Storage, Power Electronics, and Tribal Energy Sovereignty” IEEE PES Day Technical Seminar, Georgia Tech, April 14, 2022.

Atcitty, S. “Native American Energy Sovereignty: Energy Storage and Power Electronics Benefits” University Technical Seminar Series, Binghamton University, Binghamton, NY, November 10, 2021.

Atcitty, S. “SNL Power Electronics Program R&D Insights on PCS Reliability & Safety” 2022 Energy Storage System Safety and Reliability Forum, May 4-5, 2022.

Atcitty, S., M. Ropp “An Introduction to Microgrids” 2022 Arizona Tribal Energy Association Annual Meeting, February 17, 2022.

Banerjee, S. “Zinc-Based Energy Storage System Deployments and Developments for Transition to a Clean Energy Future” 241st Electrochemical Society (ECS) Meeting, Vancouver, BC, Canada, May 29 – June 2, 2022.

Bates, A.M., Y. Preger, L. Torre-Castro, K.L. Harrison, S.J. Harris, J. Hewson “Are Solid-State Batteries Inherently Safe? A Dive into Heat Release through Calorimetry” Solid-State Battery Summit, Chicago, IL, August 2-3, 2022.

Bates, A.M., Y. Preger, L. Torre-Castro, K.L. Harrison, S.J. Harris, J. Hewson “Are Solid-State Batteries Safer Than Lithium-Ion? Establishing a Basic Thermodynamic Approach for Evaluation” Soteria Webinar Series, May 26, 2022.

Borneo, D., S. Schoenung “Why is Data So Important to Powering Your Community?” Isolated Power System (IPS) Connect, Cordova, AK, July 26-29, 2022.

Borneo, D., S. Schoenung “Commissioning Coordination - Lessons Learned” IEEE Power & Energy Society (PES) General Meeting, Denver, CO, July 17-21, 2022.

Chalamala, B.R. “Modernization of T&D Grid – Decarbonization and Adapting to Climate Change” Hart Center for Engineering Leadership, Southern Methodist University, March 25, 2022.

Chalamala, B.R. “Modern Electronics Technology - Silicon Materials” Lyle School of Engineering, Southern Methodist University, March 25, 2022.

Chalamala, B.R. Organizer, Supersession SSPL04: Impact of Power Electronics on the Electrical Infrastructure, IEEE Power & Energy Society General Meeting, Denver, CO, July 21, 2022.

Chalamala, B.R. Organizer, Panel ITSLCPL09: Importance of T&D Grid Modernization to Mitigate and Adapt to Climate Change, IEEE Power & Energy Society General Meeting, Denver, CO, July 20, 2022.

Chalamala, B.R. IEEE Distinguished Lecture, Grid Modernization and Energy Storage, IEEE PES Chapter Seminar, Texas Tech University, Lubbock, TX, March 10, 2022.

Chalamala, B.R. Keynote speaker, Advances in Grid Energy Storage, Clemson University Power Research Association, Clemson University, March 4, 2022.

Chalamala, B.R. Keynote – Energy Storage for Bulk System Operations, 13th US-China Green Energy Forum, January 6, 2022.

Chalamala, B.R. Panel Session on Semiconductors, Purdue Center for Tech Diplomacy, Washington, DC, November 15, 2021.

Chalamala, B.R. "Advanced Technology and a Resilient Electric Grid" National Association of State Energy Officials (NASEO), Washington, DC, November 17, 2021.

Chalamala, B.R. "Advances in Energy Storages Technologies" 2022 IEEE APEC Applied Electronics Conference, Market and Technology Trends Industry Session, Houston, TX, March 23, 2022.

Chalamala, B.R. "Long Duration Energy Storage: Policy Gaps, Regulatory Changes and Business Opportunities" Smart Grid Observer's Long-Duration Energy Storage Forum, November 17, 2021.

De Angelis, V. "Energy and Battery Management Systems" Texas Tech University Seminar, Electrical Engineering Department, March 10, 2022.

Frischknecht, A.L. "Insights into Hydrated Ion-Conducting Polymers from MD Simulations" ACS POLY workshop on Polymers for Fuel Cells, Energy Storage, and Conversion, Napa, CA, May 15-18, 2022.
Frischknecht, A.L. "Morphology and Ion Transport in Hydrated Ion-Containing Polymers" American Physical Society March Meeting, Chicago, IL, March 14-18, 2022.

Gross, M.M., S.J. Percival, R.Y. Lee, A.S. Peretti, M.A. Rodriguez, J. Lamb, E.D. Spoerke, L.J. Small "Development of a High-Voltage, Low Temperature Molten Sodium Battery" Technical Presentation to Ambri Inc., September 20, 2021.

Lambert, T.N., N.B. Schorr, B. Wygant, R. Habing, C. Wright, A.M. Bruck, M. Kim, J. Goulart, J.W. Gallaway "The Discovery and Development of Rechargeable Zn/CuO Batteries" 241st Electrochemical Society (ECS) Meeting, Vancouver, BC, Canada, May 29 – June 2, 2022.

Lambert, T.N., "Developing New chemistries for Alkaline Zn-based Batteries" NAATBatt International Workshop on Zinc Battery Technology IV, December 16, 2021.

Maraschky, A.M., M.L. Meyerson, S.J. Percival, D. Lowry, A.M. Peretti, M.M. Gross, E.D. Spoerke, L.J. Small "Impact of Current Collector Material and Catholyte Lewis Acidity in Low-Temperature Molten Sodium Batteries" Presentation to Alkokar Group at Case Western Reserve University, Cleveland, OH, August 19, 2022.

Maraschky, A.M., R.Y. Lee, M.L. Meyerson, M.M. Gross, S.J. Percival, A.S. Peretti, E.D. Spoerke, L.J. Small "Low-Temperature Molten Sodium Batteries for Large-Scale Storage: Fundamental Studies of Metal Halide Catholyte and Cathode Materials" 241st Electrochemical Society (ECS) Meeting, Vancouver, BC, Canada, May 29 – June 2, 2022.

