High-Speed Reclosing, Switching Surges, and Bus Differential Protection Security – A Case Study

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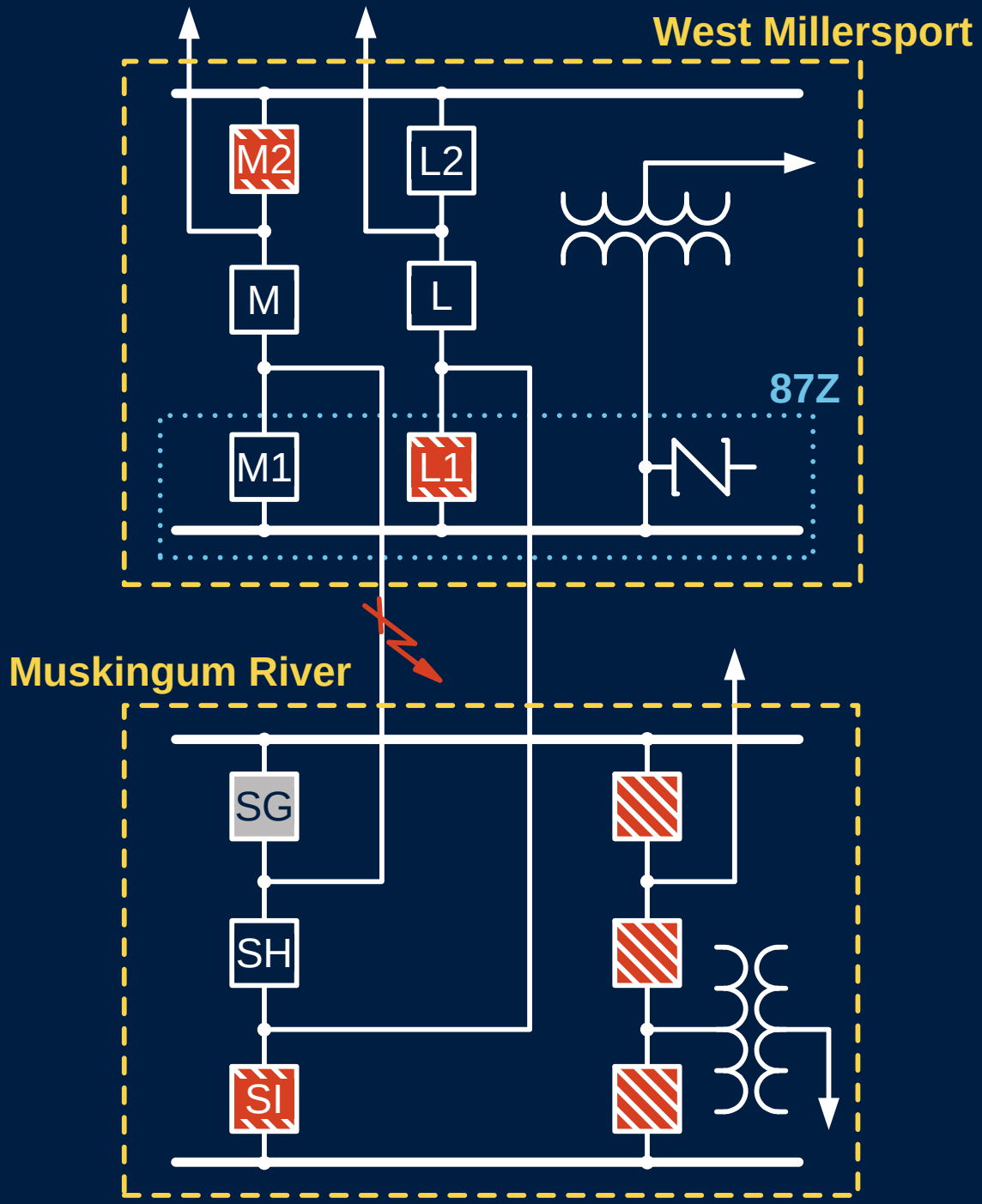
Overview

- Event description
- Event report analysis and root cause
- Line switching overview
- Event simulation
- Conclusion

Ice Storm Hits Ohio Valley

Late January, 2009

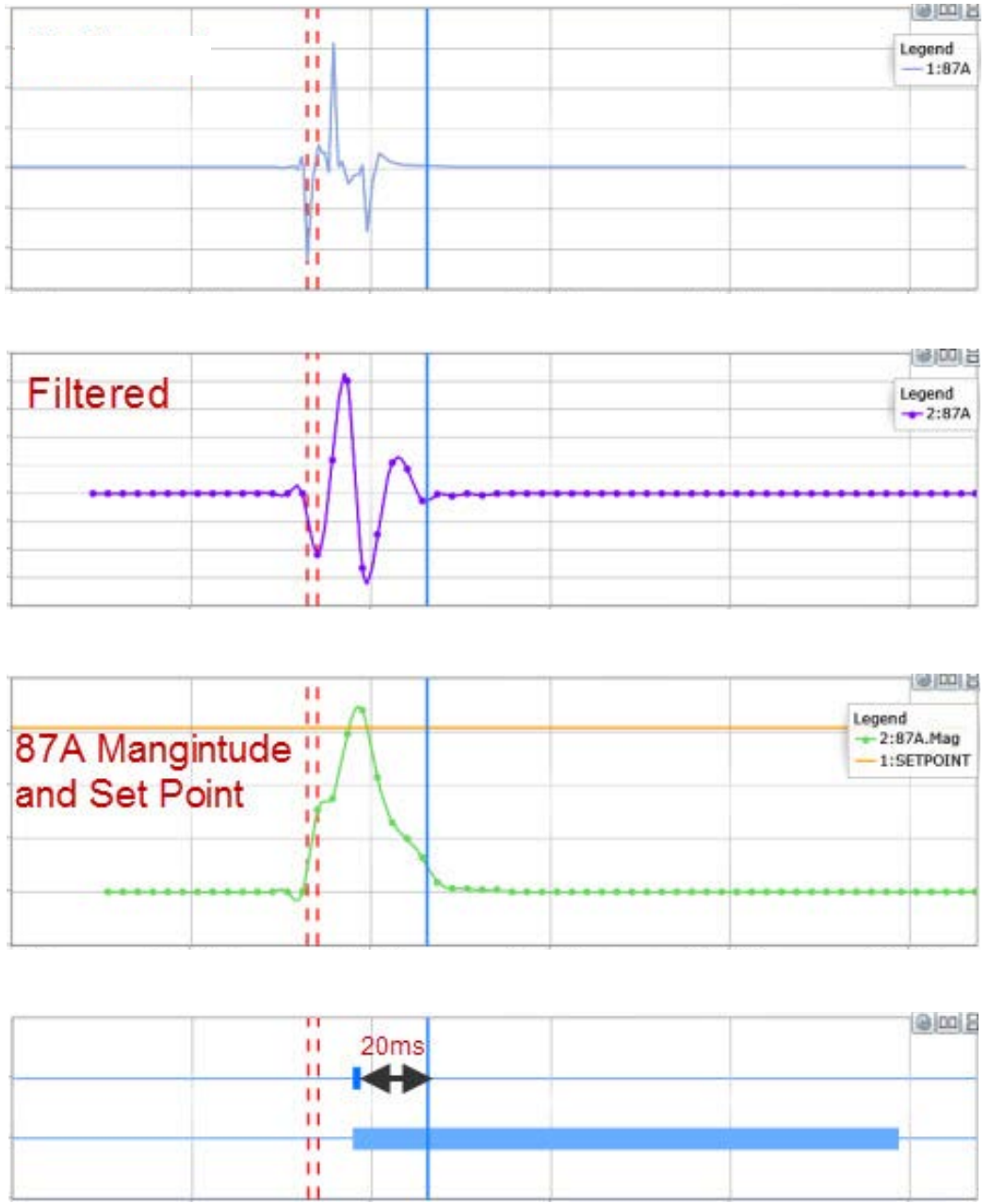
- 1.3 million customers without power
- State record – 700,000 outages in Kentucky
- Large portion of AEP service territory affected
- 345 kV West Millersport – Muskingum River
  - Double-circuit tower
  - Conductor galloping on Line 2



Event Description

January 28, 2009

- Phase-A-to-Phase-B fault on Line 2 that clears via DCB scheme
- Reclose from Breaker SG at Muskingum River
- Unexpected 345 kV Bus 1 differential at West Millersport operation



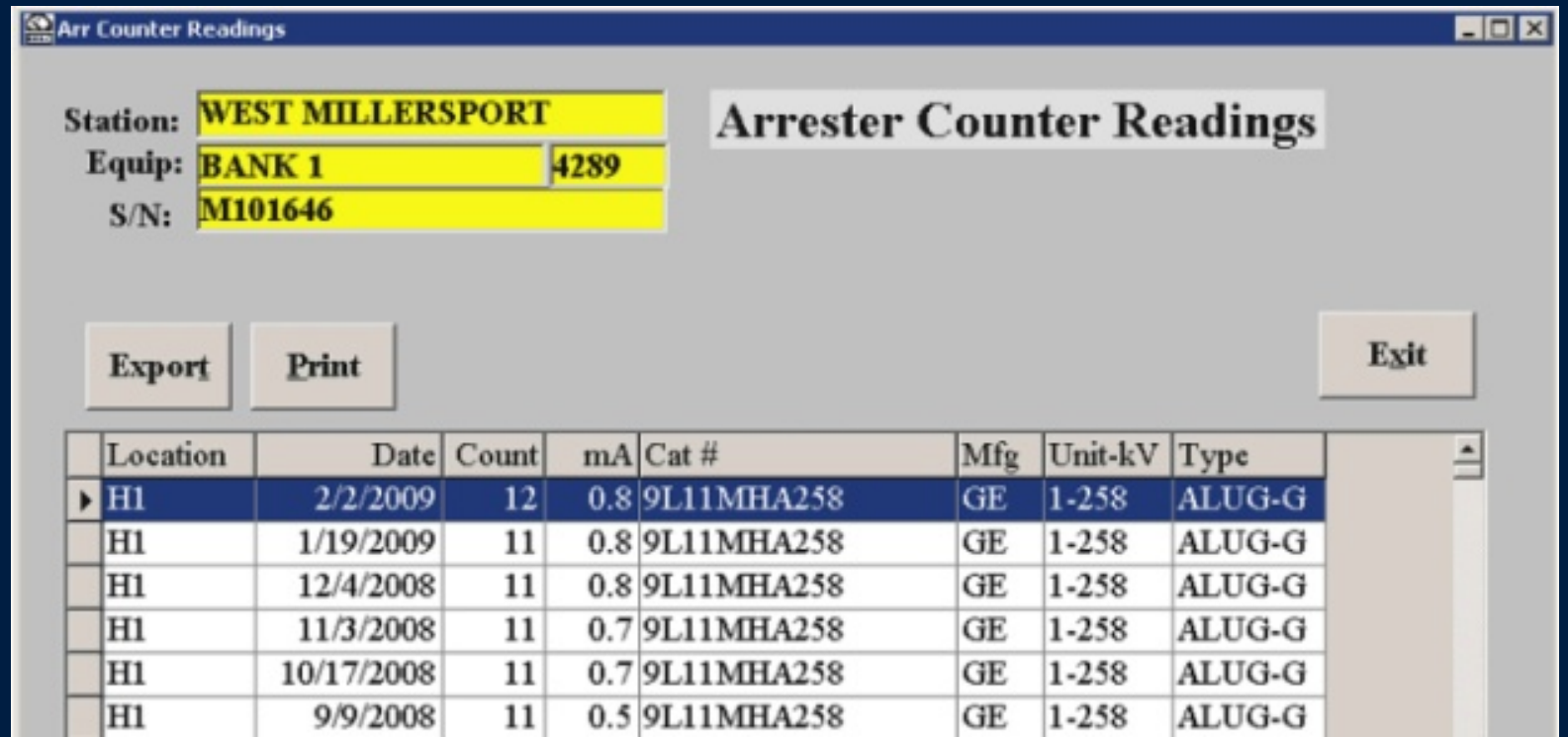
Event Report Analysis

Bus Differential – West Millersport Bus 1

- 87A1 asserts for one-eighth of a cycle (6:15:42.287 p.m.)
- Fault clears before operation of lockout relay

