Transformer Resilience and Advanced Components (TRAC)

2019 Program Review Report

October 2019

U.S. DEPARTMENT OF ENERGY | OFFICE OF ELECTRICITY

Acknowledgements

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Table of Contents

List of Abbreviated Terms

AC	Alternating Current
Al	Aluminum
C	Carbon
Ca	Calcium
CLTS	Core Loss Test System
CPES	Center for Power Electronics Systems
CVSR	Continuously Variable Series Reactor
DC	Direct Current
DGA	dissolved gas analysis
DOE	U.S. Department of Energy
dV/dt	change in voltage (delta V) divided by change in time (delta t)
DVR	Dynamic Voltage Restorer
EMI	Electromagnetic Interference
ENABLE	Environmentally Neutral Automated Building Electric Energy
EPIC	Energy Production & Infrastructure Center
EPRI	Electric Power Research Institute
FACTS	Flexible Alternating Current Transmission System
FMEA	Failure Mode and Effects Analysis
FY	Fiscal Year
GE	General Electric
GMD	Geomagnetic Disturbance
GMLC	Grid Modernization Laboratory Consortium
H	Hydrogen
HV	High-Voltage
HVDC	High-Voltage Direct Current
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers

IP	Intellectual Property
kHz	Kilohertz
MCT	Modular Controllable Transformer
MEPPI	Mitsubishi Electric Power Products Inc.
MV	Medium-Voltage
MVA	MegaVolt Ampere(s)
NRECA	National Rural Electric Cooperative Association
OE	Office of Electricity
PE	Power Electronics
PI	Principal Investigator
R&D	Research and Development
RF	Radio Frequency
SAW	Surface–Acoustic Wave
SCADA	Supervisory Control and Data Acquisition
SiC	Silicon Carbide
SSPS	Solid State Power Substation
SST	Solid State Transformer
T&D	Transmission and Distribution
TAREX	Tapless Regulating Power Transformer
TRAC	Transformer Resilience and Advanced Components (program)
TS	Transient Stability
WBG	Wide Bandgap

Executive Summary

On August 13–14, 2019, the Transformer Resilience and Advanced Components (TRAC) program within the U.S. Department of Energy's (DOE's) Office of Electricity conducted its first program review at Oak Ridge National Laboratory's Hardin Valley Campus in Knoxville, Tennessee. The meeting brought together nearly 90 participants, including representatives from utilities, equipment vendors, consultancies, academia, national laboratories, and government. The review included presentations representing 24 projects within the TRAC portfolio; each presentation was provided by a member of that project's research team. A panel of 10 formal peer reviewers evaluated the projects and provided feedback.

The TRAC program supports research and development (R&D) activities that aim to advance technologies and approaches that maximize the value and lifetimes of existing grid components and enable the next generation of grid hardware to be more adaptive, more flexible, more reliable, and more cost-effective than technologies available today. Next-generation grid components can improve equipment performance and lifetimes over current designs, simplify integration of advanced technologies, and provide new capabilities required for the future grid.

The program review solicits feedback from formal peer reviewers and attendees to ensure that program activities remain centered in high-impact focus areas, thereby optimizing the use of federal resources to fill critical R&D gaps. TRAC program management will use the expert feedback to improve the program quality, and project principal investigators (PIs) will review the evaluations to improve project efforts. In addition, the review provided attendees with an opportunity to learn more about the TRAC program's vision, direction, and ongoing activities.

The TRAC program review also served as a mechanism to further solidify the advanced grid component research community. The in-person meeting provided an opportunity for researchers and industry professionals to dialogue, exchange ideas, and build connections. Having a forum for these interactions is critical to the advancement and adoption of innovative technology solutions, especially grid hardware. Lasting and effective change requires a diverse and engaged community; the TRAC program aims to catalyze and nurture this community, which spans diverse stakeholders from material scientists and system designers to equipment manufacturers and utility engineers.

The table below provides the current status, scores, and DOE comments for each of the 24 projects presented at the review.

ES-1. Consolidated Results

<table>
<tr><th>Project Title</th><th>Status</th><th>DOE Comment</th><th>Score</th></tr>
<tr><td>Models, Methods, & Tools to Analyze High Penetration of Power Electronics in Grids</td><td>Active</td><td rowspan="2">Focus the framework on tools needed to answer fundamental questions, such as PE controller interactions, and engage a broader user community (e.g., independent system operators/regional transmission organizations).</td><td rowspan="2">7.9</td></tr>
<tr><td>HVDC Models and Methods – Extension</td><td>Closed</td></tr>
<tr><td>Evaluation of Grid Equipment Design Requirements for Improved Resilience</td><td>Closed</td><td>In future proposals, consider enhancements to address the uniqueness of transmission and distribution outages and expand the range of threats.</td><td>7.7</td></tr>
<tr><td>Continuously Variable Series Reactor (CVSR) for Distribution System Applications</td><td>Active</td><td rowspan="2">Address unintended consequences (e.g., harmonics, reactive power draw) of the technology, and consider scale-up and reliability in the next phase of the effort.</td><td rowspan="2">7.9</td></tr>
<tr><td>Tapless Regulating Power Transformer (TAREX)</td><td>Active</td></tr>
<tr><td>Development of Automated Design and Optimization Tools for High-Frequency Magnetic Components and Migration to Open-Source and High-Performance Computing Environments</td><td>Active</td><td>Consider extending techniques to more complex magnetics, and develop a valuable use case to facilitate transfer to industry.</td><td>7.6</td></tr>
<tr><td>Novel Concept for Flexible and Resilient Large Power Transformers</td><td>Closed</td><td>The team should engage with utilities to refine the value proposition and implementation in future iterations of the work.</td><td>6.8</td></tr>
<tr><td>Design, Deployment and Characterization of the World's First Flexible Large Power Transformer</td><td>New</td><td>Pay attention to risks associated with the sub-projects, and find a utility partner or test platform to advance the concept beyond the prototype.</td><td>7.7</td></tr>
</table>

Project Title	Status	DOE Comment	Score
Demonstration of a 5 MVA Modular Controllable Transformer (MCT) for a Resilient and Controllable Grid	New	Consider the full range of operating risks (e.g., power electronics [PE] failure, electromagnetic interference [EMI]) and scalability challenges such as transportation. Ensure documentation of performance when testing.	7.5
Modular Hybrid Solid State Transformer for Next-Generation Flexible and Adaptable Large Power Transformer	Active	Pay close attention to the issues associated with EMI, transients, and insulation. Identify partners to help commercialize the technology as the project moves forward.	7.6
Solid-State Power Substation (SSPS) Architecture Design	Active	Engage a broader community in the effort, especially vendors, and ensure timely communication of progress and outputs.	8.4
Flexible Large Power Solid State Transformer	Closed	Follow-on efforts will need to consider grid-forming capabilities in the controls and investigate issues with insulation.	7.9
Next-Generation Modular Flexible Low-Cost Silicon Carbide (SiC)-Based High-Frequency-Link Transformer	New	The PI needs to secure intellectual property (IP) as soon as possible to improve communications and sharing of plans with the research community.	5.6
Environmentally Neutral Automated Building Electric Energy (ENABLE) Platform	Closed	In future efforts, focus on deployments, standardization, and evaluation within residential use cases to demonstrate value.	8.1
Advanced Sensors Field Validation (MagSense)	Active	Clearly identify the intended use case and value proposition to inform the sensor tuning, device packaging, and field demonstration.	6.8
GMLC SAW Sensor Field Validation	Active	Focus on improving selectivity and sensitivity. Consider issues of implementation in the field, especially by engaging transformer manufacturers and utilities.	7.8
Optical Fiber Sensor Technology Development and Field Validation for Distribution Transformer and Other Grid Asset Health Monitoring	Active	Consider acetylene for chemical sensing in future work and technology transfer opportunities for temperature sensing to other companies working in this space.	7.3
Establishment of a Medium-Voltage (MV) Core Loss Test System (CLTS) and Application-Relevant Characterization of MV Dielectric and Insulation Materials	Active	Pay attention to measurement methods for insulation testing, and consider the impact of insulation on magnetic core measurements.	7.5

Project Title	Status	DOE Comment	Score
Microstructure Optimization of Electrical Steel Through Understanding Solidification Dynamics in Additive Manufacturing	Active	The value of early-stage R&D is recognized for its ability to open new opportunities. More effort is needed to understand the metals/materials used in this process and how they can address a performance need in grid applications.	7.4
Al/Ca Composite Conductor Characterization	Active	Consider the impact of calcium sourcing on technology adoption risks, and potentially explore applications outside electric power.	8.0
Robust Insulation for Resilient Transformers and Power Electronics	New	The PI should rapidly identify use cases for transformers as well as PE applications to inform development and testing of the insulator.	7.7
Soft Magnetic Alloy Advanced Manufacturing Through In-Line RF Processing	Active	Continue to share results and engage industry and commercial partners to facilitate tech transfer.	8.6
Metal–Oxide Nanocomposite Materials for High-Frequency and High-Power Magnetics	New		
Class II High-Temperature Ceramic Capacitor Development	New	The PI should identify relevant grid-scale applications for high-temperature capacitors and address how the material can be scaled to higher voltages.	7.9

Introduction

Overview

To date, much of the “smart grid” transformation has focused on applying advanced digital information and communication technologies to the power grid to improve the system’s reliability, resilience, efficiency, flexibility, and security. To realize the full potential of a modernized grid, advances in the grid’s physical hardware are also needed. Next-generation grid components can improve equipment performance and lifetimes over current designs, simplify integration of advanced technologies, and provide new capabilities required for the future grid. The Transformer Resilience and Advanced Components (TRAC) program supports research and development (R&D) activities that aim to advance technologies and approaches that maximize the value and lifetimes of existing grid components and enable the next generation of grid hardware to be more adaptive, more flexible, more reliable, and more cost-effective than technologies available today.

On August 13–14, 2019, the TRAC program within the U.S. DOE OE conducted its first program review at Oak Ridge National Laboratory’s Hardin Valley Campus in Knoxville, Tennessee. The program was initiated in fiscal year (FY) 2016 to fill a critical gap in DOE’s R&D portfolio, drawing on opportunities identified during the 2015 Quadrennial Technology Review. Over four years, research projects across several focus areas were supported to build out a robust and diverse portfolio necessary to address program objectives. This program review was planned and executed under the direction of Dr. Kerry Cheung (DOE), the program manager for the TRAC research program since its inception.

The meeting brought together nearly 90 participants, including representatives from utilities, equipment vendors, consultancies, academia, national laboratories, and government. The review included presentations of 24 projects within the TRAC portfolio; each presentation was provided by a member of that project’s research team. For each presentation, a panel of 10 formal peer reviewers evaluated the project and provided feedback. Additionally, all attendees were given the opportunity to provide feedback on the research program through live voting, polling exercises, and follow-up surveys. This report presents the feedback received from attendees, including summaries of the research project peer evaluations and the program-level feedback. The report also details the process used for the TRAC program review.

A complete list of participants and the agenda can be found in Appendices A and B, respectively.

Purpose

The TRAC program aims to coordinate its portfolio to maximize benefits from interrelated activities. While each technology and project can provide value to the industry individually, a coordinated portfolio approach amplifies results by leveraging synergies. Program reviews are useful in assessing and evaluating a research portfolio and informing program improvements to ensure projects continue to provide value. In general, reviews are conducted routinely (e.g., every two years) to evaluate activities based on a range of criteria including scientific merit, likelihood of technical success, actual or anticipated results, and effectiveness of research management. Results from each project evaluation and program assessment feed back into program planning and portfolio management. This important process helps guide research directions, assess progress, and direct (or redirect, if necessary) resources toward the most promising technology pathways.

Program reviews also serve as a mechanism for interested parties to learn about the status and future directions of a research program. The in-person meeting provides an opportunity for researchers and industry professionals to dialogue, exchange ideas, and build connections. Having a forum for these interactions facilitates advancement and adoption of innovative technology solutions, especially grid hardware. Lasting and effective change requires a diverse and engaged community; the TRAC program aims to catalyze and nurture this community, which spans stakeholders from material scientists and system designers to equipment manufacturers and utility engineers.

Program Review Process

Prior to the program review, a panel of peer reviewers was selected and trained to perform project and program evaluations. The project evaluations were based on presentations delivered by the project principal investigators (PIs) or their designated representatives. Peer reviewers attended the review in person to observe each project presentation and established a preliminary assessment in a customized spreadsheet with notes in real time. Based on the information captured, reviewers submitted a final evaluation against pre-established criteria, along with supporting comments, within one week of the program review. The evaluation and feedback collected from peer reviewers and other attendees will be used to improve the quality of the program and individual projects.

This section provides more detail about the process.

Project Presentations

Before the review, PIs of projects were given presentation templates to ensure consistency and were informed of the established evaluation criteria. The PIs used the templates and criteria when developing their project presentations. During the review, the PI or a designated representative delivered the presentation to the review panel and other attendees who were present. After the conclusion of the review, DOE compiles the project evaluations for review and dissemination, and PIs use the feedback to improve their efforts.

Peer Reviewers

Preparing for the review involved identifying technical professionals with relevant experience and expertise to serve as reviewers for the selected projects. These reviewers were chosen based on their technical expertise in topics of relevance to the TRAC portfolio, their professional experience related to the management of technology projects, and the diversity in organizational perspectives. The final panel composition represented a broad spectrum of expertise and perspectives.

