Development of Fault Current Controller Technology

California Energy Commission

Transmission Research Program Colloquium

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Keyue Smedley
University of California, Irvine
Smedley@uci.edu / 949-824-6710

Presentation Outline

1. Benefits of Fault Current Controllers (FCCs)
2. Research Objectives
3. Technical Approaches
4. Expected Outcomes
5. Future Work

1. Benefits of FCCs --The need for FCC

- **Increases in both generation (incl. renewables) and system load coupled with lagging investment in transmission lines has resulted in ever-increasing transmission system loading.**
- **Fault currents are beginning to exceed the capabilities of circuit breakers to safely and reliably interrupt the faults. This could result in catastrophic breaker failure and exposure of transformers and other critical equipment to damaging fault currents.**
- **Alternative (not fully satisfactory) solution is to split substation buses to distribute the fault currents to safe levels; this approach negatively impacts system reliability and flexibility of operation.**

1. Benefits of FCCs

- **Protect under-rated circuit breakers so they can continue in use.**
- **Avoid the need for higher-capacity breakers than already exist.**
- **Greatly reduce the destructive forces of high fault currents on transformers and other equipment.**
- **Limit the modifications to existing protection systems.**
- **Accommodate fault current contributions from new generation, especially renewables plants that come on-line in transmission-constrained areas.**
- **Avoid SF_6 greenhouse gas issues with high-capacity breakers.**

2. Research Objectives

- **Develop reliable, cost effective, and environmentally acceptable technology to equip the transmission grid to handle higher fault currents accompanying the growth in demand for electricity.**

Research Team

Sponsor: California Energy Commission (State of California Energy Commission)

Project Manager: CIEE (University of California)

Project advisors: PAG

Performing Institute: UC Irvine

EPRI (Electric Power Research Institute), Silicon Power: FCC manufacturer

Southern California Edison (An Edison International Company): Host of field test

Zenergy Power: FCC manufacturer

Technologies to be Evaluated

1. EPRI Solid State Fault Current Limiter (SSFCL)

Based on a new generation of advanced thyristor technology. Testing scheduled for mid-2009.

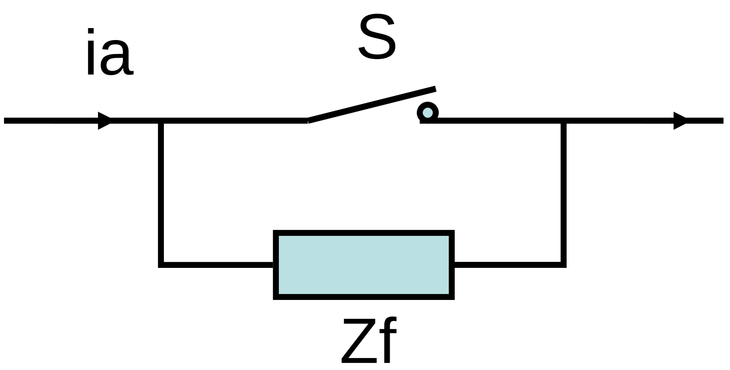
2. Zenergy (formerly SC Power Systems) High-Temperature Superconducting (HTS) Fault Current Controller

Hybrid HTS elements in combination with a saturable iron core. Testing scheduled for late 2008.

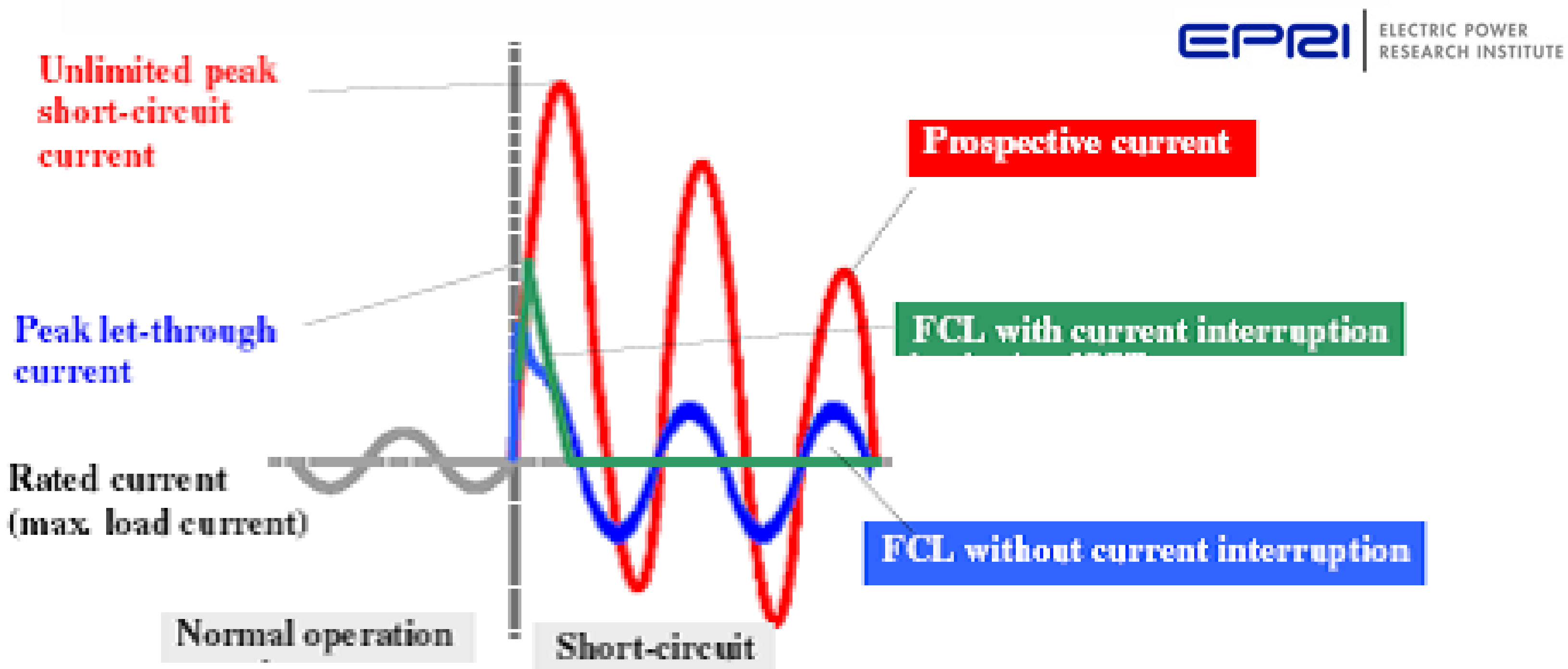
3. Siemens/American Superconductor FCC (Phase 2)

