A Bus Cleared and a Hidden Breaker Insulation Failure Revealed

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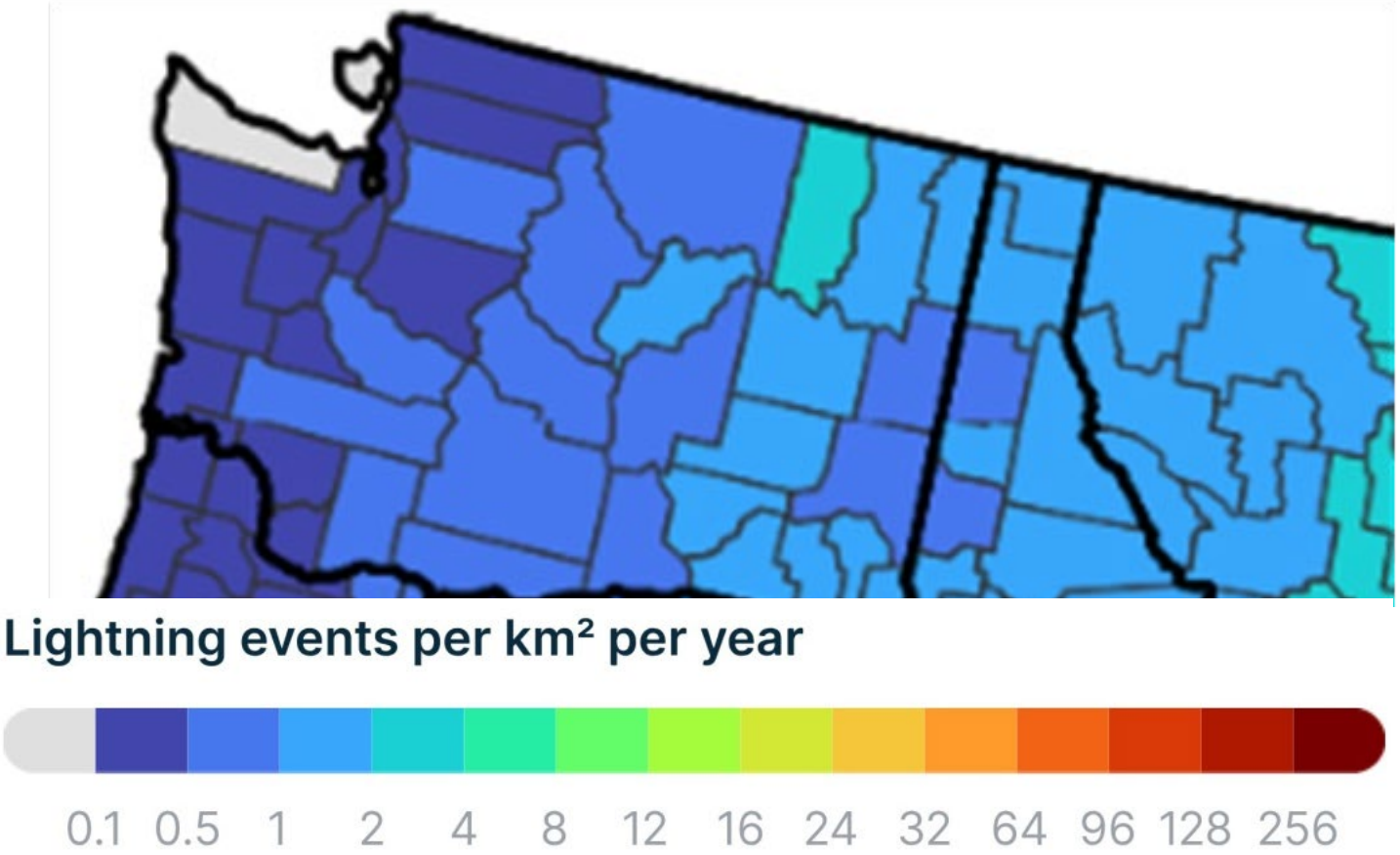
Avista service territory

