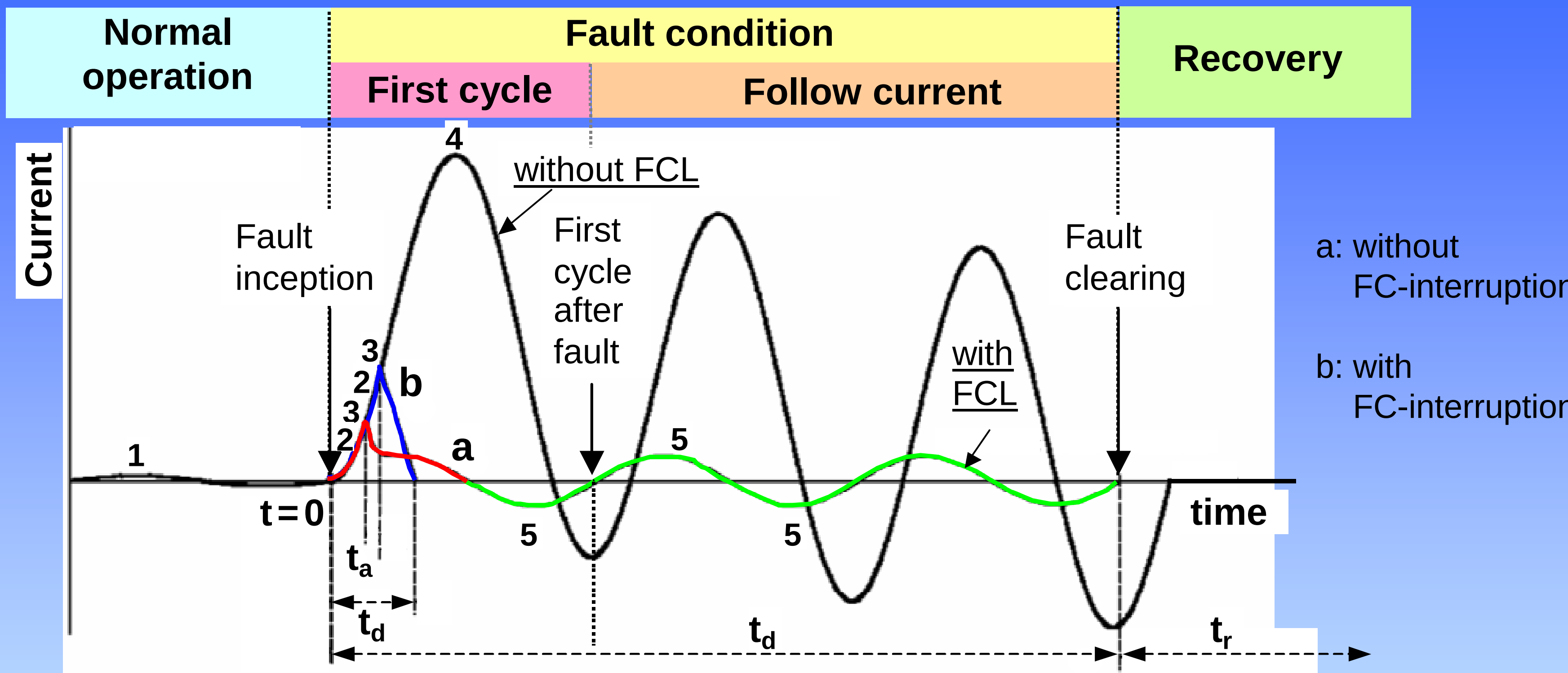
superior performance.
powerful technology.

Conductor Requirements for Superconducting Fault Current Limiters

Chuck Weber, Director – HTS Applications
Coated Conductors in Applications 2008
Houston, Texas - December 4, 2008

PHILIPS SuperPower, Inc. is a subsidiary of Royal Philips Electronics N.V.

Fault Current Limiter Functionality



U_n rated system voltage

t_a action time (from t = 0 until $î_{max}$)

t_d fault duration time

t_r recovery time

1: rated current (I_n), peak ($î_n$)

2: minimum initiating current ($î_{min}$)

3: maximum limited current ($î_{max}$)

4: peak (prospective) short circuit current ($î_p$)

5: peak value of the follow current ($î_{fol}$)

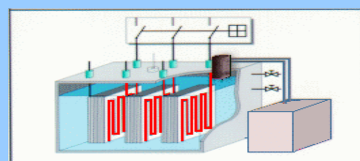
* Courtesy of Johann Jäger, Univ. of Erlangen-Nürnberg

