“Superconducting Fault Current Limiter at Knapps Corner Substation”

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Agenda

* Superconductivity and It's Application to FCL's
* Project Background and Overview
* Details of the FCL Installation
* SCFCL Performance : June 2014 – Present
* Questions and Answers

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Superconductivity – Application to FCL's

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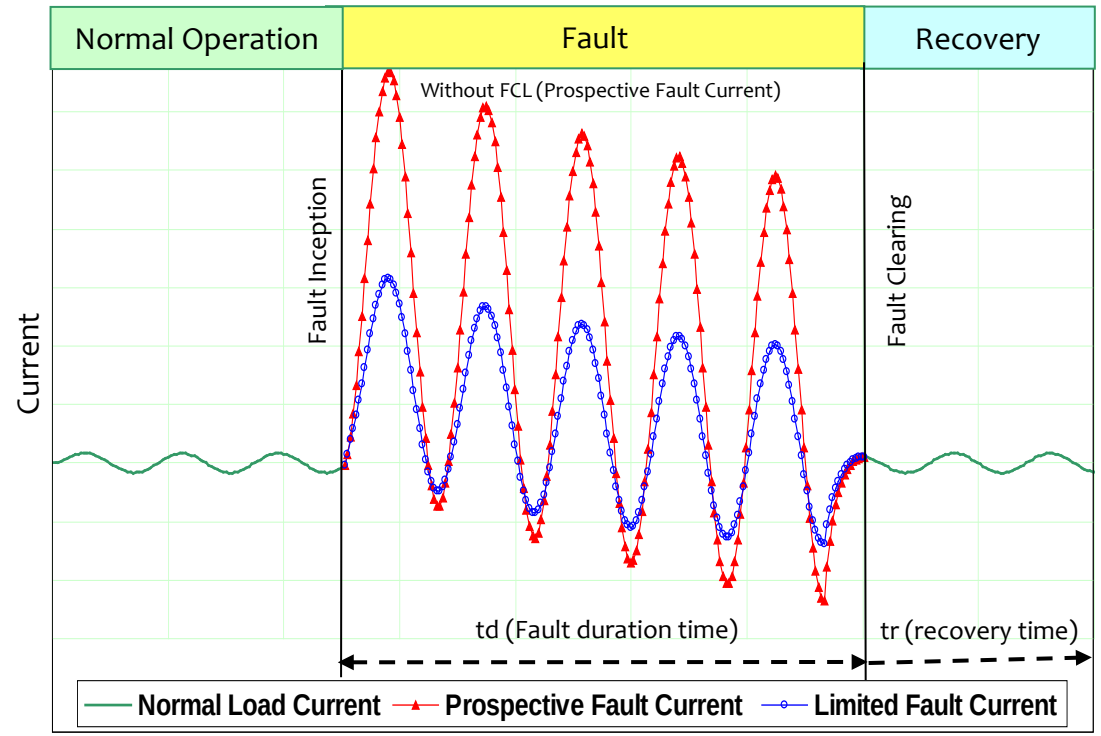
Desired Characteristics of an Ideal FCL?

An ideal Fault Current Limiter would:

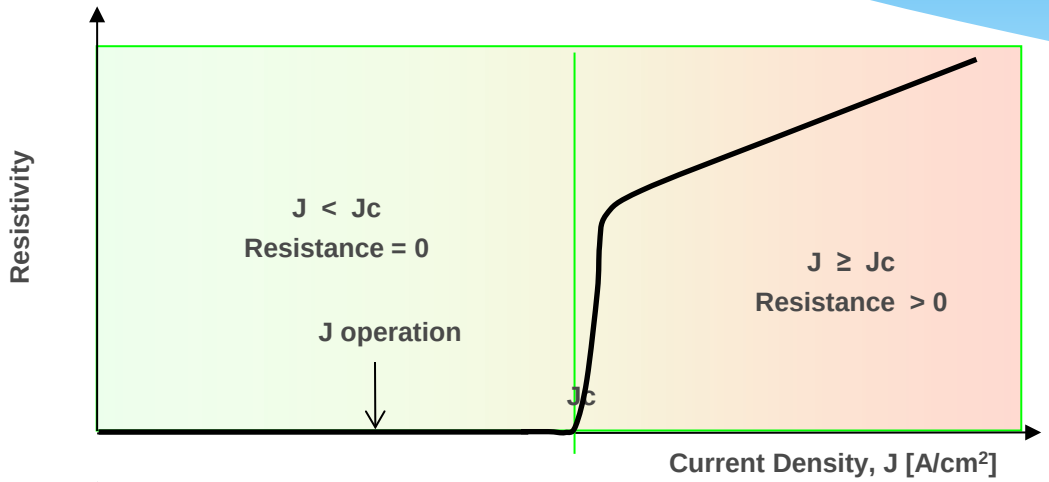
* Increase the impedance on the line well before the first fault peak (when the most damage occurs)
* In normal operation, it is virtually "transparent“ (no power or voltage loss) to the network
* Diminish the fault current by at least a factor of 2 for its duration
* Return the source impedance to its original value