Each of the projects were evaluated by five peer reviewers, with assignments made to ensure diverse and balanced perspectives. Additionally, all assignments were investigated to ensure that no conflicts of interest existed between assigned peer reviewers and the projects that they evaluated.

Reviewers received training before the formal event to ensure complete understanding of the review objectives, consistent interpretation of the criteria, and consistent application of scoring.

Below are the 10 individuals who were selected as peer reviewers, along with their professional affiliations. Appendix C provides brief biographies of each reviewer.

- Mr. Kevin Berent, Electric Power Research Institute, Inc. (EPRI)
- Dr. Rolando Burgos, Virginia Polytechnic Institute and State University (Virginia Tech)
- Dr. Michael Ennis, S&C Electric Company
- Mr. Gene Jensen, Arcadis NV
- Dr. Madhav Manjrekar, University of North Carolina at Charlotte
- Dr. Craig Miller, National Rural Electric Cooperative Association (NRECA)
- Mr. John Paserba, Mitsubishi Electric Power Products, Inc.
- Col. (retired) Paul Roege, Typhoon HIL, Inc.
- Mr. Dennis Woodford, Electranix Corporation
- Mr. Walter Zenger, USi

Project Evaluation Criteria

The reviewers evaluated each project against pre-established criteria, developed to capture the information needed for the review's purpose. These criteria included the project's relevance to DOE and OE missions, impacts on industry, accomplishments, and management. In each area of evaluation, reviewers were asked to provide a numerical score for each project, according to the following scale:

9–10	7–8	5–6	3–4	1–2
Outstanding/ Excellent	Very good/Few areas to improve	Good/Modest/ Some areas to improve	Fair/Significant weaknesses	Poor/Not adequate

In addition, reviewers were asked to identify strengths and weaknesses associated with each criterion for each project, as well as detailing any general comments or recommendations. Descriptions for each criterion and associated weights are listed below.

Relevance and Alignment (25%)

The degree to which the project, as presented, aligns with the mission, goals, and objectives of the Office of Electricity, and the TRAC research program. Key points to consider included:

- Relevance to the OE mission and the TRAC program goals to modernize the electric grid; enhance the reliability, resilience, and security of the energy infrastructure; and improve the lifetime and performance of grid components
- The degree to which the project addresses an existing, impending, or critical problem, interest, or need in the electric power industry
- The degree of alignment to the TRAC program technology objectives

Approach and Execution (25%)

The degree to which the project, as presented, includes a clear, technically sound, and effective approach for achieving the goals and outcomes presented. Key points to consider included:

- Quality of project approach, including research plan, project execution, and relevance of research team areas of expertise
- The degree to which the project approach is free of major flaws that would limit the project's effectiveness or efficiency
- The degree to which technical or market barriers are, or have been, addressed; the quality of the project design; and technical feasibility
- The degree to which technical accomplishments are being achieved and progress is being made toward overall project goals and milestones
- If this project is continuing, the degree to which the project has effectively planned its future, defined milestones, identified risks, considered contingencies to mitigate/manage risks, built in optional paths, etc.

Significance and Impact (25%)

The degree to which the project, as presented, effectively delivers or has the potential to deliver significant value beyond its research findings. Key points to consider included:

- The degree of impact or potential impact the project has on the electricity delivery system, energy markets, or society
- The likelihood that the technology or project outcomes will become a valuable, widely accepted solution for the electric power industry
- The extent to which research findings spur or enable further innovations
- The effectiveness of technology transfer or the dissemination of results
- The degree to which collaboration with the energy industry, universities, government laboratories, states, and/or end users is being, or has been, pursued

Technical Productivity and Quality (25%)

The degree to which the project, as presented, represents a valuable and appropriate use of government financial support. Key points to consider included:

- The degree of innovation and risk associated with the project and the extent to which federal investments are justified
- The relative quality and quantity of technical accomplishments and research outcomes, realized or expected, given the amount of federal funding allocated to the project
- The extent to which project accomplishments and outcomes to date are appropriate given the resources utilized

Program Reviews

Reviewers also assessed the overall program. After the project reviews, attendees participated in an interactive discussion that allowed them to provide insights and opinions concerning the direction, management, and effectiveness of the TRAC program and the strengths, weaknesses, and specific changes that could improve the program portfolio. The section on Program-Level Feedback below details the questions, responses, and discussions that occurred during this portion of the program review.

Project Evaluations

Project Information

Research projects within the TRAC portfolio are organized into four activity areas: *Modeling and Analysis*, *Next-Generation Components*, *Monitoring and Characterization*, and *Materials and Manufacturing*. In accompaniment to this report, the TRAC "Program Overview and Project Fact Sheets" document contains detailed information pertaining to the TRAC program, program activity areas, and an overview of each of the 24 projects evaluated.[1] Some projects (three sets of two projects each) were presented and evaluated together because they had connected scopes and the same PI or research group. This section summarizes the results from the peer evaluations of the 21 presentations made.

Modeling and Analysis Projects

Modeling and analysis are important activities that can support the broader adoption of new transmission and distribution (T&D) grid component technologies. Outcomes and results from analyses can be used to answer industry's key questions regarding a new technology's viability and value, such as contributions to resilience and system upgrades and the impacts of dynamic interactions between power electronic devices and systems.

These analyses increasingly require simulation tools that leverage validated models and can assess various factors (e.g., technical, market, and policy) over a wide range of timescales (i.e., milliseconds to years) and geographic scales (i.e., devices to systems).

During the peer review, the following modeling and analysis projects were evaluated:

- Models, Methods, & Tools to Analyze High Penetration of Power Electronics in Grids
    - Suman Debnath, Oak Ridge National Laboratory
- HVdc Models and Methods – Extension
    - Madhu Chinthavali, Oak Ridge National Laboratory
- Evaluation of Grid Equipment Design Requirements for Improved Resilience
    - Bjorn Vaagensmith, Idaho National Laboratory
- Continuously Variable Series Reactor (CVSR) for Distribution System Applications
    - Zhi Li, Oak Ridge National Laboratory
- Tapless Regulating Power Transformer (TAREX)
    - Zhi Li, Oak Ridge National Laboratory
- Development of Automated Design and Optimization Tools for High-Frequency Magnetic Components and Migration to Open-Source and High-Performance Computing Environments
    - Paul Ohodnicki, National Energy Technology Laboratory

Below are summarized results from the reviews of these projects.

1. U.S. Department of Energy. Transformer Resilience and Advanced Components Program: Program Overview & Project Fact Sheets, accessed January 2, 2020, https://www.energy.gov/sites/prod/files/2020/01/f70/TRAC_Program_Fact_Sheets.pdf

Project Title: Models, Methods, & Tools to Analyze High Penetration of Power Electronics in Grids **Project Title:** HVDC Models and Methods – Extension **PI:** Suman Debnath, Oak Ridge National Laboratory	**Status:** Active Closed	**Score:** 7.90

Reviewer Comments – Strengths:	**Reviewer Comments – Weaknesses:**
• Many tools are being developed in this space. This project provides value by looking across the space and providing guidance to users. • The use of commercially available software packages within this project will enable broad use of the tools being developed. • This project does a great job pointing out the gaps in current software packages and the limitations in existing (older) interconnections. • The industry needs to keep pace with power electronics (PE) infusion to the grid, and this project helps do that. • The project demonstrated a significant improvement in productivity, with the spatial paralleling method providing the biggest boost.	• It is unclear whether the proposed techniques can be broadly applied. • It is not easy to generalize the approach. • The project gives no consideration to PE controller interactions. A gap analysis of inverter interactions was not considered. • The economic benefits of the project are not clear; this seems tangential to the main objectives specified for the project. • Is the speed-up demonstrated enough to be useful?

Reviewer Recommendations:

- The project should address difficulty in permitting, siting, and building these DC systems. These are true cost drivers for DC systems.
- Future work could include a broader treatment of modeling and simulation for assessing high penetration of inverter-based generation.
- Project results would be more widely accepted if executed in conjunction with independent system operators and regional transmission operators.
- An electromagnetic transient simulation approach seems like the best path forward for achieving the goals of this project.
- Given that new models are constantly being improved, the project should place more emphasis on a process and framework so that assessments can be maintained over time.
- There should be more emphasis on the acquisition of data, which is the largest cost in an analysis.

DOE Comment:

- Focus the framework on tools needed to answer fundamental questions, such as PE controller interactions, and engage a broader user community (e.g., independent system operators and regional transmission operators).

<table>
<tr><td colspan="2">Project Title: Evaluation of Grid Equipment Design Requirements for Improved Resilience

PI: Bjorn Vaagensmith, Idaho National Laboratory</td><td>Status:

Closed</td><td>Score:

7.70</td></tr>
<tr><td>Reviewer Comments – Strengths:

• This topic is of growing interest to utilities, and the project addresses the most vulnerable components on the grid.
• The approach taken reflects best practices from other critical sectors.
• Tools for prioritizing resilience investments will be of immense value to utilities in the future.
• With further refinement, this could be a great tool for utilities to help with their resilience planning, investments, and rate cases.
• A large question for the future is whether resilience needs will be satisfied by microgrids alone, or whether the main grid or a macrogrid will be required. This project can be helpful in that analysis.</td><td colspan="3">Reviewer Comments – Weaknesses:

• There is less value in creating a suite of tools and more value in creating a tool management framework that can incorporate diverse models.
• Many important factors are not taken into account, such as geomagnetic disturbances (GMD), load variations, and weather-dependent generation sources.
• There is not enough emphasis on data. To reduce adoption cost, tools should recognize and operate from the data representations currently in use at utilities.
• By focusing only on high-level power delivery, the project provides minimal usefulness to the end-use customer. In significant events like Superstorm Sandy, much of the transmission system stayed on or was recovered quickly.</td></tr>
<tr><td colspan="4">Reviewer Recommendations:

• This project is on the right track with respect to its focus on reliability improvements. It may be beneficial to separate end-use customer causes of outages (e.g., wind blowing trees into lines followed by equipment failure versus cars hitting poles) and animal-related outages.
• Partnering with utilities will be useful for improving the quality of the project.
• The project should consider expanding scope and breadth and consider separate focuses on distribution and transmission.
• This project is useful for getting people around the table and building a common framework for discussion and decision making.
• Simulating past events will build confidence in validation.</td></tr>
<tr><td colspan="4">DOE Comment:

• In future proposals, consider enhancements to address the uniqueness of transmission and distribution outages and expand the range of threats.</td></tr>
</table>

<table>
<tr><td colspan="2">Project Title: Continuously Variable Series Reactor (CVSR) for Distribution System Applications

Project Title: Tapless Regulating Power Transformer (TAREX)

PI: Zhi Li, Oak Ridge National Laboratory</td><td>Status:
Active

Active</td><td>Score:

7.85</td></tr>
<tr><td>Reviewer Comments – Strengths:

• This technology can help to eliminate transformer overloading on the grid.
• This has the potential for use on both the transmission and distribution systems.
• The project provides a useful comparison against currently existing solutions and includes a utility partner.
• This project proposes a method for solving network problems while reducing cost.
• This is an interesting expansion of previous work that will result in a proof-of-concept prototype CVSR.
• Eliminating tap changers could significantly reduce maintenance costs.</td><td colspan="3">Reviewer Comments – Weaknesses:

• This technology has the potential to create reactive power demand, which will impact alternating current (AC) voltage, which could lead to increased operation of voltage regulators.
• The technology may generate harmonics, which may adversely impact some loads.
• The technology requires specialized transformer designs, which are costly.
• There was no consideration of the impact a nearby AC fault could have on the DC control circuit, reducing reliability.
• The project does not consider scalability.</td></tr>
<tr><td colspan="4">Reviewer Recommendations:

• The project should include some benchmarking effort.
• Testing on larger equipment would build more confidence in the results obtained.
• The research team should investigate the product portfolio of Smart Wires and evaluate the pros and cons of the proposed approach against that organization’s technology.
• The project should move up to larger equipment for prototype testing. The range of both raising and lowering voltages with the TAREX should be more clearly demonstrated.</td></tr>
<tr><td colspan="4">DOE Comment:

• Address unintended consequences (i.e., harmonics, reactive power draw) of the technology and consider scale-up and reliability in the next phase of the effort.</td></tr>
</table>

<table>
<tr><td colspan="2">Project Title: Development of Automated Design and Optimization Tools for High-Frequency Magnetic Components and Migration to Open-Source and High-Performance Computing Environments

PI: Paul Ohodnicki, National Energy Technology Laboratory</td><td>Status:

Active</td><td>Score:

7.55</td></tr>
<tr><td>Reviewer Comments – Strengths:

• The project presented a holistic approach for magnetic modeling, design, and implementation.
• This project uses automated processing instead of classical manual design and sensitivity analysis, leading to multi-objective optimization.
• The research team has significant expertise and effectively combines multiple approaches into a single tool.
• This tool could be a key component for next generation power electronic based solutions, not just transformers</td><td colspan="3">Reviewer Comments – Weaknesses:

• It is not clear whether the method will be applicable to grid-scale transformers and magnetics; scalability is not clear.
• It was not clear whether the automated scheme presented is achievable or how this tool might eventually make its way into industrial use.
• The impact may be limited, as the work is focused on the flux density and heat dissipation of the magnetic core; winding losses are a significant and key aspect of the design of magnetic components.</td></tr>
<tr><td colspan="4">Reviewer Recommendations:

• The project should consider scalability to more complicated magnetic circuits.</td></tr>
<tr><td colspan="4">DOE Comment:

• Consider extending techniques to more complex magnetics, and develop a valuable use case to facilitate transfer to industry.</td></tr>
</table>

Next-Generation Components Projects

The future grid will need to accommodate both AC and DC sources and loads, requiring advancements in both AC and DC grid components that can help route power, optimize operations, and increase system reliability and resilience. This includes the development of advanced transformers, AC and DC power flow controllers, cables and conductors, and protection equipment. Methods to reduce costs while enhancing these components' performance and reliability can support broader deployment of these technologies. New applications, improved functionality, and added value streams can also support greater adoption.