FCLs must work in conjunction with protection systems

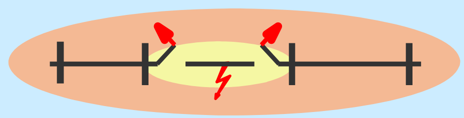
Key coordination aspects:

1. First cycle response – initiation current, action time, limitation ratio
2. ‘Rest of Fault’ response – FC interruption, duration, waveform distortion
3. Recovery response – max. fault duration, recovery time, let-thru current

Fault current limiter

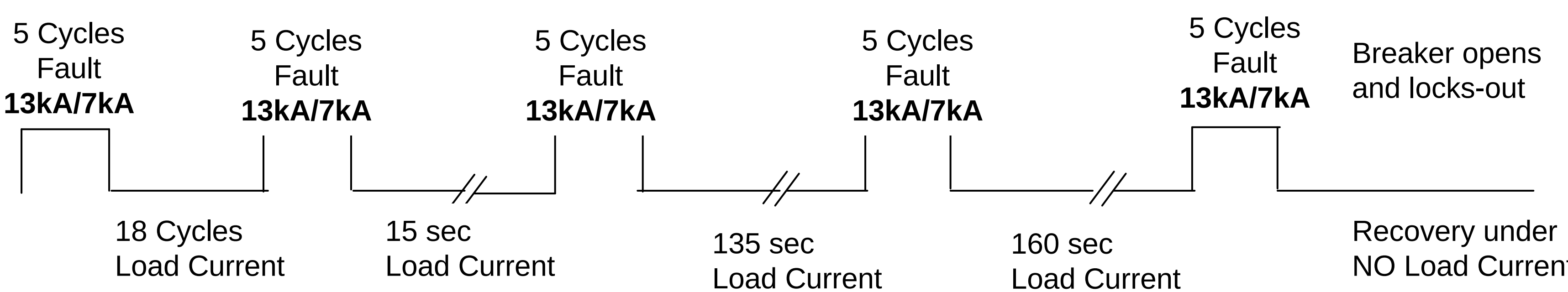


Protection system



Coordination is essential

AEP transmission line re-closure sequence



Types of Superconducting FCLs

- Resistive Type – SuperPower, AMSC/Siemens, Nexans
  - Utilizes fast quenching of HTS material
  - Internal or external shunting
  - Fail-safe design
  - With or without Recovery Under Load (RUL)

- Saturated Core Type – Zenergy
  - HTS material does not see fault (i.e. doesn’t quench)
  - Essentially building a DC coil where amp-turns are key criteria

- Hybrid Type – Korea, China
  - HTS material is removed from circuit after fault is detected
  - Typically doesn’t limit prospective current during first peak

- Many variations of each type are possible

SuperPower Inc.