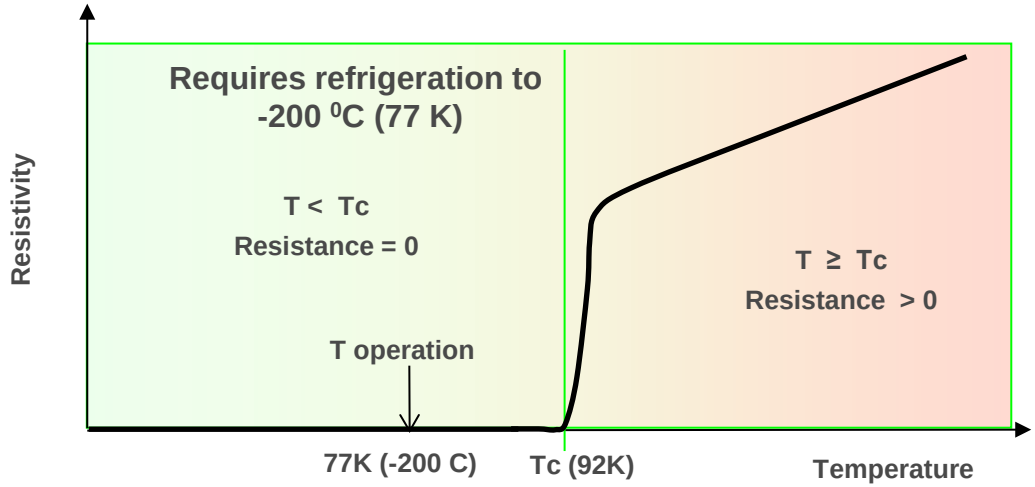
Typical current waveforms due to fault



Fault Current Limiters Reduce Fault Currents Without the Need for Mitigation

Superconductivity - Ideal for Fault Current Limiters

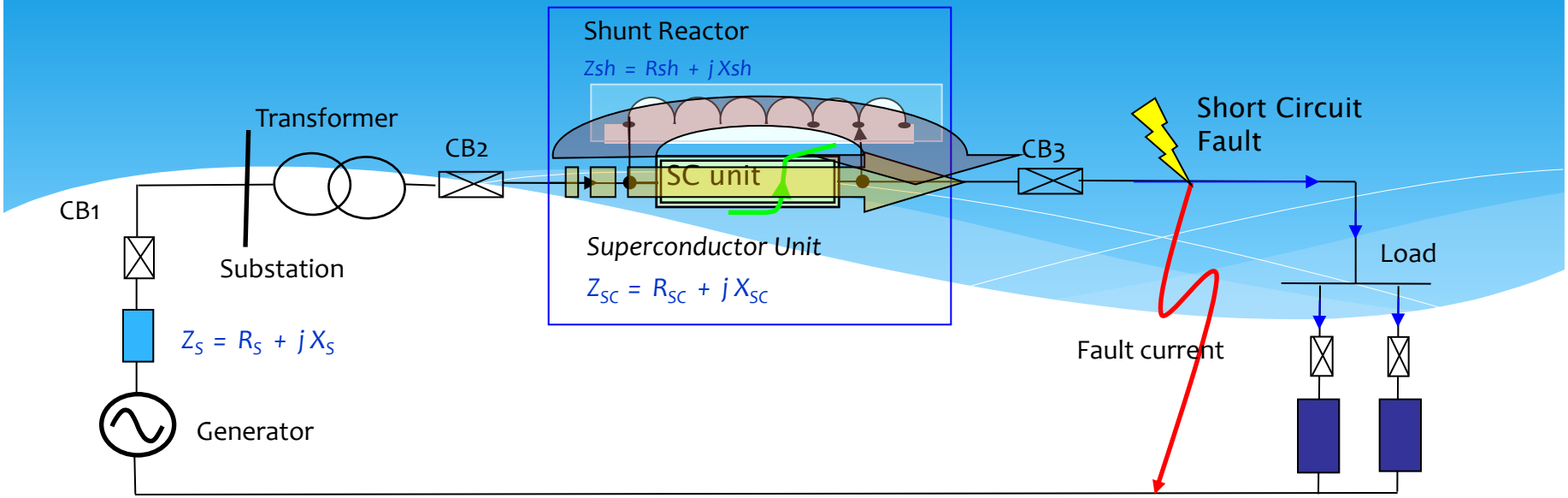




- Zero resistance during normal operation, $J < J_c$
  - Also if $B < B_c$ and $T < T_c$
- High impedance during fault condition, $J \geq J_c$,
  - **Also when** $B > B_c$ or $T > T_c$
- Uses inherent material properties. Ideal for fast switch application
  - < 1mS
- No active control needed

Superconducting Materials are Ideal for Fault Current Limiters
Fast Switching Enables First Peak Reduction