The following next-generation components projects were evaluated:

- Novel Concept for Flexible and Resilient Large Power Transformers
    - Parag Upadhyay, ABB
- Design, Deployment, and Characterization of the World's First Flexible Large Power Transformer
    - Ibrahima Ndiaye, General Electric (GE) Global Research
- Demonstration of a 5 MVA Modular Controllable Transformer (MCT) for a Resilient and Controllable Grid
    - Deepak Divan, Georgia Tech Research Center
- Modular Hybrid Solid State Transformer for Next-Generation Flexible and Adaptable Large Power Transformer
    - Alex Huang, University of Texas at Austin
- Solid State Power Substation (SSPS) Architecture Design
    - Madhu Chinthavali, Oak Ridge National Laboratory
- Flexible Large Power Solid State Transformer
    - Subhashish Bhattacharya, North Carolina State University
- Next-Generation Modular Flexible Low-Cost Silicon Carbide (SiC)-Based High-Frequency-Link Transformer
    - Sudip Mazumder, NextWatt
- Environmentally Neutral Automated Building Electric Energy (ENABLE) Platform
    - Burak Ozpineci, Oak Ridge National Laboratory

Below are summarized results from the reviews of these projects.

<table>
<tr><td colspan="2">Project Title: Novel Concept for Flexible and Resilient Large Power Transformers

PI: Parag Upadhyay, ABB</td><td>Status:

Closed</td><td>Score:

6.80</td></tr>
<tr><td>Reviewer Comments – Strengths:

• The project has set reasonable criteria for identifying modular components and critical transformer sizes.
• The team clearly understands the need and worked within the numerous constraints of the application.
• The project considers system-level impacts, incorporating customer value proposition and reducing the number of designs.</td><td colspan="3">Reviewer Comments – Weaknesses:

• There was no clear analysis of use cases that would provide maximum utility.
• The pace of this project appears to be slow.
• This approach is potentially cost-prohibitive.
• The proposal to stack the units did not seem reasonable to industry experts.</td></tr>
<tr><td colspan="4">Reviewer Recommendations:

• More engagement with utility partners would be helpful to ensure a successful outcome for this project.</td></tr>
<tr><td colspan="4">DOE Comment:

• The team should engage with utilities to refine the value proposition and implementation in future iterations of the work.</td></tr>
</table>

<table>
<tr><td colspan="2">Project Title: Design, Deployment and Characterization of the World’s First Flexible Large Power Transformer

PI: Ibrahima Ndiaye, GE Global Research</td><td>Status:

New</td><td>Score:

7.65</td></tr>
<tr><td>Reviewer Comments – Strengths:

• The research objective is set at an appropriate scale for the problem.
• The autotransformer approach seems feasible and addresses the principal concern of available space and adjustable impedance.
• The project is led by a major supplier with significant expertise.
• The proposed solution has no solid-state converter and no external reactor. This is an integrated solution that offers variable impedance without compromising transformation voltage ratio.
• Intellectual property (IP) has already been secured for this project.</td><td colspan="3">Reviewer Comments – Weaknesses:

• New advances beyond the initial IP are not specified.
• Lack of partners, especially a utility, undermines the potential impact of the project.
• The project is still in an early stage. An actual prototype will be interesting to witness. The project seems to include several sub-projects, such as the augmented T60 (transformer protection relay), novel dissolved gas analysis (DGA), and nano-composite cooling oil. These seem to add project risk.
• It was not shown how the variability of the winding was to be achieved online.</td></tr>
<tr><td colspan="4">Reviewer Recommendations:

• The project needs to define a target device rating, based on an analysis of our nation’s fleet of large power transformers and model the large power transformer prototype toward that size and voltage range.</td></tr>
<tr><td colspan="4">DOE Comment:

• Pay attention to risks associated with the sub-projects, and find a utility partner or test platform to advance the concept beyond the prototype.</td></tr>
</table>

<table>
<tr><td colspan="2">Project Title: Demonstration of a 5 MVA Modular Controllable Transformer (MCT) for a Resilient and Controllable Grid

PI: Deepak Divan, Georgia Tech Research Center</td><td>Status:

New</td><td>Score:

7.45</td></tr>
<tr><td>Reviewer Comments – Strengths:

• The project addresses variable impedance, which seemed a major source of incompatibility among currently available transformer designs.
• This project enables volt/var control and energy storage, aiding in renewable energy integration.
• The project introduces a useful incremental approach to adding PE to transformers.
• This project may open the door to other hybrid-type PE transformers.
• The prototype size is appropriate and meaningful.
• The project has useful partners lined up, which should lead to meaningful collaboration toward a more practical, usable result.</td><td colspan="3">Reviewer Comments – Weaknesses:

• It is not clear what the scale-up path is, given that the project began recently.
• The bypass switch arrangement appeared to be a significant potential failure mode.
• Impact may be limited by need to modify the transformers, albeit a small amount.
• This seemed like an interesting twist on a dynamic voltage restorer (DVR), but otherwise it is not clear that the technology is particularly innovative.</td></tr>
<tr><td colspan="4">Reviewer Recommendations:

• To ensure success, the research team should reduce the uniqueness of the transformer design, standardizing the base transformer design as much as possible.
• The project should consider scalability up to a 50 MVA target range when designing, building, testing, and transporting the 5 MVA prototype.
• The project should consider examining the system impacts for a failure (i.e., long-term bypass) of the PE.
• The project should ensure prototype testing is done such that all benefits mentioned can be proven.
• The project should consider the impact of electromagnetic interference (EMI) and failure mode and effects analysis (FMEA).</td></tr>
<tr><td colspan="4">DOE Comment:

• Consider the full range of operating risks (e.g., PE failure, EMI) and scalability challenges such as transportation. Ensure documentation of performance when testing.</td></tr>
</table>

Project Title: Modular Hybrid Solid State Transformer for Next-Generation Flexible and Adaptable Large Power Transformer **PI:** Alex Huang, University of Texas at Austin	**Status:** Active	**Score:** 7.55

Reviewer Comments – Strengths:

- The project shows a reasonable pathway for the inclusion of solid-state devices without going to an all-solid-state design.
- This project can reduce cost and enable power flow control, if achievable.
- Taking a modular approach makes sense and builds on the already understood DVR topology.
- This project furthers the industry's understanding of means for integrating PE within the evolving grid.

Reviewer Comments – Weaknesses:

- Concerns about high-voltage (HV) transients and issues in the converter were expressed, but it was not clear which team member might have the expertise to help address these concerns.
- The project is using SiC devices but has not considered EMI and insulation design with the criticality needed; these could be showstoppers.
- None of the project partners has the necessary experience to bring this new technology to market.

Reviewer Recommendations:

- The project needs to address EMI and impacts on the transformer as well as insulation if modular solutions for large power transformers are being targeted.
- The quicker lessons learned are shared across the industry, the sooner the best solutions can be found.

DOE Comment:

- Pay close attention to the issues associated with EMI, transients, and insulation. Identify partners to help commercialize the technology as the project moves forward.

<table>
<tr><td colspan="2">Project Title: Solid State Power Substation (SSPS) Architecture Design

PI: Madhu Chinthavali, Oak Ridge National Laboratory</td><td>Status:

Active</td><td>Score:

8.40</td></tr>
<tr><td>Reviewer Comments – Strengths:
This is foundational work that appears on track to provide a “roadmap” type of output, which could be valuable.
This is broad, early-stage work, based on a solid concept, and appears to have high potential for output.
This project improves our understanding of the requirements and performance of PE building blocks.
This appears to be, appropriately, a highly collaborative project.
This project addresses current issues and is also looking ahead to the future and next steps, 2.0, 3.0, etc.</td><td colspan="3">Reviewer Comments: (Weaknesses):
The project seems too broad and complicated to complete in one year.
It can be difficult to get multiple competing vendors to work together.</td></tr>
<tr><td colspan="4">Reviewer Recommendations:
This project may require more collaboration with some external entity (e.g., a university, EPRI, etc.).
The lessons learned from this effort should be communicated—in real time—to other researchers on other projects.
The project needs to include grid-forming capabilities for inverters to avoid instabilities with excessive grid-following inverters.</td></tr>
<tr><td colspan="4">DOE Comment:
Engage a broader community in the effort, especially vendors, and ensure timely communication of progress and outputs.</td></tr>
</table>

<table>
<tr><td colspan="2">Project Title: Flexible Large Power Solid State Transformer
PI: Subhashish Bhattacharya, North Carolina State University</td><td>Status:
Closed</td><td>Score:
7.90</td></tr>
<tr><td>Reviewer Comments – Strengths:
It is good to see related follow-on work spawned from the recovery transformer (RecX) project.
This project attempts to address the size and weight issues associated with conventional transformers; these issues are cost drivers for transformers and represent a significant issue in product deployment.
The project results were commensurate with the budget.
It was very good to see that hardware was built and tested, moving beyond just theory and paper studies.</td><td colspan="3">Reviewer Comments – Weaknesses:
The scope of the project is small relative to its value.
The concept of four converters in series for a solid-state transformer needs to be rethought.
The project contains few contributions to the insulation and electromagnetic compatibility design of solid state transformers (SSTs). These topics are critical and should be addressed.
Costs were not considered, as the primary focus was on disaster recovery.
It is unclear how “useful” the findings are and how they are going to be applied.</td></tr>
<tr><td colspan="4">Reviewer Recommendations:
The project needs to ensure the converters are not grid-following, as too many of them on the grid will result in control interactions.
Insulation should be addressed somehow to provide and explore development of guidelines.
The project needs to incorporate “grid forming” capabilities to provide effective short circuit capacity without the high short circuit.</td></tr>
<tr><td colspan="4">DOE Comment:
Follow-on efforts will need to consider grid-forming capabilities in the controls and investigate issues with insulation.</td></tr>
</table>

<table>
<tr><td colspan="2">Project Title: Next-Generation Modular Flexible Low-Cost Silicon Carbide (SiC)-Based High-Frequency-Link Transformer

PI: Sudip Mazumder, NextWatt</td><td>Status:

New</td><td>Score:

5.55</td></tr>
<tr><td>Reviewer Comments – Strengths:

• This seems like a unique approach, but the presentation lacked content.
• The project uses a low-power prototype to de-risk the development effort.
• The project appears to have great potential.</td><td colspan="3">Reviewer Comments – Weaknesses:

• ABB and Eaton are listed as non-paid industry advisors. It would have been helpful to have a utility as a team member as well.
• The actual circuit topology and configuration are not disclosed since a patent has not yet been filed for the technology.
• It is not clear what the distinction of the high-frequency link is.
• Given its light topology, it is unclear that the approach could handle system faults.</td></tr>
<tr><td colspan="4">Reviewer Recommendations:

• Insufficient information was provided, making it difficult to evaluate and provide recommendations for the project.
• Only a limited amount of information could be shared because of IP concerns (pre-patent). As a result, some of the value/importance of this work might have been missed, based on the current understanding.
• The project should pay attention to practical aspects such as protection, basic impulse level, system-level control, etc.
• The concept needs to be tested by small models or valid simulation.</td></tr>
<tr><td colspan="4">DOE Comment:

• The PI needs to secure IP as soon as possible to improve communications and sharing of plans with the research community.</td></tr>
</table>

<table>
<tr><td colspan="2">Project Title: Environmentally Neutral Automated Building Electric Energy (ENABLE) Platform

PI: Burak Ozpineci, Oak Ridge National Laboratory</td><td>Status:

Closed</td><td>Score:

8.10</td></tr>
<tr><td>Reviewer Comments – Strengths:

• This project represents a comprehensive end-to-end view of energy management.
• This project is useful in that it enhances load monitoring and control of residential facilities from the grid operator standpoint.
• The developed technology is useful in that it provides an interface between a residence or business and the grid.
• The project addresses, at least on the surface, issues such as cybersecurity, power conversion, and multi-vendor designs that typically cause standardization issues.
• The project includes a fully developed prototype and demonstration.
• 3D printed heatsinks show the potential of optimizing heat exchangers in other applications.</td><td colspan="3">Reviewer Comments – Weaknesses:

• The project presents no clear cost benefit for users.
• It is not clear that this technology will effectively interact or interoperate with others.
• It is unclear whether this will profitably reduce energy costs to the residence.
• The technology still needs to be realistically evaluated.</td></tr>
<tr><td colspan="4">Reviewer Recommendations:

• As soon as possible, the project should enlist the IEEE and even international-level conversation around standardizing protocols, similar to the efforts around the now-in-place IEC-61850 for substations.
• It would be good to explore ground fault handling capabilities; especially since it is for residential use.</td></tr>
<tr><td colspan="4">DOE Comment:

• In future efforts, focus on deployments, standardization, and evaluation within residential use cases to demonstrate value.</td></tr>
</table>

Sensing and Characterization Projects

Safe, reliable, and efficient operation and management of the future grid will require high-fidelity sensors and intelligence incorporated into T&D grid components to provide actionable information on their condition and environment. Enhanced monitoring will equip components with data analysis and decision-making capabilities that will complement the advances made with the “smart grid” and impart distributed intelligence to the electrical infrastructure. Additionally, testing and characterization is a critical part of the technology development process and is necessary to assess the merit of new ideas, evaluate performance, and better understand physical phenomena. The combination of testing and model validation must be conducted hand-in-hand to build confidence in the new technology.

