U.S. Department of Energy

Office of Electricity

Transformer Resilience and Advanced Components Program

Program Overview & Project Fact Sheets

Program Manager: Andre Pereira

February 1-3, 2022

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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 in 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. Under each application area are specific technologies 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

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.

Advanced Grid Integration Technologies Projects

Advanced grid integration technologies enable grid hardware to be adaptive, flexible, self-healing, resilient, reliable, and cost effective. During the peer review, the following advanced grid integration technologies projects were evaluated:

- SSPS 1.0 Hardware Prototype Development: Smart Universal Power Electronics Regulators (SUPERs) & Intelligent Power Stages (IPSs) for SSPS 1.0
    - Madhu Sudhan Chinthavali, ORNL
- SSPS 1.0 Hardware Prototype Development: IPS Hardware Prototype Development
    - Hui Li, Florida State University
- SSPS 1.0 Hardware Prototype Development: IPS Hardware Prototype Development
    - Yue Zhao, University of Arkansas
- SSPS 1.0 Hardware Prototype Development: Intelligent Power Stages (IPS)
    - Rolando Burgos, Virginia Tech
- SSPS 1.0 Hardware Prototype Development: Intelligent Power Stages (IPSs)
    - Jin Wang, The Ohio State University
- SSPS 1.0 Hardware Prototype Development: Intelligent Power Stages (IPSs)
    - Babak Parkhideh, University of North Carolina at Charlotte
- SSPS 1.0 Hardware Prototype Development: Intelligent Power Stage
    - Alex Q. Huang
- SSPS 1.0 Hardware Prototype Development: Intelligent Power Stages (IPSs)
    - Fang Luo, Stony Brook University Presentation on IPS Development
- SSPS Controller: Hardware in the loop (HIL) validation
    - Radha Krishna Moorthy, ORNL

SSPS 1.0: Hardware Development

Project Summary

The project aims at demonstrating standardized, interoperable, and scalable power electronics interfaces i.e., Smart Universal Power Electronics Regulators (SUPERs) and Intelligent Power Stages (IPSs). The SUPERs and IPSs are designed to support advanced features including online health monitoring and embedded decision-making capability.

Primary Innovation

The primary innovation of the project includes the following:
architecture of SUPER and IPS to realize all advanced functions. This includes features like high-speed (6.25 Mbps) communication links between IPSs and SUPERs, advanced embedded platforms, and standardized interconnects.

Impact

1. The project provides pathway to develop power electronics interfaces with well-defined hierarchy in controls, communication, protection, intelligence, and optimization for scalability & modularity.
2. Provides a pathway to develop a library of holistic power converters with embedded intelligence and intelligent features for SSPS 1.0.
3. Provides a pathway for interface, communication, protection standardization. Also, emulates vendor agnostic systems to access interoperability and standardization.

Commercialization/IP Status

1. M. Chinthavali and R. S. K. Moorthy, "Fundamental Building Block Concept and Architecture to Support Solid State Power Substations at the Consumer End".
2. M. Chinthavali, M. Starke and R. S. K. Moorthy, "Solid State Power Substation (SSPS) Distribution and Consumer End Grid Infrastructure".

Innovation Update

1. High speed communication links i.e., the control, and data channel between SUPER and IPS have been validated for their functionality and performance.
2. An IPS was developed at ORNL and was experimentally validated at ORNL
3. The overall architecture of SUPER with controls, communication and protection was validated at ORNL. The prototype was tested for various control modes including dc-link regulation and P/Q compensation.

PRINCIPAL INVESTIGATORS:

Dr. Madhu Chinthavali, Leader – Power Electronics Systems Integration (PESI) Group, Distinguished R&D Staff Professional, ORNL

WEBSITE: www.ornl.gov

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

FUNDING OPPORTUNITY:
AOP

LOCATION:
Knoxville. Tennessee

PROJECT TERM:
07/01/2020 to 09/30/2022

PROJECT STATUS:
Ongoing

AWARD AMOUNT (DOE CONTRIBUTION):
$9,000,000

AWARDEE CONTRIBUTION (COST SHARE):
$0

GENERAL PROJECT INQUIRIES:
chinthavalim@ornl.gov

PARTNERS:
Consortium of University Partners

4. Modular SUPER test cell capable of supporting interoperability with 2 IPS stages was built at ORNL.
5. A set of standardized and power and signal interconnects was configured for SUPER and IPS and the performance of the interconnects was verified at 1 kV DC, 480 V AC and 30 kW.
6. A library of IPS (vendor agnostic) with different topological configurations and a range of features were developed by the university partners.

IPS Hardware Prototype Development

Project Summary

The objective of this project is to develop and validate an intelligent power stage (IPS) with advanced features to improve the robustness and reliability of grid-tired converters interfacing renewable energy source and energy storage elements. The prototype will be a 3-phase interleaved DC/DC stage with a 500V-1kV DC input and a 3-phase DC/AC stage rated at 50 kW and 480 Vac. The proposed advanced features will be verified on the developed IPS hardware.

Primary Innovation

The key contributions in this project include: 1) Intelligent control of dv/dt and switching loss based on load current and device temperatures; 2) Integration of device aging prognosis and diagnosis of gate drive status; 3) up to 50Mbps enhanced EMI-immune IPS control with all fibernoptic-based bidirectional communication to SUPER and gate drives; 4) Low-latency hardware-based ZVRT/LVRT solution to suppress inrush current from 312% → 155%; and 5) a self-sustained auxiliary power supply to power IPS.

Impact

This project support/enable the revolutionary solution, SUPER with IPS structure, for renewable energy/battery storage to achieve high reliable and resilient grid integration by addressing extra challenges of new generation WBG power electronics. The proposed technologies can also enhance reliability and resiliency of current grid-tied power electronics.

Commercialization/IP Status

NA.

Innovation Update

Currently, the team has built a 50kW IPS hardware and demonstrated advanced features such as AGD and P&D functions. The grid-tied operation of IPS has been successfully tested with communication between SUPER and IPS local controller. The remainder of the work will focus on experimental verification of ZVRT/LVRT of IPS as well as communication between IPS controller and gate drivers. The integration of DC stage and AC stage will be also tested in 2022.

PRINCIPAL INVESTIGATORS:

Dr. Hui "Helen" Li, Professor, FSU
Dr. Yuan Li, Professor, FSU
Dr. Jinyeong Moon, Professor, FSU

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

FUNDING OPPORTUNITY:
AOP

LOCATION:
Tallahassee, FL

PROJECT TERM:
07/15/2020 to 07/15/2022

PROJECT STATUS:
Ongoing

AWARD AMOUNT (DOE CONTRIBUTION):
$

AWARDEE CONTRIBUTION (COST SHARE):

GENERAL PROJECT INQUIRIES:
hli@caps.fsu.edu

PARTNERS:
Oak Ridge National Lab

RELEASE DATE:
Feb. 01, 2022

IPS Hardware Prototype Development

Project Summary

The Objective of this project is to develop and demonstrate the intelligent power stage (IPS), which is an interoperable plug-and-play power stage with embedded intelligence and online health monitoring capability. Through the standardized communication interface, IPS can provide sufficient component level status information to interact with the Smart Universal Power Electronics Regulator (SUPER). The IPS developed in this project consists of an isolated DC/DC converter stage, a three-phase inverter stage, self-maintained auxiliary power supplies, sensors and a powerful control platform with communication channels. The IPS prototype will be a 480-V grid-tied inverter rated at 50-kW. The performance of the IPS and its advanced features will be firstly demonstrated at UA and then at ORNL for additional testing and demonstration with SUPER.

Primary Innovation

The advanced features of the IPS design include (1) the ability to identify the external parameter (e.g., LCL filter parameters); (2) online health monitoring and prognosis, e.g., DC link capacitance monitoring with capacitor end-of-life (EOL) indication; and (3) advanced gate driving with the ability to control the voltage overshoot, switching loss and dv/dt. In addition, the UA IPS has various innovations in the converter hardware design, such as the high-efficiency high-density silicon carbide (SiC) power stage and high frequency transformer.

Impact

The advanced features developed for IPS will enable its situational awareness, enhance the interoperability and system reliability. Further with the standardized architecture, the IPS can be easily connected to the generic testing environment or standardized SUPER to demonstrate advanced grid functionalities.

