ELECTRIC POWER RESEARCH INSTITUTE

TECHNOLOGY INSIGHTS

A Report from EPRI's Innovation Scouts

GRID-CONNECTED ADVANCED POWER ELECTRONIC SYSTEMS (GRAPES) PROJECT SUMMARIES

THE TECHNOLOGY

Power electronics is a key technology to realize smart grid. Existing power electronic controllers use silicon based devices and there is a research need for adopting wide band gap (WBG) materials such as SiC and GaN in the place of silicon in order to improve efficiency and performance of the power grid.

THE VALUE

Power electronic controllers will provide controllability, flexibility, and resiliency to the power grid. Power electronics also provide innovative ways in the most economic way to integrate renewable resources to the power grid.

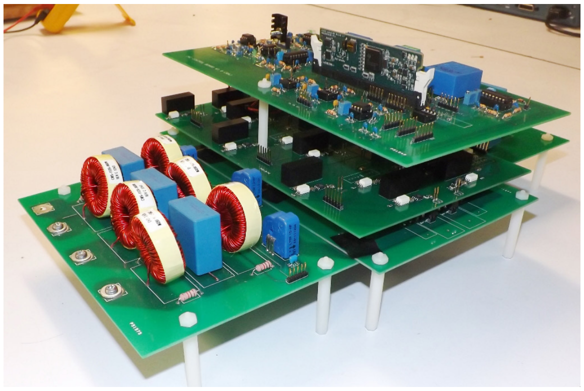
EPRI'S FOCUS

Scouting the power electronics activities around other industries and see how the advances in other industries will benefit electric power industry. Leverage the power electronics research funded by other organizations such as Department of Energy, National Science Foundation, and equipment manufacturers.

INTRODUCTION

The National Science Foundation (NSF) Industry/University Cooperative Research Center (I/U CRC) on GRid-connected Advanced Power Electronics Systems (GRAPES) operated by University of Arkansas and the University of South Carolina conducts collaborative research in power electronics. GRAPES was founded in 2009 under the NSF I/U CRC program. The NSF program provides funding for administration of the center, but the industry members' annual membership fees pay for the bulk of the research performed as part of the center in a pre-competitive, shared intellectual property arrangement. Currently GRAPES receives funding from 12 Industrial and government members including many utilities, EPRI, and other industries. EPRI is leveraging the power electronics research by collaborating with other members of GRAPES. There is an Industrial Advisory Board which plays an active role in the selection, direction and review of the research projects. The research thrust areas are chosen by the Industrial Advisory Board from proposals submitted by the faculty members at both the University of Arkansas and the University of South Carolina. These project areas reflect the synergies of technological advances and projected industrial needs. Dr. Ram Adapa of EPRI is the current Chair of the Industry Advisory Board of GRAPES. This Technical Brief provides the summaries of the on-going projects under the GRAPES research program.