How an SCFCL Works



- **Normal operation**
  - Load current flows through superconducting unit
  - SCFCL introduces nearly zero impedance and zero voltage drop
- **Fault Condition**
  - Superconductor inherently senses fault current, quenches, ***inserts high resistance in ~ 1 ms***
  - Current transfers to shunt and limits fault current
- **Recovery**
  - Superconducting unit recovers superconducting state quickly (seconds)

Fault detection and current limiting is done with passive inherent superconductor properties – laws of physics rather than electronics

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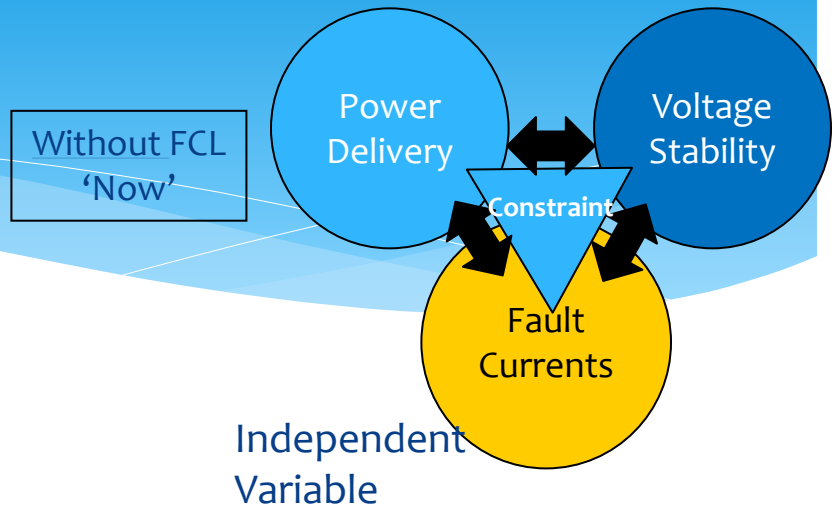
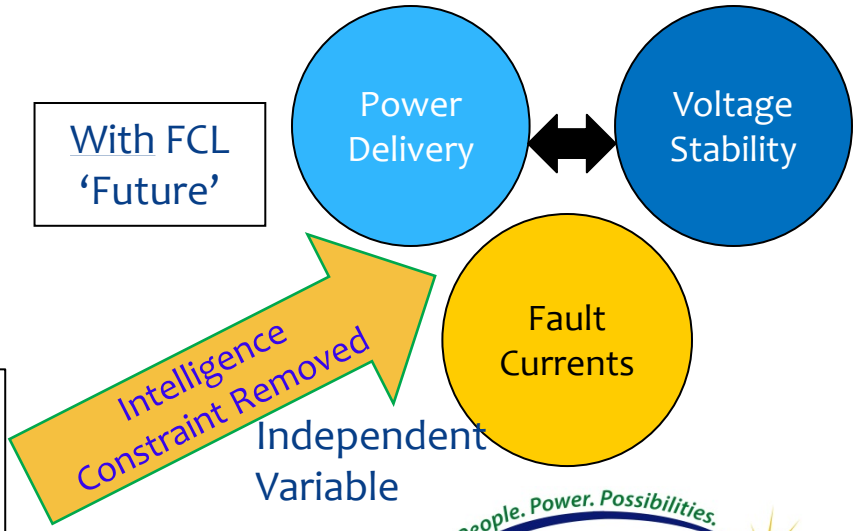
System Impact of Fault Current Limiters (FCL)

- **No FCL**
  - Fault currents are critical system design constraints
  - Power quality and voltage stability impacted with high fault currents

- **With FCL**
  - FCL removes fault current constraint - decouples Fault Current from the delivery of high quality power
  - Decoupling provides new flexibility
  - Expansion of current substations
  - Greater interconnection/reliability
  - Simpler Distributed Generation and renewables integration





FCLs alter the fundamental way the grid can evolve – Enhances Smart Grid technology and implementation

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Project Background and Overview

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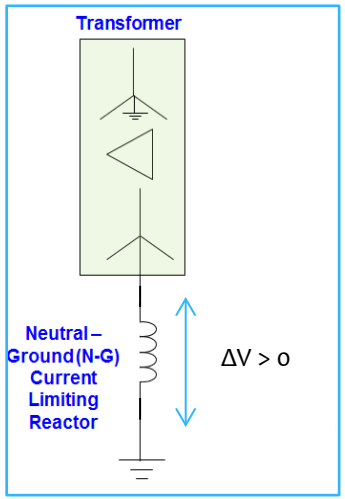
Knapps Corner Problem Statement and Solution

* *Problem:*
  * 2013 - Fault currents at Knapp's Corner were at an increased level (estimated to be at 12kA)
  * Needed a solution to get them to <10kA

* *Central Hudson Solution:*
  * Central Hudson was planning to install CLR's in-between Neutral and Ground to limit fault levels
    * This will limit fault currents… however… also results in a constant voltage between N –G when current is flowing.



