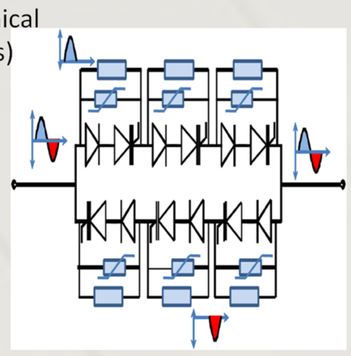
Arkansas Power Electronics International

Silicon Carbide-Based Solid-State Fault Current Control System for Vulnerability Reduction of Power Distribution Networks

System Overview

1. Detect and interrupt system faults in <1/4 cycle to limit fault duration and peak current
2. Recloser functionality with current limiting capability to test for fault presence and to trip downstream devices
3. Potential Benefits
   a. Increased component/system longevity by reducing thermal and mechanical shock (e.g., transformer windings)
   b. Improved power quality
   c. Improved system stability
   d. Reduced arc flash hazard
4. Other Applications
   a. Naval power systems
   b. Space constrained systems

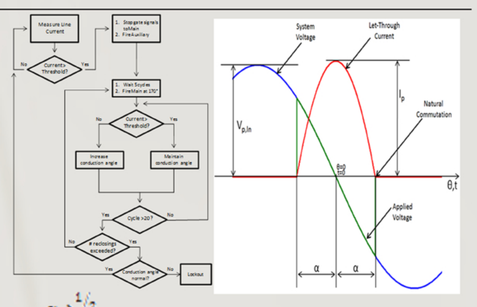


Project Objectives

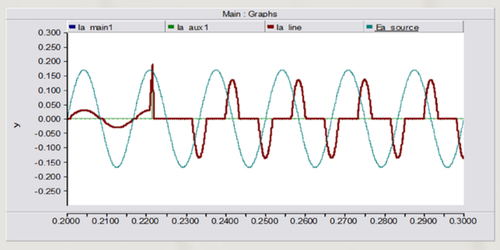
1. Philosophy of Operation
   a. Coordination with conventional protective devices
   b. Operation with distributed generation sources
   c. Power quality analysis
2. Controller Development
   a. Fault detection algorithms
   b. Reclosing operation/phase angle control
   c. Advanced features
3. Evaluation/Testing
   a. Evaluation of SiC SGTO based system
   b. Evaluation of control algorithms using computer simulation or measured fault data provided by electric utilities
4. Economic Analysis
   a. Cost/benefit analysis
   b. Polling of GRAPES member companies (11/16/10)

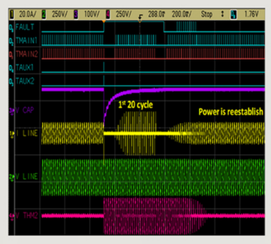
Recloser Operation

1. Natural commutation
   a. Reduces switching stress and gate drive requirements
2. Phase angle control
   a. Allows for control of let-through current magnitude



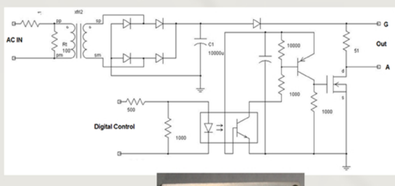
$$I_{RMS} = \left\{\frac{2V_{p,LN}^2}{\pi\omega L^2}\right\}^{1/2}\left\{\frac{-3}{4\omega}\sin(2\alpha) + \frac{\alpha}{\omega}\cos^2(\alpha) + \frac{\alpha}{2\omega}\right\}^{1/2}$$

