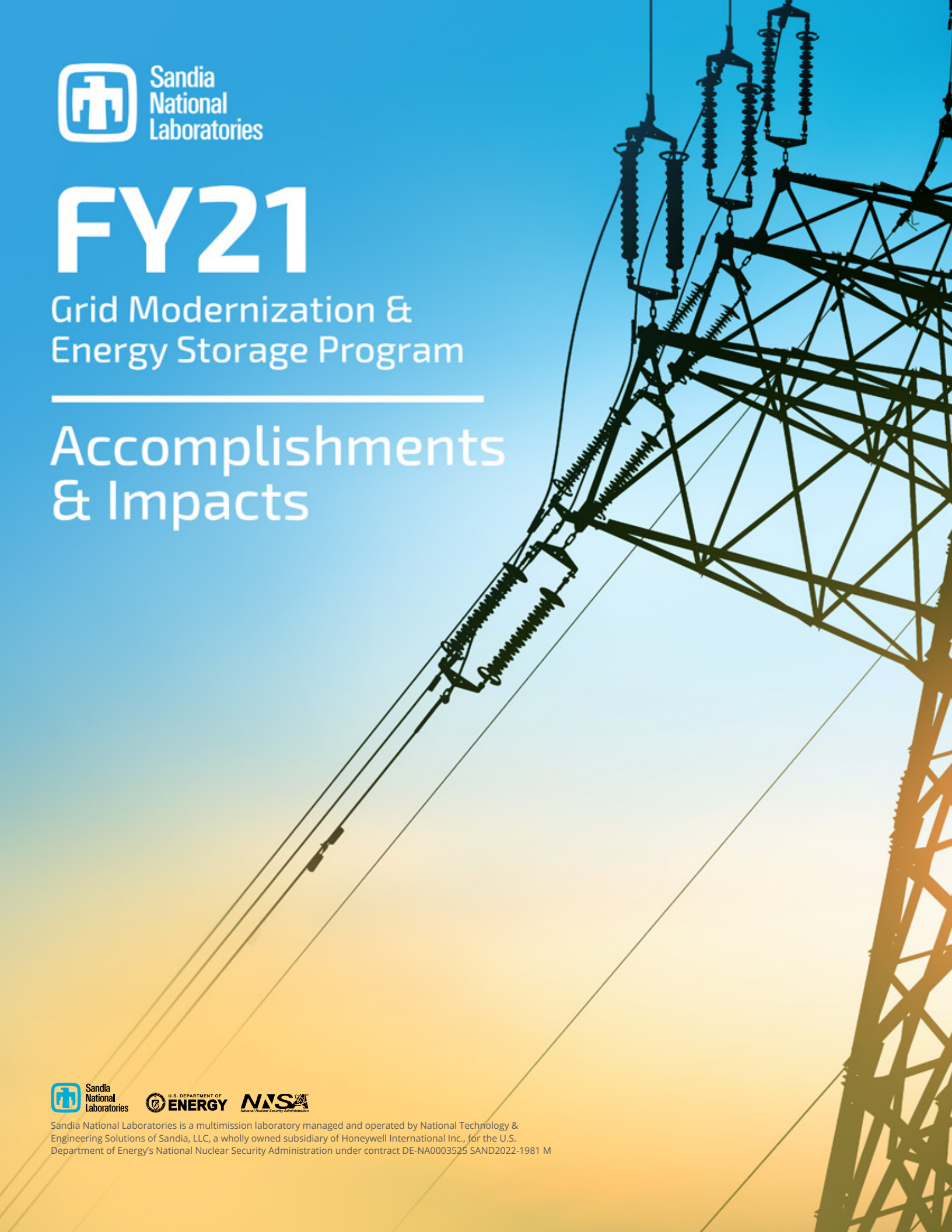
Sandia National Laboratories

FY21

Grid Modernization & Energy Storage Program

Accomplishments & Impacts



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INTRODUCTION

As we finish our second year of activities amid the coronavirus pandemic, the Sandia Grid Modernization and Energy Storage research team has made great strides 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 efforts continue to 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.

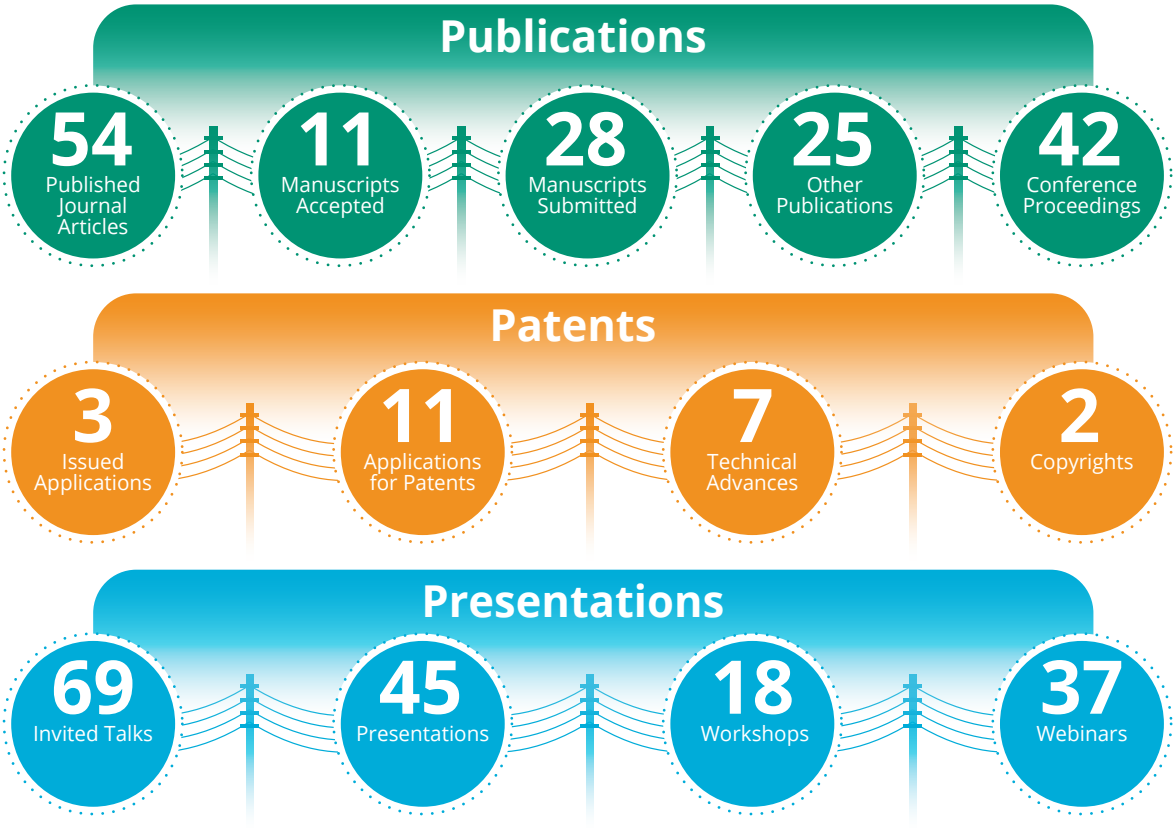
Much of the material in this report comes from the separate 2021 Accomplishments Report compiled by our Energy Storage subprogram team, a cornerstone of our grid research and achievements. The Grid Energy Storage Program at Sandia National Laboratories is focused on making energy storage cost-effective 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 2021 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.

Other sections of this report catalog key accomplishments in the following areas of our Grid Modernization and Energy Storage program: Advanced Grid Modeling, Energy and Water, Grid Security, and Renewable and Distributed Systems Integration.

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 additional ways we can team to create our modern grid and apply the outcomes of our effort. The bulk of work described in these pages is funded by the DOE Office of Electricity and key programs within the DOE Office of Energy Efficiency and Renewable Energy, namely, the Solar Energy Technologies Office and the Wind Energy Technologies Office.

The contributors to our successes are too numerous to name here, though our team wishes to express deep gratitude to the numerous program and project sponsors at the U.S. 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
Grid Modernization and Energy Storage Program Manager
Sandia National Laboratories



58 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.

169 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.

10 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.

160 Publications

Sandia researchers produced many grid modernization and energy storage-related publications, including over 50 journal articles. A list of publications is provided on pages 17 through 26.

NOTABLE ACCOMPLISHMENTS

Advanced Grid Modeling

MOD-Plan Project: The team supporting DOE OE Electricity Delivery System Transformation Program have started a multi-year effort called Emerging Grid Objectives and Multi-objective Decision Planning (MOD-Plan). The project aims to better understand emerging objectives of equity, resilience, and decarbonization and show the trade-offs between emerging and traditional planning goals. The project team has created a Technical Stakeholder Committee with regulators, industry, and national associations to incorporate their perspectives within the project on emerging grid objectives and multi-objective planning. The project is 1) developing a modeling framework that permits the application of multiple emerging objectives within the grid planning process, 2) advancing practical methods for formulating planning objectives of energy justice and equity, resilience, and decarbonization, 3) developing and reporting on metrics to measure the performance of the grid with respect to these emerging objectives. Sandia and Pacific Northwest National Laboratory (PNNL) are contributing team members.

Small Signal Stability Analysis and Estimation Project: The Small Signal Stability Analysis and Estimation Project, a collaboration between Sandia and the University of Wyoming, has successfully performed the simulations, analysis, and co-writing of the Western Electricity Coordinating Council (WECC) report, "Modes of Inter-area Power Oscillations in the Western Interconnection." This report revises the WECC modes review document from 2014 to better reflect recent grid trends, such as:

- higher penetrations of renewables and inverter-based resources
- synchronous generator retirements (21.8 GW since 2014)
- recent changes in load
- reductions in system inertia

This report will improve situational awareness and provide a better understanding of the controllability and interaction paths of electro-mechanical oscillatory modes in the WECC. The impact of the report to operating entities is that they will be able to create more reliable and resilient plans for mitigation of low damping scenarios. A public version of the report is currently in final review. The public report conveys essential information about the modes in the WECC while protecting restricted data under the Western Interconnection Data Sharing Agreement (WIDSA) and restricted Critical Energy/Electric Infrastructure Information (CEII).

