



U.S. Department of Energy
Office of Electricity

Transformer Resilience and Advanced
Components Program

**Program Overview &
Project Fact Sheets**

Program Manager: Kerry Cheung, PhD

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Program Overview

VISION STATEMENT

Technologies and approaches will be developed that help maximize the value and lifetimes of existing grid components, and enable the next-generation of grid hardware to be more adaptive, more flexible, self-healing, resilient to all-hazards, reliable, and cost-effective compared to technologies available today.

Program Motivation and Rationale

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, resiliency, efficiency, flexibility, and security. To realize the full potential of a modernized grid, advances in the grid’s physical hardware are also needed. One prime example is the development and use of utility-scale energy storage systems. 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 activities identified in this document can help accelerate grid modernization, increasing controllability, flexibility, and resilience, and realize the vision of the Transformer Resilience and Advanced Components (TRAC) program.

Program Focus

The TRAC program supports activities in high-impact focus areas where federal resources, subject to Congressional appropriations, can play an important role in filling critical research and development (R&D) gaps. The application areas and technologies highlighted in this document were identified through meetings and discussions with various stakeholder groups representing industry, academia, and national laboratories, and through the U.S. Department of Energy’s Quadrennial Technology Review process.¹ Under each application area are specific technologies (see the attached R&D Goals Summary Document) that, if objectives are met, can address some of the major challenges facing the industry, establish capabilities needed in the future, and enable new operational paradigms.

Desired Technology Attributes

Across the various application areas, there are several desired attributes associated with the design of next-generation transmission and distribution (T&D) grid technologies that will influence and shape the R&D activities within the TRAC program portfolio, including the following:

- Modularity and scalability
- Local intelligence and adaptability
- Inherent cyber-physical security
- Manufacturability and sustainability

¹ U.S. Department of Energy. *Quadrennial Technology Review 2015*, accessed August 5, 2019, <http://energy.gov/under-secretary-science-and-energy/quadrennial-technology-review-2015>.

Standardized designs do not exist for many T&D grid components, and their customized nature drives up equipment and installation costs. Modular and scalable designs would enable greater standardization and allow for more cost-effective capacity expansion. Additionally, local intelligence with embedded sensors, data processing, and communications would enable real-time health monitoring, reducing maintenance costs and enhancing system reliability by preventing failures.

With increased intelligence, future T&D grid components will have much stronger connectivity to communication and information technology networks. To mitigate vulnerabilities from evolving threats, cyber and physical security measures must be considered simultaneously and incorporated into the design of each component, rather than added as an afterthought. Finally, as new T&D grid components are designed and developed, it is important to consider the manufacturing processes and lifecycle impact of these technologies.

In addition to the R&D needed for these application areas, a range of supporting activities and issues will require consideration and attention to achieve broader adoption of innovations. These activities and issues are organized into five key categories: (1) testing and model validation; (2) simulations and analyses; (3) architectures, interoperability, and standards; (4) manufacturing and supply chain; and (5) education and training. Efforts in these supporting areas will be coordinated with R&D to amplify results that can lead to benefits, including:

- Increased energy efficiency
- Improved operations
- Enhanced asset utilization and management
- Increased system resilience
- More domestic manufacturing and jobs

Federally sponsored R&D, along with supporting activities, can complement industry efforts and help (1) promote innovation, (2) de-risk technologies that could provide significant value to the nation, and (3) facilitate broader adoption of new technologies and approaches.

The investment cycle needed to replace, upgrade, and expand the U.S. T&D systems has already begun, with annual spending increasing from \$28 billion in 2010 to \$44 billion in 2013. Missing this window of opportunity to develop and install the next-generation of T&D components required for a future grid could slow its transformation and impose significant opportunity costs to society.

Through basic and applied R&D that effectively address industry's need for enhanced T&D hardware performance and capabilities, the TRAC program will support advancement of more reliable, resilient, and flexible grid component technologies by leveraging innovative designs with power electronics, new materials, and embedded sensors and intelligence.

Summary of R&D Focus Areas and Objectives

R&D Focus Areas	Application Areas	Technologies	Objectives
Power Electronics	Advanced Transformers	Flexible and Adaptable Large Power Transformers	<ul style="list-style-type: none"> • Costs comparable to conventional units (e.g., \$10–\$15 per kilovolt-amps [kVA]) • Efficiency > 99% at all levels of loading • 25% reduction in size, weight, and footprint compared to conventional units • Controllable impedance range of 5%–21%
		Power Electronics Augmented Distribution Transformers	<ul style="list-style-type: none"> • Costs comparable to conventional units (e.g., \$25–\$35 per kVA) • Efficiency greater than prescribed standards at all levels of loading • Double the power density compared to conventional units • Self-protected against switching failures
		Solid State Power Substations	<ul style="list-style-type: none"> • System capital costs of \$80–\$100 per kVA • Efficiency > 97% at all levels of loading • Module galvanic isolation > 100 kV at high frequencies • Half the footprint of a conventional substation
	Low-Cost Power Flow Controllers	Advanced Power Routers	<ul style="list-style-type: none"> • System capital costs of \$10–\$40 per kVA • Impedance control in the range of 10%–20% of power rating • Response times < 5 milliseconds
		Medium-Voltage Direct Current Converters	<ul style="list-style-type: none"> • Installed system costs < \$100 per kVA • Efficiency > 99% at all levels of loading • Half the footprint of a converter station built with conventional converter technologies
Materials	Advanced Components	Dielectrics and Insulators	<ul style="list-style-type: none"> • Dielectric strength of > 300 V/mil (> 120 kV/cm) at the same price as conventional materials • Dielectric loss angle (tan delta) of < 0.05% at 60 hertz (Hz) at upper limit of operating conditions • Enhanced material properties remain stable over useful life of assets (e.g., 20–40 years) • Temperature withstand > 130°C in continuous operation, > 180°C in emergency situations
		Magnetics	<ul style="list-style-type: none"> • 50% reduction in energy losses for line frequency transformers compare to silicon steel at the same flux density • 50% reduction in eddy current losses for high power (kilowatts to megawatts), high frequency (10–100 kHz) transformers compared to state-of-the art materials • Costs comparable to materials used today
		Electrical Conductors	<ul style="list-style-type: none"> • Electric conductivity 50% better compared to copper or aluminum • Mechanical strength and thermal conductivity 25% better compared to copper or aluminum • Costs comparable to copper or aluminum
		Semiconductor Devices	<ul style="list-style-type: none"> • Packaged diodes and transistors that cost < \$0.10/amp at 1,200 V • Packaged diodes and transistors that can block > 5 kV and carry > 20 A • Packaged transistors with switching frequencies up to 100 kHz and low losses

R&D Focus Areas	Application Areas	Technologies	Objectives
<p>Sensors</p>	<p>Enhanced Monitoring</p>	<p>Sensing Elements</p>	<ul style="list-style-type: none"> • Accuracy better than 1% of critical value of interest • Capital cost < \$1 per sensing element for ubiquitous sensors • Sensor capital cost and lifetime commensurate with instrumented equipment and application
		<p>Integrated Data Processing and Communications</p>	<ul style="list-style-type: none"> • Installed costs < \$100 per sensor system • Installed costs < \$10,000 per instrumented grid node (e.g., substation and facility) • Support up to 10,000 nodes without performance degradation • Communication latency < 1 millisecond within 10 miles
		<p>Analytics and Applications</p>	<ul style="list-style-type: none"> • Autonomous adjustment and control to prevent unwanted events in < 5 milliseconds • Better than 99% success rates in the detection of and the protection against targeted events • Improved analytics result in > 5% savings in asset management on average

Modeling and Analysis

Modeling and analysis are important activities that can support the broader adoption of new T&D grid component technologies. Outcomes and results from analyses can be used to answer key questions that industry has regarding the viability and value of a new technology, such as contributions to resiliency and system upgrades and the impacts of dynamic interactions between power electronic devices and systems. These analyses are needed to assess value (e.g., cost-benefits), evaluate design trade-offs (e.g., lifecycle costs), and understand capabilities or limitations (e.g., efficiency gains from a DC paradigm versus reliability concerns) of adopting new technologies.