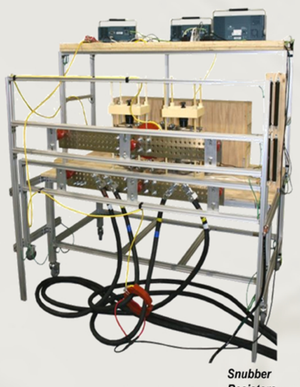


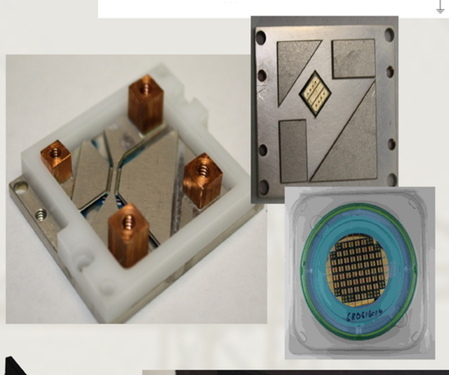


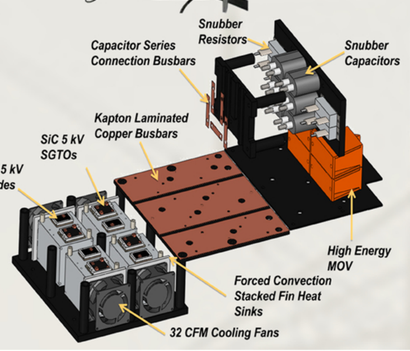
Hardware Development

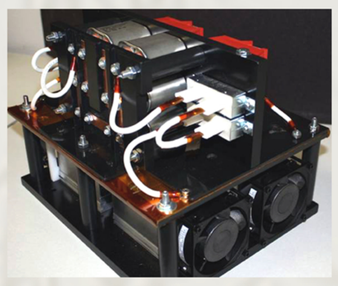
1. Development efforts have focused on 8kV SiC SGTOs
2. Separately funded





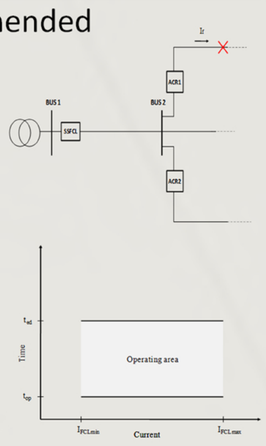


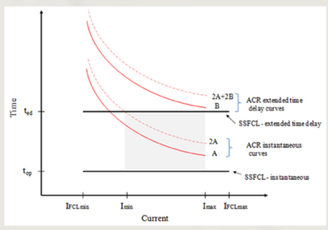


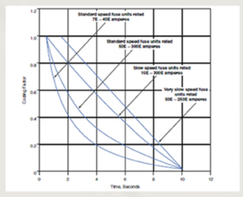


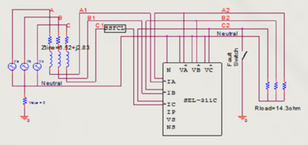
Coordination Investigations

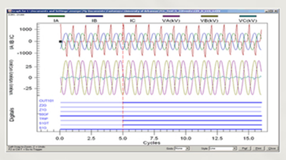
1. Investigated cases with recommended coordination procedures
   a. Upstream FCC, downstream fuse
   b. Upstream fuse, downstream FCC
   c. Upstream FCC, downstream CB
   d. Upstream CB, downstream FCC
   e. Upstream FCC, downstream ACR
   f. Upstream ACR, downstream FCC
2. Experimental measurements
   a. Upstream FCC, downstream Schweitzer SEL-311C distance relay
   b. Relay trip times were slowed significantly by the FCC





