Protection of EHV Transmission Lines With Series Compensation: BC Hydro's Lessons Learned

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Introduction

- BCH 500 kV protection systems
- Negative-sequence directional element settings
- Problems with natural system unbalances
- Single-pole tripping challenges
- Single-pole capacitor switching challenges
- Subsynchronous resonance
- Model power system testing

500 kV Protection Systems

- Identical Main 1 and Main 2
- POTT
  - 21P
  - 21G
  - 67G
  - 67Q
  - Phase selective DTT
- Dependability addressed by MPS testing

Trip and Reclose Modes

Mode	Fault	Trip	Reclose
1	Any	3PT	None
2	SLG	3PT	3PR
	Multiphase	3PT	None
3	Any	3PT	3PR
4	SLG	SPT	SPR
	Multiphase	3PT	None
5	SLG	SPT	SPR
	Multiphase	3PT	3PR

Speed and Sensitivity

Fault Type	Ground Resistance	Speed	Fault Location
Multiphase	N/A	1 Cycle	< 24% From Line Terminal
Multiphase	N/A	2 Cycles	> 25% From Line Terminal

Speed and Sensitivity

Fault Type	Ground Resistance	Speed	Fault Location
SLG	0–50 Ω	2 Cycles	0–100% Line
SLG	50–100 Ω	4–5 Cycles	0–100% Line
SLG	100–200 Ω	7 Cycles	0–100% Line
SLG	200–300 Ω	20 Cycles	0–100% Line

