Standards Developments for Fault Current Limiters

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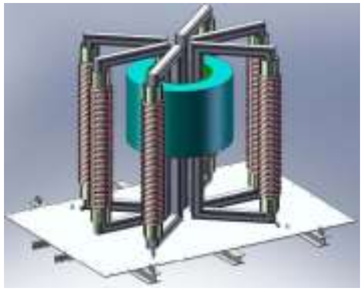
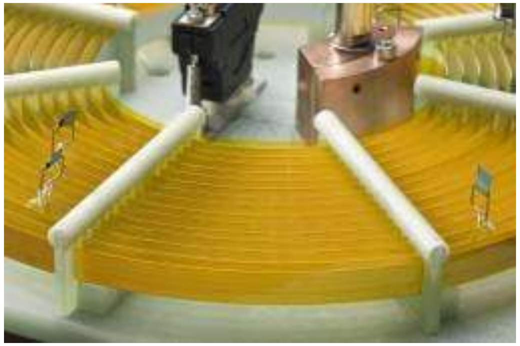
Overview

- CIGRE WG A3.23
  - "Application and Feasibility of Fault Current Limiters in Power Systems"
  - Since 2008
- IEEE PC37.302
  - "Guide for Fault Current Limiter Testing"
  - Since 2010 (2009)
- CIGRE WG D1.38
  - "Emerging Test Techniques Common to High Temperature Superconducting (HTS) Power Applications"
  - Since 2011





Why FCLs?

Compromise in Power Systems

Normal Operation:
High short-circuit capacity
(low short-circuit impedance)

- Low voltage drop (high power quality)
- High steady-state and transient stability
- Low system perturbations

Fault Condition:
Low short-circuit capacity
(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

CIGRE WG A3.23

- Definition of Terms
- Fault Current Management with Fault Current Limiters
- Past Experiences and State-of-the-Art
- Fault Current Limiter Application Issues
  - Needs and requirements, specifications, selection criteria
  - Testing, meeting of requirements
  - Impact and Interactions
  - Risk Review
  - Reliability & Availability