Converter-Interfaced Generation: A project at Sandia to develop algorithms to estimate frequency from electrical signals has resulted in multiple accepted technical papers and a technical advance. The integration of converter-interfaced generation into the grid is creating systems with low inertia conditions that become more vulnerable to power imbalances. To solve this problem, converter-interfaced generation is enabled with a controller intended to emulate the inherent inertial response of rotating generation. This controller, known sometimes as synthetic inertia, requires local frequency measurements of electrical signals. The proposed algorithms will work with the heavily distorted signals that occur near system faults. The project will use the proposed algorithms to drive synthetic inertia controllers to improve the inertial response of a test power system.

Reassessing the Market—Computation Interface to Enhance Grid Security and Efficiency: Given recent advances in computational optimization capabilities, re-considering core market and reliability processes may yield transformative advances in power grid security, reliability, and efficiency. A project, led by Sandia researcher Manuel Garcia, is reassessing the design and analysis of two market and reliability constructs. The effort has led to two publications "Requirements for Interdependent Reserve Types Providing Primary Frequency Control" and "Primary Frequency Response Reserve Products for Inverter-Based Resources." The latter introduces new primary frequency response reserve products to the electricity market including virtual inertia reserve and fast frequency response reserve products. These new reserve products will increase the security, reliability, and efficiency of the power system.

Co-optimization of Grid Resilience and Reliability: Among other impacts, research to co-optimize grid resilience and reliability has developed a two-stage stochastic optimization model to identify optimal generators for winterization, considering many winter storm scenarios. The model's objective is to reduce load shed during future polar vortex events. The work is part of a larger project, "Co-optimization of Grid Resilience and Reliability," which takes a practical approach to identify the optimal investments, preemptive actions, and restoration decisions to simultaneously improve grid resilience and reliability. The optimization models developed help utilities see the trade-offs between investing more heavily in reliability or resilience.

Machine Learning for Grid Stability: A project, led by two researchers at Sandia, has successfully improved a machine learning agent being developed to help restore the grid during blackout or near-blackout conditions. The agent was improved using discrete and continuous reinforcement learning to navigate a grid-like space. It has also been demonstrated that it can take advantage of transfer learning, allowing the agent to be partially trained for a specific system. The research uses deep reinforcement learning similar to AlphaZero to navigate a grid-state space. The agent's control variables include load and generation dispatch and the agent is trained to incrementally move the grid further away from potential instabilities. The trained agent could be used to improve system stability margins for real-time decision support.

Probabilistic Impact Scenarios for Extreme Weather Event Resilience: An effort at Sandia to establish probabilistic impact scenarios for resilience to extreme weather events has successfully created a nationwide dataset that links weather data to power outage events and restoration timelines. The dataset allows the team to query events, create signatures to demonstrate the distribution of impact severity and recovery, and to create realistic impact scenarios for use in long-term planning studies. Additionally, the researchers have developed a method to create temperature scenarios that incorporates both spatial and temporal dependencies. The scenarios allow the team to simulate system performance while planning for uncertainties in extreme temperature impacts. The research has also culminated in a published conference paper that models the impact of wildfire smoke on solar PV production. The model demonstrated robust predictive performance across a wide range of PV sites, fire conditions, and locations. This model can inform operational considerations based on smoke propagation in areas with a high prevalence of solar PV. The project has developed data-driven methods and associated computational analysis tools to create probabilistic scenarios outlining how an extreme weather event could impact the grid.

Resilient Expansion Planning under Long-Term Hazard Uncertainty: A data workflow has been created at Sandia that allows researchers to identify grid locations at a high risk of being disrupted by extreme weather events based on changing threats for both specific hazard types and specific asset classes. The work stems from a project to model long-term projections of extreme weather events that would disrupt the power grid and its associated, dependent infrastructure. By explicitly considering resilience, the projections will provide needed input to planning models.

Decentralized Decision Making for Improved Grid Resiliency: Sandia, in collaboration with the University of California, Davis and Lawrence Livermore National Laboratory, developed a test suite of decentralized transmission optimization problems over different formulations, including DC optimal power flow (DCOPF), AC optimal power flow (ACOPF), and ACOPF with second-order cone (SOC) relaxations. This test suite will allow the team to evaluate the solution quality and scalability of the decentralized optimization approaches being developed to improve the resilience of the electrical grid.

MIRACL: As part of the Microgrids, Infrastructure Resilience, and Advanced Controls Launchpad (MIRACL) Project, Sandia developed a control strategy that enables a solitary wind turbine to provide frequency regulation in an isolated power system. The system is a representation of the grid in St. Mary's and Mountain Village in Alaska. The implemented control also provided damping support to the system and improved the overall frequency response of the system to severe disturbances. The work advances the understanding of how distributed wind technologies can provide grid services—measures such as frequency regulation and damping that enhance the grid's stability and resilience. The work is funded by the Wind Energy Technologies Office within DOE's Office of Energy Efficiency and Renewable Energy.

FlexPower: An ongoing project is demonstrating that utility-scale wind and PV power generation combined with energy storage systems can provide reliability services to the bulk power system similar to conventional power plants. Sandia has developed control techniques for these hybrid systems to provide frequency support services to power systems. This hybrid power plant—composed from clusters of wind turbines, solar PV, and energy storage systems—is called a FlexPower plant. The techniques Sandia developed provide droop control and synthetic inertia for the system. Droop control and synthetic inertia are reliability services typical of conventional power plants but less common for hybrid systems. The advanced control technique alters the droop response of each participating technology to achieve a user-defined, plant-level droop response while accounting for resource availability. The work demonstrates that the FlexPower plant can effectively provide frequency support to power systems much like conventional generators.

Energy Storage Technologies and 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 FY21. For more details and information, refer to the complete report.

Battery Materials Research

Long-Duration Energy Storage Workshop: Erik Spoerke and Clifford Ho from Sandia National Laboratories, supported by PNNL and ORNL, hosted the DOE workshop: "BIG" Energy Storage: Priorities and Pathways to Long-Duration Energy Storage. The highly successful workshop on March 9–10, 2021 was well-received and had more than 1,500 registrants (500-600 simultaneous participants each day) and included national and international participation across industry, multiple national laboratories, academia, and government. This OE-led activity had active engagement across the Office of Electricity, the Office of Energy Efficiency and Renewable Energy, the Advanced Research Projects Agency–Energy, the Hydrogen and Fuel Cell Technologies Office, the Vehicle Technologies Office, and more broadly the the DOE Energy Storage Grand Challenge.

Self-Assembled Polymer Coating Approach: Tim Lambert and the energy storage materials team demonstrated a self-assembled polymer coating approach capable of selective ion transport, solving one of the fundamental problems in alkaline Zn batteries, that of zincate crossover. Using commercially relevant energy-dense electrodes with high areal capacities of 60 mAh cm^{-2}, Zn-Ni cells tested at 20% Zinc depth of discharge (DOD_{Zn}) achieve over 200 cycles while those tested at 50% DOD_{Zn} achieve over 100 cycles before failure. The 20% and 50% DOD cells deliver an average of 132 and 180 Wh L^{-1} per cycle over their lifetime respectively. Rechargeability is attributed to the highly selective diffusion properties of the 300 nm thick negatively charged coating on the separator which prevents shorting by dendrites and inhibits redistribution of the active material.

Continued Industrial Impact: Ion-selective membrane development at Sandia, led by Cy Fujimoto, continued its industrial impact with Xergy Inc., renewing their license of seven of Fujimoto's OE-supported membrane patents. Xergy Inc. is a Delaware-based company with a commitment to engineering solutions with ion-exchange membranes.

Improved Battery Performance: The Energy Storage Sodium Battery Materials team developed new NaSICON synthetic strategy that produces a 2X improvement in ionic conductivity and a 4X improvement in synthetic yield. This material is now competitive with state-of-the-art industrial (formerly Ceramatec) NaSICON. This development will not only allow improved performance of low-temperature molten Na batteries but is also being explored as a zero-crossover candidate for Zn-MnO_2 batteries and may be suitable for flow battery systems.

American Physical Society: Amalie Frischknecht served as the Chair of the Division of Polymer Physics (DPOLY) of the American Physical Society from March 2020 through March 2021. She is continuing to serve on the DPOLY Executive Committee as the Past Chair until March 2022.

Power Electronics

Best Paper Award: Luciano A. Garcia Rodriguez, Lee Gill, Jacob Mueller, and Jason Neely received the Best Paper Award for the paper "A High-Voltage Cascaded Solid-State DC Circuit Breaker Using Normally-On SiC JFETs" presented at the IEEE 12th Energy Conversion Congress & Exposition – Asia (IEEE ECCE – Asia), May 24-27, 2021.

Outstanding Young Engineer Award: Jacob Mueller received the IEEE Albuquerque Section Outstanding Young Engineer award for technical contributions to the field of power electronics. The award specifically highlighted his work developing computationally efficient models of multi-converter systems and high-performance power conversion strategies for utility-scale energy storage. Read more at https://site.ieee.org/albuquerque/.

Safety & Reliability

Most Downloaded Paper: For one full year, "Degradation of Commercial Lithium-ion Cells as a Function of Chemistry and Cycling Conditions" by Yuliya Preger, Heather Barkholtz, Armando Fresquez, Daniel Campbell, Benjamin Juba, Jessica Roman-Kustas, Summer Ferreira, and Babu Chalamala, was cited as one of the five most-downloaded papers in the *Journal of the Electrochemical Society*. In the year since publication, it has been downloaded over 23,000 times.