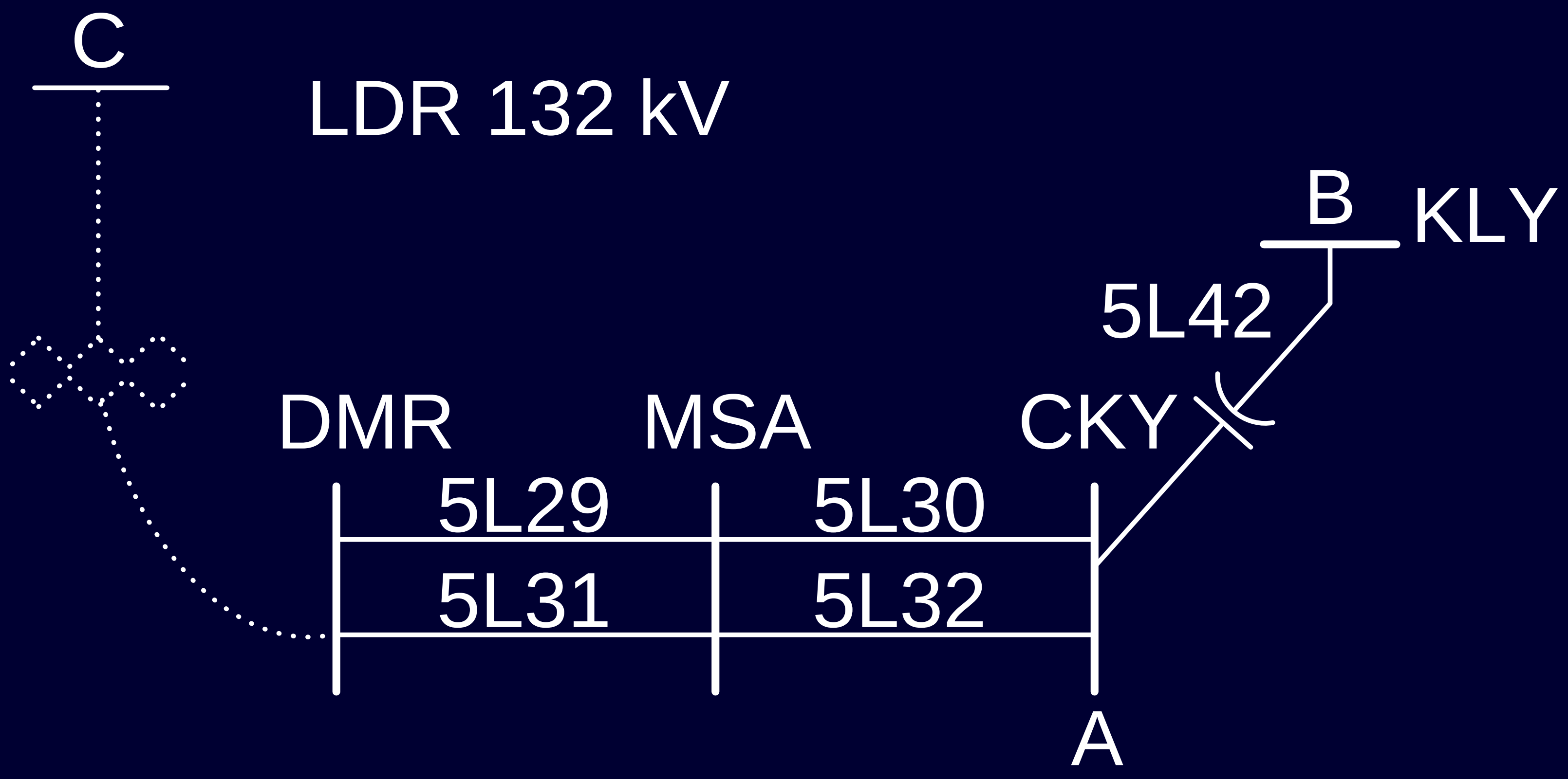
Negative-Sequence Directional Element

- Immune from zero-sequence mutual coupling
- Uses negative-sequence impedance
- High sensitivity in presence of strong sources