Measures To Limit Short-Circuit Currents

Source: CIGRE WG A.3.23, systematic revised 5/20/2011

Fault Current Limiters

Permanent impedance increase
during nominal and fault conditions

Old term: ***"passive"***

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

- High impedance transformers
- Current limiting reactors

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

Old term: ***"active"***

- Sequential tripping

- 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

Topological measures

Apparatus measures

Topological measures

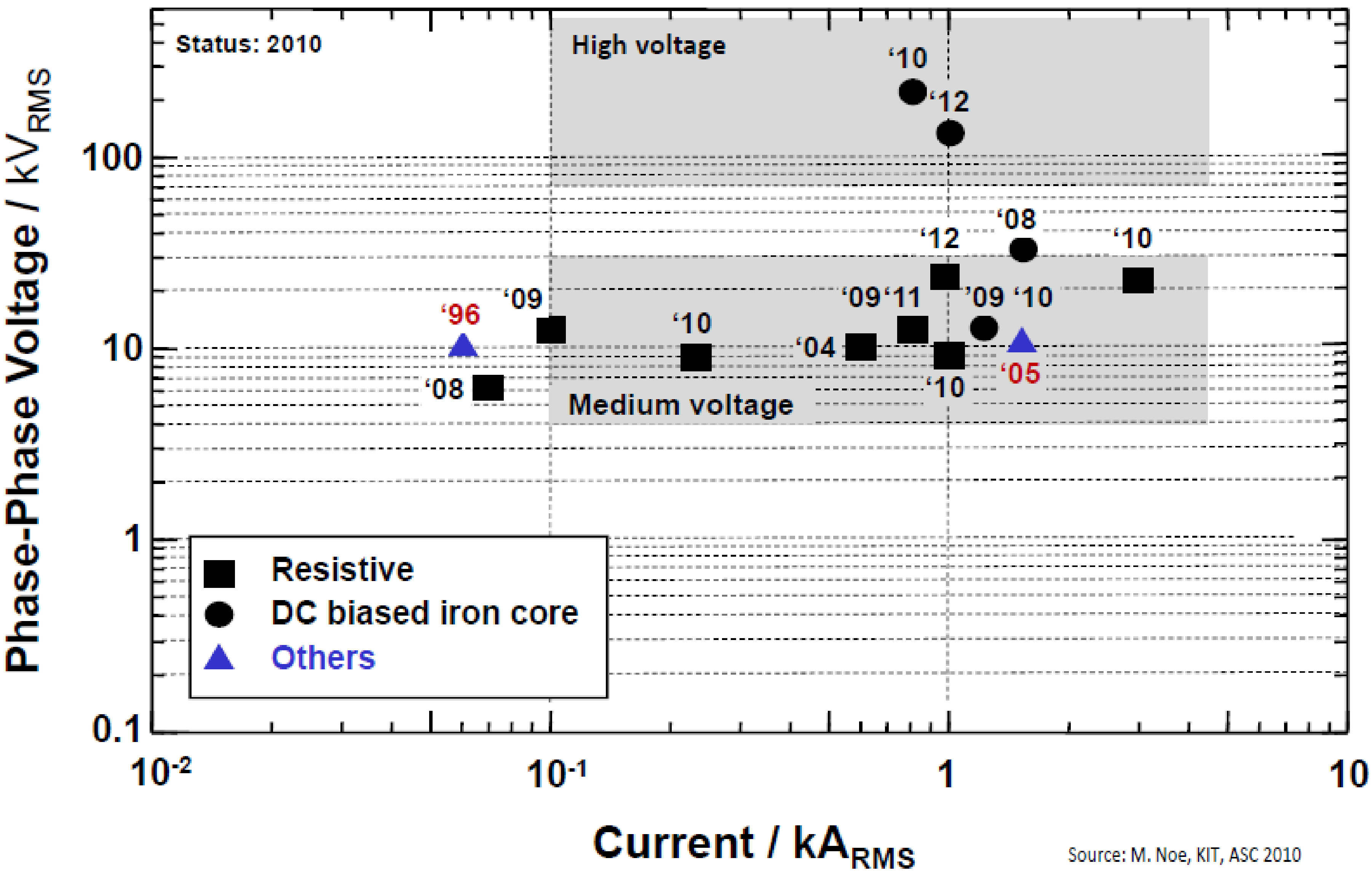
Apparatus measures

Fault Current Limiting Devices

Different FCL Technologies

- Superconducting type
  - Resistive type (may behave resistive-inductive!)
  - Saturated (DC biased) iron core
  - Shielded iron core
  - Flux lock type
- Solid-state (semiconductor type)
  - Diode-bridge type
  - Thyristor based FCL and fault current controller
  - GTO, IGCT, ETO, IGBT, SGTO based FCL and fault current controller
  - Series line compensation with FCL feature
- Others
  - Polymer PTC resistance (positive temp. coeff.)
  - Liquid metal switch
  - High arc voltage switch
  - Hybrid switching topologie