Commercialization/IP Status

n/a

Innovation Update

PRINCIPAL INVESTIGATOR:

Dr. Yue Zhao, Associate Professor, University of Arkansas (UA)

WEBSITE:
https://engineering.uark.edu/directory/index/uid/yuezhao/name/Yue+Zhao/

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

FUNDING OPPORTUNITY:
AOP

LOCATION:
Fayetteville, AR

PROJECT TERM:
07/15/2020 to 07/14/2022

PROJECT STATUS:
Ongoing

AWARD AMOUNT (DOE CONTRIBUTION):
$480,987

AWARDEE CONTRIBUTION (COST SHARE):
n/a

GENERAL PROJECT INQUIRIES:
yuezhao@uark.edu

PARTNERS:
ORNL

RELEASE DATE:
Tbd

Project initiated in July 2020 and progressing toward project objectives. Part of the results from this work has been published in a peer-reviewed journal and two conference papers.

Intelligent Power Stage (IPS)

Project Summary

Development of intelligent power stage (IPS) three-phase ac-to-dc power converter module with advanced power processing, monitoring, and diagnostic capabilities based on high efficiency Silicon-Carbide (SiC) power semiconductor devices.

Primary Innovation

Topology: 2-level ac-dc converter with split dc-bus and cascaded 3-level buck-boost dc-dc converter.
Ancillary Circuitry: fiberoptic communication network (25 Mbps) between controller, gate-drivers (GD) and sensors; high dv/dt immunity (>100 V/ns); minimized EMI susceptibility.
Monitoring and diagnostics: GD-integrated SiC MOSFET R_{dson}, T_j measurement and dc-bus voltage; dc-bus capacitance measurement based on I_d and off-state V_{ds} measurements.

Impact

– Modularity of IPS concept combined with automated-manufacturing-oriented design of proposed IPS will expectedly favor multi-supplier IPS market development attaining economy of scales benefits.

– IPS internal digital control and communication network will demonstrate a viable alternative to operating in the harsh EMI environment generated by SiC power semiconductors (main collateral effect of this technology). This is critical for modular systems as the EMI generated is proportional to the number of modules in use.

Commercialization/IP Status

PRINCIPAL INVESTIGATORS:

- Dr. Rolando Burgos, Professor, CPES Director
- Dr. Dong Dong, Assistant Professor
  Dr. Dushan Boroyevich, University Distinguished Professor

DOE PROGRAM OFFICE:

OE – Transformer Resilience and Advanced Components (TRAC)

FUNDING OPPORTUNITY:

AOP

LOCATION:

Blacksburg, VA; Arlington, VA

PROJECT TERM:

07/15/2020 to 10/15/2022

PROJECT STATUS:

Ongoing

AWARD AMOUNT
(DOE CONTRIBUTION):

$557,998.00

AWARDEE CONTRIBUTION
(COST SHARE):

$0.00

"Buck-boost dc-dc converter high-efficiency and low EMI emissions current control scheme," invention disclosure in preparation. "IPS control and sensing communication network with sub-nanosecond synchronization," invention disclosure in preparation.

Innovation Update

- Fiberoptic communication with "SUPER" has been verified
- Internal fiberoptic communication network of IPS has been verified between local controller, gate-drivers and sensors
- Full-power testing of IPS unit has been completed
- Currently working on final integration of first IPS unit to be delivered in May 2022 to ORNL for further testing

GENERAL PROJECT INQUIRIES:
rolando@vt.edu

PARTNERS:
N/A

RELEASE DATE:
February 1, 2022

Intelligent Power Stages (IPSs) at OSU

Project Summary

The project aims to improve the reliability of grid-tied power converters with advanced monitoring circuits and intelligent sensor fusion algorithms. An 80 kVA grid-tied converter prototype with the most popular circuit topology for grid-tied converters have been built to validate the proposed the advanced circuit designs and sensor fusion algorithms.

Primary Innovation

- Advanced power device on-state voltage measurement with high noise immunity
- Sensor fusion algorithms to accurately report the stress and degradation of devices and power converters
- Adjustable gate drive that helps to reduce device degradation
- Liquid metal-based power converter cooling with the inductor in the boost converter functioning as the pump

Impact

- Advanced sensing hardware and software for health monitoring of grid-tied power converters
- Advanced thermal management of grid-tied power converters by improving heat transfer coefficient.
- One MS Thesis: Jesse Pakula, Development of Control and Health Monitoring for a Grid-Tied Three-Phase Inverter Within a Group of Coordinated Inverters
- One paper published; two more planned to be submitted in 2022
- Won the 2nd Place Award at the IEEE ECCE 2021 Student Demonstration
- Four graduate students trained

Commercialization/IP Status

In discussion with leading manufacturers on health monitoring related collaborations. One patent filed and three more in preparation.

Innovation Update

An advanced detection circuit has been built and integrated into an adaptive gate drive for power modules. Sensor fusion algorithms have been experimentally validated. The 80 kVA prototype with advanced features has been fully built and validated.

PRINCIPAL INVESTIGATORS:

- Dr. Jin Wang, Professor, The Ohio State University
- Dr. Mahesh Illindala, Professor, The Ohio State University

WEBSITE: https://hvpe.osu.edu

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

FUNDING OPPORTUNITY:
Smart Universal Power Electronic Regulators (SUPERs) & Intelligent Power Stages (IPSs)

LOCATION:
Columbus, Ohio

PROJECT TERM:
07/17/2020 - 06/30/2022

PROJECT STATUS:
Ongoing

AWARD AMOUNT (DOE CONTRIBUTION):
$449,269

AWARDEE CONTRIBUTION (COST SHARE): N/A

GENERAL PROJECT INQUIRIES:
Wang.1248@osu.edu

RELEASE DATE:
02 01, 2022

Smart Universal Power Electronic Regulators (SUPERs) & Intelligent Power Stages (IPSs)

PRINCIPAL INVESTIGATORS:

- Dr. Babak Parkhideh, Associate Professor, ECE, UNC Charlotte
- James Gafford, Assistant Director, EPIC, UNC Charlotte

WEBSITE:

https://www.charlotte.edu/

https://ece.charlotte.edu/

Project Summary

The project focuses on developing and validating an intelligent power stage (IPS) incorporating system interoperability, diagnostics, and prognostics features.

Primary Innovation

- Development of an interoperable inverter with a secondary controller (IPS-SUPER).
  - Operation of the IPS with an emulated SUPER with less than 1 switching cycle delay.
- Development of key elements/sensors/modules to monitor and report on status of the IPS (Diagnostics and Prognostics).
  - Key feature for diagnostics: Shoot-through detection of SiC power modules in less than 400 nanoseconds.
  - Key feature for prognostics: Real-time on-state characterization of SiC power modules with 95% accuracy.

Impact

- This project brings unprecedented scalability to power electronics applications for the grid.

Commercialization/IP Status

- A provisional patent application has been filed on methods to monitor the performance of emerging wide bandgap power electronics. With UNCC/EPIC industrial partners, an SBIR proposal is planned to commercialize and demonstrate the developed sensors and features in a commercial inverter.

Innovation Update

- Interoperable 75kW 1 kVDC, 480VAC 3-ϕ inverter.
- Fast SUPER-IPS Control & Data Link: 30 kHz update rate.
- Fast shoot-through protection: ≤ 400 ns delay.
- In-situ real-time R_{ON} measurement

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

FUNDING OPPORTUNITY:
ORNL

LOCATION:
Charlotte, North Carolina

PROJECT TERM:
10/01/2020 to 09/30/2022

PROJECT STATUS:
Ongoing

AWARD AMOUNT (DOE CONTRIBUTION):
$350,000

AWARDEE CONTRIBUTION (COST SHARE):

GENERAL PROJECT INQUIRIES:
chinthavalim@ornl.gov

PARTNERS:
ORNL

RELEASE DATE:
Month 01, 2022

Intelligent Power Stage (IPS)

Project Summary

To design, develop and validate a high power and high power density intelligent power stage (IPS) for bidirectional DC/AC applications with standardized power ports and communication ports to allow maximum flexibility to operate with other similar IPS and to interface with an external controller.

Primary Innovation

1. High performance and low-cost SiC IPS
2. Advanced packaging with improved thermal management
3. Intelligent gate driving, Von and T measurement, OC protection
4. Self-contained auxiliary power supply unit
5. Advanced DSP+FPGA controller and communication with SUPER
6. Multiple Grid functions (Black start, LVRT)

Impact

Providing industry and national labs a compact and cost effective SiC IPS for various applications such as renewable energy integration energy storage, fast EV chargers.

Commercialization/IP Status

Still in development stage and no invention has been filed.

Innovation Update

1. A compact 11kW/L, 800V/75kVA SiC IPS is developed and tested electrically and thermally. The IPS's operation voltage, current, cooling capability, power density and efficiency are verified.
2. An intelligent gate driver is implemented. The driving capability is verified in high power test. The Von, T measurement and over current protection functions are verified.
3. An advanced DSP+FPGA controller is developed and tested. The communication with external controller is verified.
4. A self-contained auxiliary power supply is designed and tested.
5. Multiple grid functions are simulated and tested in OPAL-RT platform or on real hardware.

