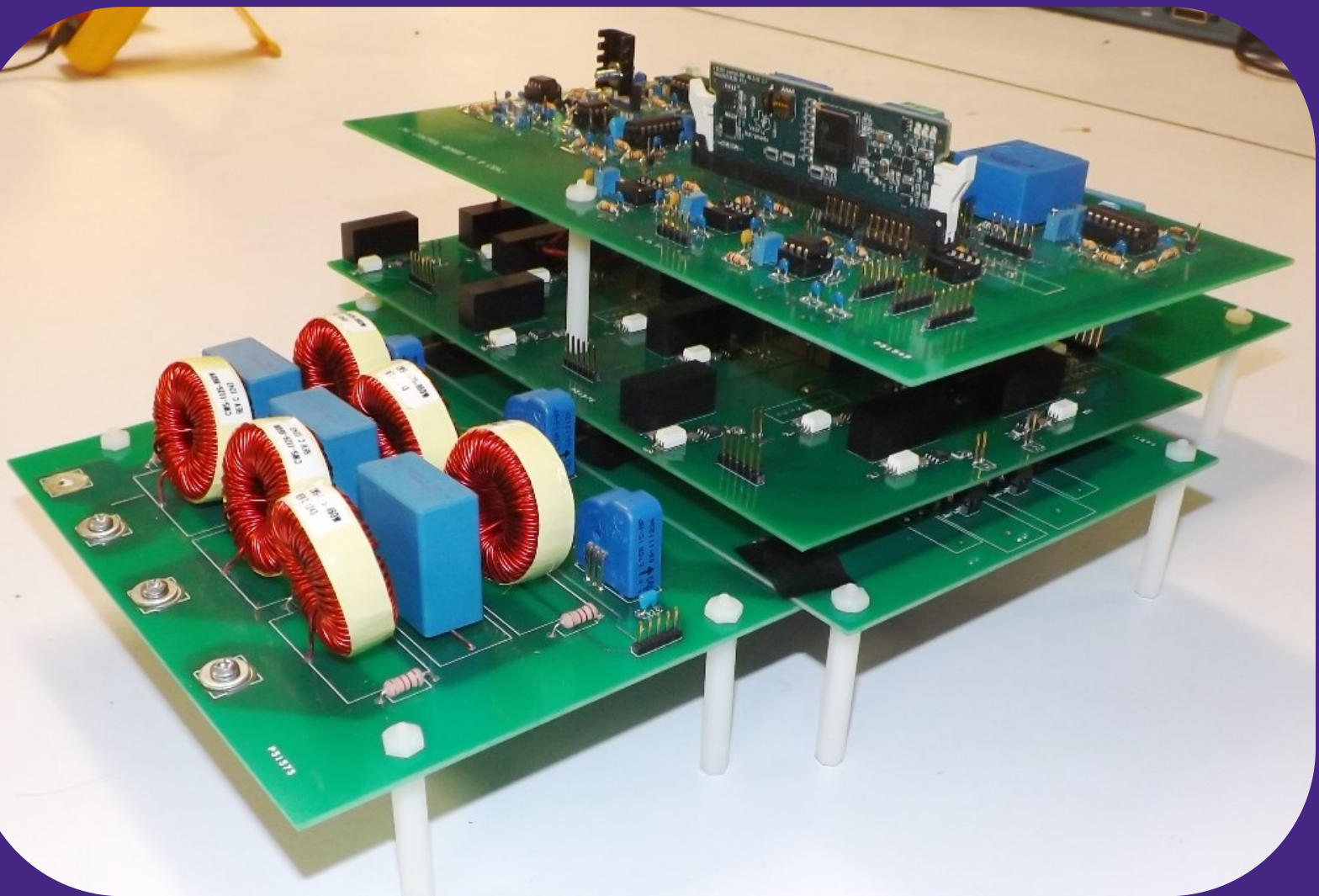




GRAPES

GRid-connected
Advanced Power
Electronic Systems



UNIVERSITY OF
ARKANSAS



UNIVERSITY OF
SOUTH CAROLINA

UNIVERSITY of WISCONSIN
UWMILWAUKEE

Welcome Letter

Dear Potential Client:

The electric power industry is critical to the economy and security of the United States. Without electric power everything stops, and these interruptions have severe economic consequences. The increasing demand for electrical energy is causing the power industry to adopt new distributed generation resources which do not currently fit well into the traditional architecture of the national power grid. Also threatening the stability of the power grid are aging equipment, lack of integration between generation, transmission, distribution and utilization, as well as acts of terrorism. There is a narrow window of opportunity to redefine the power grid and improve its robustness. This is a focus of our research and industrial partnership will pay substantial dividends.

The University of Arkansas, University of South Carolina, and University of Wisconsin-Milwaukee have outstanding laboratory facilities to support center activities, including ample computing power for ASIC, power electronics and power systems analysis ranging from personal computers up to the Star of Arkansas supercomputer. Each school has a wide array of equipment for low-, medium-, and high-voltage testing and fabrication work, including the NCREPT and HiDEC facilities at the University of Arkansas and the Virtual Test Bed at the University of South Carolina.

GRAPES currently has 16 members representing utility companies, equipment manufacturers and component suppliers. Our vertically integrated membership represents the infrastructure and technologies necessary for the definition, design, assembly, evaluation and deployment of transformative grid-connected power electronics. By investing in our research program, you will be investing in the future. Your investment will allow your company to work with our personnel and cutting edge facilities, introduce you to the next generation of power electronics engineers and allow you access to the GRAPES research portfolio. Together we can work towards building the power grid of the future.

Sincerely,



Alan Mantooth
GRAPES Executive Director



TA Walton
GRAPES Managing Director



Roger Dougal
GRAPES Co-Director

GRAPES

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About GRAPES

GRAPES is...

A National Science Foundation Industry/University Cooperative Research Center established in 2009. The GRAPES Center's mission is to accelerate the adoption and insertion of power electronics into the electric grid in order to improve system stability, flexibility, robustness and economy.

Our Focus is...

- The design, development, evaluation, control and standardization of grid-connected power electronic equipment on both the supply and load side of power systems.
- To develop new technologies for advanced power electronic systems in the areas supporting grid-connected distributed energy resources, power steering and routing devices and intelligent load-side devices.
- To develop the software and tools for controlling embedded and grid-connected power electronics to benefit the grid as well as controlled loads.
- To educate engineers who understand the power electronic technologies important to member companies and to the power industry as a whole.

The Benefits of Joining are...

- Access to research personnel
- Access to student for GRAPES research, internships and hiring
- Access to cutting-edge university research facilities
- Opportunities to network with other professionals in the power industry
- Opportunities for technology transfer (non-exclusive IP development rights)

Membership:

GRAPES currently has 16 industrial members, including power utilities, equipment manufacturers and component suppliers. This vertically integrated approach is one of GRAPES' strengths. A GRAPES membership is \$40,000 per calendar year. Each member company has representatives that sit on the GRAPES Industrial Advisory Board (IAB), which meets twice per year to vote on project funding for the upcoming year. IAB members also work with GRAPES faculty and students to determine the strategic direction of the center's work and to provide students with opportunities to intern at member companies.

Facilities:

The University of Arkansas is home to the National Center for Reliable Electric Power Transmission (NCREPT), a unique national-caliber \$5 million power electronic test facility with 3 2-MVA distribution level circuits. This facility houses regen drives, circuit breakers, transformers and controls, which allows validation of research findings and accelerated insertion of new solid-state equipment into the power grid at both source and load ends. Recently an 800 HP dynamometer was added to the center's assets.

The University of South Carolina is home to the Virtual Test Bed, a suite of software tools for the prototyping of large-scale, multi-disciplined dynamic systems. It allows proof-testing of new designs prior to hardware construction. The applications driving development of the software primarily relate to advanced power systems such as those for "more electric" implementations of land, air and sea vehicles, or those for Smart Grid in fixed terrestrial systems.



GRAPES faculty, staff, students and IAB members meet twice each year to review ongoing projects and determine which new projects to pursue.

GRAPES' mission is to accelerate the adoption and insertion of power electronics into the electric grid in order to improve system stability, flexibility, robustness and economy.

We expect to accomplish that mission by focusing on the following main objectives:

- **To develop new technologies** for advanced power electronic systems in the areas supporting grid-connected distributed energy resources, power steering and routing devices and intelligent load-side devices.
- **To develop the software and tools** for controlling embedded– and grid-connected power electronics to benefit the grid as well as controlled loads.
- **To educate engineers** who understand the power electronic technologies important to the member companies.

Membership Benefits

GRAPES Members benefit greatly from their membership in the center. Some of the major benefits are:

- Members have non-exclusive rights to the entire GRAPES research portfolio under the conditions outlined in the Membership Agreement. This includes reports, papers, theses, dissertations, and all protected intellectual property generated by the center.
- All members have the opportunity to propose research ideas and focus areas for research. As part of GRAPES' ongoing activities, all IAB members are invited to work with researchers on the strategic planning work of the center, ensuring a constant focus on the most relevant issues in the power industry today.
- Members have an ongoing interaction with center personnel. Members receive information from the center through monthly email updates, semi-annual project review conference calls, strategic planning meetings, semi-annual face-to-face meetings and through direct interaction with GRAPES faculty and students.
- An opportunity to work with the graduate students who are the next generation of power engineers. GRAPES focuses strongly on IAB member interaction with students both so that students can be intimately familiar with the issues they will face when they go to work and so that IAB members have the opportunity to meet their future employees!
- A significant leverage on the research dollars invested into GRAPES research. With 16 members and support from government agencies such as the National Science Foundation, GRAPES members can leverage their research dollars more than 17:1 in the GRAPES center.