FCL R&D Trends
SCFCL Field Tests – planned and carried out



Source: M. Noe, KIT, ASC 2010

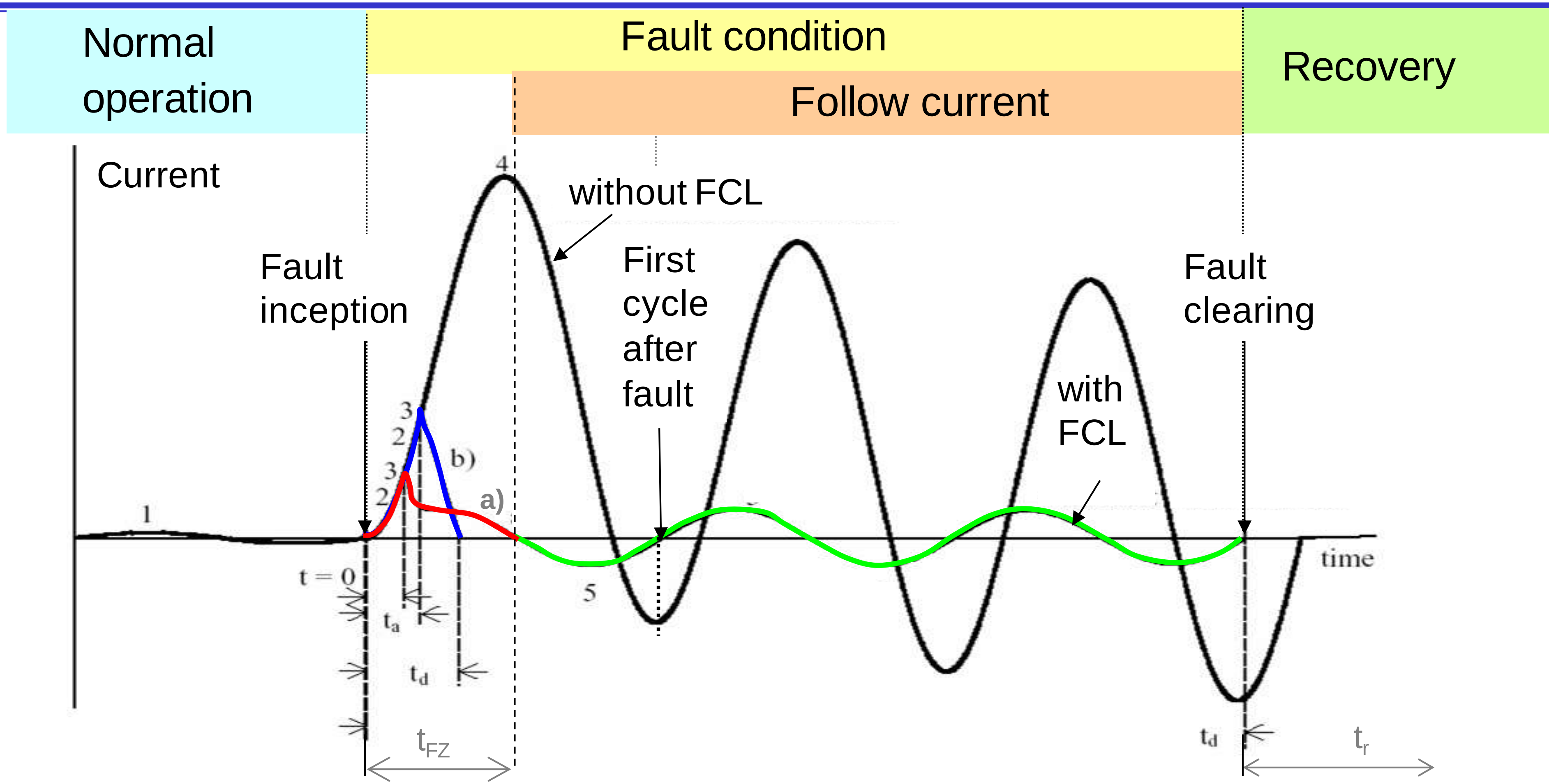
CIGRE WG A3.23

- Feasibility and Economic Issues
  - Technical and economic benefits of fault current limiter applications
  - Selected case studies
  - Environmental benefits and acceptance issues of FCL applications
- Modeling Aspects
  - FCL modeling approaches
  - Effect of non-linear characteristic of resistive type SCFCL on simulation
  - Example case study by PSS/E and EMTDC
- Conclusions
- Reference List

IEEE WG PC37.302

- Definitions
  - **Fault current limiter**: a device, which offers condition-based increase in resistive and/or reactive impedance between normal conducting mode and current limiting mode to limit the prospective peak and RMS fault current in an alternating current power system to the desired value.
- FCL Technology - State of The Art
- Specifications
  - Electrical Performance
  - Physical and Operational Parameters
  - Environmental
  - Safety
  - Lifespan