Energy Storage Systems Safety & Reliability Forum: Sandia organized the Energy Storage Systems Safety & Reliability Forum (April 20-21) on behalf of the Office of Electricity Grid Energy Storage Program. Conference organization was led by Josh Lamb with support from David Sokoloff, Marisa Montes, and Sam Roberts. At its peak, there were over 300 attendees in the virtual meeting. The event included participants from national laboratories, independent testing and research organizations, battery manufacturers, electric utilities, and first responders.

Battery Safety: Josh Lamb, lead for the Energy Storage Safety & Reliability program, was Guest Editor for the May 2021 special edition of the *MRS Bulletin*, focused on materials developments in battery safety.

***BatteryArchive.org* Launches:** In September 2020, Valerio De Angelis and Yuliya Preger launched *BatteryArchive.org*, the first public repository for easy visualization and comparison of battery degradation data across institutions. In the year since its launch, the site has been used by thousands of individuals across academia, industry, and utilities to understand how lithium-ion batteries perform in

different conditions and to save money in their own testing.

Easy, Online, Thermodynamic Calculator: Randy Shurtz and John Hewson released the thermodynamic web calculator at https://www.sandia.gov/ess-ssl/thermodynamic-web-calculator/ allowing users an easy tool for estimating the heat production during battery failure based on user-entered parameters. This provides a tool to drive toward the model-based design of grid-scale battery systems.

Fire Safety Science Research Subcommittee Co-chair: John Hewson was selected co-chair of the Research Subcommittee for the International Association of Fire Safety Science (IAFSS). The Research Subcommittee's mission is to highlight research needs in emerging areas and research results from the IAFSS member community that can be applied to these emerging areas. Energy storage safety is one of the emerging areas of focus.

Open-Source Battery Lifecycle Framework Software: Valerio De Angelis and Yuliya Preger open-sourced the Battery Lifecycle (BLC) Framework software. The BLC is an open-source platform that provides tools to visualize, analyze, and share battery data through the technology development cycle, including data from material characterization, cell testing, manufacturing, and field testing.

Graduate Student Research Poster Highlighted at AEC: V. O'Brien, R.D. Trevizan, and V.S. Rao's "Detection of False Data Injection Attacks Targeting State of Charge Estimation of Battery Energy Storage Systems" won First Place in the poster competition for graduate students at the 11th Advanced Energy Conference (AEC). Victoria O'Brien is currently performing her dissertation research at Sandia.

Analytics

Open-Source Energy Storage Valuation Tool: The goal of the energy storage analytics thrust area is to develop methods and algorithms to evaluate energy storage systems from both a technical and economic perspective. QuESt is the flagship open-source energy storage valuation tool that is available on GitHub. This year, Sandia released a new version of QuESt that incorporates a technology selection tool. Sandia researchers also developed the back end of two new applications: QuESt Equity and QuESt Performance. QuESt Equity evaluates peaker plant replacement with storage plus solar while considering energy justice (e.g., negative impacts of pollution from peaker plants in urban areas). QuESt Performance employs a building and HVAC model to properly size energy storage systems in extreme (hot and cold) climates. Often the parasitic loads from heating and cooling impact the required storage system size and these factors are infrequently considered.

Energy Storage Finance Summits: In collaboration with Richard Baxter at Mustang Prairie Energy and K&L Gates, Sandia organized two energy storage finance summits. These meetings bring together leaders from finance with energy storage developers and government officials. In addition, Sandia worked with Richard Baxter to update the annual energy storage pricing survey.

Demonstration Projects Analysis: The Energy Storage Analytics team continued to perform analysis efforts for demonstration projects including Picuris Pueblo (New Mexico), Rhode Island, Isle Au Haut (Maine), North Carolina Electric Cooperatives, Hyde Park (New Mexico), Vermont Electric Coop, and Poudre Valley (Colorado).

Cooperative Research and Development Develops Tools to Help Utilities Size, Locate, and Value Energy Storage for Decarbonization: The Sandia energy storage team signed a cooperative research and development agreement (CRADA) with PNM to develop tools to help utilities size, locate, and value energy storage as they work toward decarbonization goals and mandates. Initial efforts have quantified

the variability of proposed renewable generation and the ramp rate requirements to maintain reliability. This variability will be used to estimate the quantity of energy storage required for ancillary services (e.g., frequency regulation, spinning reserve, etc.). In addition, the project team has started analyzing scenarios using an in-house production cost modeling tool known as EGRET/PRESCIENT.

Working Group Formed: In February 2021, the IEEE-SA Standards Board approved the formation of the Working Group, "Energy Storage Management Systems in Grid Applications," whose purpose is to draft a standard for recommended practice in the development and deployment of Energy Storage Management Systems (ESMS) in grid applications. David Schoenwald is the Working Group Chair, and Tu Nguyen is the Working Group Vice-Chair. This working group is currently active with regular monthly meetings. A draft of the recommended practice is expected to be ready for balloting by IEEE-SA in late 2022.

Draft Guide to Streamline the Interconnection of Energy Storage Systems with Distribution Systems: Michael Ropp co-chaired the P1547.9 Working Group. The IEEE P1547.9 "Draft Guide for Using IEEE Std 1547™ for Interconnection of Energy Storage Distributed Energy Resources with Electric Power Systems" is an all-new standard designed to streamline the interconnection of energy storage systems with distribution systems by clarifying and expanding on the application of IEEE Std 1547-2018 to energy storage. This standard was co-sponsored by Standards Coordinating Committee 21 and the Energy Storage and Stationary Batteries committee, thus bringing together power systems and energy storage subject matter experts in a way not previously done in the 1547 series of standards.

Lending Expertise to Battery Management Systems Standards and Best Practices: David Rosewater served as chair of IEEE working group 2686 - Battery Management Systems in Energy Storage Applications. The working group has developed full descriptions of battery management functions including voltage management, current management, temperature management, and charge management and has made strides this year in formulating specific recommendations on appropriately configuring a battery management system to a specific battery technology in a specific grid connected application. This work is actively building consensus and best practices for battery management design.

Other notable accomplishments in the area of analytics include:

- Strengthened Sandia's collaboration with Quanta Technology to improve distribution expansion planning for energy storage. This includes the development of a probabilistic integrated resource planning tool that will be incorporated into QuESt in 2022.
- Filed a provisional patent application for "Energy Storage-Based Packetized Delivery of Electricity" which also leverages a Laboratory Directed Research and Development project.

Demonstration Projects

Social Equity for Energy Storage: Sandia and PNNL were selected to lead the Project Development and Deployment for the DOE Social Equity for Energy Storage program. Projects for this program will be selected in alignment with the DOE's Justice40 initiative which supports disadvantaged communities affected by unreliable and expensive energy system and supplies.

Safety and Operations Training: Sandia, in collaboration with PNNL, provided safety and operations best practices training to first responders and local fire departments. In FY21, training was provided to the Decorah, IA Volunteer Fire Department for the recently commissioned Alliant Energy project and to the Red Feather Lakes & Crystal Lakes, CO Volunteer Fire Department for the Poudre Valley/NRECA project.

Advancing Energy Storage Technologies in California: Sandia entered into a Memorandum of

Understanding (MOU) with the California Energy Commission (CEC), establishing the framework for how Sandia and the CEC will coordinate to advance energy storage technologies in California. As part of this MOU, Sandia will assist CEC in a range of activities including technical evaluation of projects and performance validation of commissioned projects.

Demonstration Projects Span the US: A Sandia team is contributing to active demonstration projects in many states throughout the country. Examples include:

- Providing technical assistance with the request for proposal (RFP) and bid analysis resulting in the July 2021 commissioning and ribbon cutting of the 2.5MW, 2.9MWh Alliant Energy BESS installation in Decorah, IA, which also includes a data sharing agreement in which Sandia is receiving live, streaming BESS data which will be used to validate many laboratory level tests and theories with real-world operational data.
- Providing technical assistance for sizing, economic analysis, and project development for the four partnership projects with NRECA's Rural Energy Storage Deployment Program (RESDP). Of the four, one is complete, two are in the construction and equipment installation phase, and one is awaiting equipment delivery. Three are expected to be fully operational by late 2021 / early 2022.
- Providing technical assistance to the Alaska Village Electrical Cooperative (AVEC) project which will electrically connect two rural villages (St. Mary's & Mountain Village) together via a grid bridge system supported by a 1MW, 1MWh BESS.
- Provided technical assistance with the RFP, project development, and the project design review for the Albuquerque Public Schools' Atrisco Heritage Academy High School project. The project has completed the BESS system site design and has received the stamped and approved design drawings. The 721 kW Tesla Megapack 2 battery system has been procured and on-track for delivery June 2022.
- Providing technical assistance to Santa Fe Community College throughout their 100kW/85kWh battery energy storage system project which is successfully commissioned and ready for microgrid operations.
- The Sandia Demonstrations Projects Team is also coordinating with the college and local first responders to provide first responder safety training.

New Zinc Technology Systems Arrive for Assessment: The first of three Urban Electric Power (UEP) Zinc-Manganese Oxide 3kW/13kWh battery systems for the Navajo Tribal Utility Authority project have been delivered to the Demonstration Projects team for pre-deployment assembly and testing. The UEP system utilizes a new zinc technology that will be assessed to determine whether it is a viable replacement for the high maintenance flooded lead acid batteries currently in use in NTUA's fleet of off-grid residential solar PV/battery systems. The system is expected to be deployed in Q1 of FY22.