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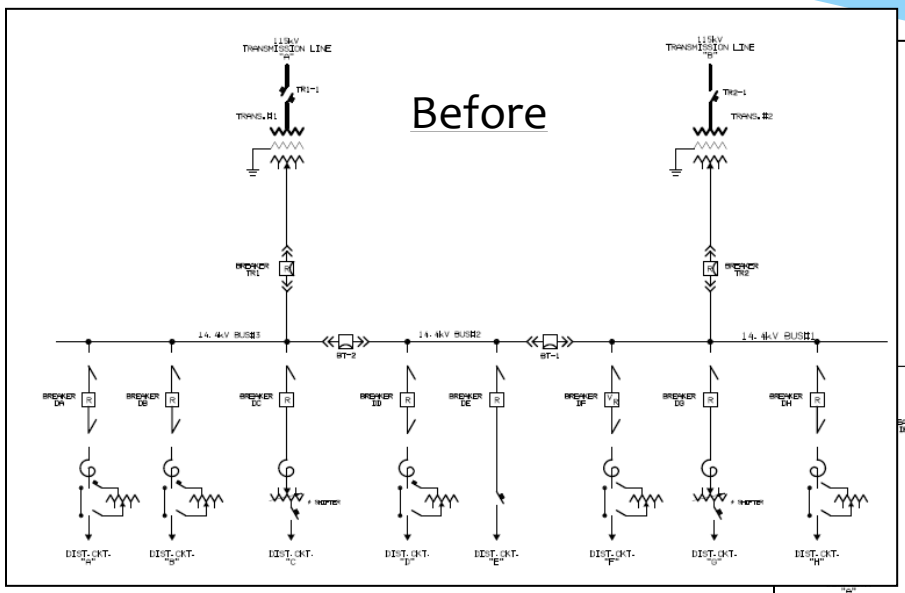
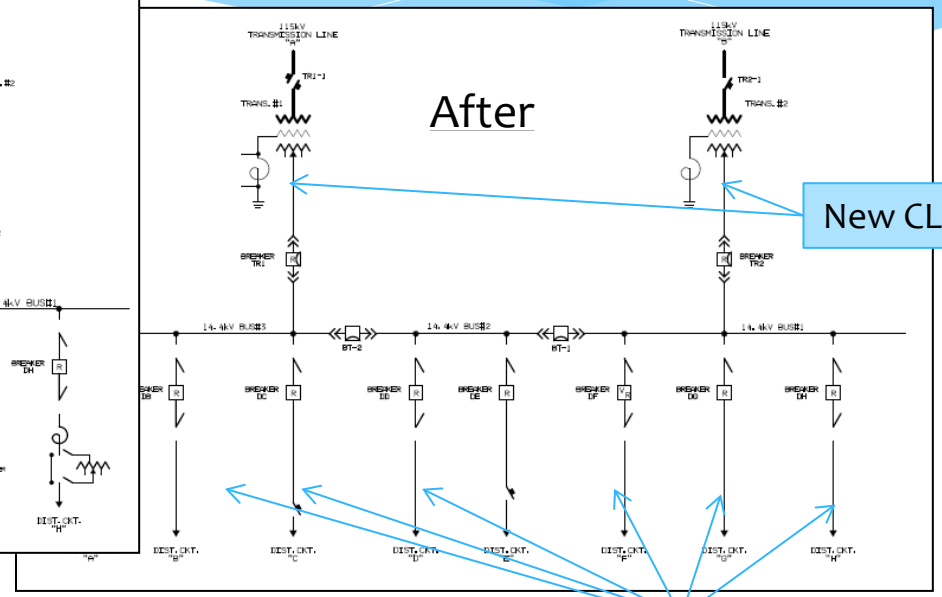
Some Additional Benefits to Central Hudson by Adding the CLR's

1. Allowed the separation of the bus





2. Elimination of voltage regulators and reactors on each circuit

Removed Circuit Regulators and Reactors

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… Happening in parallel… AMAT's Fault Current Limiter Program

* Applied Materials was applying for a NYSERDA project for a SCFCL Product Demonstration and in need of a host –utility.
  * AMAT already had a unit operational at it's Silicon Valley corporate location – 3Phase / 13.8kV / 1000A ratings

* Timing between Central Hudson's reactor installation and AMAT's demonstration needs matched up.

* AMAT's addition of a Superconducting Unit to Central Hudson's Reactor will minimize the constant V_{drop} when current is flowing