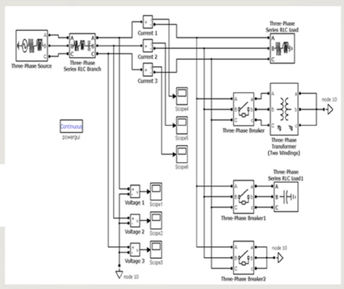


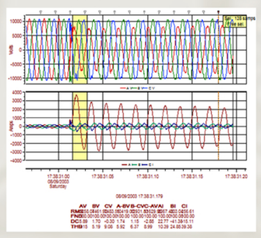


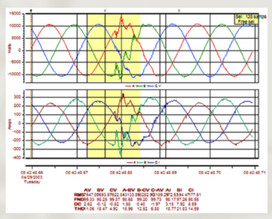


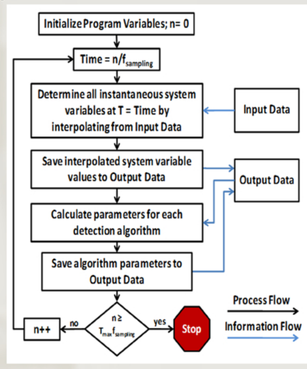
Fault Detection

1. Fault Detection Algorithms
   a. Current threshold
   b. Model
   c. Inverse time
   d. Least squares Fourier series decomposition
   e. Arc flash detection
   f. Advanced alternatives: fuzzy logic, wavelets, neural networks, morphological methods
2. Security Concerns
   a. Sensitive triggering makes false triggering more likely.
   b. There is great interest in various relay blocking/restraint methods
3. Evaluation of Methods
   a. Matlab program (flowchart at right)
   b. Accepts input from SimPower simulations (or other package) or recorded data from digital relays in service.









NCREPT — University of Arkansas

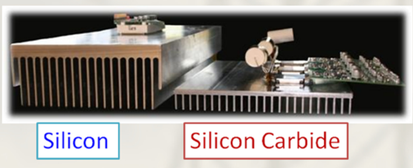
DOE STTR Phase 2
Contract DE-FG02-08ER86340
Collaborating with National Center for Reliable Power Transmission (NCREPT) at University of Arkansas

Commercialization of Silicon Carbide Power Modules for High Performance Energy Applications

DOE Phase III XLERATOR , Award# DE-OE0000527, Office of Electric Delivery & Energy Reliability
Technical Project Officer: Imre Gyuk, Principal Investigator: Jared Hornberger

Advantages of Silicon Carbide (SiC)

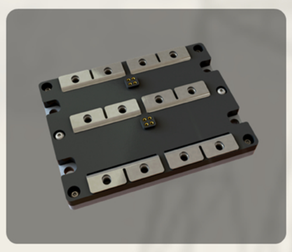
- **Electrical Advantages**
  - Very high voltage blocking
  - Very low switching losses (up to 1/10th of Silicon)
  - Low on-resistance
  - Up to 10s of GHz switching range
- **Thermal Advantages**
  - SiC device theoretical limit exceeds 600 °C
  - SiC has a very high thermal conductivity—excellent for power devices and thermal transfer, increases power density



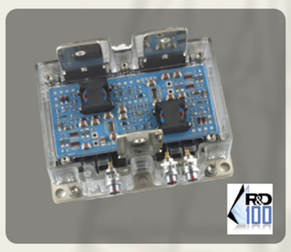
Silicon | Silicon Carbide

	Efficiency			Passive Cooling System	
	California Energy Commission	European	Peak	Heat Sink Size Volume (cm³) / Weight (kg)	Volumetric Power Density (W / cm³)
SIIGBT Inverter	95.0 %	94.8 %	95.5 %	7 / 6.12	1.75
SIC JFET Inverter	98.3 %	98.1 %	98.6 %	7 / 6.12	1.75
SIC JFET Inverter @ 150 °C	97.5 %	97.3 %	97.8 %	2.3 / 1.4	8.6

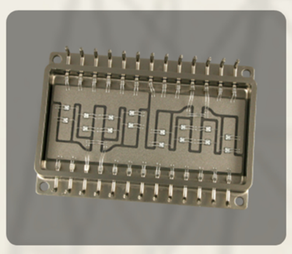
APEI, Inc. Silicon Carbide Power Modules



Features
- High current capability (>150 Amps)
- General use power module
- High Temperature (250 °C)