Full HTS design. Siemens/AMSC are in negotiations with DOE on project scope, schedule,and funding. Testing scheduled for 2010.

3. Technical Approaches -- How do FCCs work



- Normal operation: switch S is closed to allow current to flow freely to the load.
- Fault condition: Switch S is open so that an impedance Zf is inserted into the current path to limit the fault current flow.

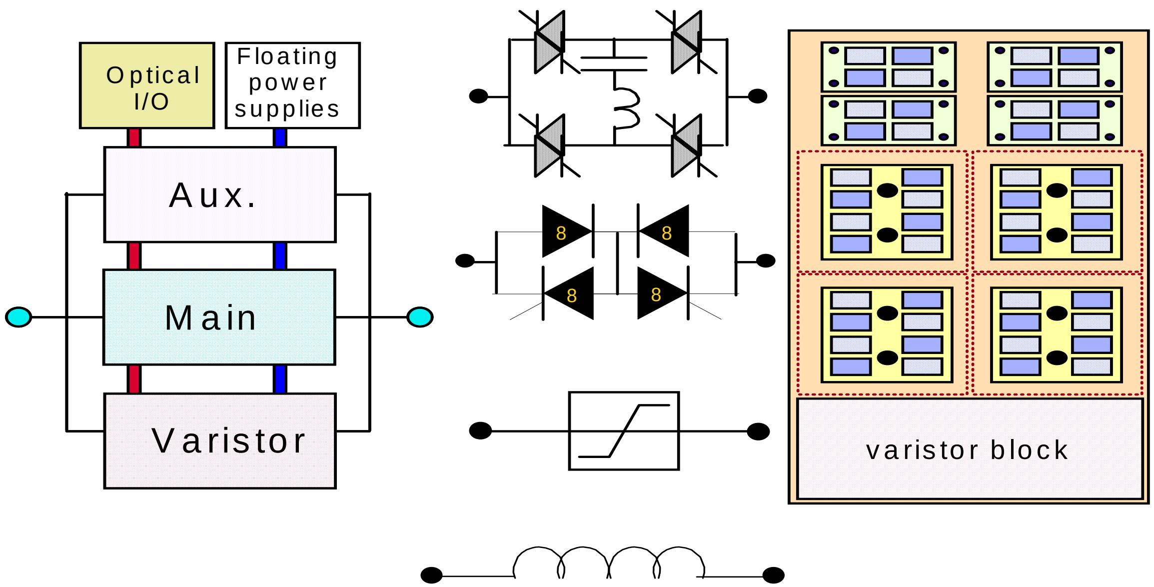


Current levels as controlled by the FCC must be coordinated with system protection schemes to allow breakers to operate normally, and safely interrupt the fault current.