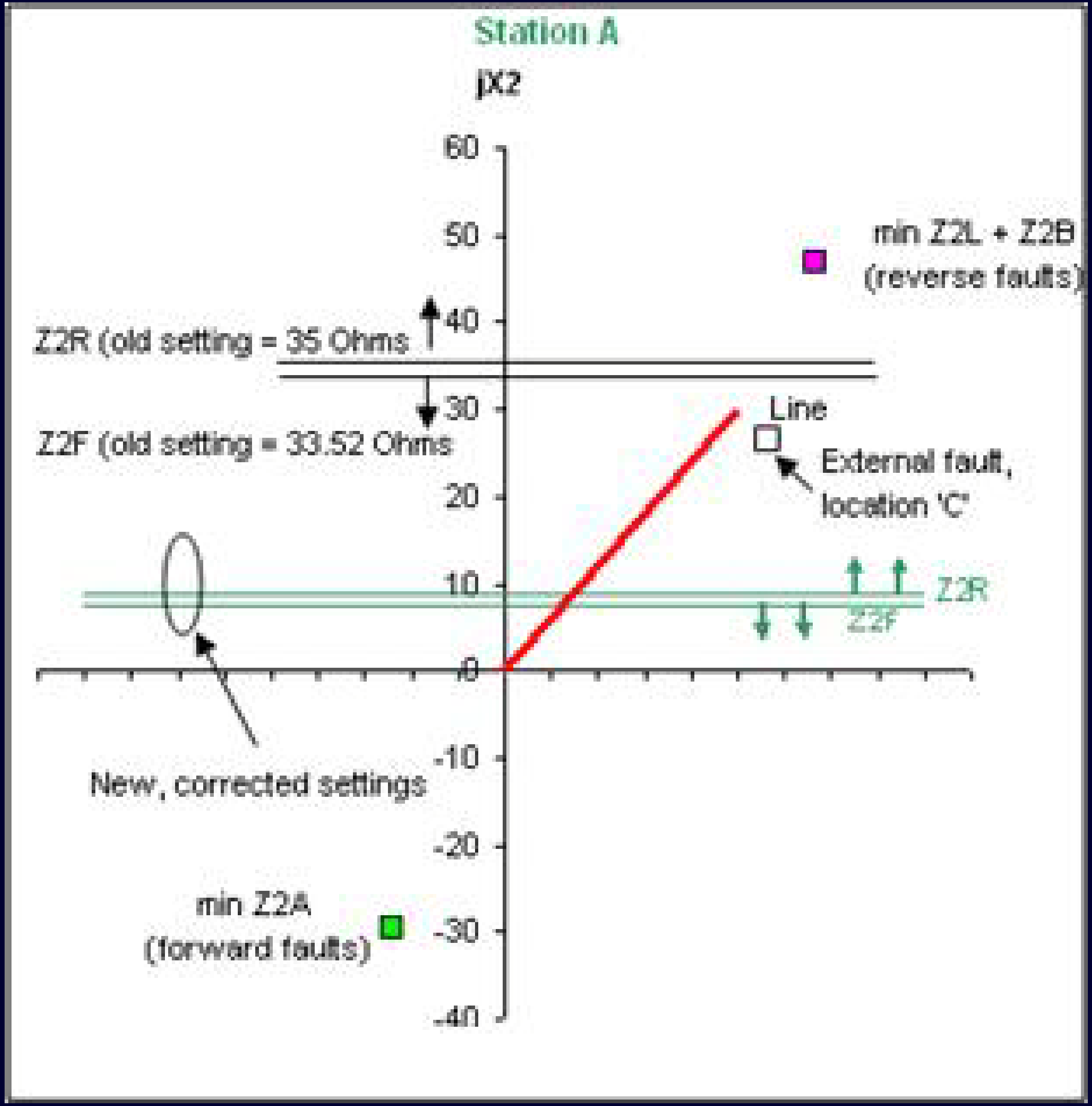
Negative-Sequence Directional Element

- Direction based on Z_2 sign
  - Positive = Reverse
  - Negative = Forward
- Two settings methods
  - Set based only on line impedance
  - Also consider source impedances