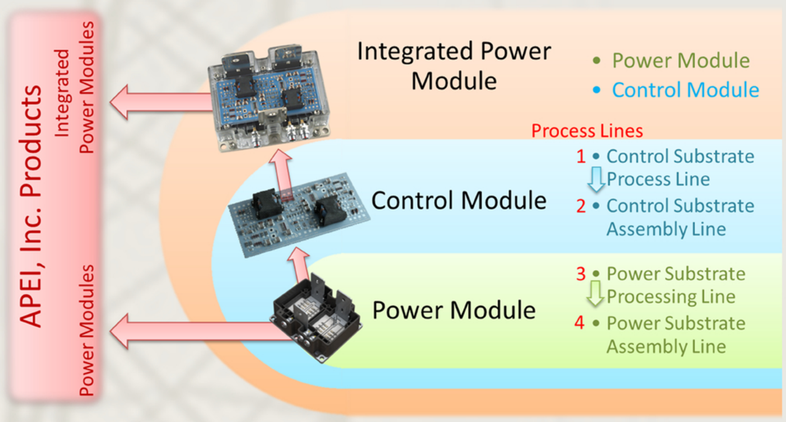


Features
- Integrated gate driver
- High current capability (>150 Amps)
- Designed for traction application
- High Temperature (250 °C)