PRINCIPAL INVESTIGATORS:

- Dr. Alex Q. Huang, Professor, Semiconductor Power Electronics Center, The University of Texas at Austin
- Dr. Ruiyang Yu, Research Scientist,
- Zibo Chen, Research Assistant,
- Houshang Salimian, Research Assistant

WEBSITE: https://spec.ece.utexas.edu/

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

FUNDING OPPORTUNITY:
Funded via ORNL

LOCATION:
Oakridge, TN

PROJECT TERM:
06/25/2020 to 06/30/2022

PROJECT STATUS:
Ongoing

AWARD AMOUNT (DOE CONTRIBUTION):
$552,433

AWARDEE CONTRIBUTION (COST SHARE):
$0

GENERAL PROJECT INQUIRIES:
aqhuang@utexas.edu

PARTNERS:

RELEASE DATE:
Jan 04, 2022

Intelligent Power Stages (IPSs)

Project Summary

This project will develop an intelligent power stage (IPS) for grid tied power conversion. The IPS developed in this project is expected to have a standardized interface and can be controlled by SUPER using standardized communication protocol. The IPS will have a series of advanced functions for its health monitoring, prognostic, diagnostic and lifetime prediction, as well as lifetime active control.

Primary Innovation

This IPS provides stanarized modularity and sclability for grid-tied power conversion with health monitoring functions. The coverter uses split-phase toipology, integrated sensors, and 3D system assembly with optimized heatsink, and thus can achieve high power density and high efficiency. The system is controlled by a real-time self-evolving digital twin for health monitoring, prognostic and diagnostic, and thus can significantly reduce the complexity of maintenance. The proposed digital twin based health monitoring can identify the system condition without additional sensor, and thus can further improve the system reliability.

Impact

This research work provides a framework for standardization of the power converter industry and its future manufacturing. It can significantly enhance the scalability and manufacturability for future power electronics systems. The success of this work has the potential to extend “Moore’s Law” to power converter industry.

Commercialization/IP Status

IP Disclosure is under preparation.

Innovation Update

The team has demonstrated the advanced concepts at low power with power hardware-in-loop simulation platform and scaled-down converter, including the sensing system and system health monitoring using the digital twin. The team is currently working on full power converter demonstration with all advanced features.

PRINCIPAL INVESTIGATORS:

Dr. Fang Luo, Associate Professor, Stony Brook University

WEBSITE:

https://www.stonybrook.edu/commcms/electrical/people/-core_faculty/luo_fang

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

FUNDING OPPORTUNITY:
Intelligent Power Stages (IPSs)

LOCATION:
Stony Brook, NY

PROJECT TERM:
07/02/2020 to 07/01/2022

PROJECT STATUS:
Ongoing

AWARD AMOUNT (DOE CONTRIBUTION):
$350,000

AWARDEE CONTRIBUTION (COST SHARE): $0

GENERAL PROJECT INQUIRIES:

Fang.luo@stonybrook.edu

PARTNERS:

RELEASE DATE:
Jan 01, 2022

SSPS Controller: Hardware in Loop Validation

PRINCIPAL INVESTIGATOR:

Dr. Radha Sree Krishna Moorthy, R&D Associate Staff, ORNL

WEBSITE: www.ornl.gov

Project Summary

The project aims at developing the controls, communication, and optimization hierarchy crucial for realizing the concept of solid-state power substation (SSPS) in the distribution section of the grid. To realize this objective, SSPS controller, device controllers for the nodes and hubs will be developed and validated using a controller hardware in the loop (CHIL) test bed.

Primary Innovation

The primary innovations of the project include the following: framework for futuristic grid architecture with SSPS, framework for SSPS controller capable of both steady-state and dynamic coordination to maximize the utilization of downstream resources and system features. The framework will investigate the possibility to incorporate AI techniques and establish transactive markets for nodes and hubs.

Impact

The project will provide solutions for real world grid modernization and integration problems through advanced integrated open research platforms. Above all, the project will validate the impact of SSPS 1.0 in the distribution grid and provide pathways for deployment for SSPS 1.0.

Commercialization/IP Status

The following invention disclosure has been filed:

M. Chinthavali, M. Strake and R. S. K. Moorthy, "SSPS Controller Architecture: Coordinated Optimization and Control of Multiple Solid-state Power Substations in Electrical Distribution Network".

Innovation Update

1. The technical approach required to validate the SSPS framework in real-time environment has been formulated. The base cases crucial to highlight the impact of SSPS on the distribution grid has been established.
2. The coordination techniques required in the SSPS controller has been identified and optimization and AI based techniques required to establish the coordination have been identified.
3. The feeder required to study the impact of SSPS in the distribution grid has also been identified and placements of the nodes/hubs in the feeder has been established based on feeder sensitivity analysis.

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

FUNDING OPPORTUNITY:
AOP

LOCATION:
Knoxville, Tennessee

PROJECT TERM:
09/01/2021 to 08/30/2023

PROJECT STATUS:
Ongoing

AWARD AMOUNT (DOE CONTRIBUTION):
$500,000

AWARDEE CONTRIBUTION (COST SHARE): $0

GENERAL PROJECT INQUIRIES:
krishnamoorr@ornl.gov

PARTNERS:
N/A

RELEASE DATE:
August 30, 2023

Advanced Power Control Equipment Projects

Advanced power control equipment will help meet the needs of a modernized gridwith electronic/electrical power conversion and control products. The following advanced power control equipment projects were evaluated:

- SuperFACTS: Super-Flexible & Robust AC Transmission System
    - Vahan Gevorgian, NREL
- Continuously Variable Series Reactor (CVSR) for Distribution System Applications
    - Sonny Xue, ORNL
- Multi-Port Modular Medium-Voltage (M3) Transactive Power Electronics Energy Hub
    - Madhu Sudhan Chinthavali, ORNL
- Design, Deployment, and Characterization of the World's First Flexible Large Power
    - Ibrahima Ndiaya, General Electric
- Demonstration of a 5 MVA Modular Controllable Transformer (MCT) for a Resilient and Controllable Grid
    - Deepakraj Divan, Georgia Tech
- Modular Hybrid Solid State Transformer for Next Generation Flexible and Adaptable Large Power Transformer
    - Alex Q. Huang, University of Texas at Austin
- Next-Generation Modular Flexible Low-Cost Silicon Carbide (SIC)-Based High-Frequency-Link Transformer
    - Sudip Mazumder, NextWatt

Super-Flexible and Robust AC Transmisison System Devicestem (SuoperFACTS)

Project Summary

SuperFACTS concept proposes a grid stability enhancing solution that combines mature grid supporting technologies under the central advanced control system capable of addressing all main grid integration challenges for variable generation and improve reliability of power grids. SuperFACTS scalable concept combines grid forming battery energy storage (GFM BESS) and synchronous condenser (SC) functionality in a single system that depending on use case can be controlled to provide fully dispatchable and flexible operation using energy storage component, provide a full range of existing and future ancillary and reliability services to the grid (similar or better than conventional sources), maintain adequate levels of grid strength and inertia, and provide fault current for proper operation of protection systems. The main objective of this project is to develop a validation platform and demonstrate the SuperFACTS system at scale and develop models and conduct simulations to demonstrate benefits at system level.

Primary Innovation

The SuperFACTS concept is an innovative "standard building block" scalable and highly reliable solution that can be sized and deployed in numbers to provide services on transmission, sub-transmission, and distribution levels, in microgrids and island power systems. The main innovative aspect of proposed SuperFACTS system lays in the area of smart integrated controls for hybrid BESS-SC systems using existing mature technologies.