McNamara, W. "Energy Storage Regulations and Policies" Government Accounting Office Technology Assessment on Grid Energy Storage, July 8, 2022.

McNamara, W. "Long-Duration Energy Storage in a Decarbonized Future – Policy Gaps, Needs, and Opportunities" TechConnect World Innovation Conference & Expo, Washington, D.C., June 13-15, 2022.
McNamara, W., "Long Duration Energy Storage (LDES): Policy Challenges" Energy Storage Summit USA 2022, March 34-24, 2022.

Monson, T.C., T.E. Stevens, C.J. Pearce, M.R. Hoyt, E.C. Vreeland, R.E. Delaney, S. Atcitty, B. Zheng, C.H. Belcher, Y. Zhou, E.J. Lavernia "Iron Nitride Based Soft Magnets Through Spark Plasma Sintering" The Minerals, Metals, and Materials Society (TMS) Annual Meeting & Exhibition, Anaheim, CA, February 27 – March 3, 2022.

Mueller, J., Y. Preger, A. Kurzawski, J. Hewson "Energy Redistribution in Response to Thermal Runaway" 2022 Energy Storage System Safety and Reliability Forum, May 4-5, 2022.

Mueller, J., Y. Preger, A. Kurzawski, J. Hewson "Advanced Power Conversion Architectures for Next-Generation Energy Storage Systems" University of Houston Power Seminar Series, April 20, 2022.

Mueller, J. "Enabling Energy Storage for Grid Applications Through Advanced Power Electronics" IEEE Energy Conversion Congress & Expo (ECCE), October 10-14, 2021.

Passell, H., M. DeMenno, L. Malczynski, W. McNamara, J. Jacobson, J. Ellison, D. Poindexter "Stakeholder-Driven Model for Energy Storage and Decarbonization in New Mexico (ESD-NM)" New Mexico Public Regulatory Commission (PRC), August 3, 2022.

Passell, H., W. McNamara "Sandia's Policy & Outreach Program" CESA Energy Storage Working Group, April 11, 2022.

Passell, H., "Changing Infrastructure Needs. What Coordination is Needed Among Entities?" Wisconsin Public Utility Institute, March 9, 2022.

Rosewater, D.M. "Can Batteries Replace Gas Peakers? The Complex Problems of Sizing and Cost-Benefit Analysis when Replacing a Peaker Plant with Energy Storage" Monthly Sigma Xi / IEEE Albuquerque Meeting, Albuquerque, NM, April 21, 2022.

Spoerke, E.D. "Beyond Batteries: Diverse 'Potential' Energy Storage Solutions for Long-Duration Energy Storage" Pacific Northwest Efficiency Exchange 2022. April 14-15, 2022.

Spoerke, E.D. "Materials Chemistry in Large-Scale Energy Storage: A Key to Unlocking our 'Potential' Energy Future" Spring 2022 Department of Materials Science and Engineering Colloquium at The Ohio State University, January 28, 2022.

Spoerke, E.D. "Long-Duration Energy Storage: Emerging Technologies and Applications" IEEE Energy Conversion Congress & Expo (ECCE), October 10-14, 2021.

Spoerke, E.D., M.M. Gross, A.S. Peretti, S.J. Percival, R. Lee, J. Lamb, M. Rodriguez, L.J. Small "Developing 'Really Cool' Low Temperature Molten Sodium Batteries" TechConnect World Innovation Conference & Expo, Washington, D.C., Oct. 18-20, 2021.

Spoerke, E.D., M.M. Gross, A.S. Peretti, S.J. Percival, R. Lee, J. Lamb, M. Rodriguez, L.J. Small "Materials Chemistry in Battery Energy Storage: A Key to Unlocking Our 'Potential' Energy Future" Fall Chemical & Materials Engineering Department Seminar at University of Kentucky, September 22, 2021.

Spoerke, E.D., M.M. Gross, A.S. Peretti, S.J. Percival, R. Lee, J. Lamb, M. Rodriguez, L.J. Small "Advancing the Promise of Low-Temperature Molten Sodium Batteries" International Symposium on Materials for Energy Storage and Conversion (mESC-IS), September 14-17, 2021.

Tamrakar, U. "Energy Storage for Voltage Regulation of Active Distribution Networks" IEEE Siouxland Section Speaking Event, Brookings, SD, January 18, 2022.

Torres-Castro,L., A. Bates, J. Lamb, T. Tanim, L. Walker "Thermal Runaway Detection with Multiple Diagnostic Strategies" 39th Annual International Battery Seminar, Orlando, FL, March 28-31, 2022.

Torres-Castro, L. "Are Energy Storage Systems Safe?" Graduate Seminar in Materials Science & Engineering at the University of Puerto Rico-Mayaguez, March 23, 2022.

Trevizan, R.D. "Battery Energy Storage Technology and Applications" Renewable Energy Specialization Seminar of Pontifícia Universidade Católica do Rio Grande do Sul, November 6, 2021.

Wittman, R. "Introduction to Redox Flow Batteries" IEEE PES ESSB Summer 2022 Meeting, Sonoma, CA, June 13-17, 2022.

Wittman, R., A. Fresquez, B. Chalamala, Y. Preger "Systematic Cycle and Calendar Aging of Commercial 18650 LFP Lithium-Ion Cells" 241st Electrochemical Society (ECS) Meeting, Vancouver, BC, Canada, May 29 – June 2, 2022.

Wygant, B.R., I.V. Kolesnichenko, N.B. Schorr, T.N. Lambert "Lithiation of a Unique C-S Species in Amorphous FeS4/C Cathodes for Li Batteries" 241st Electrochemical Society (ECS) Meeting, Vancouver, BC, Canada, May 29 – June 2, 2022.

Yadav, G.G. "The Advent of Aqueous >2.85V Zn-MnO_2 batteries: Uncovering Novel Mechanisms in this New High Voltage Chemistry" Annual Fall Energy Storage Technology and Innovation Conference (NY-BEST), Binghamton, NY, October 27, 2021.