- Population of 1.7M
- Miles of transmission lines
  - 700 miles at 230 kV
  - 1,600 miles at 115 kV

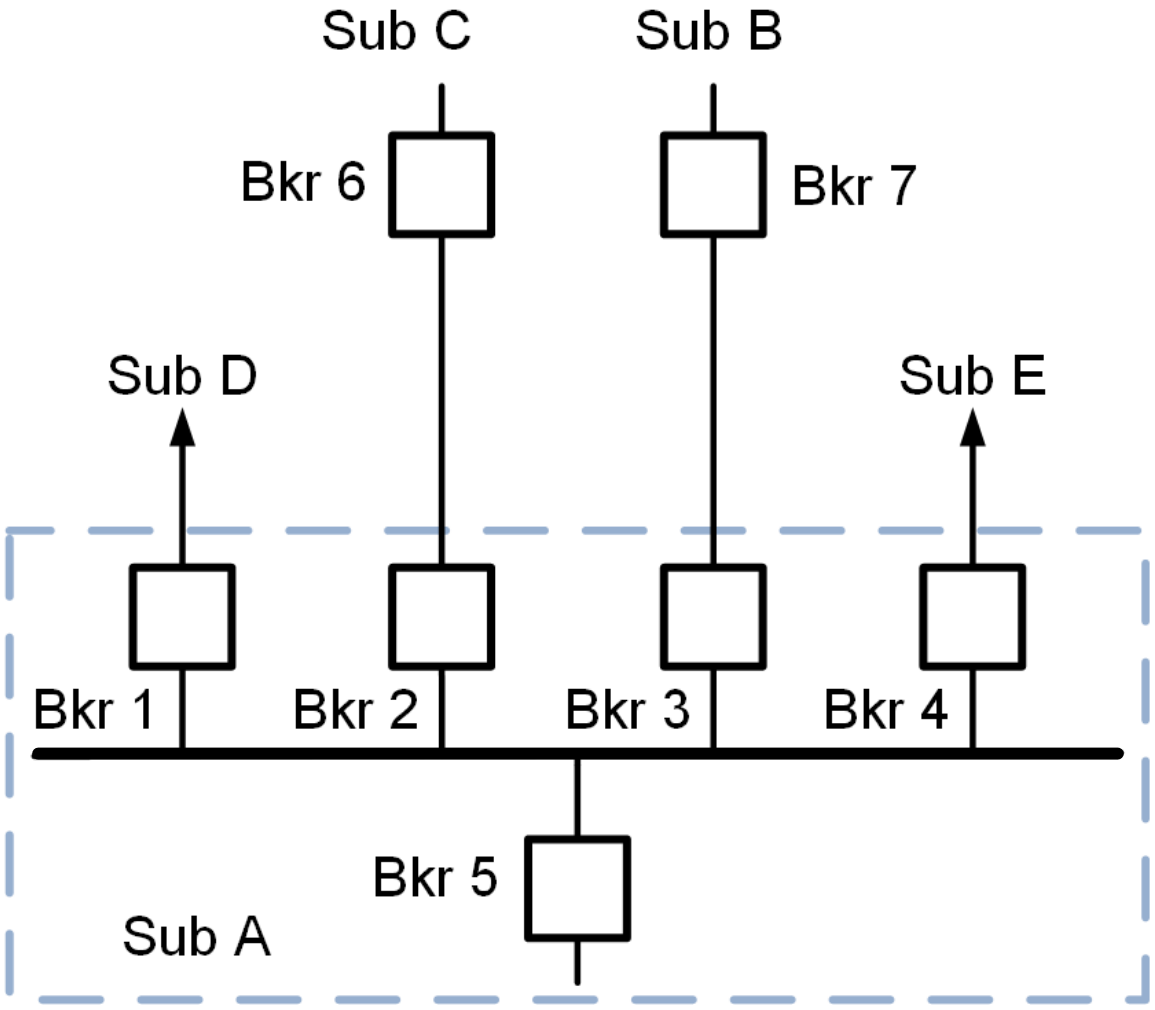
Day of event – background

- Historically low lightning density occurred in area
- Substation did not have
  - Lightning arrestors on breakers
  - Shield wires on transmission lines