  → Impedance only when needed during fault

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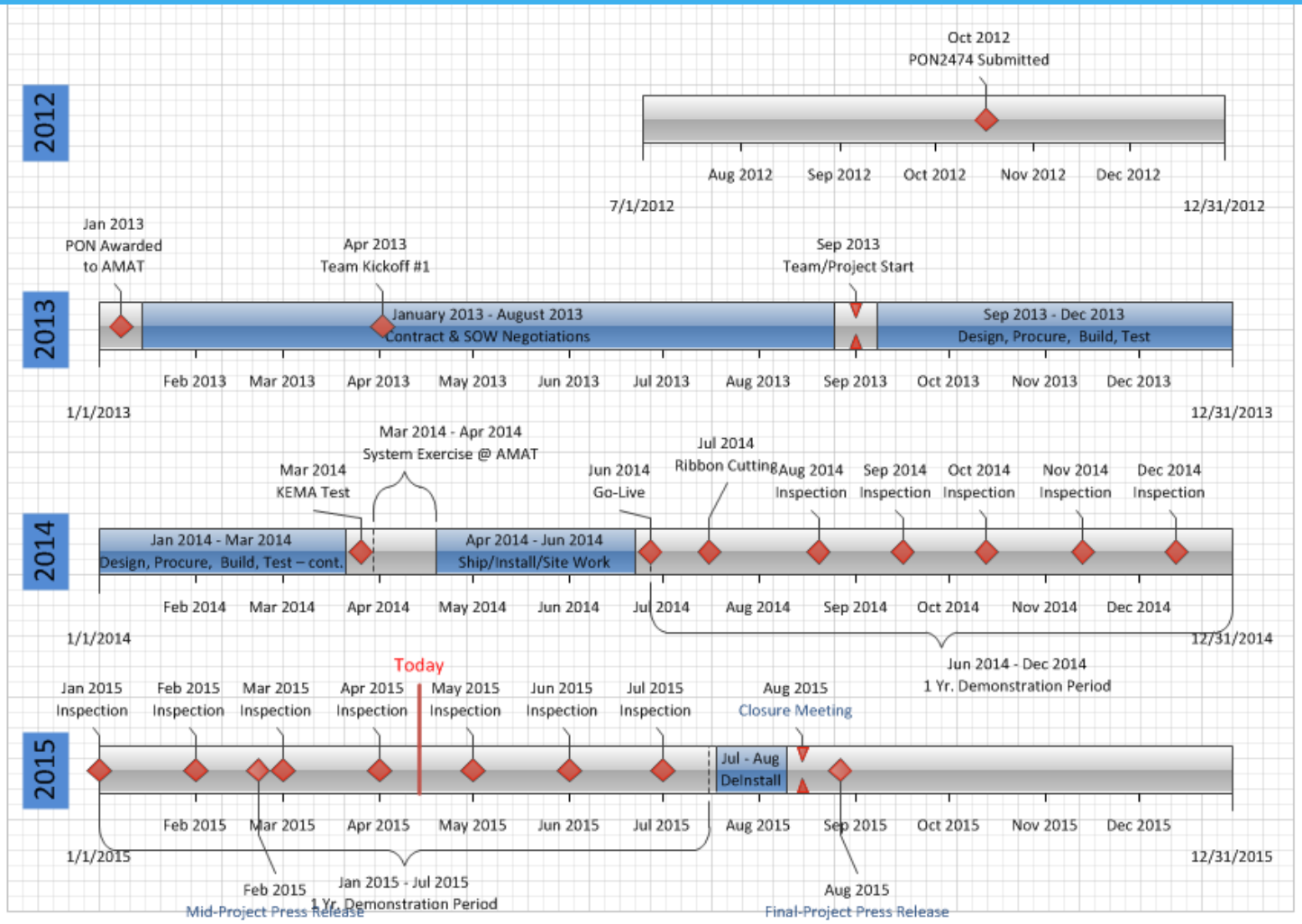
A Combination of Efforts

* Applied Materials, Central-Hudson (a New York State utility) and SuperPower (HTS tape supplier) jointly worked to install and demonstrate a SCFCL at Central Hudson's Knapps Corner Substation.
  * 11.5kV – Neutral to Ground Installation
  * 1.75 years - (including site design, one year demo phase and decommissioning)
  * Funding from NYSERDA to Applied is ~$1.2 million to be matched at 50% cost-share (cash + in-kind) by the proposal team partners.

* This FCL device will:

1. Be transparent to the grid under nominal condition
2. Insert impedance into the system when a fault occurs.
3. Allow for the reduction of the first peak of the fault and will limit the fault to a desired level

Project Schedule Overview



- **Key Milestones**
- 9/13 – Project Start
- 3/13 - KEMA Testing
- 4-6/14 – Site Preparation
- **GO LIVE – 6/14**
- 12 month demonstration – 6/14 - present

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Knapp's Corner Overview – Poughkeepsie, NY

* 115/14.4kV Substation in Downtown Poughkeepsie, NY (22MVA @ peak)
* Customer Base – 34,400 (Galleria Mall, Rt. 9 businesses plus residential)
* Experiences ~10 faults per year and need to reduce levels
* Currently installing a 0.2 Ω reactor in neutral-ground location