Yadav, G.G., J. Huang, M. Weiner, S. Yang, K. Vitale, S. Rahman, K. Keane, S. Banerjee "Improvements in Performance and Cost Reduction of Large-Scale Rechargeable Zinc|Manganese Dioxide Batteries and a Future Roadmap Driven through Real World Applications" 241st Electrochemical Society (ECS) Meeting, Vancouver, BC, Canada, May 29 – June 2, 2022.

Yadav, G.G., M. Weiner, A. Upreti, J. Huang, X. Wei, T.N. Lambert, N.B. Schorr, N.S. Bell, S. Banerjee "The Advent of Aqueous >2.85V Zn-MnO_2 Batteries: Uncovering Novel Mechanisms in This New High Voltage Chemistry" 241st Electrochemical Society (ECS) Meeting, Vancouver, BC, Canada, May 29 – June 2, 2022.

Conference Presentations

Renewable & Distributed Systems Integration

Broderick, R. "DRC final presentation" DOE SETO visit, Albuquerque, NM, February 10, 2022.

Dow, A. R. R., R. Darbali-Zamora, J. D. Flicker, F. Palacios III, J. T. Csank, "Development of Hierarchical Control for a Lunar Habitat DC Microgrid Model Using Power Hardware-in-the-Loop", IEEE 49th Photovoltaic Specialists Conference (PVSC), Philadelphia, PA, June 5-10, 2022.

Jones, C.B., W. Vining, T. Haines, "Current & Future Photovoltaic System Impacts on City-Wide Grid Performance & Neighborhood Microgrids" IEEE PVSC Conference, April 22, 2022.

Haines, T., M. Donnelly, D. Trudnowski "Power System Toolbox Updates to Enable Long-Term Variable Time-Step Dynamic Simulation" 2022 IEEE Power & Energy Society General Meeting (PESGM), Denver, CO, July 21, 2022.

Hossain-McKenzie, S., B. Jones, A. Chavez "Proactive Intrusion Detection and Mitigation project" Final SETO Review presentation, Albuquerque, NM, December 1, 2021.

Advanced Grid Modeling

Barba, P., R. Byrne, T. Nguyen "Energy storage price targets to enable energy arbitrage in CAISO" 2022 IEEE Power & Energy Society General Meeting (PES GM), Denver, CO, July 17-21, 2022.

Elliott, R.T.,"Utility-scale Energy: New Methods for Transient Stability Control and Assessment" NASPI Work Group, virtual meeting, April 12-14, 2022.

Elliott, R.T., D. Schoenwald "Visualizing the Inter-Area Modes of the Western Interconnection" 2022 IEEE Power & Energy Society General Meeting (PES GM), Denver, CO, July 17-21, 2022.

Garcia, M., F. Wilches Bernal, R. Baldick "Primary Frequency Response Reserve Products for Inverter-Based Resources" 55th Hawaii International Conference on System Sciences, Maui, HI, January 4-7, 2022.

Gilletly, S. "Using Machine Learning for Predictive Modeling of Weather Impacts on Utility-scale Photovoltaic Systems", Sandia Machine Learning/Deep Learning Workshop, July 2022.

Hosseinpour, H., L. Padilla and L. Matzen "Small Multiple Visualizations in Support of Different Reasoning Tasks" Annual Meeting of the Psychonomic Society, Nov. 2022.

Jackson, N.D., "Characterization of extreme weather events during large scale power outages" Society for Risk Analysis Annual Meeting, December 2021.

Miyagishima, F., S. Augustine, O. Lavrova, H. Nademi, S. Ranade, and M. Reno "Maximum Power Point Tracking and Voltage Control in a Solar-PV based DC Microgrid for Simulink" IEEE North American Power Symposium (NAPS), Oct. 2021.

Pena, B. D., L. Blakely, M.J. Reno "Data-Driven Detection of Phase Changes in Evolving Distribution Systems" Texas Power and Energy Conference (TPEC), College Station, Texas, Feb. 28, 2022.

Paruthiyil, S., R. Montoya, A. Bidram, and M. J. Reno "A Numerical Method for Fault Location in DC Systems Using Traveling Waves" IEEE North American Power Symposium (NAPS), Oct 2021.

Peppanen, J., M. Hernandez, J. Deboever, M. Rylander, M. J. Reno "Distribution Load Modeling – Survey of the Industry State, Current Practices and Future Needs" IEEE North American Power Symposium (NAPS), Oct. 2021.

Reno, M. J."Data-Driven Grid Integration" Panel for IEEE Photovoltaic Specialists Conference (PVSC), June 2022.

Reno, M. J. "Leveraging AMI for DER Interconnection and Model Validation" Panel for IEEE PES General Meeting, July 2022.

Reno, M. J. "Machine Learning Based Fault Detection and Location in Electric Power Distribution Systems" Panel for INFORMS Annual Meeting, October 2021.

Reno, M. J. "Modeling and Analysis with High Penetration PV, Including Advanced Software Tools" Plenary Panel for IEEE Innovative Smart Grid Technologies (ISGT), April 2022.

Reno, M. J. “Using Artificial Intelligence for Grid Data” Southeastern Energy Conference, April 2022.

Summers, A., T. Patel, R. C. Matthews, M. J. Reno “Prediction of Relay Settings in an Adaptive Protection System” 2022 IEEE PES ISGT, Washington, DC, Oct. 10-12, 2022.

Talkington, S., S. Grijalva, M. J. Reno, and J. Azzolini “Recovering Power Factor Control Settings of Solar PV Inverters from Net Load Data” IEEE North American Power Symposium (NAPS), Oct. 2021.

Wall, E., M. El-Assady, P. Masters, H. Hosseinpour, A. Endert, R. Borgo, P. Chau, A. Perer, H. Schupp, H. Strobelt and L. Padilla. “Trust Junk and Evil Knobs: The Duality of Trust-Calibration Design Choices” ACM Conference on Intelligent User Interfaces, October 2022.

