Utility Needs Survey for Fault Current Limiters

International Workshop on Coated Conductors for Applications (CCA08)

Hilton University of Texas, Houston, TX

December 4-6, 2008

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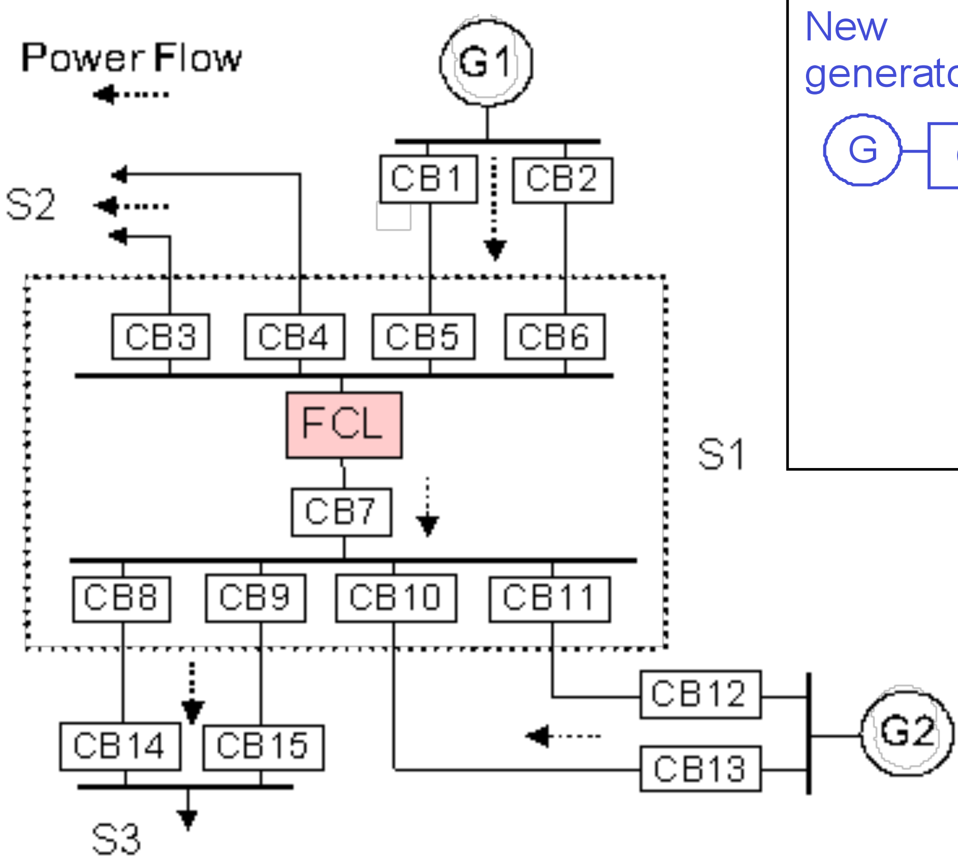
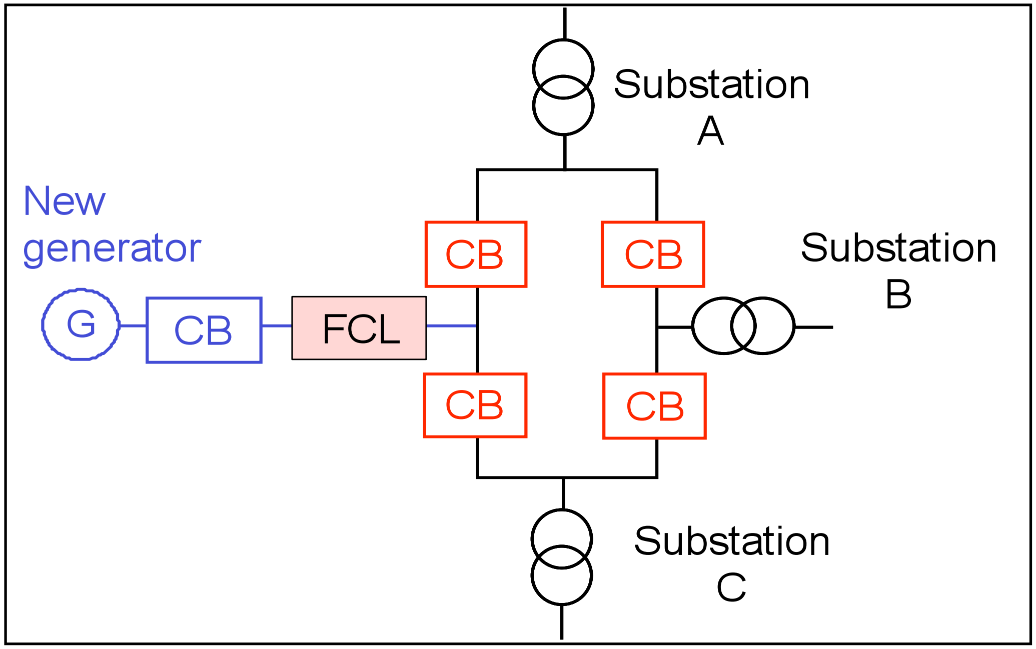
Utility Need for Fault Current Limiters