In support of these analyses, simulation tools that leverage validated models and can assess various factors (e.g., technical, market, and policy) over a wide range of time-scales (i.e., milliseconds to years) and geographic-scales (i.e., devices to systems) will be needed. A thorough evaluation of the potential costs and benefits of deploying new component technologies at scale will require modeling and simulation of the economic and operational impacts of the technologies within a large-scale power system model. These analyses may include production cost modeling, power flow, dynamic stability, and potentially even time-domain transient simulations.

Modeling and Analysis Projects

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



Models, Methods, & Tools to Analyze High-Penetration of Power Electronics in Grids

DOE Program Office: OE – Transformer Resilience and
Advanced Components (TRAC)

Location:
Knoxville, Tennessee

Project Term:
05/01/2019 to 01/30/2020

Project Status:
Current Project

Principal Investigator:
Dr. Suman Debnath, R&D Staff, ORNL

Website:
<https://www.ornl.gov/group/eesig>

Project Summary

This project proposes to survey, assess, and analyze commercially-available, open-source, and lab-developed tools that can support the assessment and evaluation of power electronics in future grids with high penetration levels. The study will include aspects that range from power flow analysis to dynamics evaluation (including hardware-in-the-loop testing) for such systems. The outcome of the project would include a document identifying the state-of-the-art and the challenges and gaps associated with the current generation of toolsets available to assess the technical impact of introducing high-penetration of power electronics.

Primary Innovation

Quantifying gaps in existing tools for tomorrow's grid with a high-penetration of power electronics is a first-of-its-kind.

Potential Impact

This project will identify gaps that exist with commercial tools to simulate a high-penetration of power electronics in the grid. The gaps will play a significant role in identifying future research required to develop new tools for tomorrow's upgraded grid.

Commercialization/IP Status

n/a

Innovation Update

The project is currently underway. The framework for the gap analysis is being developed.

General Project Inquiries:
debnaths@ornl.gov

Partners:
PNNL

Release Date:
Tbd



HVdc Models and Methods – Extension

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Location:
Knoxville, TN

Project Term:
10/01/2017 to 06/30/2019

Project Status:
Completed

Principal Investigators:

Dr. Madhu Chinthavali, Group Leader, ORNL
Dr. Suman Debnath, R&D Staff, ORNL
Dr. Yuri Makarov, Chief Scientist, PNNL
Jessica Lau, Sr. Technical Project Manager, NREL

Website:

<https://www.ornl.gov/group/peem>

Project Summary

This project sought to develop models and methods to explore and quantify the technical and economic benefits of high-voltage direct current (HVdc) systems and fast response VSC technologies through provision of controlled active/reactive power and fast response. The developed models and methods can be applied to study other power electronics technologies and scenarios like the ongoing North American Electric Reliability Corporation (NERC) led studies to identify the problems associated with power electronics-based technologies as they are integrated into the bulk power system.

Primary Innovation

The ability to use information across multiple tools have been successfully demonstrated along with the capability to identify economic benefits associated with advanced control methods applied to power electronics. The feasibility of using MTdc systems to provide fast frequency response at multiple points of injections has also been demonstrated in this project for the first time. The ability to provide combined congestion management and frequency response utilizing a higher penetration HVdc system (like the HVdc macrogrid) has also been demonstrated.

Impact

The tools, models, and methods to evaluate the benefits of HVdc system (e.g., frequency support, voltage control, and congestion relief) will be a key enabler to understand the value proposition introduced by the fast acting HVdc systems.

Commercialization/IP Status

Two Universities are using the developed models for research on MTdc systems. There are ongoing discussions with multiple industry partners for access to the VSC and MTdc systems models and the various control methods.

Innovation Update

Project has been completed, with the final report submitted. The results from this work have been published in a peer-reviewed journal and three conference papers. There are at least three more journal papers and two conference papers that are in press and/or submitted.

General Project Inquiries:

chinthavalim@ornl.gov

Partners:

NREL
PNNL

Release Date:

June 30, 2019



Evaluation of Grid Equipment Design Requirements for Improved Resilience

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Location:
Idaho Falls, Idaho

Project Term:
9/15/2017 to currently in progress

Project Status:
In final stages

Principal Investigator:

Dr. Bjorn Vaagensmith, Power Systems Researcher, Idaho National Laboratory

Website:

<https://bios.inl.gov/Lists/Researcher/DisplayOverrideForm.aspx?ID=754>

Project Summary

The project developed a tool suite to determine and prioritize key power grid equipment that would have the best return on investment in terms of resilience improvements. Critical infrastructure sectors were analyzed for best practices that may be applicable toward improving power grid resilience.

Primary Innovation

The tool suite developed combines power flow contingency analysis, probabilistic risk assessment, and adaptive capacity resilience metrics to analyze power grid systems. Contingency analysis determines what fails, probabilistic risk assessment ranks each contingency in term of likelihood and the most likely contributing component to a system failure, and the adaptive capacity provides a system level analysis of where more real and reactive power flexibility is needed. Best practices identified by other critical infrastructure sectors generally fell into four phases: design, plan, operate, and evaluate. The tool suite described above can be used to aid in the design, plan, and evaluate phases.

Potential Impact

This tool suite will enable utilities to select the most impactful system upgrades by quantifying resiliency improvements to their system and understanding which disturbances are most likely to affect system performance by focusing on the most likely contingencies to occur.

Commercialization/IP Status

Testing tool suite on Idaho Falls Power's power grid. Negotiations with another utility partner is underway. A Provisional patent has been filed.

Innovation Update

Tool analysis on IEEE 14 bus system won best paper at Resilience Week 2018.

General Project Inquiries:

Ethan.Huffman@inl.gov

Partners:

Idaho Falls Power

Release Date:

Aug 20, 2018



Continuously Variable Series Reactor (CVSR) for Distribution System Applications

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Funding Opportunity:
AOP

Location:
Oak Ridge, TN

Award Amount (DOE Contribution):
\$450,000

Project Term:
11/01/2018 to
06/30/2020

Awardee Contribution (Cost Share):

Project Status:
Current Awardee

Principal Investigator:

Zhi Li, R&D Staff, ORNL

Website:

<https://www.ornl.gov/group/pes>

Project Summary

Continuously Variable Series Reactor (CVSR) is a novel low-cost power flow control technology developed by Oak Ridge National Laboratory (ORNL), partnering with the University of Tennessee Knoxville and SPX Transformer Solutions, Inc. It was originally designed to address power flow control issues in transmission systems. The same concept also has great potential in applications for the distribution grid, especially ones with meshed grid configurations (e.g., the secondary network to feed metropolitan areas). Distribution applications may have different requirements for CVSR, however, such as more compact designs to fit in the narrow utility vaults in downtown areas. Understanding specification requirements of CVSRs used in distribution applications and valuation of the applications are the main focuses of the project. Device and system level analyses will be conducted to develop CVSR specifications and prove its value in distribution grid.

Primary Innovation

Identifying representative use cases of CVSR in distribution system applications (D-CVSR) and developing the specifications. A proof-of-concept, prototype D-CVSR will be developed.

Potential Impact

Success of this project will enable the development and deployment of a low-cost power flow control for distribution applications. The project will also help to establish the valuation of the technology, providing stakeholders insights into the benefits and risks.

Commercialization/IP Status
n/a

Innovation Update
The project is currently underway.