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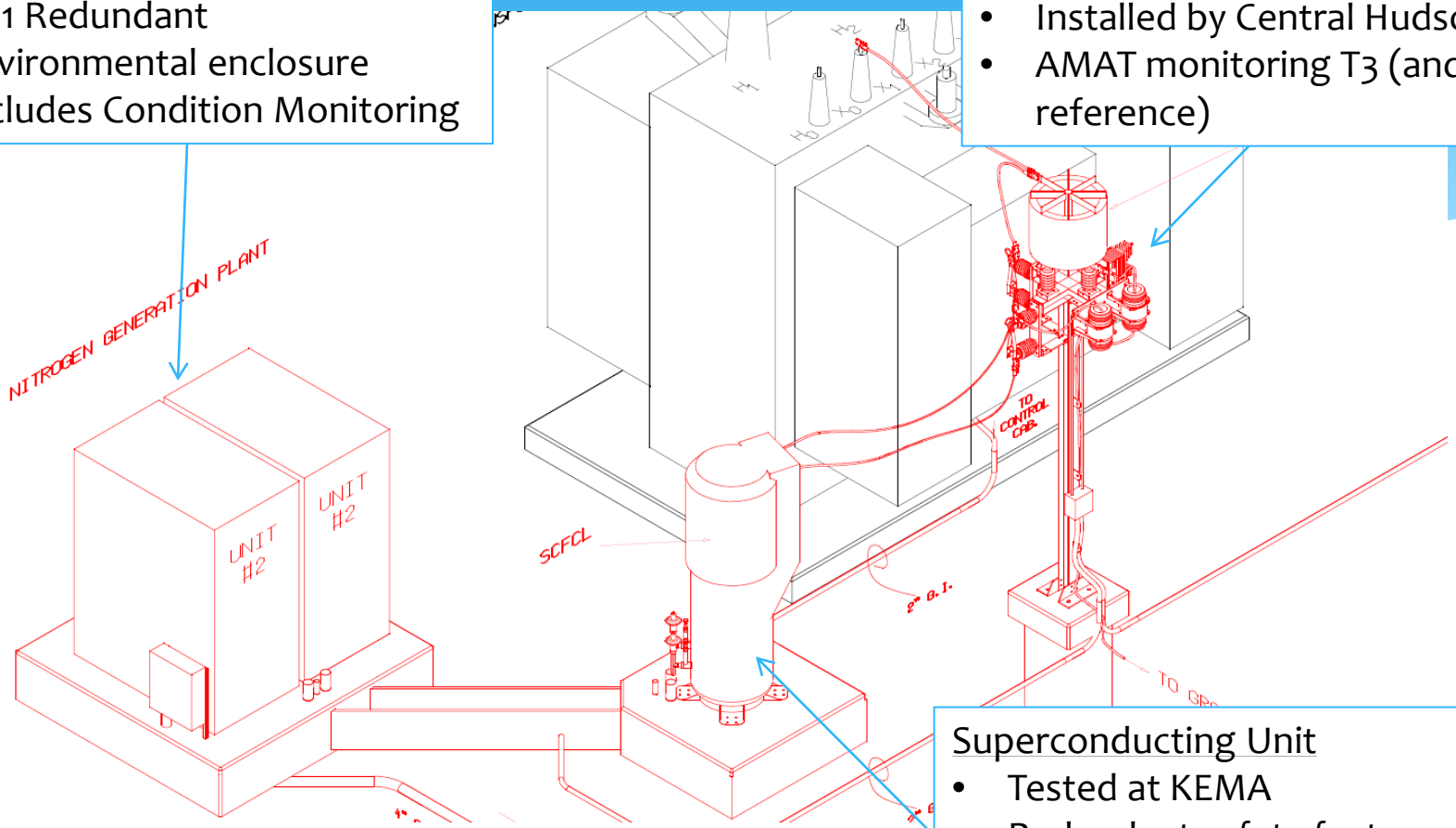
SCFCL System Layout – Central Hudson

Refrigeration Units (2)
- N+1 Redundant
- Environmental enclosure
- Includes Condition Monitoring

Reactor (+CT/PT)
- Installed by Central Hudson
- AMAT monitoring T3 (and T1 for reference)



Superconducting Unit
- Tested at KEMA
- Redundant safety features
- Environmental Cover
- Optimized boil-off

System
- Lessons learned from SCLA installation
- KEMA tested for SC, BIL and AC withstand

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Details of the FCL Installation

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Installation Images & Effort

Foundations were required for :

1. Refrigeration units
2. Reactors
3. SC Unit
4. Utility Transformer
5. Cable Trenches (LN2, Signal)

Refrigeration Units were first to go in.

* Both units placed in second day.
* Mounting, power up and LN2 generation quickly followed
* Both units were installed and debugged in the first few days

Installation Images & Effort– cont.

The 15kV Class Superconducting unit was the next to go in.

* Some pre-assembly was required and performed by AMAT personnel on the unit
* All rigging was done by Central Hudson members throughout the project
* Once Installed SC unit was filled manually with Liquid Nitrogen via 230l dewars
  * This allowed the refrigeration units to generate and fill in prep for commission.

Installation Images & Effort– cont.