BUS TIE





NEW GENERATION

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Taxonomy of Fault Current Limiters

Permanent impedance increase

during nominal and fault conditions

Condition based impedance increase

Small impedance at nominal load
Fast increase of impedance at fault

Split into sub-grids

Introduce higher voltage

Split bus bars

High impedance transformer

Current limiting reactor

Sequential tripping

Fuse based device (<36 kV)

Stand alone HV fuse (< 1 kA)

Commutating current limiters (<5 kA)

NOVEL CONCEPTS

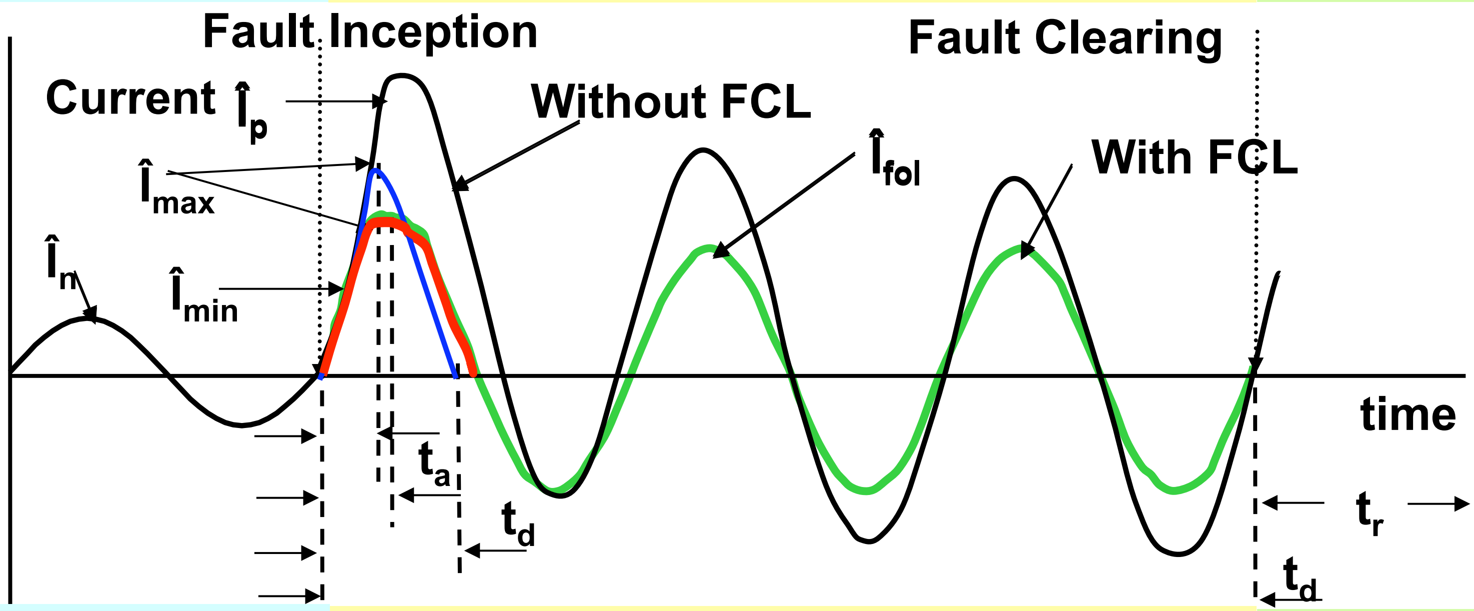
- **Superconductors**
- **Semiconductors**
- **Hybrid systems**