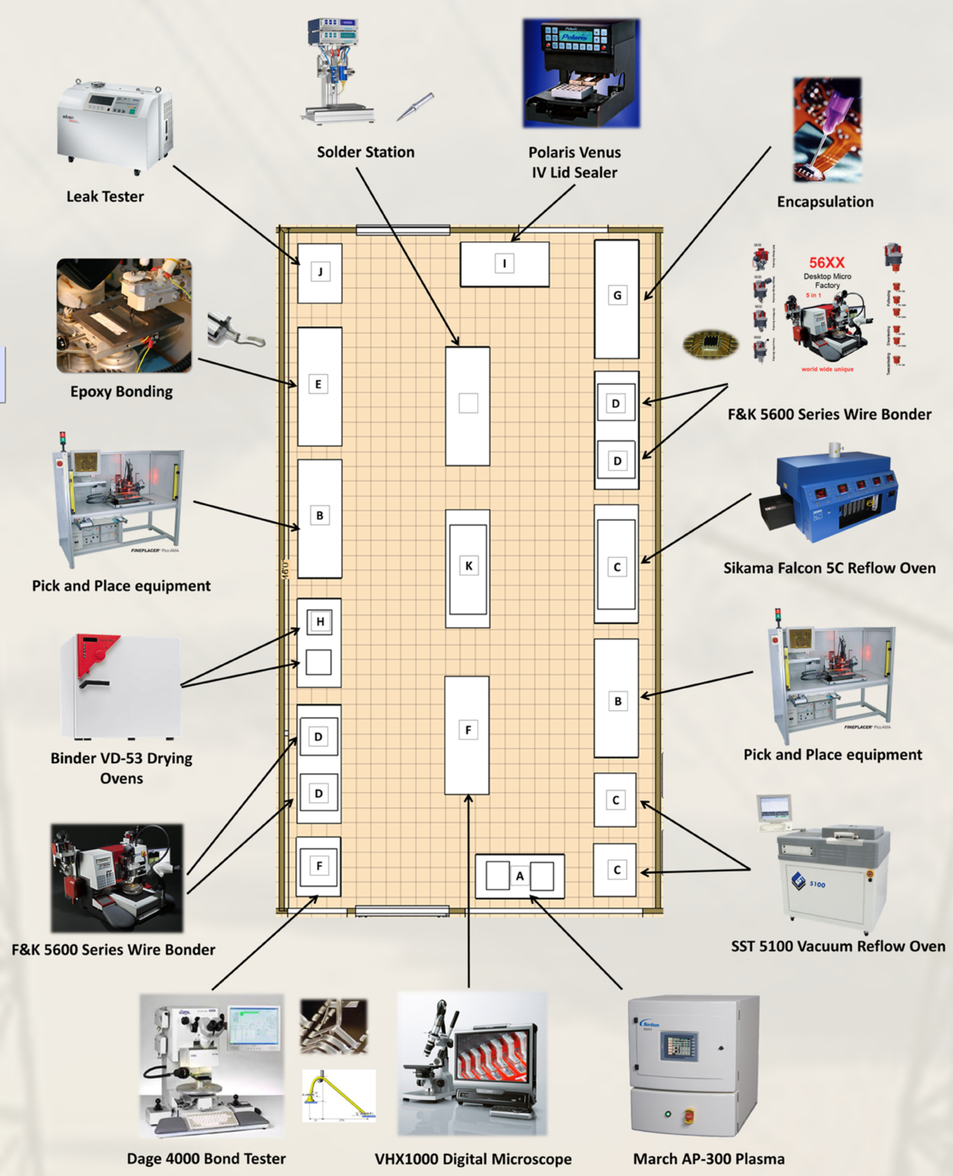


Features
- Hermetically sealed
- High current capability (up to 100+ Amps)
- Designed for aerospace application
- High Temperature (300 °C)

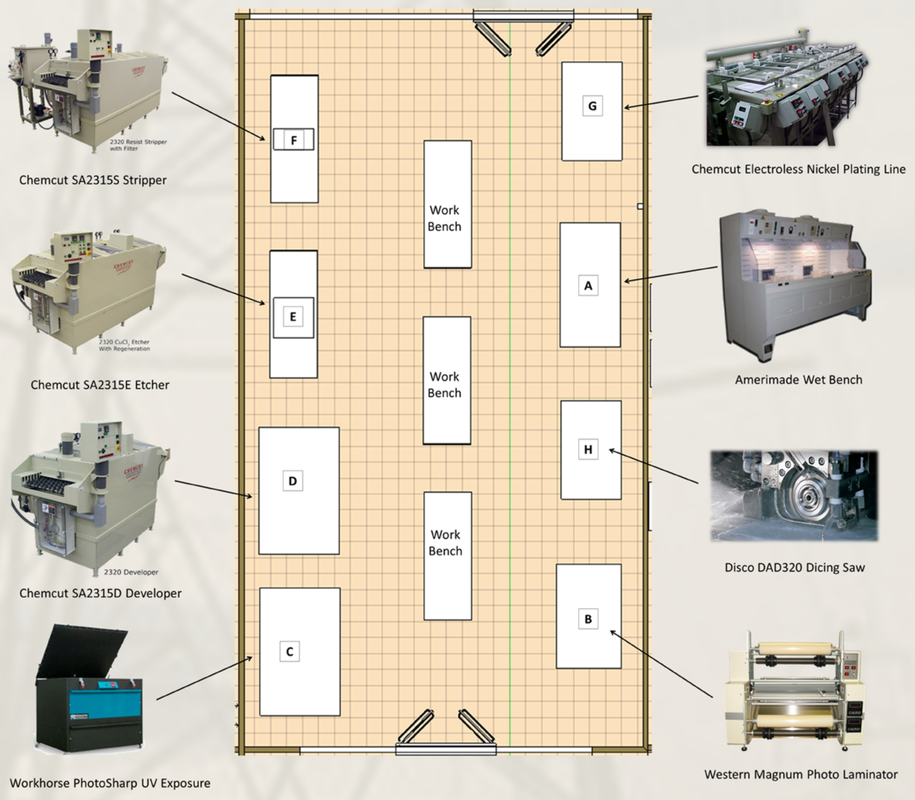
Power electronic devices are ubiquitous on the grid processing more than $300 billion annually. Some 20-30% of this energy is lost due to the inefficiencies of these systems. Over the past ten years, with SBIR support, APEI has been developing next generation power electronics using silicon carbide (SiC) based systems with the capability of reducing electrical energy waste by 90% over current silicon systems. APEI has received an R&D100 award for its innovative work. The present SBIR III grant will support life time testing of prototypes, optimize the manufacturing process, and commercially release the SiC power modules.



Electronics Assembly Manufacturing Line



Power Substrate Manufacturing Line



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