Office of Electricity Delivery and Energy Reliability

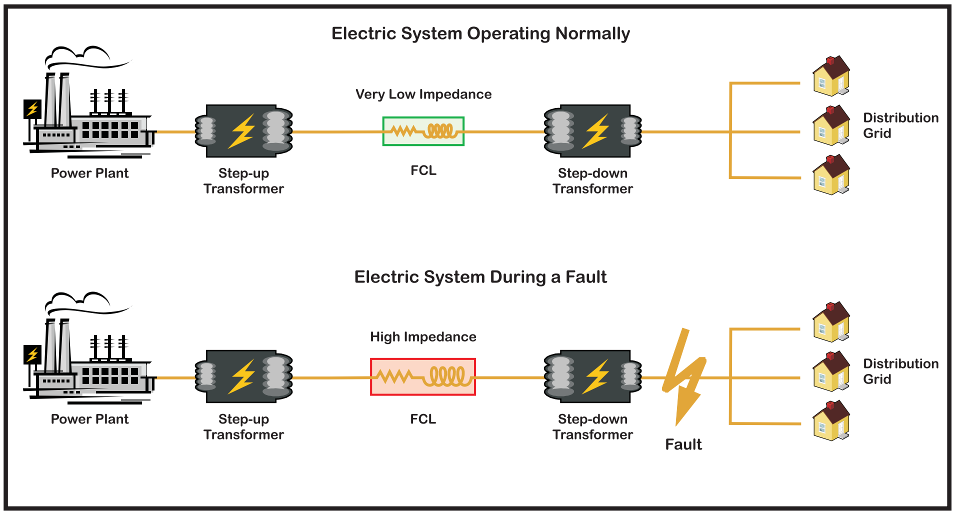
Superconducting & Solid-state Power Equipment

Plugging America Into the Future of Power

Fault Current Limiters

WHAT ARE FCLs?

A fault is an unintentional short circuit, or partial short-circuit, in an electric circuit. A variety of factors such as lightning, downed power lines, or crossed power lines cause faults. During a fault, excessive current—called fault current—flows through the electrical system often resulting in a failure of one section of that system by causing a tripped circuit breaker or a blown fuse. A fault current limiter (FCL) limits the amount of current flowing through the system and allows for the continual, uninterrupted operation of the electrical system, similar to the way surge protectors limit damaging currents to household devices. Currently, two broad categories of FCL technologies exist: high-temperature superconducting and solid-state.



During a ground fault, an FCL safely mitigates the excess energy that would normally effect utility transmission and distribution equipment, preventing damage.

TYPES OF FAULT CURRENT LIMITERS

- High-temperature superconducting (HTS) FCLs use superconducting-based material and reduce fault currents by introducing a larger-than-normal impedance into the path of the fault current.
- Solid-state FCLs use high-speed solid-state switching devices to rapidly insert an energy absorbing impedance into the circuit to limit the fault current.

WHY DO WE NEED FCLs?

The need for FCLs is driven by rising system fault current levels as energy demand increases and more distributed generation and clean energy sources, such as wind and solar, are added to an already overburdened system. Currently, explosive fault-limiting fuses are utilized to limit fault current, but they require a service call to replace the fuse after it blows and they are only available for voltages below 35 kV. Series reactors are also used but they have constant high reactive losses, are bulky, and contribute to grid voltage drops. FCLs overcome these weaknesses. Additionally, rising fault current levels increase the need for larger and often costly high impedance transformers. However, in contrast to these transformers, FCLs operate with little to no impedance during normal operation which allows for a more stable system.

WHAT ARE THE BENEFITS TO UTILITIES?

FCLs offer numerous benefits to electric utilities. For instance, utilities spend millions of dollars each year to maintain and protect the grid from potentially destructive fault currents. These large currents can damage or degrade circuit breakers and other expensive T&D system components. Utilities can reduce or eliminate these replacement costs by installing FCLs. Other benefits include:

- Enhanced system safety, stability, and efficiency of the power delivery systems
- Reduced or eliminated wide-area blackouts, reduced localized disruptions, and increased recovery time when disruptions do occur
- Reduced maintenance costs by protecting expensive downstream T&D system equipment from constant electrical surges that degrade equipment and require costly replacement
- Improved system reliability when renewables and DG are added to the electric grid
- Elimination of split buses and opening bus-tie breakers
- Reduced voltage dips caused by high resistive system components
- Single to multiple shot (fault) protection plus automatic resetting

FCLs are a supporting technology in the Smart Grid.