Substation layout

- Substations of interest – Sub A, Sub B, and Sub C
- 230 kV bus and lines
- Sub A protection
  - High-impedance bus diff (87B1)
  - Percentage-restrained bus diff (87B2)
- Line protection
  - Distance
  - 87L

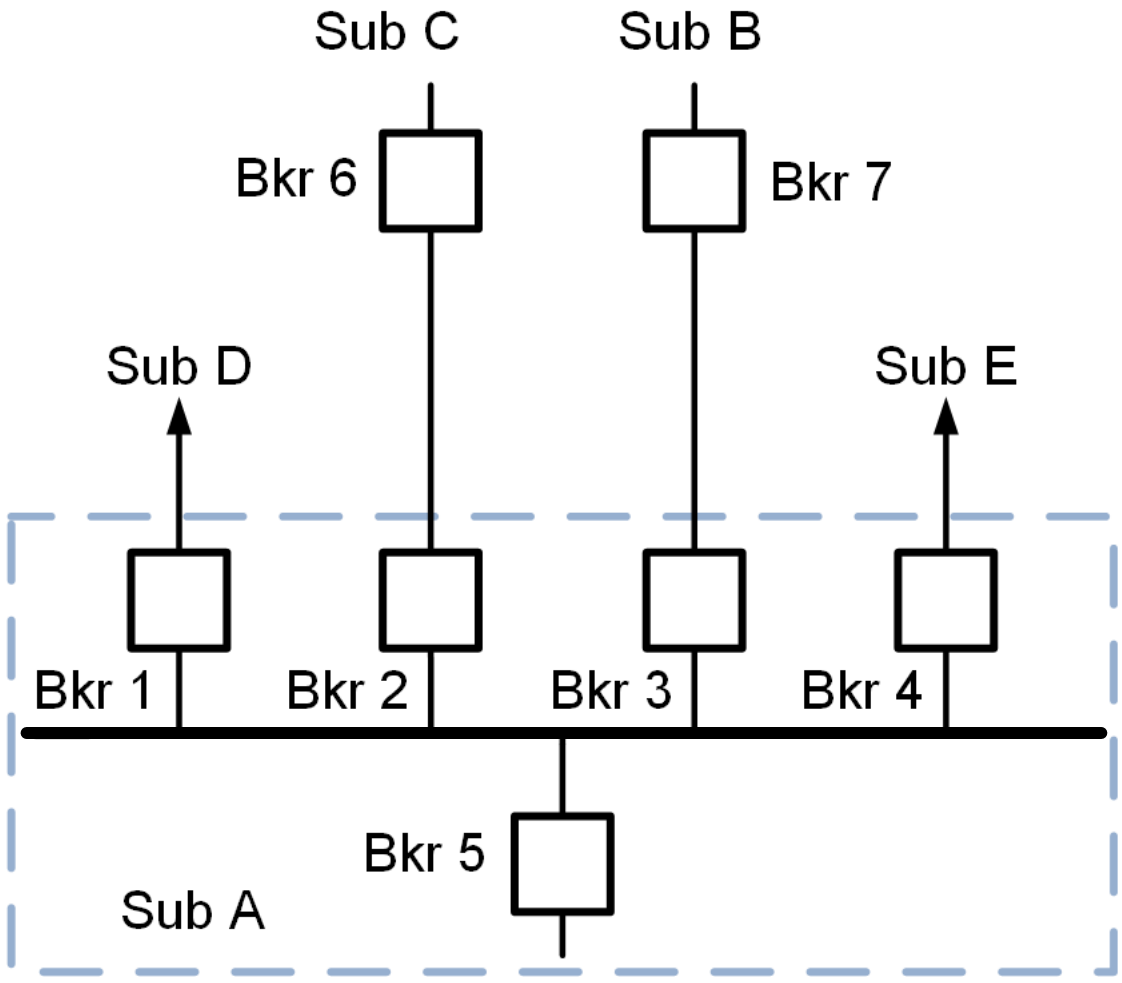