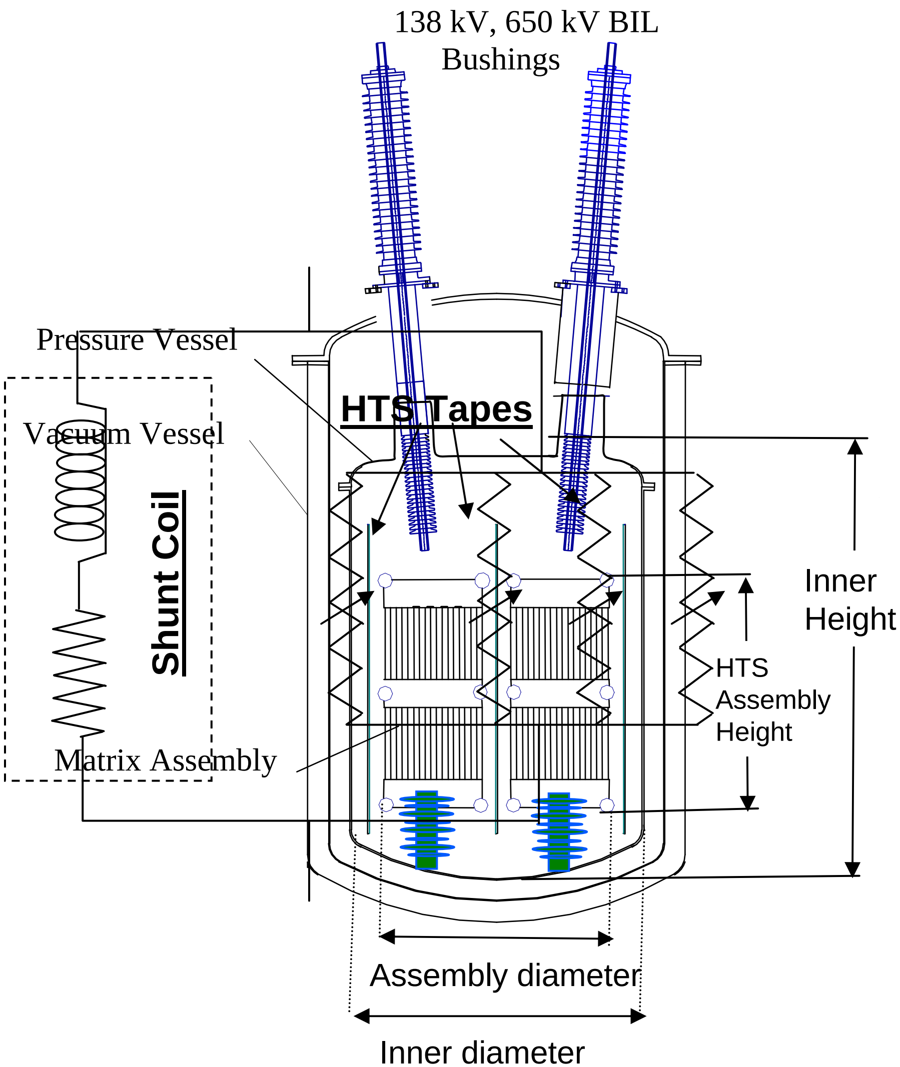
SuperPower SFCL program overview

Partners

AMERICAN ELECTRIC POWER, Department of Energy, EPRI, Los Alamos National Laboratory, Oak Ridge National Laboratory, Sumitomo Electric

Specifications

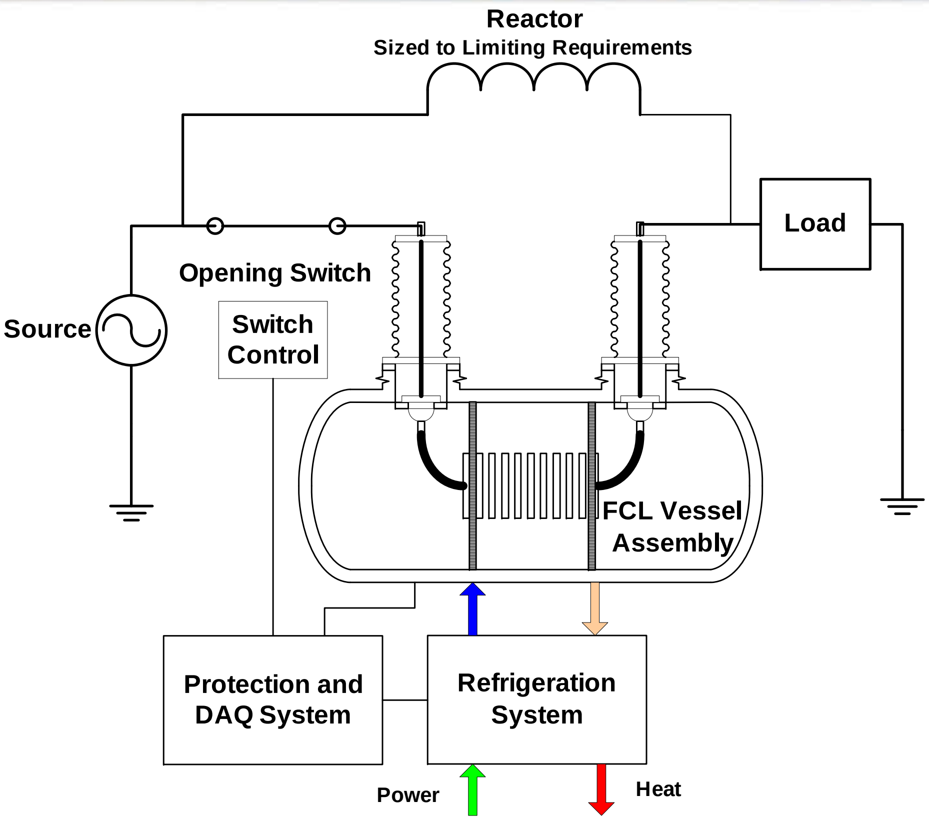
- YBCO based, resistive type FCL
- 138 kV class device
- Fault Current – 13.8 kA
- Load Current – 1,200 A_{rms}
- Design fault current – 37 kA
- Design device response – Recover to superconducting state after a fault carrying full load current