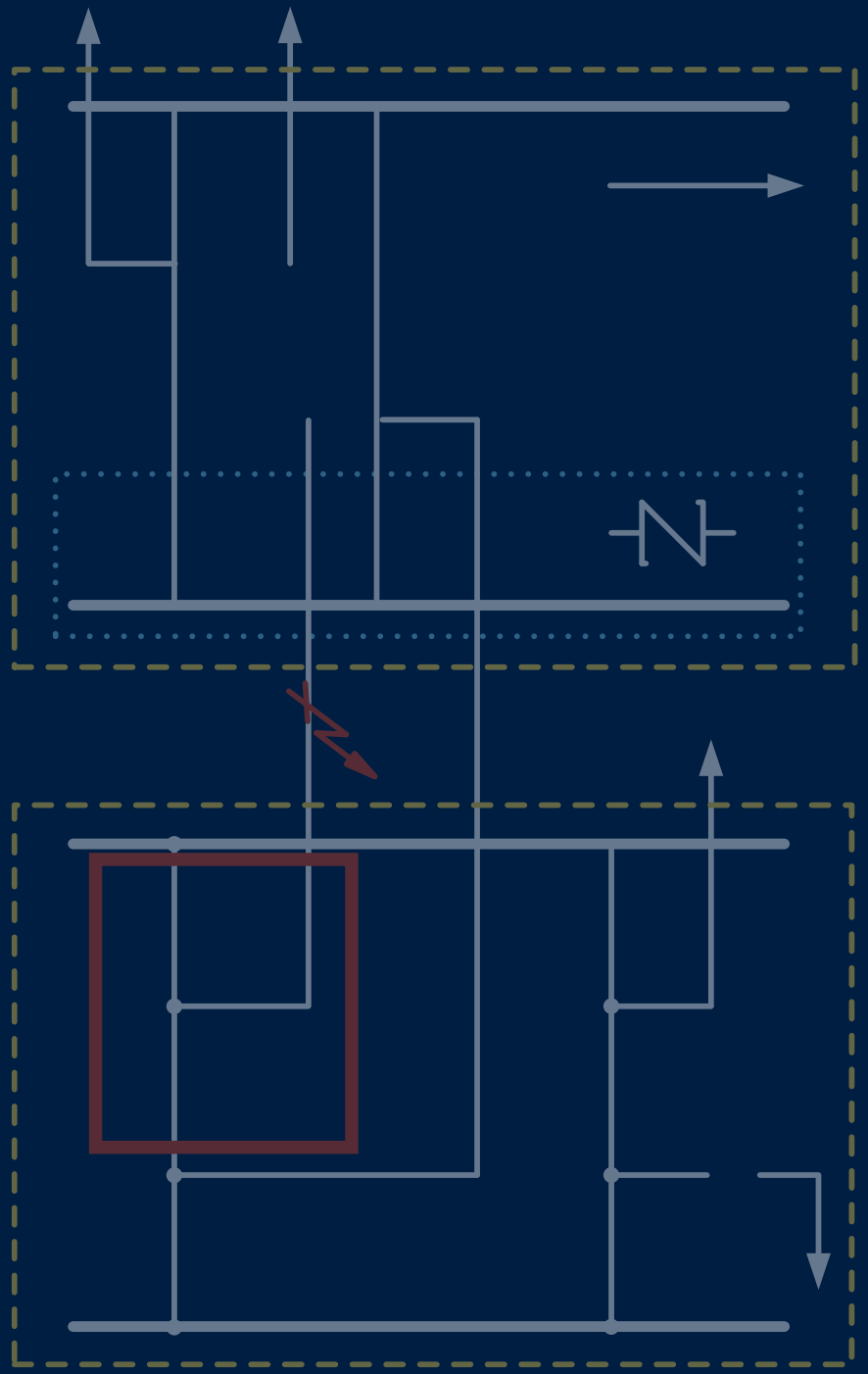
H1 Bushing Surge Arrester Counter Indicates Operation

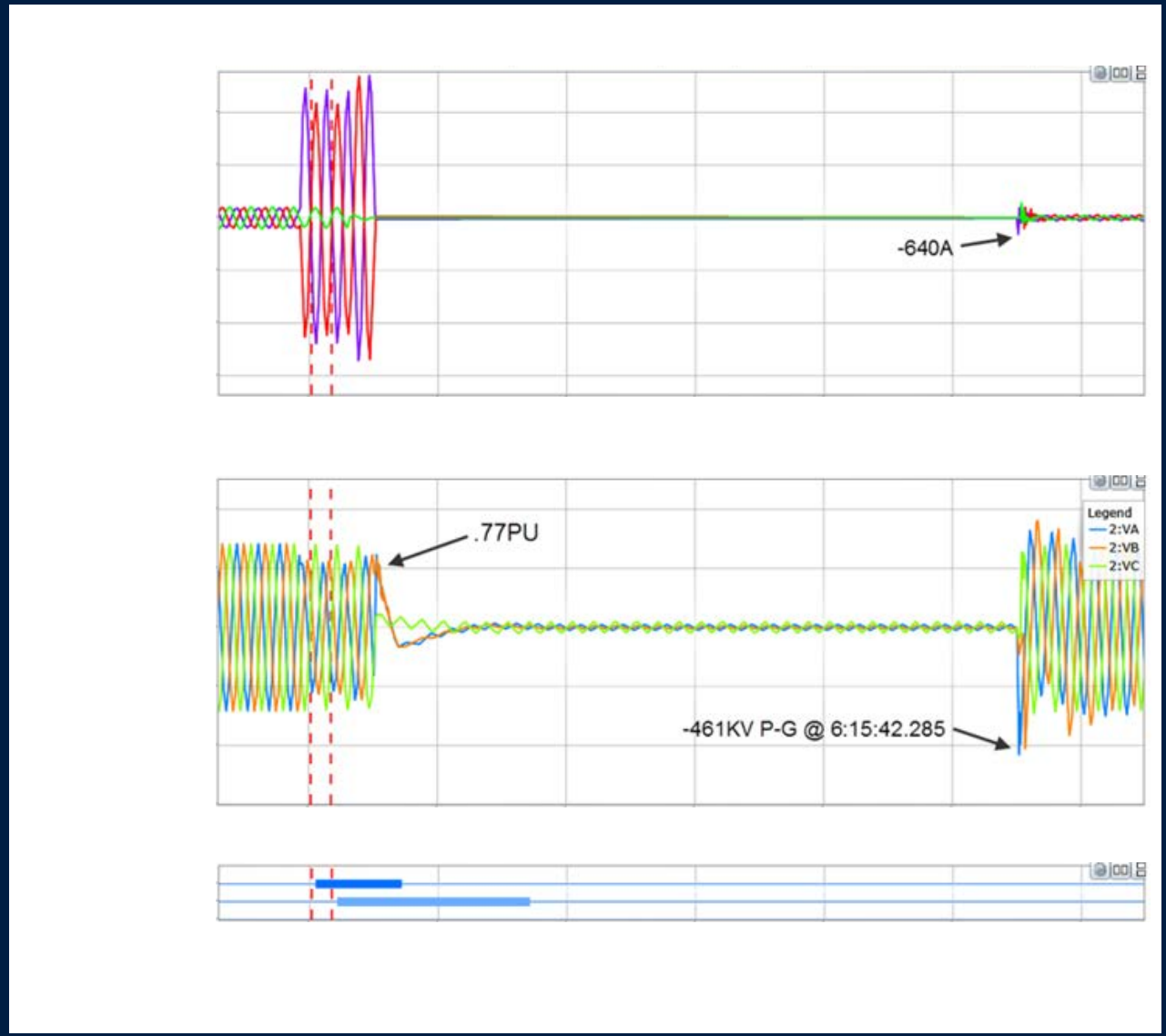
Why does the surge arrester operate?

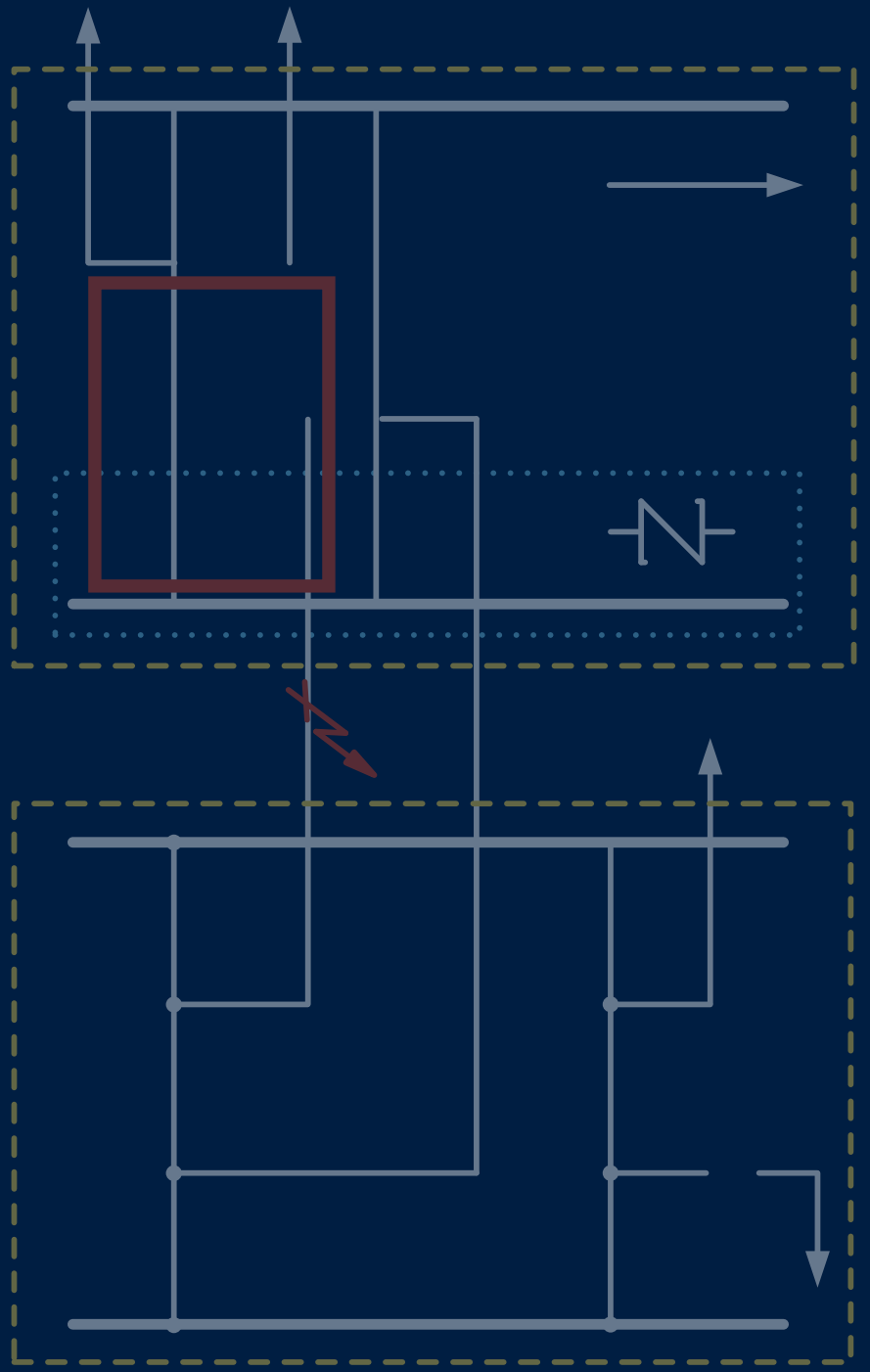


Location	Date	Count	mA	Cat #	Mfg	Unit-kV	Type
H1	2/2/2009	12	0.8	9L11MHA258	GE	1-258	ALUG-G
H1	1/19/2009	11	0.8	9L11MHA258	GE	1-258	ALUG-G
H1	12/4/2008	11	0.8	9L11MHA258	GE	1-258	ALUG-G
H1	11/3/2008	11	0.7	9L11MHA258	GE	1-258	ALUG-G
H1	10/17/2008	11	0.7	9L11MHA258	GE	1-258	ALUG-G
H1	9/9/2008	11	0.5	9L11MHA258	GE	1-258	ALUG-G