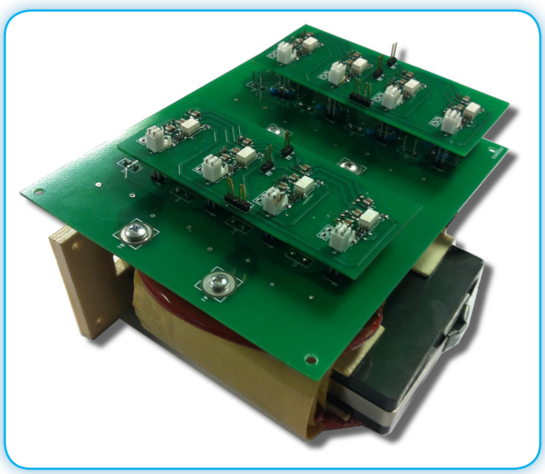
POWER DENSE POWER ELECTRONIC INTERFACES FOR DISTRIBUTED GENERATION



Several renewable energy sources (e.g., wind turbines) and non-renewable energy sources (e.g., microturbines using natural gas as fuel), broadly classified as distributed generation sources (DG), produce sinusoidal voltages at frequencies which are different from the grid frequency, or produce DC voltages which are not compatible with grid voltages. Most existing topologies use electrolytic capacitors, which are well known to be the weakest link in power converters. Thus, there is a need for power electronic interfaces for connecting DG which have high power density and are reliable. The indirect matrix converters (IMC) have volume advantages with few efficiency penalties over standard back-to-back converters. The main objective of this research is to develop IMC's which are reliable and have high power density to interconnect DC that require AC/AC conversion or DC/AC conversion with a high-frequency stage. The disadvantage of removing the electrolytic capacitors is that there is no energy storage element to provide ride-through capabilities so this research will also investigate the viability of using the boosting operation of the IMC after developing the SiC-based IMC prototype.

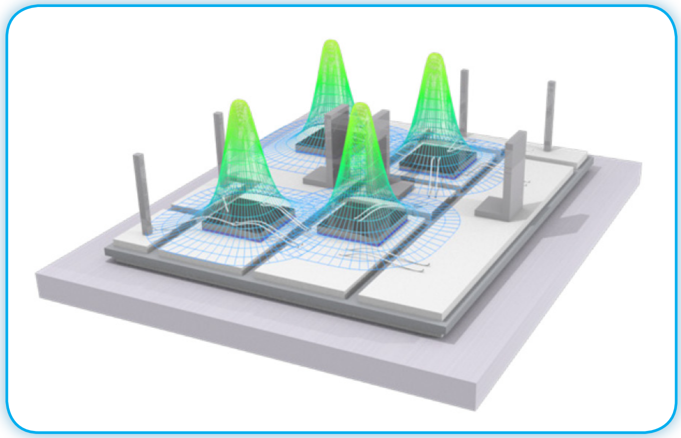
SOLID STATE TRANSFORMER

The traditional fundamental-frequency power transformer is a key component in many applications where it is necessary to step up or step down from one voltage level to another. This operation is done efficiently but at the expense of needing a large size/volume. There are several new applications where size or volume is critical. A solid-state transformer brings desired size or volume reductions as the expense of lower efficiencies and greater system complexity. The main goal of this project is to develop a modular solid-state transformer for applications characterized by space limitations, interconnection of solar or wind farms, or high fault currents. Modules are connected in series on the high-voltage (HV) side and in parallel or in series on the low-voltage (LV) side depending on the selected application. The HV DC side of the SST module consists of a three-level full bridge topology switching under zero-current and zero-voltage switching. The LV DC side could be a two- or three-level full bridge topology depending on the applications. It is envisioned that the high-frequency (HF) link operates at 20 kHz and a HF transformer provides the required voltage ratio for the selected application. Initially, the research team will consider silicon carbide 1.7kV MOSFETs for the HV side that will be packaged by UA. The LV side of the SST could use the same devices but their voltage rating will depend on the selected application. Applications for this prototype are not only in distribution systems but also for electric train traction. So, the potential for a product in this space is also important.



POWER MODULE LAYOUT SYNTHESIS TOOL

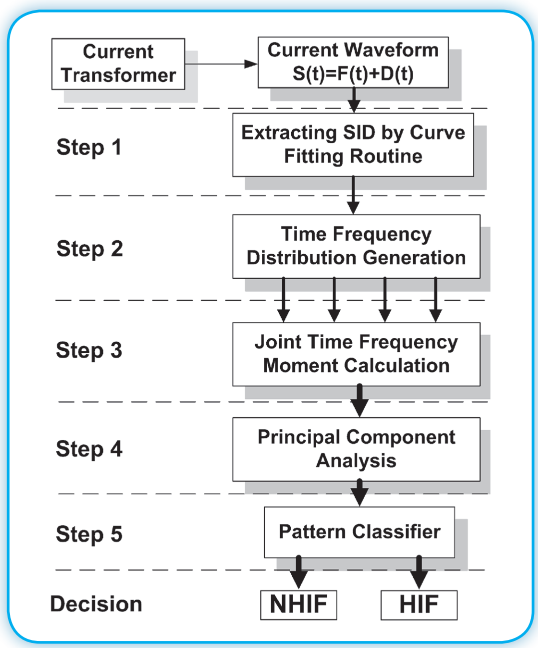
A multi-year project into the design and implementation of a CAD tool that is used to analyze and optimize the simultaneous electrical, mechanical and thermal issues involved in power module design. This project focuses on the development of algorithms for thermal model