Representative Waveform - CIGRE

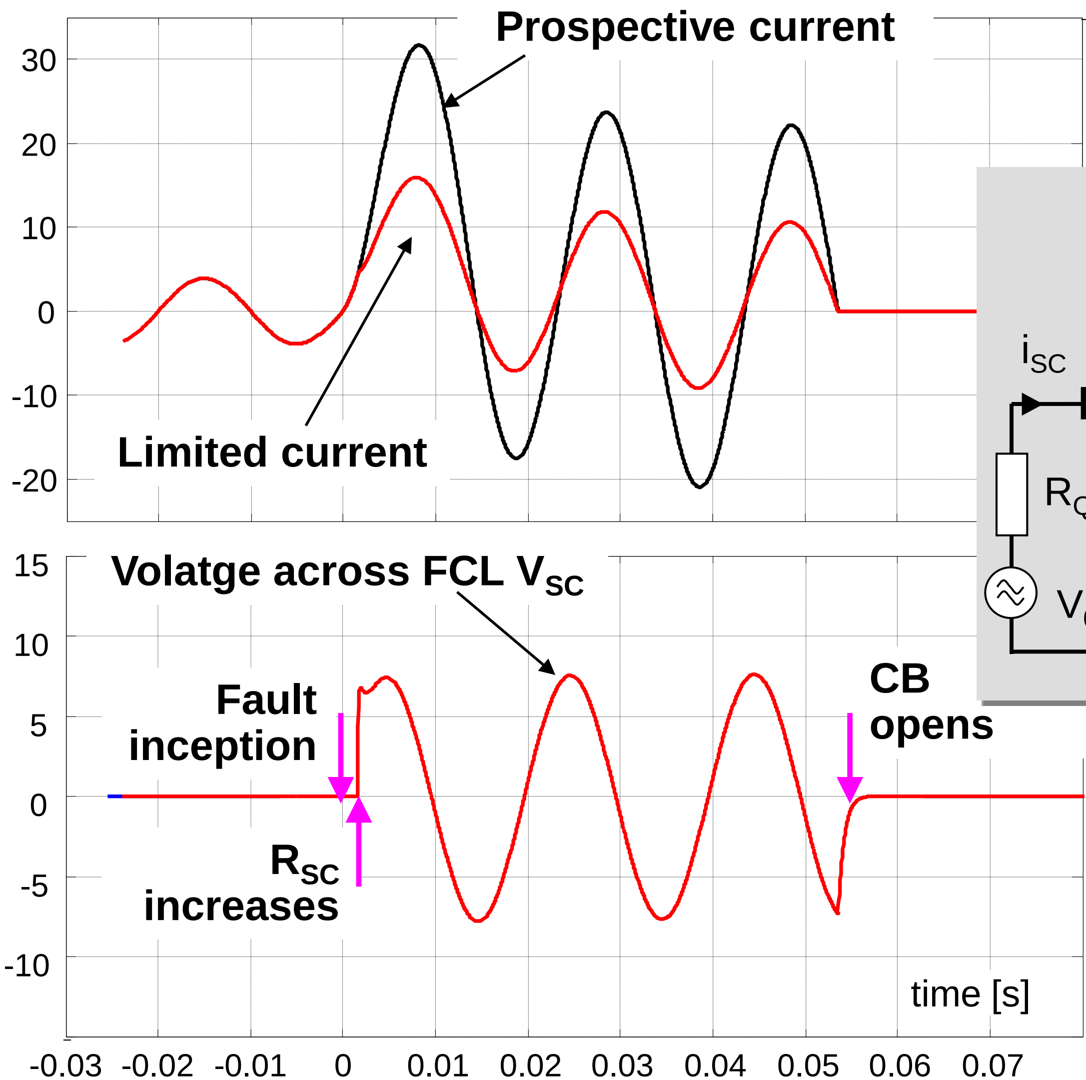


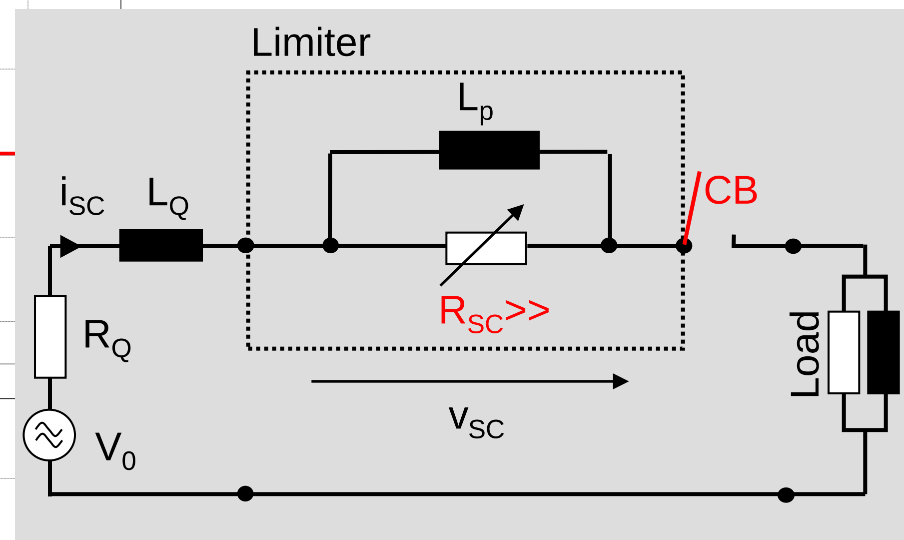
t_a action time (from t = 0 until 3)
t_d fault duration time (from t = 0 and fault clearing)
t_{FZ} first zero crossing time

1: load current (In)
2: minimum initiating current
3: first peak value of limited current
4: prospective (peak) short circuit current
5: first peak value of the follow current

t_r recovery time (between current interruption and return of the FCL to its low impedance state)