General Project Inquiries:

Liz2@ornl.gov

Partners:

University of Tennessee, Knoxville
University of Central Florida

Release Date:

n/a



Tapless Regulating Power Transformer (TAREX)

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Funding Opportunity:
AOP

Location:
Oak Ridge, TN

Award Amount (DOE Contribution):
\$500,000

Project Term:
09/01/2017 to
08/31/2019

Awardee Contribution (Cost Share):

Project Status:
Closed

Principal Investigator:
Zhi Li, R&D Staff, ORNL

Website:
<https://www.ornl.gov/group/pes>

Project Summary

Voltage regulation is a critical grid control challenge that power engineers have dealt with since the advent of electricity. On-load tap changing power transformer, or on-load tap changer (OLTC), is the trusted workhorse for voltage regulation in the power industry. Unfortunately, these tap changing transformers suffer from disadvantages such as coarse control, limited durability, high cost, and limited availability. This project is investigating a tapless voltage regulating transformer (TAREX) based on the concept of a saturable-core reactor (SCR). The TAREX magnetically regulates the voltage on the secondary side, and thus eliminates the mechanical tap changer. The project seeks to understand the mechanism of the voltage regulation of TAREX, provide a proof-of-concept, and develop preliminary understanding of its impacts on power systems.

Primary Innovation

The concept of TAREX, voltage regulation by the dc-biased magnetization, is proven for the first time. And its mechanism is extensively analyzed by using multiple modeling/testing approaches.

Potential Impact

Successful development of this technology will enable continuous regulation of voltage. The results of the project will provide applicable insights into the physics behind the proposed technology and guidance on future R&D work for scale up.

Commercialization/IP Status

One invention disclosure in process of filing.

Innovation Update

The project is closed.

General Project Inquiries:
Liz2@ornl.gov

Partners:
n/a

Release Date:
TBD



Development of Automated Design and Optimization Tools For High Frequency Magnetic Components and Migration to Open Source and High Performance Computing Environments

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Location:
Pittsburgh, PA

Project Term:
04/1/17 to 03/31/2020

Project Status:
Current Awardee

Principal Investigator:

Dr. Paul R. Ohodnicki, Jr.

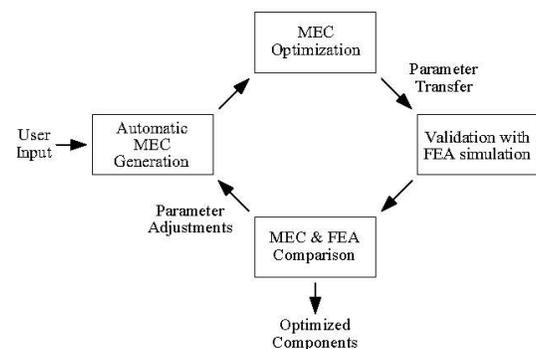
Materials Scientist / Technical Portfolio Lead
National Energy Technology Lab / DOE

Website:

www.netl.doe.gov

Project Summary

An automatic magnetic equivalent circuit (MEC) generation method is being studied and developed to enable novel magnetic component design and optimization processes and the sampling of a more global design space. Such advanced design and optimization methods can evaluate hundreds of thousands of potential designs, and the developed methods can benefit from higher and/or parallel computing power to leverage more accurate multi-physics model-based approaches in addition to a larger design optimization space.



Primary Innovation

Developing a methodology for generating automatically derived MEC models by leveraging finite element method (FEM) or related high-fidelity simulations results while improving model accuracy. Migrating developed optimization methods and tools to leverage high-performance computing facilities for multi-objective optimization and co-simulations for enabling magnetics design and deployment.

Potential Impact

A simplified magnetic component design approach with high fidelity would allow users to identify a subset of basic parameters to generate a broad range of optimized designs.

Commercialization/IP Status

Tools have been developed and will be described in detail within the peer-reviewed scientific literature. Open source versions are also under development and will be made available publicly.

Innovation Update

Project initiated in April of 2019 and progressing toward project objectives.

General Project Inquiries:
Paul.Ohodnicki@netl.doe.gov

Partners:
n/a

Release Date:
Tbd

Next Generation Components

Transformers are essential components in both the T&D systems. The electric grid has evolved and developed around the alternating current (AC) transformer but increasing direct current (DC) generation sources and loads, including energy storage that can serve as both, will warrant new considerations for the functionality of these grid components and their coordination. As the grid evolves to accommodate more renewable and distributed energy resources and changing consumer loads, these ubiquitous components must also evolve. Transformers are ripe for innovation; they have been made with essentially the same materials and designs since the beginning of the electric power industry in the 19th century.

Greater penetration of variable renewables resources and clean energy technologies will affect the operating conditions in which transformers will need to be designed. For example, harmonic distortions produced by wind turbine generators, solar inverters, battery power conversion systems, and other factors often result in significant stray and eddy current losses that may contribute to premature failures. Furthermore, mass market adoption of electric vehicles and customer-sited distributed generation may result in rapid changes in current and voltage, produce excessive loading, lead to phase imbalances, and cause overheating in distribution transformers.

Power flow controllers are proven technologies that can help direct electricity to where it is needed in a networked system. These components can help overcome challenges associated with more dynamic operating conditions caused by variable generation, power line congestion, loop flows, and reduced system inertia. They can also be used to defer capacity upgrades needed to meet increased peak demand. FACTS devices along with HVDC systems are flow control technologies with a history of commercial success. However, these technologies are generally large and expensive, which limits the situations where they can be used.

Methods to reduce the costs associated with AC and DC power flow controllers, while enhancing their performance and reliability, can support broader deployment of these technologies. 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 resiliency. New applications, improved functionality, and added value streams can also support greater adoption.

Next-Gen Components Projects

- *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, 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, UT Austin
- *Solid State Power Substation (SSPS) Architecture Design*
Madhu Chinthavali, ORNL
- *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, ORNL



Novel Concept for Flexible and Resilient Large Power Transformers

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Funding Opportunity:
DE-OE0000854

Award Amount (DOE Contribution):
\$445,380

Awardee Contribution (Cost Share):
\$89,076

Location:
Raleigh, NC

Project Term:
12/30/2016 to
12/29/2017

Project Status:
Project Completed

Principal Investigator:
Parag Upadhyay, Principal Scientist,
ABB Corporate Research

Website:
<https://new.abb.com/about/technology>

Project Summary

This project investigated a novel approach to construct, transport, install, and service large power transformers. The effects of the proposed system on LPT lead time, efficiency, cost, impedance matching, transportation, and lifetime were considered. The project results provided a thorough understanding of the potential customer value and conclusions regarding the best manner in which the proposed system can be implemented.

Primary Innovation

Since LPTs are generally tailored to customer specifications, units are not readily interchangeable, and their high costs prohibit extensive spare inventories. This study investigates a modular, flexible, and adaptable LPT design solution which can facilitate long-term replacement in the event of both catastrophic failures as well as scheduled replacements, thereby increasing grid resilience.

Potential Impact

- Common designs for multiple transformer power and impedance levels
- Reduction in the time to replace a transformer in the field
- Improvement in cost effectiveness
- Easier transportation

Commercialization/IP Status

Small scale pilot installation proposed to validate the concept, manufacturing, and added costs. Economic losses due to downtime needed for cost justification.

Innovation Update

Project completed including high level design and analysis on thirty test cases covering the complete power and voltage range selected for the project.

General Project Inquiries:
parag.upadhyay@us.abb.com

Partners:
University of Tennessee Knoxville

Release Date:
03/14/2017



Design, Deployment, and Characterization of the World's First Flexible Large Power Transformer

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Funding Opportunity:
DE-FOA-0001876 (DE-OE0000908)

Location:
Niskayuna, NY

Award Amount (DOE Contribution):
\$2,375,922

Project Term:
08/01/2019–
07/31/2021

Awardee Contribution (Cost Share):
\$593,981

Project Status:
Not Started

Principal Investigator:
Ibrahima Ndiaye, Senior Engineer,
GE Research

Website:
GE Research – <https://www.ge.com/research/>
Prolec GE – <http://prolecge.com/en/prolec-us/>

Project Summary

The objective of the proposed project is to design, build, and test in the field a prototype of a flexible LPT to demonstrate the feasibility of the concept and its performance in operation. The prototype will be a 230 kV, 60 MVA autotransformer manufactured to allow three transmission class interconnection voltages at the secondary side: 161 kV, 138 kV and 115 kV. The transformer will be designed to allow adjustment of its short circuit impedance from 4% to 18% both under load and off-line. The design will meet IEEE standards C57.12.00 and C57.12.90 as well as the utility partner specifications. The performance of the prototype will be analyzed and compared to a conventional transformer with the similar power and voltage ratings.