Impact

Deployment of SuperFACTS systems in strategic locations and substations in power systems will allow:

- More accelerated scale-up deployment of renewables
- Stable operation of distribution grids with extremely high shares of variable generation
- Standalone operation of separated segments of the grid
- Operation of critical infrastructure during disasters
- Mobile SuperFACTS concept (truck mount or train mount versions) for black-start and stable operation of any section of a power system or an island as a resiliency and fast recovery resource during unintentional islanding or system separations

PRINCIPAL INVESTIGATOR:

- Dr. Vahan Gevorgian, Chief engineer
- NREL team: S, Shah, W. Yang,
- P. Koralewicz, R. Wallen

WEBSITE: www.nrel.gov

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

FUNDING OPPORTUNITY:
AOP

LOCATION:
Golden, CO

PROJECT TERM:
10/01/2020 to 9/30/2022

PROJECT STATUS:
Ongoing

AWARD AMOUNT (DOE CONTRIBUTION):
$800,000

AWARDEE CONTRIBUTION (COST SHARE): $0

GENERAL PROJECT INQUIRIES:
vahan.gevorgian@nrel.gov

PARTNERS:
N/A

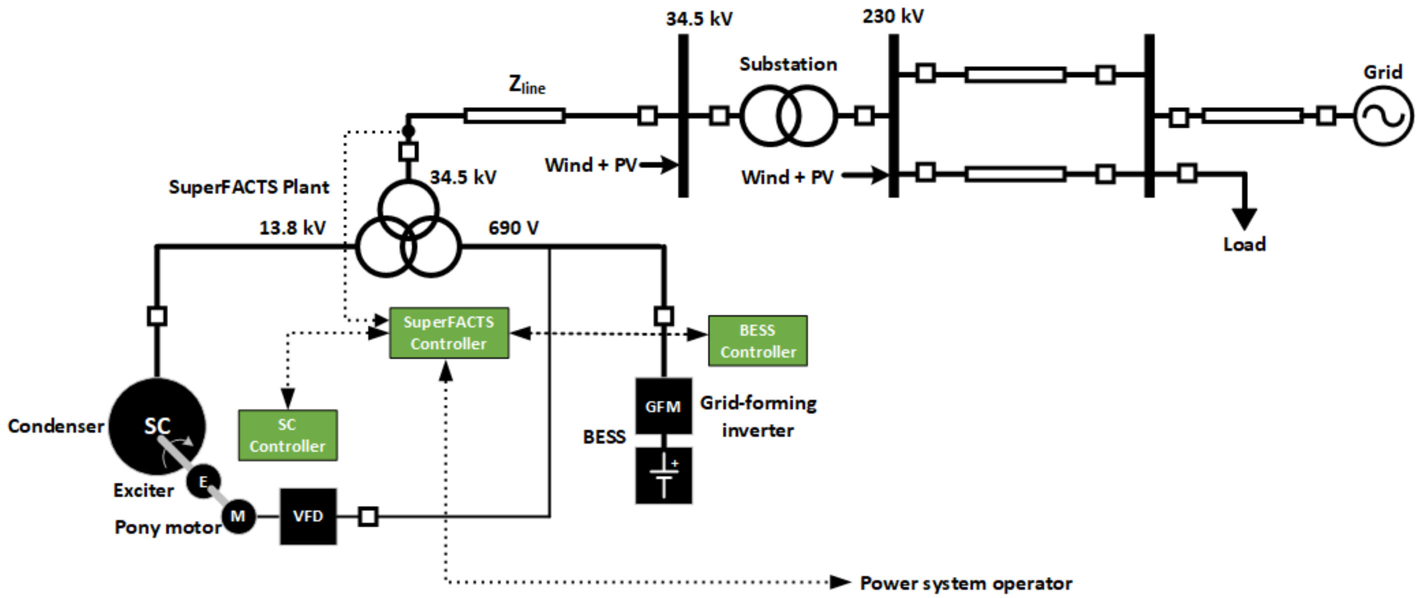
RELEASE DATE:
01, 2021

Because of storage component, the proposed concept will offer a solution to address all reliability and most economic integration challenges of variable renewable generation into power grid: variability, uncertainty, location-specificity and non-synchronous nature. It will address other fundamental challenges of IBRs such as degrading grid strength and lack of overcurrent capability. It is the only solution capable of addressing all grid integration challenges for renewable generation via innovative and transformational (and yet economic) hardware and control software solutions. There are no other systems that offer similar capability combining the "best of two worlds" – synchronous generators and IBRs. This concept is expected to have significant impact on many OE programmatic goals.

Commercialization/IP Status

The project is in proof-of-concept validation and demonstration stage at NREL.

SuperFACTS System



Innovation Update

- All milestones for this project have been met.
- The SuperFACTS system is under validation testing at NREL using 1 MW/1MWh GFM BESSS and 2.2 MVA SC.
- PSCAD Model of the system has been developed and tested for different use cases
- Real-time controller has been developed and deployed
- Testing will start in Jan 2022 on real and controlled grids

Continuously Variable Series Reactor (CVSR) for Distribution System Applications

Project Summary

Continuously Variable Series Reactor (CVSR) is a novel low-cost technology originally designed to address power flow control issues in transmission systems. The same concept also has great potentials in applications for the distribution grid, especially for the ones with meshed grid configurations in metropolitan areas. However, the distribution applications may have special requirements for CVSR, such as better compactness to fit in the narrow utility vaults in downtown areas. The objective of the project is the validation and valuation of CVSR in distribution applications through specifications analysis, prototype development and testing, and grid integration study.

Primary Innovation

Representative use cases of CVSR and associated specifications for distribution system applications were identified. The first 3-ph CVSR prototype for distribution grid was developed and tested.

Impact

Success of this project will enable the development and deployment of a low-cost power flow control for distribution applications. The project helps the valuation of the technology, and thus provides stakeholders insights into the benefits and risks.

Commercialization/IP Status

The project preliminarily proves the value of CVSR for distribution system applications and advanced the TRL level of the distribution CVSR. It helps pave the road for the commercialization of the technology in future project.

Innovation Update

Most of the project tasks have been completed. The second prototype will be tested when its manufacture is completed.

PRINCIPAL INVESTIGATORS:

- Dr. Zhi Li, R&D Staff, Oak Ridge National Laboratory
- Prof. Aleksandar Dimitrovski, University of Central Florida
- Prof. Kevin Tomsovic, University of Tennessee Knoxville

WEBSITE: www.ornl.gov; www.ucf.edu

www.utk.edu

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

FUNDING OPPORTUNITY:
AOP

LOCATION:
Oak Ridge, TN

PROJECT TERM:
11/01/2018 to 12/31/2021

PROJECT STATUS:
Ongoing

AWARD AMOUNT (DOE CONTRIBUTION):
$625,000

AWARDEE CONTRIBUTION (COST SHARE):

GENERAL PROJECT INQUIRIES:
liz2@ornl.gov, ADimitrovski@ucf.edu,

PARTNERS:
University of Central Florida, University of Tennessee Knoxville

RELEASE DATE:
February 01, 2022

Multi-Port Modular Medium-Voltage (M3) Transactive Power Electronics Energy Hub

Project Summary

The goal of this project is to design, develop, and demonstrate foundational technologies and capabilities for multiport power electronics energy hubs (a.k.a. HUB) that can serve as intelligent devices to coordinate and control several different sources and loads.

Primary Innovation

The development of hub controller architecture is the primary innovation in the project. The features of the hub controller include automation of energy flow between loads and assets, gid services like harmonic distortion management, modular and scalable agent-based software platform to support vendor agnostic power electronic interfaces.

Impact

The project will develop the SSPS hubs and the associated and will validate the hub and controller functionalities using a 480 V and MV section of the grid. Thus, the project will provide the pathway for deployment of hubs in the grid and support bottom-up grid modernization.

Commercialization/IP Status

1. M. Starke, B. Xiao, M. Chinthavali "A Low Voltage DC Power Electronic Hub to Support Buildings," IEEE International Conference on DC Microgrids (IDCM), July 2021

Innovation Update

1. CHIL validation of the 480 V hub both in grid connected/islanded mode of operation with the hub controller. Additionally, grid functions i.e., voltage regulation and frequency regulation have been validated using CHIL.
2. Development of hardware prototype of the 480 V hub and validation of transient operation of the hub.
3. The model of the MV hub has been developed and validated in real-time environment.
4. Medium voltage devices based dc-dc converter

PRINCIPAL INVESTIGATORS:

Dr. Madhu Chinthavali, Leader – Power Electronics Systems Integration (PESI) Group, Distinguished R&D Staff Professional, ORNL

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

FUNDING OPPORTUNITY:
AOP

LOCATION:
Knoxville, Tennessee

PROJECT TERM:
02/15/2020 to 02/15/2023

PROJECT STATUS:
Ongoing

AWARD AMOUNT (DOE CONTRIBUTION):
$5.3 M

AWARDEE CONTRIBUTION (COST SHARE):
$1.3 M

GENERAL PROJECT INQUIRIES:
chinthavalim@ornl.gov

PARTNERS:
Industry and University Partners

RELEASE DATE:
February 15, 2023

Design, Development and Characterization of the World's First Flexible Large Piower Transformer

PRINCIPAL INVESTIGATORS:

- Dr. Ibrahima Ndiaye, Technology Manger, GE Research
- Mr. Enrique Betancourt, Applied R&D Manager, Prolec GE

WEBSITE:
https://www.ge.com/research/#

Project Summary

The project objective is to design, build, and deploy the world's first flexible large power transformer (LPT). The prototype is a 165kV, 60/80/100MVA autotransformer with three LV ratings including 57.5kV, 69kV and 80.5kV and a leakage impedance adjustable online from 4.3% to 9.3%. An augmented transformer relay is also developed for the dynamic protection of the flexible LPT. Anticipated results include an >99.5% efficiency; a size and weight within 120% of comparable conventional LPT; compliance with IEEE standards C57.12.00 and C57.12.90; 6 months of field-testing data demonstrating comparable performance with conventional LPT.