Leadership Team



Dr. Alan Mantooth, Executive Director

Dr. Mantooth received his B.S.E.E. and M.S.E.E. from the UA in 1985 and 1986, respectively, and his Ph.D. from the Georgia Institute of Technology in 1990. Professor Mantooth serves as the Executive Director of GRAPES. His research is in the areas of power semiconductor devices, power and analog circuit design, and design automation algorithms.

Dr. Roger Dougal, Co-Director and USC Site Director

Dr. Dougal received his Ph.D. from Texas Tech University in 1983. He is the Co-Director and USC Site Director for GRAPES, with interests in smart-grid applications of power electronics, power scheduling and routing in microgrids, and simulation-based design tools. He is also Chair of the EE department at USC and leads research both in advanced naval power systems and design tools for integrated engineering plants.



Dr. Juan Carlos Balda, UA Site Director

Dr. Balda received his B.S.E.E. from the Universidad Nacional del Sur in Bahia Blanca, Argentina in 1979. He received his Ph.D.E.E. from the University of Natal in Durban, South Africa in 1986. He is the Department Head of Electrical Engineering at the University of Arkansas and is the UA Site Director for the GRAPES I/UCRC. His research deals with power electronics interfaces applied to distribution systems.

Dr. Adel Nasiri, UWM Site Director

Dr. Nasiri received his PhD degree in electrical engineering from Illinois Institute of Technology, Chicago, IL, in 2004. He worked for Moshanir Power Engineering Company from 1998-2001 and for ForHealth Technologies, Inc., Daytona Beach, FL from 2004-2005. Dr. Nasiri is presently Professor and Associate Dean for Research in the Department of Electrical Engineering and Computer Science at the University of Wisconsin-Milwaukee. His research interests are renewable energy systems including wind and solar energy, microgrids, and energy storage. He has been the primary investigator of several federal and industry funded research projects and holds five patent disclosures.



Dr. T.A. Walton, Managing Director

Mr. Walton received his B.S. and M.S. in Chemical Engineering from the UA in 1981 and 1983, respectively. After more than 25 years working in industry, Mr. Walton joined the UA staff in 2009. He is the Managing Director for both GRAPES and NCREPT. He serves on the UA Black Alumni Association Board of Directors.

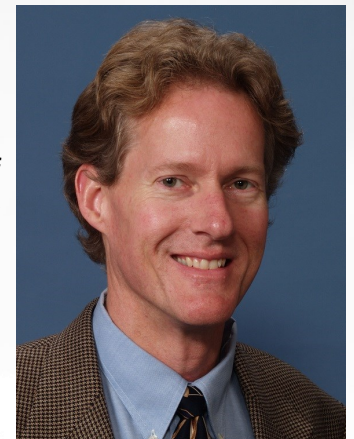


Dr. Simon Ang, University of Arkansas

Dr. Ang received his B.S.E.E. from the University of Arkansas, his M.S. from the Georgia Institute of Technology, and his Ph.D. from Southern Methodist University. He is a Fellow of IEEE, the Electrochemical Society, the IET (UK), and the City and Guilds of London Institute (UK). His research interests include power electronic and microelectronic packaging. Dr. Ang is the Director of the High Density Electronics Center at the University of Arkansas.

Dr. Roy McCann, University of Arkansas

Dr. McCann received his B.S. and his M.S. in Electrical Engineering from the University of Illinois at Urbana. He received his Ph.D. from the university of Dayton. He is a Professor at the University of Arkansas and is a Director of NCREPT. His research is in the area of grid-connected battery energy storage systems, modeling and simulation of electric power systems, and control of power system dynamics.



Dr. Yue Zhao, University of Arkansas

Dr. Zhao received a B.S. degree in Electrical Engineering from Beijing University of Aeronautics and Astronautics, Beijing, China in 2010 and a Ph.D. in Electrical Engineering from the University of Nebraska-Lincoln in 2014. He is an assistant professor at the University of Arkansas. His current research interests include electric machines and drives, power electronics, and renewable energy systems.

Dr. Andrea Benigni, University of South Carolina

Dr. Benigni leads research related to simulation-based design of applications for power systems with high penetration of renewables and PE converters. He joined USC in 2014 after 5 years at the E.ON. Energy Research Center in Aachen, Germany. He published more than 30 papers related to the use and development of simulation methods and techniques for smart grid applications. He is co-founder of Gridhound, a small company focused on cloud-based voltage monitoring services for power distribution systems.



Faculty



Dr. Herb Ginn, University of South Carolina

Dr. Ginn received his B.S., M.S., and Ph.D. in Electrical Engineering from Louisiana State University. He teaches courses in control systems, power electronics, and power systems. His research interests include power electronics applications in power systems as well as power phenomena and compensation in power distribution systems.

Dr. Enrico Santi, University of South Carolina

Dr. Santi received his B.S. from the University of Padua, Italy and both his M.S. and Ph.D. from Caltech. He worked for five years at TESLaco as a power electronics design engineer and has been teaching at USC since 1998. His current research interests are in modeling, control, and simulation of advanced electrical power distribution systems and in physics-based modeling of power semiconductor devices.



Dr. Rob Cuzner, University of Wisconsin-Milwaukee

Dr. Cuzner received his B.S.E.E. from Brigham Young University in 1988, his M.S.E.E. and Ph.D. from the University of Wisconsin-Madison in 1990 & 2013 respectively. He worked for 24 years in industry before joining the University of Wisconsin-Milwaukee. His research interests are low voltage and medium voltage AC and DC distribution architectures for Naval shipboard, community microgrids, smart homes and buildings and industrial parks, microgrids fault protection and integration of wide band gap power semiconductors into grid compatible packaged systems.



Dr. Lingfeng Wang, University of Wisconsin-Milwaukee

Dr. Wang received his Ph.D. from the Electrical and Computer Engineering Department at Texas A&M University in 2008. He is an Associate Professor in the Department of Electrical Engineering at the University of Wisconsin-Milwaukee, where he directs the Cyber-Physical Energy Systems Laboratory. His research interests are focused on the reliability, cybersecurity, resiliency, and flexibility aspects of contemporary electric power grids.



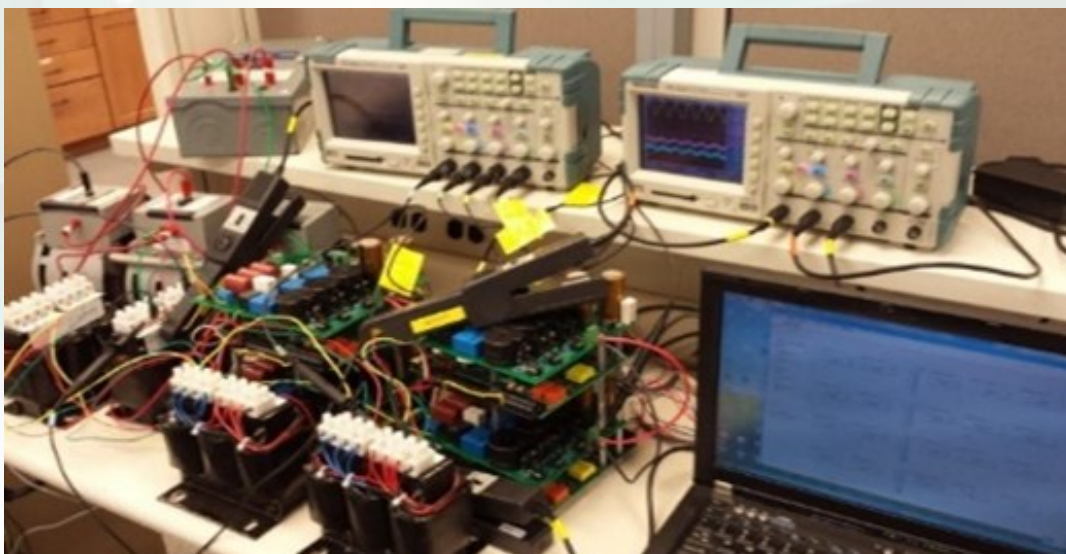
Future Hybrid Microgrids (GR-14-08)

Microgrids enable integration of distributed energy resources and increase the reliability of the power grid. Power electronic interfaces are the key components of future microgrids since power flows are subject to ac/dc, dc/dc and dc/ac conversions.

This project includes the design and construction of hybrid-microgrid prototypes based on power electronics in the MVA power range which have efficiency and system complexity issues not encountered in low-scale prototypes. As the power ratings of power electronic interfaces increase, their base impedances



decrease. Thus, ac microgrid stability becomes compromised by the low-pass filter resonant propagation. To this effect, a scaled-down microgrid prototype has been built for verification purposes and safely testing the proposed ac/dc converter control algorithms. The high-power equipment (i.e., converters, transformers, circuit breakers, etc.) at NCREPT have been modified to form a microgrid testbed. A new microgrid infrastructure is under construction for proving the new control algorithms, which aim at mitigating the high-power microgrid stability issues.