Event Report Analysis
Muskingum River Line 2

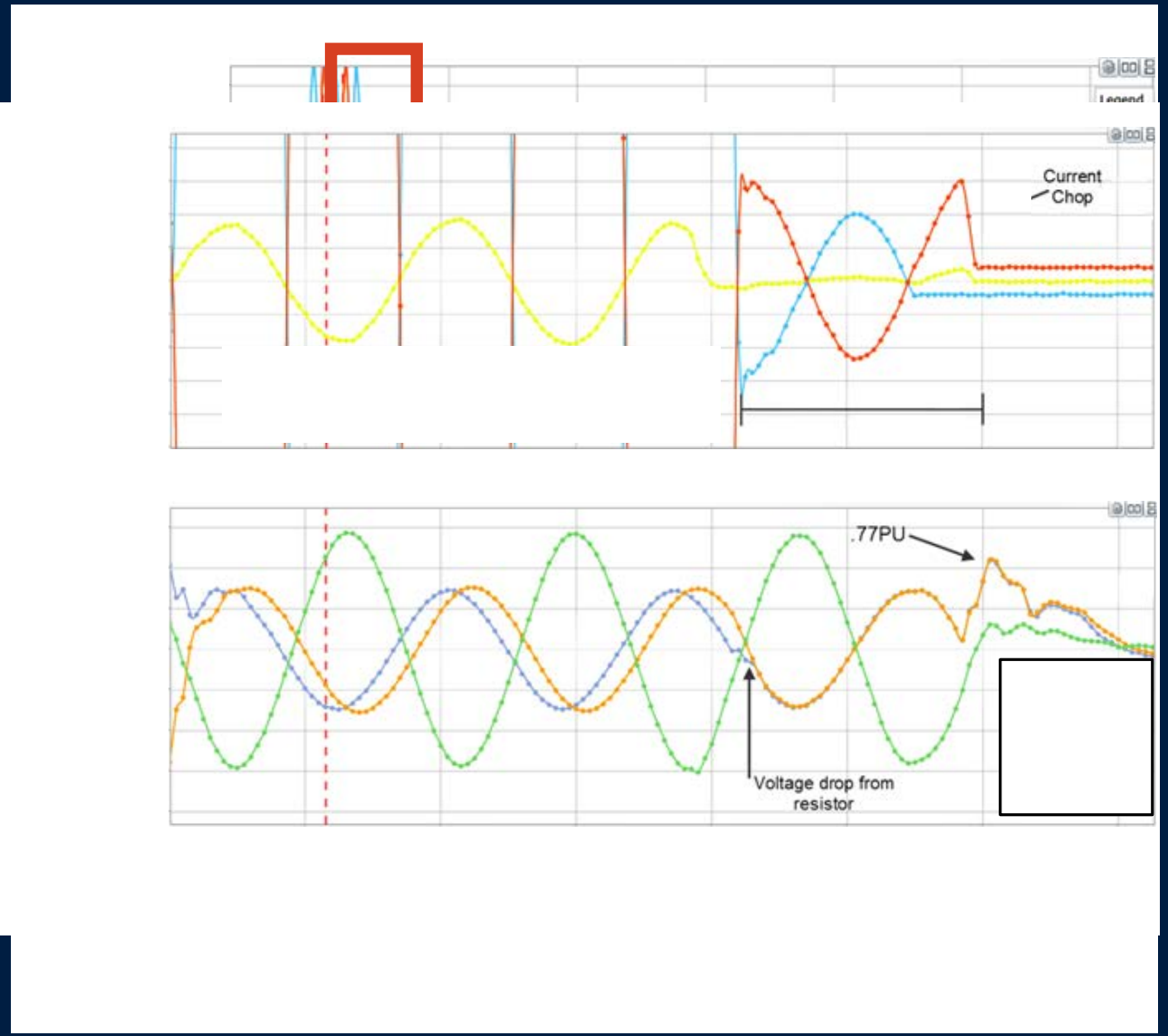


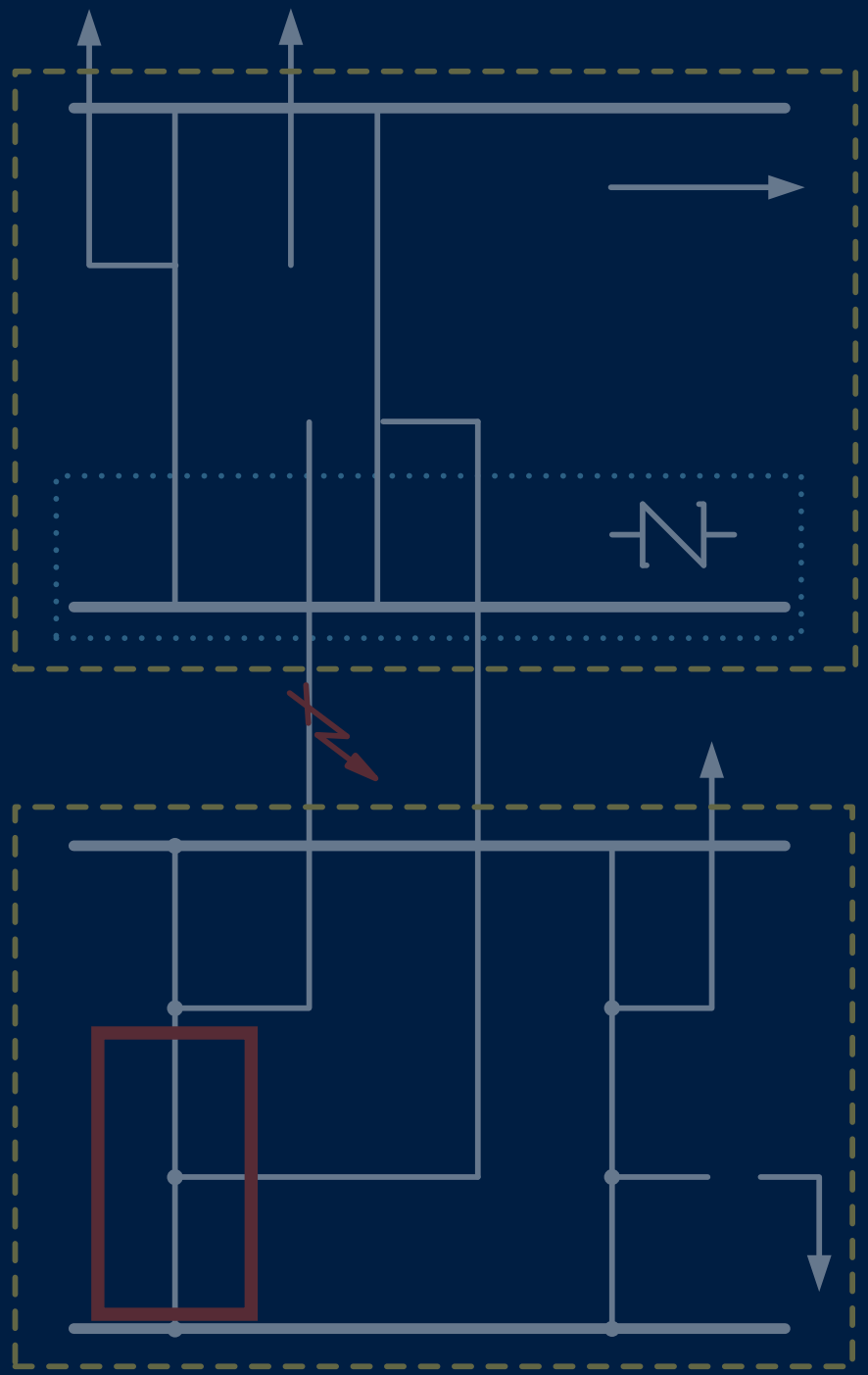




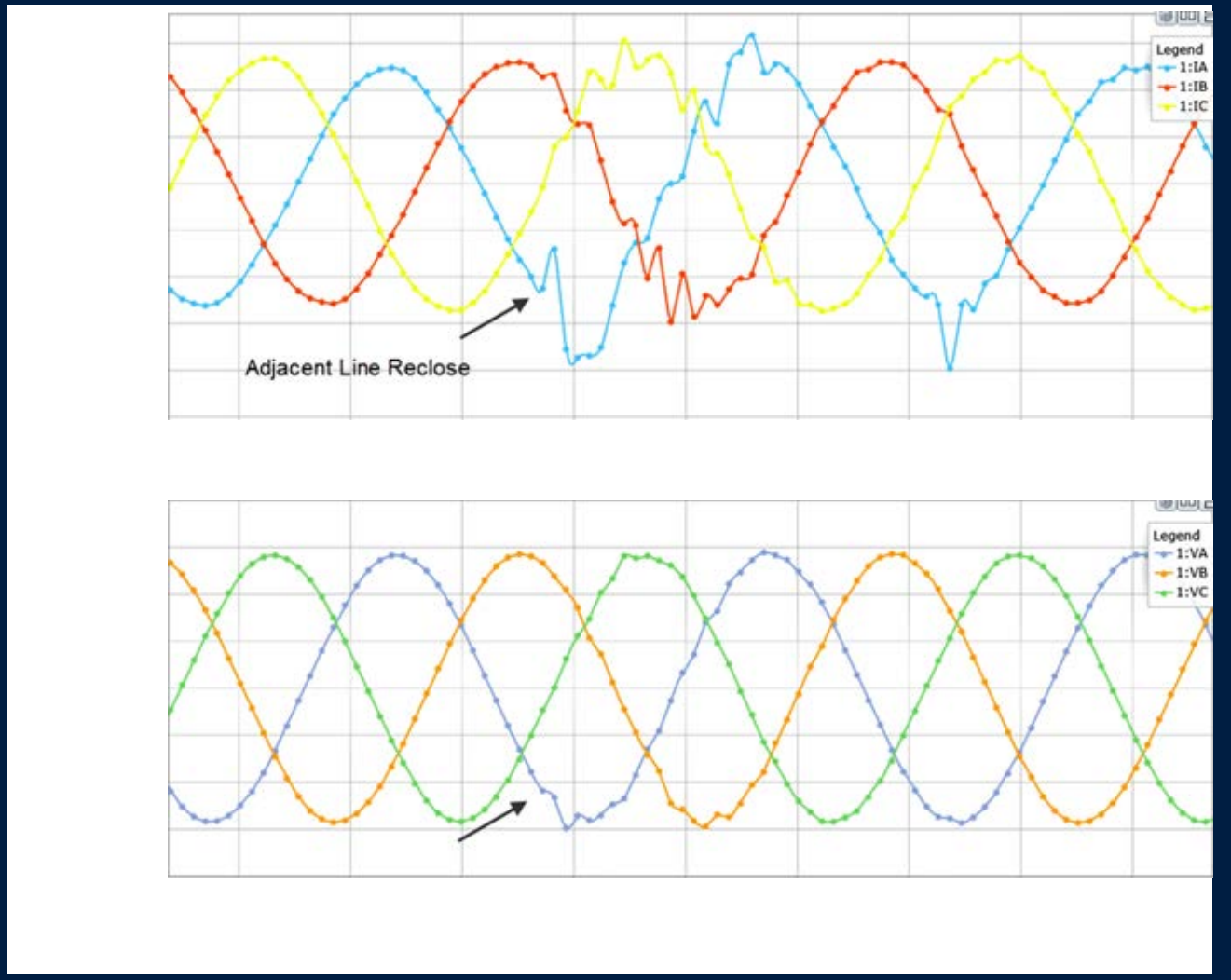
Event Report Analysis

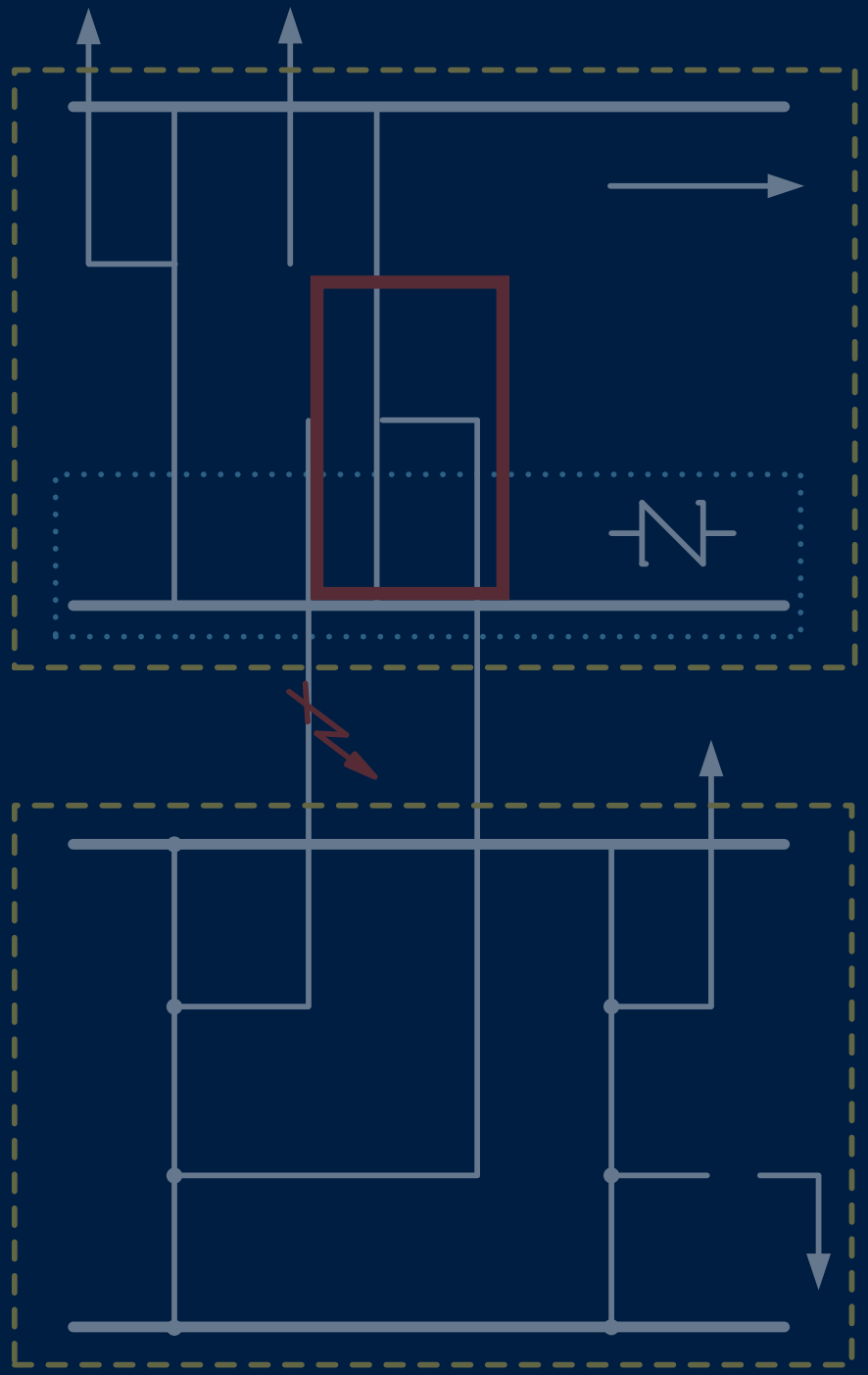
West Millersport Line 2





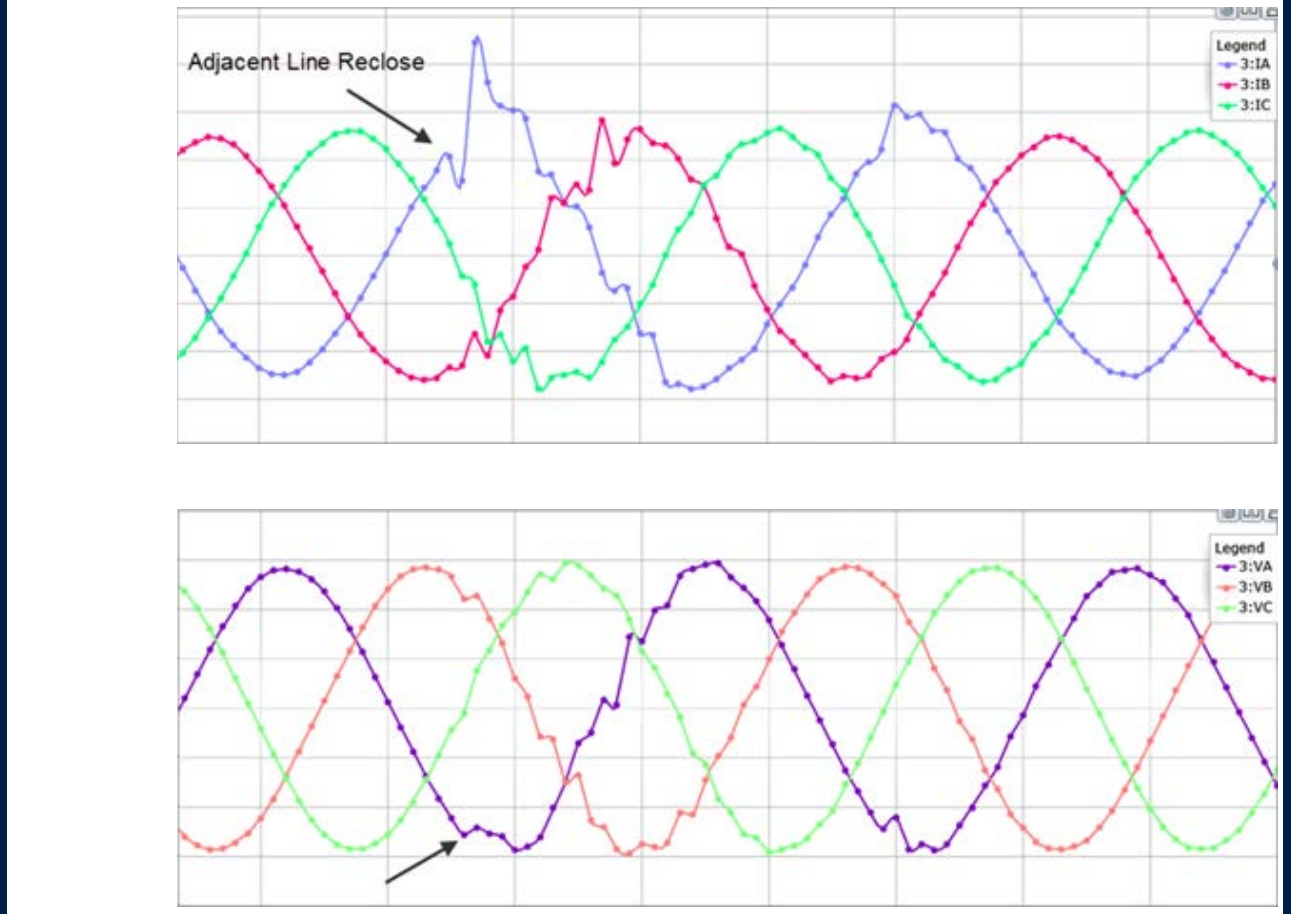
Event Report Analysis
Muskingum River Line 1