Wilches-Bernal, F., M. Jiménez-Aparicio, M.J. Reno “An Algorithm for Fast Fault Location and Classification Based on Mathematical Morphology and Machine Learning” IEEE Innovation Smart Grid Technologies ISGT North America Conference, February 2022.

Wilches-Bernal, F., M. Jiménez-Aparicio, M.J. Reno “A Machine Learning-based Method using the Dynamic Mode Decomposition for Fault Location and Classifications” 2022 IEEE Innovation Smart Grid Technologies ISGT North America Conference, Washington, D.C., Feb 21-24, 2022.

Zikai Xu, J. Pierre, R. Elliott, D. Schoenwald, F. Wilches-Bernal, B. Pierre, “Cramer-Rao Lower Bound for Forced Oscillations under Multi-channel Power Systems Measurements,” proceedings 17th International Conference on Probabilistic Methods Applied to Power Systems (PMAPS), June 2022.

Energy Storage

Acharya,K., N. Paudel, B. Ale Magar, T.N. Lambert, I. Vasiliev “Ab Initio Study of the Discharge Mechanism of CuO Cathodes Modified with Bi2O3 in Zn/CuO Batteries” American Physical Society March Meeting, Chicago, IL, March 14-18, 2022.

Ale Magar, B., N. Paudel, T.N. Lambert, I. Vasiliev “Ab initio Studies of the Electrochemical Properties of Zn and ZnO in Rechargeable Zn/MnO_2 Batteries” American Physical Society March Meeting, Chicago, IL, March 14-18, 2022.

Allerman, A.A., M.H. Crawford, A.T. Binder, A. Armstrong, G.W. Pickrell, V.M. Abate, J. Steinfeldt, R.J. Kaplar “Selective Area Regrowth of p-type GaN and AlGaN for Power Diodes” 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022.

Atcitty, S. “States and Tribes Unlocking Historic Federal Investments in Resilience” Panel Member, Resilience Week 2022, Washington, DC, Sept 27, 2022.

Atcitty, S. “Renewable Energy Deployment with Equity and Justice Panel” Panel Member, American Solar Energy Society (AES) 51st Annual National Solar Conference, University of New Mexico, Albuquerque, NM, June 23, 2022.

Atcitty, S. participated in the “Power Electronics - What to Consider in PCS technology in the Near Term?” panel session at the 2022 Energy Storage System Safety and Reliability Forum, May 4-5, 2022.

Atcitty, S. “Energy Storage, Power Electronics, and Tribal Energy Sovereignty” 11th Annual Graduate Student Conference on the 21st Century Energy Transition, Speaker and Panel Member, Arizona Student Energy Conference, Flagstaff, AZ, April 6-8, 2022.

Atcitty, S. co-chaired the "Power Converters for Utility Applications" session at the Applied Power Electronics Conference and Exposition (APEC), Houston, TX, March 20-24, 2022.

Atcitty, S. "Grid Energy Storage and Advanced Power Conversion Systems" (Primary Industry Session Presenter) Applied Power Electronics Conference and Exposition (APEC), Houston, TX, March 20-24, 2022.

Atcitty, S. participated as an invited panel member for the American Indian Science & Engineering Society Graduate/Industry Discussion Panel, University of New Mexico, November 30, 2021.

Atcitty, S. "Energy Storage Power Electronics and Native American Energy Sovereignty" University of New Mexico Seminar Series, October 13, 2021.

Bates, A.M., Y. Preger, L. Torres-Castro, K.L. Harrison, S.J. Harris, J. Hewson "Are Solid-State Batteries Safe? A Thermodynamic Analysis" TechConnect World Innovation Conference & Expo, Washington, D.C., June 13-15, 2022.

Bates, A.M.,co-chaired the "Emerging Energy Storage Materials — Lithium-Metal Batteries" session at the 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022.

Bates, A.M., and A. Kurzawski co-chaired the "Safety and Reliability I" session at the 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022.

Bates, A.M., J. Langendorf, J. Lamb, Y. Preger, L. Torres-Castro, K.L. Harrison, S.J. Harris, J. Hewson "Thermal Stability of Solid-State Battery Components with Liquid Electrolyte" 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022.

Bates, A.M., Y. Preger, L. Torres-Castro, K.L. Harrison, S.J. Harris, J. Hewson "Are Solid-State Batteries Safer than Lithium-ion Batteries?" 39th Annual International Battery Seminar, Orlando, FL, March 28-31, 2022.

Bates, A.M., Y. Preger, L. Torres-Castro, K.L. Harrison, S.J. Harris, J. Hewson "Are Solid-State Batteries Always Safer Than Lithium-ion Batteries? Establishing a Basic Thermodynamic Approach for Evaluation" IAPG Chemical Working Group (CWG) Safety Panel, February 11 & 18, 2022.

Bates, A.M., Y. Preger, L. Torres Castro, K.L. Harrison, S.J. Harris, J. Hewson "Safety Impacts of Liquid Electrolyte Inclusion in Solid State Batteries" 2021 MRS Fall Meeting and Exhibit, November 30 - December 7, 2021.

Benson, A.G. "Statistical Cost Modeling for Behind-the-Meter Battery Energy Storage Systems" IEEE Power & Energy Society (PES) General Meeting, Denver, CO, July 17-21, 2022.

Benson, A.G. "Trends in BTM Energy Storage in California" DOE Energy Storage Financing Summit, January 19-20, 2022.

Bera, A. "Sizing Energy Storage to Aid Wind Power Generation: Inertial Support Variability Mitigation" (poster) IEEE Power & Energy Society (PES) General Meeting, Denver, CO, July 17-21, 2022.

Bock, J., S. Bishop, J. Mueller "High Temperature Capacitor Development" FY22 TRAC Program Annual Peer Review, February 3, 2022.

Brownell, M.P., A.L. Frischknecht, M. Wilson "Atomistic Modeling of Elastomer Performance During

Exposure to High-Pressure Hydrogen" 2021 MRS Fall Meeting & Exhibit, November 30 - December 7, 2021.
Chalamala, B.R. "Advances in Energy Storages Technologies" Applied Power Electronics Conference and Exposition (APEC), Houston, TX, March 20-24, 2022.