Projects

Distributed Power Quality Improvement using Power Electronics and Digital Signal Processing (GR-16-03)

This project addresses power quality improvement for compensation of non-periodic load currents using sharing among distributed power electronic converters. A new technique is under development for load power quality improvement using three co-located power quality conditioners. Using simulation based on real-world data, compensator control methods have been developed for compensation and power quality improvement of highly distorting loads, such as those found in steel mills. The compensator consists of three co-located devices with different calculation windows, called fast compensator, reactive compensator, and slow compensator. Each one of them is responsible for the compensation of one phenomenon in the non-periodic current: sharp edges, reactive current, and low frequency modulation. In order to improve the flexibility of the technique, a fuzzy based adaptive window is used for the slow compensator to find the optimum window for different load characteristics. In the current stage of this project a prototype demonstrator is under construction for experimental validation of the proposed method.

PMU Role in Evaluating PV Generation Impact on Transmission Grid (GR-15-05)

The increasing adoption of MW utility scale solar photovoltaic (PV) arrays presents challenges to existing electrical distribution systems. Large scale solar PV arrays may be located in areas where the feeder design was based on unidirectional power flows. With distributed PV generation, there may be disruptions to systems protection and compensation equipment. This project investigates the use of distribution-level phasor measurement units to monitor and control distribution systems that include large PV sources in order to develop methods of mitigating voltage disruptions. The result is an understanding and recommendation for the use of real-time PMU information to control the local distribution and transmission system using FACTS and D-FACTS equipment to compensate for the effects of solar PV generation.

Physics-based Analytical and Compact Modeling of GaN Power Devices for Advanced Power Electronics (NSF-15-06)

Advances in wide bandgap materials such as SiC and GaN have led to substantial advances in power semiconductor devices and are now positioned to dominate the next generation of power electronics replacing silicon devices. This research focuses on the creation and validation of analytical models for state-of-the-art GaN power devices. The market share of GaN power devices is expected to reach a staggering \$15.6 billion by 2022, mainly due to the growing demands in the power and energy sector, the communication infrastructure sector, and the power electronics market. GaN devices are expected to reduce overall energy conversion losses down to 1%, resulting in annual savings of nearly \$40 billion in US revenues. A high-efficiency and green energy infrastructure is vital for reducing over-

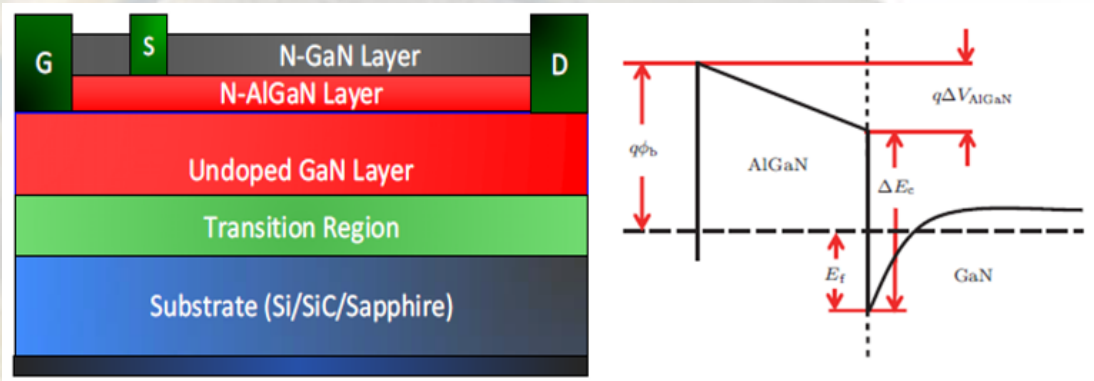


Fig. 1 Conventional normally-on device and its corresponding energy-band diagram.

all expenditures and reducing the carbon footprint of the electronics industry and the environment. The expected outcome from this fundamental research focuses on developing physics-based compact device models for circuit simulations that will help electronics engineers rapidly develop circuit designs and prototypes based on GaN devices. Impacts of this model will enable a side-by-side comparison of GaN and silicon devices at the design and analysis phase. This in turn will likely promote increased usage of GaN semiconductor technology. The models generated in this research will be open access and made publicly accessible on the NSF Industry/University Co-Operative Research Center website under the Grid-Connected Advanced Power Electronics Systems (GRAPES) center site.

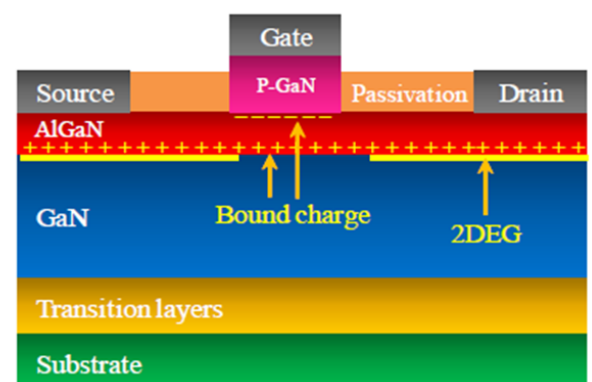


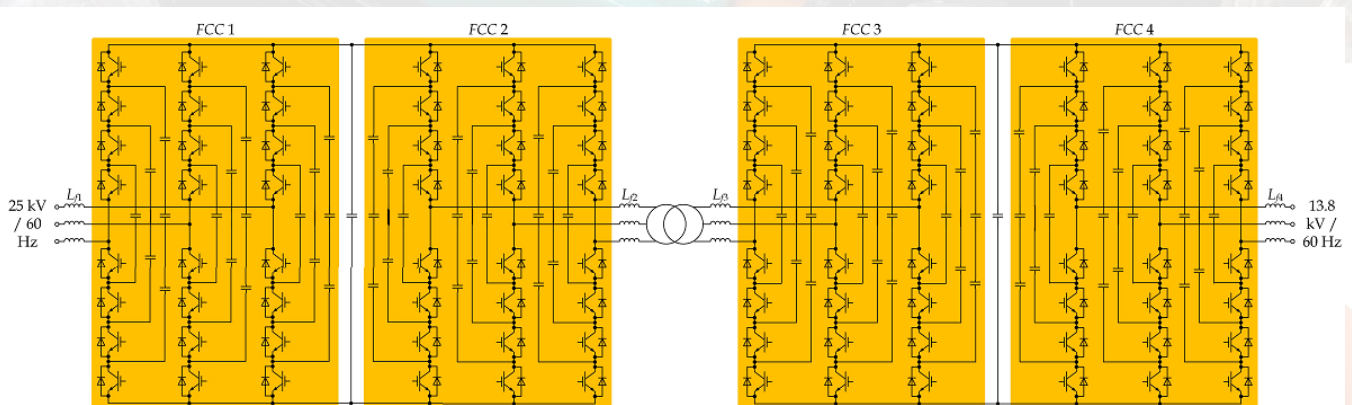
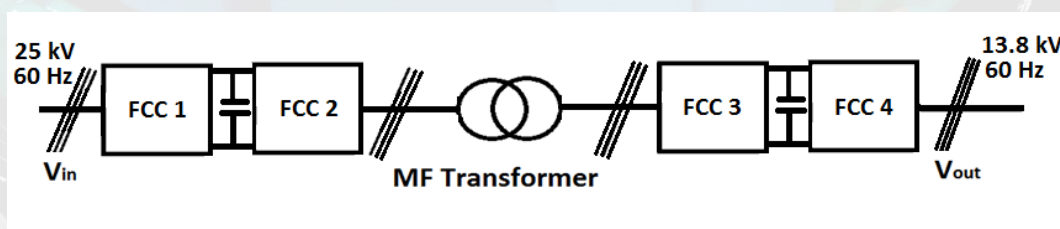
Fig. 2 Normally-off device with p-type GaN gate.

Projects

Conventionally, the GaN device is a normally-on device. The device is shown in Fig.1 with its corresponding band diagram. GaN devices for power electronics applications are modified as shown in Fig. 2 with a p-type GaN gate and an AlGaN buffer layer. The discontinuity in polarization between the AlGaN barrier layer and p-GaN cap layer brings about the desired normally-off operation by lifting the conduction band above the Fermi-level.

Mobile Power Substations (GR-15-03)

Developing power grids that are resilient under disruptive events is one of the main objectives of electric utilities. A light-weight mobile power substation connecting two distribution feeders having different voltage levels would be a useful piece equipment to be deployed under emergency conditions. To this end, the main goal of this project is to evaluate potential designs for a mobile power substation characterized by its light weight so it can be transported in a single truck to interface two medium-voltage distribution systems operating under emergency conditions. The research team would evaluate arrangements providing electric isolation or not. Electric isolation will be implemented through the use of a medium-frequency transformer. Initial research will be centered on the modular multilevel converter (MMC) used in HVdc terminals since it may lead to a design with the highest power density.