Event analysis

Event date – June 27, 2023

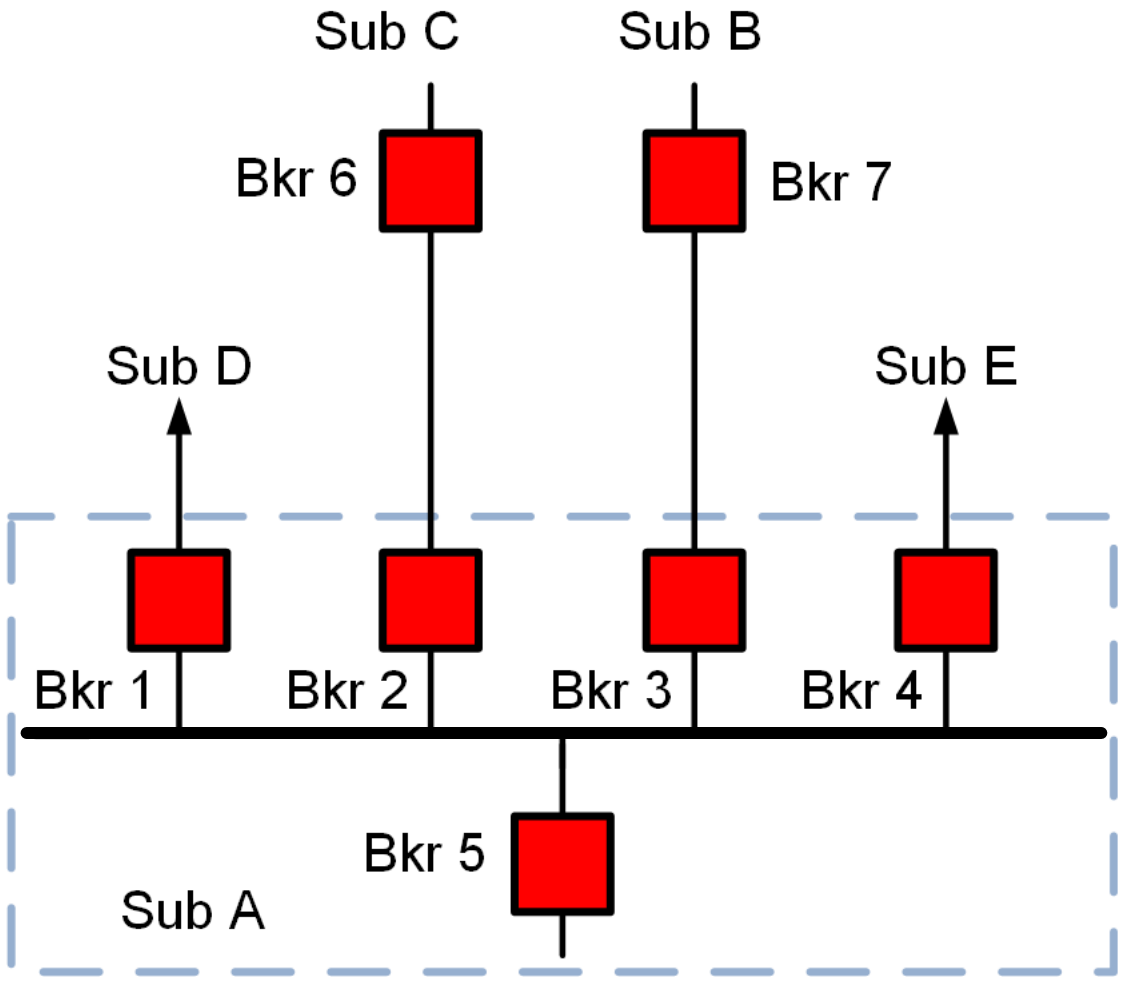
Initial information and assumptions

- Sub A–Sub B line and Sub A bus tripped at same time
- No damage was visible at Sub A
- Technicians reenergized Sub A