Policy & Outreach

Webinars Connect State Regulators with Subject Matter Experts: Sandia's Energy Storage Policy & Outreach team, led by Will McNamara and Howard Passell, provided a direct service to state commissions by hosting independent, objective, educational webinars for state regulators about energy storage issues to better equip them to make sound energy storage policy decisions and achieve clean energy goals. The team met this objective primarily through the delivery of customized workshops to state public utility commissions (PUCs) including presentations on energy storage technology, economics, and policy topics specific to the state's interests. These workshops featured subject matter experts from Sandia; other national laboratories; and representatives from industry, universities, or other regulatory bodies. See the Webinars section for details of all their PUC webinars held in FY2021.

Other Achievements & Recognitions

New Chapters Expand DOE Energy Storage Handbook: Sandia's Energy Storage Program wrote, edited, managed, and published 13 chapters for the DOE Energy Storage Handbook. The handbook is for readers interested in the fundamental concepts and applications of grid-level energy storage systems (ESSs). The handbook provides high-level technical discussions of current technologies, industry standards, processes, best practices, guidance, challenges, lessons learned, and projections about energy storage as an emerging and enabling technology.

Energy-Water Systems Integration

Effects of Droughts and Climate Change on Thermoelectric Power Plants and Reservoir Water: Sandia and collaborators have released a study highlighting the important role detailed reservoir behavior simulations can play to capture the effects of drought and climate change on thermoelectric power plants that rely on reservoir water as a source of cooling. Although a reservoir's water supply is generally more reliable than an unregulated stream or river, it can still be depleted during a severe drought—leading to curtailed power production or the threat of a power shortage. The published study explores the effects of projected climate change and drought on water storage at 30 major reservoirs in Texas. The results include key insights related to power system operations and planning and underscore the significance of accounting for reservoir behavior in planning studies.

Grid Security

Containerized Application Security for Industrial Control Systems (CAPSec): Sandia and partners have successfully demonstrated that operational technology (OT) software can be live-upgraded and live-migrated without downtime within Fort Belvoir's microgrid environment. The project, Containerized Application Security for Industrial Control Systems (CAPSec), is focused on securely upgrading, patching, and migrating software in real time for OT environments without a loss of availability. CAPSec R&D provides utilities with the ability to upgrade, patch, and migrate OT software more immediately rather than at periodically scheduled maintenance intervals. The project partners are Fort Belvoir Night Vision Electronics and Sensors Directorate, Schweitzer Engineering Laboratories, Pacific Northwest National Laboratory, and Grimm (SMFS, Inc.).

Survivable Industrial Control Systems: Sandia and several partners have successfully shown that cyber-physical threats can be automatically detected using machine learning algorithms analyzing network data and physical measurements. The project, Survivable Industrial Control Systems (ICS), is focused on automatically detecting and responding to cyber-physical threats in real time for OT environments. The Survivable ICS R&D provides utilities with the ability to automatically defend their networks against cyber-physical threats. The project is a partnership between Sandia, the Georgia Institute of Technology, the Georgia Tech Research Institute, Fort Belvoir Night Vision Electronics and Sensors Directorate, Schweitzer Engineering Laboratories, Pacific Northwest National Laboratories, and Grimm (SMFS, Inc.).

Artificial Diversity and Defense Security (ADDSec): Another Sandia collaboration has shown that cyber threats could be automatically detected using machine learning algorithms analyzing Software Defined Networking data. The threats detected were automatically mitigated using moving target defense strategies within Fort Belvoir's microgrid environment. The project, Artificial Diversity and Defense Security (ADDSec), is focused on automatically detecting and responding to cyber threats in real-time for OT environments. The ADDSec R&D provides utilities with the ability to automatically defend their networks against cyber threats. The project is a partnership between Sandia, Fort Belvoir Night Vision Electronics and Sensors Directorate (NVESD), Schweitzer Engineering Laboratories, and Grimm SMFS, Inc.

Note: Additionally, the above projects were successfully integrated into a single solution and demonstrated to the Cybersecurity for Energy Delivery Systems (CEDS) program management team within the DOE Office of Cybersecurity, Energy Security, and Emergency Response (CESER).

Software Defined Networking for Energy Delivery Systems (SDN4EDS): Sandia performed and documented a security assessment of the Software Defined Networking for Energy Delivery Systems (SDN4EDS) blueprint. Mitigation strategies were provided for each of the security findings discovered and have also been applied to commercially available SDN technologies as a result of the project. The SDN4EDS project is focused on developing a secure blueprint for deploying Software Defined Networking technologies within OT environments. The project is a partnership between Pacific Northwest National Laboratories, Sandia National Laboratories, the National Renewable Energy Laboratory, and Schweitzer Engineering Laboratories.

Digital Twins: Sandia and partners have successfully gathered experimental results comparing the performance of genetic algorithms and reinforcement algorithms on grid control algorithms. The current R&D shows that the genetic algorithms perform more accurately, while the reinforcement learning algorithms execute faster. The comparisons stem from the Digital Twin Project, which is developing reinforcement learning algorithms to detect cyber-physical threats within OT environments. The project is a partnership between Lawrence Livermore National Laboratories, Sandia National Laboratories, Oak Ridge National Laboratory, Schweitzer Engineering Laboratories, University of Toledo, and Southern California Edison.

Hardening the Electrical Grid Against Electromagnetic Pulses: Interactions between electromagnetic pulses (EMP) and the electrical grid can result in transients that can impact the operation of grid components—even to the point of component failure. A project underway at Sandia is focused on the coupling of energy from EMP to the grid, understanding the size and duration of the resulting transients that reach susceptible components, the likelihood of component failure, and mitigation strategies. Partnerships with the Department of Energy (DOE), Department of Homeland Security (DHS), and the Nuclear Regulatory Commission (NRC) are actively improving the understanding of these interactions and addressing the risks. Sandia has performed shielding effectiveness measurements at a nuclear power plant, has tested select components found in electrical generation plants, and is performing conducted susceptibility tests on components found in nuclear power plants. Information from these tests will inform decisions on how best to harden the electrical grid against EMP.

Securing Power Transmission Corridors: Sandia has delivered two assessments to further protect and secure power transmission corridors. For the effort, Sandia surveyed currently marketed technologies and provided a report on viable solutions to sense and detect intrusions. The work leverages Sandia's expertise in physically securing national assets and infrastructure.

Renewable and Distributed Systems Integration

Puerto Rico Recovery and Resilience: Sandia worked on Puerto Rico recovery and resilience under an intra-agency reimbursable work agreement (IRWA) funded by Federal Emergency Management Agency and coordinated through the DOE Office of Electricity. Sandia's work focused on a variety of topics, which included stakeholder needs for resilient energy systems, resilience node siting, microgrid design, and employing the social burden metric to optimize the impact of resilience investments. A key part of this work has been Sandia's partnership with Puerto Rican universities: the University of Puerto Rico, Mayaguez (UPRM) and Ana G. Mendez University, Gurabo (UAGM-Gurabo). These partnerships have greatly enhanced the effectiveness of the work, including stakeholder outreach and capacity building among locals. For example, Sandia provided training on its Microgrid Design Toolkit (MDT) to

22 students, most of whom then used the tool in their capstone projects. Similarly, five students and five staff members participated in training on Sandia's Resilience Node Cluster Analysis Tool (ReNCAT), and now actively use it and contribute to its ongoing development. University partners are also working closely with four communities in Puerto Rico to collect information on existing infrastructure, critical needs, and possible resilient energy solutions such as microgrids. Detailed information from these communities has included electric demand profiles, information on off-grid community water systems, and the current state of electricity service (e.g., duration and consequences of outages). All this information has greatly enhanced the process, methodology, and ultimately, the impact of the resilient energy solutions Sandia is developing.

Robust DC Microgrids: Sandia has been engaged by NASA to develop components for and simulate microgrids for NASA's proposed lunar base. NASA's proposed lunar base is composed of two main units, the Habitat (Hab) module, which will have crew living area as well as scientific labs, and the In Situ Resource Utilization (ISRU) facility, which will mine regolith for water and propellant. Initially, it is thought that these areas will be completely independent. However, as the lunar base evolves and grows, these areas will be connected via tie-line so that power and assets can be shared. As part of the Space Act Agreement between NASA and Sandia, Sandia will be focusing on: the development of a controller for ISRU-only microgrid; the development of the controller for the ISRU/Hab combined microgrid; and real-time and hardware-in-the-loop simulations of the ISRU/Hab combined microgrid.

Protection, Control, and Modeling of Low-Voltage Networks Workshop: Sandia's work to protect microgrids expanded into protecting meshed systems, such as microgrids with multiple points of interconnection, networked microgrids, and downtown low-voltage secondary network systems. In August of 2021, Sandia and Quanta Technologies hosted a workshop titled "Protection, Control, and Modeling of Low-Voltage Networks" with ComEd, ConEd, Oncor, Pepco, and BGE. The workshop presented some of Sandia's work on the protection of downtown low-voltage networks and identified other utility challenges for further research to integrate clean, resilient power generation into downtown power networks.

Resilient Operation of Networked Microgrids (RONM) Software Demonstration: In the Resilient Operation of Networked Microgrids (RONM) project, Sandia demonstrated the capability of its software to determine optimal control decisions for multiple microgrids on a model of an SDG&E system. In multiple contingency scenarios, the tool was able to reconfigure combinations of the distribution system and different microgrids to maintain operations while also ensuring constraints were met around system stability and protection. NREL and Sandia also demonstrated this sequence of events in hardware-in-the-loop (HIL) to show that the inverter controls were stable, and the relay picked up all faults based on the settings determined by RONM.