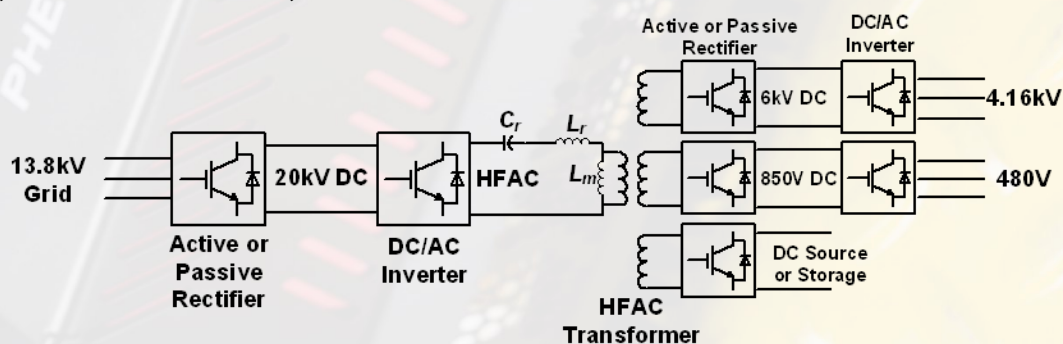
Notional block diagram and topology of a mobile power substation based on flying capacitor converters

Multi-Port Bi-Directional Resonant Solid State Transformer (GR-16-06)

There is a shift in the decades-old paradigm of energy generation and distribution. The emerging concept includes new elements such as Distributed Generations (DG), energy storage, DC systems, and power electronics-based systems. The conventional 60Hz transformers cannot meet the flexibility and controllability demanded by this new paradigm. The goal of this project is to develop the concept for an efficient medium voltage Solid State Transformer (SST) to enable smart and reliable Distribution Systems (DS) for grid power. Many researchers have worked on the SST concept. However, this enabling technology did not make a significant penetration into the utility grid due to several drawbacks: low efficiency, low voltage/power capabilities, cost and resilient packaging of enabling high band gap devices, and concerns regarding fault protection.

The objective of this project is to use Medium Voltage (MV) Wide Band Gap (WBG) devices (i.e. SiC switches and diodes) to increase both SST voltage and power so it can be applied at the DS level. In addition, a novel resonance feature has been added to the SST concept to significantly increase its conversion efficiency. This resonant operation along with proper controls enables usage of low cost no-load disconnects or breakers for system fault protection. Detailed analyses of the proposed system will be performed both for the power electronics system design as well as application and integration in a DS.

There is an impending need in future electrical distribution systems for flexible, controllable, compact, and efficient medium voltage transformers. There are many opportunities for commercialization for the proposed system if the efficiency can be increased to 98%-99%. Potential applications include all of the utility distribution systems, microgrids, AC/DC networks, DC data centers, etc.



One of the notational architectures for the resonant MV SST.

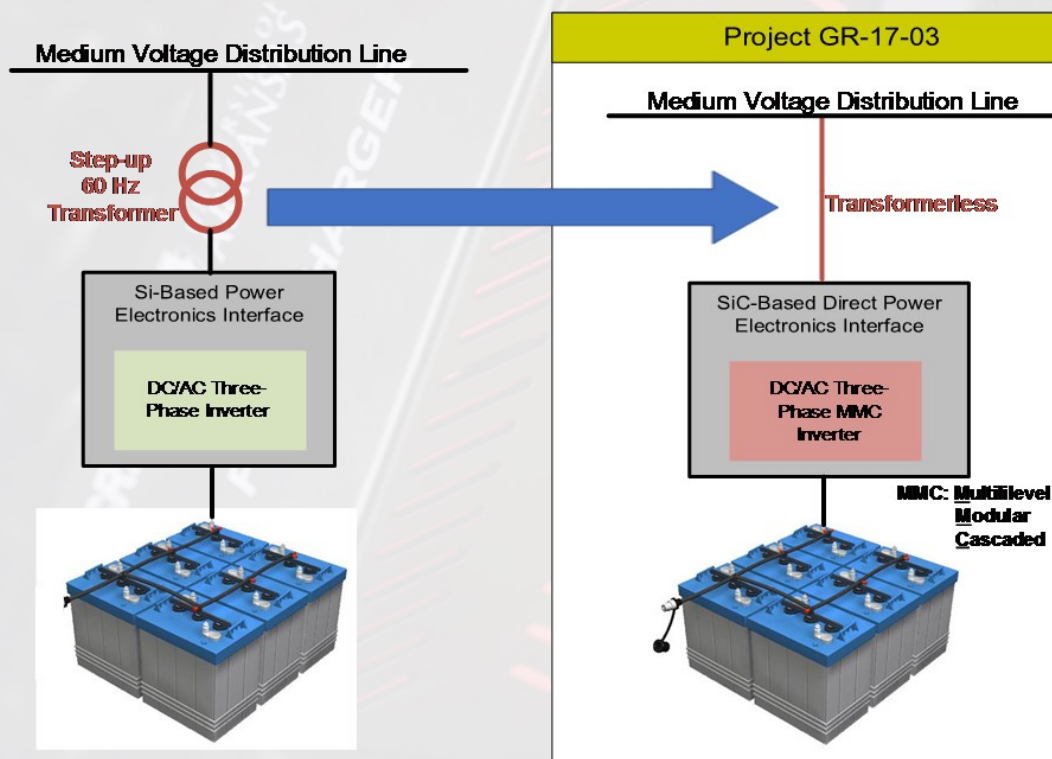
Projects

Distributed Energy Resources: A Testbed for Distributed Autonomous Control Concepts for High-Power Microgrids (GR-17-10)

Both the University of Wisconsin-Milwaukee (UWM) and the University of Arkansas (UA) have worked on several microgrid controls projects including high-power microgrids, hierarchical control, virtual droop control, and central control. There are several research tasks within Project GR-17-10 to be performed jointly by UWM and UA, (i) to develop the concept for distributed microgrid controls, (ii) to evaluate the reliability improvement using distributed controls, (iii) to build an HIL setup to test and implement microgrid control, (iv) to implement a high-power microgrid testbed (MGTB) at the UA National Center for Reliable Electric Power Transmission (NCREPT), and (v) to develop autonomous and predictive concept in a microgrid with higher penetration of renewables. Tasks I, ii, and v will be performed at UWM, led by Prof. Adel Nasiri. The concept of the distributed control system is based on installing fast and low cost controllers at each distributed source or smart load. The reliability assessment will be conducted using Markov Chain theory. Both UWM and UA will perform task iii on different platforms, with UWM on NI CompactRIO-based system and UA on Typhoon-based system. UA will perform task iv using the existing three back-to-back voltage-source converters, the so-called regen benches that will be connected in parallel to the point of common coupling in order to emulate different type of generators and loads. These regen benches would emulate wind power, photovoltaics arrays and other generators to determine their interaction and stability problems in high-power microgrids. The regen benches would work in two modes: the grid-connected and island modes. The UWM controller will be implemented on a system with real renewable sources and loads. The controller will take into account the forecast for renewable energy generation and load to minimize the stress on energy storage and improve power quality in the microgrid. The ultimate goal of this project is to compare the performances and differences between the UA high power testbed and the UWM testbed with high renewable penetration so a set of guidelines could be produced.

SiC-Based Direct Power Electronics Interface for Battery Energy Storage System into Medium Voltage Distribution System (13.8 kV) (GR-17-03)

This project involves the design and construction of a SiC-based direct power electronics interface for a battery energy storage system (BESS), which is to be integrated into a 13.8 kV medium-voltage distribution system. Normally, to interface a BESS to a medium-voltage distribution line, a step-up transformer is required to boost the inverter output voltage. The use of the transformer provides convenient isolation, however using a transformer to meet medium-voltage inverter insulation requirements leads to substantially higher leakage inductance, increased switching losses and limited transformer power transfer capability. Recent advances in high voltage power semiconductor devices, medium-voltage (≥ 10 kV) SiC power modules present an opportunity to realize a transformerless interface, shown in the Fig.1 below. Transformerless topologies, and the use of wide bandgap devices, have the potential for reducing cost and size of passive components for the medium-voltage inverter. To satisfy the medium voltage basic insulation level (BIL) requirements for the power electronics interface, modular multilevel cascade (MMC) inverters provide a better solution. This battery energy storage system interface will also include fault protection circuitry and communication protocols. The performance



of the control algorithms for a BESS equipment will be tested through an experimental prototype at the National Center for Reliable Electric Power Transmission (NCREPT) using the 13.8 kV distribution system.

Fig.1. Development of SiC-based transformerless interface for battery energy storage system

Projects

Coordinated Optimal Voltage Regulation for the Next-Generation Distribution Grids with High Penetration of PV Generation (GR-17-08)

Photovoltaic (PV) generation has been extensively deployed in the modern distribution systems. However, high penetration of PV generation also brings about severe challenges to the grid operations. Among all the challenges, voltage violation is the most critical, since the current voltage regulation schemes are designed to manage on-way power flow and cannot easily accommodate the fast changing dynamics in the distribution grids. In addition, the existing grid infrastructures are ill-equipped to gain real-time visibility of distributed PV generations, since the data acquisition and monitoring systems typically do not extend beyond substations and/or distribution feeders and are not designed to handle real-time processing of large volumes of data. To address these issues, a coordinated optimal voltage regulation (COVoR) framework is proposed to enable high penetration of PV generations. To accomplish this goal, three specific objectives are expected to be achieved. Firstly, we envision a self-sensing network enabled by the sensing and communication capabilities of smart inverters. Based on these measurements, a scalable and optimal scheme will be developed to partition the distribution grid into dynamic voltage regulation (VR) zones. Secondly, we will develop an advanced multi-agent system based cooperative control method for reactive power sharing among PV inverters within a local VR zone. Thirdly, we will fully exploit and upswing the advanced grid supportive capabilities of smart inverters by using model predictive control.