Primary Innovation

The primary innovation of the proposed technology is the introduction of flexible impedance coils that allows the LPT to have an online adjustable leakage impedance. Indeed, the impedance of the flexible LPT can be changed while in operation without an impact on the transformer turn ratio (TTR). Additionally, the flexible LPT has three secondary transmission class voltage ratings.

Impact

This technology offers a "universal spare" for the transmission class LPT, helps reduce LPT inventory cost and US dependency on foreign suppliers. It increases the grid flexibility, its reliability and its resiliency as it can adapt to grid reconfiguration and contingency plans.

Commercialization/IP Status

A first patent (11,087,913) was issued was a second (2021/0151235) is published. A third is in preparation for application.

Prolec GE is considering initiating a New Product Introduction (NPI) process for the commercialization of the technology.

Innovation Update

On September 3, 2021 the energization of the world's first flexible LPT was completed at a Cooperative Energy substation in Columbia, MS. The prototype will undergo six months of field validation.

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

FUNDING OPPORTUNITY:
DE-FOA-0001876 Next Generation Transformers – Flexible and Adaptable Designs

LOCATION:
Niskayuna, New York

PROJECT TERM:
10/01/2019 to 05/31/2022

PROJECT STATUS:
Ongoing

AWARD AMOUNT (DOE CONTRIBUTION):
$2,375,922

AWARDEE CONTRIBUTION (COST SHARE):
$593,981

GENERAL PROJECT INQUIRIES:
ndiaye@ge.com

PARTNERS:
Prolec GE

Cooperative Energy

RELEASE DATE:
January 10, 2022

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

PRINCIPAL INVESTIGATORS:
Dr. Deepak Divan, Professor
Georgia Institute of Technology

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, and fail-normal design.

Primary Innovation

Modular controllable transformers (MCTs) consist of fractionally rated power converters integrated with standard HV transformers rated at 10-200 MVA. MCTs provide unprecedented resiliency for high-impact low-frequency events through flexibility in configuration, easier transportability, and faster restoration time. In addition, the MCT provides dynamic control to mitigate congestion issues and to integrate higher levels of variable renewable energy on the grid.

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 improves overall grid resiliency and reliability. It also addresses the logistical and economic barriers, by allowing the build of smaller rated standardized transformers that can be built and inventoried.

Commercialization/IP Status

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

Innovation Update

When coupled with energy storage, MCTs can enable multi-terminal AC systems (MTACs) at a fraction of the cost of multi-port DC systems (MTDCs). MTACs can potentially improve system stability, damp undesired oscillations, frequency control, and provide additional controlled paths to transport or integrate large amounts of power.

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

FUNDING OPPORTUNITY:
DE-FOA-0001876

LOCATION:
Atlanta, GA

PROJECT TERM:
06/01/2019 to 05/30/2022

PROJECT STATUS:
Ongoing

AWARD AMOUNT (DOE CONTRIBUTION):
$1,798,315

AWARDEE CONTRIBUTION (COST SHARE):
$495,032

GENERAL PROJECT INQUIRIES:
ddivan@gatech.edu

PARTNERS:
Southern Company, Delta Star, Inc., and Clemson University

RELEASE DATE:
June 01, 2019

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

PRINCIPAL INVESTIGATORS:

Dr. Alex Qin Huang, Professor, The University of Texas at Austin

WEBSITE: https://spec.ece.utexas.edu

Project Summary

The project aims to develop and demonstrate a modular Hybrid Solid State Transformer for a flexible and adaptable large power transformer comprising of a medium voltage solid state AC-AC converter and a traditional 60Hz transformer. Thanks to the solid-state element advanced control functions would be demonstrated that otherwise would not be possible.

Primary Innovation

The primary innovation is the conception of the Hybrid Solid State Transformer (HSST). Novel converter and device designs would be conceived to realize a single stage direct medium voltage AC-AC Solid State Transformer (SST) required for the HSST unit. A comprehensive control and monitoring system would also be developed.

Impact

The Hybrid concept would enable a modularized design approach to realizing large power transformers, improving the logistics and deployment of such units. Significant cost savings are possible due fractional power rating of the SST whilst still offering a considerable degree of control. The HSST design allow for any standard transformer to be retrofit to form an HSST unit without the need for additional compiling transformer or auxiliary windings. Advanced control and protection concepts integrated to the SST offer a wide array of functionalities that improve grid resiliency and reliability.

Innovation Update

To enable a medium voltage operation, a novel 7.2kV/60A switch has been developed. A single stage DAB based SST has been developed and tested, capable of a 3500V/500V operation at a peak power of 100kW and peak efficiency of >98%. The SST has been coupled with a 60Hz transformer to form a 500kVA 20kV/4kV HSST. The developed HSST has been tested to demonstrate an array of functionalities such as voltage regulation and power injection. A comprehensive modelling and control development has aided in that effort. Finally, a sophisticated monitoring and protection system has been conceived to keep track of both the high frequency and low frequency operation of the HSST.

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

FUNDING OPPORTUNITY:
DE-FOA0001876

LOCATION:
Austin, Texas

PROJECT TERM:
03/18/2019 to 05/31/2022 (With NCE)

PROJECT STATUS:
Ongoing

AWARD AMOUNT (DOE CONTRIBUTION):
$1,730,000

AWARDEE CONTRIBUTION (COST SHARE):
$433,000

GENERAL PROJECT INQUIRIES:
aqhuang@utexas.edu

PARTNERS:

- Raytheon Technologies
- Argonne National Laboratory
- Temple University
- Control Transformers
- Siemens

RELEASE DATE:
Jan 03, 2022

Next-Generation Modular Flexible Low-Cost Silicon Carbide (SiC)-Based High-Frequency-Link Transformer

Project Summary

The project research objectives are to provide an innovative design for a high-frequency-link (HFL) large power transformer (LPT) that is more flexible, lighter, and resilient than current 60-Hz LPT designs. Research efforts will focus on developing the lab scale HFL-LPT prototype that demonstrates proof-of-concept and performance evaluation. The project specific objectives include the following: a) Design, fabricate, and test a 100-kVA module for a three-phase 20 kHz HFL-LPT; and b) Demonstrate a cascaded multi-HFL-LPT for three-phase high-power operation.

Primary Innovation (of the proposed HFL-LPT)

True single-stage power conversion; Reduced device count; Integrated magnetics; Soft switching; Up/down capability;
Input-output continuous; EMI filtering reduced; Multi-functional
Modularly scalable (3 x 1phase; 3 phase)

Impact

- Peak efficiency of HFL-LPT module exceeding 97.5% demonstrated so far without customized SiC MOSFET modules
- Operation of 20-kHz HFL-LPT module demonstrated with significantly lighter nanocrystalline- and integrated-magnetics based transformer compared to 60-Hz LPT approach and demonstrated with single stage compared to conventional multi-stage HFL-LPT approach
- Scaled-power HFL-LPT conducted, demonstrating modular operation. Rated-power three-phase HFL-LPT operation in Feb’22.