AMSC SuperLimiter™ Basic Specifications

Requirement	Prototype System	Production Units
Nominal Voltage	115kV rms	115-138kV
Insulation Class	138kV	138kV
Nominal Current	1,200A	>2,000A
Maximum Site Unlimited Fault Current	63kA	>80kA
Site Limited Current	40kA	As required by customer
Trip Current	1.6pu	As required by customer

* Courtesy of Bruce Gamble, AMSC

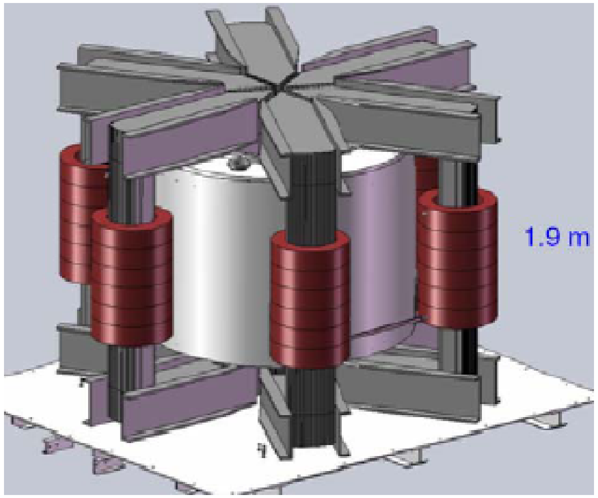


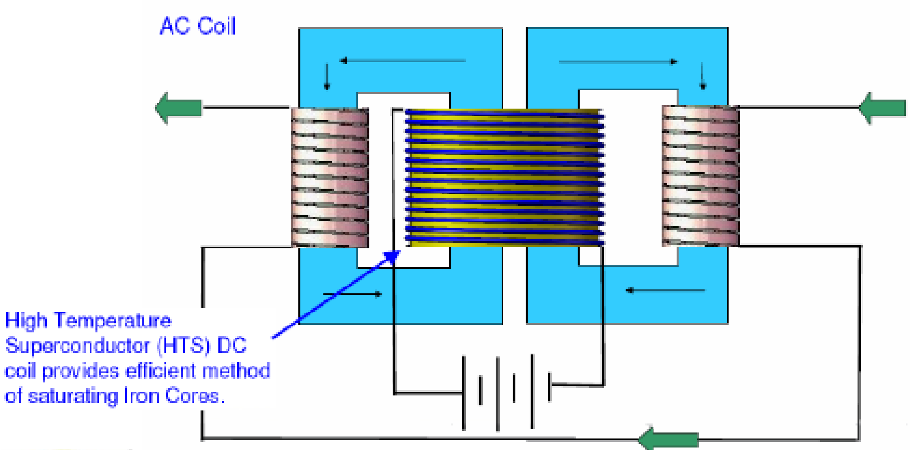
- AMSC 1 cm wide wire
- Siemens bifilar coil technology
- Nexans high voltage terminations

ZENERGY POWER

DOE is sponsoring Zenergy Power to design, build, and test a 138 kV transmission-class saturable core reactor FCL.

- Intermediate goal is to design, build, and test a distribution-class saturable core reactor FCL: 26 kV, 2000 A with a prospective fault current of 30 kA, fault current reduction of 40-50%, and steady state impedance of < 1%. Delivery to site by end of June 2010.
- Intermediate devices use 1G HTS coils, but the ultimate devices will use commercially available 2G wire.
- Delivery of the 138 kV device is targeted for September 2011.