abstraction, constrained optimization at the lumped-element level of representation and layout synthesis of power modules accounting for the electrical parasitics, thermal management issues and mechanical constraints imposed by common substrate materials. The researchers will develop a prototype software package that runs on a Windows-based personal computer or a Linux machine that will determine the optimal geometry of the placement and orientation of the chips on the substrate that meets the electrical performance criteria while minimizing area and material waste in an effort to minimize cost.

GPS-BASED SMART RECLOSER

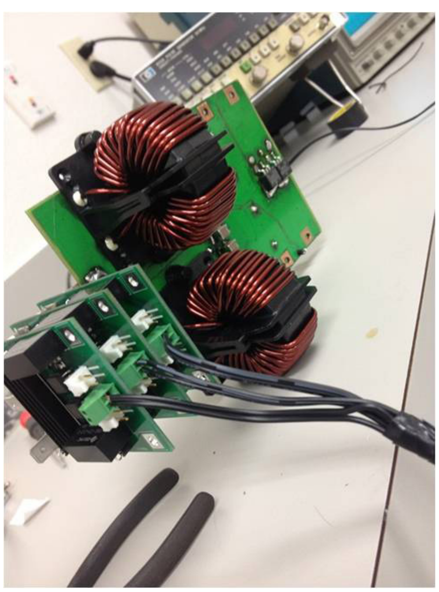
This project has two primary goals aimed at the design of the next generation of reclosers with enhanced fault detection capabilities and semiconductor switches. The first goal of this project is to design a detection technique for high impedance faults in distribution network. High impedance fault (HIF) is one of the most challenging faults in power system network, since HIF does not produce any significant change that could be detected using traditional power system protection techniques. In this project, our technical approach is time-frequency



analysis (TFA), a well-known tool for investigating transient and stationary signals by simultaneous use of time and frequency. We will apply TFA technique in order to extract signatures from HIF. The extracted features will be classified using pattern recognition technique in order to achieve detection of the HIF. The detection method will be evaluated by means of four criteria; (1) dependability, (2) security, (3) speed, and (4) cost. Next we will pinpoint the faulted feeder, and locate the HIF using provided time-synchronized voltage and current data in distribution. The second goal is the exploratory scoping of feasibility, technical competitiveness, and system requirements for a hybrid circuit recloser having both power electronic and mechanical elements. The hybrid recloser could 1) enable controlled current testing of a circuit prior to reclosing, so as to avoid reclosing into a persistent hard fault, 2) permit soft-restart of the disconnected grid segment.