Primary Innovation

The key contributions in this project include: 1) addition of an online adjustable leakage impedance, 2) development of an augmented transformer management relay to ensure the protection of flexible transformer with adjustable impedance, 3) field demonstration in a high voltage substation to demonstrate manufacturing feasibility, compliance to industry requirements and standards, and the performance in real-time operation, 4) validation of a new insulating fluid to further optimize the size and footprint of the flexible transformer, and 5) development of low-cost, maintenance-free multivariable gas sensors for continuous monitoring of LPTs.

Potential Impact

Flexible LPTs with online leakage impedance will be able to adapt to the evolving conditions of the grid and provide support in short-circuit management and power flow controls.

Commercialization/IP Status

US Patent US20180330862 is published. An invention disclosure application on the current proposed technology is already submitted.

Innovation Update

Project has not started yet.

General Project Inquiries:
ndiaye@ge.com

Partners:
Prolec GE

Release Date:
Tbd



Demonstration of a 5 MVA Modular Controllable Transformer (MCT) for a Resilient and Controllable Grid

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Funding Opportunity:
DE-FOA-0001876

Location:
Atlanta, GA

Award Amount (DOE Contribution):
\$1,798,315

Project Term:
07/01/2019 –
06/30/2021

Awardee Contribution (Cost Share):
\$495,032

Project Status:
Current Awardee

Principal Investigator:
Deepak Divan, Professor
Georgia Institute of Technology

Website:
www.CDE.gatech.edu

Project Summary

The project team will design, build and test a 5 MVA 24 kV/12 kV modular controllable transformer (MCT) and demonstrate its functionality, which includes modularity, interoperability through variable impedance and connection of multiple voltage levels, power flow control, storage integration, and fail-normal design.

Primary Innovation

The project proposes an MCT—a smaller rated standardized building block that can be used to replicate any high-power transformer. The proposed MCT approach provides transformer resiliency improvement, power flow/impedance controllability, and storage integration. The MCT is based on standard transformers with minimal modifications and fractionally rated converters, allowing the team to achieve above stated system objectives at a lower cost compared to state-of-art approaches.

Potential Impact

The MCT creates a building block for the future grid by integrating a modest level of dynamic control with a smaller rated modular transformer. It provides flexibility in locating devices, increases system capacity through power routing, increases renewable energy integration through volt-VAR control and energy storage, and improves overall grid resiliency and reliability. It also addresses the logistical and economic barriers by allowing smaller rated standardized transformers that can be built and inventoried. They can also be transported using standard trucks, cutting down restoration time dramatically.

Commercialization/IP Status

Basic intellectual property (IP) is issued. Additional IP, if any, will be filed during the project duration.

Innovation Update

Project will start in the near future.

General Project Inquiries:
ddivan@gatech.edu

Partners:
Delta Star
Southern Company
Clemson University

Release Date:
Tbd



Modular Hybrid Solid State Transformer for Next Generation Flexible and Adaptable Large Power Transformer

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Funding Opportunity:
DE-OE0000905

Award Amount (DOE Contribution):
\$1,730,824

Awardee Contribution (Cost Share):
\$433,110

Location:
Austin, TX

Project Term:
3/18/2019 to
3/17/2021

Project Status:
In progress

Principal Investigator:

Dr. Alex Q. Huang, Professor, University of Texas at Austin

Website:

<http://www.ece.utexas.edu/people/faculty/alex-q-huang>

Project Summary

The project team will design and test a 500 kVA Hybrid Solid State Transformer (H-SST) as a full-scale building block for next generation flexible and adaptable LPTs. The selected power level and voltage level of the H-SST is suitable for constructing 138 kV LPTs with an output voltage of 4 kV, 35 kV, 69 kV or 115 kV. Multiple new designs will be involved, including a H-SST topology based on input series and output parallel (ISOP) concept, a medium voltage SiC power switch (“Austin SuperMOS”), an isolated 100 kVA SiC AC to AC SST module and associated soft switching control. The project team will also develop and validate a model of the H-SST to enable the simulation of LPTs at various voltage and power levels. Advanced sensor technology will be used to collect data from the H-SST to monitor the health status of the H-SST and enable its long-term reliability.

Primary Innovation

Develop and demonstrate a modular Hybrid Solid State Transformer (H-SST) for next generation flexible and adaptable LPT. Demonstrate advanced control functions of the H-SST that is currently not available in traditional transformers.

Potential Impact

Optimal configuration of the H-SST could lead to reduce cost and maximized functionalities, such as power flow control and voltage regulation. Demonstration of a new DAB based SST could motivate further medium voltage power electronics uses.

Commercialization/IP Status

n/a

Innovation Update

Targeting late 2019 to test 100 kVA DABSST and demonstrate >97% peak efficiency. Integration of the DABSST with the 60 Hz Line Frequency Transformer planned for mid-2020, and testing of the H-SST in late 2020.

General Project Inquiries:

aqhuang@utexas.edu

Partners:

Temple University
Argonne National Laboratory
United Technology Research Center
Control Transformer
Siemens

Release Date:

Tbd



Solid State Power Substation (SSPS) Architecture Design

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Location:
Knoxville, TN

Project Term:
6/01/2019 to 5/30/2020

Project Status:
Current Awardee

Principal Investigator:
Dr. Madhu Chinthavali, Group Leader, Electric Energy Systems Integration
Oak Ridge National Laboratory

Website:
<https://www.ornl.gov/group/eesig>

Project Summary

A solid-state power substation (SSPS), a substation with the strategic integration of high-voltage power electronic converters, can provide system benefits and support evolution of the grid. Design and development of a flexible, standardized power electronic converter can enable the economy of scale needed to help accelerate cost reductions and improve reliability. SSPS converters will serve as energy hubs that can electrically isolate system elements and provide bi-directional AC or DC power flow control from one or more sources to one or more loads, regardless of voltage or frequency. SSPS converters will also include functional control, communications, protection, regulation, and other features necessary for the safe, reliable, resilient, and cost-effective operation of the future grid. Modular, scalable, flexible, and adaptable power electronics building blocks (PEBBs) are needed to enable different configurations and multiple applications within SSPS. Some design requirements at the substation application level (initially for SSPS 1.0) must be addressed at the converter and PEBB levels. Clear requirements would enable and guide innovation, allowing converter building block designs with different internal components and layouts to be compatible and interoperable.

Primary Innovation

This project focusses on developing the architectures for SSPS 1.0 by developing new converter topologies, and define the SSPS 1.0 architecture, converters, and PEBB requirements and identify the power electronics building block specifications (which includes controls and communication interfaces) that can scale up to 34.5 kV and 10 MW for distribution level “substation” applications.

Potential Impact

This project can create advance power electronics systems that can be integrated into the grid at different levels and provide new benefits—new functionality, new topologies, and enhanced control of power flow and voltage—to the evolving grid infrastructure.

Commercialization/IP Status

n/a

Innovation Update

New start.