Three Approaches

- EPRI/Silicon Power: Use semiconductor switches to insert an inductor (active)
- Zenergy: Use saturable magnetic core to alter the insertion impedance (passive)
- American Superconductor: Use the superconductor quench effect to insert impedance (inherent)

EPRI/Silicon Power Approach

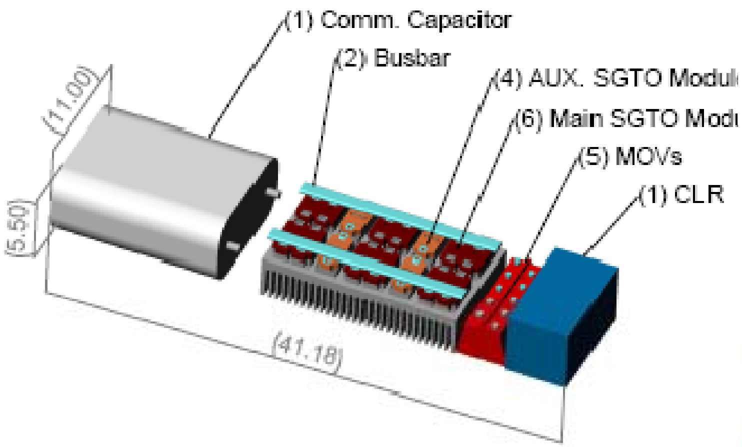


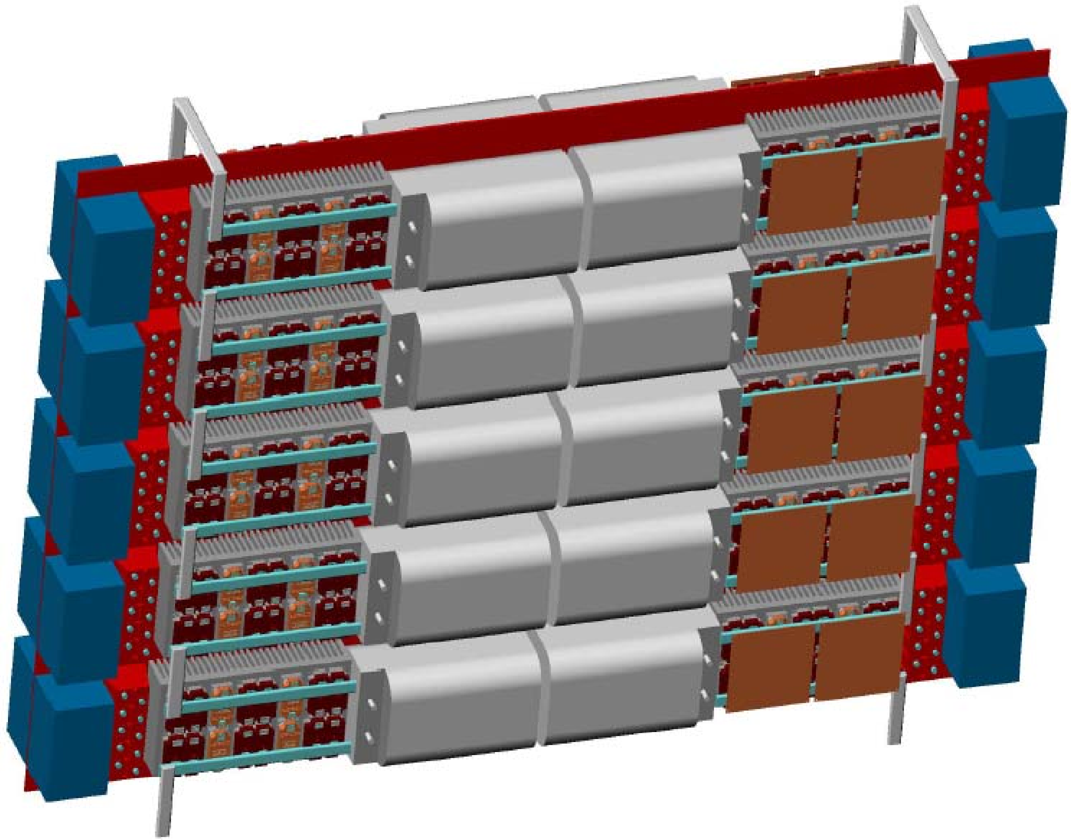
- Main: Switches in an inductor
- Aux: Damps the spikes during switching transient
- Varistor: Over voltage protection
- Optical I/O: communication
- Floating power supplies: power the operation

15 kV, 1200A FCC Design

- **Modular, scalable, standardized design**
- **Robust design for indoor/outdoor use**
- **Environmentally friendly**
- **Easy to operate; supervisory control**
- **Use of off-the-shelf components**
- **Use of advanced power semiconductor device (SGTO) for better performance**
- **Use of soft switching techniques for stress free switching**