0.2 Ohm Reactor being lifted into place

* CT's and PT's included in these assemblies

Truly a Team Effort

* Material on-site to Commissioning was <2 weeks
* No major issues to report in project install
* Collaboration was exceptional

SCFCL Performance
June 2014 - Present

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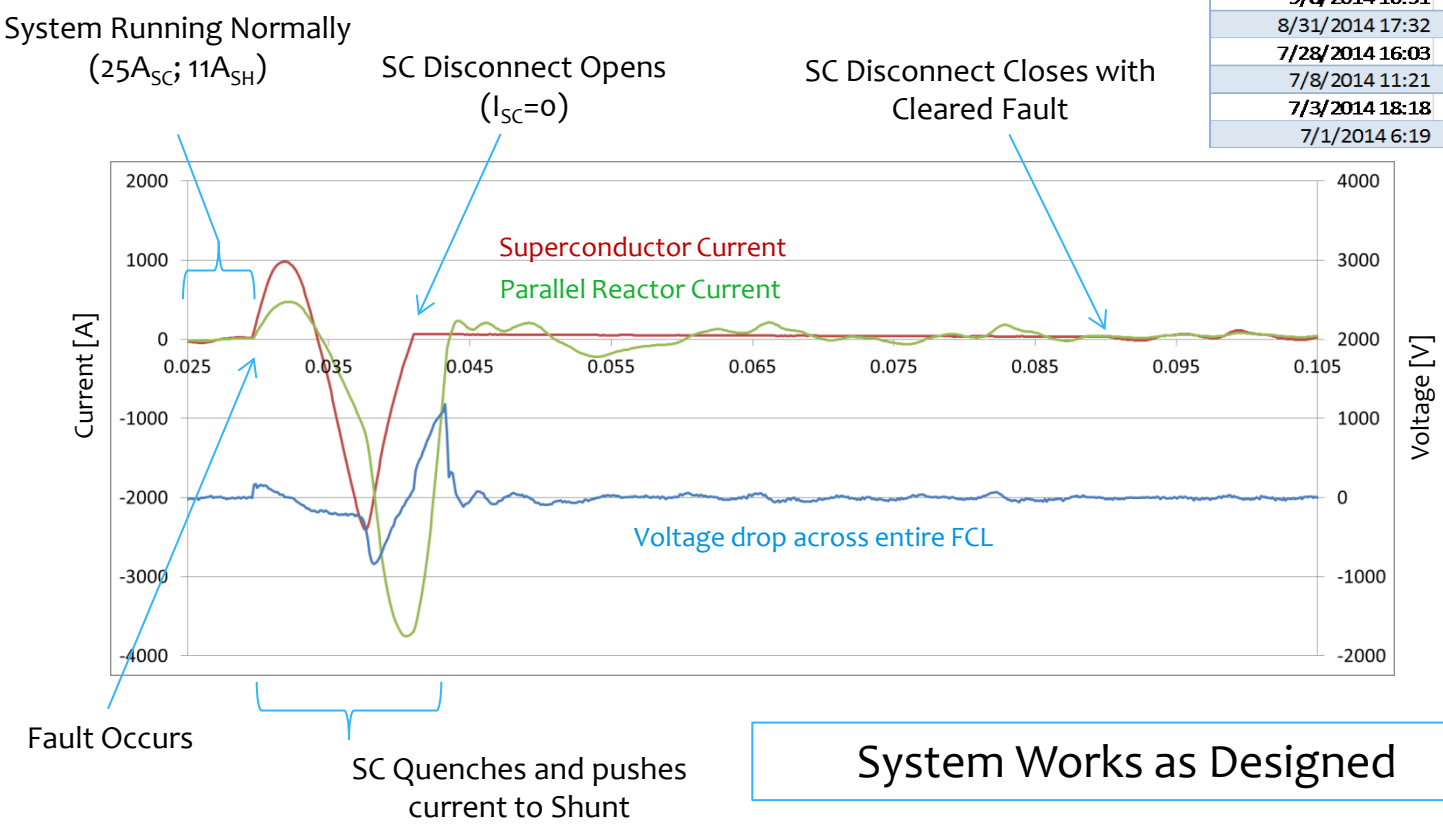
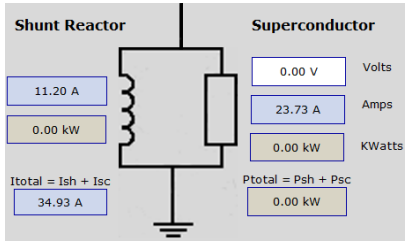
Central Hudson FCL Performance Summary

- Total of 15 Actual Faults Captured and Reduced (all faults recorded)
- Largest Fault level captured 4600 A limited value - numerous faults >3kA

Faults at Transformer 3 Since FCL Commission		
Time of Fault	Peak of Fault (kA)	FCL Operate?
1/5/2015 11:09	1800	Yes
11/26/2014 17:41	4000	Yes
11/13/2014 21:46	3300	Yes
11/8/2014 7:18	4000	Yes
11/6/2014 7:40	4600	Yes
10/18/2014 11:20	2350	Yes
10/16/2014 5:29	2400	Yes
9/9/2014 13:09	2000	Yes
9/9/2014 12:32	1400	Yes
9/8/2014 10:51	1900	Yes
8/31/2014 17:32	1800	Yes
7/28/2014 16:03	3200	Yes
7/8/2014 11:21	3700	Yes
7/3/2014 18:18	950	Yes
7/1/2014 6:19	3000	Yes