The following sensing and characterization projects were evaluated:

- Advanced Sensors Field Validation (MagSense)
    - Sigifredo Gonzalez, Sandia National Laboratories
- GMLC SAW Sensor Field Validation
    - Timothy McIntyre, Oak Ridge National Laboratory
- Optical Fiber Sensor Technology Development and Field Validation for Distribution Transformer and Other Grid Asset Health Monitoring
    - Paul Ohodnicki, National Energy Technology Laboratory
- Establishment of a Medium-Voltage (MV) Core Loss Test System (CLTS) and Application-Relevant Characterization of MV Dielectric and Insulation Materials
    - Paul Ohodnicki, National Energy Technology Laboratory

Below are summarized results from the reviews of these projects.

<table>
<tr><td colspan="2">Project Title: Advanced Sensors Field Validation (MagSense)

PI: Sigifredo Gonzalez, Sandia National Laboratories</td><td>Status:

Active</td><td>Score:

6.80</td></tr>
<tr><td>Reviewer Comments – Strengths:
Development of non-intrusive current sensors for abnormality and fault detection is innovative. Specifically, high-impedance faults, AC or DC, can be detected using the proposed technology.
The sensor appears to be tunable, and hence an array of sensors is possible.
This technology provides the potential for advanced detection of the circumstances that lead to catastrophic conditions.
The project has already resulted in three filed patents and many published academic papers, demonstrating its innovativeness.</td><td colspan="3">Reviewer Comments – Weaknesses:
It is not clear how this device relates to critical infrastructure or network resilience. For example, cybersecurity is mentioned, but it is unclear how this project improves cybersecurity.
It is unclear how the selectivity of the sensor was relevant to any specific phenomenon of the overhead wire's infrastructure. The selection of 100 kHz seemed arbitrary.
The test system seems like a very haphazard test location, and temperature characterization has not been performed.
The sensor package was incapable of HV installation, and there were no relevant partners for the project.</td></tr>
<tr><td colspan="4">Reviewer Recommendations:
This project could benefit from the inclusion of more illustrative information about anticipated benefits (how the technology is different from, and better than, other options) and change in outcomes.
The project team should investigate harmonic detection and alternative means to power the signal conditioning circuit (e.g., harvesting power in the line).</td></tr>
<tr><td colspan="4">DOE Comment:
Clearly identify the intended use case and value proposition to inform the sensor tuning, device packaging, and field demonstration.</td></tr>
</table>

<table>
<tr><td colspan="2">Project Title: GMLC SAW Sensor Field Validation

PI: Tim J. McIntyre, Oak Ridge National Laboratory</td><td>Status:

Active</td><td>Score:

7.75</td></tr>
<tr><td>Reviewer Comments – Strengths:

• This project has the potential to be quite helpful, if the cost is low enough to enable broad application in the field.
• The principles of operation were explained well, and the research team provided a thorough comparison against existing methods.
• The research team has a working proof of concept and a patent for the technology, which demonstrate the innovativeness of the technology and its potential for success.</td><td colspan="3">Reviewer Comments – Weaknesses:

• Questions remain regarding the lifetime of sensors in situ, as well as the effects of vibration, the expected sensor sensitivity, and other risks.
• There are concerns about the signal-to-noise rejection ratio.
• After three years, the results seem interesting but marginal, with significant improvements in sensitivity still required.
• Selectivity is clearly a question, but the PI seems sensitive to this question, and it is worthwhile to pursue answers.
• It is unclear how the signals and antennas will perform in the field when exposed to electromagnetic fields.</td></tr>
<tr><td colspan="4">Reviewer Recommendations:

• The research team would benefit from having a transformer manufacturer as a partner or adviser.</td></tr>
<tr><td colspan="4">DOE Comment:

• Focus on improving selectivity and sensitivity. Consider issues of implementation in the field, especially by engaging transformer manufacturers and utilities.</td></tr>
</table>

<table>
<tr><td colspan="2">Project Title: Optical Fiber Sensor Technology Development and Field Validation for Distribution Transformer and Other Grid Asset Health Monitoring

PI: Paul Ohodnicki, National Energy Technology Laboratory</td><td>Status:

Active</td><td>Score:

7.30</td></tr>
<tr><td>Reviewer Comments – Strengths:

• An optical fiber method for health assessment would address industry demand for monitoring technology with broad applications.
• Fiber optic materials’ immunity to EMI, non-destructive nature, resistance to harsh conditions, and low cost make them desirable for transformer applications.
• Five patent applications have been filed for this technology, and many academic papers have been filed, demonstrating the innovativeness of this approach.
• The researchers utilized an interesting application of statistics for interpreting sensor readings to optimize optics.</td><td colspan="3">Reviewer Comments – Weaknesses:

• The team took on H_2 detection rather than the more critical C_2H_2, and the project showed a very limited number of collaborators.
• It is unclear why the focus was on distribution-level vs. transmission-level transformers.
• Project success becomes more difficult because of the focus on distribution-level sensing (i.e., cost pressure is higher for distribution applications).
• Gaining wide industry acceptance may prove difficult.
• This project represents a worthwhile scientific effort and produces more industry knowledge, but the “value” of this kind of sensor on the grid (versus thermocouples or other alternatives) is questionable.</td></tr>
<tr><td colspan="4">Reviewer Recommendations:

• The project should consider looking at some of the work Hyperion is doing to embed fiber optics into transformer windings.
• It would be interesting to investigate how related technology advancement (i.e., fiber) would influence the capabilities and cost of this development.</td></tr>
<tr><td colspan="4">DOE Comment:

• Consider acetylene for chemical sensing in future work and technology transfer opportunities for temperature sensing to other companies working in this space.</td></tr>
</table>

Project Title: Establishment of a Medium-Voltage (MV) Core Loss Test System (CLTS) and Application-Relevant Characterization of MV Dielectric and Insulation Materials **PI:** Paul Ohodnicki, National Energy Technology Laboratory	**Status:** Active	**Score:** 7.50

Reviewer Comments – Strengths:	**Reviewer Comments – Weaknesses:**
• The project is well aligned, as characterization of magnetics is critical for the design of converter and grid apparatuses in general. • The project uses a strong systematic approach to assess losses under various non-sinewave excitations. • Methods developed in this project may be used in other applications, e.g., voltage insulation, improved filter design, etc. • The project presents a clear methodology with tangible output. • Efforts to distribute new results are already in place.	• It may prove difficult to test all types of relevant excitation waveforms. • It seems like the project focuses on finding incremental learning about, and improvements to, things that are already known.

Reviewer Recommendations:

- The impact of insulation design on magnetic core measurements should be considered.
- Other insulation measurement methods, such as acoustic or photon detectors, may be more appropriate to avoid the displacement currents that would be measured by any current transformer used to detect partial discharge.

DOE Comment:

- Pay attention to measurement methods for insulation testing, and consider the impact of insulation on magnetic core measurements.

Materials and Manufacturing Projects

Materials and their physical properties are fundamental to the performance of all T&D grid components. Certain properties either enable component capabilities or limit their design; these factors include electrical conductivity, dielectric strength, mechanical strength, thermal conductivity, magnetic permeability, and switching speeds of materials. Capitalizing on power system trends and addressing associated challenges will require advanced components with new materials that can overcome fundamental limitations imposed by existing materials. Additionally, manufacturing processes directly affect the physical properties of materials. Innovations in manufacturing techniques, such as roll-to-roll printing and additive manufacturing, can also be leveraged to enable the production of new designs not achievable with conventional processes.

The following materials and manufacturing projects were evaluated:

- Microstructure Optimization of Electrical Steel Through Understanding Solidification Dynamics in Additive Manufacturing
    - Alexander Plotkowski, Oak Ridge National Laboratory
- Al/Ca Composite Conductor Characterization
    - Iver Anderson, Ames Laboratory
- Robust Insulation for Resilient Transformers and Power Electronics
    - Jesse Reeves, Idaho National Laboratory
- Soft Magnetic Alloy Advanced Manufacturing Through In-Line RF Processing
    - Paul Ohodnicki, National Energy Technology Laboratory
- Metal–Oxide Nanocomposite Materials for High Frequency and High-Power Magnetics
    - Paul Ohodnicki, National Energy Technology Laboratory
- Class II High-Temperature Ceramic Capacitor Development
    - Jonathan Bock, Sandia National Laboratories

Below are summarized results from the reviews of these projects.

<table>
<tr><td>Project Title: Microstructure Optimization of Electrical Steel Through Understanding Solidification Dynamics in Additive Manufacturing

PI: Alexander Plotkowski, Oak Ridge National Laboratory</td><td>Status:

Active</td><td>Score:

7.42</td></tr>
<tr><td>Reviewer Comments – Strengths:

• The project plan conveyed an effective, incremental, step-wise approach to exploring manufacturing capabilities for power conversion applications.
• Project methods can be readily employed to heatsinks, magnetics, packaging, and a slew of other components in power converter designs. Lessons learned concerning printed metallurgy could be applied elsewhere.
• If this approach can be used for rapid replacement or more reliable/efficient devices, long-term impacts could be substantial.
• The project has five papers published, two presentations given, one patent filed, and two patent applications in process, demonstrating that the project is innovative and has impacts beyond its technical scope.</td><td colspan="2">Reviewer Comments – Weaknesses:

• It is not clear whether the purpose is to develop improved materials or new core shapes or something else.
• The project seems very exploratory, trying different methods without a good understanding of the material and how its manufacturing is accomplished.
• The team has not been able to show how the process could be scaled to achieve the objectives the researchers set for themselves.
• The project seems light on fundamentals, focusing on microstructure. It is unclear what characteristics are desirable and what current limitations/problems exist.
• The competing demands of electrical and mechanical performance could have been recognized from the beginning.</td></tr>
<tr><td colspan="3">Reviewer Recommendations:

• The research team is encouraged to focus even more on the metallurgy, the core science behind the manufacturing process.
• The technique proposed offers a particular opportunity to explore nonhomogeneous material solutions—for example, embedding carbon fibers into the mix for strength.
• The metallurgy should be addressed first; perhaps different materials may be a better match for the 3D printing process.</td></tr>
<tr><td colspan="3">DOE Comment:

• The value of early-stage R&D is recognized for its ability to open new opportunities. More effort is needed to understand the metals/materials used in this process and how they can address a performance need in grid applications.</td></tr>
</table>

<table>
<tr><td colspan="2">Project Title: Al/Ca Composite Conductor Characterization

PI: Iver Anderson, Ames Laboratory</td><td>Status:

New</td><td>Score:

8.04</td></tr>
<tr><td>Reviewer Comments – Strengths:
The research plan includes collaboration with a testing laboratory at the university, which is beneficial for success.
The project poses a clear research question, followed by a logical investigation approach.
This project has high potential to impact other applications and to simplify HVDC power lines.
Publications and patents are strong, indicating innovation and broader reach.</td><td colspan="3">Reviewer Comments – Weaknesses:
Joining the cable seems likely to be a problem since crimping it increases resistance.
The risk related to sourcing a suitable calcium powder supply remains unaddressed.</td></tr>
<tr><td colspan="4">Reviewer Recommendations:
It would be useful to investigate any effect or impact on partial discharge and the insulation system of cables.
Electric aircraft applications could be explored.</td></tr>
<tr><td colspan="4">DOE Comment:
Consider the impact of calcium sourcing on technology adoption risks, and potentially explore applications outside electric power.</td></tr>
</table>

Project Title: Robust Insulation for Resilient Transformers and Power Electronics **PI:** Jesse Reeves, Idaho National Laboratory		**Status:** New	**Score:** 7.70
Reviewer Comments – Strengths: • The project team has chosen an interesting insulation material with thermal properties applicable to multiple power apparatus types. • At this early stage, this project has high risk but potential for high reward.	**Reviewer Comments – Weaknesses:** • It is not very clear what the end result is meant to be. • The output of this project appears to apply to both large power transformers (in oil) and PE (in air), potentially diluting the objective and usefulness. • The protection against electromagnetic pulses and its use in PE are not clear.		
Reviewer Recommendations: • The project should consider accelerated life testing to advance user acceptance. • The research team should investigate dv/dt in addition to dielectric strength.			
DOE Comment: • The PI should rapidly identify use cases for transformers as well as PE applications to inform development and testing of the insulator.			