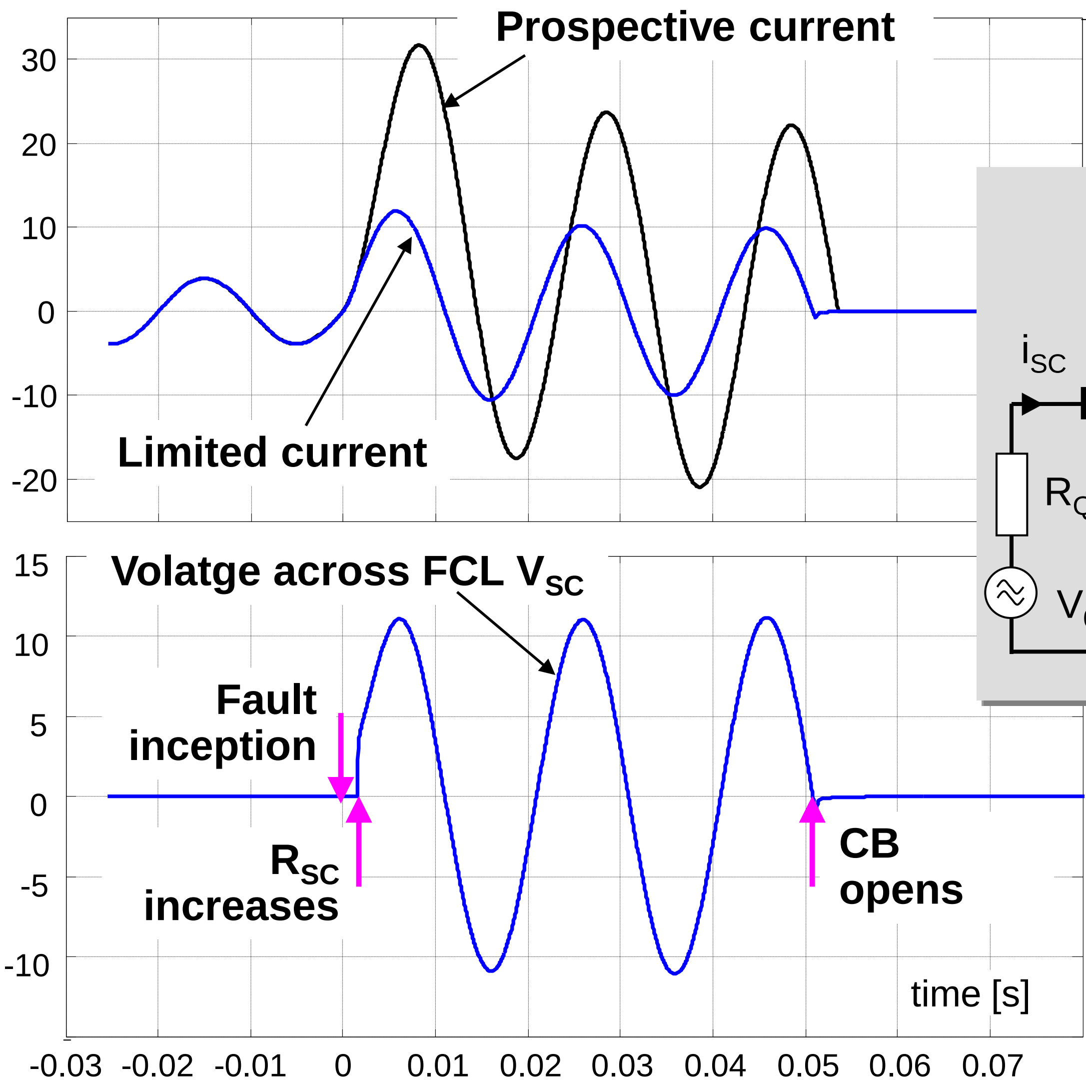
Basic FCL Principle

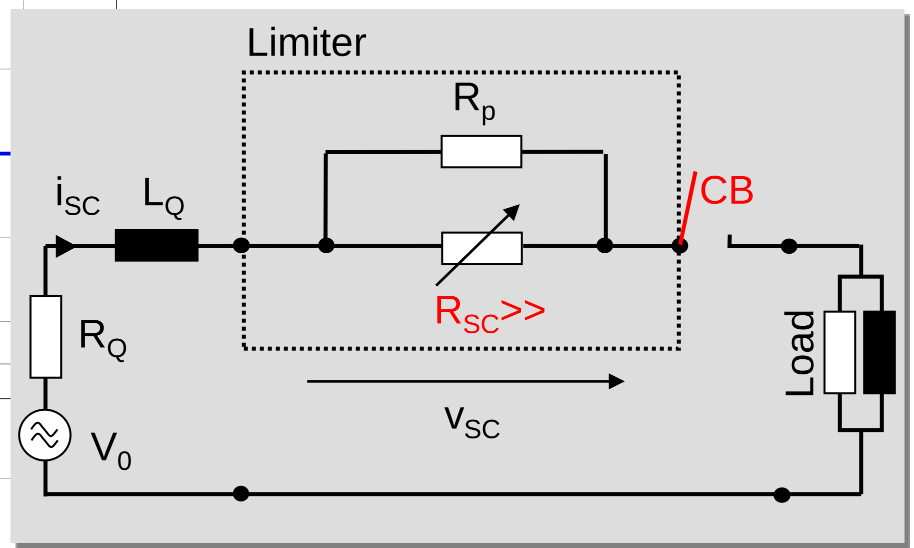




Resistive type SCFCL with **inductive** shunt

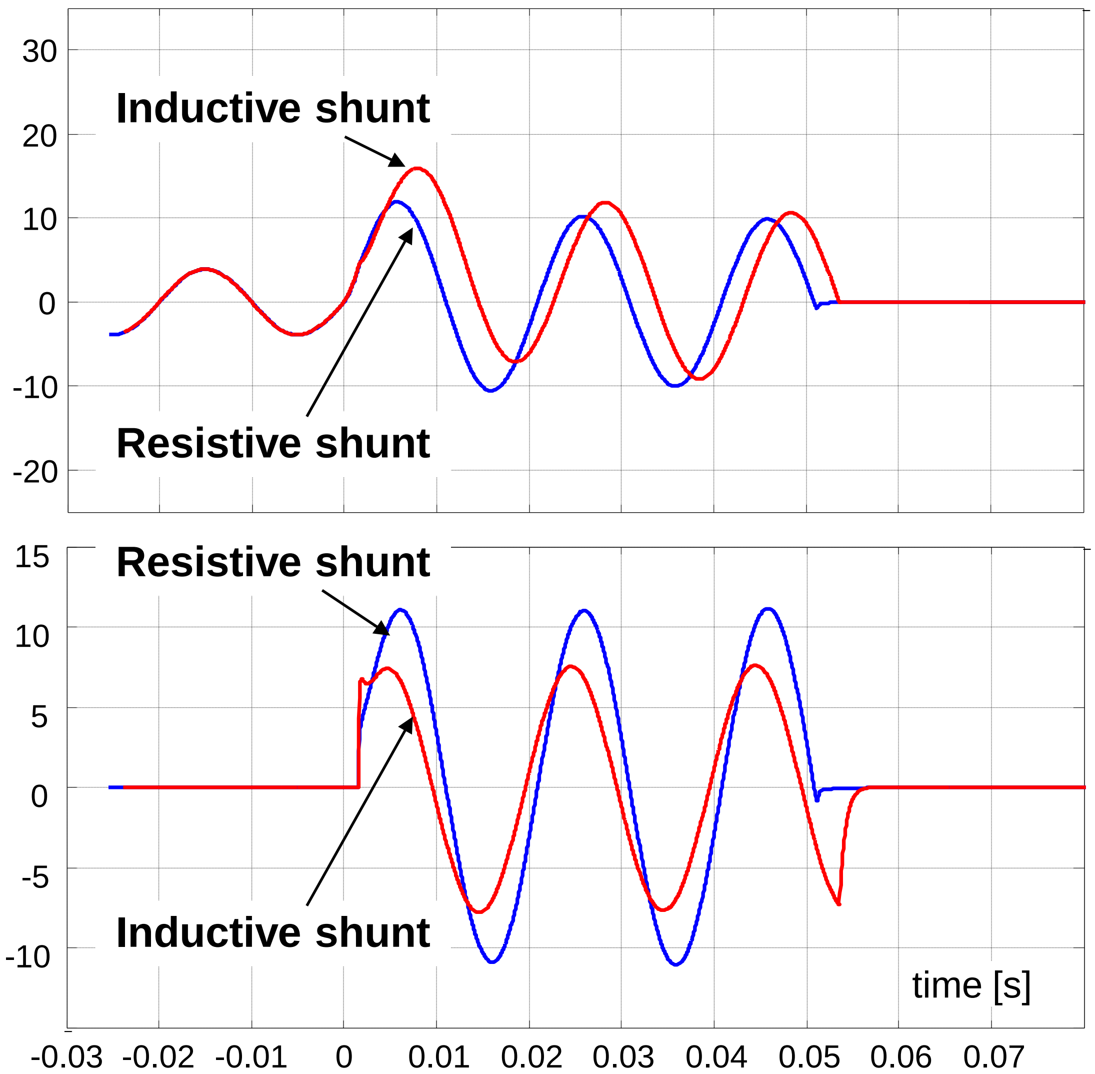
Basic FCL Principle





Resistive type SCFCL
with **resitive** shunt

Resistive Versus Reactive Shunt



System parameters

I_P/I_N = 10

I_{LIM}/I_P = 0.5 (steady state)