Misapplied Z2F Setting



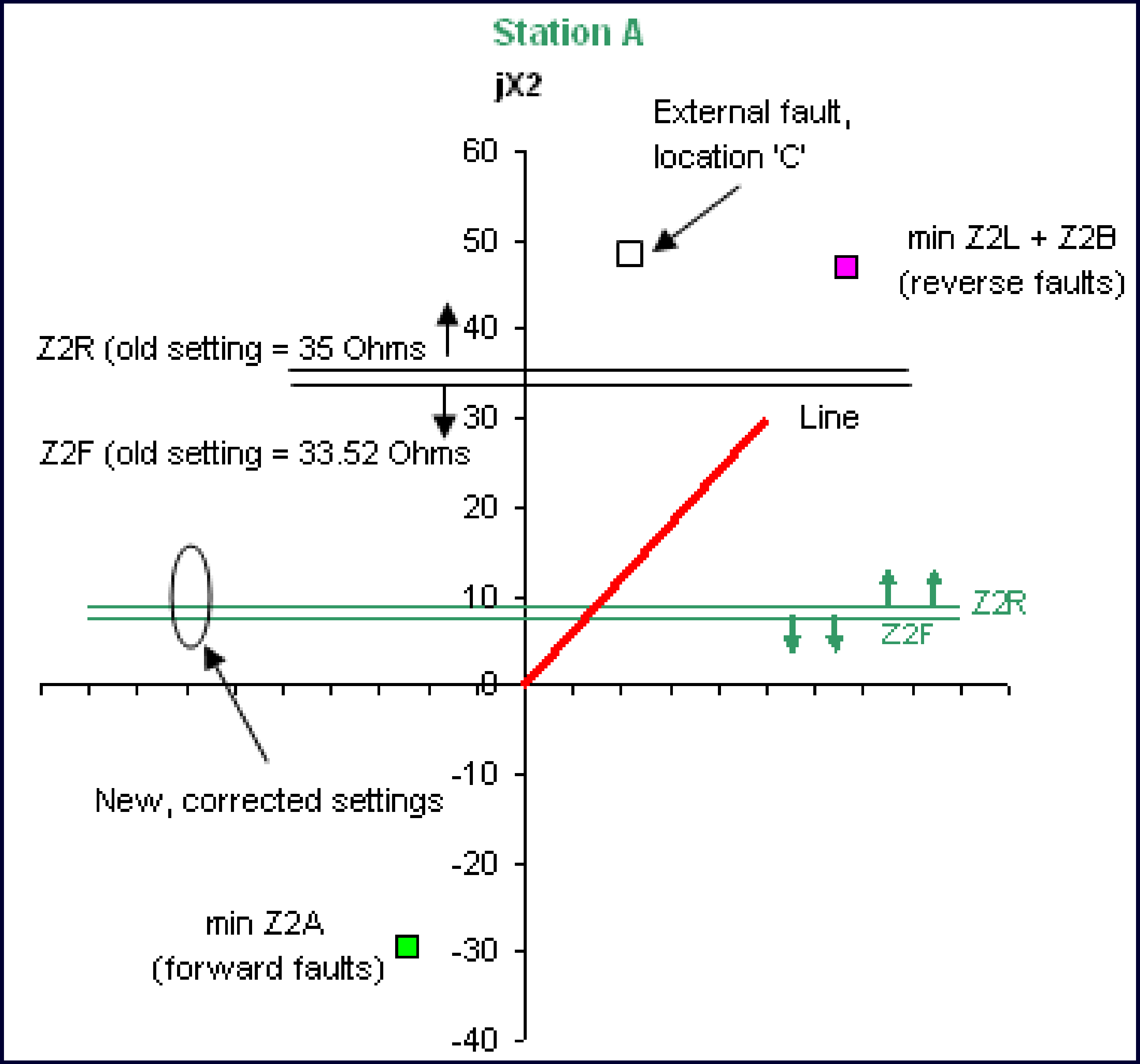
Misapplied Z2F Setting



Natural System Unbalances

- Symmetrical components
  - Simplification
  - Real power systems not perfectly symmetrical
- Unbalance sources
  - Lines not perfectly transposed
  - Series capacitor protection
  - Different submarine cable lengths per phase
- Ratio a2 = I2 / I1