Cho, J., G.G. Yadav, J. Huang, M. Nyce, M. Weiner, T.N. Lambert, S. Banerjee "The Low-Maintenance Application of Hydrogel Electrolytes to Zn|MnO_2 Rechargeable Batteries" 2021 AIChE Annual Meeting, Boston, MA, November 7-11, 2021.
Clark, W. "Project Process: Developing & Deploying Battery Energy Storage Systems" 2022 IEEE/PES Transmission and Distribution Conference & Exposition (T&D), April 25-28, 2022.

Clark, W. "Closing the BESS Installation Code Gap: What Is the Intersection of Product Listing & Installation Standards/Codes and What is Really Required?" NRECA Annual Meeting & TechAdvantage Conference & Expo, Nashville, TN, March 7-9, 2022.

Clark, W., D. Borneo "BESS Project Commissioning" TechConnect World Innovation Conference & Expo, Washington, D.C., Oct. 18-20, 2021.

Cooper, E., E. De Anda, E. Flitz, Z. Kedzierski, H. Kim, A. Dato, T. Monson "Investigating the Dielectric Constant of Functionalized Barium Titanate Within a Polymer Nanocomposite" 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022.

De Angelis, V. participated in a "Long Duration Energy Storage Technologies" panel discussion at the Global Clean Energy Action Forum, Pittsburgh, PA, September 21-23, 2022.

De Angelis, V. co-chaired the "Novel Materials for Li-Ion Technologies" session at the 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022.

De Angelis, V. "Analyzing and Manipulating Data with the PyData Stack" part of the Introduction to Data Science for Battery Degradation tutorials, 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022.

De Angelis, V. "Battery Systems Integration and Communication" IEEE PES ESSB Committee Meeting, Gulf Shores, AL, January 24-28, 2022.

De Angelis, V. was an invited panelist on the "Non-Li Technologies and Solar Integration" session at the Southern Africa Energy Storage Systems Symposium, sponsored by the American National Standards Institute (ANSI), October 20-21, 2021.

Frischknecht, A.L. "Phase Behavior of Polymer-Grafted Nanoparticles" 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022.

Bastos, F., R. Weed, T. Nguyen, R.H. Byrne "Replacing Transmission Infrastructure with Solar and Energy Storage Systems: An Islanded Microgrid Case Study" 2022 IEEE PES Innovative Smart Grid Technologies Conference North America (ISGT N.A.), New Orleans, LA, April 24-28, 2022.

Garcia, M. "Sandia and UT Collaboration: Power System Resilience Investment Projects" Sandia Day at the University of Texas at Austin, Austin, TX, March 30-31, 2022.

Garcia, M. "Three-Stage Decision Making to Enhance Power System Resilience" Energy and Homeland Security External Advisory Board Meeting, Livermore, CA, May 16-18, 2022.

Gao, T., M.J. Stevens, A.L. Frischknecht, I. Nakamura "Molecular Dynamics Simulations for the Molecular Polarization of Salt-Free and Salt-Containing Liquids with Stockmayer Fluids and Ensemble Neural Networks" 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022.

Gilbert, S., S. Rosenberg, P. Kotula, T. Kmieciak, M. Meyerson, M. Siegal, L. Biedermann "Tuning YSZ- and SiNx-Based Granular Metal Conductivity by Controlling Island Morphology and Interface Interactions" 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022.
Gill, L., L.A. Garcia Rodriguez, J. Mueller, J. Neely "A Comparative Study of SiC JFET Super-Cascode Topologies" IEEE Energy Conversion Congress & Expo (ECCE), October 10-14, 2021.

Gross, M.M., S.J. Percival, R.Y. Lee, A.S. Peretti, E.D. Spoerke, L.J. Small "Lower Temperature, Lower Cost Molten Sodium Batteries" 2021 MRS Fall Meeting and Exhibit, Boston, MA, November 30 - December 7, 2021.

Hawkins, B., D.E. Turney, G.G. Yadav, A.M. Kiss, T.N. Lambert, S. Banerjee, R. Messinger "Electrochemically Active ZnO Discharge Product Formed in Rechargeable Zn-Alkaline Batteries: Performance Effects and Mechanistic Insights" 2021 AIChE Annual Meeting, Boston, MA, November 7-11, 2021.

Hill, R.C., A. Peretti, M.M. Gross, L.J. Small, E.D. Spoerke, Y-T. Cheng "Characterization of NaSICON Solid Electrolytes Exposed to Thermal and Electrochemical Cycling in Molten Sodium Environment" 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022.

Hill, R.C., J. Hempel, A.S. Peretti, L.J. Small, E.D. Spoerke, Y-T. Cheng "Electro-Chemo-Mechanical Behavior of NaSICON Solid Electrolytes in Molten Sodium Batteries" University of Kentucky 2022 Materials and Chemical Engineering Symposium in Lexington, KY, May 5, 2022.

Hill, R.C., M.M. Gross, A.S. Peretti, L.J. Small, E.D. Spoerke, Y-T. Cheng "Structural and Mechanical Characterization of NaSICON Solid Electrolytes Upon Cycling in Molten Sodium" 2021 MRS Fall Meeting and Exhibit, Boston, MA, November 30 - December 7, 2021.

Ho, C. "Long-Duration High-Temperature Thermal Energy Storage for Grid and Industrial Applications" TechConnect World Innovation Conference & Expo, Washington, D.C., Oct. 18-20, 2021.

Kaplar, R. "Vertical Gallium Nitride Devices for Medium-Voltage Power Electronics" IEEE Energy Conversion Congress & Expo (ECCE), October 10-14, 2021.