Commercialization/IP Status

IP STATUS:

- Title: Solid-State Power-Conversion System
- Inventor: Sudip K Mazumder
- Application No. 62/953,465
- Original Filing Date: December 24, 2019
- US Utility Application and Int. PCT Application filed, Dec 2020
- US Patent Application No. 17/134,178
- PCT International Application PCT/US20/67047

POTENTIAL PARTNERS:
Eaton, ABB, Silicon Power Corp., Licensing possibilities

Innovation Update

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

FUNDING OPPORTUNITY:
DE-OE0000909

LOCATION:
Hoffman Estates, IL

PROJECT TERM:
09/23/2019 to 06/30/2022 (with NCE)

PROJECT STATUS:
Ongoing

AWARD AMOUNT (DOE CONTRIBUTION):
$1,499,545

AWARDEE CONTRIBUTION (COST SHARE):
$375,361

GENERAL PROJECT INQUIRIES:
sudipkumarmazumder@gmail.com

PARTNERS:
University of Arkansas

RELEASE DATE:
Feb 01, 2022

- US utility patent filed and international PCT application filed.
- Design, optimization, and fabrication of nanocrystalline-core based integrated magnetics (IM) completed (for the HFL-LPT), integrating the HF transformer and filter inductors
- Design and optimization of the HFL-LPT module SiC-FET-based power and DSP- and fiber-optics-based control stages completed
- Fabrication, testing, and characterization of an HFL-LPT module including power and control stages conducted and demonstrated
- Design, fabrication, testing, and characterization of additional HFL-LPT modules for a three-phase being carried out for demo in Feb'22
- Design, fabrication, testing, and characterization of a cascaded multilevel HFL-LPT using 2 HFL-LPT three phase modules to be demonstrated in June'22

Advanced Materials Based Components Projects

To support a modern resilient, reliable, and secure electric grid, advanced materials based components are needed to meet the many demands and expectations of the electric grid of the future. The following advanced materials based components projects were evaluated:

- Optical Fiber Sensors for Selective Detection of Acetylene Dissolved in Transformer Oil
    - Michael Buric, NETL
- Al/Ca Composite Conductor Characterization
    - Iver Anderson, AMES
- Enabling Soft Magnetics for Power Conversion Applications
    - Jagan Devkota, NTEL
- High Temperature Ceramic Capacitor Development
    - Jonathan Anton Bock, SNL
- Robust Insulation for Transformers and Power Electronics
    - Bjorn C. Vaagensmith, INL

NATIONAL ENERGY TECHNOLOGY LABORATORY

Optical Fiber Sensors for Selective Detection of Acetylene Dissolved in Transformer Oil

PRINCIPAL INVESTIGATORS:

- Dr. Michael Buric, Staff Scientist Functional Materials Team, NETL
- Dr. Jeffrey Wuenschell, Research Scientist, NETL / Leidos

WEBSITE: www.netl.doe.gov

Project Summary

The anticipation and prediction of power transformer faults is a critical component in the task of ensuring electrical grid reliability. The goal of this project is to leverage optical fiber sensing technology combined with advanced data analytics to provide real-time, spatially distributed transformer monitoring.

Primary Innovation

New functional thin films have been developed for selective optical fiber-based detection of key gas markers of transformer oil degradation (e.g., acetylene). Ni-nanoparticle incorporated oxides, combined with a metal-organic framework (MOF), have shown great promise for this application and for further development towards field testing.

Impact

The gold standard for transformer monitoring is currently dissolved gas analysis (DGA), whereby total combustible gas and acetylene content is monitored from oil samples to detect thermal or arcing faults. This work aims to supplement DGA with a real-time, spatially resolved sensing tool to lower maintenance cost and improve failure risk assessment.

Commercialization/IP Status

As the project moves forward, development of IP associated with gas sensing materials and fiber optic interrogator technology is anticipated.

Innovation Update

Work in FY21 demonstrated improved sensitivity and selectivity of acetylene sensing materials for arc detection. Moving into FY22, the focus will be on sensor and optical interrogator development, with an eye towards field testing.

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

LOCATION:
Pittsburgh, PA

PROJECT TERM:
01/01/2021 to 07/01/2023

PROJECT STATUS:
Ongoing

AWARD AMOUNT (DOE CONTRIBUTION):
$450,000

AWARDEE CONTRIBUTION (COST SHARE):
$0

GENERAL PROJECT INQUIRIES:
Michael.Buric@netl.doe.gov

RELEASE DATE:
Feb. 3, 2022

Al/Ca Composite Conductor Characterization

Project Summary

Lightweight aluminum/calcium (Al/Ca) metal/metal composite conductors are being developed to use in mono-type wound cable for low-loss overhead transmission lines, especially for HVDC power transmission. Results revealed high strength, conductivity, and sag resistance (likely) for heavily drawn Al/Ca (11.5vol.%) composite wires with filamentary Ca reinforcement within an Al matrix. Al/Ca cables will compete with cable types, ACSR and ACCR, which use a dissimilar core for strength and exterior Al-alloy for conduction.

Primary Innovation

Compared to costly sag-resistant ACCR cables (~5X ACSR cost), strength and conductivity of as-drawn Al/Ca(11.5vol.%) mono-type cable (~2-3X ACSR) is higher in as-drawn form, up to 150C. Use above 150C (up to 220C) raises strength (up to 25%) without embrittlement, but conductivity dipped to 9%IACS below ACSR. Fortunately, reduced (starting) Ca% raises conductivity (due to increased Al matrix%), but loses some strength. This design flexibility is being exercised and tested to gain further advantage.

Impact

If Al/Ca composite conductors are fully developed and their properties are verified in cable form, the benefits of this cable can be exploited to build out the US transmission grid with thousands of miles of HVDC and HVAC lines. Calculated estimates show that Al/Ca cable (compared to ACSR Bluebird), will have 12% lower losses and need 11% fewer towers to connect isolated renewable or C-free energy sources to cities/factories.

Commercialization/IP Status

Design and plan for full processing schedule and testing is being set with Ca powder (on-hand) and Al powder (from Valimet) to be compacted as short cylinders (@Gamma Alloys), canned (@Ames), warm extruded to billet (@ UAC), drawn to wire (@Fort Wayne Metals), wound as cable (@Southwire), and tested (@UNCC). Composite conductor and stranded cable technology granted 2014 US patent and available for license.

Innovation Update

PRINCIPAL INVESTIGATORS:

Dr. Iver E. Anderson, Senior Metallurgist, Ames Lab (USDOE)

WEBSITE: www.ameslab.gov

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

FUNDING OPPORTUNITY:
Agreement 1.22.510

LOCATION:
Ames, Iowa

PROJECT TERM:
10/01/2019 to 02/28/2022

PROJECT STATUS:
Ongoing

AWARD AMOUNT
(DOE CONTRIBUTION):
$400,000

AWARDEE CONTRIBUTION
(COST SHARE): $0

GENERAL PROJECT INQUIRIES:
andersoni@ameslab.gov

PARTNERS:
n.a.

RELEASE DATE:
February 3, 2022

Achieved pilot-scale quantities of high-quality Ca and Al powders for producing sufficient Al/Ca conductor (1 mm dia.) to test wound cable. Developed gas atomization method (planned transfer to Ervin Industries by SBIR) to produce fine (<100 μm) passivated Ca powder in pilot-scale (3 kg) batch, sufficient for conductor/cable fabrication experiments. Experimental wire fab/testing also showed that commercial Al powder (from Valimet) has needed purity for Al/Ca conductors. Selection of optimum Ca vol.% range for Al/Ca is in-progress on experimental extruded billets with as-drawn wires.

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

Project Summary

The project has previously established a core loss test system (CLTS) with 1.2kV SiC MOSFET with capacity for square wave excitations and developed datasheets of representative core materials for public use. Under the active project, a new version of CLTS with the capability to handle 3kV+ Medium Voltage (MV) voltage levels with capability to excite application-relevant square waves was designed and established. A representative MV component (transformer) was characterized using the newly established test system and the results were compiled in the form of a datasheet. A test system for characterizing insulation materials is also being established to enable a more complete MV testing facility.

Primary Innovation

Soft magnetic materials and insulation materials are being characterized under practical excitation conditions and on full fabricated components at scale rather than simply performing tests of constituent materials under idealized testing conditions.

Impact

The test results will be compiled in the form of a datasheet and published to the public. The power electronics community will have access to more reliable, accurate, and relevant testing information required to optimize the MV components.

Commercialization/IP Status

The test results on the characterization of magnetic components and insulation materials are being compiled in the form of datasheets. These will be published as a resource. The facilities will be available to the community for characterizing the samples and components.

Innovation Update

The project has established an MV CLTS and demonstrated a successful testing of a 2.5kV, 40kVA transformer for SST applications at 1 -10kHz

PRINCIPAL INVESTIGATORS:

- Dr. Jagannath Devkota, Research Scientist, National Energy Technology Laboratory
- Darryl Shockley, Supervisory General Engineer, National Energy Technology Laboratory

WEBSITE: www.netl.doe.gov

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

LOCATION:
Pittsburgh, PA

PROJECT TERM:
04/01/2020 to 03/31/2022

PROJECT STATUS:
Ongoing

AWARD AMOUNT (DOE CONTRIBUTION):
$621,607

AWARDEE CONTRIBUTION (COST SHARE):
$000,000

GENERAL PROJECT INQUIRIES:
jagannath.devkota@netl.doe.gov

PARTNERS:
North Carolina State University, University of Pittsburgh

RELEASE DATE:
Month 01, 20XX

square wave excitations. Initial datasheet has been developed and submitted for review by the program office.