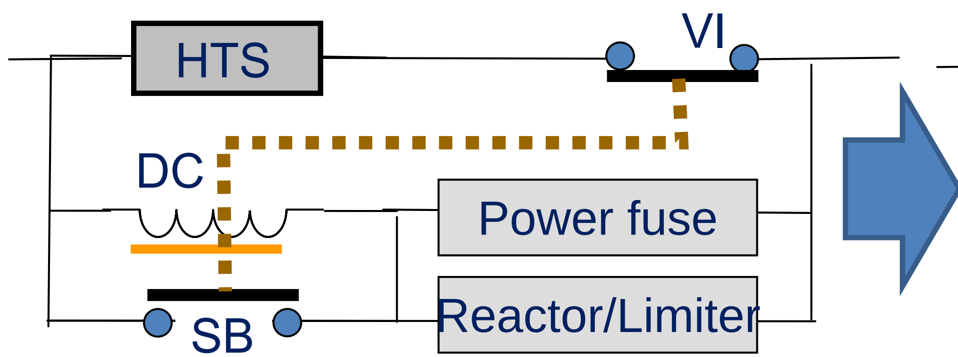




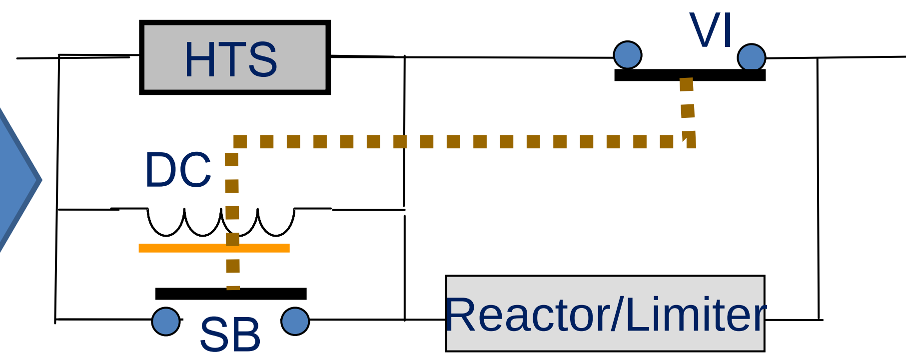
* Courtesy of Larry Masur, Zenergy Power

NAVIGANT

Hybrid SFCL – Co-developed by KEPCO and LSIS

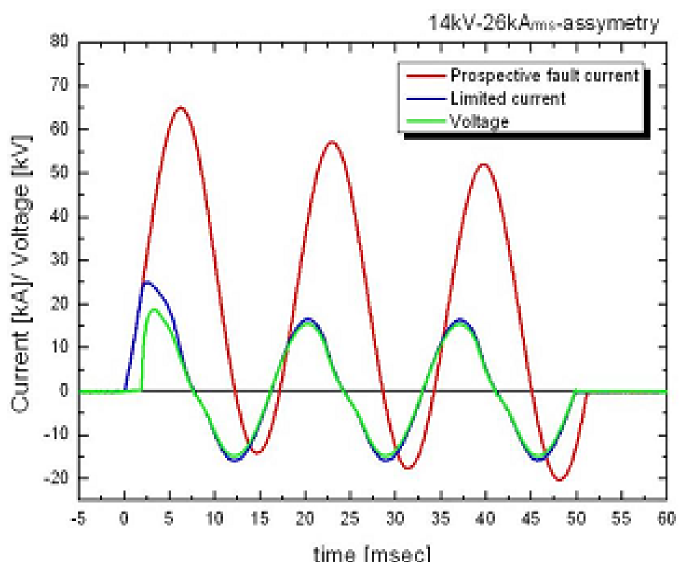


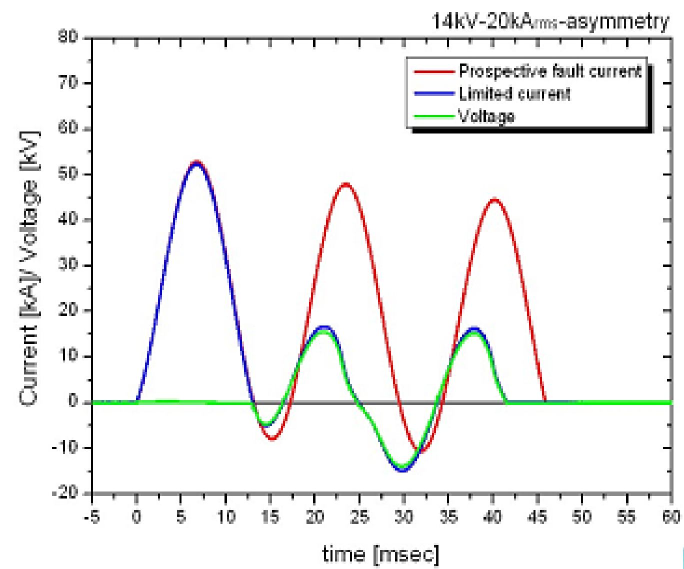
(1) 1st peak limiting type



(2) 1st peak NON- limiting type

1st peak limiting (Left) and 1st peak non-limiting (Right) types





* Courtesy of Ok-Bae Hyun, KEPRI

SuperPower Inc.

Wire Requirements for SFCLs

Relative Importance of HTS Wire Characteristics

	Resistive Type w/ RUL	Resistive Type w/o RUL	Saturated Core Type	Hybrid Type
Cost	4	2	1	3
Uniformity (I_c & Quench)	2	1	5	2
Long Length	5	3	4	7
Normal State Resistance	3	6	7	6
AC losses	7	7	6	5
Robustness – Mechanical & Electrical Integrity	1	4	2	4
Current Density	6	5	3	1