Kong, Y., P. Kathayat, L. Cho, K.O. Findley, J.G. Speer, B. Kagay, C. San Marchi, J.A. Ronevich "Microstructural Engineering of Mn-Alloyed Duplex Steels and Accelerated Test Method Development to Achieve Low-Cost, High-Performance Solutions for Hydrogen Storage and Delivery" 2021 MRS Fall Meeting and Exhibit, November 30 - December 7, 2021.

Kurzawski, A., J. Hewson "The Role of Heat Transfer in Mitigation of Cascading Thermal Runaway" 241st Electrochemical Society (ECS) Meeting, Vancouver, BC, Canada, May 29 – June 2, 2022.

Kurzawski, A., R. Shurtz, L. Torres-Castro, J. Hewson "Intra-Particle Diffusion-Limited Thermal Runaway Predictions in Lithium-Ion Systems" 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022.

Kurzawski, A. co-chaired the "Installing Storage Systems Safely: Fire Risks and Hazards" panel at the Energy Storage Summit USA 2022, March 23-24, 2022.

Lavrova, O., S. Atcitty, G. Cowles, V. De Angelis, J. Huang, S. Augustine "Extreme Solar: Towards 24-7

Renewable Energy" 49th IEEE Photovoltaic Specialists Conference, Philadelphia, PA, June 5-10, 2022.

Maraschky, A.M., R.Y. Lee, S.J. Percival, M.M. Gross, A.S. Peretti, E.D. Spoerke, L.J. Small "Experimental and Modeling Studies of Metal Halide Catholyte and Cathode Materials to Enable Low-temperature Molten Sodium Batteries" 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022.

McNamara, W., V. DeAngelis "Long Duration Energy Storage (LDES) in a Decarbonized Future – Policy Gaps, Needs, and Opportunities" TechConnect World Innovation Conference & Expo, June 13-15, 2022.

Meyerson, M.L., S.J. Percival, A.M. Maraschky, L.J. Small "Redox Mediated Li-S Flow Battery for Grid-Scale Energy Storage Applications" 241st Electrochemical Society (ECS) Meeting, Vancouver, BC, Canada, May 29 – June 2, 2022.

Meyerson, M.L., S.J. Percival, S. Rosenberg, A.M. Maraschky, L.J. Small "Higher Surface Area Lithium Anode for Mediated Lithium-Sulfur Flow Batteries" American Chemical Society (ACS) 2022 Spring Meeting, San Diego, CA and Virtual, March 20-24, 2022.

Meyerson, M.L., S. Rosenberg, S. Dickens, L.J. Small "Redox Mediated Li-S Flow Battery for Grid-Scale Energy Storage Applications" Materials Research Society (MRS) Fall Meeting, Boston, MA, November 30 – December 7, 2021.

Meyerson, M.L., S. Rosenberg, S. Dickens, L.J. Small "Redox Mediated Li-S Flow Battery for Grid-Scale Energy Storage Applications" Southwest Regional Meeting of the American Chemical Society, Austin, TX, October 31 - November 3, 2021.

Mueller, J., co-chaired the "Medium Voltage Circuit Topologies and Controls" session at the Sandia Power Electronics Workshop, August 23-24, 2022.

Mueller, J., co-chaired the "Design & Control of Power Converters for Utility Applications" session at the Applied Power Electronics Conference and Exposition (APEC), Houston, TX, March 20-24, 2022.

Mukundan, R., S. Maurya, B.L. Davis, T.M. Anderson "Non-Aqueous Flow Battery Development" TechConnect World Innovation Conference & Expo, Washington, D.C., Oct. 18-20, 2021.

Neely, J., co-chaired the "Devices & Components" session at the Applied Power Electronics Conference and Exposition (APEC), Houston, TX, March 20-24, 2022.

Obert, J., R.D. Trevizan, A. Chavez "Efficient DER Voltage Control Using Ensemble Deep Reinforcement Learning" Artificial Intelligence for Industries 2022 (ai4i 2022), Laguna Hills, CA, September 19-21, 2022.

O'Brien, V., R.D. Trevizan, V.S. Rao "Detection of False Data Injection Attacks in Ambient Temperature-Dependent Battery Stack," Sandia National Laboratories Intern Summer Symposium, July 25-28, 2022.

O'Brien, V., R.D. Trevizan, V.S. Rao "Detection of False Data Injection Attacks in Battery Stacks Using Physics-Based Modeling and Cumulative Sum Algorithm" Texas Tech University 21st Annual Graduate Student Research Poster Competition, March 3, 2022.

Paudel, N., B. Ale Magar, K. Acharya, T.N. Lambert, I. Vasiliev "First-Principles Study of the Surface Properties of ZnO Anode Material in Rechargeable Zn/MnO_2 Batteries" American Physical Society March

Meeting, Chicago, IL, March 14-18, 2022.

Percival, S.J., R.Y. Lee, L.J. Small "Electrochemical Simulations of Molten Salt Catholytes Reveal Speciation Can Surpass Kinetics for Iodide Oxidation Rates" American Chemical Society (ACS) 2022 Spring Meeting, San Diego, CA and Virtual, March 20-24, 2022.

Preger, Y., V. De Angelis "Open-Source Software to Accelerate the Development of Energy Storage Systems" TechConnect World Innovation Conference & Expo, Washington, D.C., June 13-15, 2022.

Preger, Y., O. Dutta, D. Rosewater, I. Derin, L. Torres-Castro, H. Wang, V. De Angelis "Open-Source Software to Accelerate the Development of Energy Storage Systems" Batteries Gordon Research Conference, Ventura, CA, June 5-10, 2022.

Preger, Y., "A Mechanism-based Assessment of 'Knees' in Lithium-ion Battery Aging Trajectories" IAPG Chemical Working Group (CWG) Safety Panel, October 1, 2021.

Rosewater, D.M. "Battery Management System Standard: IEEE P2686 Recommended Practice for Battery Management Systems in Energy Storage Applications" 2022 Energy Storage System Safety and Reliability Forum, May 4-5, 2022.

Rosewater, D.M., D. Schoenwald, and M. Ropp participated in the "IEEE Standards – What are the new developments in performance and reliability C&S?" panel session at the 2022 Energy Storage System Safety and Reliability Forum, May 4-5, 2022.