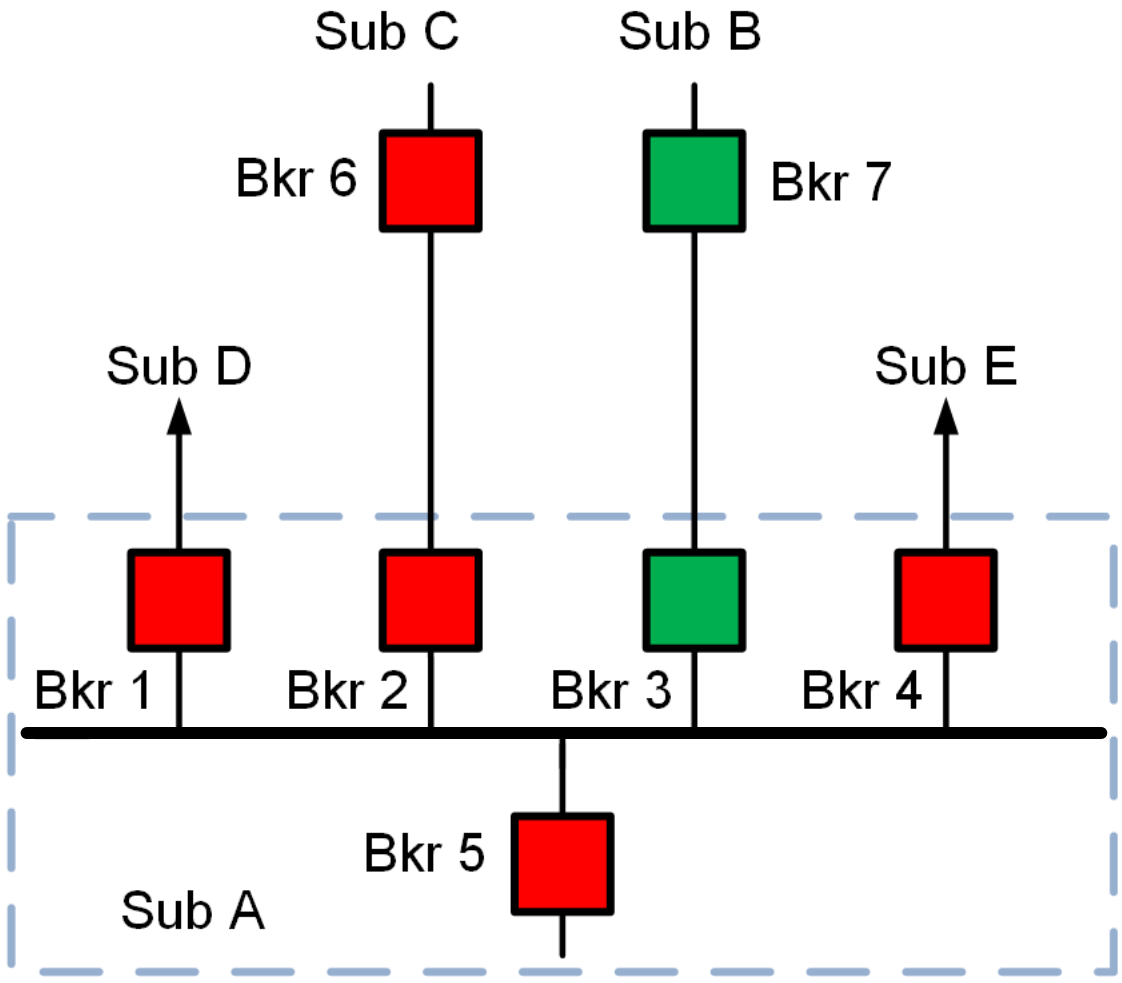
Sequence of Events – BG fault

Time	Event
16:37:00.5165	Sub A–Sub B line fault



Sequence of Events – Sub A–Sub B line trips

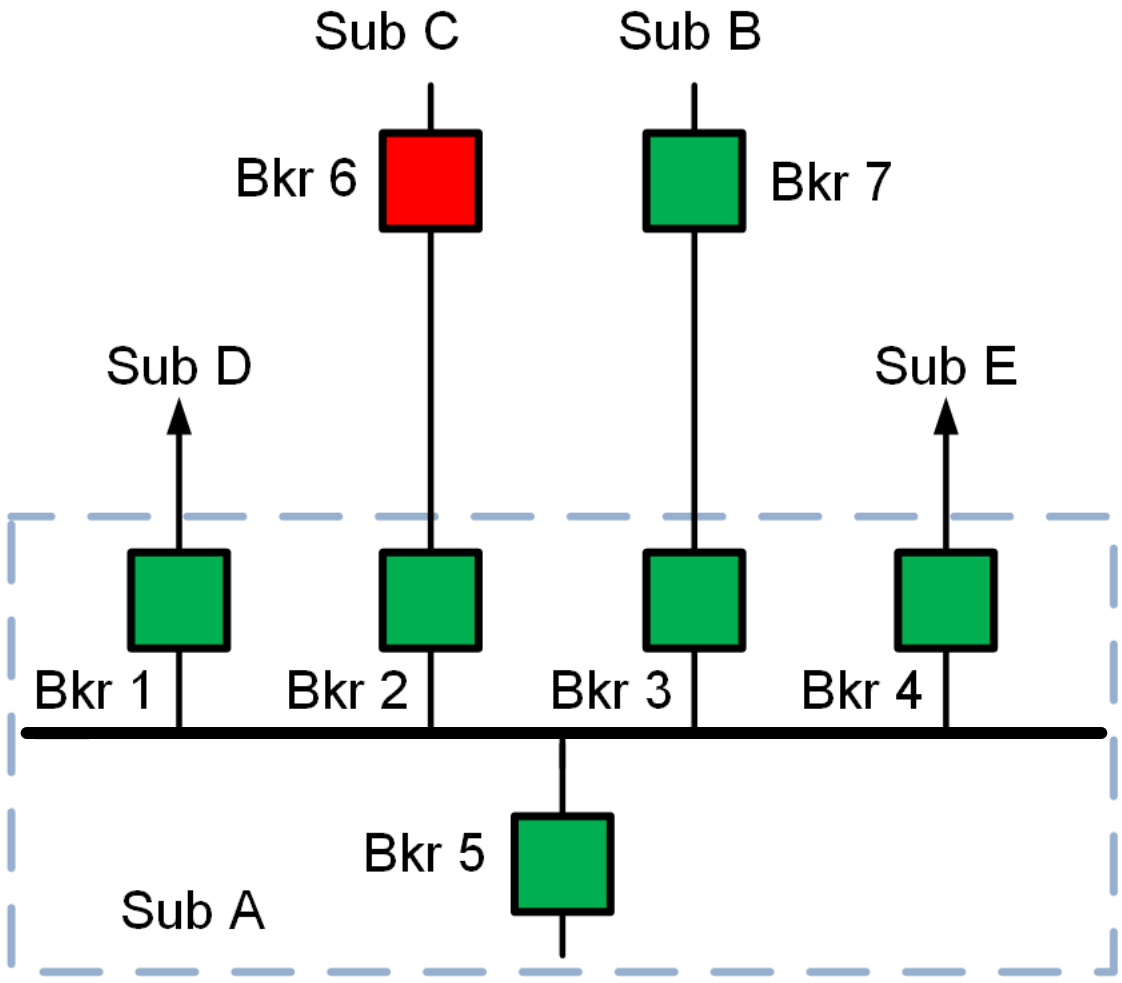
Time	Event
16:37:00.5165	Sub A–Sub B line fault
16:37:00.5270	Sub A–Sub B line relays trip



Sequence of Events – Sub A bus clears

Time	Event
16:37:00.5165	Sub A–Sub B line fault
16:37:00.5270	Sub A–Sub B line relays trip
16:37:00.9546	87B1 trips Sub A bus
16:37:00.9850	Bkr 1, Bkr 2, Bkr 4, Bkr 5 52As begin deasserting