General Project Inquiries:
chinthavalim@ornl.gov

Partners:
n/a

Release date:
Tbd



Flexible Large Power Solid State Transformer (FLP-SST)

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Funding Opportunity:
DE-FOA-0001579 (DE-OE0000856)

Award Amount (DOE Contribution):
\$271,475

Awardee Contribution (Cost Share):
\$81,253

Location:
Raleigh, NC

Project Term:
04/01/2017 to
08/31/2018

Project Status:
Completed

Principal Investigator:

Dr. Subhashish Bhattacharya, Professor, North Carolina State University

Website:

<https://www.ece.ncsu.edu/people/sbhatta4/>

Project Summary

The novel concept of Flexible Large Power Solid State Transformer (FLP-SST) is proposed with an objective to achieve greater standardization to increase grid resilience. The FLP-SST is a modular solution, where flexible voltage ratings will be achieved by series/parallel connection of a basic building blocks. Each building block comprises a power electronics based medium-frequency transformer to achieve required voltage isolation and variable step-up and step-down voltage ratios. These standard basis building blocks reduce manufacturing and inventory costs, enable greater interchangeability, and reduce the size and weight vs. conventional line frequency transformers.

Primary Innovation

In recent years, wide-bandgap devices (such as SiC and GaN) have evolved as the most promising power devices with high blocking voltage capabilities along with superior switching and conduction characteristics. Such higher voltage semiconductors can be used to achieve medium voltage operations without using modular structured power converter topologies. With the incorporation of SiC devices, modular converters, and high-frequency transformers, SSTs can be viable solutions to realize and meet the challenges associated with the current LPTs.

Potential Impact

The proposed FLP-SST units can be connected in a modular connection to achieve higher voltage and power operations, potentially averting the need for intricate and expensive procurement and manufacturing process of conventional LPTs. Compared to LPTs, which may be affected by volatility in steel and copper prices, SSTs can be easily produced and transported. As FLP-SST is lightweight and further modular, they can be transported in a convenient way.

Commercialization/IP Status

Technology licensing terms through the NCSU Office of Tech Transfer.

Innovation Update

N/A

General Project Inquiries:

sbhatta4@ncsu.edu

Partners:

Carnegie Mellon University
New York Power Authority

Release Date:

8/31/2018



Next-generation modular flexible low-cost silicon carbide (SiC) based high-frequency-link transformer

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Funding Opportunity:
DE-FOA-0001876 (TBD)

Location:
[Hoffman Estates, IL;
Fayetteville, AR]

Award Amount (DOE
Contribution):
TBD

Project Term:
TBD

Awardee Contribution (Cost
Share):
TBD

Project Status:
Pre-award; in contract
negotiation

Principal Investigator:

Sudip K Mazumder
President
NextWatt LLC

Website:

<http://www.nextwattllc.com/>

Project Summary

This project will provide an innovative design for large power transformers (LPTs) that is more flexible and adaptable than current LPT designs. Research efforts will focus on developing a lab-scale, high-power prototype that demonstrates proof-of-concept and allows for performance evaluation of the prototype.

The project intends to: a) to design, fabricate, and test a module for a high-frequency-link LPT (HFL-LPT) and b) demonstrate a cascaded multi-HFL-LPT module for three phase high-power operation. An HFL-LPT could address some technical limitation of conventional low frequency (i.e., 60 Hz) LPTs. Reduced size and weight will make HFL-LPTs easier to transport compared to conventional 60 Hz LPTs, and variable impedance and secondary side voltage improve flexibility. This project will also explore reducing the number of solid-state devices required compared to state-of-the-art solid-state transformers to reduce cost and complexity.

Primary Innovation

Novel HFL-LPT wide-bandgap modular technology that reduces complexity, number of devices, and power-conversion stages.

Potential Impact

Flexible LPT, solid state transformer, power electronic transformer, multilevel converter

Commercialization/IP Status

IP filing is under consideration at NextWatt LLC for the novel technology. DOE is aware of this.

Innovation Update

Project has not started yet. It is under pre-award and close to initiation of contract negotiation.

General Project Inquiries:

sudipkumarmazumder@gmail.com

Partners:

Silicon Power Corporation

NCREPT

University of Illinois at Chicago

Release Date:

Tbd



Environmentally Neutral Automated Building Electric Energy (ENABLE) Platform

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Location:
Knoxville, Tennessee

Project Term:
3/1/2017 to 4/30/2019

Project Status:
Project Completed

Principal Investigator:
Burak Ozpineci, Group Leader, Oak Ridge National Laboratory

Website:
<https://www.ornl.gov/group/peem>

Project Summary

The ENABLE platform allows direct flexible control of individual loads and sources allowing modularity and scalability for various higher and lower power levels. It also serves as the electric grid gateway or an energy router to the buildings allowing smart power management.

An isolated, bidirectional 5 kW ENABLE power module was designed using SiC power devices for higher efficiency and power density compared with silicon-based designs. A 5kW prototype was fabricated that could accommodate wide-ranging variable DC bus voltage. Circuit simulation results confirmed that the design meets the requirements and all components operate within safe limits. The prototype was successfully tested at power levels up to 5 kW, and the measured maximum efficiency was 94.4%.

Primary Innovation

The ENABLE platform represents a unique and significant technology breakthrough. Previous developments operated for given input sources and load conditions did not provide flexibility for expansion or addition of new components. The ENABLE concept has solved these issues and introduced a modular, scalable, interoperable, and efficient energy router hardware system.

Potential Impact

The ENABLE-based system offers modularity, scalability, hybrid distribution for AC, DC, and/or high-frequency AC, interactive smart meter capabilities, and direct control of ENABLEd-compliant appliances.

Commercialization/IP Status

The project's industrial partner, FlexPower Control is working on commercializing this technology under the SPIN name.

Innovation Update

The project is complete.

General Project Inquiries:
burak@ornl.gov

Partners:
FLEXPOWER

Release Date:
April 15, 2019

Sensing and Characterization

Today's grid is a complex and expansive electrical machine consisting of tens of millions of components and technologies that must work reliably together. Most of the physical infrastructure do not possess the capability to provide their status to system operators, so engineering estimates and routine inspections are used to ensure their performance. This paradigm will not suffice for a future grid that is expected to be flexible and adaptable to wide fluctuations from power supplies and dynamic operations with bi-directional power flows. It will also be extremely difficult to reconfigure the system in real-time to mitigate the impact of disruptions and facilitate the recovery from natural and man-made events.

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.

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. Because field validation of advanced transmission and distribution (T&D) grid components can be expensive and risky, small-scale testing and modeling is often used to predict performance and issues prior to system scale-up. While computational capabilities have advanced to support more complex modeling activities, the results are only as good as the underlying model. The combination of testing and model validation must be conducted hand-in-hand to build confidence in the new technology, which will help accelerate its development.

Validated models that produce realistic results with high confidence are needed before industry will integrate new T&D grid component technologies, especially those based on power electronics, into their operating and control systems. Accurate component models are also useful to evaluate the performance and value of new capabilities in planning and design tools. Ensuring that there are adequate testing capabilities, proper test procedures, realistic use cases, and system models will be important for these activities. For example, testing capabilities that can simulate GMDs, EMPs, and cyber attacks are needed to help identify vulnerabilities from these threats and inform new design requirements that can mitigate impacts.

Sensing and Characterization Projects

- *Advanced Sensors Field Validation (MagSense)*
Sigifredo Gonzalez, SNL
- *GMLC SAW Sensor Field Validation*
Timothy McIntyre, ORNL
- *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*
Paul Ohodnicki, NETL



Advanced Sensors Field Validation (MagSense)

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Location:
Albuquerque, NM

Project Term:
04/01/2016 to 03/01/2019 (extended to 03/01/2020)

Project Status:
Current awardee

Principal Investigator:
Sigifredo Gonzalez
Principal Member of Technical Staff
Sandia National Laboratories

Website:
<https://energy.sandia.gov/energy/ssrei/gridmod/renewable-energy-integration/>

Project Summary

This project will develop and demonstrate low-cost, frequency selective current sensor (MagSense) that will allow for observation of grid components health, provide detection of abnormal behavior/patterns, and support real-time detection of catastrophic failures. This approach will incorporate usability into instrumentation and interrogation of acquired signal.