Event Report Analysis

West Millersport Line 1



Muskingum River – West Millersport Summary

- DCB scheme clears Phase-A-to-Phase-B fault on Line 2
- Air blast breaker at West Millersport Line 2 chops current on Phase B
- Muskingum River Line 2 recloses and sees over 600 A of inrush current
- West Millersport Line 2 sees brief 2.5 pu peak-to-ground overvoltage

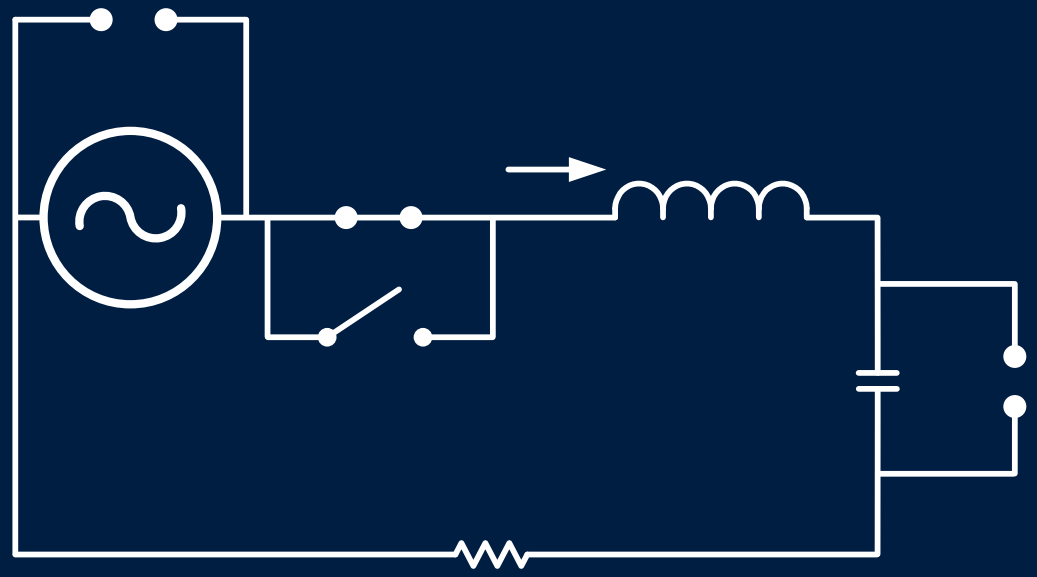
Further Investigation

- Why is there a voltage transient?
- How does reclose at Muskingum River lead to overvoltage at West Millersport?

Line Switch Overview

- Single-phase representation
- Traveling wave representation
- AEP testing and history

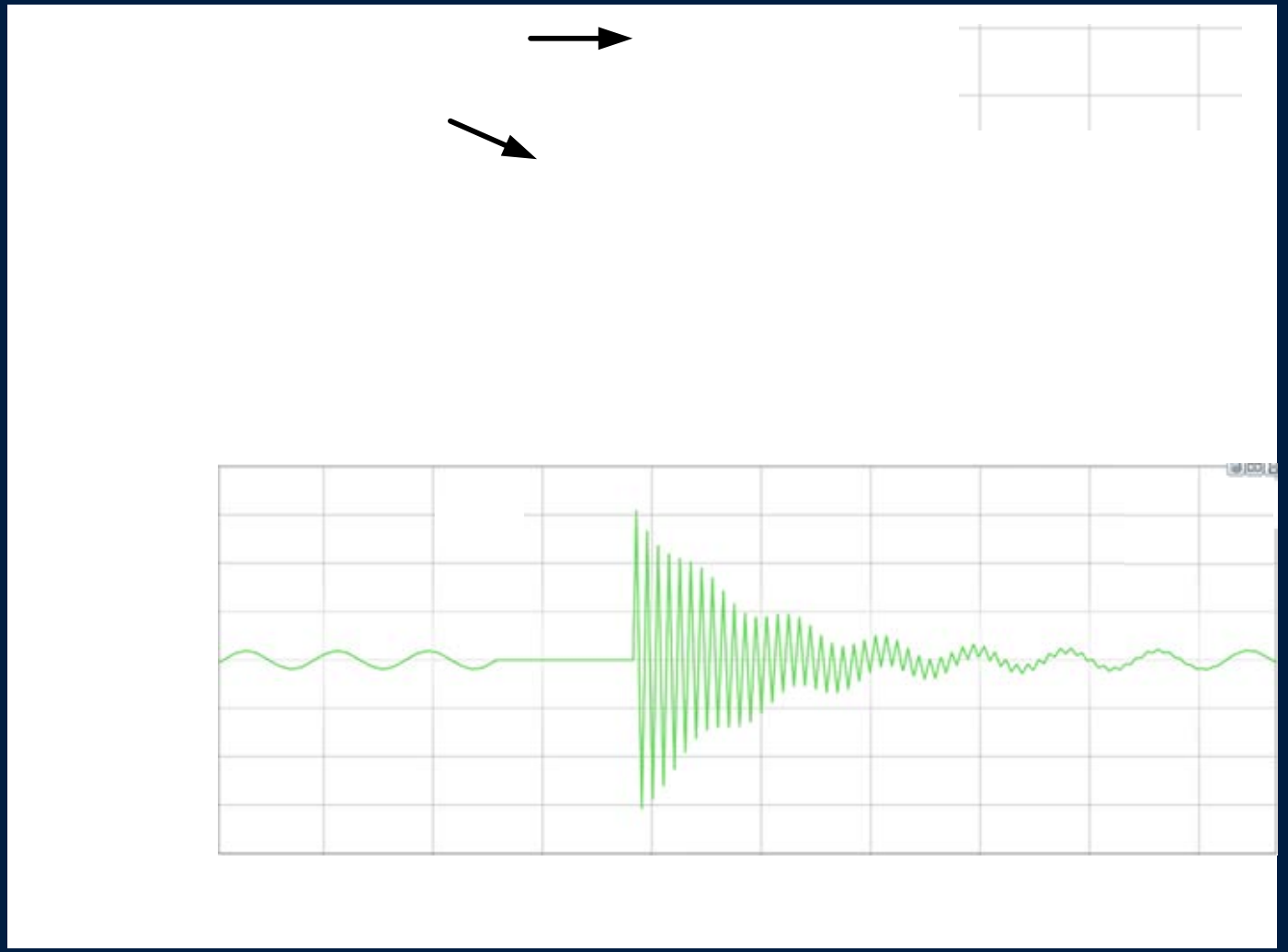
Single-Phase Switching Model
Natural Frequency Response