Power Stack Assembly

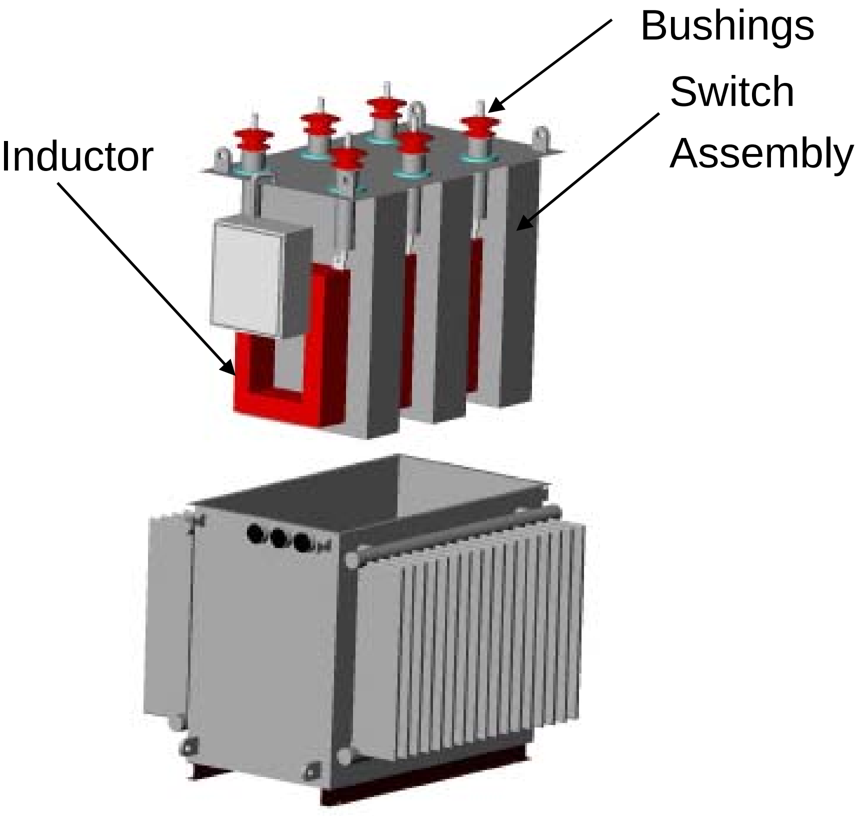




Internal Arrangement

Features:

- Modular
- Lifting Provision
- Galvanic Isolation to Controls
- Liquid cooled for better thermal and electric stress management