AMSC's Team Includes:

- Southern California Edison
- Nexans
- the University of Houston
- Los Alamos National Laboratory
- Siemens AG

Zenergy Power's Team Includes:

- DOE's Los Alamos National Laboratory
- American Electric Power
- Southern California Edison Inc.
- Zenergy Power GmbH
- Zenergy Power Pty Ltd.

SuperPower's Team Includes:

- Sumitomo Electric Industries Ltd.
- Nissan Electric Co. Ltd.
- DOE's Los Alamos National Laboratory
- American Electric Power
- DOE's Oak Ridge National Laboratory

EPRI's Team Includes:

- Silicon Power Corporation

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FCL Projects

The Office of Electricity Delivery and Energy Reliability is funding three HTS FCL projects carried out by American Superconductor, Zenergy Power, Inc., and SuperPower, Inc. It is also funding one solid-state FCL project led by the Electric Power Research Institute (EPRI).

HTS Fault Current Limiters

The HTS fault current limiter projects currently underway are either resistive or inductive.

- In a resistive HTS FCL, the HTS material absorbs the fault current by quickly switching the HTS material from a superconducting state to a highly resistive state, which then limits the fault current. This transition occurs automatically and triggers the current to transfer into a current limiting coil or reactor.
- In an inductive HTS FCL, the large fault current desaturates the iron core of the series AC coils and the increased reactance limits the fault current.

Solid-State Fault Current Limiters

This type of limiter switches power into an energy absorber within a few microseconds of a fault current, preventing the onset of damaging current from reaching utility assets, such as circuit breakers.

Zenergy Power, Inc.

Zenergy Power will design, test, and demonstrate a 138- kilovolt transmission class inductive HTS FCL. In this type of FCL, a high-temperature superconductor is used with a direct current (DC) power supply to saturate an iron core series reactor in-line with the current that is to be limited. In this device, the AC line current of the power grid is always carried by conventional copper conductors formed into AC coils. The HTS material is used only to form a very strong electromagnet—the DC coil—that saturates an iron core inside the AC coils with a DC magnetic flux. The Zenergy device is referred to as a "saturable reactor." It is the large AC fault current that drives the AC iron core out of saturation – increasing the AC reactance and thereby limiting the current that flows in the power grid and acts as an "auto-reactor".

Zenergy fault current limiter operating in Southern California Edison's Avanti Circuit

SuperPower, Inc.

SuperPower will design, test, and demonstrate, on the American Electric Power grid, a 138-kilovolt resistive HTS FCL that features a matrix design. This design consists of parallel 2G HTS elements and conventional copper coils. By using a cold shunt coil, no external or ancillary components or equipment are required; the device is self-contained. Operational feasibility is expected to be made possible by SuperPower's 2G HTS material, which has a very rapid response time (~0.5ms) and enables the device to recover to the superconducting state while carrying load current from other (non-faulted) lines.

American Superconductor

American Superconductor (AMSC) is addressing the development and in-grid testing of a three-phase, high-voltage, 138-kilovolt resistive HTS FCL called a SuperLimiter™, which uses second generation (2G) wire. The SuperLimiter™ features a proprietary Siemens-developed, low inductance coil technology that makes the FCL invisible to the grid until it switches to a resistive state. The design uses high voltage components developed by Nexans and demonstrated on the DOE-funded LIPA cable project. AMSC is employing resistive FCLs because they are expected to be simpler and more compact in design.

EPRI

DOE awarded a contract to EPRI to develop a 69-kVclass solid-state current limiter (SSCL), slated to be delivered in 2009. Working as a subcontractor, Silicon Power Corporation in Malvern, Pennsylvania, is developing the SSCL, which uses super gate turnoff thyristor (SGTO) semiconductor switches to rapidly switch the SSCL from a low-impedance state to a higher impedance state. The goal is to build and test several smaller-scale devices, leading up to a 69- kilovolt, 1000-amp, single-phase SSCL, which will look much like a transformer and will be cooled internally by a circulated cooling fluid.

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