Primary Innovation

Two methods are being pursued to control magnetic domain structure in order to improve material performance and achieve a resonant peak using CoFe alloy films. The first is an annealing furnace used to heat the material past the Curie temperature and cool it while exposed to an applied magnetic field. The second method is to electrodeposit the CoFe films in a magnetic field.

Potential Impact

This development can be utilized to detect high impedance ground, line-to-line, or arc faults on the distribution and the bulk power system. Frequency selectivity allows to tune detection to a specific type of signature associated with component degradation or imminent component failure, which allows asset owners to better manage fleets and maximize performance.

Commercialization/IP Status

The status of the MagSense material and the interrogator circuitry are at TRL 4-5. Patents awarded during this work: J. R. Pillars, et al., "Microfabricated Magnetostrictive Resonator," U.S. Patent No. 10, 260,969 (16 April, 2019) J. R. Pillars, et al., "Electrodeposition Process For CoFe Magnetostrictive Resonators," U.S. Patent No. 10,215,648 (2 February, 2019); J. R. Pillars, et al., "Electrodeposition Process For CoFe Magnetostrictive Resonators," U.S. Patent No. 10,132,699 (11 November, 2018).

Innovation Update

Currently, the team has demonstrated that MagSense sensor prototypes can detect different types of abnormal current signatures (such as DC current on a neutral or AC currents of high frequencies and 60Hz signal). The remainder of the work will focus on fine tuning of MagSense performance and accuracy of the event detection. A final demonstration of the device will use a passive permanent magnet as the biasing field with no active interrogation.

General Project Inquiries:
sgonza@sandia.gov

Partners:
n/a

Release Date:
Tbd



GMLC SAW Sensor Field Validation

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Funding Opportunity:
GMLC Lab Call

Location:
Oak Ridge, TN

Award Amount (DOE Contribution):
\$1.55M

Project Term:
2016-2020

Awardee Contribution (Cost Share):

Project Status:
Ongoing

Principal Investigator:

Timothy J. McIntyre, Energy & Environmental Sensors Program Manager, Oak Ridge National Laboratory

Website:

<https://www.ornl.gov/group/ses>

Project Summary

This project employs, for the first time, completely passive wireless sensor technology (PWST) for the challenging task of gas detection. Methane, in particular, is not highly reactive at room temperature. Further, other dissolved gases that indicate differing degradation mechanisms, have similar spectral features that make them difficult to resolve. The current state-of-the-art dissolved gas detectors use gas chromatography with mass spectrometry (GCMS). Laboratory-grade GCMS systems can cost more than \$100 thousand. Several companies have developed ruggedized systems that can be field deployed on transformers costing approximately \$50-60 thousand. There are a great number of transformers that utility companies would like to actively monitor, but the cost is too large to do so.

Primary Innovation

PWST functionalized for multiple gas detection. Sensors are direct digitally printed and can be very low cost (project goal is <\$1.00/sensor). The PWST interrogation system cost target is <\$1,000/sensor network and will be capable of communicating with many sensors simultaneously.

Potential Impact

Deployment of PWSTs will provide utility asset owners the ability to monitor in real time the state-of-health of critical assets. Management decisions for maintenance, repair or replace can be made based upon data rather than schedule alone.

Commercialization/IP Status

A patent was granted on June 11, 2019 and several licensing inquiries are being evaluated.

Innovation Update

n/a

General Project Inquiries:
seaysg@ornl.gov

Partners:
n/a

Release Date:
Tbd



Optical Fiber Sensor Technology Development and Field Validation for Distribution Transformer and Other Grid Asset Health Monitoring

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Location:
Pittsburgh, Pennsylvania

Project Term:
4/1/2017 – 12/31/2019

Project Status:
Current Awardee

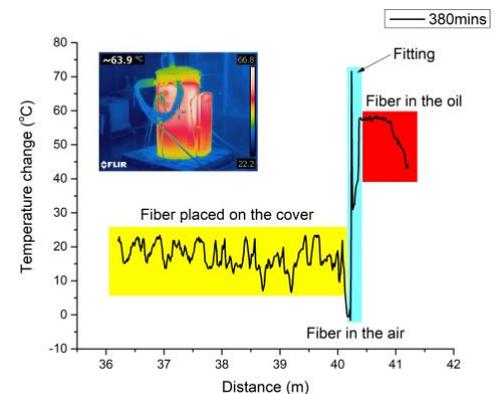
Principal Investigator:
Dr. Paul R. Ohodnicki, Jr.
Materials Scientist / Technical Portfolio Lead
National Energy Technology Lab / DOE

Website:
www.netl.doe.gov

Project Summary

Low-cost optical fiber sensor technology was developed and demonstrated for internal temperature monitoring as well as “proxy dissolved gas analysis (DGA)” in electrical assets such as distribution transformers. A specific emphasis was placed on developing and integrating advanced functional sensor layers with the optical fiber platform to allow for low cost optical components that can meet industry informed target metrics.

The project is also field validating a suite of different optical fiber sensing technologies for single point, multi-point, and fully distributed temperature sensing internal to a distribution transformer.



Primary Innovation

Newly developed sensing layers based upon noble metal (Au and Pd) nanoparticles embedded within a dielectric matrix were applied to the optical fiber sensing platform to functionalize for temperature and gas phase chemistry under conditions relevant for dissolved gas analysis of power transformers.

Potential Impact

Ubiquitous monitoring of internal conditions within distribution grid assets can provide an improved understanding of the internal operational conditions of distribution grid assets during normal and abnormal grid conditions and offer a pathway towards an enhanced resiliency and reliability of the distribution system and the broader electrical grid infrastructure.

Commercialization/IP Status

One patent application was awarded, and the others are still under review with the USPTO. Discussions are on-going regarding potential commercialization paths.

Innovation Update

The team has developed and demonstrated a combined temperature and H₂ sensing probe capable of monitoring over the full range relevant for dissolved gas analysis and internal temperature monitoring of distribution assets such as distribution transformers.

General Project Inquiries:
Paul.Ohodnicki@netl.doe.gov

Partners:
n/a

Release Date:
Tbd



Establishment of a Medium Voltage (MV) Core Loss Test System (CLTS) and Application Relevant Characterization of MV Dielectric and Insulation Materials

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Location:
Pittsburgh, PA

Project Term:
4/1/2017 – 3/31/2020

Project Status:
Current Awardee

Principal Investigator:
[Dr. Paul R. Ohodnicki, Jr.](#)
Materials Scientist / Technical Portfolio Lead
National Energy Technology Lab / DOE

Website:
www.netl.doe.gov

Project Summary

In FY17 and FY18, a core loss test system (CLTS) with 1.2kV SiC MOSFETs was developed to characterize both (1) commercially available magnetic cores and (2) selected magnetic cores under application relevant and practical square wave excitation conditions. In FY19, NETL will continue the efforts, and the CLTS testing capability will be expended to include application conditions relevant to Medium Voltage (MV) apparatus, such as transformers for Solid State Power Substation. A new version of CLTS will be engineered for capability to handle 3kV+ MV voltage levels. In addition, NETL will expand on test capabilities by initiating development of insulating material testing capabilities for the MV range of 3kV+ and approaching 15kV+ in the future.

Primary Innovation

Soft magnetic cores and insulation materials will be characterized under relevant excitation conditions and on full fabricated cores and insulation samples at scale rather than simply performing tests of constituent materials under idealized testing conditions.

Potential Impact

Test results will yield more accurate characterizations and will fill a critical need to enable successful technology development and deployment in the next generation of MV solid state power electronics converters. The power electronics community will have access to more reliable, accurate, and relevant testing information required to optimize components for MV applications.

Commercialization/IP Status

Data sheets from core and insulation material characterization are available as a resource to the community. The core testing system will be described in peer-reviewed scientific journal. Facilities will be available for characterizing selected samples and components.