Designing Resilient Communities: The Designing Resilient Communities (DRC) project has greatly improved DOE's understanding of the connection between community needs and grid resilience planning and design approaches. The project developed a Resilient Community Design Framework which improves connectivity between communities and the grid investment planning process. A series of five reports cover various aspects of how to implement the framework, which was developed from stakeholder workshops that convened city governments, their respective electric utilities, and key stakeholders such as the National Association of Regulatory Utility Commissioners (NARUC), the World Resources Institute (WRI), and the former 100 Resilient Cities organization. Resilience metrics, which the project helped develop and validate, have been applied via technical assistance in San Juan, Puerto Rico and San Antonio, TX. Resilience metrics, such as social burden, can be used to estimate whether the grid is contributing equitably to community resilience. Distribution system design approaches and modeling techniques that advance adaptive power system protection capabilities have been evolved through DRC. These approaches and techniques help fill one of the last remaining gaps to affordable, 100% renewable, inverter-dominated microgrids.

Adaptive Protection and Control for High-Penetration PV and Grid Resilience: Sandia is involved in a project to design a scalable adaptive protection platform (APP) for distribution systems and microgrids (AC, DC, and hybrid) with high penetrations of distributed energy resources (DERs). The platform's design will incorporate software and hardware solutions that improve the selectivity and sensitivity of the underlying distribution system protection. As part of the effort, Sandia is creating local adaptive modular protection (LAMP) units, capable of communication-free operation under certain circumstances. The LAMP units, once deployed on protective Intelligent Electronic Devices (IEDs), guarantee that the protection system can operate reliably, even when extreme events occur. New, device-level protection algorithms are also being developed—as that can protect the equipment in low inertia distribution systems. Additionally, the team is creating fault location techniques suitable for traditional and inverter-based networks using time-domain samples and physics-based analysis of the transient behavior for precise and fast fault location. Sandia is working with Emera Technologies to demonstrate these new adaptive protection and relaying algorithms in their DC microgrid on Kirtland Air Force Base.

Distributed Energy Resource Cybersecurity Standards Development Project: Currently, the solar industry is operating with little application-specific guidance on how to protect and defend their systems from cyberattacks. A 3-year, Department of Energy (DOE) Solar Energy Technologies Office-funded project helped advance the distributed energy resource (DER) cybersecurity state-of-the-art by (a) bolstering industry awareness of cybersecurity concepts, risks, and solutions through a webinar series and (b) developing recommendations for DER cybersecurity standards to improve the security performance of DER products and networks. Sandia led a team designed to reduce standard and guide writing times by creating well-researched recommendations that could act as a starting place for national and international standards development organizations. Working within the SunSpec/Sandia DER Cybersecurity Workgroup, the team produced guidance for DER cybersecurity certification, communication protocol standards, network architectures, access control, and patching. The team also led subgroups within the IEEE P1547.3 *Guide for Cybersecurity of Distributed Energy Resources Interconnected with Electric Power Systems* committee and pushed a draft to ballot in October 2021.

Resilient Alaskan Distribution System Improvements Using Automation, Network Analysis, Control, and Energy Storage (RADIANCE): As part of the RADIANCE project, Sandia has performed a resilience analysis, co-authored a detailed cybersecurity plan, and built a hybrid cyber-physical digital blueprint of the Cordova system (including a new battery energy storage system) using OPAL-RT Hypersim. Sandia continues to optimize the responsiveness and efficacy of the digital blueprint. The RADIANCE project aims to perform a full-scale regional deployment of advanced technologies and methods for the regional distribution grid in the City of Cordova, AK to enhance its resilience and operations under harsh weather, cyber-threats, and dynamic grid conditions. This project has provided a significant benefit to the city of Cordova and provides a case study for other communities and grid operators to use when deploying advanced technologies and improving the resilience of their own systems.

PUBLICATIONS

Journal Publications

Advanced Grid Modeling

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- J. Johnson, R. Darbali, A. Summers, C. Hansen “Digital Twin Advanced Distribution Management System (ADMS) and Methods” Non-Provisional Patent No. 17/193,715, Filed March 5, 2021

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- S. Hossain-McKenzie, A. Summers, N. Jacobs, C.B. Jones, B. Wright, A. Chavez, J. Johnson, and J. Obert “Proactive Intrusion Detection and Mitigation System” SD-15424, April 7, 2020.
- J. Hernandez-Alvidrez, N. Gurule, M. Reno “Method of Interfacing a Grid Forming Inverter to PHIL Testbed” SD-15261, November 10, 2019.
- F. Wilches-Bernal, M. Reno, J. Hernandez-Alvidrez “A Dynamic Mode Decomposition Scheme to Detect Power Quality Events” SD-15527, July 27, 2020.

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- R.T. Elliott “The Power and Energy Storage Systems Toolbox -- PSTess v.1.0” Copyright 2021 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

Advanced Grid Modeling

- B. Pierre "Co-Optimizing Electric Grid Resilience and Reliability" Texas Energy & Security Workshop, August 2021.
- B. Pierre "Electric Grid Resilience and Reliability Co-Optimization" National Associations of State Energy Officials (NASEO): Workshop on Perspectives on Resilience, June 2021.
- Brian Pierre, "Electric Grid Resilience and Reliability Co-Optimization," Invited presentation to Hawaiian Electric on Improving Grid Resilience to Severe Storms, June 2021.
- B. Pierre "A Framework to Co-Optimize Grid Resilience and Reliability Decisions" Sandia/DOE Grid Modernization & Energy Storage Lunch and Learn sessions, April and May 2021.
- B. Pierre "Electric Grid Resilience and Reliability Co-Optimization" California Public Utility Commission Workshop on the Value of Resiliency, April 2021.
- B. Pierre "Grid Resilience Optimization while Considering Initial Transient Response and Long-Term Restoration," IEEE ISGT Panel Session, February 2021.
- B. Pierre "A Framework to Co-Optimize Grid Resilience and Reliability Decisions" Albuquerque Science & Society Distinguished Public Talks (held by IEEE and Sigma Xi Albuquerque Sections), December, 2020.
- B. Pierre "Co-Optimizing Investment Decisions for Electric Grid Resilience and Reliability" 2020 INFORMS conference, November, 2020.
- B. Pierre "Optimizing for Grid Resilience while Considering Initial Transient Impacts and Long-Term Restoration" Resilience Week Conference, October, 2020.
- R.T. Elliott and A. Alam, "WIMRG Task 2 Update: Modal Analysis of Base Cases," WECC JSIS Open Session, November, 2020.
- R.T. Elliott "Spring 2018 BPA Tests: Initial Modal Analysis Results" WECC WIMRG Open Session, January, 2021.
- R.T. Elliott "Stabilizing Transient Disturbances Using Utility-Scale Energy Storage Systems" DOE
- Cybersecurity, Energy Security, and Emergency Response: Deep Dive on Puerto Rico, March 2021.
- R.T. Elliott "A First Look at Long Range WECC Planning Cases" WECC WIMRG Open Session, April 2021.
- R.T. Elliott "A Regularized Framework for Multi-Channel Modal Analysis" NASPI Work Group Virtual Meeting, April 2021.
- D.J. Trudnowski and R.T. Elliott "WI Modes Study: IBR Modeling in Future Base Cases" NERC IRPWG Meeting, April 2021.
- F. Wilches-Bernal "Controls for Enhancing Grid Operations" presented to the IEEE and Sigma Xi Albuquerque Sections, October, 2020.

Energy Storage Technologies & Systems

- S. Atcitty "Role of Power Electronics and Wide Bandgap in Grid-tied Energy Storage Systems" South Dakota State University's PES Day, April 13, 2021.
- S. Atcitty "Native American Energy Sovereignty: Energy Storage and Power Electronic Benefits" Applied Power Electronics Conference (APEC) 2021, June 14–17, 2021.
- S. Atcitty "Role of Power Electronics and Wide Bandgap Semiconductors for Energy Storage Systems" and "Native American Energy Sovereignty: Energy Storage and Power Electronics Benefit" Missouri University Science & Technology Technical Seminar, Aug 31, 2021.
- B.R. Chalamala "Resilience Framework, Methods, and Metrics for the Electricity Sector" (Super session) IEEE Power and Energy Society General Meeting, July 27, 2021.
- B.R. Chalamala "Safety of Grid Energy Storage Systems and Training Needs" (Panel on Energy Storage Grid Integration) IEEE Power and Energy Society General Meeting, July 27, 2021.
- B.R. Chalamala "Energy Storage and Evolution of the Electric Grid: Stabilizing the RE Dominated

Utility Grid Through Storage" (Keynote) Intersolar India, Smarter E India Conference, December 10, 2020.