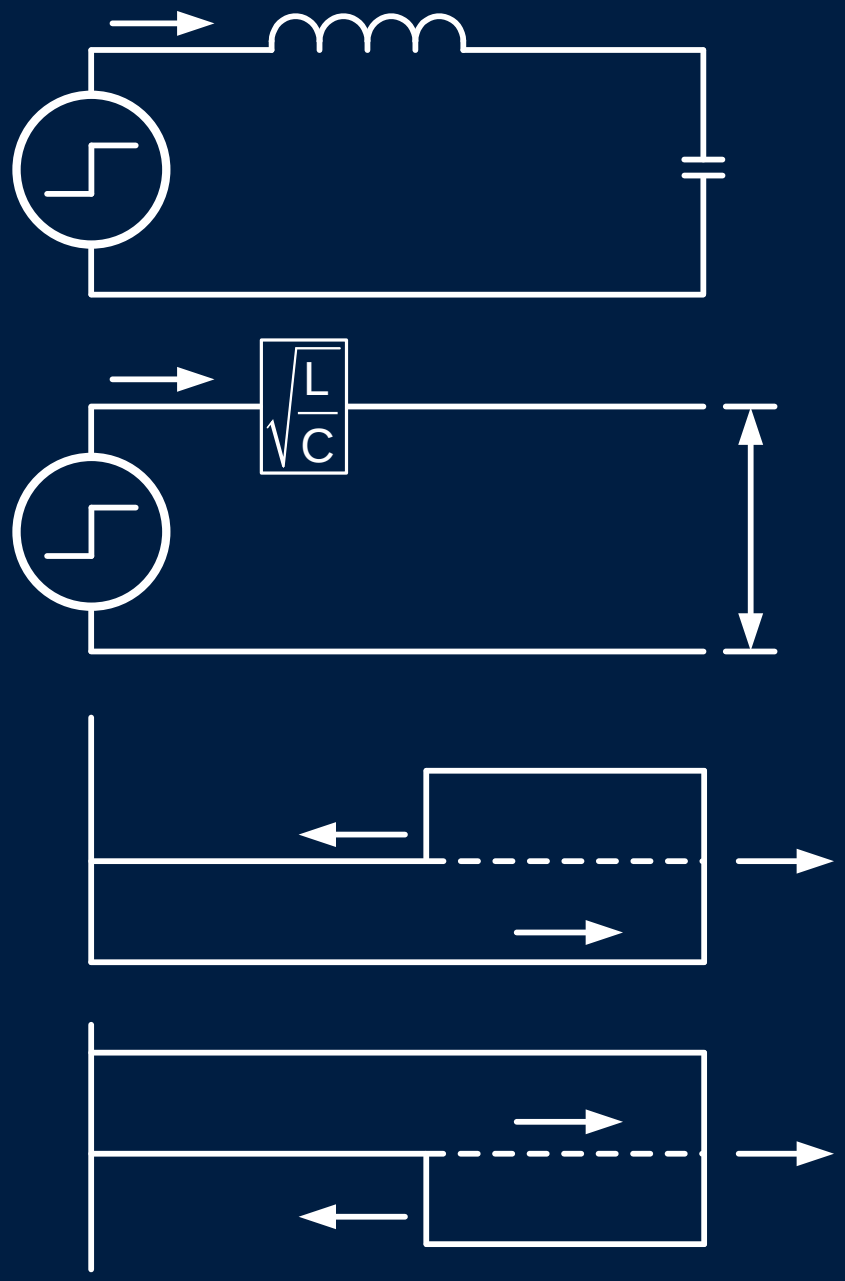


$$Vc = Vc(0) + (Vm - Vc(0))(1 - \cos \omega_0 (t))$$

$$Vc = (-)1 + (1 - (-)1) \bullet (1 - (-)1)$$

$$Vc = 3$$





Traveling Wave Representation

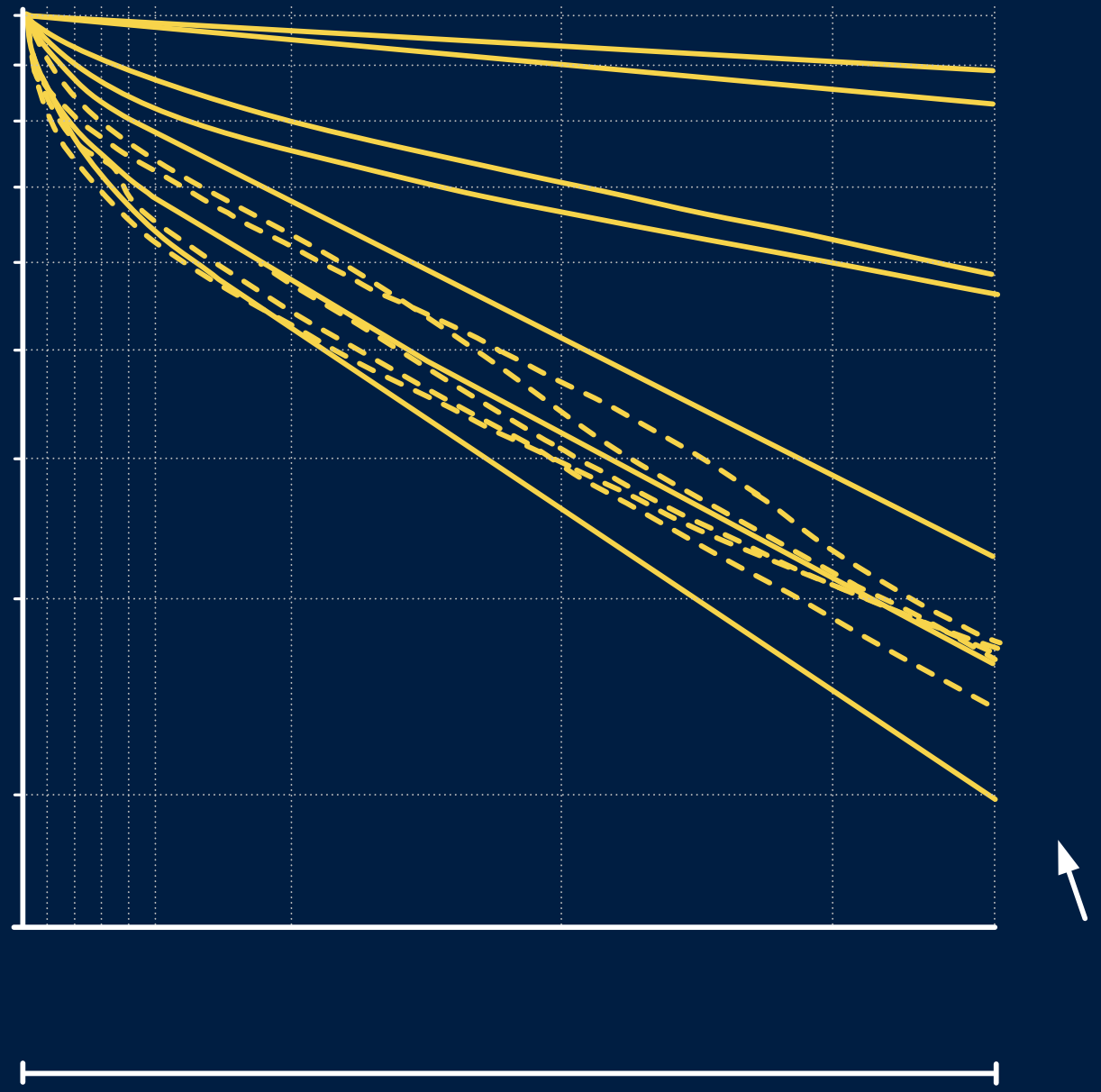
- Voltage doubling effect at open terminals

$$V3 = \frac{[2 \bullet ZB]}{[ZB + ZA]} \bullet V1$$

- –1 pu trapped charge + (2 pu step) • 2 = 3 pu

AEP Testing

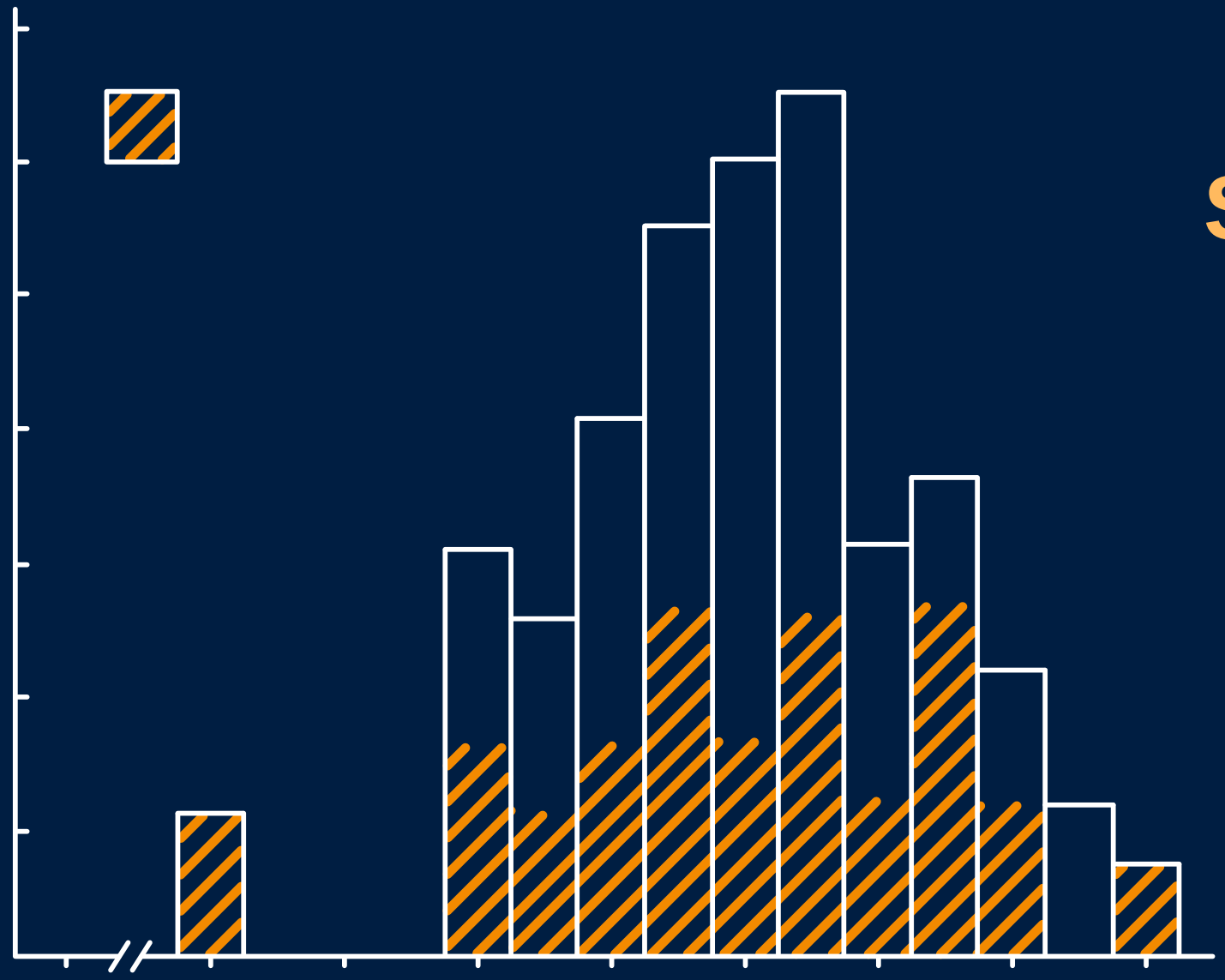
- Trapped charges decay over time, aided by shunt connections such as towers and PTs
- Weather affects time constants
- High-speed reclosing allows less time for trapped charge to drain
- High-speed reclosing increases transient overvoltages on reclose



AEP Trapped Charge Testing

After 30 cycles,
0.6 pu trapped charge
is possible on
transmission lines
even in sleet conditions

Data: “Weather, Corona, and the Decay of Trapped Energy on Transmission Lines”



AEP Field Measurement of Switching Surges

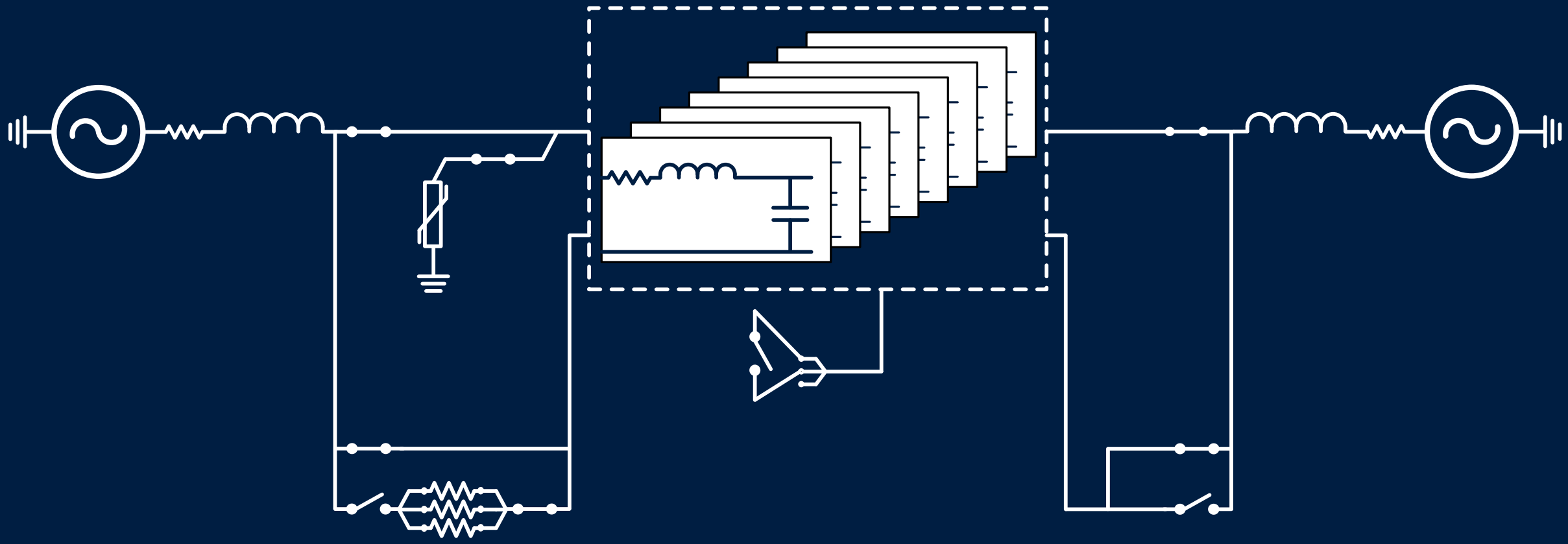
- Statistical study was carried out in early 1960s
- Receiving end of reclosed line could expect average of 2.4 pu overvoltage

Data: “Field Measurement of Switching Surges on Unterminated 345-kV Transmission Lines”