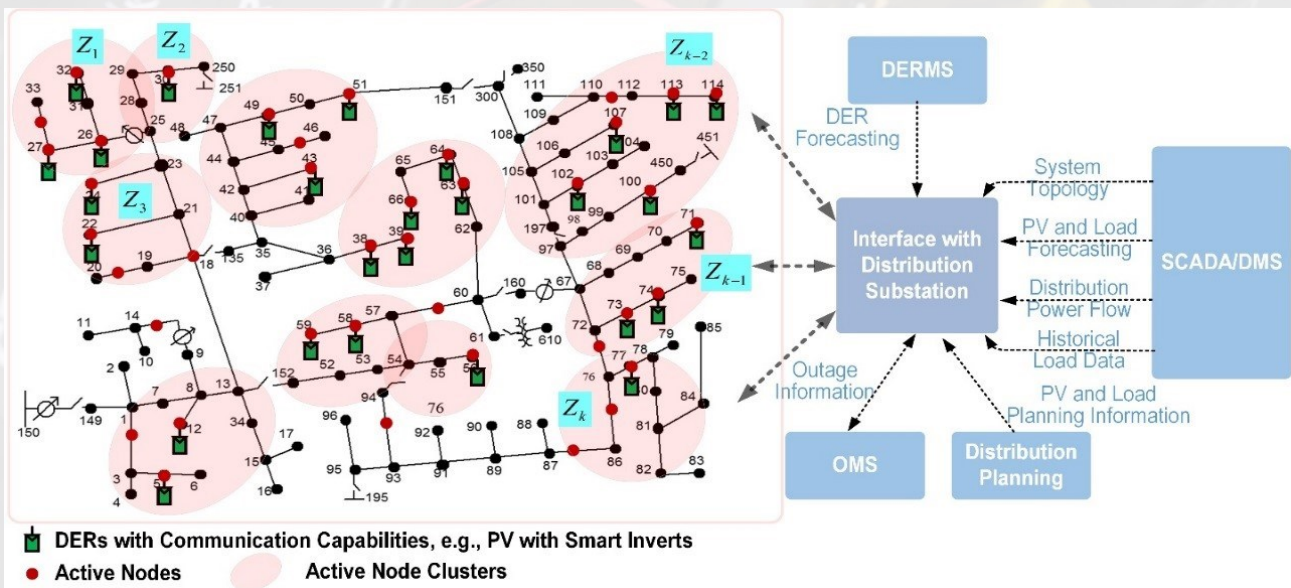


Fig.1. An illustration of the proposed coordinated voltage regulation framework

High Step-Up/Down Transformerless Modular-Multilevel DC-DC Converter (GR-16-02)

This project develops and builds a high step-up/down transformerless dc-dc modular multilevel converter (MMC) that would be applicable to MV distribution-level power systems. The design achieves high voltage ratios for interfacing renewable energy sources such as photovoltaic, wind turbine and line interactive UPS systems. The converter uses an MMC approach operating in resonant mode in order to improve overall efficiency. This topology operates to step-up the input voltage with 1:10 or larger conversion ratio. As a bidirectional converter, it also provides step-down capability at the same voltage ratio (10:1 or greater). By eliminating the presence of a magnetic core transformer as used in conventional designs, this project provides a small, low-cost, direct, and simple solution for high step-up/down converters while meeting the safety and isolation requirements given by IEC and UL standards.

A High Power Real-time Photovoltaic Source Simulator (GR-16-04)

High power, e.g., 1 MW, photovoltaic (PV) source simulators can be utilized to evaluate the performance and study the grid integration issues of the utility scale PV inverters in the laboratories. However, due to the high cost of commercial PV simulators at MW level, which are usually programmable DC power supplies, this testing capability is not common in public testing facilities. In this project, a hybrid PV simulator is proposed to emulate PV arrays up to MW scale. The reference curves can be either generated by using an actual PV cell to ensure the high fidelity, or obtained by using model based methods, such that repeatable results can be produced. The power stage will consist of a grid-connected active front end and an interleaved dc-dc converter. A novel sliding mode controller will be developed to ensure the reference tracking performance and the bandwidth of the PV simulator. Both hardware-in-the-loop simulation and experimental studies will be performed to validate the effectiveness of the proposed PV simulator.

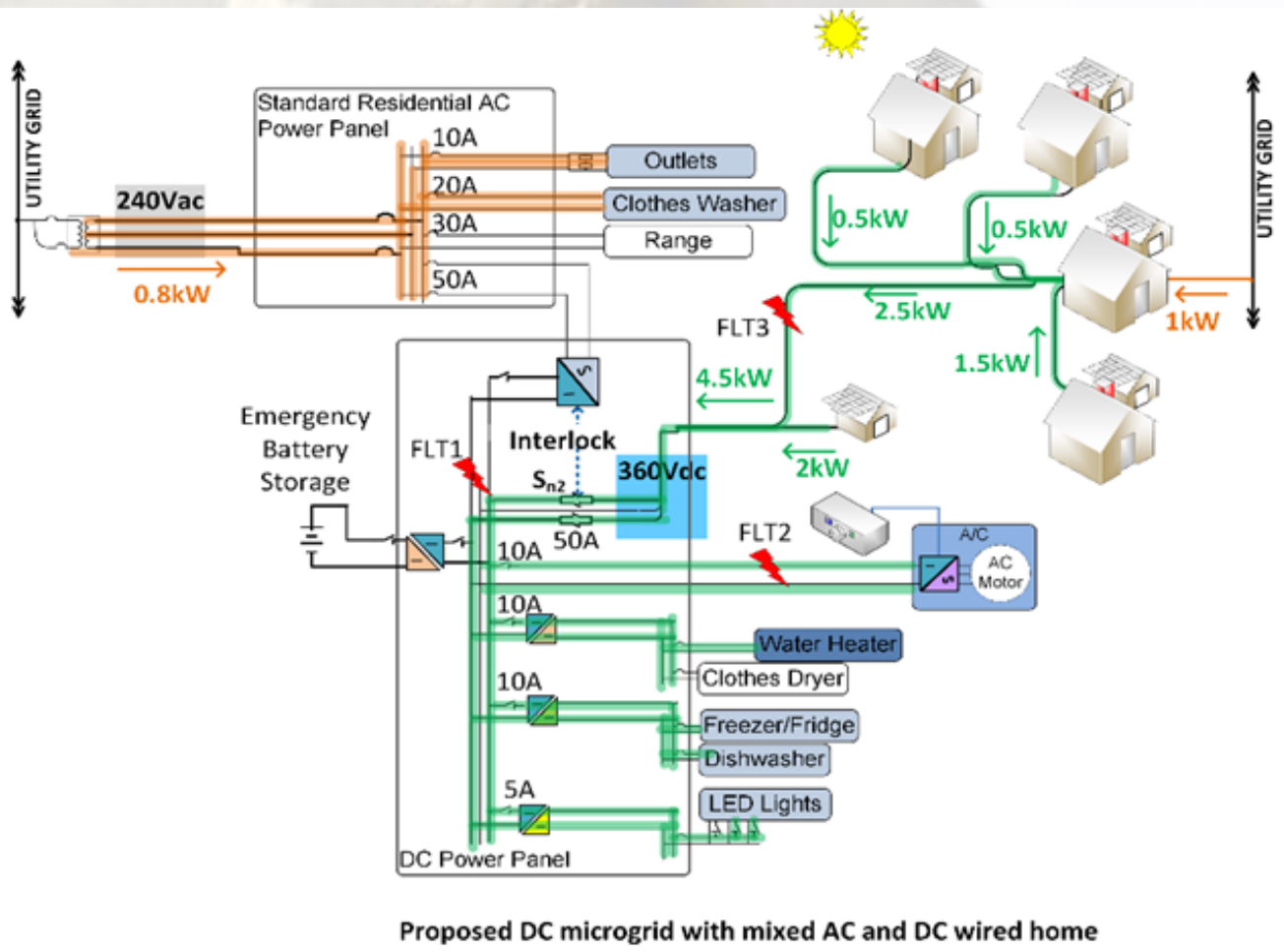
Projects

Fault Protection and Coordination in a DC Community Microgrid (GR-16-05)

Community microgrids have emerged as an alternative to address the rising societal demands for electric infrastructures that are able to provide premium reliability and power quality levels while at the same time being economically and environmentally friendly. The focus of this project is a community microgrid that supplies electricity to a group of houses within a neighborhood or several connected neighborhoods in close proximity. Such a system provides a unique opportunity for every day consumers to take advantage of renewable energy resources, such as solar through shared use. Further benefit comes through inter-connection of DC enabled smart homes which have the best chance of driving towards net zero energy usage. The benefit of DC interconnection of homes through a microgrid is lower cost and less complex integration of multiple shared energy sources and integration with energy storage. However, the most significant roadblock to such systems is the availability of safe and reliable protective distribution equipment. In conventional AC distribution, fault current is limited by the source impedance of the upstream distribution feed and the closer a fault is to that feed, the higher the fault current will be. Radial distribution of circuit breaker protected branches from the transformer feed to a house and then to the individual loads provides a time-proven method for isolating a fault closest to its location. A DC fed home has very different characteristics when fault behavior is considered, especially if the DC distribution includes multiple sources of power such as Solar PV, Battery back-up and DC converted utility feed. If a near zero-ohm fault is suddenly applied, the fault characteristic is dominated by energy storage on the bus and inter-connecting cables. So effective DC protective circuits must be able to discern faults and isolate them from the rest of the system on the order of microseconds. The purpose of this project is develop and test solid state circuit breaker based radial distribution systems that can act to isolate faults with minimal need for sensing circuitry and without inter-device communications. A unique approach is proposed which utilizes normally-on Wide Band Gap (WBG) Silicon Carbide (SiC) JFET or Gallium Nitride (GaN) HEMT devices as the fault interrupting solid state switch and a fast-starting isolated DC/DC converter as the protection driver.