Soft Magnetic Alloy Advanced Manufacturing Through In-Line RF Processing

Project Summary

Radio frequency (RF)-based techniques for optimized thermal treatments of soft magnetic amorhhous and nanocrystalline alloys are developed and demonstrated to enable advanced component designs through local permeability engineering. A series of systematic structure, property, and performance interrelationship studies of the RF-processed alloys are being pursued with the goal to (1) reduce losses, (2) enhance spatial resolution of permeability variations, and (3) improve in-line rocessing of tape wound core materials. In addition, a new roll-to-roll RF/microwave processing technique to scale the manufacturing process of amorphous and nanocomposite alloys is being developed.

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 that are being 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.

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

NETL has previously developed intellectual property on this approach to soft magnetic alloy.

Innovation Update

The project has demonstrated the phase transformation in soft magnetic alloy through RF heating for batch processing of lab samples to yield nanocrystalline microstructures. A roll-to-roll RF/microwave processing system to scale the manufacturing process for manufacturing of magnetic cores is being setup.

PRINCIPAL INVESTIGATORS:

- Dr. Jagannath Devkota, Research Scientist, National Energy Technology Laboratory
- Darryl Shockley, Supervisory General Engineer, National Energy Technology Laboratory

WEBSITE: www.netl.doe.gov

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

LOCATION:
Pittsburgh, PA

PROJECT TERM:
04/01/2020 to 03/31/2022

PROJECT STATUS:
Ongoing

AWARD AMOUNT (DOE CONTRIBUTION):
$163,045

AWARDEE CONTRIBUTION (COST SHARE):
$000,000

GENERAL PROJECT INQUIRIES:
jagannath.devkota@netl.doe.gov

PARTNERS:
North Carolina State University, University of Pittsburgh

RELEASE DATE:
Month 01, 20XX

Development of High Saturation Soft Magnetic Materials for High-Frequency and High-Power Applications

PRINCIPAL INVESTIGATORS:

- Dr. Jagannath Devkota, Research Scientist, National Energy Technology Laboratory
- Darryl Shockley, Supervisory General Engineer, National Energy Technology Laboratory

WEBSITE: www.netl.doe.gov

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

LOCATION:
Pittsburgh, PA

PROJECT TERM:
04/01/2020 to 03/31/2022

PROJECT STATUS:
Ongoing

AWARD AMOUNT (DOE CONTRIBUTION):
$234,377

AWARDEE CONTRIBUTION (COST SHARE):
$000,000

Project Summary

This project aims to develop wet chemistry-based, scalable manufacturing processes of new soft magnetic composites (SMCs) that could be relevant for high frequency (kHz – MHz) and high power (kW – MW) power conversion applications. Techniques are being investigated to produce metallic-based nanocomposite core materials with a desired combination of (1) saturation induction and (2) losses for high frequency applications in power conversion. Candidate materials that are being explored are nanocomposites comprising of candidate nickel-iron and silicon-iron alloy systems as well as metal/oxide structures.

Primary Innovation

Large-scale manufacturing process of potential high frequency and high power-compatible SMCs with controlled microstructures has been an issue for decades. The current task proposes to identify wet chemistry-based scalable synthesis of SMCs that provide greater flexibility for engineering permeability, saturation magnetization, and resistivity through controlled microstructures and materials composition.

Impact

Proposed wet chemistry-based synthesis methods would produce new SMCs at scale and low cost that would enable a new paradigm in high frequency magnetic component design to meet the need of wide band gap (WBG) applications. This would also provide a pathway to optimize the materials properties at atomic level to create new materials for emerging ultra-WBG switches.

Commercialization/IP Status

Initial results are being presented at a major magnetics conference. Discussions are underway for potential IP.

Innovation Update

The project is active and has successfully demonstrated the bottom-up synthesis of SMCs with reasonable magnetic saturation and permeability. Their compacts into toroidal cores have shown promising results.

GENERAL PROJECT INQUIRIES:
jagannath.devkota@netl.doe.gov

PARTNERS:
North Carolina State University, University of Pittsburgh

RELEASE DATE:
Month 01, 20XX

High Temperature Capacitor Development

PRINCIPAL INVESTIGATORS:

- Dr. Jonathan Bock, Materials R&D
- Dr. Sean Bishop, Materials R&D
- Dr. Jacob Mueller, Power Electronics R&D

WEBSITE: www.sandia.gov

Project Summary

This project focuses on development of material and component-level knowledge of ceramic capacitors for DC-Links for high performance power electronics. This includes both developing new high temperature/high lifetime dielectrics and understanding both device and DC-Link level characterization/modeling of Ceralink capacitors.

Primary Innovation

- Degradation mechanics have been investigated for a promising next-generation dielectric material, BZT-BT, for DC-Link capacitors.
- Ceralink capacitors' device-level behavior has been studied and suggests some complexity in DC-link level modeling. Accurate and accessible design tools are being developed to maximize impact of these capacitors in practical high-performance converters.

Impact

- This work shows that certain chemistries of BZT-BT have promise of showing the high resistance and low degradation needed for high temperature capacitors, but concern exists for fabrication of low-cost product. This informs risk associated with commercialization.
- Accurate and accessible design tools developed here should reduce effort of incorporating Ceralinks into power conversion designs.

Commercialization/IP Status

- Despite promising material properties, this work raises concerns for fabricating low-cost product with BZT-BT, increasing risk of any potential commercialization effort. No IP is expected from this work.
- No IP is expected from Ceralink efforts.

Innovation Update

Future work is focused on finalizing BZT-BT work via publication efforts, development of design tools for Ceralink capacitors, and – schedule allowing - utilizing the degradation characterization equipment, built here for our BZT-BT efforts, for characterization of commercialized MLCC's to understand lifetime and physics of failure in grid-relevant environments.

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

LOCATION:
Albuquerque, NM

PROJECT TERM:
09/01/2019 to 09/01/2022

PROJECT STATUS:
Ongoing

AWARD AMOUNT (DOE CONTRIBUTION):
$1,000,000

AWARDEE CONTRIBUTION (COST SHARE):
$0

GENERAL PROJECT INQUIRIES:
Jabock@sandia.gov

PARTNERS:
N/A

RELEASE DATE:
Month 01, 2022

Robust Insulation for Transformers and Power Electronics

PRINCIPAL INVESTIGATORS:

- Dr. Bjorn Vaagensmith, Power Systems Researcher, INL

WEBSITE: www.INL.gov

Project Summary

Solid-state transformers (SST) place unique operating demands on electrical insulation within its high voltage, frequency, and temperature environment. Advanced electrical insulation materials able to tolerate higher operating frequencies, voltages, and temperatures could enable more robust SST devices. This work explores silica based mats, various polyimide composites and commercial off the shelf ceramic fabrics potential as a next generation transformer insulation material.

Primary Innovation

1) Testing high temperature tolerant binders to improve the machinal strength of fibrous silica mats. 2) Exploring the effects of nano particle additives in polyimide composites. 3) Testing commercial off the shelf ceramic fabrics. 4) Exploring novel materials composites performance in transformers via simulation.

Impact

This work seeks to enable robust SST designs by advancing transformer electrical insulation material to withstand the confluence of high voltage, temperature, and electrical frequency.

Commercialization/IP Status

N/A

Innovation Update

Electrospun silica mats had excellent electrical and thermal properties but were mechanically weak. The electrical properties of a silres Ren 50 (a high temperature binder) were tested for the first time and found to be excellent. Various methods to incorporate the binder into the mat, however, were unsuccessful. Polyamide films with various combinations of boron nitrite, alumina, and silica nanoparticals had good mechanical, and thermal properties. At 10 kHz electrical frequency and below, however, polyimide fills were limited to 350 °C operating temperature. Simulations revealed Alumina, to be the best candidate for allowing heat to quickly diffuse away from the transformer coils.