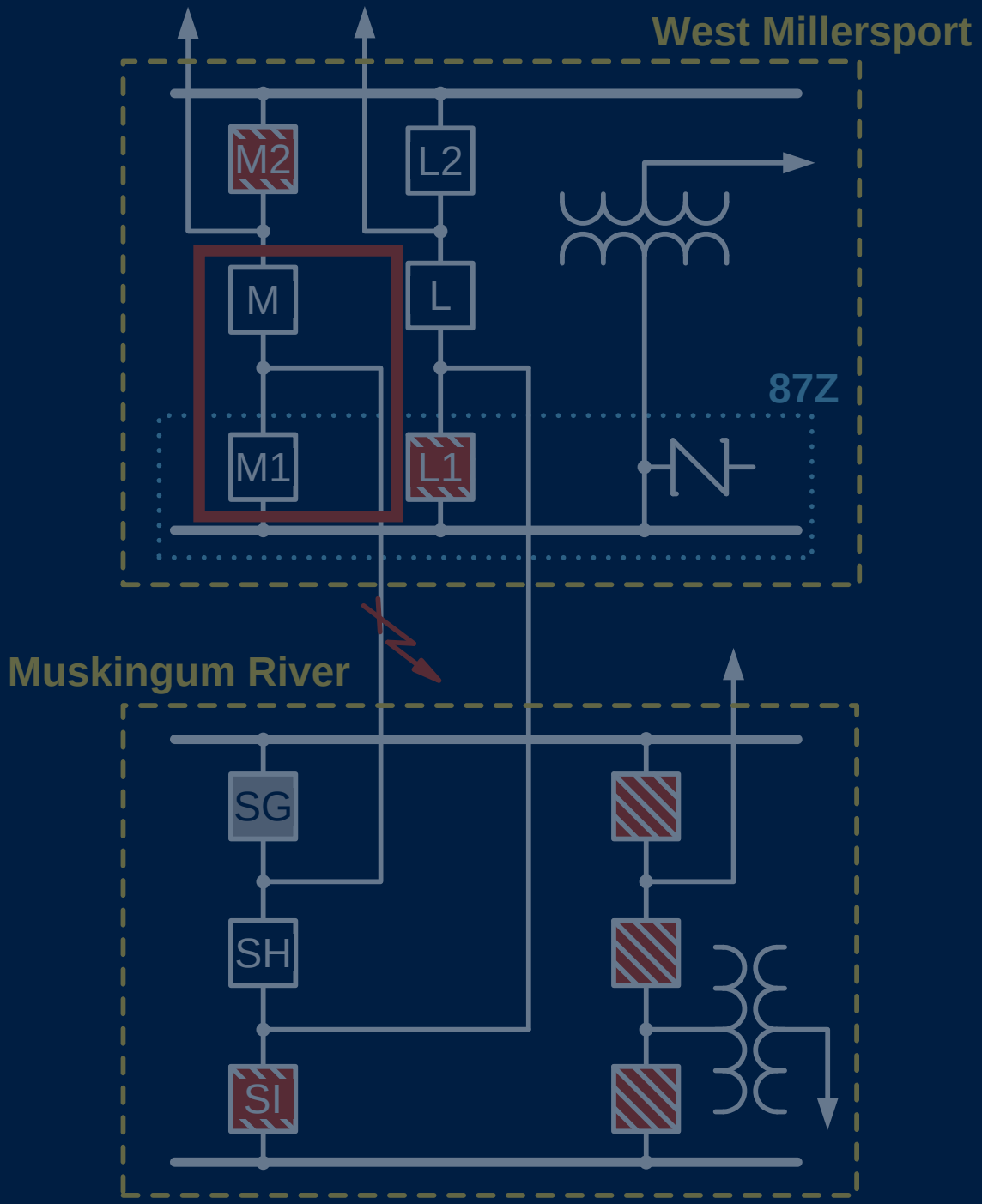
Relay Security

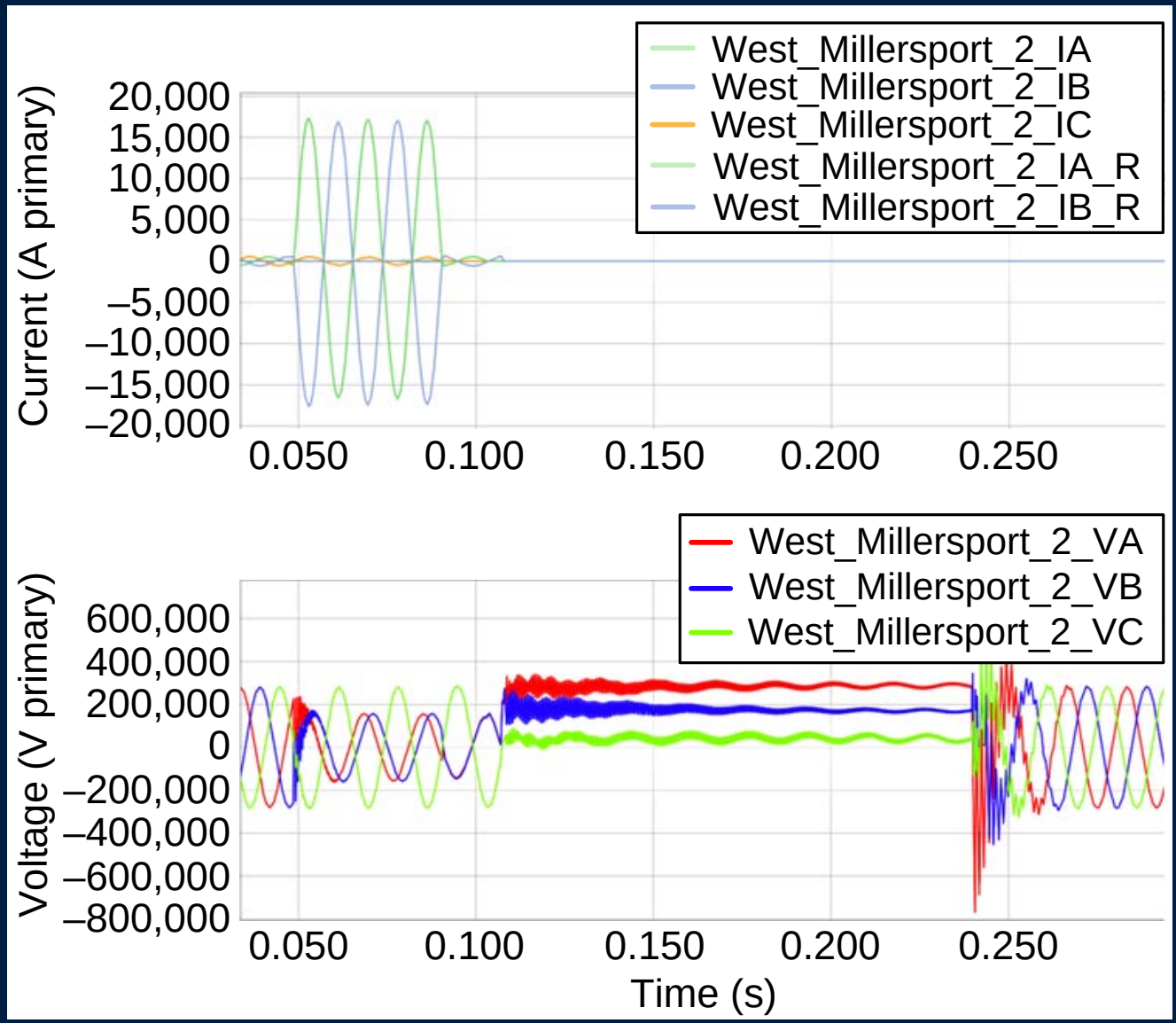
- If surge arrester is within zone of protection, add at least 1.0-cycle time delay
  - Surge arrester event length
  - 0.75-cycle filter delay (half cosine filter)
  - 0.25-cycle safety margin
- Check relay vendor’s recommendations for surge arresters in zone of protection