Innovation Update

The project is active and has successfully demonstrated a core loss test system for full-scale magnetic components up to 100kHz, 1kV, and 50A excitation on the primary winding. Data sheets have been developed for representative core materials from both commercial vendors and on-going DOE projects and collaborations.

General Project Inquiries:
Paul.Ohodnicki@netl.doe.gov

Partners:
n/a

Release Date:
Aug-Oct 2018; and tbd

Materials and Manufacturing

Materials and their physical properties are fundamental to the performance of all T&D grid components. Properties such as electrical conductivity, dielectric strength, mechanical strength, thermal conductivity, magnetic permeability, and switching speeds of materials either enable component capabilities or limit their design. To address power system trends and challenges, advanced components with new materials will be necessary to overcome fundamental limitations imposed by existing materials.

Simultaneously, material innovations developed for other sectors can be leveraged to address some of the challenges associated with current T&D components. Some new functions and enhancements possible with advanced components with new materials include self-healing capabilities, added strength, increased lifetimes, smaller sizes, lighter weight, higher power density, and environmental sustainability.

The impact of manufacturing processes and supply chains are important to the success of new T&D grid components, especially if they involve new design architectures or new materials. Ease of manufacturing, transportation, assembly, and process scalability need to be considered in technology R&D to help address concerns with cost. Additionally, manufacturing processes directly affect the physical properties of materials and will need to be precisely controlled to effectively incorporate advanced components into next-generation T&D grid hardware technologies. 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.

To ensure the security, integrity, and interoperability of new T&D grid components, supply chains and performance validation associated with the underlying materials, subcomponents, and systems will require attention. Attention to these issues is important to mitigating vulnerabilities to cyberattacks, especially with new technologies that have greater use of sensors and embedded intelligence, as well as vulnerabilities to supply shocks. Evaluation of supply chain issues, acceptance testing, and compliance testing can help to address some of these concerns, encourage greater sustainability in manufacturing, and promote U.S. competitiveness.

Materials and Manufacturing Projects

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



Microstructure Optimization of Electrical Steel Through Understanding Solidification Dynamics in Additive Manufacturing

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Location:
Knoxville, TN

Project Term:
10/1/2017 to 09/30/2019

Project Status:
Current Awardee

Principal Investigator:

Alex Plotkowski, Research Associate,
Deposition Science & Technology Group,
Materials Science & Technology Division, Oak
Ridge National Laboratory

Website:

<https://www.ornl.gov/staff-profile/alex-j-plotkowski>

Project Summary

The project intends to demonstrate additive manufacturing (AM) fabrication of electrical steels used in transformer cores with complex structures and geometries not possible with conventional technology and to use next generation materials that are difficult to fabricate to optimize the functional performance of soft-magnetic alloys.

Primary Innovation

New compositions of electrical steel alloys with controlled solidification microstructures will allow new design methodologies for next generation transformer cores that are more efficient, reliable, and robust compared to current technologies.

Potential Impact

Successful development of AM technologies for electrical steel will enable a reduction in lead time for critical LPT components. Advanced control of the material composition, structure, and component design also shows potential for improved energy efficiency and opportunities for unique designs for ancillary function (e.g., active cooling). This research has applications in other devices that utilize soft-magnetic components, such as electric motors.

Commercialization/IP Status

Provisional Patent filed: Plotkowski, Pries, Stump, List, Carver, Dehoff: "Additive Manufacturing of Complex Thin Wall Cross-Sections for Soft-Magnetic Materials", Submitted Dec. 5, 2018. Provisional Patent Filed.

Open-source code copyright: Stump, Plotkowski, Ferguson, Sisco: "3D Thesis (3d THERmal Simulation Software)", Submitted Dec. 21, 2018.

Innovation Update

ORNL has successfully fabricated both Fe-3Si and Fe-6Si AC soft-magnetic devices using a laser powder bed fusion additive manufacturing process. Testing of these components shows a reduction in power losses compared to conventionally manufactured non-oriented electrical steel laminates, and a significant improvement over the previous state-of-the-art in additively manufactured soft-magnets (Figure 1).

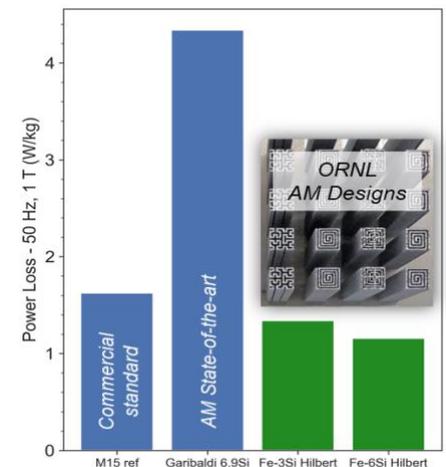


Figure 1: Power losses of electrical steel devices at 50 Hz, 1 T, showing ORNL designs with lower losses than commercial non-oriented steel, and significant improvements over previous state-of-the-art AM materials.

General Project Inquiries:
plotkowskij@ornl.gov

Partners:
n/a

Release Date:
Tbd



Al/Ca Composite Conductor Characterization

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Location:
Ames, Iowa

Project Term:
10/01/2019 to 09/30/2021

Project Status:
Current Awardee

Principal Investigator:
Iver Anderson, Senior Metallurgist,
Ames Laboratory (US DOE)

Website:
<https://www.ameslab.gov/dmse>

Project Summary

This project continues the development of core-less Al/Ca Composite Conductors for overhead transmission line applications. Refinement of an *in-situ* gas-based technique for the reactive passivation of Ca powder during atomization is needed to permit rapid transition of this technology.

Primary Innovation

This project will: a) conduct a full-length experimental gas atomization trial of Ca, and test the flammability, ignition point, and other surface characterization measurements of the resulting Ca powder; b) prepare a new experimental extruded billet from the finer gas atomized Ca powder and fully draw it into wire for testing; c) conduct prolonged (>1000h) thermal stability experiments on the wires and compare the resulting microstructure and strength/conductivity to earlier results; d) prepare sufficient atomized Ca powder to produce pilot-scale billet for wire drawing into short cable for performance testing; and e) perform short cable performance testing at university partner and report results. Characterization will include electrical conductivity, tensile strength, and calorimetry to establish a robust thermal stability temperature limit.

Potential Impact

The successful completion of this project could lead to introduction of a new type of cable material to the power transmission marketplace that would benefit from lower transmission losses and greater resistance to line sag, with the most important advantages coming from installation on wider spaced towers over the longer distances that are common for HVDC transmission applications.

Commercialization/IP Status

A US patent has been issued based on prior work: A.M. Russell, I.E. Anderson, H.J. Kim, A.E. Freichs, "Aluminum/Alkaline Earth Metal Composites and Method for Producing," U.S. Patent No. 8,647,536 B2, issued February 11, 2014. Collaboration with the prospective technology transition partner for the Ca powder is anticipated to advance into an option agreement.

Innovation Update

The project is currently underway and progress will be reported on anticipated results from planned Ca powder making.

General Project Inquiries:
andersoi@ameslab.gov

Partners:
n/a

Release Date:
Tbd



Robust Insulation for Resilient Transformers and Power Electronics

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Location:
Idaho Falls, Idaho

Project Term:
15/Sep/2019 to 04/Apr/2021

Project Status:
Awarded to INL

Principal Investigator:
Dr. Jesse Reeves, Research Engineer, Idaho National Lab

Website:
<https://inl.gov/>

Project Summary

The project aims to develop a high temperature tolerant electrical insulation that can function as a replacement for oil impregnated paper in transformers, not just in the final application but throughout the manufacturing process. This would facilitate performance improvements in the market without retooling or reengineering industrial manufacturing process lines of interest.

Primary Innovation

The nanomaterial properties of silica are being leveraged to develop a bulk composite material similar to paper. Related materials of recent design have either the mechanical or the thermal properties of interest, but not both. This project is merging concepts from recent nanomaterial designs to achieve the desired mechanical, thermal, and electrical properties needed for a transformer insulation.