Projects

The new SSCB detects short circuit faults by sensing its drain-source voltage rise, and draws power from the fault condition to turn and hold off the SiC JFET. This new circuit breaker technology offers a reaction time of 1-2 μ s, about 10X faster than any previously reported solid state circuit breakers and 10,000X faster than any mechanical circuit breakers.



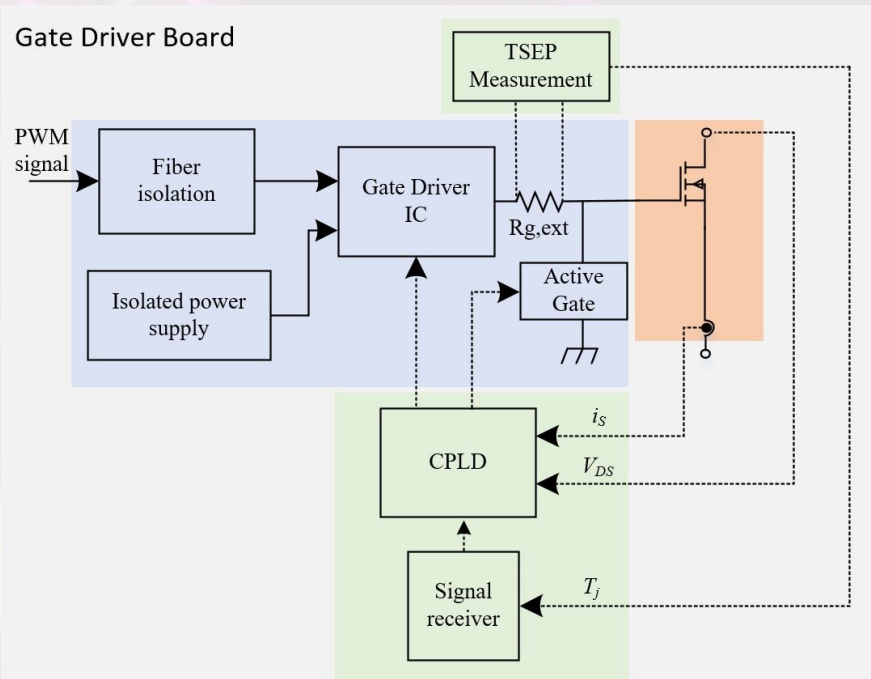
Projects

Optimized Gate Drivers for High Voltage Power Devices (GR-17-04)

This project's main focus is to develop a gate driver with an integrated power supply to drive high-voltage silicon carbide (SiC) devices. In particular, the focus is on the 10 kV SiC MOSFET, which is available and has been tested in some literature studies. The capability of commercially available gate drivers do not meet the requirements needed to efficiently drive SiC devices at the 10 kV

voltage level. However, the use of high-voltage SiC devices in power electronics is increasing. This calls for the development of research techniques and growth in the area. Thus, this project aims to develop and optimize a gate driver board for the 10 kV SiC MOSFET with the goal of optimizing the performance, cost, and size.

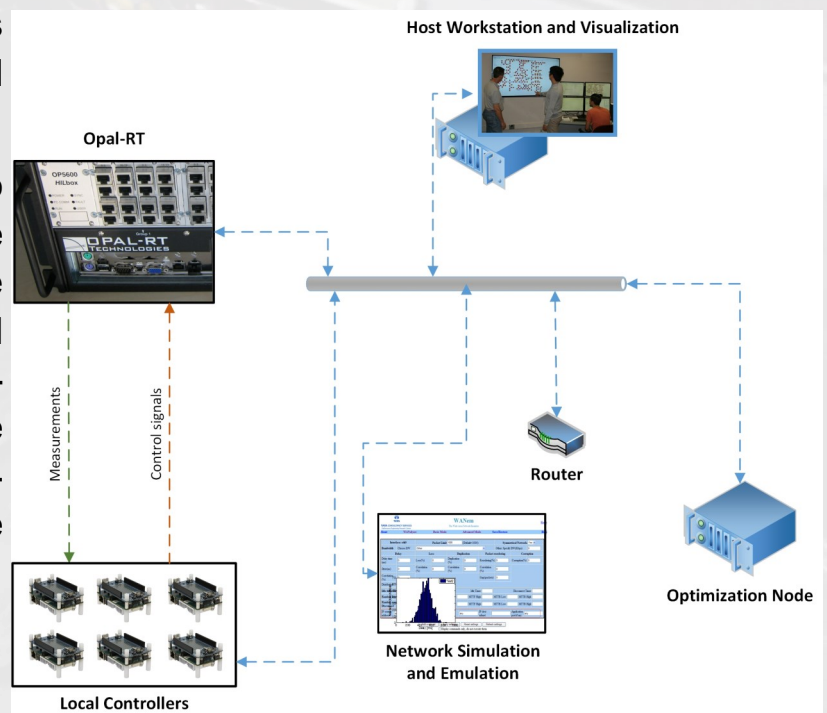
The scope of the project addresses the main issues inhibiting the development of the SiC device gate drivers, such as isolation, dv/dt EMI tolerance, and protection. The small collection of research which analyzes the performance and characterizes the high-voltage SiC MOSFET is used to determine the gate driver's needs. Ongoing research and industry needs are considered in the optimization of the gate driver board design. A PCB will be fabricated for the design, and the testbed for the module will be created. The design cycle will consist of both simulated and physical testing, including the development of a double-pulse test at high-voltage to be done at the National Center for Reliable Electric Power Transmission (NCREPT). This testbed development will also serve as a standard for future research projects in this area. In addition to the optimization of the main driver functions, alternate laminate technologies will be considered including the use of LTCC (low-temperature co-fired ceramic), which would increase voltage isolation.



PV Inverter Control to Sustain High Quality of Service (GR-14-05)

Distribution systems are being challenged by voltage fluctuation due to the increasing penetration of distributed photovoltaic (PV) generation. The overall goal of this project is to define strategies for the planning, control, and coordination of PV plants that take into consideration quality-of-service requirements. We have been conducting research on the following topics:

- ◆ A stochastic approach to optimum placement of photovoltaic generation in distribution feeders. We apply a stochastic method based on kernel density estimation to identify the optimum location of PV generations in distribution feeders. Probabilistic load flow is used to take into consideration the uncertainty of the PV output and the load demand. A 38-node distribution system located at Walterboro, SC is modeled to test the proposed algorithm.
- ◆ Day-ahead optimal scheduling of PV inverters, OLTC and capacitor banks in distribution feeders: A day-ahead optimal scheduling for reactive power of PV inverters and tap position of on-load tap changers (OLTC) is proposed. The objective is to minimize the node voltage deviations and power losses while keeping the frequency of the in-traday tap changer operations under a predefined value. The PV power and load demand are forecasted day-ahead. Simulations are conducted of a modified IEEE 34 node and IEEE 123 node distribution system with and without the optimal control. A Monte Carlo-based probabilistic load flow simulation is proposed to compare the results with and without forecast errors on the PV generation output and load demand.
- ◆ Real time control of PV inverters. To compensate for hardly predictable generation and load variability we are developing a fast real time control that correct the setting of the day-ahead optimal scheduling. We are testing this system using our laboratory infrastructure in a hardware in the loop approach.



Projects

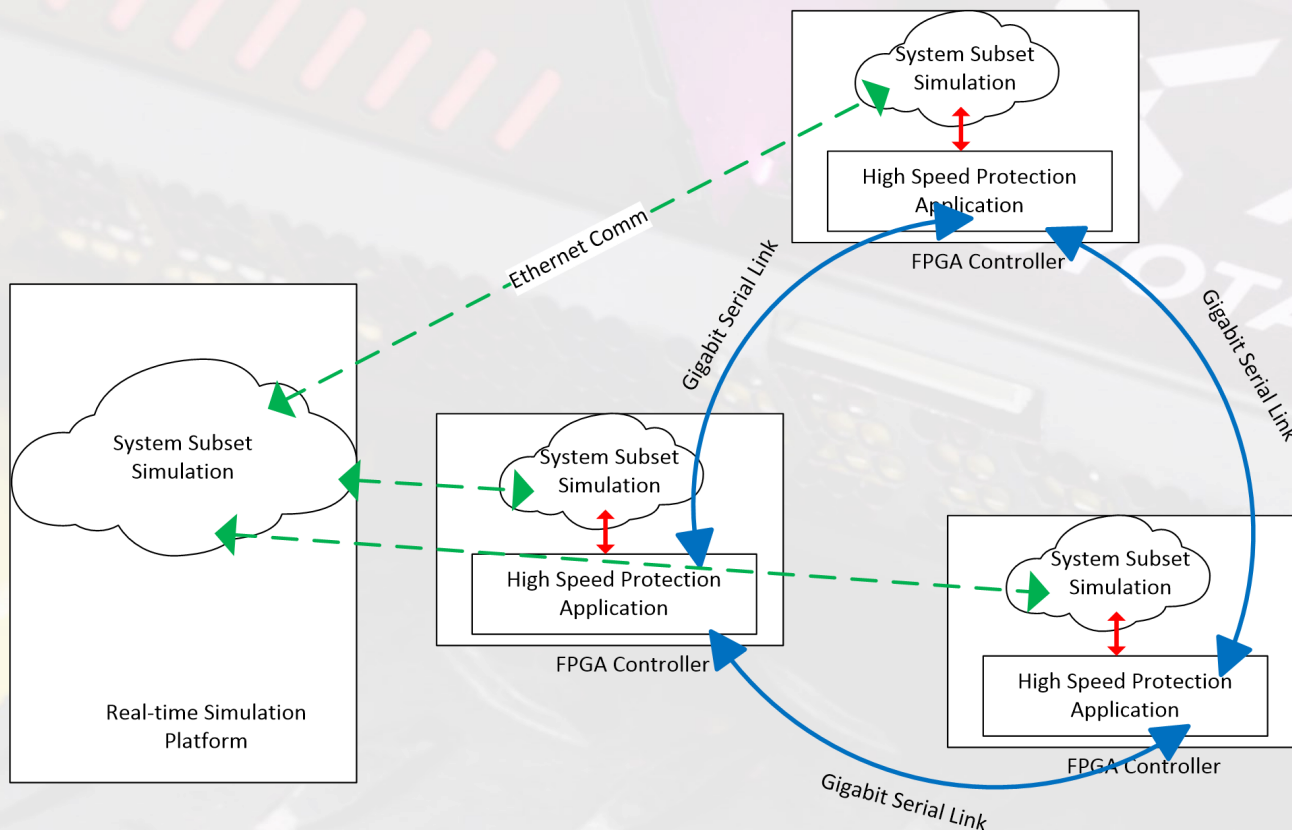
Fault Detection and Management Needs Development Protective Relaying Methods for Microgrids (GR-17-02)