ATP-EMTP Simulation

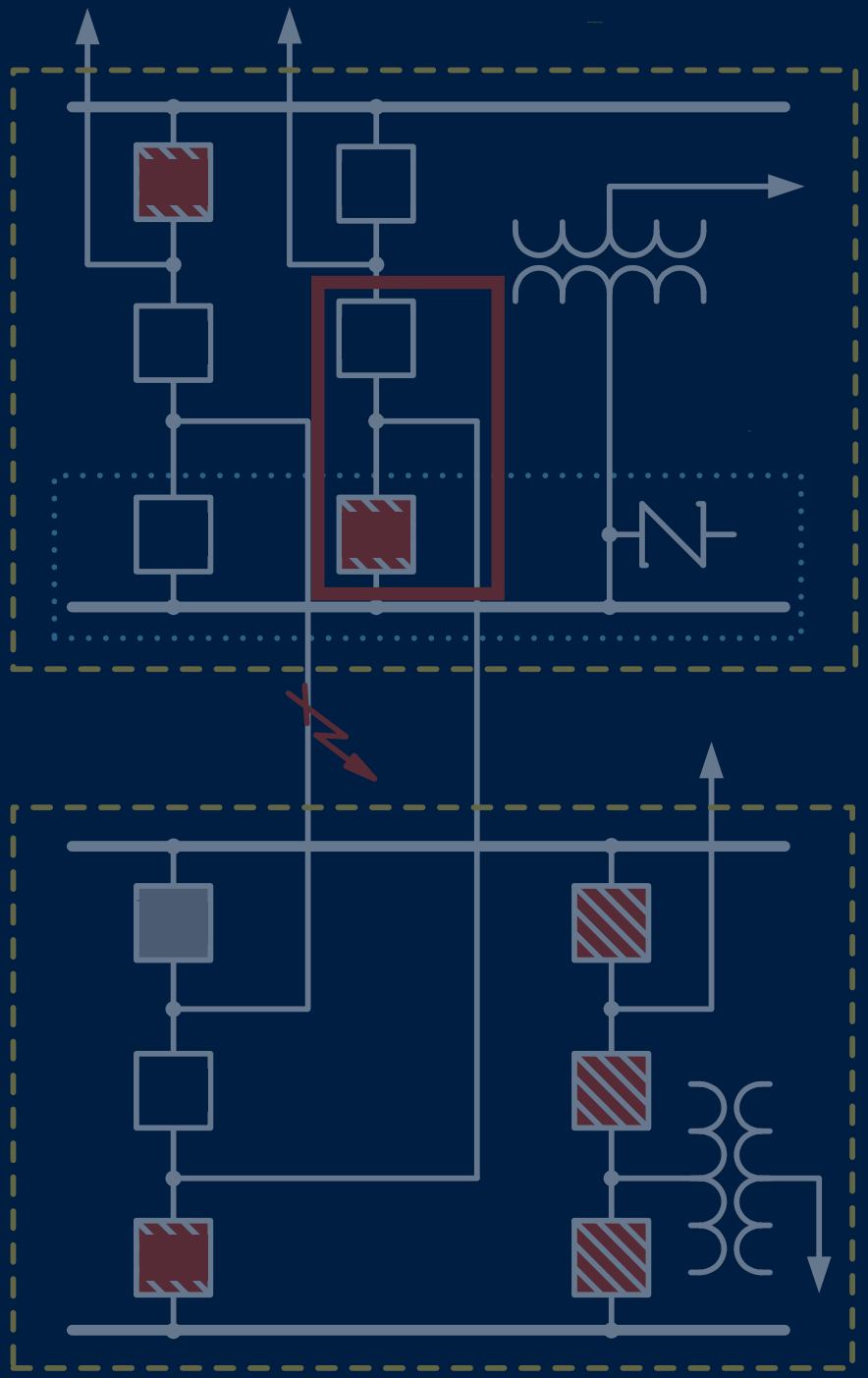


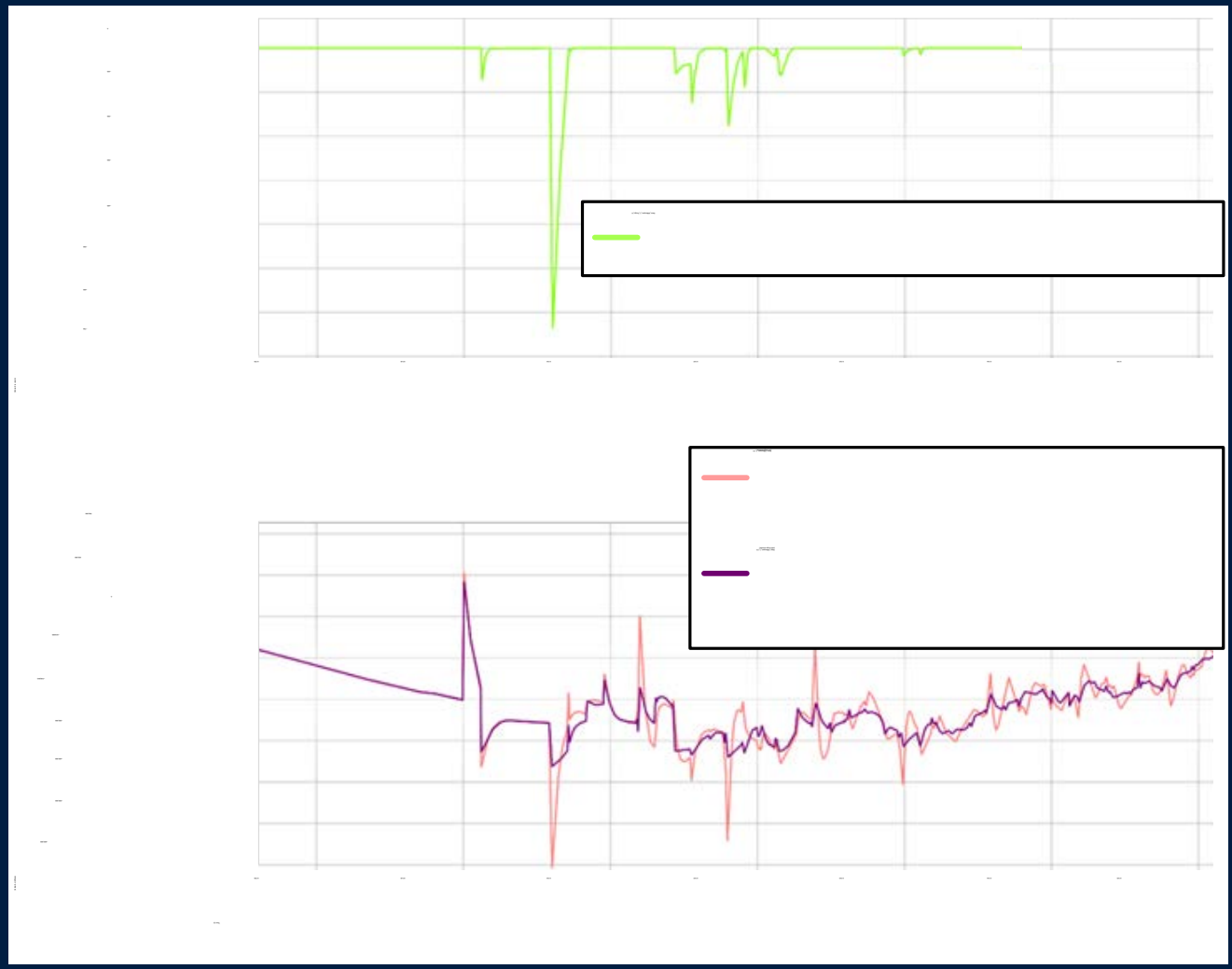
Simulation
West Millersport Line 2





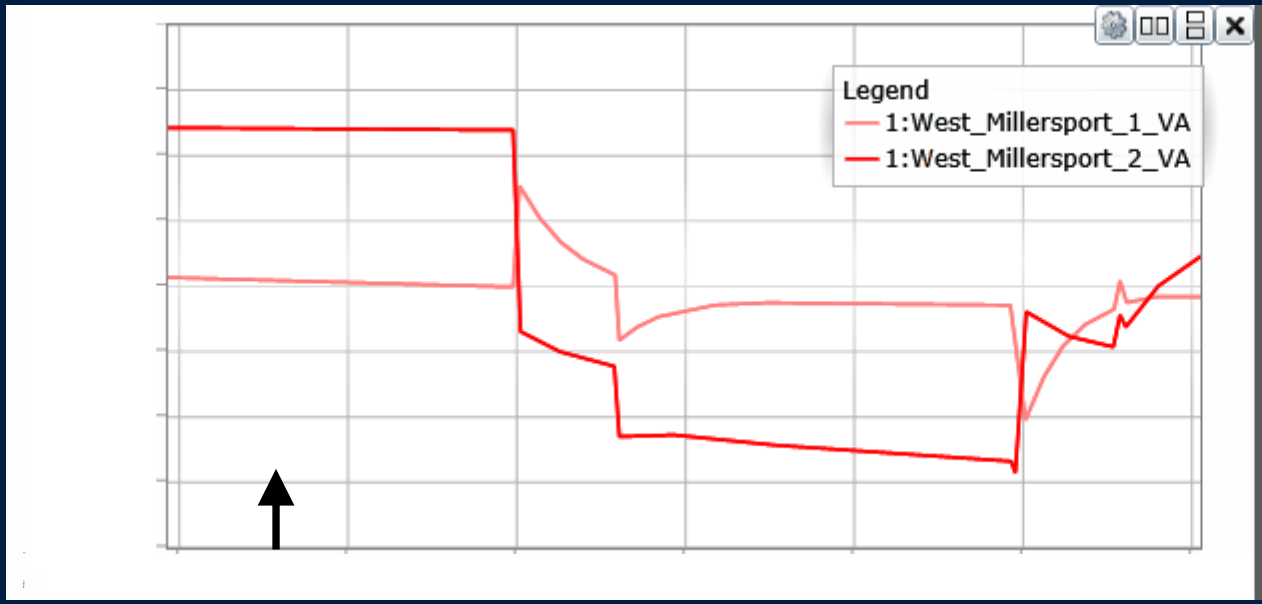
Simulation
West Millersport Line 1

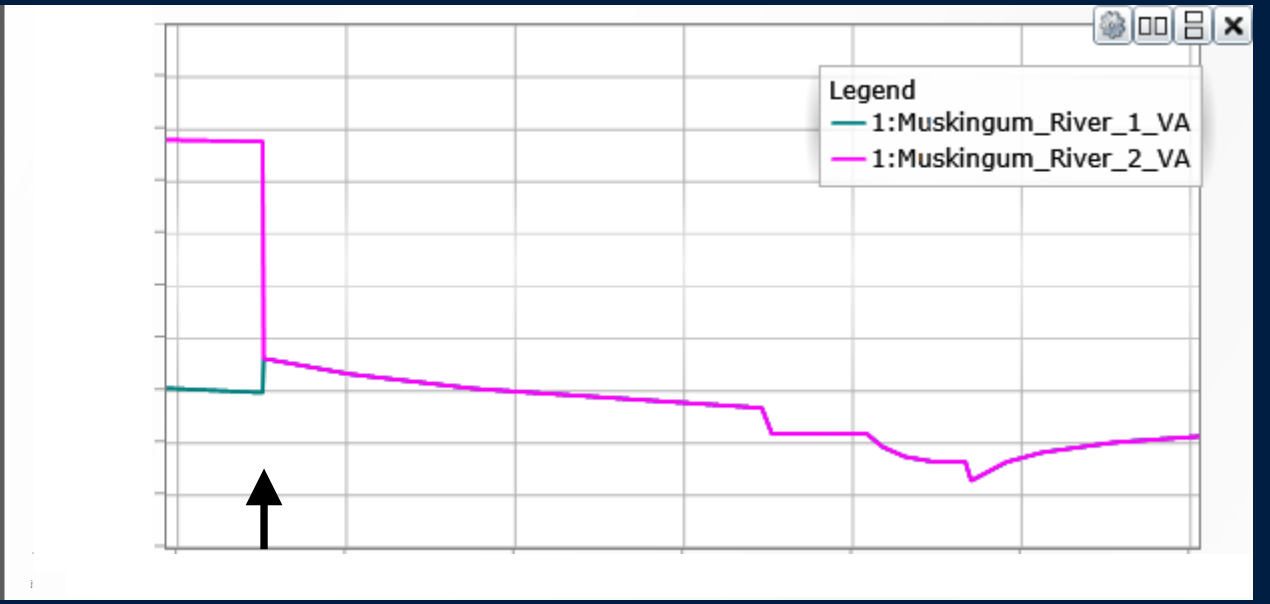




Simulation Results

- Shows trapped charge on line
- Validates surge arrester operation during reclose
- Provides view of wave propagation


Legend
1:West_Millersport_1_VA
1:West_Millersport_2_VA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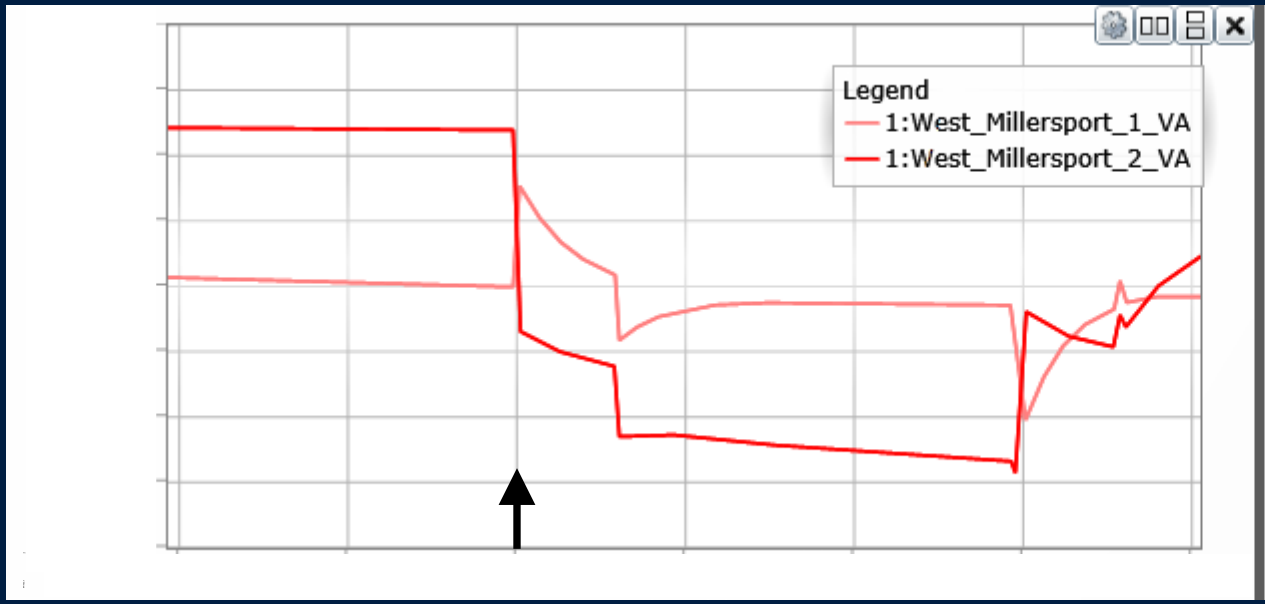
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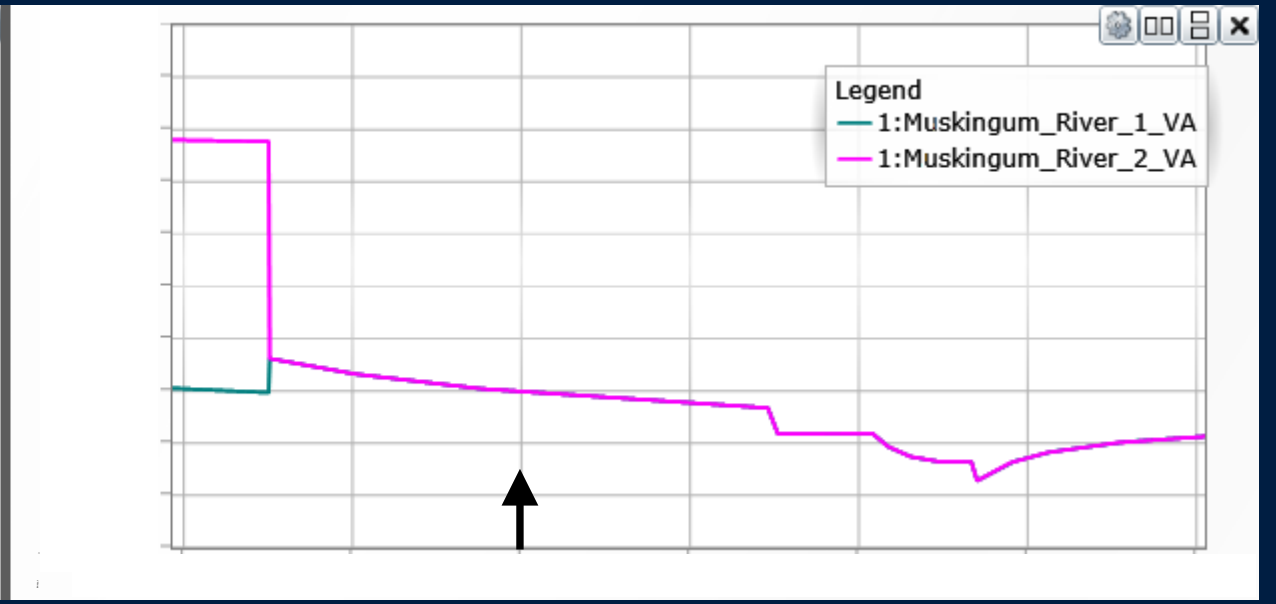
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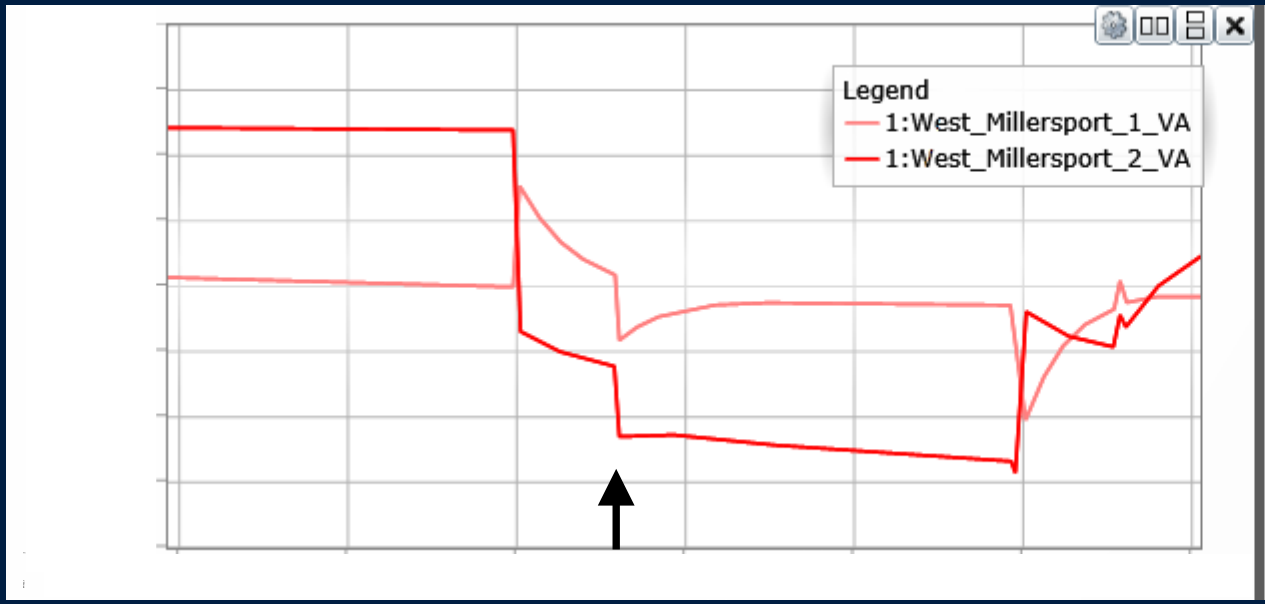
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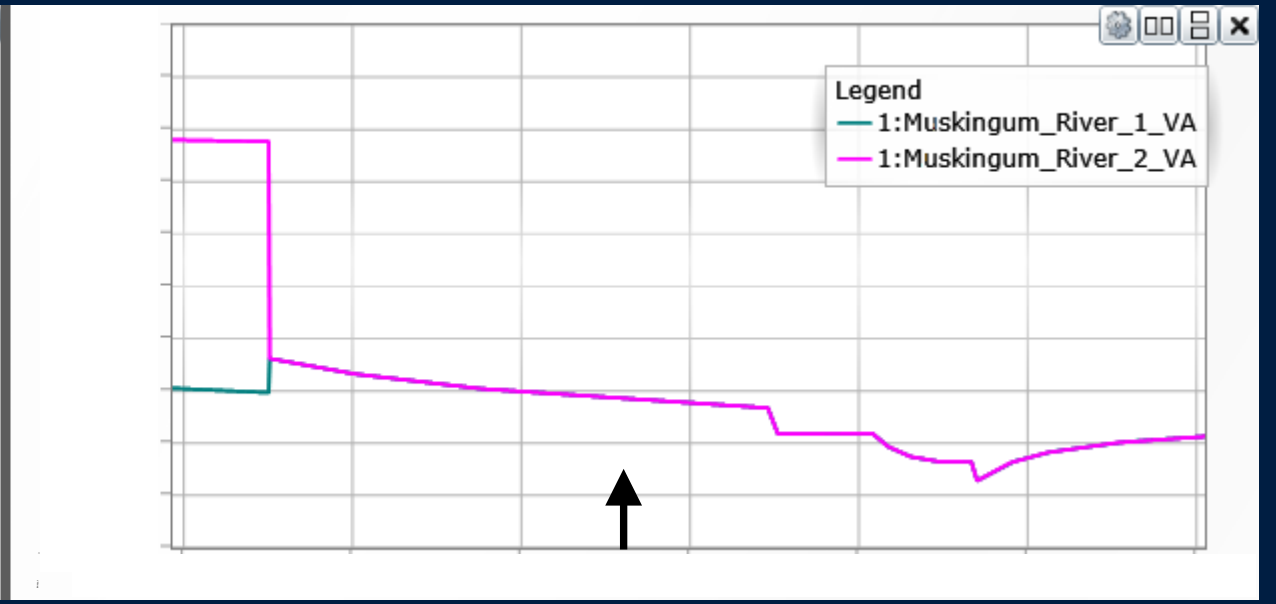
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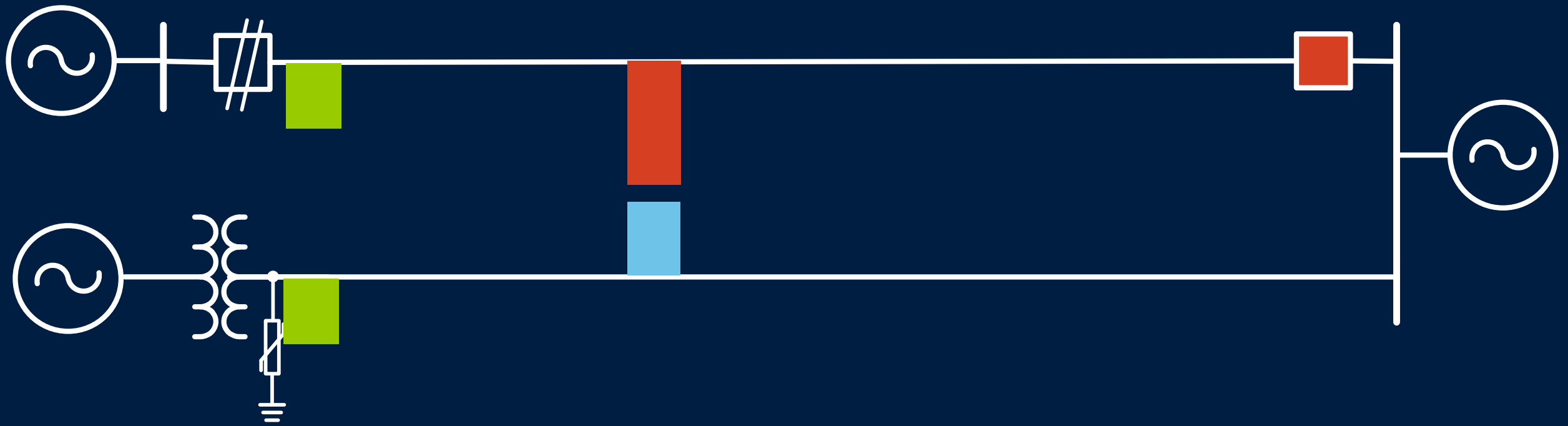