Potential Impact

A successful product will tolerate high temperature excursions common during geomagnetic disturbance (GMD) events that would otherwise damage transformers. The material would also facilitate smaller transformers and power electronics designs, which could reduce the cost of stockpiling spares, a strategy often cited as a possible mitigation to an electromagnetic pulse (EMP) event.

Commercialization/IP Status

The energy I-Corp program process was applied to the project with significant industry interest specific to corrosion resistance and high temperature filtration applications. INL filed a patent on June 4, 2019.

Innovation Update

A laboratory-directed research and development (LDRD) project was initiated based on TRAC research completed in 2016. Additional TRAC funding will leverage the LDRD to explore promising composites.

General Project Inquiries:
Ethan.Huffman@inl.gov

Partners:
BSU
CAES
NETL

Release Date:
Tbd



Soft Magnetic Alloy Advanced Manufacturing Through In-Line RF Processing

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Location:
Pittsburgh, Pennsylvania

Project Term:
10/1/2019 – 3/31/2021

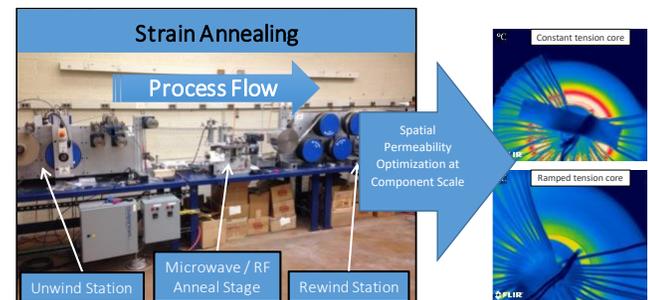
Project Status:
Current Awardee

Principal Investigator:
Dr. Paul R. Ohodnicki, Jr.
Materials Scientist / Technical Portfolio Lead
National Energy Technology Lab / DOE

Website:
www.netl.doe.gov

Project Summary

Advanced in-line manufacturing processes combined with high performance soft magnetic nanocrystalline alloys have recently been demonstrated to enable advanced component designs through local permeability engineering. New techniques for optimized thermal treatments can enable new component designs. In FY20, new approaches to advanced manufacturing processing of metallic amorphous and nanocomposite-based alloys will be developed and demonstrated to optimize the performance and core properties for system- and device-level applications. More specifically, new concepts for local microwave processing of core materials will be pursued to (1) reduce losses, (2) enhance spatial resolution of permeability variations, and (3) improve in-line processing of tape wound core materials. Development of new roll-to-roll RF/microwave processing techniques for amorphous and nanocomposite alloys will also be explored. In addition to manufacturing scale research and development efforts, a series of systematic structure, property, and performance interrelationship studies will also be pursued.



Primary Innovation

The proposed manufacturing technique is highly novel and directly transferable to full-scale processing lines of amorphous and nanocomposite alloy manufacturers. Alloy classes to be investigated include commercial Fe-based alloy systems to understand the potential for improving performance and reducing manufacturing costs of existing state-of-the-art commercial alloys, and emerging Co-based and FeNi-based alloy systems.

Potential Impact

Scalable manufacturing processes would enable a new paradigm in high-frequency magnetic component design for high power and frequency applications with optimized performance.

Commercialization/IP Status

This project will begin on 10/1/2019. NETL has previously developed intellectual property on this approach to soft magnetic alloy.

Innovation Update

Project research will begin in full in calendar year 2019.

General Project Inquiries:
Paul.Ohodnicki@netl.doe.gov

Partners:
n/a

Release Date:
Tbd



Metal / Oxide Nanocomposite Materials for High Frequency and High Power Magnetics

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Location:
Pittsburgh, Pennsylvania

Project Term:
10/1/2019 – 3/31/2021

Project Status:
Current Awardee

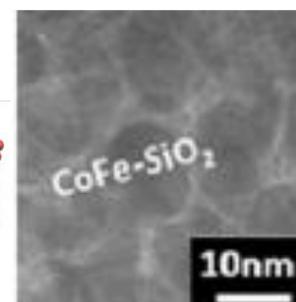
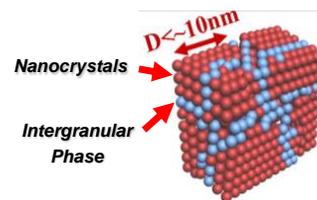
Principal Investigator:
Dr. Paul R. Ohodnicki, Jr.
Materials Scientist / Technical Portfolio Lead
National Energy Technology Lab / DOE

Website:
www.netl.doe.gov

Project Summary

New magnetic core materials, compatible with advanced or additive manufacturing processes, could enable high-power and high-frequency magnetic components in emerging power conversion applications at grid scale.

Nanocomposite
Microstructure



This project seeks to fill a gap in commercially available core materials with a sufficient combination of (1) saturation induction and (2) losses in order to achieve efficiencies, power densities, and reliabilities required for emerging power conversion applications. Advanced oxide and metallic-based nanocomposite core materials for high-frequency switching applications (kHz – MHz) and high-power applications (kW – MW) will be explored. Emerging concepts for integration of ferrite cores and powder-based materials with metallic nanocomposite core materials will also be explored.

Primary Innovation

To date, metal oxide/metal nanocomposite systems have not been compatible with large-scale advanced manufacturing processes due to the need for extremely fine-scale microstructural control. The current task proposes to identify core materials and designs for which synthesis of the insulating intergranular phase is compatible with large scale advanced manufacturing.

Potential Impact

New core materials compatible with scalable manufacturing processes would enable a new paradigm in high frequency magnetic component design for high power and frequency applications, including the potential for advanced and additively manufactured components with optimized performance.

Commercialization/IP Status

This project will begin on 10/1/2019.

Innovation Update

The team is currently staffing the project and will begin research in full later in calendar year 2019.

General Project Inquiries:
Paul.Ohodnicki@netl.doe.gov

Partners:
n/a

Release Date:
tbd



Class II High Temperature Ceramic Capacitor Development

DOE Program Office: OE – Transformer Resilience and Advanced Components (TRAC)

Location:
Albuquerque, NM

Project Term:
09/2019–08/2021

Project Status:
Current Awardee

Principal Investigator:
Jonathan A. Bock,
Senior Member of Technical Staff
Sandia National Laboratories

Website:
<http://energy.sandia.gov>

Project Summary

Replacements for ceramic dielectrics which retain high permittivities at temperatures $>125^{\circ}\text{C}$ have been developed (E.g. $\text{Bi}(\text{Zn}_{0.5},\text{Ti}_{0.5})\text{O}_3\text{-BaTiO}_3$). However, commercialization of capacitors made from these dielectrics is blocked by their wear-out under DC lifetime and incompatibility with non-Nobel metal electrodes. This project will investigate the use of strategies to extend DC lifetime proven successful in pure BaTiO_3 dielectrics (acceptor doping and core-shell structures). Additionally, this project will investigate the use of coated Ni powders when sintering the capacitor layups. The carbonate-based coating will create a local low oxygen partial pressure to decrease Ni oxidation and will simultaneously dope any spurious oxide to assure conductivity. If successful, this may be a route toward processability of BZT-BT with more cost-effective Ni electrodes.

Primary Innovation

The transfer of strategies from pure BaTiO_3 dielectrics into high temperature ceramic dielectric compositions may extend the lifetime of devices and allow for cost-effective electrode materials in production at scale.

Potential Impact

Lowering of barriers for commercialization of Class II ceramic capacitors at temperatures $>150^{\circ}\text{C}$ may provide a solution for high temperature DC link capacitors for wide bandgap-based power electronics.

Commercialization/IP Status

No IP to report currently.

Innovation Update

Project is a new awardee with work to start shortly at Sandia Labs

General Project Inquiries:
Jabock@Sandia.Gov

Partners:
n/a

Release Date:
Tbd