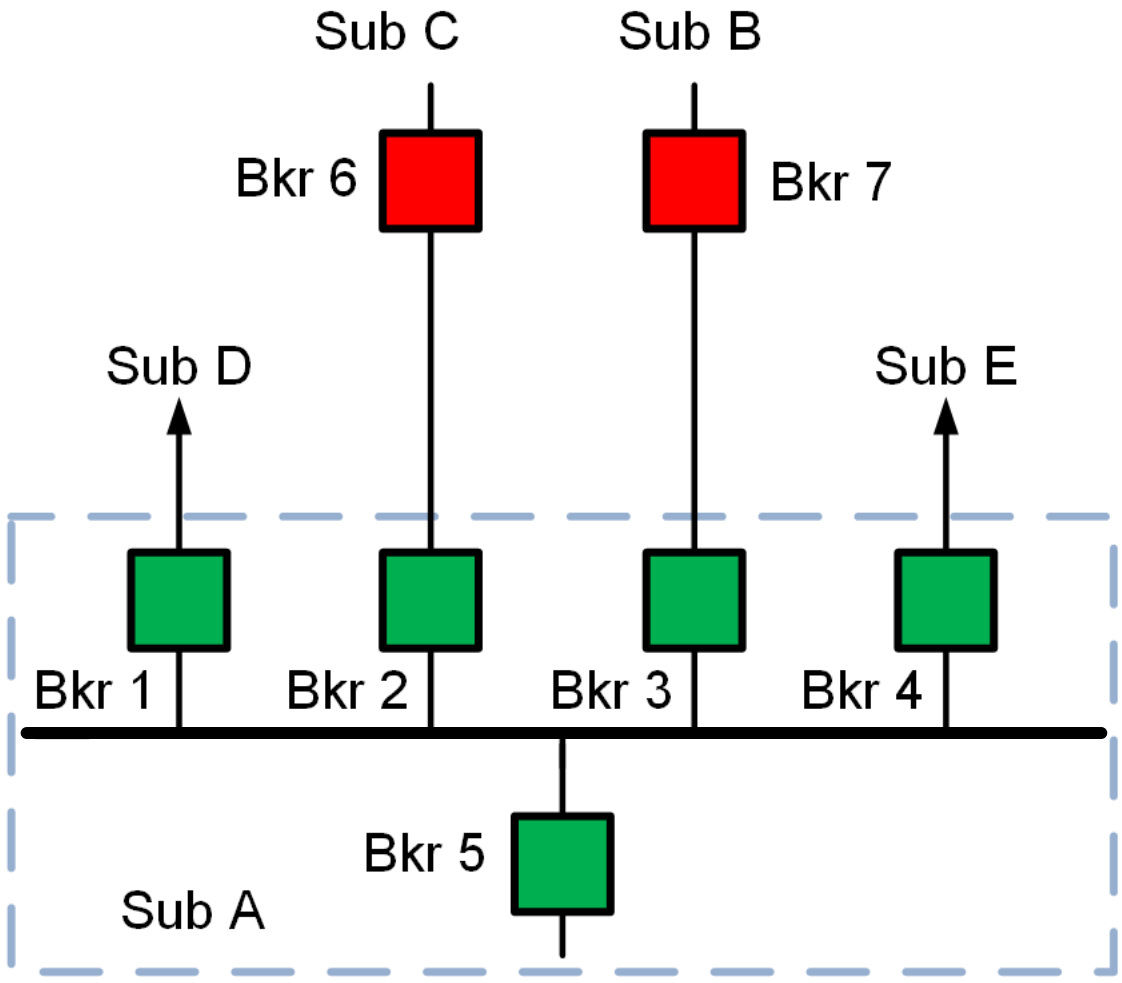
~428 ms



Sequence of Events – Sub B recloses

Time	Event
16:37:00.5165	Sub A–Sub B line fault
16:37:00.5270	Sub A–Sub B line relays trip
16:37:00.9546	87B1 trips Sub A bus
16:37:00.9850	Bkr 1, Bkr 2, Bkr 4, Bkr 5 52As begin deasserting
16:37:01.6553	Sub B Bkr 7 recloses