X/R = 10

Representative Waveforms for Developing Parameterization

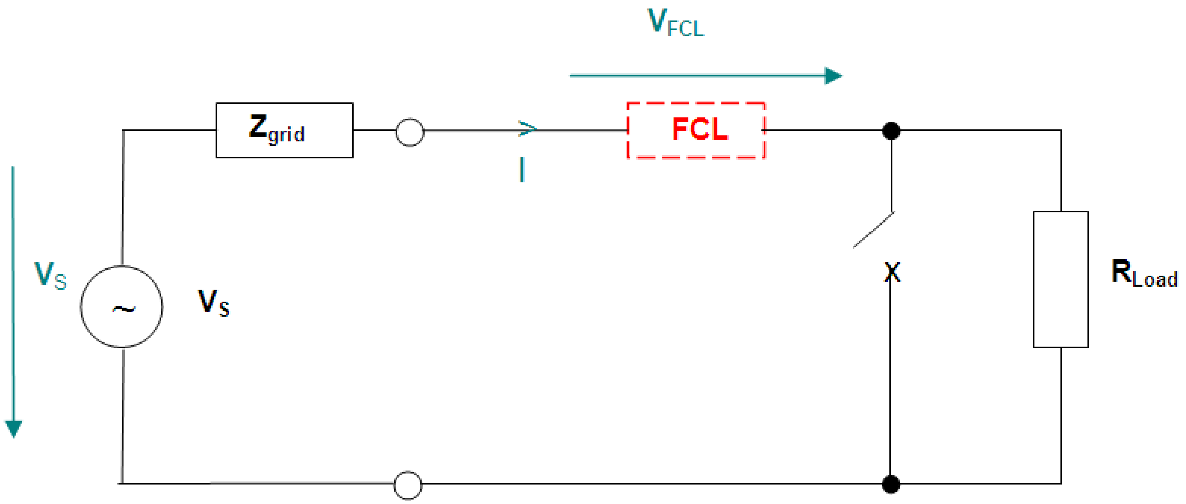


Figure 1: *circuit example*

$$|Z_S| = \sqrt{R_S^2 + X_S^2} = 0{,}05 \quad (1)$$

$$\frac{X_S}{R_S} = 20 \quad (2)$$

$$R_L = \sqrt{\left(\frac{V_S}{I_L}\right)^2 - X_S^2} - R_S \quad (3)$$

$$f = 60 \text{ Hz}$$

$$V_S = 1\,pu$$

$$I_L = 1\,pu$$

$$R_S = 0.0025\,pu$$

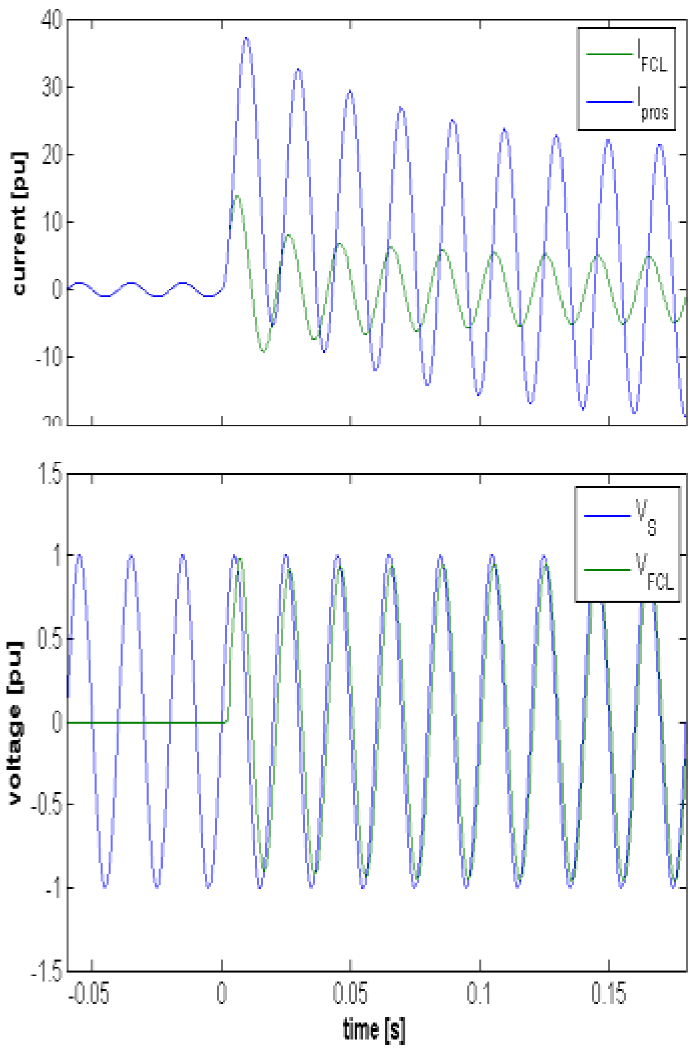
$$X_S = 0.0499\,pu$$

$$R_L = 0.9963\,pu$$

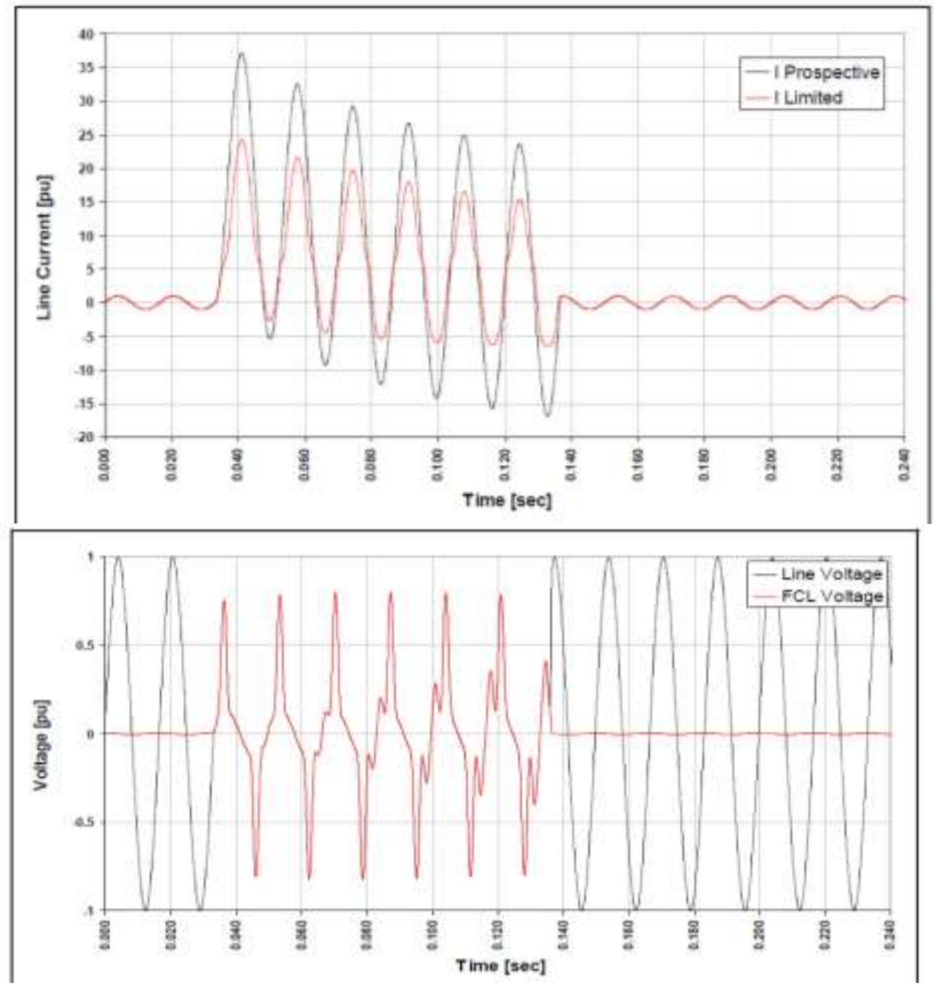
- Two current & two voltage traces
- Time sequence
  - Fault inception at a source voltage zero crossing
  - 2 cycles pre-fault
  - 6 cycles fault
  - 6 cycles pos-tfault
  - Recovery under load:
    - if so, then show the recovery behavior
    - if not. indicate recovery time