Natural System Unbalances



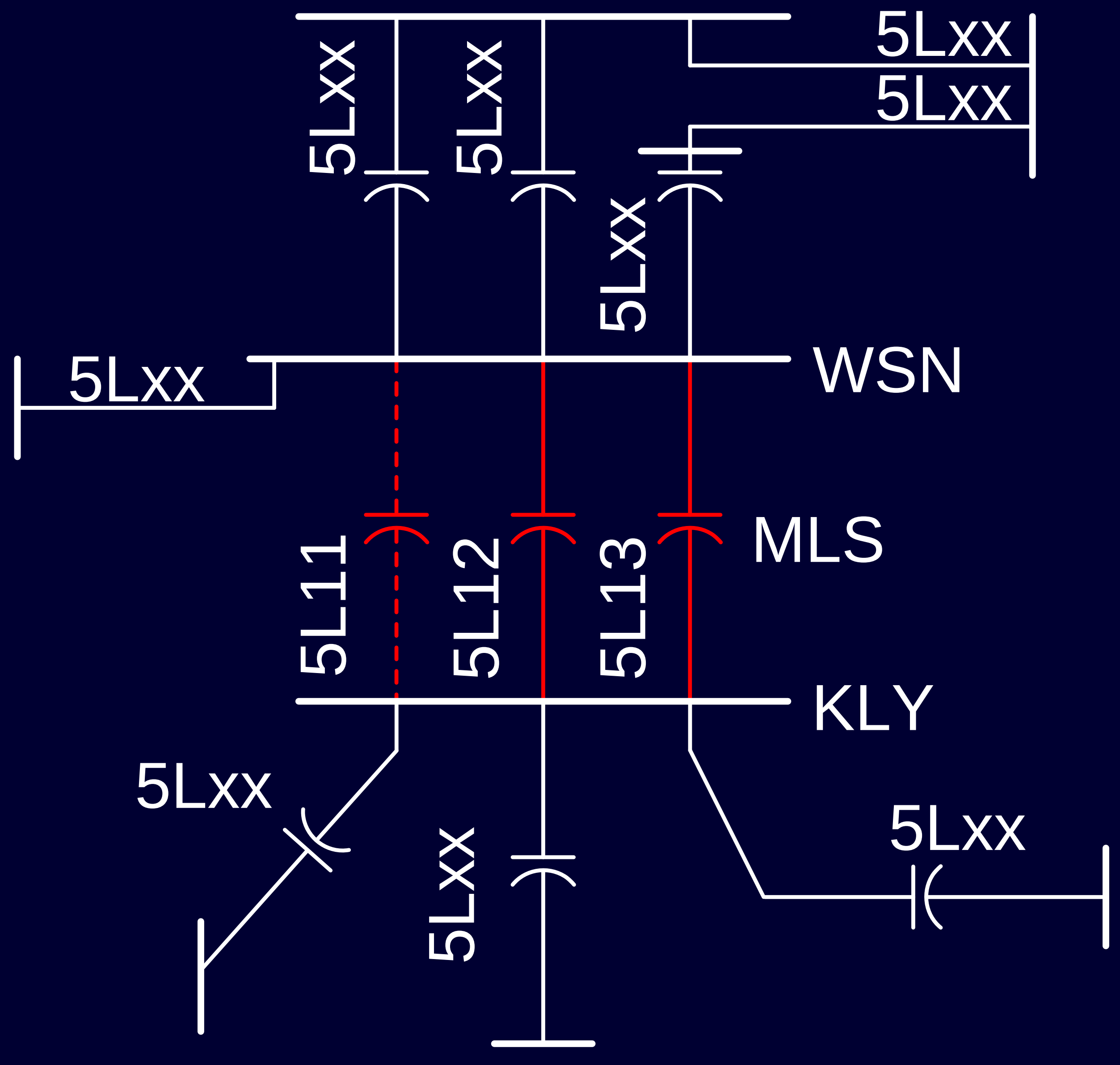
Single-Pole Switching

- 32Q asserts forward during SPO
  - POTT misoperates
  - Disable sensitive elements during SPO
- Lead / follow single-pole reclosing
  - Line is SPO until follow terminal closes
  - Remote SPO signaling
  - Fast reclose supervision elements

