Past CIGRE and Emerging IEEE Guide Documents on FCLs

Michael “Mischa” Steurer
Leader Power Systems Research Group at FSU-CAPS
Email: steurer@caps.fsu.edu, phone: 850-644-1629

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Why FCLs?

Design trade off in power systems

High short-circuit capacity during normal operation (low short-circuit impedance)
- Low voltage drops
- High power quality
- High steady-state and transient stability
- Low system perturbations

Low short-circuit capacity during fault conditions (high short-circuit impedance)
- Low thermal and mechanical strain
- Reduced breaker capacity

Optimal solution FCL
- Low impedance during normal operation
- Fast and effective current limitation
- Automatic and fast recovery
History of CIGRE’s Work on FCLs

- CIGRE WG 3.10, 1996 – 2003, 15 members from 9 countries
  - TB 239 „Fault Current Limiters in Electrical Medium and High Voltage Systems“
    - First international group to look at FCLs – initial technology overview
    - Started to define FCL behavior in the grid

- CIGRE WG 3.16, 2003 – 2008, 11 members from 8 countries
    - General systematic to assess the impact on system protection
    - Technology independent - FCL as black box

- CIGRE WG 3.23, 2008 – 2012, 25 members from 11 countries
    - Comprehensive FCL technology overview
    - Examples of FCL applications

TB = Technical Brochure
Fault Current Limiting Measures

PC37.302 adopted from CIGRE TB 497

Permanent impedance increase during nominal and fault conditions

Old term: “passive”

- Splitting into sub grids
- Introducing a higher voltage range
- Splitting of bus bars

Topological measures

Apparatus measures

Topological measures

Apparatus measures

Fault Current Limiting Devices

Condition based impedance increase
Small impedance at nominal load
Fast increase of impedance at fault

Old term: “active”

- Fuse based devices (< 36 kV)
- Stand alone HV fuse (< 1 kA)
- Commutating Current Limiters (< 5 kA)

Emerging Concepts

- Superconductors
- Solid-State Devices
- Magnetic Effects
- Hybrid Systems

Scope of IEEE PC37.302
&
FCL must limit the first peak

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Fault Current Limiting Devices
IEEE WG PC37.302
Guide for Fault Current Limiter Testing

• Established: June 2010, PAR expires Dec 2014
  – Recognizing the need for general guidance on FCL testing to ease market introduction

• Sponsors: IEEE Switchgear (PE/SWG) Committee
  – Power & Energy Society/Substations (PE/SUB)
  – Power Electronics Society/Standards Committee (PEL/SC)

• Balloting planned for Dec 2013
  – Register and ballot via IEEE Standards Association

• Contact: Mischa Steurer
  – steurer@caps.fsu.edu, 850-644-1629
  – Chair of IEEE WG PC37.302
  – Former member of CIGRE WG A3.16, A3.23
IEEE WG PC37.302
Guide for Fault Current Limiter Testing

• Follows template/structure of other equipment testing standards with clauses
  3. Definitions
  4. Introduction
  5. Specification
  6. Design Tests
  7. Production (Routine) Tests
  8. Field Tests

• Does not prescribe any specific value
  – Provides parameter definitions for fully describing any FCL behavior

• References numerous other IEEE and IEC standards for applicable procedures, test setups, etc.

Major effort to develop general framework which maintains FCL technology independence
C37.302 – Clause 3
Definitions

• Fault Current Limiter (FCL)
  – A device which limits the prospective peak and/or RMS fault current in an alternating current power system to the specified value by providing condition-based increase in resistive and/or reactive impedance between normal conducting mode and current limiting mode. The FCL may consist of discrete functionally integrated, spatially separated equipment

• Provides parameter definitions to fully describe FCL behavior
  – Needed to substantially expand parameter set given by CIGRE TB 497 to meet the needs of the FCL testing guide

No definition of FCL existed previously

This is the consensus in WG PC37.302
C37.302 – Clause 3
Definitions – FCL modes

• **C mode:** normal conducting
  – the FCL is in its low impedance state

• **CL mode:** current limiting
  – generally, the FCL is in its high impedance state
  – some technologies may constantly transition between high and low impedance during the current limiting phase

• **I mode:** interruption
  – the FCL has interrupted the fault current flow (if applicable)
  – Transitions to and from other modes: IC, CLI, ICL
C37.302 – Clause 4
FCL Technical Principles