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

LOCATION:
Idaho Falls, Idaho

PROJECT TERM:
09/15/2019 to 06/03/2020

PROJECT STATUS:
Completed

AWARD AMOUNT
(DOE CONTRIBUTION):
$500,000

AWARDEE CONTRIBUTION
(IN KIND):
$30,000

GENERAL PROJECT INQUIRIES:
Bjorn.Vaagensmith@INL.gov

PARTNERS:
University of Utah

RELEASE DATE:
Jan 03, 2021

Other Projects

Throughout the program, there are a few projects that did not fall into one of the three main technology areas, but still accelerates modernization of the grid by addressing challenges with large power transformers (LPTs), Solid State Power Substations (SSPS), and other critical grid hardware components. The following other projects were evaluated:

- System Resiliency Evaluation Tool
    - Carol A. Reid, INL
- Scalable Hybrid Large-Scale dc-ac Grid Analysis Methods
    - Suman Debnath, ORNL, Marcelo (PNNL), and Josh (NREL)
- Demonstration of Advanced Monitoring and Data Analytics of Power Transmission Lines
    - Jonathan Marmillo and Kristine Engel, ORNL

MASTERRI: Modeling And Simulation for Targeted Electrical Reliability and Resilience Improvements

PRINCIPAL INVESTIGATORS:

- Dr. Bjorn Vaagensmith, Power Systems Researcher, INL
- Shawn West, Senior Power Systems Researcher, INL

WEBSITE: www.INL.gov

Project Summary

This work aims to test a previously developed methodology (i.e., MASTERRI), which integrates power flow simulations, probabilistic risk assessment, and resilience metrics, on a real-world power grid. The results of this test will be evaluated by power engineers familiar with the system to assess to accuracy and utility of the MASTERRI methodology.

Primary Innovation

The combination of power flow simulations and probabilistic risk assessment allows utilities to quantify the severity of an event as well as the likelihood of its occurrence.

Impact

MASTERRI was able to identify issues that were validated by power engineers as legitimate. The likelihood of the occurrence as also validated by engineer's experiential intuition and reasoning. The tool was identified to have two main areas of added value. Firstly, the system impact and likelihood data would aid engineers in deciding what system upgrades are most impactful or the best system reconfiguration during adverse events avoid negative consequences. Secondly, MASTERRI also aids engineers to communicate these results to non-engineering management.

Commercialization/IP Status

Working with a venture capital group to explore license out Patent App. PCT/US19/4253 and submitted an Energy I-Core proposal to perform customer discovery for the technology.

Innovation Update

The resilience metrics did not provide clear actionable results that were easy to understand. More research on how to implement these metrics or into new types of resilience metrics is needed. Future work also includes developing a relationship between frequency and consequence. A technology commercialization funding project was awarded with the aim to develop MASTERRI into an easy-to-use software application.

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

LOCATION:
Idaho Falls, Idaho

PROJECT TERM:
01/20/2020 to 09/30/2021

PROJECT STATUS:
Completed

AWARD AMOUNT (DOE CONTRIBUTION):
$500,000

AWARDEE CONTRIBUTION (IN KIND):
$0

GENERAL PROJECT INQUIRIES:
Bjorn.Vaagensmith@INL.gov

PARTNERS:
Duke Energy

RELEASE DATE:
January 03, 2021

Scalable Hybrid Large-Scale dc-ac Grid Analysis Methods

Project Summary

Develop characterization methods and tools to evaluate reliability, transient stability, and economics of large-scale dc architectures in ac grids. Approach uses (i) advanced fast-acting control in HVdc substations for improved reliability, (ii) high-fidelity EMT models of dc scenarios (with specialized numerical simulation algorithms), (iii) scalable hybrid simulation of PSCAD-PSSE (EMT and TS dynamics) through E-TRAN, (iv) economic benefits quantification of dc architectures.

Primary Innovation

- Advanced simulation algorithms for fast simulation of high-fidelity models of scalable dc architectures to enhance number of nodes studied in dc architectures,
- Library of dc network components' models (vendor agnostic HVdc converter substations, breakers, dc line/cable, scalable radial MTdc, meshed MTdc, and MTdc grid architectures),
- Control and protection algorithms in scalable dc architectures and individual HVdc converter substations to introduce reliability-by-design,
- Hybrid EMT-TS simulation methods for scalable dc-ac architecture studies including event analysis on dc architectures) and system wide feasibility and control benefits from MTdc,
- Economic quantification methods to quantify benefits from enhanced reliability and high bandwidth control introduced by dc architectures and by system wide MTdc control,
- Assessment of resilience support provided by MTdc support,
- Development of meshed MTdc TS dynamic models consistent with EMT model and for grid-forming and grid-following controls to serve as comparison base of performance, and to inform about limitations and uses of TS base models,
- Recommendations and guidelines for use of EMT models, TS models, and hybrid EMT-TS models.

Impact

i. Inform policy makers of the pathway to introduce infrastructure upgrades in existing ac grids.

PRINCIPAL INVESTIGATORS:

- Dr. Suman Debnath, R&D Staff, Oak Ridge National Laboratory (ORNL)
- Dr. Jiazi Zhang, Research Engineer, National Renewable Energy Laboratory (NREL)
- Dr. Marcelo Elizondo, Power System Researcher, Pacific Northwest National Laboratory (PNNL)
- Dr. Joshua Novacheck, Electric System Research Engineer, National Renewable Energy Laboratory (NREL)

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

FUNDING OPPORTUNITY:
Lab Call

LOCATION:
Oak Ridge, TN
Seattle, WA
Denver, CO

PROJECT TERM:
10/01/2021 to 01/01/2023

PROJECT STATUS:
Ongoing

AWARD AMOUNT
(DOE CONTRIBUTION):
$960,000

AWARDEE CONTRIBUTION
(COST SHARE): N/A

$XXX,000

ii. Tools and methods developed to enable reliable and resilient integration of clean energy, aligning with goals of meeting 100% clean energy target by 2035 (and 100% renewables by 2050).

iii. Disseminate information to industry and educate planners on methods applied for studying future ac-dc power grids.

iv. Provide industry with reliability-by-design approach in control systems for different MTdc architectures in US: radial, meshed, and grid architectures of MTdc. Quantify gaps in existing control systems.

GENERAL PROJECT INQUIRIES:
debnaths@ornl.gov

PARTNERS:
ORNL, PNNL, NREL

RELEASE DATE:
January 03, 2022

Commercialization/IP Status

N/A

Innovation Update

- NREL team leveraged existing ReEDS model and developed capacity expansion models for VSC macrogrid design.
- NREL team developed the capacity expansion models of:
- baseline system without macrogrid design
- baseline system with proposed industry HVDC projects before 2026
- 5 potential options of radial MTdc system in near-term future (Scenario 0)
- 3 potential options of meshed MTdc in mid-term future (Scenario 1)
- Based on the system cost, wind and PV capacity expansion results, the NREL team provided the most valuable Scenarios 0 and 1 design options (and is iterating with ORNL and PNNL).
- NREL coordinated with PNNL to identify the PCM and AC power flow baseline cases using WECC 2028 ADS and MMWG EI 2026 raw cases connected with B2B HVDC lines.

Demonstration of Advanced Monitoring and Data Analytics of Power Transmission Lines

Project Summary

ORNL, LineVision, and Xcel Energy outfitted 3 transmission lines with advanced non-contact sensors (EMF and LiDAR) to monitor for 12 months and collect data from conductors to determine power market efficiencies gained from Dynamic Line Ratings (DLR) as well as planning efficiencies achieved from novel conductor health assessments.

Primary Innovation

Advanced transmission line monitoring applications were demonstrated on utility lines by using LineVision's patented sensor systems. The collected data were analyzed with data analytics applications for DLR valuation and planning benefits evaluation.

Impact

Average DLR exceeded static reference ratings by 9-33% in winter months and 26-36% in summer months at the monitored sites; Available on monitored lines over 85% of the time. The impact to Xcel Energy, and utilities in general, is more transmission capacity available today to integrate renewable energy via a cost-effective technology. Utilizing DLR will provide a significant increase in capacity and greater flexibility in operations.

Commercialization/IP Status

Demonstrated sensor systems and data analytics applications are commercial products developed by LineVision.

Innovation Update

One-year data collection is in progress. A digital twin was created for each of the lines under test based on the data already collected.

PRINCIPAL INVESTIGATORS:

- Dr. Zhi Li, R&D Staff Member, Oak Ridge National Laboratory
- Jonathan Marmillo, VP Product, LineVision Inc.
- Kristine Engel, Applications Engineer, LineVision Inc.

www.ornl.gov

www.linevisioninc.com

DOE PROGRAM OFFICE:
OE – Transformer Resilience and Advanced Components (TRAC)

FUNDING OPPORTUNITY:
AOP

LOCATION:
Minnesota, Wisconsin, Colorado

PROJECT TERM:
01/01/2021 to 06/30/2022

PROJECT STATUS: Ongoing

AWARD AMOUNT
(DOE CONTRIBUTION): $500,000

AWARDEE CONTRIBUTION
(COST SHARE): $350,000

GENERAL PROJECT INQUIRIES:

liz2@ornl.gov

jmarmillo@linevisioninc.com

PARTNERS:
Xcel

RELEASE DATE:
February 01, 2022