Project Title: Soft Magnetic Alloy Advanced Manufacturing Through In-Line RF Processing **Project Title:** Metal–Oxide Nanocomposite Materials for High-Frequency and High-Power Magnetics **PI:** Paul Ohodnicki, National Energy Technology Laboratory	**Status:** Active Active	**Score:** 8.55

Reviewer Comments – Strengths:	**Reviewer Comments – Weaknesses:**
• The protypes to be built and tested in this project should be valuable for advancing the state of the art. • This project has strong potential to impact the rate and cost of high-power PE device evolution. • It appears the project is beginning with scalability in mind. • The project succeeds in illustrating uncertainties in engineering and manufacturing in this domain.	• Multiple years of work are required before a product will be available.

Reviewer Recommendations:

- Though it is early, it is recommended that the researchers find a commercial partner to enable the research to become a product.
- Testing capabilities and research results would be important to share among the community; they highlight gaps in engineering, manufacturing, and quality assurance.

DOE Comment:

- Continue to share results and engage industry and commercial partners to facilitate tech transfer.

<table>
<tr><td colspan="2">Project Title: Class II High-Temperature Ceramic Capacitor Development

PI: Jonathan Bock, Sandia National Laboratories</td><td>Status:

New</td><td>Score:

7.90</td></tr>
<tr><td>Reviewer Comments – Strengths:

• The project uses a clear forensic evidence and science-based approach for finding a solution.
• The project has the potential to impact lower-power applications.
• The project could impact both existing device reliability/lifetime and especially future devices.</td><td colspan="3">Reviewer Comments – Weaknesses:

• The focus of this project is not in a range relevant for grid-scale applications.
• This approach may be cost-prohibitive because of the use of Pt.
• How widespread application and adoption would be achieved was not clear.</td></tr>
<tr><td colspan="4">Reviewer Recommendations:

• The developed technology may be applied in aircraft applications in need of high-temperature capacitors.
• It would be beneficial to scale up the device to higher voltages.
• Fabrication appears to be a constraint on material options; perhaps innovations (e.g., additive manufacturing) are possible.</td></tr>
<tr><td colspan="4">DOE Comment:

• The PI should identify relevant grid-scale applications for high-temperature capacitors and address how the material can be scaled to higher voltages.</td></tr>
</table>

Program-Level Feedback

Portfolio Assessment

To assess the TRAC portfolio at the program level, attendees were asked a series of questions to elicit feedback in five areas: (1) program relevance, (2) program focus, (3) program scope, (4) program resources, and (5) overall impressions. This section details the questions, responses, and discussions that occurred during this portion of the program review.

Program Relevance

Question One: How well do the TRAC program activity areas address industry needs?

In general, the TRAC program attempts to ground activities in industry needs. The first question asked participants about the alignment of each program activity area, supported by the projects presented, with the needs of industry. Participants rated each activity area on a scale of 1 to 5, where 1 indicates no alignment with industry needs and 5 is complete alignment. The distribution of responses is represented by the background chart on each line.

Results and Discussion:

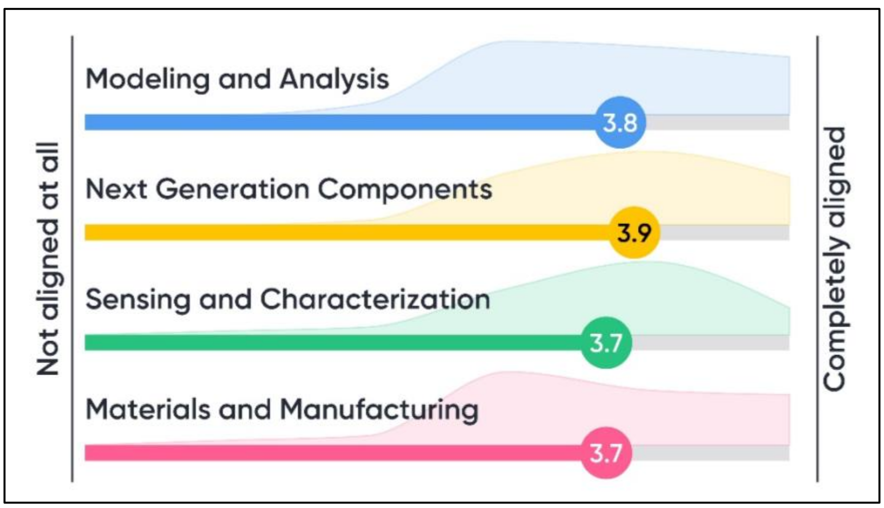

Figure 1. Results of audience poll on program relevance. Question One (n=43)

On average, all four program activity areas were rated nearly identically—between 3.7 and 3.9. *Next-Generation Components* was rated most closely aligned with industry needs, followed by *Modeling and Analysis*. Note, however, that the distribution of votes varied between technical areas. While there seemed to be general consensus around the average rating for *Next-Generation Components* and *Sensing and Characterization*, the other two areas, *Modeling and Analysis* and *Materials and Manufacturing*, showed much broader distribution in responses.

In discussion of these results, participants noted that *Modeling and Analysis* could consider how the grid will change as advanced components and other innovations work their way into the grid.

Moreover, faster devices are creating a data-rich environment, which requires new tools for modeling, characterization, and analysis. Regarding *Materials and Manufacturing*, more quantitative specifications and targets are needed to define materials performance. Without such targets, it is difficult to predict what impact materials will have.

Question Two: What activities are missing from the portfolio to address industry needs?

As a follow-up, participants were asked to identify additional topics and activity areas the program should consider beyond the four identified. Participants could submit any number of short (fewer than 25 characters) answers.

Results and Discussion:

The word cloud below depicts the responses; the font size of any one topic indicates the number of times that idea was submitted. However, only identical submissions are grouped; similar, but non-identical, submissions are displayed separately.

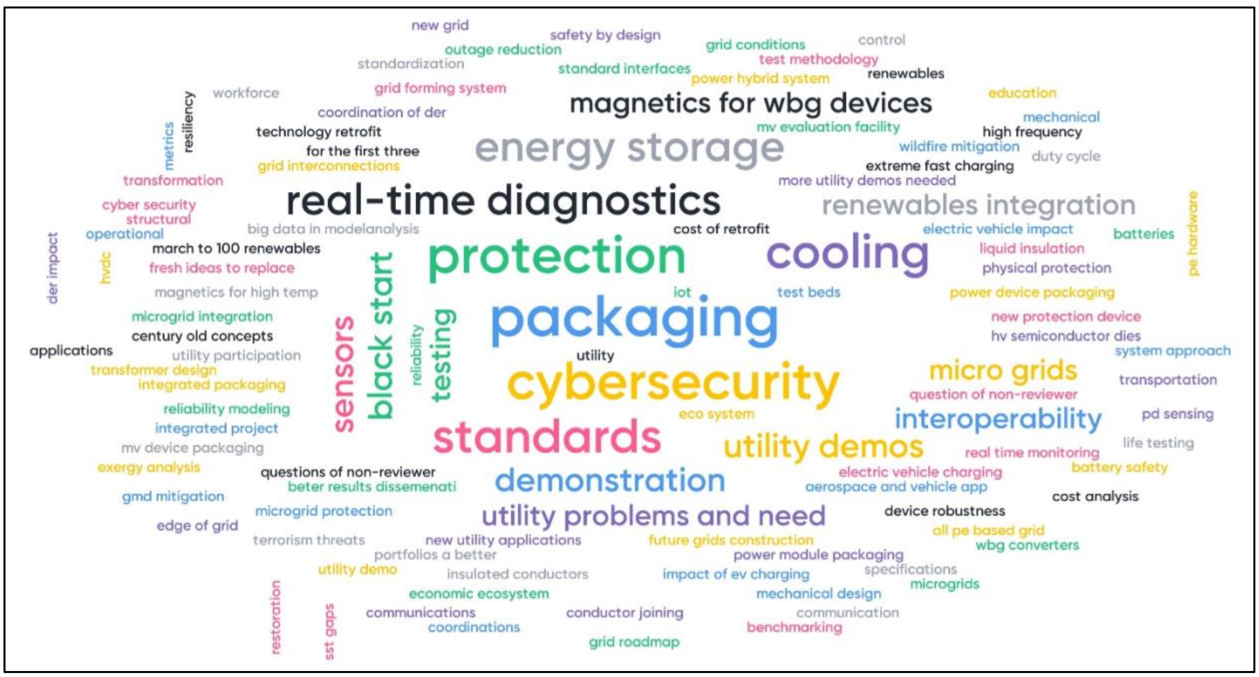

Figure 2. Word cloud results of program relevance. Question Two (n=109)

Results suggest strong interest in several key activity areas, as well as reinforcement of technologies within the TRAC program scope. There were also suggestions that fall outside the program scope but are nonetheless important to consider.

New program activities areas and aspects to consider include:

- Component design considerations, including safety, resilience, robustness, restoration, new ideas to replace old concepts (e.g., transformers), mechanical elements, and structural elements
- Standards, standardization of interfaces, specifications, and metrics
- Testing, including methods, testbeds, and benchmarking and capabilities for MV and evaluation of reliability and lifetimes

- Workface and education, including dissemination of results
- Utility engagement, including demonstrations and addressing utility problems, needs, and applications
- Threat mitigation (e.g., GMD, wildfire, terrorism) and black start
- Exploration of new grid concepts (e.g., hybrid, all PE-based) and managing the transformation (e.g., roadmapping, construction, retrofitting), including analysis (e.g., costs, interconnections, exergy) with a systems approach (e.g., ecosystem, economics, integrated projects)

Technologies to emphasize in the program include:

- Integrated PE packaging and modules for MV and high duty cycles
- PE hardware and its impacts, including wide-bandgap (WBG) converters, SSTs, and HVDC
- Real-time diagnostics of grid conditions spanning sensors, monitoring, and partial discharge
- Technologies to improve thermal management
- Insulated conductors, including joints
- New devices for physical protection
- High-temperature and high-frequency magnetics for WBG devices
- Advanced materials, including liquid insulation and HV semiconductor dies

Issues and technologies that fall outside the program scope include:

- Cybersecurity, communications interoperability, and the Internet of Things
- Energy storage, batteries, and their safety
- Transportation issues such as electric vehicle charging, extreme fast charging, and their impacts
- Microgrids, their integration, and associated protection
- Grid operational issues, including controls, coordination, protection, distributed energy resource impacts, grid edge, and 100% renewables integration
- Big data issues in modeling and analysis

In open discussion, concerns about the effect of advanced components on black-start scenarios and on resilience and restoration generally were raised. For example, after Superstorm Sandy, many “dumb” substations were restored faster than “smart” ones in part because “smart” components may require more communication with other devices. In the immediate aftermath of the storm, communications were down, so coordination during restoration was difficult. The TRAC program could illuminate options for restoration when there are no communications and no power, and enough time has passed that even battery back-ups are running down.

The lifetime reliability of new devices is still uncertain, which creates risk for utilities deploying new devices. New test protocols and certifications could support advances and mitigate this risk. Utilities also need advancements that address their needs in context. Component-centered projects all need to serve a system goal. Developing a system-level focus could help to support the direction of projects, as well as improving the portfolio as a whole.

Program Focus

Question One: Where should grid hardware R&D be focused?

For each program activity area, research projects can focus on addressing issues within the transmission system or distribution system, as well as challenges in the near term or the long term. Participants were asked to provide feedback as to the preferred focus of TRAC program activity areas, and associated projects, along these two dimensions.