Schorr, N.B., D.J. Arnot, A.M. Bruck, J. Gallaway, T.N. Lambert "Copper Oxide Cathodes for Rechargeable Alkaline Zinc Batteries" 2021 MRS Fall Meeting and Exhibit, November 30 - December 7, 2021.

Schorr, N.B., I. Kolesnichenko, L. Merrill, K.L. Harrison, T.N. Lambert "High-Capacity Retention in Lithium Batteries Utilizing Nano Iron Sulfide Particles" 2021 MRS Fall Meeting and Exhibit, November 30 - December 7, 2021.

Shurtz, R., A. Kurzawski, J. Hewson "Competitive Reactions and Heat Transfer Effects Applicable to Thermal Runaway Onset in Lithium-Ion Batteries" 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022.

Simmons, K., L. Fring, W. Kuang, Y. Shin, R. Shrestha, C. San Marchi "Morphological Changes and Their Effects on Material Properties in Natural Gas Medium Density Polyethylene Pipe in Low Pressure Hydrogen" 2021 MRS Fall Meeting and Exhibit, November 30 - December 7, 2021.

Shurtz, R., and L. Torres-Castro co-chaired the "Characterizing Battery Degradation and Failure Modes" session at the 2022 MRS Spring Meeting & Exhibit, May 8-13, 2022.

Small, L.J., R.Y. Lee, S.J. Percival, M.M. Gross, A.S. Peretti, M.L. Meyerson, E.D. Spoerke "Understanding Electrochemical Processes in Molten Salt Catholytes for Low-Temperature Molten Sodium Batteries" 2021 MRS Fall Meeting and Exhibit, Boston, MA, November 30 - December 7, 2021.

Spoerke, E.D. "'Dirt Cheap' Energy Storage: Clay-Based Separators for Solid State Storage" TechConnect World Innovation Conference & Expo, Washington, D.C., June 13-15, 2022.

Spoerke, E.D. and A. Maraschky co-chaired the "A03- Large Scale Na and Li Batteries" session at the 241st

Electrochemical Society (ECS) Meeting, Vancouver, BC, Canada, May 29 – June 2, 2022.

Spoerke, E.D., M.L. Meyerson, A.M. Maraschky, A.S. Peretti, S.J. Percival, M.M. Gross, R.Y. Lee, J. Lamb, L.J. Small "Molten Salt-Based Batteries for Safe, Reliable Long-Duration Energy Storage" 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022.

Spoerke, E.D., M.M. Gross, M.L. Meyerson, L.J. Small, S.J. Percival "Low Temperature Molten Sodium Batteries for Long-Duration Energy Storage" 2021 MRS Fall Meeting and Exhibit, Boston, MA, November 30 - December 7, 2021.

Spoerke, E.D., and I. Gyuk co-chaired the "Energy Storage Symposium" at TechConnect World Innovation Conference & Expo, Washington, D.C., Oct. 18-20, 2021.
Torres-Castro, L., J. Lamb, J. Hewson, R. Shurtz, Y. Preger "Accelerating Rate Calorimetry Investigations of Thermal Runaway in Multiple Formats and Capacities" 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022.

Torres-Castro, L., A. Bates, J. Lamb, T. Tanim, L. Walker "Diagnostics for Thermal Runaway Detection" 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022.

Torres-Castro, L., co-chaired the following sessions at the 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022:

- "Characterizing Degradation and Failure Modes"
- "Emerging Energy Storage Materials II"
- "Fast Charging II"
- "Interphase and Interfaces"
- "Safety and Reliability II"
- "Thermal Characterization of Energy Storage Materials and Devices I"
- "Thermal Characterization of Energy Storage Materials and Devices II"

Whang, G., D. Ashby, A. Lapp, I. Kolesnichenko, T. Lambert, A.A. Talin, B.S. Dunn "New Insights on Reaction Pathways for FeS2 Cathodes" 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022.

Wittman, R.M., M. Dubarry, S. Ivanov, J. Kustas, J. Langendorf, R. Grant, G. Taggart, B Chalamala, Y. Preger "Path Dependence of Li-Ion Battery Degradation During Cycling to 80% Capacity" 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022.

Wittman, R.M., A. Fresquez, B. Chalamala, Y. Preger "Systematic Long-Term Cycling of 18650 Li-ion Batteries Beyond 80% Capacity" The Electrochemical Society (ECS) Fall 2021 Conference, October 10-14, 2021.

Wygant, B.R., L. Merrill, T.N. Lambert, K.L. Harrison "A System-Level Approach to Li Metal/Iron Fluoride Batteries Enabled by Optimal Electrolyte Choice" 2021 MRS Fall Meeting and Exhibit, November 30 - December 7, 2021.

Zhou, X., C. Nowak, M. Foster, R. Sills, J.A. Ronevich, C. San Marchi "Machine-Learning Studies of Hydrogen Effects on Stacking Fault Energies in an $Fe_{0.70}Ni_{0.11}Cr_{0.19}$ Austenitic Stainless Steels" 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022.

Organizational Workshops

Advanced Grid Modeling

Jackson, N.D., and H. Baroud (Vanderbilt University), "Symposium: Resiliency Modeling of Energy Systems – Part I", Society for Risk Analysis Annual Meeting, Virtual, December 7, 2021.

Jackson, N.D., and H. Baroud (Vanderbilt University), "Symposium: Resiliency Modeling of Energy Systems – Part II", Society for Risk Analysis Annual Meeting, Virtual, December 7, 2021.

Kaplar, R., co-organized the "Ultra-Wide Bandgap Materials and Devices" symposium at the 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022.

Nguyen, T., organized and hosted the "Energy Storage for Grid of The Future: Emerging Technologies, Applications and Trends" session at the IEEE Energy Conversion Congress & Expo (ECCE), October 10-14, 2021.