- Iron core inductor – Tap selectable for limiting current selection



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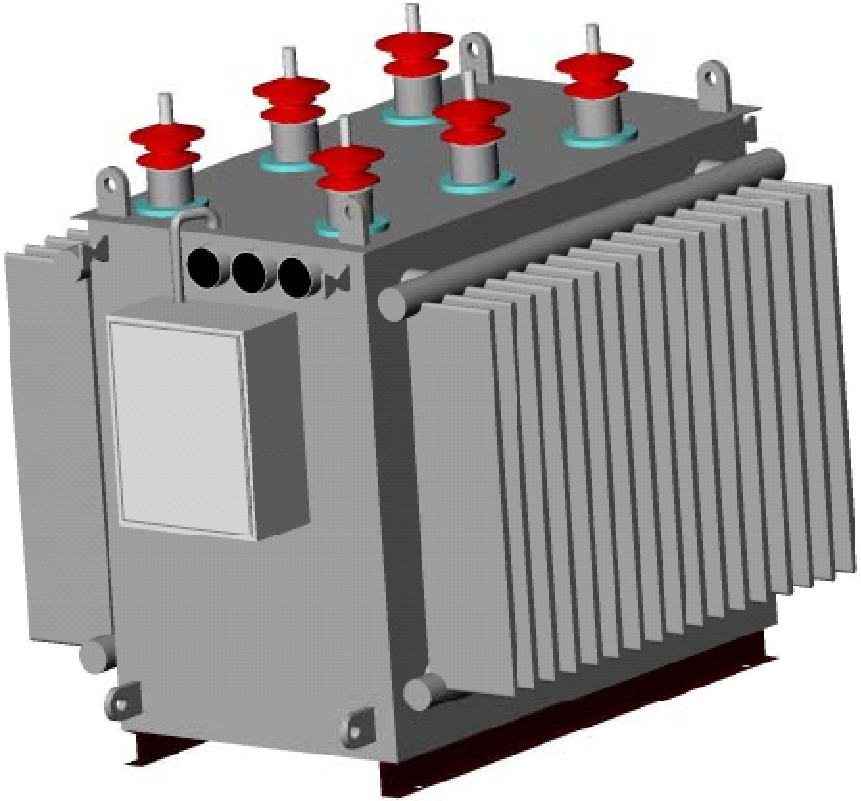
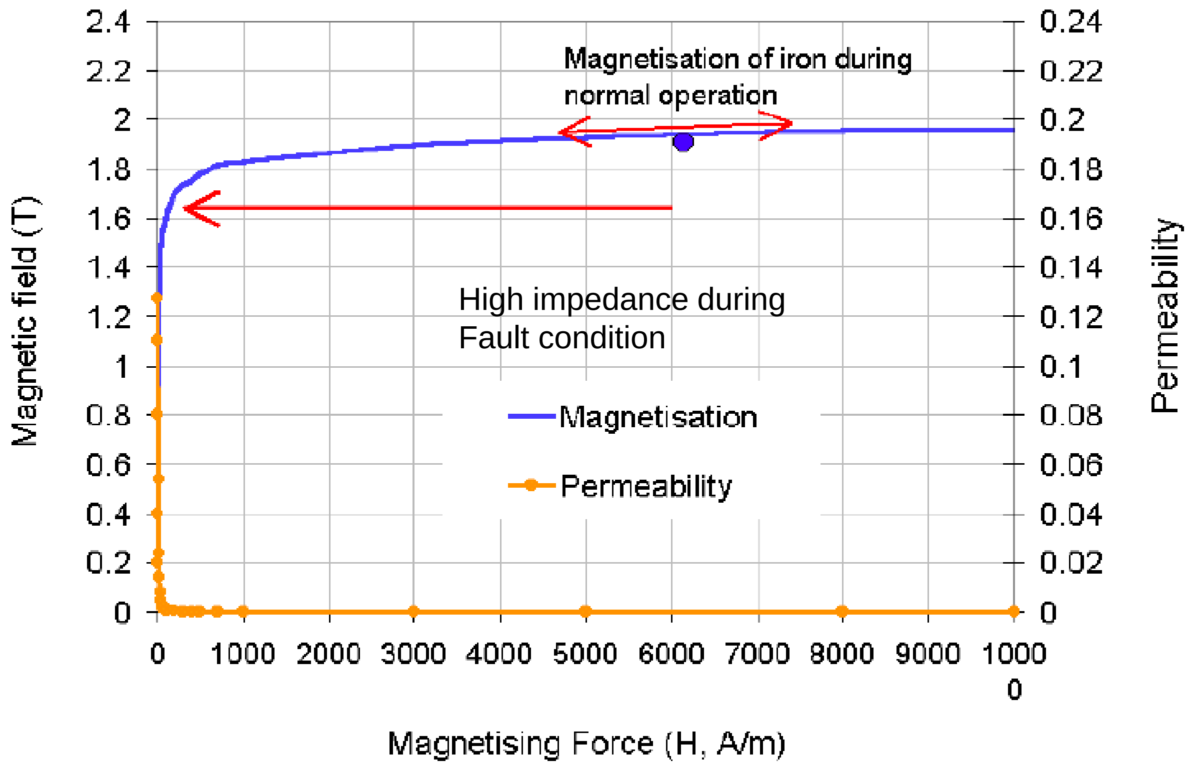
15kV 1200A FCC