Results and Discussion:

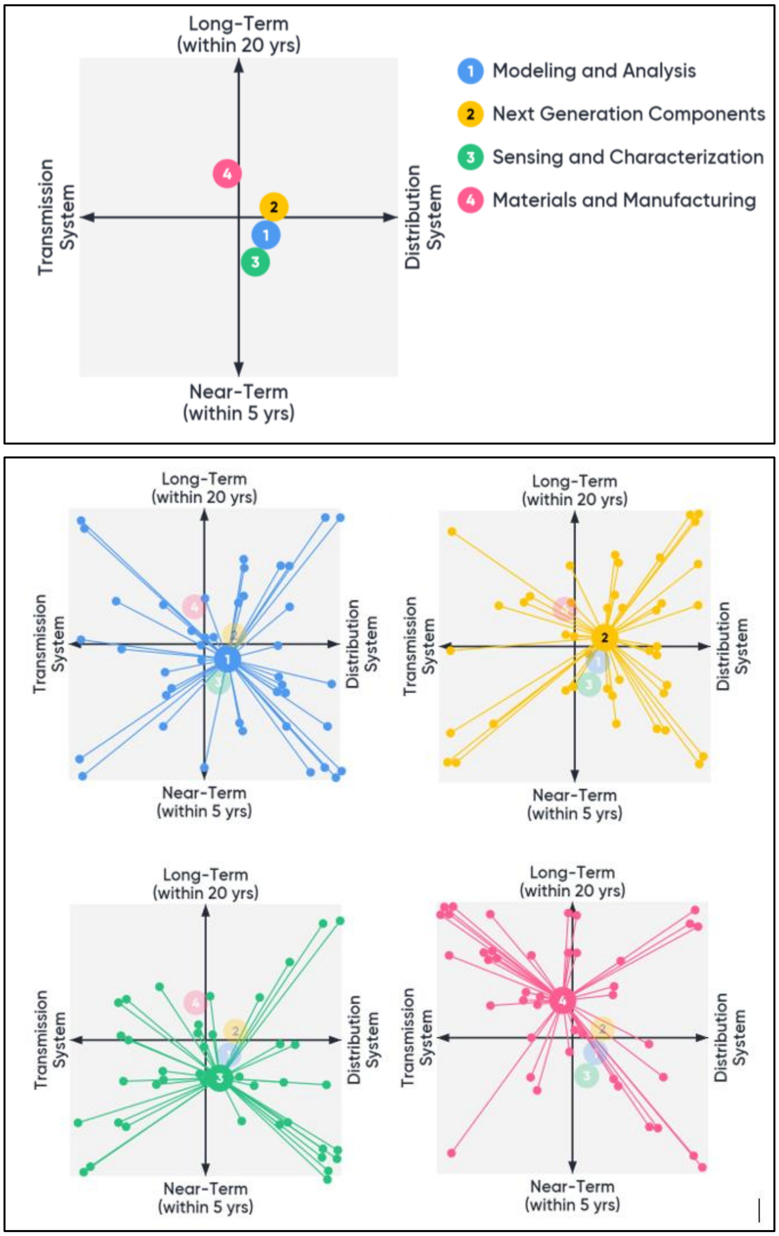

Figure 3. Top: Results of audience poll on program focus.
Bottom: Individual votes plotted for each category. Question One (n=42)

On average, results clustered around the center, indicating the need for a diverse and balanced portfolio of projects. However, *Materials and Manufacturing* and *Next-Generation Components* trended toward long-term focus, while *Modeling and Analysis* and *Sensing and Characterization* trended toward near-term focus. This result makes sense, as next-generation materials and components make more of an impact in the longer term, while sensors, monitoring, and modeling have more of an impact in the near term. Additionally, only *Materials and Manufacturing* trended toward transmission system needs, while the others leaned toward the distribution system, indicating the challenges of developing and adopting new materials in the transmission system. Individual votes, however, showed diverse opinions. Part of the reason for the spread could be tied to the diverse perspectives of the participants among the organizations they represent and their individual planning horizons.

In open discussion, participants recommended that the TRAC program focus on demonstrations, testing, and validation of prototypes. The program could spur industry with more demonstrations, specifically partnering with utilities that are willing to pilot new technologies. Such demonstrations could be enabled through successful near-term results and would support more personnel in the field willing to build and demonstrate hardware to push innovation.

While the average of the votes placed *Materials and Manufacturing* toward long-term focus, two arguments emerged in discussion. On the one hand, materials R&D takes time, so a long-term focus seems fitting. On the other hand, materials are a key input to new components. That is, near-term R&D in materials could facilitate, and may be necessary for, next-generation component development. *Modeling and Analysis* typically focuses on specific component hardware, but system modeling could help to reduce overall risks. Finally, there was a suggestion that certain efforts, like developing plans and methods for replacing any large power transformer, could be formulated like Grand Challenges initiatives to encourage multi-discipline coordination and demonstrations.

Question Two: “The program should focus on…”

Attendees were asked to indicate the level to which they agreed with four different prompts about management philosophies and approaches for the program. Responses were on a scale of 1 to 5, where 1 indicates strong disagreement and 5 represents strong agreement. The prompts, each preceded by “The program should focus on…”, and the average responses are shown below. The distribution of responses is represented by the background chart on each line.

Results and Discussion:

On average, participants most strongly agreed that the program should focus on “high-risk, high-reward technologies,” closely followed by “issues not actively addressed by industry” and “developing foundational research capabilities.” These results are aligned with the general perceived role for federal support in the R&D enterprise. Participants, on average, neither agreed nor disagreed with the focus on “technology commercialization efforts.” However, the distribution of individual results varied substantially across the prompts.

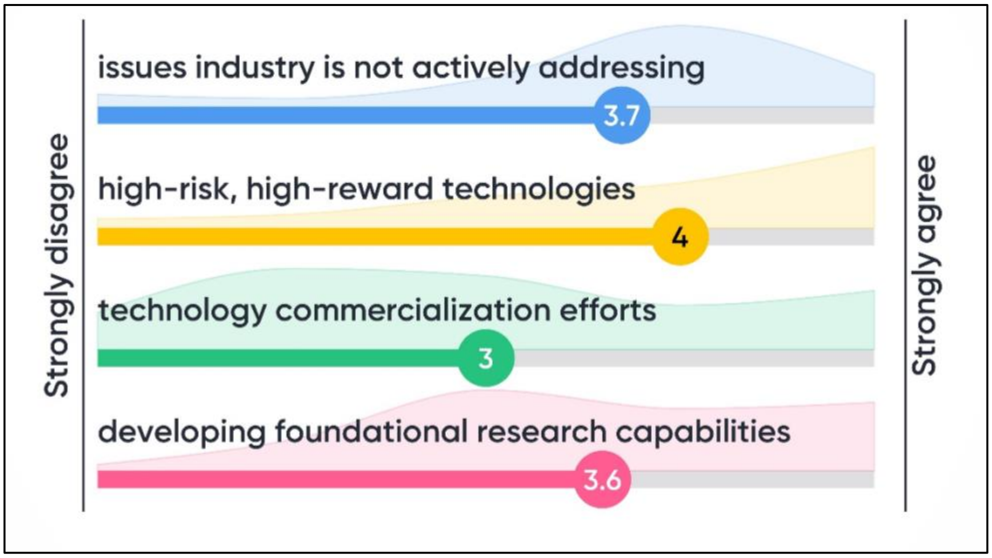

Figure 4. Results of audience poll on program focus. Question Two (n=41)

The modal (i.e., most popular) response to focusing on “high-risk, high-reward technologies” was “strongly agree,” and some participants stated that greater risks could be taken. In general, neither the program nor the funded researchers want or expect their research efforts to fail, but a lack of failed projects could indicate insufficient risk-taking. It was suggested that projects that do not reach their goals still need to publish results.

“Issues industry is not actively addressing” drew some consensus, in accordance with the average score of 3.7, while “developing foundational research capabilities” saw less consensus despite garnering a similar average score (3.6). Regarding the latter topic, participants expressed concerns about duplicating capabilities already existing in the private sector or in other organizations.

“Technology commercialization efforts” received a broad distribution of votes, though “disagree” was the most frequent response. Fundamental tension exists around commercialization efforts by government programs. On the one hand, DOE should not compete with industry and focus on funding R&D, which industry will enact if the targeted outcome meets an industry need. On the other hand, impact is greatest at the commercialization stage, which therefore warrants some focus. Other suggestions during discussion were to focus more on partnering with industry on research to encourage adoption and on knowledge sharing and outreach.

Program Scope

Question One: Which components/technologies are most important for the TRAC program to invest in?

With respect to program scope, participants were asked to vote for up to three components/ technologies from the list presented. This question was meant to solicit responses to provide a sense of prioritization for the different technologies that fall within the TRAC program scope. “Other” was not listed as a response option.

Results and Discussion:

Three tiers emerged in the results. SSTs, advanced materials, and large power transformers comprise the first tier, followed by asset monitoring, distribution power flow controllers, and MVDC converters. These results align fairly well with the current program portfolio and the planned research directions moving into the future.

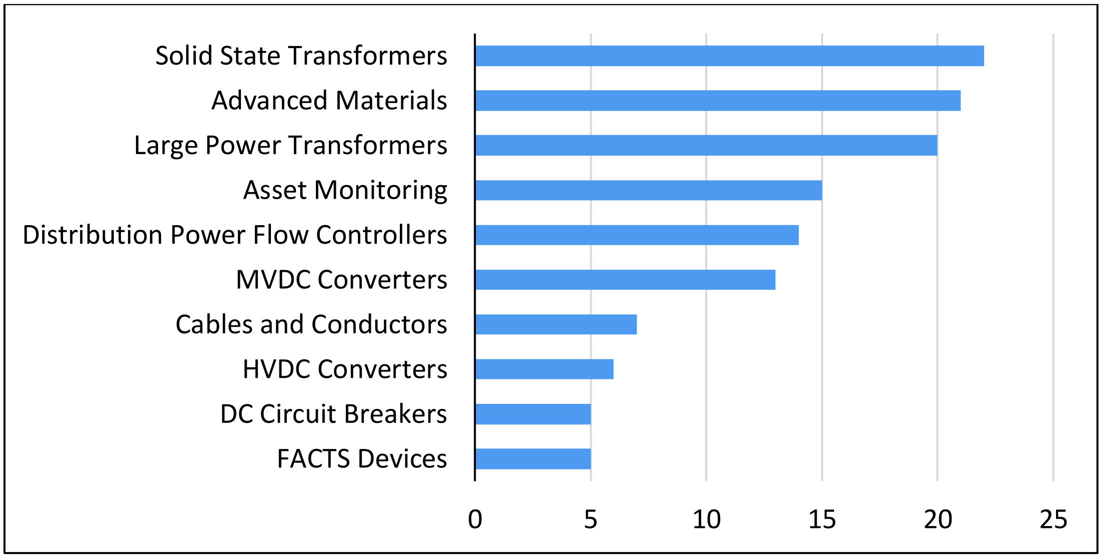

Figure 5. Results of audience poll on program scope. Question One (n=43)

Question Two: What other components/technologies should the TRAC program be investing in?

As a follow-up, participants were asked to suggest additional components and technologies (beyond those identified in the previous question) the TRAC program should consider for investments. Participants could submit short (fewer than 25 characters) answers without limit.

Results and Discussion:

The word cloud below depicts the responses; the font size of any one topic indicates the number of times that idea was submitted. However, only identical submissions are grouped; similar, but non-identical, submissions are displayed separately.

Results suggest strong interest in several key activity areas, as well as reinforcement of technologies within the TRAC program scope. There were also suggestions that fall outside the program scope but are nonetheless important to track and consider.

Results are similar to the word cloud under program relevance, but the emphasis is different.

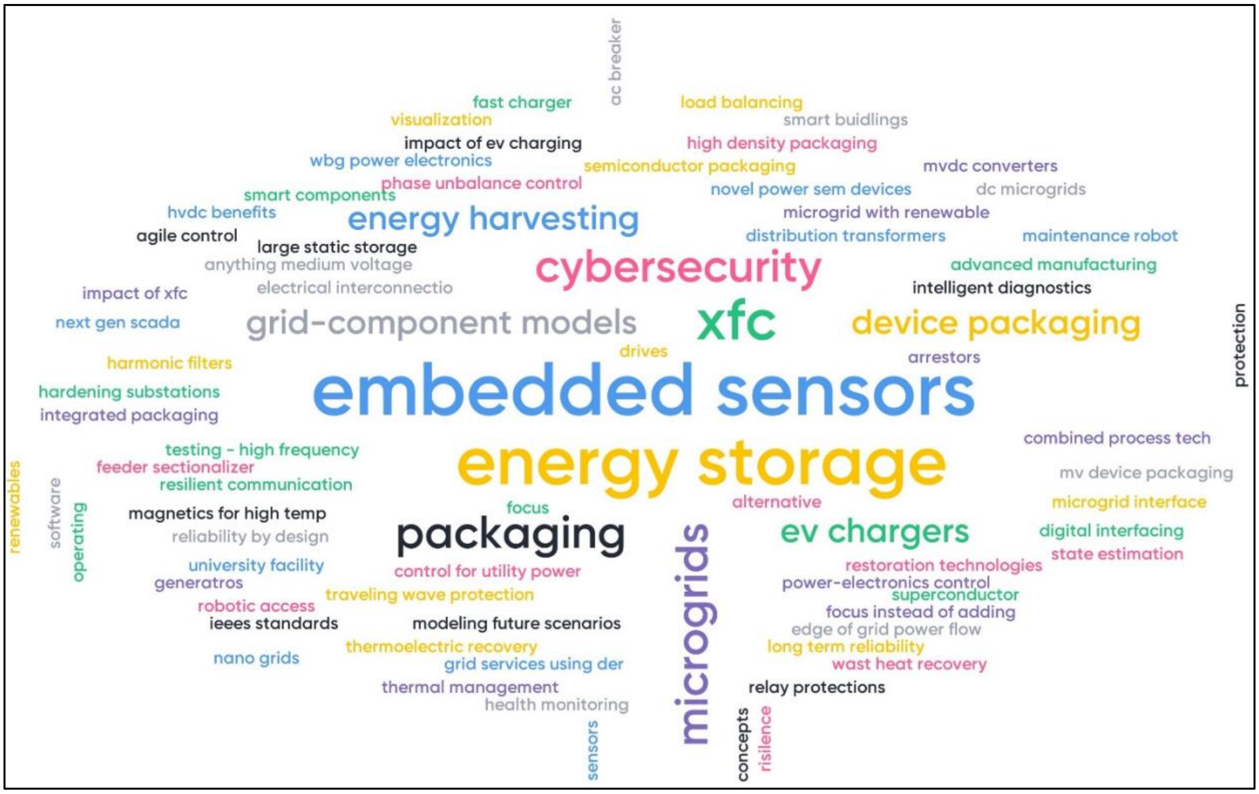

Figure 6. Results of audience poll on program scope. Question Two (n=77)

Technologies to consider or emphasize in the program include:

- MV technology, including DC converters and integrated, high-density semiconductor device packaging
- Advanced materials including power semiconductors, magnetics for high temperatures, and super conductors
- Embedded sensors for smart components, health monitoring, and intelligent diagnostics
- Distribution controllers and transformers to address phase unbalance, load balancing, sectionalizing, and edge of grid power flow, including PE-based technologies
- Protection equipment, including arrestors, AC breakers, harmonic filters, and hardening of substations
- Interface technologies that support electrical and digital interconnections (e.g., microgrids)
- Restoration technologies

Technology aspects to consider in the program include:

- Grid component models as well as modeling future scenarios (e.g., HVDC benefits)
- Alternative concepts including robotics and their application to maintenance
- Resilience and reliability by design
- IEEE standards and other standards
- Long-term reliability, including testing at higher frequency and thermal management

Technologies that fall outside the program scope include:

- Electric vehicle chargers, including extreme fast charging
- Microgrids, including DC microgrids, nanogrids, and all-renewables
- “Software” technologies such as state estimation, next-generation SCADA, and visualization
- Energy storage (e.g., large, static)
- Protection methods and relays
- Energy harvesting (e.g., thermoelectric, waste heat) and combined process technologies
- Generators, renewables, smart buildings, and grid services with distributed energy resources
- Cybersecurity and resilient communications
- Advanced manufacturing techniques and industrial drives

While energy storage is featured prominently in the word cloud, the technology is addressed by other programs in DOE and OE. However, the TRAC program should address the interface between energy storage and the grid since there are multiple storage options and control methods with vastly different implications, ranging from the grid services provided (e.g., frequency response or voltage regulation) to new cybersecurity concerns. Additionally, the loss of inertia as the grid transitions to inverter-based power will have consequences, as inertia provides inherent stability to grid operations.