- B.R. Chalamala "Battery Energy Storage Technologies" (Closing Plenary) ESIG 2020 Fall Technical Workshop, November 12, 2020.
- B.R. Chalamala "Energy Storage and Evolution of the Electrical Grid" University of Texas at Arlington, Electrical Engineering Colloquium, November 6, 2020.
- B.R. Chalamala "Advances in Grid Energy Storage: Implications for Operational Energy" 3rd DoD Power and Energy Summit, National Harbor, MD, July 14, 2021.
- B.R. Chalamala "Energy Storage and the Electric Grid" AIChE 2nd Battery and Energy Storage Conference, October 22, 2020.
- B.R. Chalamala "Electric Grid Modernization – Overview" Summer School on Materials for Energy Storage and Conversion, Ankara, Turkey, September 10, 2021.
- B.R. Chalamala, V. De Angelis, E.D. Spoerke, C. Ho "Materials Technology Gaps for Low-Cost Grid Storage" 5th International Symposium on Materials for Energy Storage and Conversion, September 15, 2021.
- B.R. Chalamala "Best Practices for Bulk Energy Storage Integration in Power System" (Plenary Panel Session) 2021 IEEE PES Innovative Smart Grid Technologies Latin America (ISGT-LA), September 16, 2021.
- A.L. Frischknecht "Morphology and Ion Transport in Hydrated Ion-Containing Polymers" American Chemical Society (ACS) Fall Meeting, Atlanta, GA, August 25, 2021.
- L.A. Garcia Rodriguez, L. Gill, J. Mueller, J. Neely "A High-Voltage Cascaded Solid-State DC Circuit Breaker Using Normally-ON SiC JFETs" IEEE 12th Energy Conversion Congress & Exposition – Asia (IEEE ECCE – Asia), May 24–27, 2021.
- J.C. Hewson "Modeling and Analysis of Battery Safety" Energy Storage Systems Safety and Reliability Forum, April 20-21, 2021.
- J. Lamb "Development of DOE Energy Storage Safety Strategy Document" Energy Storage Systems Safety and Reliability Forum, April 20–21, 2021.
- J. Lamb, et al. "Evaluating the impact of Energy Density on Thermal Runaway" 239th Meeting of Electrochemical Society (ECS), May 30–June 3, 2021.
- T.N. Lambert "Recent Progress in Alkaline Zn/MnO2 Batteries" NAATBatt International Workshop on Zinc Battery Technology III, the Advanced Science Research Center at CUNY, New York, New York, November 18, 2020.
- T.N. Lambert, N.B. Schorr, D.J. Arnot, et. al. "Advances in Alkaline Conversion Batteries for Grid Storage Applications" 2021 MRS Spring Meeting & Exhibit, April 17–23, 2021.
- T.N. Lambert "Alkaline Zn-based Batteries for Grid Storage Applications" Argonne National Laboratories Stationary Storage Speaker Series, June 17, 2021.
- W. McNamara and H. Passell "Energy Storage Policy and Outreach Program" and "Peace Engineering at Sandia National Laboratories" 11th Sandia Earth Science Symposium, May 24, 2021.
- T.A. Nguyen "Maximizing the Savings for Utility Customers using Behind-the-Meter Energy Storage" Sigma Xi - Science & Society Distinguished Public Talks, University of New Mexico, October 2020.
- T.A. Nguyen "Energy Storage Technologies and Grid Services" Current Status and Development Perspectives of Solar Photovoltaic Power Technology in Vietnam, June 2021.
- T.A. Nguyen "Energy Storage Management System and Valuation" IEEE Smart Grid R&D Committee Meeting, August 2021.
- T.A. Nguyen "QuESt – An Open-source Software Application Suite for Energy Storage Evaluation" DOE Energy Storage Financing Summit, September 2021.
- Y. Preger "A Survey of the Safety of Aged Li-ion Batteries" Wards Intelligence, Focus: Electrification Conference, November 18–29, 2020.
- Y. Preger "Predictive Maintenance Practices for Operational Safety of Battery Energy Storage Systems" International Battery Seminar, March 9–11, 2021.
- Y. Preger "Degradation of Commercial Li-ion Cells Beyond 80% Capacity" Energy Storage Systems Safety and Reliability Forum, April 20–21, 2021.

- Y. Preger and J. Lamb "Battery Safety and Reliability: Tools to Understand Risk in Grid-scale Energy Storage Systems" Department of Energy Lunch and Learn.
- Y. Preger and J. Mueller "Influence of Current Ripple on Battery Degradation" at the Battery Safety Council Forum 9, November 2020, and the Interagency Power Group Chemical Working Group Safety Panel, February 2021.
- M. Ropp "IEEE P1547.9: A New Standard to Help Streamline Energy Storage Interconnection with Distribution" Energy Storage Systems Safety and Reliability Forum, April 20–21, 2021.
- D.M. Rosewater "Grid-scale Energy Storage Hazard Analysis & Design Objectives for System Safety" Energy Storage Systems Safety and Reliability Forum, April 20–21, 2021.
- E.D. Spoerke "Hydrogen's Contributions to a Clean, Long-Duration Energy Future" Western Green Hydrogen Initiative (WGHI) Virtual Summer Workshop, June 2021.
- E.D. Spoerke "Materials Chemistry in Energy Storage: A Key to Unlocking Our 'Potential' Energy Future" Fall Chemical & Materials Engineering Department Seminar, University of Kentucky, September 2021.
- U. Tamrakar "Smart Inverter Functions and Features for Power System State Estimation" live presentation and Q&A during the panel session entitled "Technological Advancements for Large Scale Adoption of Smart-Inverters" at the IEEE PES 12th Conference on Innovative Smart Grid Technologies (ISGT 2021), February 16–18, 2021.
- L. Torres-Castro "Safety Overview of Battery Energy Storage System Technologies" Resilience Week 2020, October 19-23, 2020.
- L. Torres-Castro "Are Batteries Safe?" University of Puerto Rico-Rio Piedras Seminar Series, April 7, 2021.
- L. Torres-Castro "Mitigation of Failure Propagation: A Model-Based Experimental Design" Energy Storage Systems Safety and Reliability Forum, April 20–21, 2021.
- R.D. Trevizan "Cybersecurity of Internet-of-Things-based Smart Energy Storage Systems" IEEE Power and Energy Society (PES) General Meeting, July 26–29, 2021.
- D.E. Turney "Overview of Performance and Cost of Known Technology" NAATBatt International Workshop on Zinc Battery Technology III, the Advanced Science Research Center at CUNY, New York, New York, November 18, 2020.
- R. Wittman "Overview of Aqueous Battery Safety and Reliability Concerns" Energy Storage Systems Safety and Reliability Forum, April 20–21, 2021.
- R. Wittman, H.D. Pratt III, T.M. Anderson, Y. Preger "Gas Evolution from Mixed-Acid Vanadium Redox Flow Batteries" 239th Meeting of Electrochemical Society (ECS), May 30–June 3, 2021.

Renewable & Distributed Systems Integration

- J. Johnson "Roadmap for Solar Cybersecurity" Resilience Week, October 19–22, 2020.
- J. Johnson "Securing Vehicle Charging Infrastructure" Grid Integration Tech Team (GITT) Meeting, Online, November 9, 2020.
- M. Ropp, Addressed the New Mexico Public Regulatory Commission, May 5, 2021.
- J. Johnson "DER Cybersecurity Stakeholder Engagement, Standards Development, and EV Charger Penetration Testing" IEEE Energy Conversion Congress and Exposition: 2021 Special Session on Cybersecurity for Power Electronics, Vancouver, Canada, October 10–14, 2021.
- J. Johnson "Power Hardware-in-the-Loop Research at Sandia National Laboratories: Devices-to-Systems," Panel Discussion: The Role of Power Hardware-in-the-Loop (PHIL) for the Power Systems Modernization, RT21 Conference, September 16–17, 2021.
- J. Johnson "Hardening Wind Energy Systems from Cyber Threats" DOE Wind Energy Technologies Office Peer Review, August 3, 2021.
- J. Johnson "P1547.3 Draft Guide for Cybersecurity Distributed Energy Resources Interconnected with Electric Power Systems: Subgroup 1 Update" February 23, 2021.
- J. Johnson, T. Tansy "Solar Cybersecurity Activities, Priorities, and Key Updates" National Association

of State Energy Officials (NASEO)/National Association or Regulatory Utility
- Commissioners (NARUC) Cybersecurity Advisory Team for State Solar (CATSS) Advisory Group Meeting, December 3, 2020

Technical Presentations

Advanced Grid Modeling

- M. Garcia "Convex Hull Pricing for the AC Optimal Power Flow Problem" Institute for Operations Research and the Management Sciences (INFORMS) Annual Meeting, November, 2020.
- M. Garcia "Primary Frequency Response Reserve Requirements with Application to ERCOT" FERC Software Conference, June, 2021.

Defense Energy

- J. Young, M. Cook, and D. Wilson "The Optimal Control of an Electric Warship Driven by an Operational Vignette" IEEE Electric Ship Technologies (Virtual) Symposium, ESTS 2021, Arlington, Virginia, August 3-6, 2021.
- W. Weaver (MTU), R. Robinett (MTU), D. Wilson, and S. Glover "Reduced Order Model of a Four Zone Medium Voltage DC Electric Ship" IEEE Electric Ship Technologies (Virtual) Symposium, ESTS 2021, Arlington, Virginia, August 3-6, 2021.
- R. Matthews, L. Rashkin, S. Glover, and N. Doerry (NSWCPD) "Stabilization of Generator Frequency Under Pulsed load Condition Using Regenerative Propeller Braking" IEEE Electric Ship Technologies (Virtual) Symposium, ESTS 2021, Arlington, Virginia, August 3-6, 2021.