<u>Features</u>:

- Rugged steel structure for Indoor/ Outdoor Installations
- Painted per ANSI C57.12.28
- Grounding Pads on Front Left and Rear Right, 2” from Edges
- Lifting Lugs for Tank & Power Assembly
- Provision for Pad Mounting
- Top mounted Bushings for power connections
- Local Operator Controls mounted inside the Box with Aux Power and Remote Interface
- Size – 5’h x 4’w+fins x 6’d



Zenergy Approach



- Normal operation: DC bias saturates the magnet to provide low impedance.
- Fault condition: the fault current pushes the core out of saturation yielding high impedance.

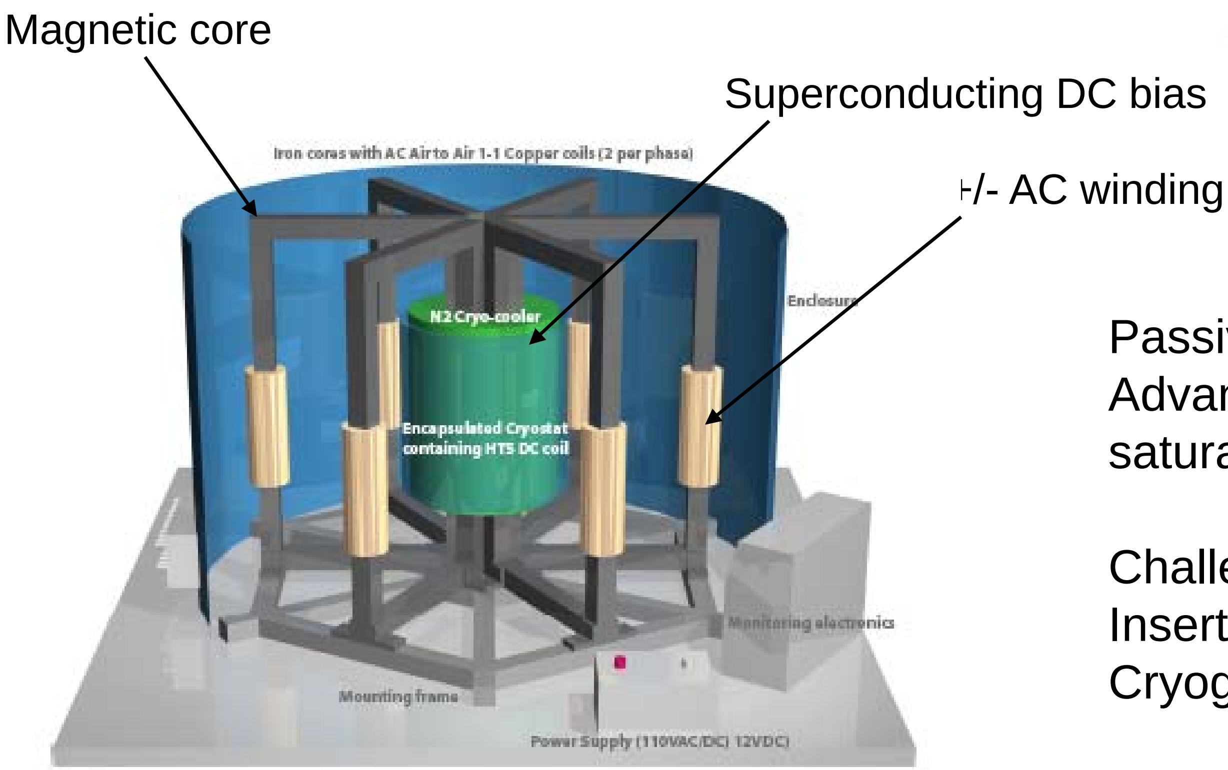
Zenergy FCC Design Features

ZENERGY POWER

- **12.47 kV**
- **1200 A steady-state**
- **12 kA fault current**
- **clip fault current by 10 to 20%**
- **fault duration up to 30 cycles**
- **multiple, reoccurring faults**
- **no electrical or mechanical switching**

Zenergy FCC Architecture

ZENERGY POWER

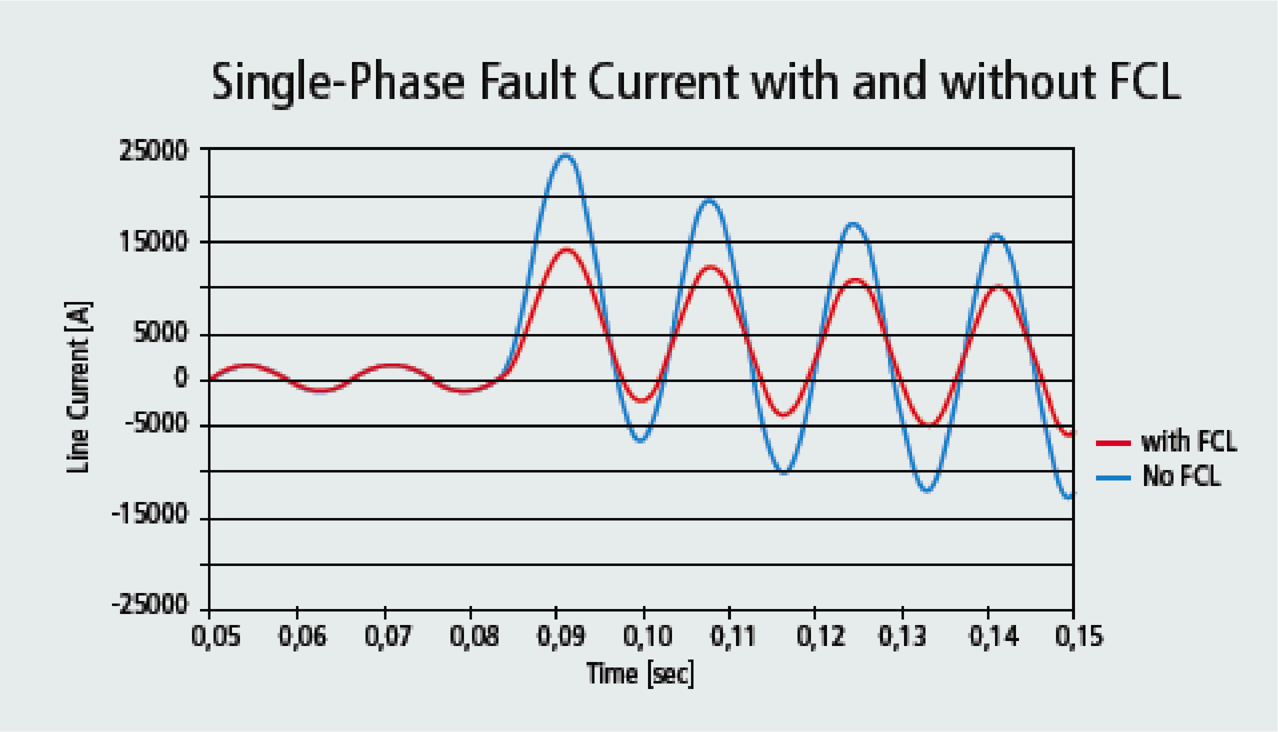


Passive method
Advanced superconducting saturable magnetic core

Challenges:
Insertion impedance
Cryogenic cooler maintenance

For a normal AC load, impedance of the winding is minimal.
Under a fault condition, impedance of the winding jumps up limiting the current through the line.