Embedded sensors and energy storage will be necessary for more advanced, active control. However, integrating new hardware and controls will require demonstration. Advanced sensing and measurement can allow for use of capacity in components, which was previously disregarded. Additionally, electric vehicle fast charging could require changes in infrastructure that the TRAC program should investigate. SSTs integrated with energy storage could address the impact of extreme fast charging on the grid and provide an essential step in a roadmap for near-term deployment of SSTs.

Program Resources

Attendees provided feedback on TRAC program resources. Participants began by reviewing historic funding profiles, including their breakdown into topic areas (see Figure 7). In addition to the four main program activity areas (*Modeling and Analysis*, *Next-Generation Components*, *Sensing and Characterization*, and *Materials and Manufacturing*), program resources were also used to support projects under the Grid Modernization Laboratory Consortium, DOE’s Small Business Innovation Research/Small Business Technology Transfer program, and other activities. After reviewing the budgetary information, participants were invited to respond to the following questions.

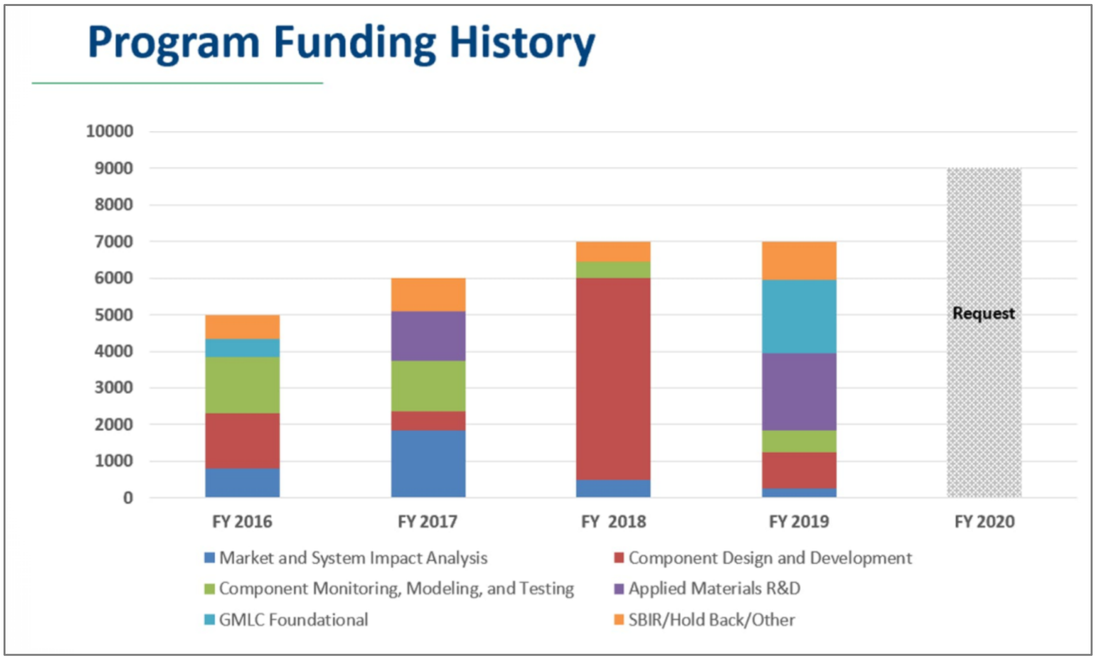

Figure 7. TRAC program funding history, FY 2016–2020 (in thousands of dollars)

Question One: What level of federal funding is necessary to adequately address outstanding grid hardware needs?

To gauge the level of effort required to adequately address industry needs, participants were asked to identify the level of federal funding they felt was needed to support R&D, demonstrations, pilot projects, deployments, and other activities necessary to advance grid hardware technologies. Participants were asked to select a single option ranging from less than $50 million per year to more than $250 million per year.

Results and Discussion:

The responses suggest a Gaussian distribution around the peak at $100 million per year with a long tail on the high side (more than $250 million per year). There were 20 votes (50%) for funding higher than this peak and only 12 votes (30%) for funding lower than the peak. This result indicates that, in addition to current TRAC program funding levels, more resources are needed to sufficiently address the challenges associated with next-generation grid hardware.

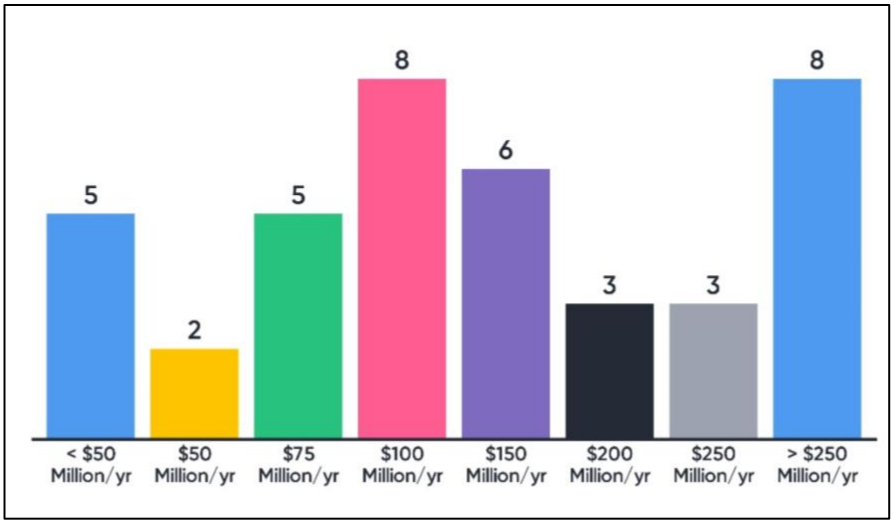

Figure 8. Results of audience poll on program resources. Question One (n=40)

Question Two: In an ideal portfolio, how would you spread resources?

In this exercise, participants were asked to determine, from the perspective of a program manager, how best to distribute funding resources across the four program activity areas and an "Other Activities" category. The goal was to solicit input on the relative distribution of resources that participants felt would provide a well-balanced research portfolio.

Results and Discussion:

Participants collectively dedicated one-third of program funding to *Next-Generation Components*; "Other Activities" received the least amount of funding at 6%. The average weight given to each category is displayed in Figure 9 below.

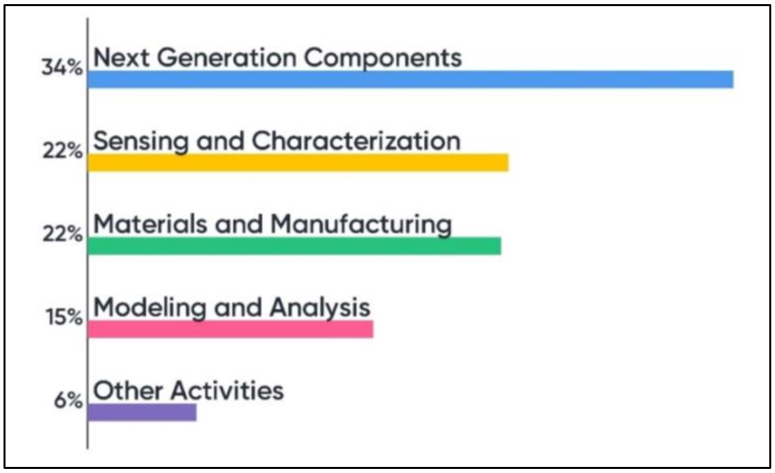

Figure 9. Results of audience poll on program resources. Question Two (n=41)

Overall Impression

Question One: "Overall Impression: The TRAC program…"

To capture participants' overall impression of the TRAC program, participants were asked to indicate the level to which they agreed with four different prompts about the program. Responses were on a scale of 1 to 5, where 1 indicates strong disagreement and 5 represents strong agreement. Each prompt was preceded by "Overall Impression: The TRAC program…".

Results and Discussion:

"Strongly agree" was the modal response about the program's *uniqueness*, its *value to industry*, and its *balance and management*. The percentage of positive ratings (either "agree" or "strongly agree" as a percent of all submitted responses) for each of these metrics was 73%, 83%, and 83%, respectively, demonstrating strong agreement with all three prompts. The one area where the TRAC program could improve lies in *engaging stakeholders*, as the modal response was "neither agree nor disagree." However, the percentage of positive ratings was 55%, indicating that, although the modal response was neutral, it was outweighed by positive responses once "agree" and "strongly agree" are added together. Results indicate that, although this may be the weakest of the four areas, the program still does a decent job of engaging stakeholders.

The average responses are shown in Figure 10. The distribution of responses is represented by the background chart on each line.

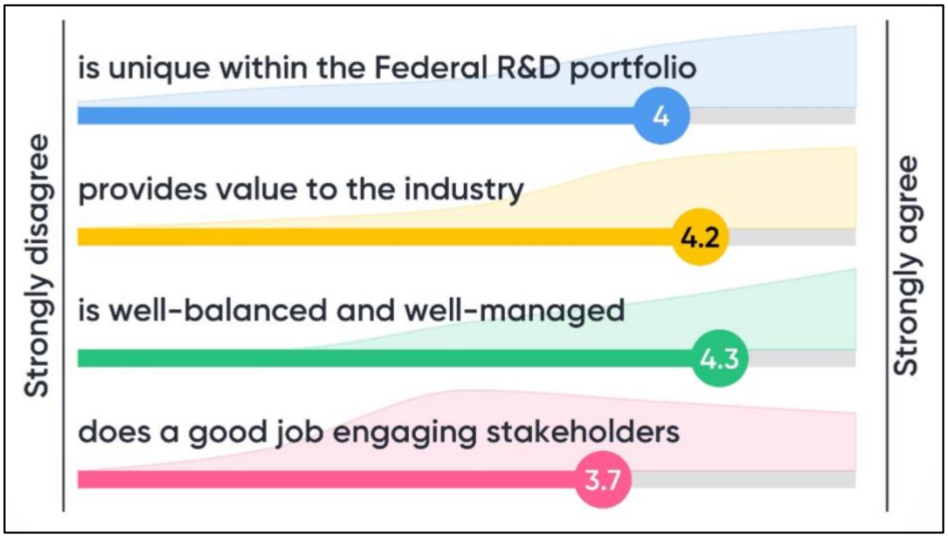

Figure 10. Results of audience poll on overall program impression (n=42)

Regarding stakeholder engagement, one concern related to the immediate circumstances; participants noted that greater utility representation, including investor-owned utilities, should have been sought for the program review. Similarly, public service commissioners or their staff members would also be useful for review of program activities. That said, the TRAC program's principal stakeholders may be not the utilities but rather the equipment producers who would incorporate TRAC program results into their grid components.

Other comments suggested ways to formalize industry feedback. A formal request for information process could help with gathering industry feedback in a well-documented process and could expand the base of utility participants. Individual funded projects could have industry advisory boards to provide ongoing feedback and perhaps be involved in reviews. Industry feedback could also be shared with DOE in quarterly reports. Finally, participants noted that knowledge sharing is key. The TRAC program should actively share reports and outcomes with interested utilities.