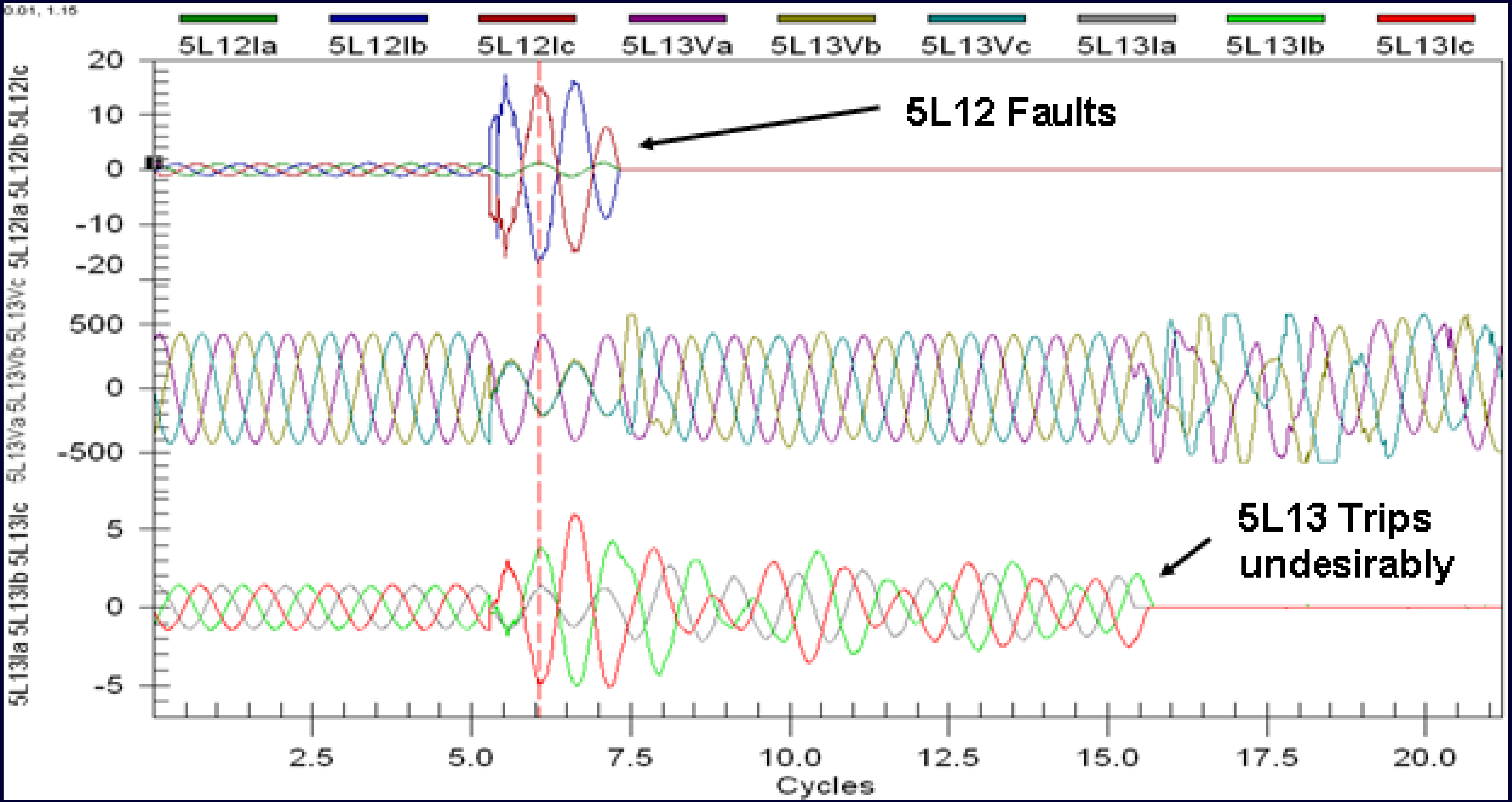
Capacitor Bypass Switching

- Series capacitors bypass single pole
- Automatic reinsertion 10 cycles after line closed
- 15-cycle spurious bypass
- Elements with most sensitive settings delayed by 17 cycles
- Digital communication can send bypass status from midline capacitor