Expected Operation Waveforms



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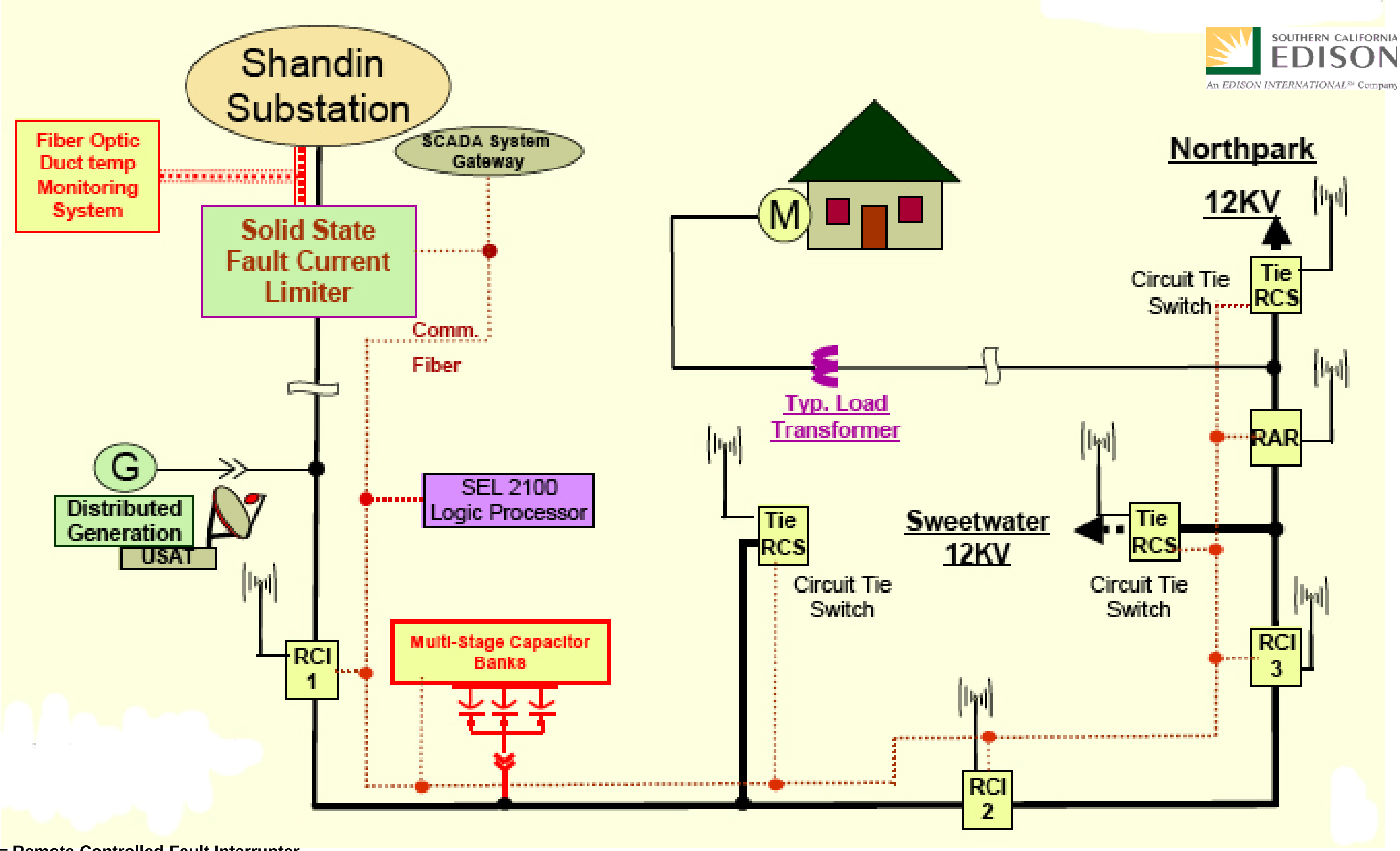
SCE Circuit of Future -- Real Test Bed

SOUTHERN CALIFORNIA EDISON
An EDISON INTERNATIONAL Company

- **New circuit**
- **Will serve approximately 2,000 customers**
- **Overhead / Underground facilities**
- **New hardware and protection schemes**
- **High speed communications**



RCI = Remote Controlled Fault Interrupter
RCS = Remote Controlled Switch
RAR = Remote Automatic Recloser

Future Work

- Conduct FCC design refinements
- Build FCC prototype
- Controlled test at testing facilities
- Field test at SCE circuit of the future