Appendix A. List of Participants

Iver Anderson, Ames Laboratory

Stan Atcitty, Sandia National Laboratories

Tolga Aytug, Oak Ridge National Laboratory

Aaron Bain, Tennessee Tech University

Juan Carlos Balda, University of Arkansas

Arthur K. Barnes, Los Alamos National Laboratory

Kevin Berent, EPRI

Subhashish Bhattacharya, North Carolina State University Freedom Systems Center

Jonathan Bock, Sandia National Laboratories

Sanjay Bose, US Department of Energy

Rolando Burgos, Virginia Tech

Klaehn Burkes, Savannah River National Laboratory

Kerry Cheung, US Department of Energy

Madhu Chinthavali, Oak Ridge National Laboratory

David Cooper, Southwire Company

Robert T. Dawsey, Flex Power Control

Suman Debnath, Oak Ridge National Laboratory

Ryan Dehoff, Oak Ridge National Laboratory

Aleks Dimitrovski, University of Central Florida

Keith Dodrill, U.S. Department of Energy, National Energy Technology Laboratory

Chad Eckhardt, Ermco-Gridbridge

Ayman El-Rafaie, Marquette University

Michael G. Ennis, S&C Electric Company

Johan Enslin, Clemson University

Jeffrey A. Fleeman, American Electric Power

Vahan Gevorgian, National Renewable Energy Laboratory

Sigifredo Gonzalez, Sandia National Laboratories

Charles J Hanley, Sandia National Laboratories

Eric Hsieh, US Department of Energy

Alex Qin Huang, University of Texas at Austin

Gene Millard Jensen, Arcadis

Peng Jin, Peking University Shenzhen Graduate School

Ray Johnson, EPB – Chattanooga

Ken Keels, North American Transmission Forum

Thomas King, Oak Ridge National Laboratory

Maciej Kumosa, University of Denver

Olga Lavrova, New Mexico State University

Dominic Fred Lee, Oak Ridge National Laboratory

Zhi Li, Oak Ridge National Laboratory

Madhav Manjrekar, University of North Carolina at Charlotte

Sudip K. Mazumder, Nextwatt LLC

Scott McCall, Lawrence Livermore National Laboratory

Tim Mcintyre, Oak Ridge National Laboratory

James McIver, Siemens Transformer

Omar Mendez, Prolec GE

Craig Miller, National Rural Electric Cooperative Association (NRECA)

Scott Morgan, Energetics, A Division of Akimeka LLC

Ibrahima Ndiaye, GE Research

Paul Ohodnicki, U.S. Department of Energy, National Energy Technology Laboratory

Burak Ozpineci, Oak Ridge National Laboratory

Zach Pan, ABB Inc.

Parans Paranthaman, Oak Ridge National Laboratory

John J. Paserba, Mitsubishi Electric Power Products, Inc.

Andrew Peck, Enlighten Luminaires

Ping Phou, Southern California Edison

Dale Player, Commonwealth Edison

Alexander Plotkowski, Oak Ridge National Laboratory

Thomas Prevost, Weidmann Electrical Technology Inc.

David Purpura, Siemens

Jesse Lee Reeves, Idaho National Laboratory

Donald Brent Richardson, Dow Chemical

Paul E. Roege, Typhoon-HIL, Inc.

Perry Schugart, Silicon Power Corporation

Stephen Sikirica, U.S. Department of Energy, Advanced Manufacturing Office

Gregory Scott Smitth, Flex Power Control

Gui-Jia Su, Oak Ridge National Laboratory

David Arthur Syracuse, Silicon Power Corporation

Emmanuel Taylor, Energetics, A Division of Akimeka LLC

Kevin Tomsovic, University of Tennessee

Parag Upadhyay, ABB Inc.

Bjorn Vaagensmith, Idaho National Laboratory

Anthony Van Buuren, Lawrence Livermore National Laboratory

Fred Wang, University of Tennessee and Oak Ridge National Laboratory

Roger Wicks, Dupont

Dennis Allan Woodford, Electranix Corporation

Walter Zenger, USi

Yue Zhao, University of Arkansas

Sheng Zheng, Oak Ridge National Laboratory

Appendix B. Program Review Agenda

Day 1—Tuesday, August 13

TIME	AGENDA
7:30 – 8:00 am	**Registration and Breakfast**
8:00 – 8:10 am	**Welcome and Introductions** Rick Raines, Director, Electrical and Electronics Systems Research Division, Oak Ridge National Lab
8:10 – 8:20 am	**Purpose, Agenda, Logistics** Emmanuel Taylor, Energetics
8:20 – 8:50 am	**Keynote Speaker** Sanjay Bose, Senior Technical Advisor, U.S. Department of Energy
8:50 – 9:15 am	**TRAC Program Overview** Kerry Cheung, TRAC Program Manager, U.S. Department of Energy
9:15 – 9:30 am	**BREAK**
9:30 – 11:30 am	**Group 1—Modeling and Analysis (30 min each)** ➢ Suman Debnath, ORNL *Models, Methods, & Tools to Analyze High-Penetration of Power Electronics in Grids; HVdc Models and Methods – Extension* ➢ Bjorn Vaagensmith, INL *Evaluation of Grid Equipment Design Requirements for Improved Resilience* ➢ Zhi Li, ORNL *Continuously Variable Series Reactor (CVSR) for Distribution System Applications; Tapless Regulating Power Transformer (TAREX)* ➢ Paul Ohodnicki, NETL *Development of Automated Design and Optimization Tools for High Frequency Magnetic Components and Migration to Open Source and High-Performance Computing Environments*
11:30 am – 12:30 pm	**LUNCH**
12:30 – 2:30 pm	**Group 2—Next-Gen Components 1 (30 min each)** ➢ Parag Upadhyay, ABB *Novel Concept for Flexible and Resilient Large Power Transformers* ➢ Ibrahima Ndiaye, GE Global Research *Design, Deployment and Characterization of the World's First Flexible Large Power Transformer* ➢ Prasad Kandula, Georgia Tech Research Center *Demonstration of a 5 MVA Modular Controllable Transformer (MCT) for a Resilient and Controllable Grid* ➢ Alex Huang, UT Austin *Modular Hybrid Solid State Transformer for Next Generation Flexible and Adaptable Large Power Transformer*
2:30 – 2:45 pm	**BREAK**

2:45 – 4:45 pm	**Group 3—Next-Gen Components 2 (30 min each)** ➢ Madhu Chinthavali, ORNL *Solid State Power Substation (SSPS) Architecture Design* ➢ Subhashish Bhattacharya, North Carolina State University *Flexible Large Power Solid State Transformer* ➢ Sudip Mazumder, NextWatt *Next-generation modular flexible low-cost silicon carbide (SiC) based high-frequency-link transformer* ➢ Burak Ozpineci, ORNL *Environmentally Neutral Automated Building Electric Energy (ENABLE) Platform*
4:45 pm	**Adjourn**
6:00 pm	**No Host Dinner:** *Calhoun's Oak Ridge, 100 Melton Lake Peninsula, Oak Ridge, TN*

Day 2—Wednesday, August 14

Time	Agenda
7:30 – 8:00 am	**Registration and Breakfast**
8:00 – 8:15 am	**Overview of the Day, Logistics**
8:15 – 10:15 am	**Group 4—Sensing and Characterization** (30 min each) ➢ Sigifredo Gonzalez, SNL *Advanced Sensors Field Validation (MagSense)* ➢ Timothy McIntyre, ORNL *GMLC SAW Sensor Field Validation* ➢ Paul Ohodnicki, NETL *Optical Fiber Sensor Technology Development and Field Validation for Distribution Transformer and Other Grid Asset Health Monitoring* ➢ Paul Ohodnicki, NETL *Establishment of a Medium Voltage (MV) Core Loss Test System (CLTS) and Application Relevant Characterization of MV Dielectric and Insulation Materials*
10:15 – 10:30 am	**BREAK**
10:30 am – 12:30 pm	**Group 5—Materials and Manufacturing** ➢ Alexander Plotkowski, ORNL (30 min) *Microstructure Optimization of Electrical Steel Through Understanding Solidification Dynamics in Additive Manufacturing* ➢ Iver Anderson, Ames National Laboratory (30 min) *Al/Ca Composite Conductor Characterization* ➢ Jesse Reeves, INL (20 min) *Robust Insulation for Resilient Transformers and Power Electronics* ➢ Paul Ohodnicki, NETL (20 min) *Soft Magnetic Alloy Advanced Manufacturing Through In-Line RF Processing;* *Metal / Oxide Nanocomposite Materials for High Frequency and High-Power Magnetics* ➢ Jonathan Bock, SNL (20 min) *Class II High Temperature Ceramic Capacitor Development*
12:30 – 1:30 pm	**LUNCH**
1:30 – 3:00 pm	**Portfolio Discussion and Feedback Session**
3:00 – 3:15 pm	**BREAK**
3:15 pm	**Facility Tours (MDF, PE Lab)**
4:45 pm	**Adjourn**

Appendix C. Peer Reviewer Bios

Mr. Kevin Berent, Electric Power Research Institute, Inc. (EPRI)

Kevin Berent is a Technical Executive at EPRI. Kevin's current work at EPRI focuses on transmission and substations, and includes topics such as resilience, physical security, countering the drone threat, safety by design, and training. Some of his previous projects centered around sulfur hexafluoride (SF6) and alternatives to SF6. Prior to EPRI, Mr. Berent was a director at the North American Transmission Forum (NATF) and a manager at the SERC Reliability Corporation. For over a decade, he has focused on improving the reliability and resilience of the bulk electric system in the United States, Canada, and other international locations.

Dr. Rolando Burgos, Virginia Polytechnic Institute and State University (Virginia Tech)

Dr. Rolando Burgos is currently a professor at the Center for Power Electronics Systems (CPES) at Virginia Tech, a member of the CPES Executive Board, and chair of the CPES consortium on Wide-Bandgap High Power Converters and Systems (WBG-HPCS), where he is leading several research programs on the dynamic and stability impact of power electronics in grid applications, and on the development of grid-scale WBG-based modular power converters.

Dr. Michael Ennis, S&C Electric Company

Michael G. Ennis is the Senior Director for Technology and Breakthrough Innovation at S&C Electric Company. Dr. Ennis has been involved in technology and innovation at S&C since joining it in 1996. While his main focus is power system control, he has worked with novel materials and sensors, as well as their characterization and modeling, mostly for MV applications.

Mr. Gene Jensen, Arcadis NV

Gene Jensen is a Principal Consultant at Arcadis and holds 38 years' experience in all phases of the electric utility business. Mr. Jensen spent 3 years leading implementation of AEP's $466 million smart grid projects, with efforts focused on three projects: the South Bend Smart Meter Pilot, the AEP Texas Smart Meter deployment, and the Columbus Ohio GridSmart project. These projects showcased the following smart grid applications: smart meters; volt/var control; advanced metering infrastructure; home area networks; community energy storage; and fault location, isolation, and service restoration (FLISR, aka distribution automation).

Dr. Madhav Manjrekar, University of North Carolina at Charlotte

Dr. Madhav Manjrekar is an Associate Professor at the University of North Carolina in Charlotte and also serves as an Assistant Director of the Energy Production & Infrastructure Center (EPIC). Dr. Manjrekar has led technology and innovation teams in the areas of energy and power systems for more than 20 years. Prior to joining academia in 2012, he worked as the Vice President of Global Research and Innovation at Vestas (the wind turbine company) and has held various leadership and management positions at Siemens, Eaton, and ABB.

Dr. Craig Miller, National Rural Electric Cooperative Association (NRECA)

Dr. Craig Miller is the Chief Scientist at NRECA, where he oversees a broad research portfolio. Dr. Miller is a technologist with an extensive background in the physical sciences, information technology, and systems engineering. He is a serial entrepreneur and inventor who has worked in the area for 40 years. He earned his Ph.D. at the University of Virginia.

Mr. John Paserba, Mitsubishi Electric Power Products, Inc.

John J. Paserba joined the Mitsubishi Electric Power Products Inc. (MEPPI) in 1998, after over 10 years with General Electric. He is currently the Vice President of the Power System Group, with executive responsibility for seven business units and a national sales and marketing organization. He is an IEEE Fellow. His has worked and held leadership roles in the areas of power systems engineering systems studies, power electronic flexible alternating current transmission system (FACTS) installations in power systems, and HV and MV switchgear equipment and applications.

Col. (retired) Paul Roege, Typhoon HIL, Inc.

Colonel (retired) Paul Roege has nearly 40 years of experience leading engineering, construction, and research. He has led multi-discipline design and construction efforts, including establishment of engineering standards and quality programs, and support of operational activities ranging from industrial facilities to medical, laboratory, command and control, and process facilities. Representative roles include management of military construction programs in Europe, Asia, Africa, and Central America, and technical leadership of nuclear facilities and site infrastructure on DOE sites. Col. Roege is a registered professional engineer and a West Point alumnus with graduate degrees from Boston University (business) and the Massachusetts Institute of Technology (nuclear engineering).

Mr. Dennis Woodford, Electranix Corporation

Dennis Woodford, President of Electranix Corporation, is a former planning engineer from Manitoba Hydro and served as the executive director of the Manitoba HVDC Research Centre. He is a Life Fellow of IEEE and an international member of the National Academy of Engineering.

Mr. Walter Zenger, USi

Walter Zenger is the Director of Research at USi and has extensive experience in electric utility asset management, power cable accessory manufacturing, cable application engineering, and R&D of monitoring and diagnostic technologies for electric utility applications. Mr. Zenger has served as the principal investigator for contracts with government R&D organizations such as DOE and NYSERDA. He is a member of the IEEE Power & Energy Society and Cigre.