Detail of the FCL Operation at Central Hudson





Simplified Configuration at Central Hudson

System Works as Designed

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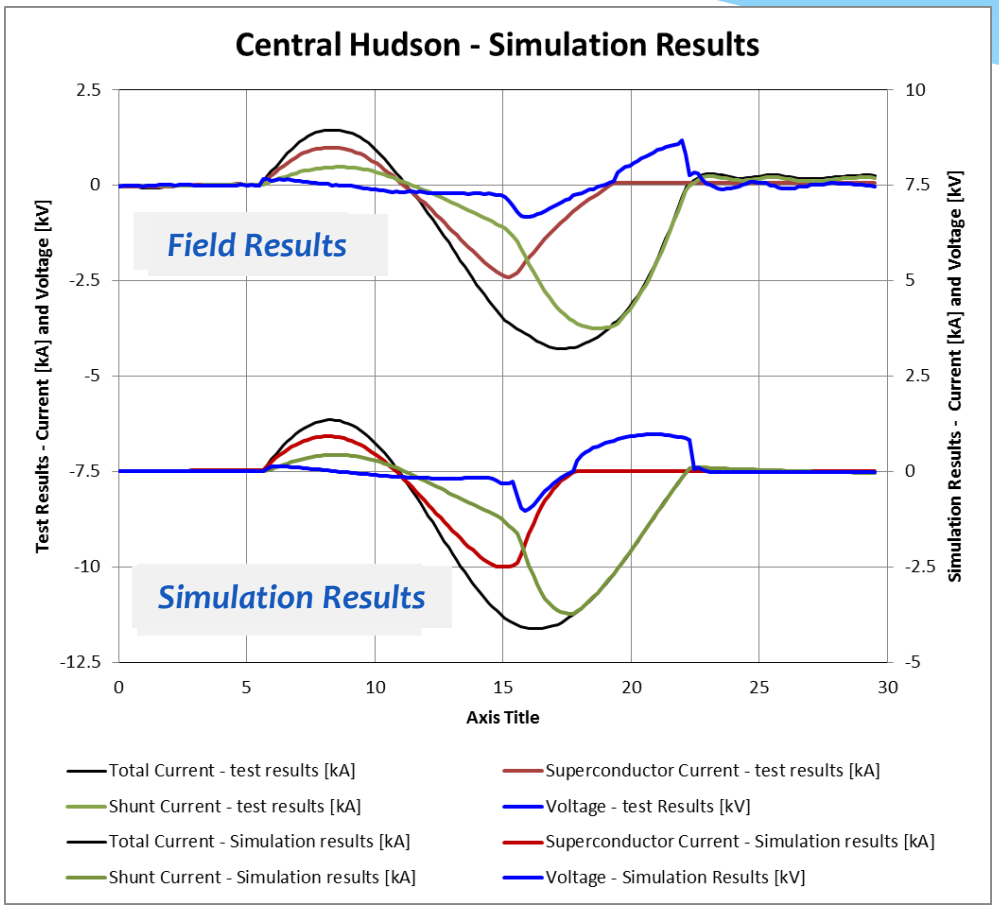
Central Hudson – Predicted vs. Actual Results



- Very close correlation to actual data and simulated (predicted) results
- Both clearly show shift from SC Unit to Shunt Reactor

****Simulated results biased on y-axis for comparison**

Operation Performance is well Understood and Predictable

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Lessons learned… It gets very cold in Poughkeepsie!

* Implemented learnings from SCLA to get the heat out… Now they are too cold during winter (Jan 8; -15°F in Poughkeepsie) – systems 'too efficient'
  * Actuate valves with Nitrogen vs. Air (will not freeze) due to water in lines
  * Remove all Chiller heat from enclosure to prevent over-temp of compressor

Final Product Resolution: Control ambient inside enclosure to manage within a window (Heat and AC). – simple products are available on the market.

Meantime: Added internal heaters to keep enclosure warm, adding insulation to louvered panels, temperature controlled exhaust fan.

1.5 kW heater installed to keep local area of refrigerator warm

Temp Controlled Exhaust Fan (>80F)

Significant louver openings

'All' chiller heat exhausted from enclosure

Numerous learnings… most centered around ambient control

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Project Next Steps

* Continue to monitor progress and fault performance
* Schedule a decommission in Summer 2015
* Final report of performance and findings to be compiled and presented at project completion (est. August 2015)
* Leverage knowledge and learnings going forward to enable technology transfer

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Overall Summary

* Central Hudson and Applied Materials collaborated on a ~2yr effort to install a SCFCL in grid though generous funding by NYSERDA
* System is currently in 3rd quarter of demonstration period
* Unit was 100% in-service with regular scheduled inspections
  * 15 Faults captured and system operated as expected
  * Although SC Unit required no maintenance, lessons were learned on the refrigeration units
* This project has helped enable a recent order of (2) 115kV Transmission-class AMAT FCL's for Early 2016 commissioning

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Thank You!

Q&A

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