Subsynchronous Resonance



Subsynchronous Resonance



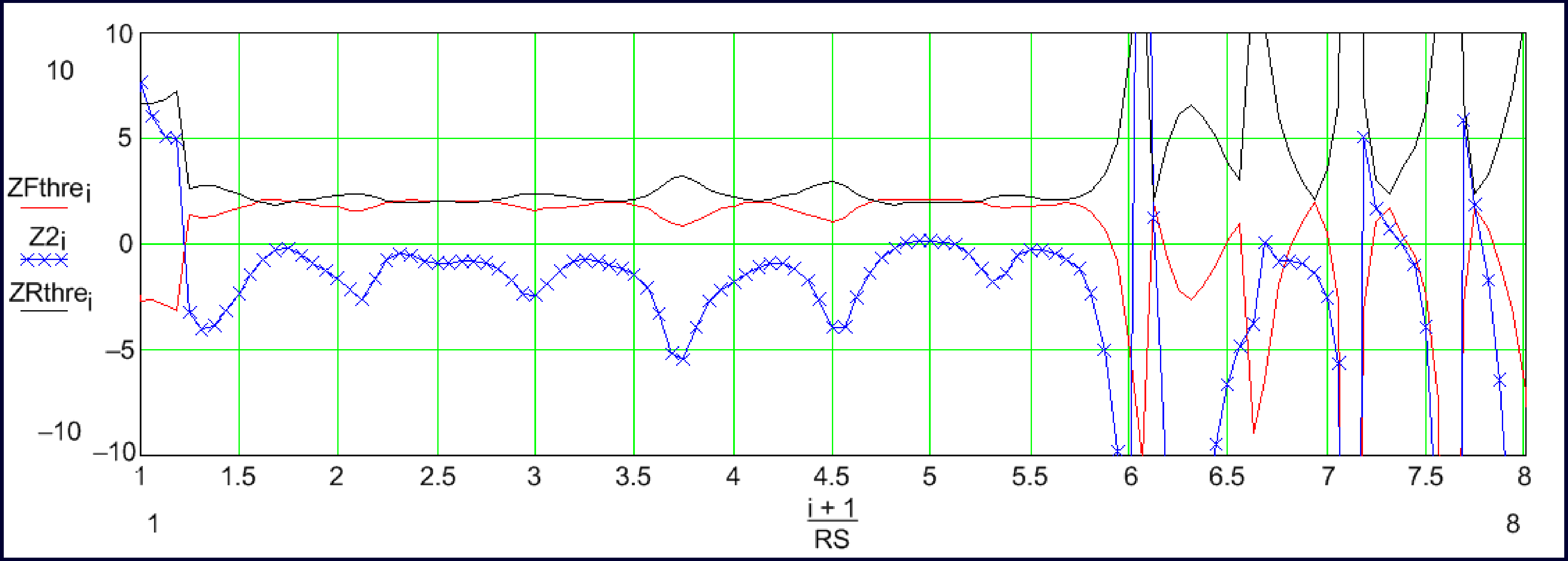
Subsynchronous Resonance

- 38 Hz resonance excited by BC fault
  - B, C phases only
  - I1, I2 components measured
  - Consistent with phase-to-phase unbalance
  - Current flowed in single remaining line
- Similar to SPO condition in 38 Hz system

Subsynchronous Resonance

- 38 Hz only attenuated by digital filters
- Both terminals assert forward for SPO
- Solution still under study

Subsynchronous Resonance



Transient Testing

- Mitigates common-mode failure risk
- Testing uses many tools
  - RTDS® allows for thousands of test cases
  - Event reports get to root cause
  - Computer-based models provide understanding of algorithm response
- Analysis of actual events used to improve

Transient Testing

- Close cooperation
  - Protection planning engineers
  - System planning engineers
  - Transient testing engineers
- 5 to 7 load flow cases
  - Source impedance cases
  - Parallel transmission paths SPO
  - Extreme but realistic load flow conditions

Test Procedure

- Basic tests
  - Selected internal and external faults
  - Zone 1 margins
  - Sensitivity limits
- Special tests
  - SOTF
  - Evolving faults
  - Reclosing sequences
  - Pilot element coordination margin tests

Batch Tests

- 5 to 7 load flow cases
- 10 to 12 fault locations
- 10 fault types
- Multiple points on wave
- 0, 50, 100, 200, 300 Ω SLG faults

Batch Tests

- 1500 to 2500+ internal and external fault shots
- 720 to 1500+ SLG faults with resistance
- Analysis
  - Capture data in text files
  - Import data into Microsoft® Excel®
  - Analyze results versus specifications
  - Run multiple times until results are acceptable

Conclusions

- POTT using 21, 67N, and 67Q elements can achieve high sensitivity
- Care must be taken in applying 32Q elements
- Natural system unbalances can affect security with highly sensitive settings

Conclusions

- Sensitive elements must be carefully disabled
  - Single-pole trip lines
  - Single-pole series capacitor switching
- Subsynchronous resonance can cause 67Q elements to trip in POTT scheme

Conclusions

- Analysis of all undesired operations to get to root cause important to reliability
- Transient testing important part of validating design and settings
- Two appendixes
  - Details test procedures
  - Examples of two methods for setting 32Q