Because the microgrid is a dynamically changing mesh that will respond differently to faults depending on its configuration, achievement of reliable fault discrimination drives complexity and cost. When short circuit faults occur within a microgrid multiple sources of energy can feed the fault, including adjacent electronic loads with front-end filter/storage capacitors—this is particularly the case with DC microgrids where sudden fault inception is characterized only by connected capacitors and cable inductances. An array of additional corner case scenarios exist each of which must be handled in a different way.

This project is a collaborative effort between UWM (Cuzner) and USC (Ginn, Benigni) to develop Hardware in the Loop (HiL) and Power Hardware in the Loop (PHiL) test platforms to develop protective relaying approaches for AC, DC and hybrid AC/DC microgrids. Presently, UWM has developed a Controller-Hardware in the Loop (CHiL) system that enables the study of timing propagation delays between distributed controllers embedded within Distributed Energy Resources (DERs), reliability of a decentralized microgrid control architecture and demonstration of scalability concepts. The UWM CHiL consists of Compact RIO units used to collect feedback information and interface with a Tertiary controller implemented in LabView. USC has developed an Integrated Grids Laboratory (InteGraL) that supports combined simulation of power and communication grids for testing distributed solutions for control and monitoring in distribution grids. The InteGraL system uses OPAL RT for power system simulation, NS3-RT and Apposite N-91 for communication network emulation, Compact RIO to emulate distributed control and data collection interfaces and multi-purpose ARM based processors to augment the HiL real-time simulation capability, 10 Gbit communication between nodes is available. The plan is to augment the CHiL and PHiL systems at UWM and USC to add high speed serial communications for protective relaying.

Projects

Common FPGA-based high speed serial communications implementations will be incorporated into the communication network emulations in order to research distributed and centralized schemes for achieving fault discrimination within the microgrid and to develop self-healing systems having autonomous fault detection, isolation and reconfiguration capabilities. This effort is part of a wider vision to enable collaborative research encompassing all levels of microgrid systems control an application to various industries.



NCREPT (UA)

The National Center for Reliable Electric Power Transmission (NCREPT) started its operation as a research center in 2005 and its 13.8 kV, 6 MVA test facility was opened on October 31, 2008. The test facility is suitable for testing distributed energy resources under IEEE 1547 and UL1741 standards.



- **Energy Efficient.** Test power is recirculated through the testing loop so the power drawn from the grid is limited to the system losses, enabling a cost-effective test facility.
- **Highly Reconfigurable.** NCREPT has two test loops, one at 480 V and one at either 4.16 kV or 13.8 kV. This allows for a wide range of power levels for testing.
- **Variable Voltage.** The test voltage can be varied from 0 to 528 V in the first test loop and from 0 to 15.18 kV in the second test loop due to the variable voltage capability imparted by NCREPT's VVVF Drive.
- **Variable Frequency.** The VVVF Drive also enables varying the fundamental frequency of the tests. Typically these are varied between 40 Hz and 70 Hz, but values outside that range are possible, though they require derating.
- **Dynamometer:** 100 hp, 4,000 rpm dynamometer test stand allows testing and evaluation of motors and drives.

Facility Rental:

- **Fixed weekly facility rental fee (government rates available)**
- **Utility costs based on actual usage**
- **Specialized equipment configurations available (additional fees may accrue)**
- **Fees for third-party certification (if required)**

For more information, please contact:

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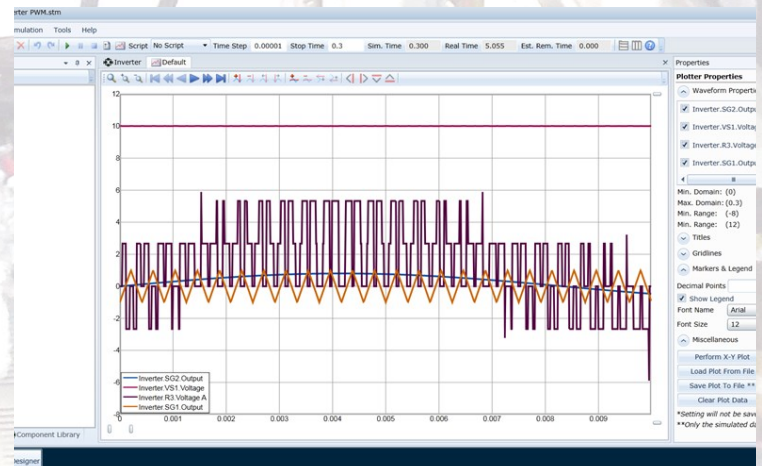
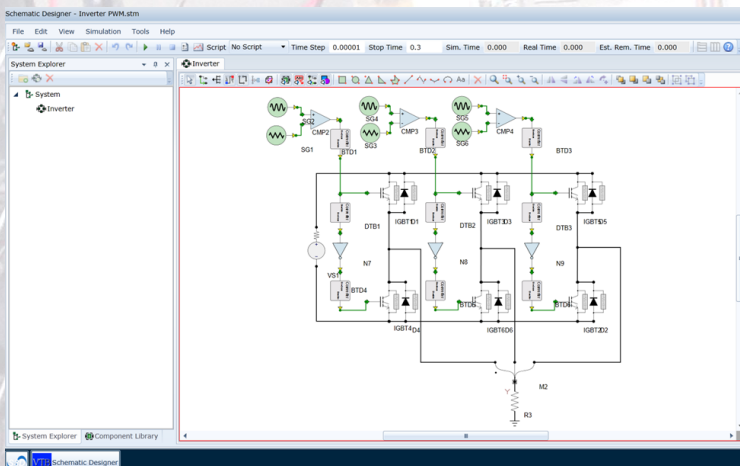


Virtual Test Bed (USC)

The Virtual Test Bed (VTB) comprises a suite of software for rapid virtual prototyping of large-scale, multi-disciplined dynamic systems. The VTB software suite includes the following:

- Schematic Designer is the central user tool for composition and visual presentation of system models, allowing assembly of component models into system models.
- Entity Designer aids developers in the creation of new simulation entities (such as new component models). A user interface allows the model developer to specify and characterize their new simulation entity.
- Module Designer allows users to define and package new reusable models that are based on subsystems created with Schematic Designer.

The VTB simulation framework includes several solvers that use distinct algorithms to implement and execute the system model. It also includes an extensive library of simulation models, belonging to one of two categories: Entities are elementary devices whose behaviors are defined programmatically via a compiled engine or mathematically via an interpreted engine. Modules are subsystems made up of other components and a number of exposed parameters. These modules are treated as individual components in Schematic Designer. VTB provides means for integrating models that were previously built in other simulation environments into a unified system model. Finally, VTB provides methods to exploit the COM interface provided by some tools, such as Matlab, to integrate models into VTB via co-simulation.



Power Electronics Testing

National Center for Reliable Electric Power Transmission (NCREPT)

University of Arkansas, <http://ncrept.uark.edu>

NCREPT was created in 2005, and its 13.8 kV, 6 MVA regenerative power test facility was opened on October 31, 2008. This facility is suitable for conducting distributed energy resource interconnection equipment (e.g., inverters) under IEEE1547 and UL1741 standards, evaluating electric and hybrid vehicle motors and a variety of other medium- and high-voltage power electronic equipment testing.

Energy Efficient

Test power is re-circulated through the testing loop so the power drawn from the grid is limited to system (heat) losses, enabling a cost-effective test facility. The regenerative drives REGEN1, REGEN2 and REGEN3 constitute the core of the test facility, since they handle the power flow, mimic sources and loads, and control power recirculation. Each regenerative drive consists of back-to-back three phase two-level converters. The first converter, or “load simulator”, draws or injects three phase currents at a user specified power factor. This allows mimicry of specific grid conditions (e.g., particular power factors, power levels, and even faults) or pieces of equipment (e.g., generators). The second converter regulates the dc-bus voltage and re-injects the reactive power associated with the first converter so no reactive power is provided by the utility system. The control scheme of the converters allows decoupled control of the reactive and real power flows, greatly increasing facility flexibility.