Topological	**Apparatus**	**Topological**	**Apparatus**

MEASURES

FCL Parameters Graph

I Normal operation	II Fault condition	III Recovery



rated system voltage (Un) ($\hat{i}_n$):rated current (peak)	$\hat{i}_{min}$: **minimum initiating current** $\hat{i}_{max}$: **maximum limited current** $\hat{i}_p$: **peak (prospective) short circuit current** $\hat{i}_{fol}$: **peak value of the follow current** t_a: **action time: from t = 0 until** $\hat{i}_{max}$ t_d: **fault duration time**	Recovery time t_r time between current interrupt and return of FCL to (initial) low impedance state

“Ideal” Fault Current Limiter

- Zero line impedance during normal conditions
- Fast reaction to fault
- Discern between fault and temporary over-current
- Allow follow current for downstream protection coordination
- Maintain voltage rise to within operating limits
- Immediate recovery
- Redundancy

Utility Needs Survey: Observations and Conclusions

- Most common measure for current limitation used today is passive
  - Series reactors and/or high impedance transformers
- Reasons for reassessment of future needs for limiting fault currents:
  - Breaker ratings and bus bracing issues
  - Regulatory requirement for mandatory connection of independent power producers (IPPs) to the grid

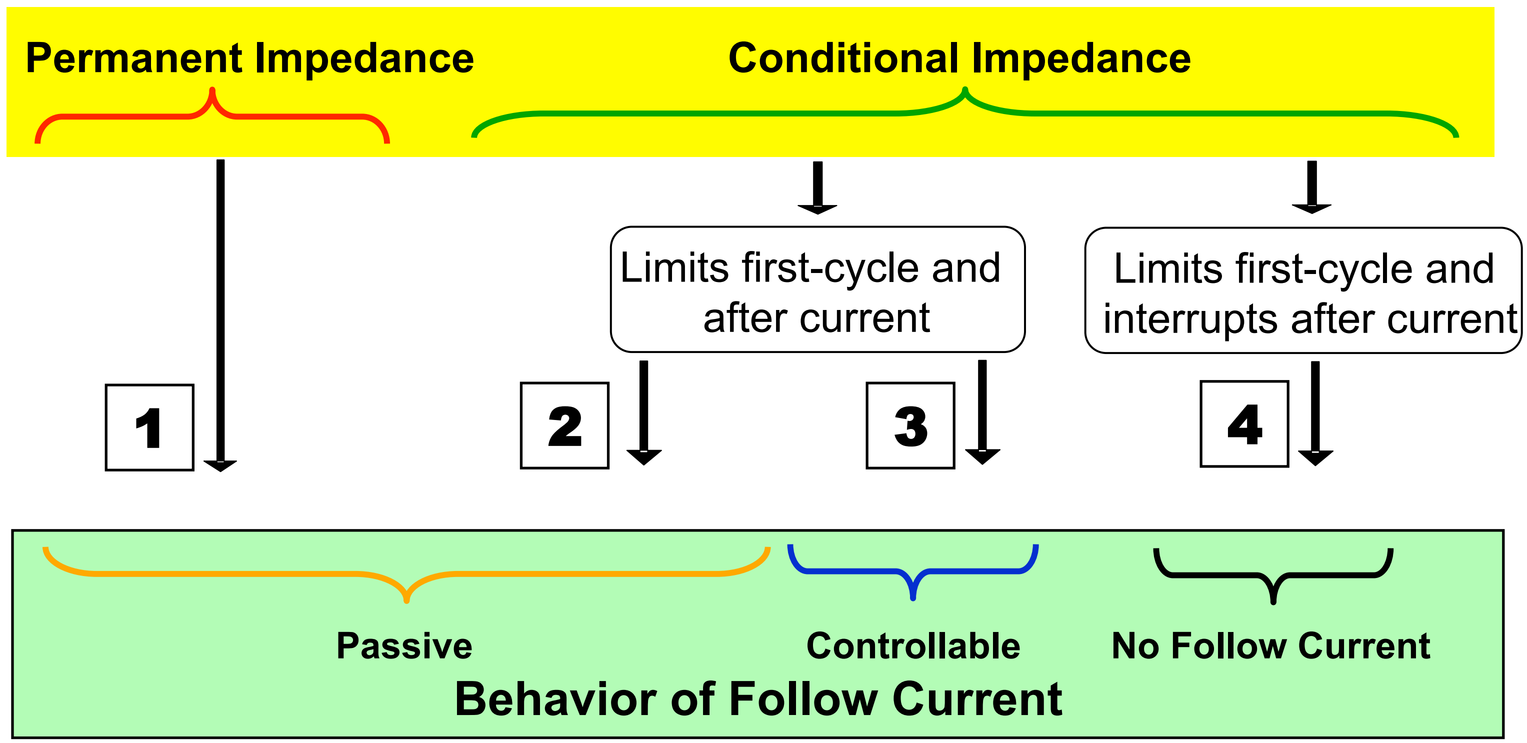
Utility Needs Survey: Observations and Conclusions – 2