Nguyen, T., D. Rosewater, D. Schoenwald, led working groups P2686 (Battery Management Systems) and P2688 (Energy Storage Management Systems) at the IEEE PES ESSB Summer 2022 Meeting, Sonoma, CA, June 13-17, 2022.

Passell, H., moderated the "Policy Track: Regional Policy Design for Solar and Other Advanced Energy Technologies" session at the ASES Solar 2022 conference, Albuquerque, NM, June 21-24, 2022.

Pierre, B., "Grid Resilience Planning Workshop" Multi-objective Decision Planning (MOD-Plan) project, Albuquerque, NM, December 2021.

San Marchi, C.,"Advanced Materials for Hydrogen and Fuel Cell Technologies" 2021 MRS Fall Meeting and Exhibit, November 30 - December 7, 2021.

Spoerke, E., I. Gyuk "Energy Storage Symposium" TechConnect World Innovation Conference & Expo, Washington, D.C., June 13-15, 2022.

Spoerke, E., co-organized the "Ion-Conducting Ceramics" symposium at Electronic Materials and Applications (EMA) 2022, Orlando, FL. January 19-21, 2022.

Torres-Castro, L., co-organized the "Emerging Materials for Electrochemical Energy Storage Devices—Degradation and Failure Characterization—From Composition, Structure and Interfaces to Deployed Systems" symposium at the 2022 MRS Spring Meeting & Exhibit, Honolulu, HI, May 8-13, 2022.

WEBINARS

Renewable & Distributed Systems Integration

Haines, T. "Flexible Control of Synthetic Inertia in Co-located Clusters of Inverter-based Resources" 2022 IEEE Power and Energy Conference at Illinois (PECI), Virtual, March 11, 2021.
Johnson, J. "Risk Management for DERs" SunSpec & Sandia DER Cybersecurity Webinar, January 27, 2022.
Lave, M. "Puerto Rico 100," public kick-off meeting, February 16, 2022.

Advanced Grid Modeling

Trudnowski, D. "Impact of Forced Oscillations" North American Synchro Phasor Initiative (NASPI) webinar series, March 20, 2022.

Energy Storage Technologies & Systems

Atcitty, S, "An Introduction to Microgrids and Energy Storage" 2022 Tribal Energy Webinar: Technologies of the Energy Transition, DOE Indian Energy Webinar Series, August 3, 2022.

Atcitty, S. "Tribal Energy Equity and Resiliency" DOE Office of Electricity's Microgrid & Energy Storage Applications for Resilience & Energy Equity Webinar, November 19, 2021.

Borneo, D. "Building Community Resilience with Green Mountain Power" May 18, 2022.

Borneo, D. "Commissioning an Energy Storage System: Lessons Learned" September 7, 2022.

Bera, A. "Installation and Troubleshooting of QuESt" QuESt Introductory Tutorials, August 10-11, 2022.

Borneo, D. "New Federal Funding for Energy Storage: What's Available and How to Qualify" August 9, 2022.

Borneo, D. "Solar+Storage for Clean Energy and Cost Savings at Albuquerque Public Schools" November 5, 2021.

Borneo, D. "State of the U.S. Energy Storage Industry: 2021 Year in Review" February 24, 2022.

Borneo, D., S. Schoenung "Energy storage systems to support Facilities: Battery Storage and Microgrids" DOE Better Buildings Accelerator Program – Sustainable Corrections Infrastructure Partnership, June 14, 2022.

Guan, H. "Energy Storage for Social Equity (ES4SE): An Introduction to the DOE-OE Initiative" November 1, 2021.

Guan, H. "Energy Storage for Social Equity Initiative" PNNL Informational Webinar, November 8, 2021.

Olinsky-Paul, T., "Sterling MA Energy Storage Project" DOE Better Buildings Accelerator Program – U.S. DOE Weatherization and Intergovernmental Programs Office, Sustainable Corrections Infrastructure Partnership Accelerator (SCIP) panel discussion, June 14, 2022.

The Energy Storage Systems Policy and Outreach Program continued its series of energy storage webinars with the **Introduction to Microgrids & Energy Storage for Emergency Grid Resilience**, in collaboration with Iowa State University's Electric Power Research Center and FEMA Regions 5 & 7 and FEMA HQ. All sessions included introductory comments from Dr. Imre Gyuk. Topics included:

- November 05, 2021 – An introduction to microgrids and energy storage (ES), with Will McNamara and Summer Ferreira, and others.
- November 12, 2021 – "Stakeholder" presentations on emerging threats to the grid and the response from microgrids and ES.
- November 19, 2021 – Microgrids and ES applications for resilience and energy equity, with Stan Atcitty
- December 03, 2021 – Microgrids an ES engineering challenges for interconnection and interoperability, including Mike Ropp and Dave Schoenwald, and others.
- December 10, 2021 – Microgrids and ES for emergency grid resilience policy and regulatory topics, including Will McNamara.

The Energy Storage Systems Policy and Outreach Program continued its series of energy storage webinars with the **Illinois Commerce Commission**. Topics included:

- November 16, 2021 – An introduction to energy storage (ES), with Howard Passell, Will McNamara, and others.
- November 30, 2021 – A roundtable with speakers from various other states about their ES strategies.
- December 07, 2021 – Engineering details, including project development with Dan Borneo, interconnection with Mike Ropp, and others.
- December 14, 2021 – ES Benefit-Cost Analyses and ES valuation, with Howard Passell, Will McNamara, Tu Nguyen, and others.
- January 11, 2022 – Battery storage for generation and transmission/distribution deferral.
- January 18, 2022 – Strategies for ES and decarbonization.

The Energy Storage Systems Policy and Outreach Program continued its series of energy storage webinars with the **Southeast Energy Storage** at the request of Southern Research Institute (focused on energy storage technology, economic and policy issues impacting the Southeastern U.S regulators). Topics included:

- April 05, 2022 – An introduction to energy storage (ES), with Howard Passell, Ray Byrne, and Will McNamara.
- April 19, 2022 – ES system integration, including interconnection and safety.
- May 03, 2022 – ES technology life cycle issues, including recycling and second use.

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