• Treats FCL as black box
  – Refers to CIGRE TB 497 for technology overview in open literature

• FCL types consistent with TB 497
  – A1: behavior with a current waveform that can be accurately described by power frequency and DC components after transitioning into CL mode
  – A2: current waveform, which after transitioning into CL mode, requires additional parameters or information during each current loop besides power frequency and DC components in order to be accurately described
  – B: A1 or A2 but with interruption by FCL

Example: Air core reactor parallel with solid state switch

Example: Saturated iron core type
Example: Type A1 – Resistive Behavior

Current through FCL

AND

Fault inception

Fault clearing by circuit breaker

Voltage across FCL

Waveforms are parameterized
Example: Type A2

Current through FCL

Fault inception

Fault clearing by circuit breaker

Voltage across FCL

Waveforms are parameterized
C37.302 – Clause 5
Specifications

• Provides parameter descriptions (no values) by which FCLs may be specified & rated
  – Electrical
    • Prospective fault current, Rated power frequency, Rated steady-state voltage drop, Rated losses, etc
  – Physical and Operational
    • Footprint, Height, Weight, Cryogenic system maintenance, etc.
  – Environmental
    • Proper thermal performance, Temperature regulation for electronics, Transport conditions, Storage, etc.
  – Safety
  – Lifespan
• Provides guidance on how to parameterize the fault current limitation and recovery process

• Technology independent; applicable to all types of FCLs A1, A2, B

![Diagram of FCL recovery process]

- FCL in C mode ready to limit
- FCL in CL mode limiting fault current
- Partial recovery process
  - $\Delta t_{pr}$
- FCL in CL mode, ready to limit rated fault current
  - and ready to carry below rated continuous current
  - and ready to carry up to rated continuous current
- FCL in C mode, ready to limit rated fault current and enter CCL transition
  - and ready to carry below rated continuous current
  - and ready to carry up to rated continuous current
- FCL is C mode fully recovered
- FCL is CL mode, ready to limit
- FCL is CL mode rated recovered
- FCL in C mode
- $t_{da}$
- $t_{k,CL}$
- $\Delta t$
- $\Delta t_{pr R}$
- $\Delta t_{pr}$
- $\Delta t_{R}$

With load current
With fault current
Without load current
With load current

Time
C37.302 – Clause 6
Design Tests

- Voltage Withstand: Power Frequency, Lightning Impulse, Switching Impulse, Chopped-Wave, Partial Discharge
- Current Withstand: Continuous, Surge, Short-Time and Peak Withstand
- Harmonic Distortion
- EMC, Audible Sound, Seismic, Visual Inspection
- Short-circuit current limitation
- Recovery
- FCL Technology-Specific

Similar to other equipment

FCL specific
Short-Circuit Current Limitation Test

Test Circuit

<table>
<thead>
<tr>
<th>Test number</th>
<th>Applied current condition</th>
<th>Duration</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rated continuous current of FCL ( I_r )</td>
<td>3 sec. minimum</td>
<td>To verify the expected insertion impedance</td>
</tr>
<tr>
<td>2</td>
<td>Rated maximum prospective short-circuit current of FCL ( I_{p,max}, I_{k,max} )</td>
<td>10 cycles</td>
<td>To verify the rated limited short circuit withstand current of the FCL during peak and RMS current limiting action</td>
</tr>
<tr>
<td>3</td>
<td>Rated continuous current of FCL ( I_r )</td>
<td>twice the expected recovery time</td>
<td>To verify the recovery time. The duration should be long enough to ensure recovery.</td>
</tr>
<tr>
<td>4</td>
<td>Rated maximum prospective short-circuit current of FCL ( I_{p,max}, I_{k,max} )</td>
<td>10 cycles</td>
<td>To repeat test 2</td>
</tr>
</tbody>
</table>

Example of test Sequence

- Generator (G) connected to the line CB through the CT.
- FCL (Fault Current Limiter) connected to the external bypass CB.
- Digital recorder measuring the current.
- Load connected to the line CB.
- Short Circuit CB protecting the system.
Conclusions

• CIGRE TB 239, 339, and 497 provide very good overview on FCL technologies, applications, and power system impact

• IEEE C37.302 will provide the first guide for testing
  – Substantially expanded the definitions of waveforms and associated parameters to adequately describe FCL behavior
  – Defines a framework for FCL recovery
  – Maintains technology independence

• Possible topic for next WG
  – Guide for Application of FCLs in Power Systems