Energy Storage Technologies & Systems

- B. Ale Magar, N. Paudel, T.N. Lambert, I. Vasiliev "Ab Initio Study of the Influence of Structural Defects on the Electrochemical Properties of MnO2 in Rechargeable Zn/MnO_2 Alkaline Batteries" Four Corners Section Meeting of the American Physical Society, October 23–24, 2020.
- B. Ale Magar, N. Paudel, T.N. Lambert, I. Vasiliev "First Principles Studies of the Cycling Mechanism of MnO_2 Modified with Bi, Cu, and Mg in Rechargeable Zn/MnO2 Batteries" March Meeting of the American Physical Society, March 15–19, 2021.
- A.M. Bates "Thermal Modeling of Liquid Electrolyte in Solid-State Batteries" Solid-State Battery Summit, August 3–4, 2021.
- J. Cho, J. Huang, G.G. Yadav, M. Nyce, M. Weiner, A. Upreti, R.J. Messinger, S. Banerjee "Electrochemical Evaluation of the Application of Hydrogel Electrolytes to Rechargeable Zn| MnO_2 Alkaline Batteries" Electrochemical Society PRiME, October 4–9, 2020.
- V. De Angelis and Yuliya Preger "BatteryArchive.org – Insights From a Public Repository for Visualization, Analysis, and Comparison of Battery Data Across Institutions" 239th Meeting of Electrochemical Society (ECS), Virtual, May 30 – June 3, 2021.
- A. Furlani Bastos, T.A. Nguyen, R.H. Byrne "Optimal Dispatch of Energy Storage Systems for Harmonic Mitigation and Power Factor Correction" 30th International Symposium on Industrial Electronics (IEEE ISIE), June 20–23, 2021.
- M.M. Gross, A.S. Peretti, S.J. Percival, L.J. Small, M. Rodriguez, E.D. Spoerke "Advancing Low-Temperature Molten Sodium Batteries by Interfacial Engineering of Ceramic Electrolytes" Electrochemical Society PRiME, October 4–9, 2020.
- M.M. Gross, A.S. Peretti, S.J. Percival, L.J. Small, M. Rodriguez, E.D. Spoerke "Engineering Ceramic Electrolyte Interfaces for Low-Temperature Molten Sodium Batteries" Materials Research Society (MRS) Spring/Fall Meeting & Exhibit, November 27 – December 4, 2020.
- M.M. Gross, S.J. Percival, R.Y. Lee, A.S. Peretti, M. Rodriguez, E.D. Spoerke, L.J. Small "High-

Performance Low-Temperature Molten Sodium Batteries Enabled by Improved Charge Transfer Across Interfaces" 2021 MRS Spring Meeting & Exhibit, April 17–23, 2021.

- J. Hernandez, A. Etemadi, S.J. Roberts-Baca, V. Koushik Muthyapu "Developing a Logistic Regression Method for Valuation of Grid-Level Energy Storage Systems" 8th IEEE Conference on Technologies for Sustainability (SusTech 2021), April 22–24, 2021.
- S. Kolhekar, S. Banerjee "Effect of KOH Concentration on Mn(III) Dissolution in Rechargeable γ-MnO_2 Cathodes" Electrochemical Society PRiME, October 4–9, 2020.
- R. Hill, Y.T. Cheng, A.S. Peretti, E.D. Spoerke, L.J. Small "Mechanical Characterization of Montmortillonite Sodium Ion Conductors" Materials Research Society (MRS) Spring/Fall Meeting & Exhibit, November 27 – December 4, 2020.
- S. Kolhekar, S. Banerjee "Effect of KOH Concentration on Mn(III) Dissolution in Rechargeable γ-MnO_2 Cathodes" Electrochemical Society PRiME, October 4–9, 2020.
- S. Kolluri, A. Subramaniam, P. Mittal, Y. Preger, K. Shah, V.R. Subramanian "Parameter Estimation of Lithi- um-ion Battery Models Using a Novel Tanks-in-Series Approach" Electrochemical Society PRiME, October 4–9, 2020.
- W. McNamara "Energy Storage: An Overview of Emerging Policies at the State Level" IEEE PES Energy Storage and Stationary Battery Committee, IEEE PES Industry Technical Support Leadership Committee, September 30, 2020.
- W. McNamara "Role of Energy Storage in Integrated Resource Planning" Center for Advanced Power Engineering Research (CAPER) Fall Meeting, November 11, 2020.
- M.L. Meyerson and L.J. Small "Mediated Lithium-Sulfur Flow Batteries for Grid-Scale Energy Storage" American Chemical Society (ACS) Spring Meeting, April 5–30, 2021.
- M.L. Meyerson and L.J. Small "Mediated Lithium-Sulfur Flow Battery for Grid-Scale Energy Storage" 239th Meeting of Electrochemical Society (ECS), May 30 – June 3, 2021.
- T.C. Monson, T. Stevens, C. Pearce, M. Hoyt, E. Vreeland, R. Delaney, S. Atcitty, B. Zheng, C. Belcher, Y. Zhou, E. Lavernia, T. Rupert "New pathways to iron nitride soft magnets" 65th Annual Conference on Magnetism and Magnetic Materials, November 2–6, 2020.
- T.C. Monson, T. Stevens, C. Pearce, M. Hoyt, E. Vreeland, R. Delaney, S. Atcitty, B. Zheng, C. Belcher, Y. Zhou, E. Lavernia, T. Rupert "New Pathways to Iron Nitride Soft Magnets" Magnetics 2021, January 19-20, 2021.
- T.C. Monson, T. Stevens, C. Pearce, M. Hoyt, E. Vreeland, R. Delaney, S. Atcitty, B. Zheng, C. Belcher, Y. Zhou, E. Lavernia, T. Rupert "New Iron Nitride Soft Magnetic Components" Applied Power Electronics Conference (APEC) 2021, June 14–17, 2021.
- N. Paudel, B. Ale Magar, T.N. Lambert, I. Vasiliev "Ab Initio Study of the Influence of Structural Defects on the Electrochemical Properties of MnO_2 in Rechargeable Zn/MnO_2 Alkaline Batteries" Four Corners Section Meeting of the American Physical Society, October 23–24, 2020.
- N. Paudel, B. Ale Magar, T.N. Lambert, I. Vasiliev "Influence of Surfaces on the Electrochemical Properties of MnO_2 in Rechargeable Zn/MnO_2 Batteries" March Meeting of the American Physical Society, March 15–19, 2021.
- S.J. Percival, R.Y. Lee, M.M. Gross, A.S. Peretti, E.D. Spoerke, L.J. Small "Electrochemistry of the NaI-$AlBr_3$ Low Temperature Molten Salt System: Implications for Applied Battery Performance" American Chemical Society (ACS) Spring Meeting, April 5–30, 2021.
- S.J. Percival, R.Y. Lee, M.M. Gross, L.J. Small, A.S. Peretti, E.D. Spoerke "Electrochemistry of the NaI-$AlBr_3$ Low Temperature Molten Salt System: Implications for Applied Battery Performance" 2021 MRS Spring Meeting & Exhibit, April 17–23, 2021.
- L.J. Small, S.J. Percival, R.Y. Lee, M.M. Gross, A.S. Peretti, E.D. Spoerke "Molten Salt Catholyte for Low-Temperature Molten Sodium Batteries" Materials Research Society (MRS) Spring/Fall Meeting & Exhibit, November 27 – December 4, 2020.
- L.J. Small, M.M. Gross, S.J. Percival, R.Y. Lee, A.S. Peretti, E.D. Spoerke "Materials Development for High-Performance Interfaces in Low-Temperature Sodium Batteries" American Chemical Society (ACS) Spring Meeting, April 5–30, 2021.

- E.D. Spoerke, M.M. Gross, S.J. Percival, R.Y. Lee, L.J. Small "Implementing Low Temperature Strategies to Advance 'Really Cool' Molten Sodium Batteries" Electrochemical Society PRiME, October 4–9, 2020.
- E.D. Spoerke, A.S. Peretti, E. Coker, M. Rodriguez, M.M. Gross, S.J. Percival, L.J. Small, R. Hill, Y.T. Cheng "Solid State Ion Conductors to Enable Low Temperature Molten Sodium Batteries" Electrochemical Society PRiME, October 4–9, 2020.
- E.D. Spoerke, A.S. Peretti, E. Coker, M. Rodriguez, M.M. Gross, S.J. Percival, L.J. Small "Solid State Materials to Enable Molten Sodium Batteries" Materials Research Society (MRS) Spring/Fall Meeting & Exhibit, November 27 – December 4, 2020.
- E.D. Spoerke, M.M. Gross, A.S. Peretti, S.J. Percival, L.J. Small "Hybrid Solid State 'Chaperone' Phases to Improve Solid State Sodium Electrolytes" 239th Meeting of Electrochemical Society (ECS), May 30 – June 3, 2021.
- L. Torres-Castro "Mitigation of Failure Propagation: A Model-Based Experimental Design" International Battery Seminar, March 9–11, 2021.
- I. Vasiliev, B. Ale Magar, N. Paudel, T.N. Lambert "Phase Transformations of the MnO_2 Cathode Material in Rechargeable Zn/MnO2 Batteries: An Ab Initio Study" March Meeting of the American Physical Society, March 15–19, 2021.
- R. Wittman "Correlating Materials Degradation Trends to Electrochemical Indicators in Systematic Long-Term Cycling of Commercial Li-Ion Batteries" 2020 ECS Fall Meeting, October 4–9, 2020.
- R. Wittman, M. Dubarry, S. Ivanov, A. Fresquez, J. Langendorf, R. Grant, G. Taggart, B.R. Chalamala, Y. Preger "Comprehensive Electrochemical and Materials Characterization of Commercial Li-ion Battery Degradation" 239th Meeting of Electrochemical Society (ECS), May 30 – June 3, 2021.
- D. Xing, C. Xie, K. Wang, T. Liu, B. Hu, J. Wang, A. Agarwal, R. Singh, S. Atcitty "3.3-kV SiC MOSFET Performance and Channel-Length Related Short-Circuit Capability" IEEE Workshop on Wide Bandgap Power Devices and Applications in Asia (WiPDA-Asia), September 23–25, 2020.

Energy & Water

- K. Klise "WNTR Briefing" to Melissa Kelmbara, virtual, May 18, 2021.
- K. Klise "WNTR Briefing" to DOE Water Power Technologies Office, EE Technical Assistance and Weatherization, June 23, 2021.

Renewable & Distributed Systems Integration

- B. Jeffers, "Social Burden and ReNCAT", California Public Utilities Commission, June 17, 2021.
- B. Jeffers, "Utility Business Innovation Network (UBIN)", May 5, 2021.

Organizational Workshops

Advanced Grid Modeling

- M. Garcia "Sandia National Laboratories: Overview of Electricity Markets Projects" Virtual presentation, February 2nd, 2021.
- Ryan Elliott presented to the WECC Western Interconnection Modes Review Group (WIMRG) on January 15, 2021.
- L. Swiler "VVUQ Best Practices in Computational Science/Engineering Problems with some thoughts about extensions to NAERM" to the NAERM Team on January 21, 2021.