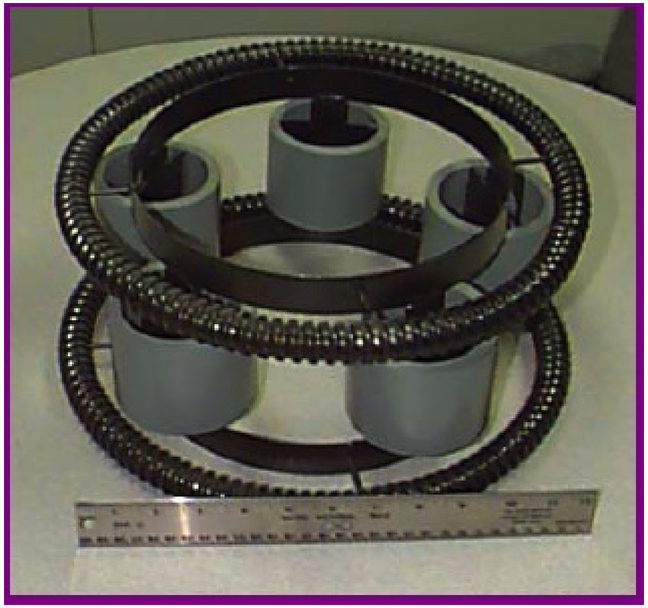
Project Status

- **Kick-off meeting held at UC-Irvine January 9, 2008.**
- **Project advisory meeting held at CIEE , Sacramento April 15, 2008.**
- **Test plan working meeting held at SCE held April 17, 2008 to refine test protocols with the assistance of SCE engineers. It included an inspection tour of the Circuit of the Future substation site.**
- **Test protocol and testing plans for EPRI and SC Power devices have been developed and are under final review by SCE engineers.**
- **Zenergy conducted controlled tests at PowerTech Labs in December 2007.**
  - **Unit performed mostly as expected. Some glitches encountered.**
  - **Unit is currently undergoing re-design and modification for installation at SCE.**
  - **Re-testing scheduled for late September 2008.**
  - **Installation at COF scheduled for November 2008.**
  - **Field testing December 2008 to mid-2009**
- **EPRI Prototype currently under construction.**
  - **Factory testing and delivery to SCE expected by March 2009.**
  - **Field testing scheduled for April – November 2009.**

AMSC Approach (Phase 2 project)

American Superconductor

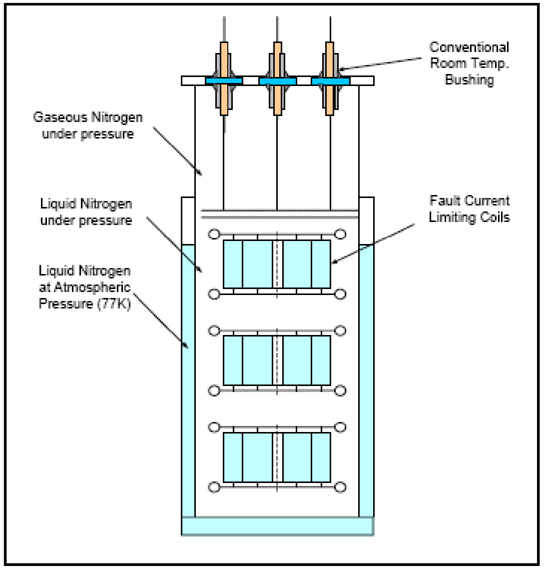
- Structure: Second Generation (2G) Coated Conductor. HTS filaments sandwiched between a stainless steel layer and a backing substrate.
- Normal operation: current flows through the HTS filaments; zero resistance to current.
- Fault condition: Current exceeds HTS “critical current,” shunts excess current into stainless steel layer, which provides high impedance. Heat dissipated into liquid nitrogen bath.



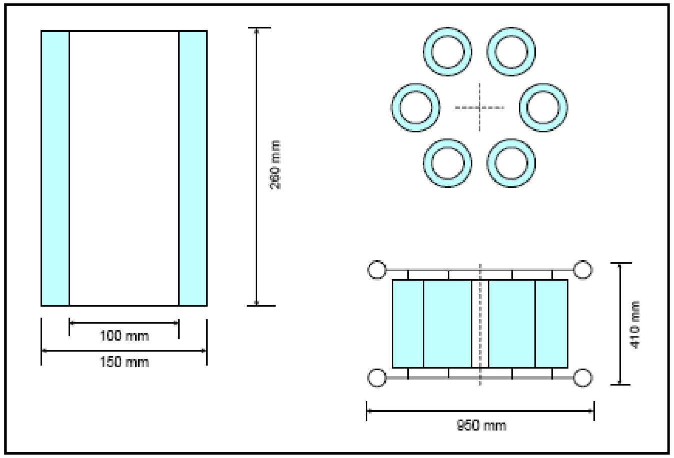
Scale model: gray cylinders are HTS coils

Stainless Steel Stabilizer
YBCO HTS Filament
Substrate

FCC Prototype Architecture



3-Phase FCL Assembly



A Phase Module with individual Non-inductive HTS Coils

American Superconductor™

American Superconductor Status

- **DOE selected the American Superconductor team, which included Siemens, Nexans, SCE and the TRP, in mid-2007 for development and demonstration of a superconducting FCC.**
- **Different technological approach from Zenergy; will use HTSC coils of 2G wire in LN_2 bath.**
- **AMSC team in final negotiations with DOE for project scope and cost, estimated to be about $25M total, of which DOE pays about half. Proposed TRP contribution $600K.**
- **Estimated start date: October 2008.**
- **Estimated end date: December 2012.**

Project Contacts

- Dr. Keyue Smedley, Principal Investigator, UC–Irvine
  - 949-824-6710
  - smedley@uci.edu
- William Schram, Zenergy
  - 650-403-0581
  - wschram@zenergy.com
- Ashok Sundaram, EPRI
  - 650-855-2304
  - asundara@epri.com
- Lloyd Cibulka, CIEE
  - 510-290-3875
  - Lloyd.Cibulka@ucop.edu

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Questions?