Representative Waveforms - Examples

HTS resistive w/ resistive shunt type

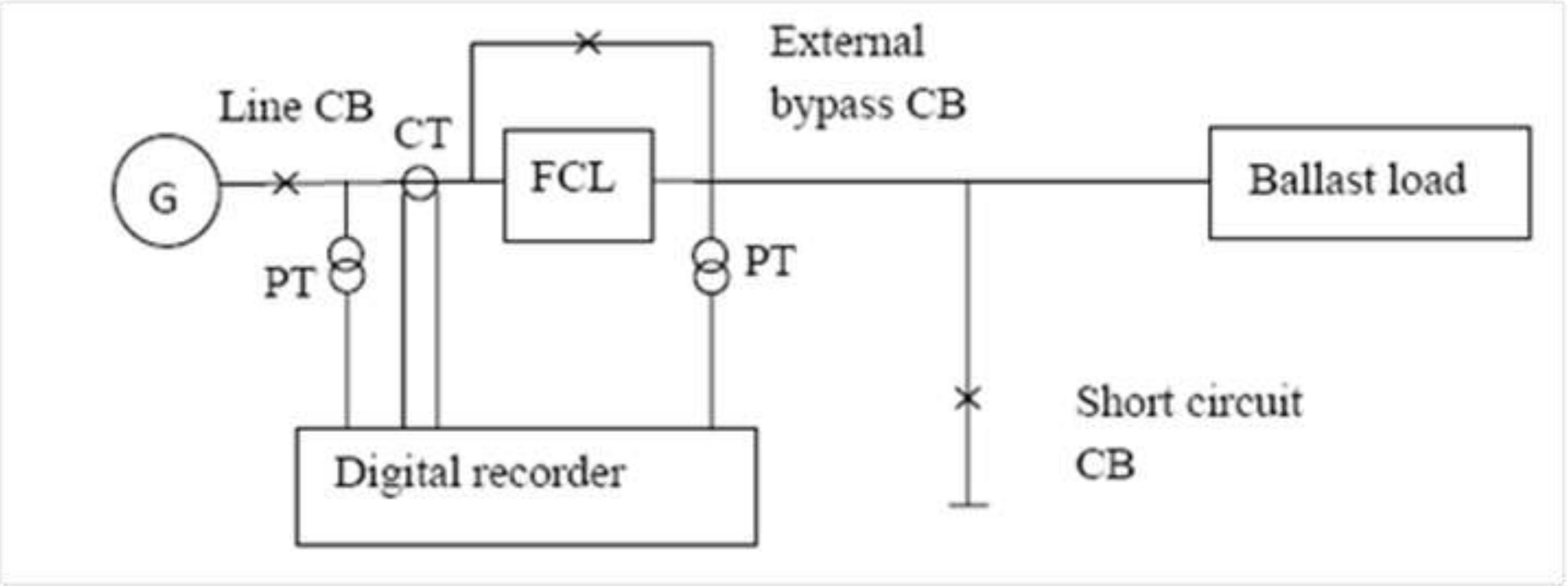


Saturated iron core type



- Design Tests
  - Dielectric tests
    - Power Frequency Voltage Withstand
    - Lightning Impulse Voltage
    - Switching Impulse Voltage
    - Chopped-Wave Voltage Impulse
    - Partial Discharge
    - Control Circuit Voltage Withstand
  - Current carrying and functional tests
    - Continuous Current (temp. rise, power loss, v drop)
    - Short-Time Withstand Current
    - Harmonic Distortion
    - Current Limiting (initiating, limited, action)
    - Recovery
    - Circuit Breaker Operation

Current Limiting Test Circuit



IEEE WG PC37.302

- Design Tests
  - Other tests
    - Protective Device
    - Electromagnetic Compatibility
    - Audible Sound
    - Vibration
    - Polarity
    - FCL Technology Specific Tests
- Production (routine) tests
- Field tests

Concluding Remarks

- Fault Current Limiters (FCL) are emerging Smart Grid technologies
- Where to find more information
  - CIGRE brochure 239 “*Fault Current Limiters in Electrical Medium and High Voltage Systems”*
  - CIGRE brochure 339 *“Guideline on the Impacts of Fault Current Limiting Devices on Protection Systems”*
  - EPRI *“Fault Management Guide Book”*
  - M. Noe and M. Steurer*, ”High Temperature Superconductor Fault Current Limiters – Concepts, Applications, and Development Status”*, Supercond. Sci. Technol., No 20, 2007


Supercond. Sci. Technol. 20 (2007) R15–R29

TOPICAL REVIEW

High-temperature superconductor fault current limiters: concepts, applications, and development status

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