Defense Energy

- B. Jeffers "Resilience Metrics for the North American Energy Resilience Model" at Western Regional Partnership - December 17, 2020.

Energy Storage Technologies & Systems

- DOE Long Duration Energy Storage Workshop, March 9–10, 2021. Team led by Erik Spoerke organized a 2-day DOE workshop on Long-Duration Energy Storage (March 9–10). The meeting dramatically exceeded expectations with over 1600 registrants, 600 participants engaging multiple DOE offices, national labs, and a collection of national and international participants in academia and industry.
- Valerio De Angelis, Session Chair for "Battery and Energy Management Needs for Lithium and non-Lithium Energy Storage Systems" IEEE Power and Energy Society (PES) General Meeting, July 26–29, 2021.
- Josh Lamb "Mitigation Strategies for Propagating Battery Failures in Pouch Cell Batteries" Interagency Power Group Chemical Working Group Safety Panel, October 2020.
- Yuliya Preger and Dr. Imre Gyuk, Organizers of the half-day tutorial "Enabling Safe Operation of Energy Storage Systems for Enhanced Resilience" for Resilience Week 2020.
- Yuliya Preger, Lead Organizer for "Symposium on Advancement of Lithium-Based High-Energy Density Batteries at Multiple Scales, Factoring in Safety" Materials Research Society (MRS) Spring/Fall Meeting & Exhibit, November 27–December 4, 2020.
- Yuliya Preger, Co-chair for Battery Student Slam Symposium at the 239th Meeting of Electrochemical Society (ECS), May 30–June 3, 2021.
- Noah Schorr, Lead Organizer for "Symposium ENO9 Advances in Conversion Electrodes for Reliable Electrochemical Energy Storage" 2021 MRS Spring Meeting & Exhibit, April 17–23, 2021.
- Erik Spoerke, Organizer for "Symposium on Ion Conducting Ceramics" American Ceramic Society's Conference on Electronic Materials and Applications (EMA), January 2021.
- Ujjwol Tamrakar, Session Chair for "TS-51: Modern Power Conversion Schemes for Electric Vehicles II" 30th International Symposium on Industrial Electronics (IEEE ISIE), June 20–23, 2021.
- R.D. Trevizan, Session Chair for "Innovation and Adoption of New Grid Technologies" IEEE PES 12th Conference on Innovative Smart Grid Technologies (ISGT 2021), February 16–18, 2021.

Grid Security

- S. Hossain-McKenzie "Enabling Online, Dynamic Remedial Action Schemes by Reducing the Corrective Control Search Space" at 2020 IEEE SmartGridComm – November 11–13, 2020.
- I. Onunkwo "Cybersecurity in Distributed Energy Resources: Threat Analysis, Interoperability, and Dynamic Defense of Energy Delivery Systems" at 2020 North America Smart Energy Week – October 28, 2020.
- A. Chavez "Dynamically Defending Operational Technology Networks" at Electric Grid Community of Practice event, February 25, 2021.

Renewable & Distributed Systems Integration

- B. Jeffers, A. Wachtel, B. Garcia, and D. Melander, ReNCAT 2.0 training to UPRM, April 2021.

WEBINARS

Advanced Grid Modeling

- M. Garcia "The Future of Grid Operations and Markets: Uncertainty Management" Industry-Wide Webinar marking the end of the Network Optimized Distributed Energy Systems (NODES) ARPA-E project, March 31, 2021.

Energy Storage Technologies & Systems

- S. Atcitty "Microgrids for Resilient Electricity Systems" DOE Office of Indian Energy's Tribal Energy webinar series, June 30, 2021.
- J. Lamb hosted "Materials Developments in Battery Safety" for an MRS webinar, May 26, 2021.
- H. Passell, et al. New Mexico Public Regulatory Commission ES Webinar Series, "Achieving NM's Carbon Free Mandate," Nov. 2020–Feb. 2021 (4-session webinar)
- H. Passell, et al. New Jersey Bureau of Public Utilities ES Webinar Series, Jan. – Mar. 2021 (4-session webinar)
- Y. Preger "Ensuring Safety of Grid-Scale Energy Storage Systems" IEEE Smart Grid, September 15, 2021.
- M. Ropp "IEEE P1547.9: A New Standard to Help Streamline Energy Storage Interconnection with Distribution" New Mexico Public Regulatory Commission Interconnection Rules Revision meeting, February 18, 2021.
- M. Ropp "IEEE P1547.9: A New Standard to Help Streamline Energy Storage Interconnection with Distribution" Northeast Council of Public Utility Commissioners DOE Energy Storage Webinar Series, May 21, 2021.
- R.D. Trevizan "Cybersecurity of Battery Energy Storage Systems," IEEE Smart Grid, March 11, 2021.

The Energy Storage Systems Policy and Outreach Program began its series of energy storage webinars with Iowa State's Electric Power Research Center and the Organization of MISO States:

- Topics in the first session held July 31, 2020, included an introduction to energy storage, an overview of energy storage systems, and an overview of energy storage policy.
- Topics in the second session held August 28, 2020, included energy storage applications and value stacking and using analytics to improve the value proposition for energy storage.
- The third session held September 11, 2020, highlighted multiple energy storage case studies.
- Topics in the fourth session held September 25, 2020, included energy storage policy and regulatory special topics.
- Topics in the fifth session held October 9, 2020, included energy storage project development and energy storage finance.
- Topics in the final session held October 23, 2020, included power systems and energy storage R&D.

The Energy Storage Systems Policy and Outreach Program continued its series of energy storage webinars with the New Mexico Public Regulation Commission (NM PRC):

- Topics in the first session held November 10, 2020, included energy storage for meeting peak load in California and Nevada and policy issues for using energy storage for peak load in New Mexico.
- Topics in the second session held December 8, 2020, included energy storage transmission and distribution (T&D) Deferral, a regulatory best practices and lessons learned roundtable, and the New Mexico policy perspective on energy storage for T&D deferral.
- Topics in the third session held January 5, 2021, included an Introduction to energy storage & electrification, understanding electric vehicle integration, electric vehicle adoption rates, and policy issues associated with electrification in New Mexico.
- Topics in the final session held February 9, 2021, included energy storage and multiple use applications, energy storage for resilience, and policy and planning for resilience.

The Energy Storage Systems Policy and Outreach Program continued its series of energy storage webinars with the New Jersey Board of Public Utilities (NJBPU):

- Topics in the first session held January 25, 2021, included Introductions to Energy Storage, Energy Storage Systems, Energy Storage Multiple Use Applications and Economics, Federal Energy Storage Policy Issues, and State Energy Storage Policy Issues.
- Topics in the second session held February 8, 2021, included an overview of Electricity Delivery Companies (EDC), a panel discussion focused on Streamlining Interconnection, and Energy Storage Safety.
- Topics in the third session held on February 22, 2021, included an introduction to energy storage cost benefit analyses, energy storage economics, information on FERC orders 841 & 2222, and policy levers for making energy storage cost effective in New Jersey.
- Topics in the final session held on March 8, 2021, included the role of energy storage in supporting overburdened communities, an overview of energy storage programs in CA, NY, & MA with an emphasis on overburdened communities, information on the CA Self Generation Incentive Program, and policies supporting energy storage for Peaker plants and impacts on overburdened communities.

The Energy Storage Systems Policy and Outreach Program continued its series of energy storage webinars with the New England Consortium of Public Utility Commissions (NECPUC):

- Topics in the first session held March 19, 2021, included an overview of state & federal energy storage policy and deployments and introductions to energy storage technologies and energy storage economics.
- Topics in the second session held April 2, 2021, included Decarbonization, Energy Storage, and Electrification; and CA-self Generation Incentive Program, Watt Time, and Getting Greenhouse Gasses out of ES.
- Topics in the third session held April 16, 2021, included the Connecticut Green Bank Report on Cost/Benefit Analysis; MA State of ES and Clean Peak Energy Standard; and CEC Programs, State Energy Agencies Roundtable.
- Topics in the fourth session held April 30, 2021, included presentations from each of the six commissions in NECPUC (CT, RI, MA, NH, ME, and VT) and reflections on the state presentations.
- Topics in the fifth session held May 21, 2021, included streamlining interconnection (IEEE P1547.9), fire safety codes, success stories, and measurable impacts.
- Topics in the sixth session held June 4, 2021, included federal policy and storage; FERC Orders 841, 2222, and 2222a; and an ISO New England Panel on Storage in Regional Markets.
- Topics in the final session held June 25, 2021, included CESA Policy Best Practices for NE States, and Energy Storage, Equity, and Resilience.

The Energy Storage Systems Policy and Outreach Program concluded its series of energy storage webinars with the Wisconsin Public Service Commission (PSC):

- Topics in the first session held April 28, 2021, included introductions to energy storage policy, technologies, and economics.
- Topics in the second session held May 12, 2021, included an introduction to energy storage benefit cost analysis and an overview of energy storage benefit cost analysis in the United States.
- Topics in the third session held May 26, 2021, included an overview of California's Self-Generation Incentive Program, getting greenhouse gases out of energy storage, and dual use policy.
- Topics in the fourth session held June 9, 2021, included project development and commissioning, interconnection and other technical issues associated with multiple use applications and energy storage system safety.
- Topics in the fifth session held June 23, 2021, included a survey of energy storage technologies spanning batteries, CAES, hydrogen, thermal, and gravity systems.

- Topics in the final session held July 14, 2021, included interconnection policy, avoiding stranded assets, energy equity and energy storage, and environmental justice.

Renewable & Distributed Systems Integration

- J. Johnson, Monthly SunSpec/Sandia DER Cybersecurity Workgroup Webinar Series, Jan–Oct 2021.

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