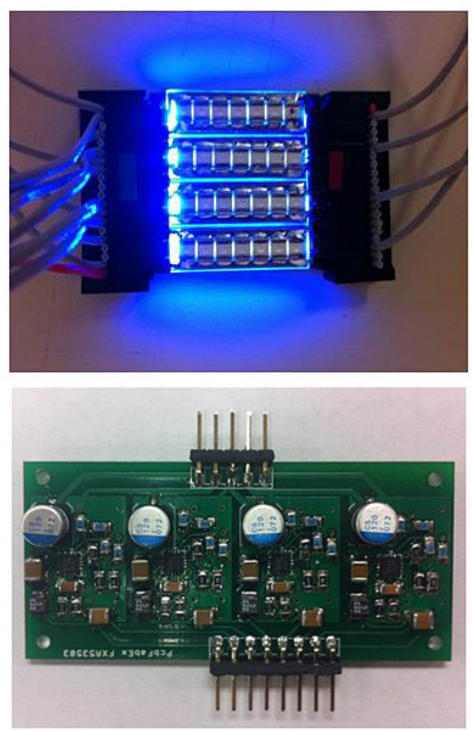
MODULAR MULTILEVEL CONVERTER FOR TRANSMISSION LEVEL BATTERY STORAGE

This project investigates the design of a modular multilevel power converter (MMC) for interfacing battery energy storage to the transmission level electric utility grid. An investigation of appropriate energy storage technologies will be conducted in order to set the parameters for the converter design. The converter will then be optimized in terms of a multi-stage output topology, switching device selection, and DC-DC battery interface. Overall, this provides a basis for developing MW capacity transmission level modular multi-stage converters. Grid storage technologies will be mainly considered for the functions of frequency regulation, damping of subsynchronous resonance, voltage support, and reserve capacity. Relative costs, power levels, and charge/discharge profiles will be tabulated and used to establish the range of parameters for a converter that will be suitable for grid-connected energy storage technologies. The project will include the development of an IEEE-style benchmark of a regional transmission system that would benefit from battery storage with an SSSC interface. A prototype SSSC z-source converter will be built and validated based on the analysis and simulations described above.

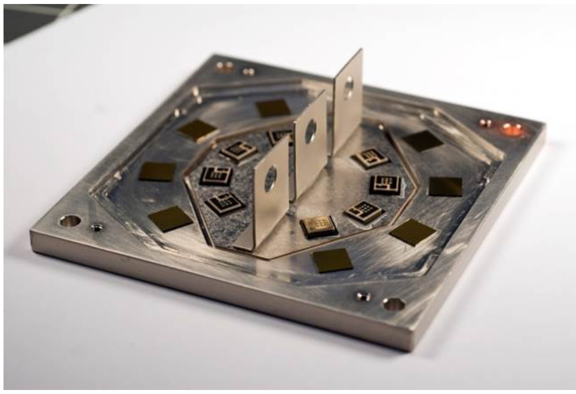


GAN OPTICAL ISOLATION FOR WIDE BANDGAP POWER ELECTRONIC SYSTEMS

There is a need for power switches that can operate at high voltage, at high temperatures and at high switching frequencies with low losses. Power switchers fabricated from a wide bandgap material such as SiC or GaN can outperform conventional silicon switchers, due to material property advantages. One common problem in grid-connected applications is the need for high-voltage-isolation of gate drivers, while yet operating efficiently at the high switching frequencies and high temperatures enabled by wide bandgap devices. The gate driver must also provide the appropriate protection and sensing functions needed for reliable power converter operation. The goal is to develop a high-performance optical control for SiC and GaN devices. This includes optical supply of gate control energy, optical switching of gate potentials, and optical feedback of sensed quantities such as main switch current. Thus protection and current sensing capabilities are an integral part of the proposed interface. The optical coupling will be realized using GaN devices that provide superior speed, efficiency and voltage-isolation capability. An additional advantage for GaN power devices is that the proposed drive can be technologically compatible with GaN processes used for power device fabrication, so that eventually a monolithically integrated GaN power device with optically isolated drive can be realized. But as a first step, GaN optical control of SiC power switches will be realized. This project is funded jointly by GRAPES and an NSF Fundamental Research Grant.