Highly Reconfigurable

Fig. 1 depicts four different test cells for the equipment under test (EUT). There are two test loops; the first at 480 V using test cell EUT1 and the second at either 4.16 kV or

13.8 kV using test cells EUT2, EUT3 or EUT4 and the taps available on transformers T1 to T6.

Variable Voltage and Frequency

With the VVVF drive (Fig. 1), test voltages can be varied between 0 to 528 V for the first test loop and between 0 and 15.18 kV for the second test loop, enabling soft starts for any test. VVVF also enables variation of the test fundamental frequency (e.g., 60 Hz or 50 Hz). Other frequencies are also possible within the limitations of the power transformers (Table 1).

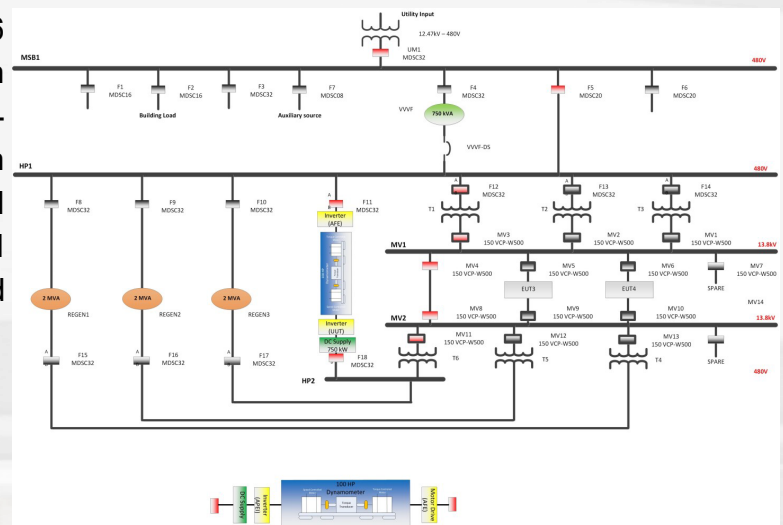


Figure1. One-Line Diagram of the NCREPT Test Facility

Motor Drive Testing

NCREPT is also home to a 100 hp, 4,000 rpm dynamometer test stand, which allows testing and evaluation of a variety of products, including electric and hybrid vehicle inverters, vehicle traction drives and other motors and drives.

DC Power Testing (Current and Future)

NCREPT has a 750 kW dc power supply capable of providing between 0 and 660 Vdc. Future plans include construction of a 2 MW dc supply with capability between 0 and 1500 Vdc and associated load banks. This will increase NCREPT’s testing capabilities in the areas of vehicle traction drives, DC breakers and much more.

Power Electronics Testing

National Center for Reliable Electric Power Transmission (NCREPT)

University of Arkansas, <http://ncrept.uark.edu>

Parameter	Rating
Power	Up to 6 MVA
Medium Voltages	13.8 kV or 4.16 kV (line-line) variable from 0 V to 15.18 kV
Low Voltages	480 V (line-line); variable from 0V to 528 V
Frequency	40 Hz or 70 Hz—Values outside this range (e.g., up to 400 Hz or down to 20 Hz) are possible, but require derating
Currents	300 A at 13.8 kV / 1000 A at 4.16 kV
Loads	Active loads fully programmable; test energy is recirculated
DC Supply	750 kW / 0—666 Vdc
Dynamometer	100 HP, 7,000 rpm; (up to 200 HP possible for short durations)

Standard Tests per IEEE 1547-UL 1741

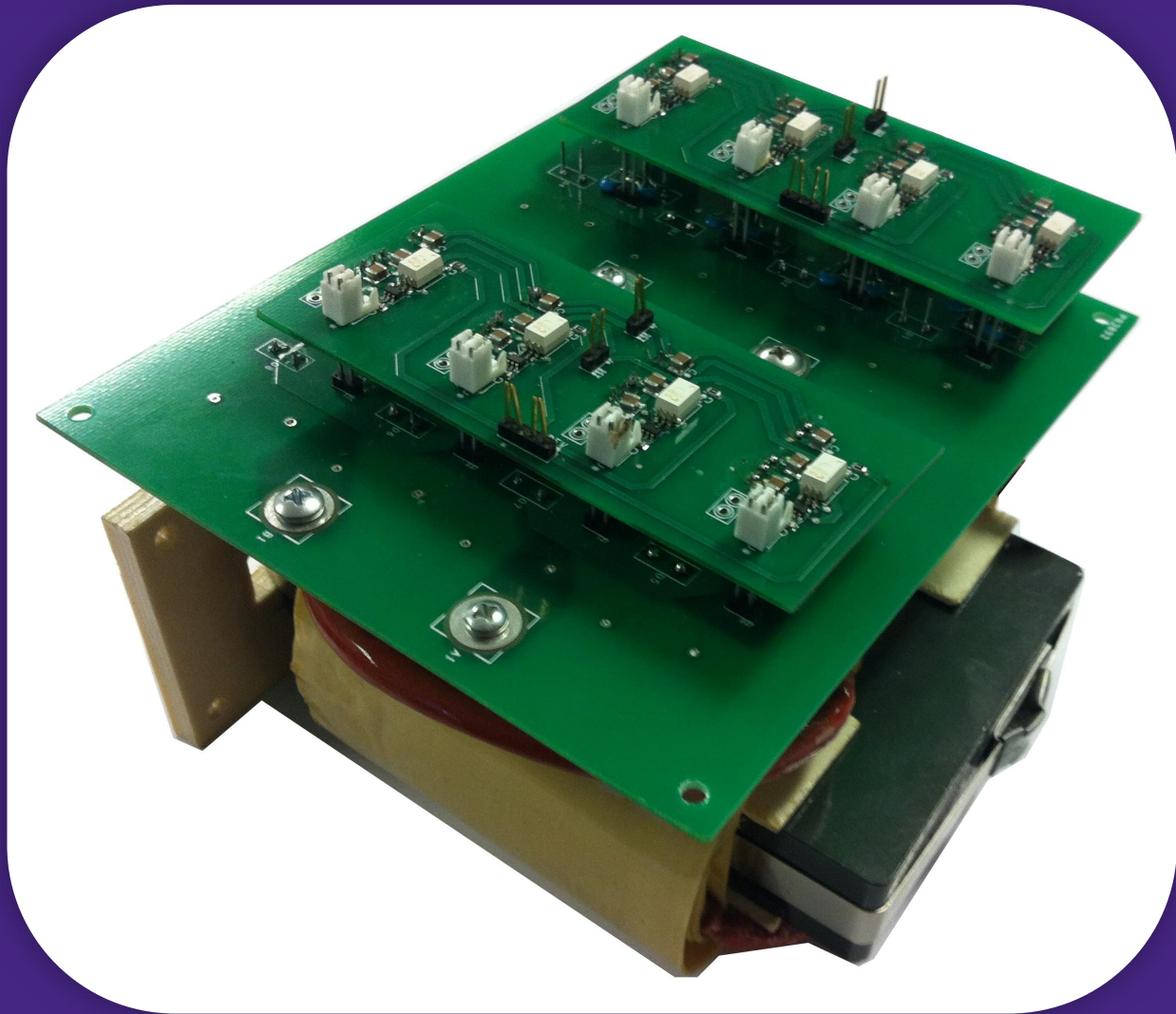
The following tests per IEEE 1547 and UL 1741 standards can be performed at NCREPT test facility:

1. Maximum Voltage Measurements (UL-1741/42)
2. Temperature: Ambient 25°C (UL-1741/43)
3. Dielectric Voltage Withstand Test (UL-1741/44)
4. Output Power Characteristics – Output Ratings (UL-1741/45.2)
5. Input Range (UL-1741/45.3)
6. Abnormal Tests: Output Overload Test (UL-1741/47.2)
7. Abnormal Tests: Short-Circuit Test (UL-1741/47.3)
8. Abnormal Tests: DC Input Miswiring Test (UL-1741/47.4)
9. Abnormal Tests: Ventilation Test (UL-1741/47.5)
10. Abnormal Tests: Component Short- and Open-Circuit (UL-1741/47.6)
11. Abnormal Tests: Load Transfer Test (UL-1741/47.7)
12. Grounding Impedance Test (UL-1741/48)
13. Operational Temperature (IEEE- 1547.1/5.1.2.1)
14. Storage Temperature (IEEE-1547.1/5.1.2.2)
15. Response to Abnormal Voltages (IEEE- 1547.1/5.2)
16. Response to Abnormal Frequency (IEEE-1547.1/5.3)
17. Synchronization (IEEE-1547.1/5.4, method 2)
18. Protection from EMI (IEEE-1547.1/5.5.1)
19. Surge Withstand (IEEE-1547.1/5.5.2)
20. Paralleling Device (IEEE-1547.1/5.5.3)
21. Limitation of dc Injection (IEEE-1547.1/5.6)
22. Unintentional Islanding (IEEE-1547.1/5.7)
23. Open Phase (IEEE-1547.1/5.9)
24. Reconnection to Area EPS (IEEE-1547.1/5.10)
25. Harmonics (IEEE-1547.1/5.11)



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