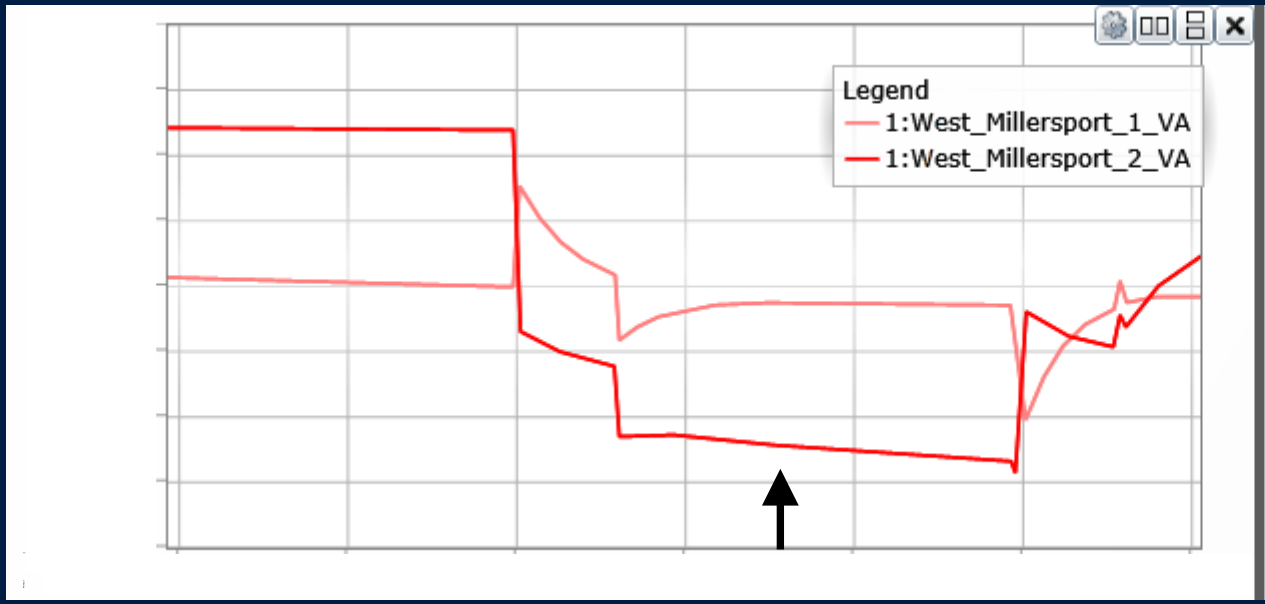
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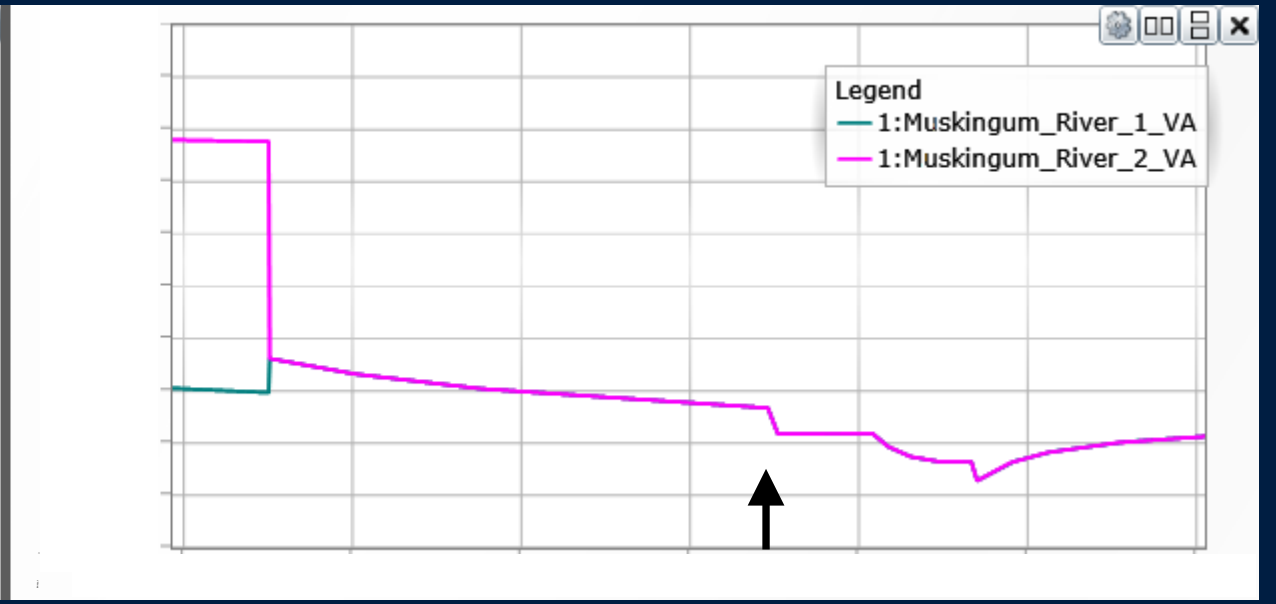
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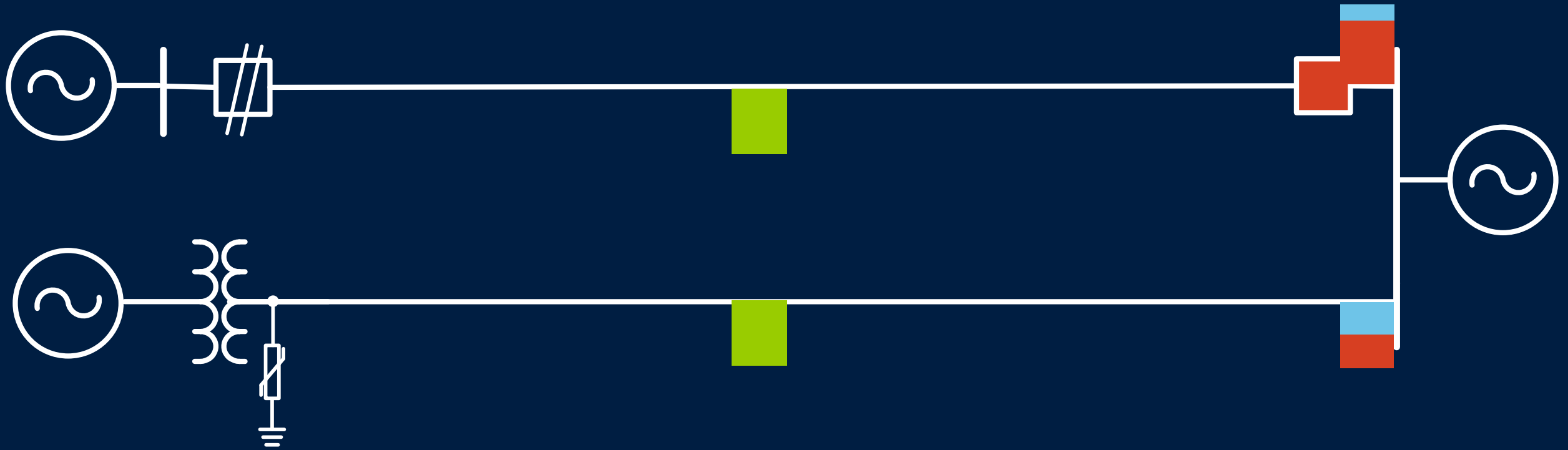

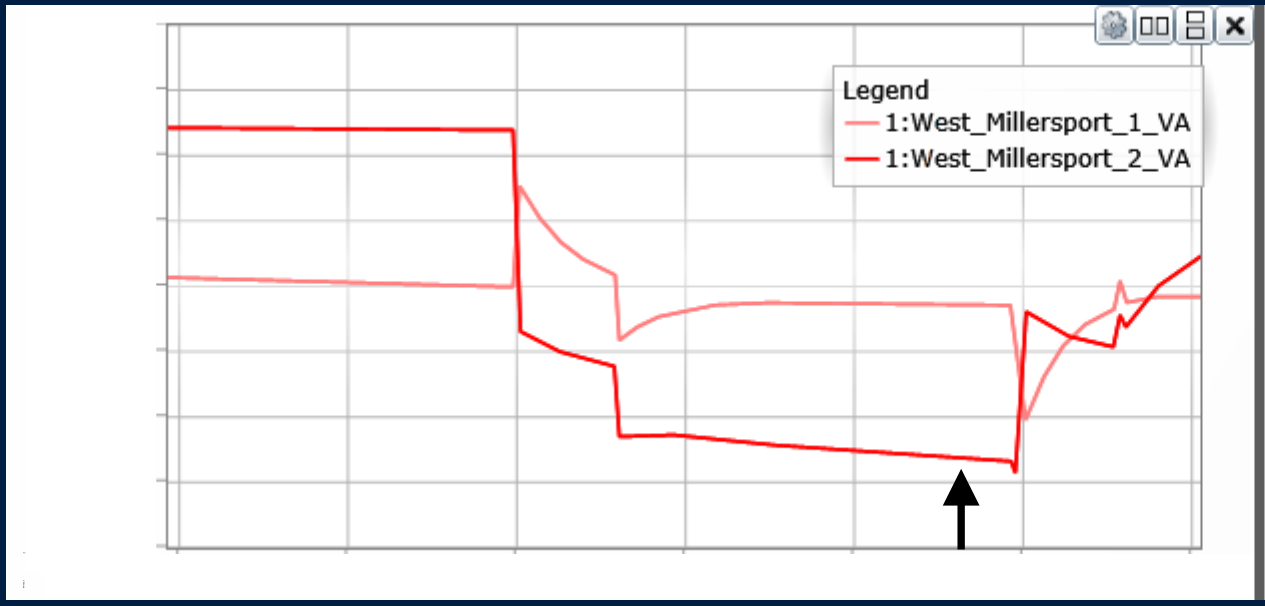
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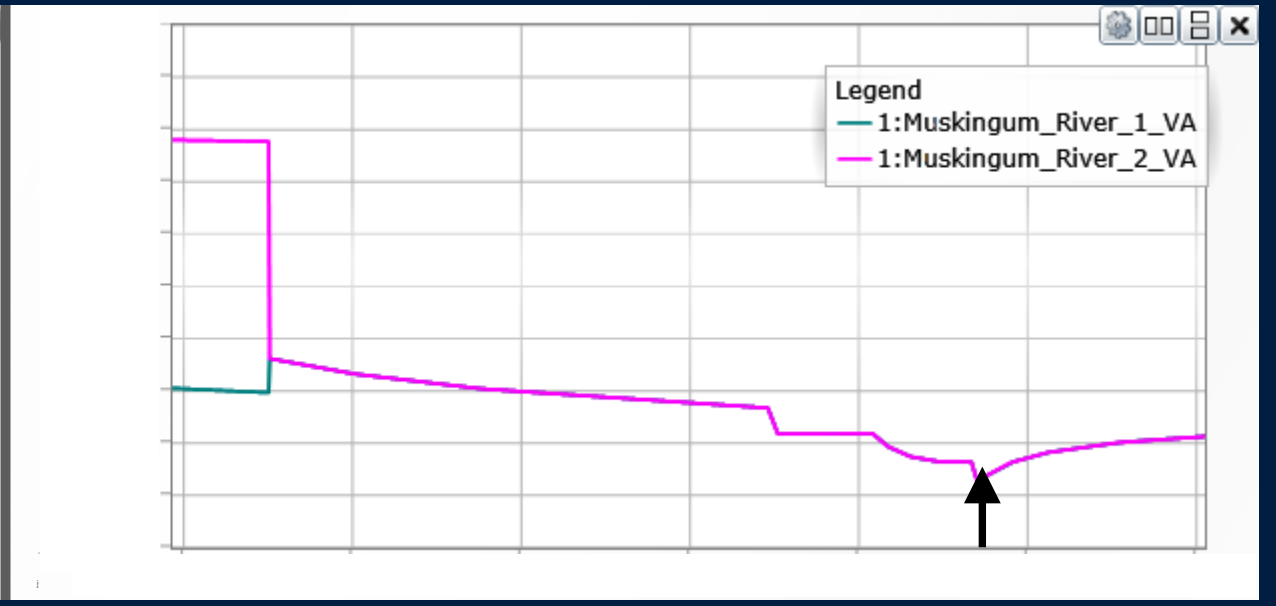
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Conclusion

- Extreme switching surges occur when energizing line out of phase with trapped charge on line
- High-speed reclosing allows less time for trapped charge to drain, increasing switching surge possibility
- Surge arresters can operate during switching surges

Conclusion (continued)

- Series of events led to 87Z operation
  - Elevated switching surges due to operation on adjacent line
  - Elevated trapped charge on faulted phase from current chop during breaker operation
  - Reclose out of phase with trapped charge on line
  - No time delays for 87Z element

Conclusion (continued)

- Differential relays must remain secure for surge arrester operation
  - Settings engineer adds manual time delay
  - Relay vendor offers built-in surge arrester security
- High sample rate data help users see fast moving transients and identify root cause

Questions?