- Potential market: approximately 2 FCLs per utility per year
  - Assumes FCLs most cost effective means to manage fault currents
- Cost: 50% would accept 2 to 5 times cost of a circuit breaker (CB) for a novel FCL device
  - Assumes no CB of adequate rating is available
- “Low total cost of ownership” and “Fail safe design” are most important features of a FCL
  - “Losses” and “Size” matter less
  - “Inherently self triggering” is least important feature.
- Need for standard specifications for test procedures

Together…Shaping the Future of Electricity

Appendix

Classification of FCL Follow Current Behavior



1. Limiting reactor
2. Superconducting fault current limiter (resistive type)
3. Solid-state fault current limiter (without parallel impedance)
4. Pyrotechnic fault current limiter (without parallel impedance)

Relative Importance Of FCL Characteristics

FCL characteristics	Resp.	Low	Low-Med	Med	Med - High	High	Highest	Average
Low capital cost	27	0	1	5	3	5	13	Med - High
Low total cost of ownership	27	0	0	2	1	6	18	High
Small size	26	1	1	4	9	6	5	Med - High
Low losses	27	0	2	4	7	12	2	Med - High
Fail safe design	27	0	1	2	3	3	18	High
Inherently self-triggering	27	2	2	3	7	9	4	Med - High
Low maintenance	27	0	0	0	3	12	12	High
Controlled fast reclosings	25	1	1	2	6	11	4	Med - High
Total responses	27							
Additional comments	4							

High Voltage Testing – AC Withstand & PD

Test	Conditions	Values			
		Breakers C37.06, Table 4	Transformer C57.12.00, Table 6	Reactor C57.16, Table 5	Proposed MFCL
60Hz Withstand	1 minute withstand (dry)	310kV			310kV
60Hz Withstand	10 second withstand (wet)	275kV			275kV
Applied Voltage			275kV	335kV	
Induced Voltage (PD)			125kV for 1 hour, 145kV for 120 sec, 125kV for 1 hour		125kV for at least 5 min, 145kV for 120 sec, 125kV for 1 hour

Source: SuperPower, US DOE Readiness Review, April 9, 2008

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FCL High Voltage Testing – Impulse

Test	Conditions	Values			
		Breakers C37.06, Table 4	Transformer C57.12.00, Table 6	Reactor C57.16, Table 5	Proposed MFCL
BIL Lightning Impulse	1.2x 50μs	650kV 3(+) &3(-)	650kV	650kV 1 reduced & 3(+)	1 reduced full (650kV), 2 chopped (715kV- 3μs chop), 1 full (650kV) (-) polarity
Chopped Wave	2μs chop	838kV 3(+) & 3(-)			
	3μs chop	748kV 3(+) & 3(-)			
Chopped Wave	3μs chop		715kV 1 reduced full, 2 chopped, 1 full (-) polarity	715kV 1 reduced full, 1 full, 1 reduced chopped, 2 chopped, 2 full(+) polarity	
Switching Impulse	250 x 2500μs	NA	540kV 1 reduced, 2 full either (+) or (-)	540kV 1 reduced, 15 full (+) (2 disruptive discharges are allowed)	540kV 1 reduced, 2 full (+) 1 reduced, 2 full (-)

Source: SuperPower, US DOE Readiness Review, April 9, 2008

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