Optically Isolated Gate Driver for Wide Bandgap High-speed Devices

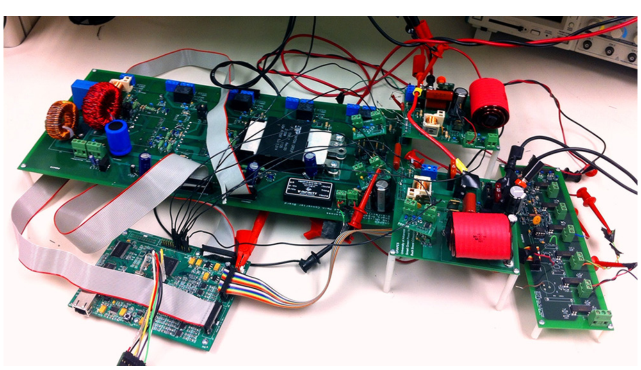


POWER MODULE PACKAGING

The first phase of the power module packaging project (GR-10-01) concentrated on achieving the high-voltage (10kV or higher) breakdown requirements of the power electronic modules consisting of two power semiconductor devices. A new dielectric based on the polyamide imide embedded with nano particles was developed using a sol-gel method. It was demonstrated that this dielectric could increase the breakdown voltage of the power module. Several power module architectures were also developed, in particular, the concept for a double-sided high-voltage power module. For practical applications in grid-tied power electronic applications, the current-carrying capability of these power electronic modules should be increased. Due to the relatively small current carrying capability of the wide-bandgap power semiconductor devices, it is necessary to parallel several of these devices in practical power electronic modules. As a continuation of the current SiC power module development effort, we propose to improve power processing capability of high voltage SiC power modules through optimized device paralleling.

SMART GREEN POWER NODE – INITIAL DESIGN AND PROTOTYPE BUILD

A “green power node” is a communicative power electronic system that manages the flow of power between (mostly DC) on-site power resources such as generation, storage, and loads, while it also provides a bidirectional interface to a 240 V single-phase residential grid connection that supports smart grid management. Example power sources that may connect to this system include photovoltaic cells or fuel cells. Example storage systems include batteries (stationary, or in a vehicle). Example loads include variable-speed drives in heat pumps, electric vehicles, kitchen appliances, and consumer electronics. In the first phase of this project, GRAPES researchers worked to provide a general-purpose node to integrate DC and AC power and load resources in residential power systems and to provide standardized grid-side connection, with the objective of making the system dispatchable from the grid side and uninterruptable on the customer side. Universal and bidirectional power ports on the DC side connect to a variety of power resources. Network data interface for local and grid-area data access is included in the system. In the second phase of this project, researchers are constructing a field-testable prototype of the green power node.



TRANSIENT STABILITY IMPROVEMENTS IN WIND FARMS USING PE AND FACTS DEVICES

The goal of this work is to investigate transient stability issues related to wind farms and how these issues can be mitigated through control. Different types of wind farms (type C and type D) will be simulated. Two cases will be considered: without and with FACTS-based series compensation. In the case of no series compensation, modal analysis and time-frequency methods will be used to find the optimal location of damping filters, of the active, passive or hybrid type. The second case of series transmission line compensation using FACTS devices (TCSCs and GCSCs) will then be examined. Series compensation increases line loadability but introduces resonant modes that cause sub-synchronous resonance (SSR) problems. The project will investigate the design of coordinated controllers for FACTS devices and for the power electronic converters used for wind farm interface to the grid (type C and D) to damp SSR oscillations. The Time-Frequency Technique (TFT) of analysis will be used together with modal analysis to gain additional insight into system dynamics.

ASSESSMENT OF RAPID VOLTAGE COLLAPSE INDUCED BY POWER ELECTRONICS

Transmission-level power system studies invariably include power-flow analysis for the purposes of ensuring line and transformer ratings are adequate and to assess the probability of voltage collapse. These power-flow studies are used in transmission planning and in operation of the bulk power system (on-line power flow). Load models are essential, especially if the study concerns voltage collapse. Increasing power electronic front ends (e.g., motor drives) with high control bandwidths may make existing load models inadequate, decreasing situational awareness for operators. In particular, if the load is modeled too simplistically, the model may have drastically different response to a change in the voltage than does the actual load. This project proposes that time-synchronized data acquired by phasor measurement units (PMUs) in conjunction with advanced signal processing techniques will ensure that accurate time-varying load models are available for use in voltage stability studies.

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