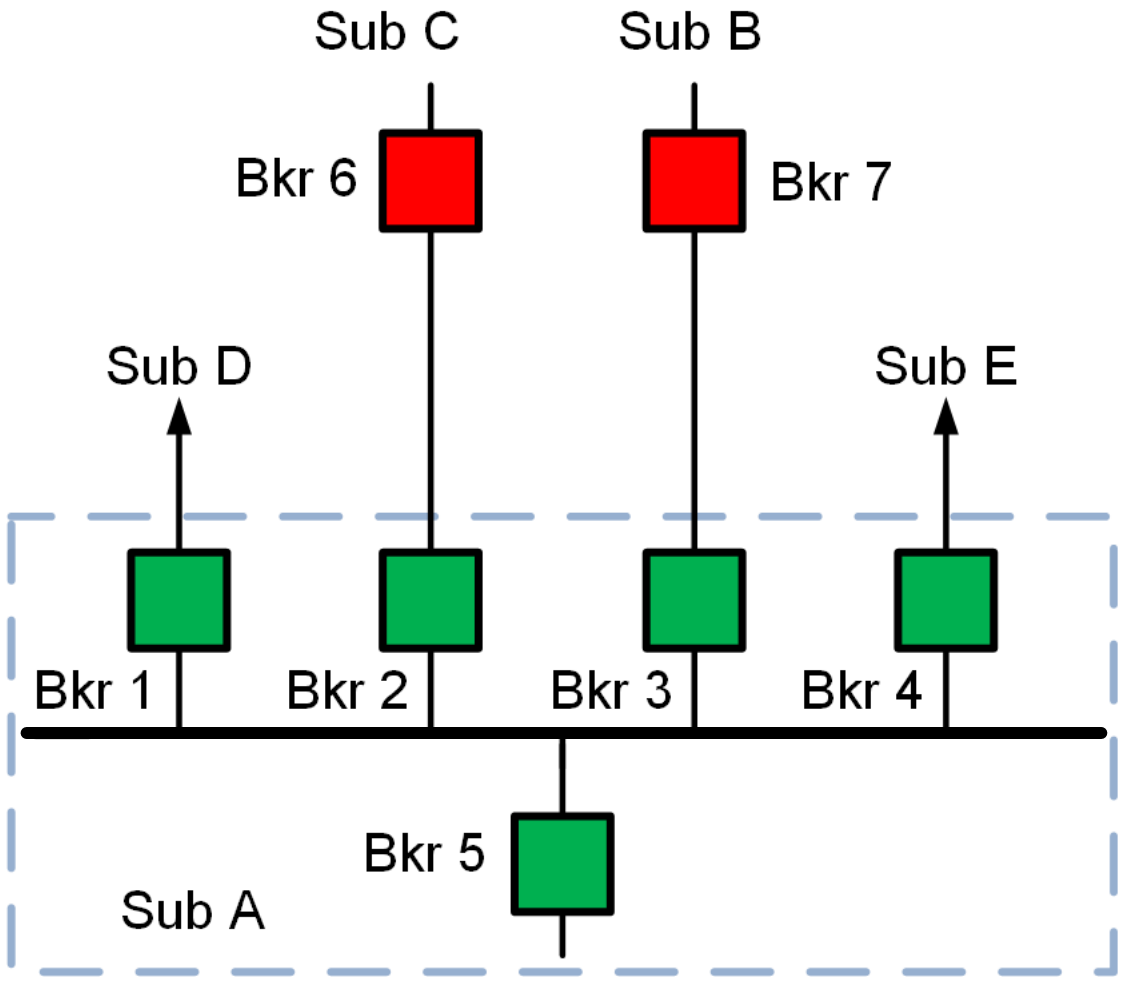
~1 s



Sequence of Events – Sub A bus clears again

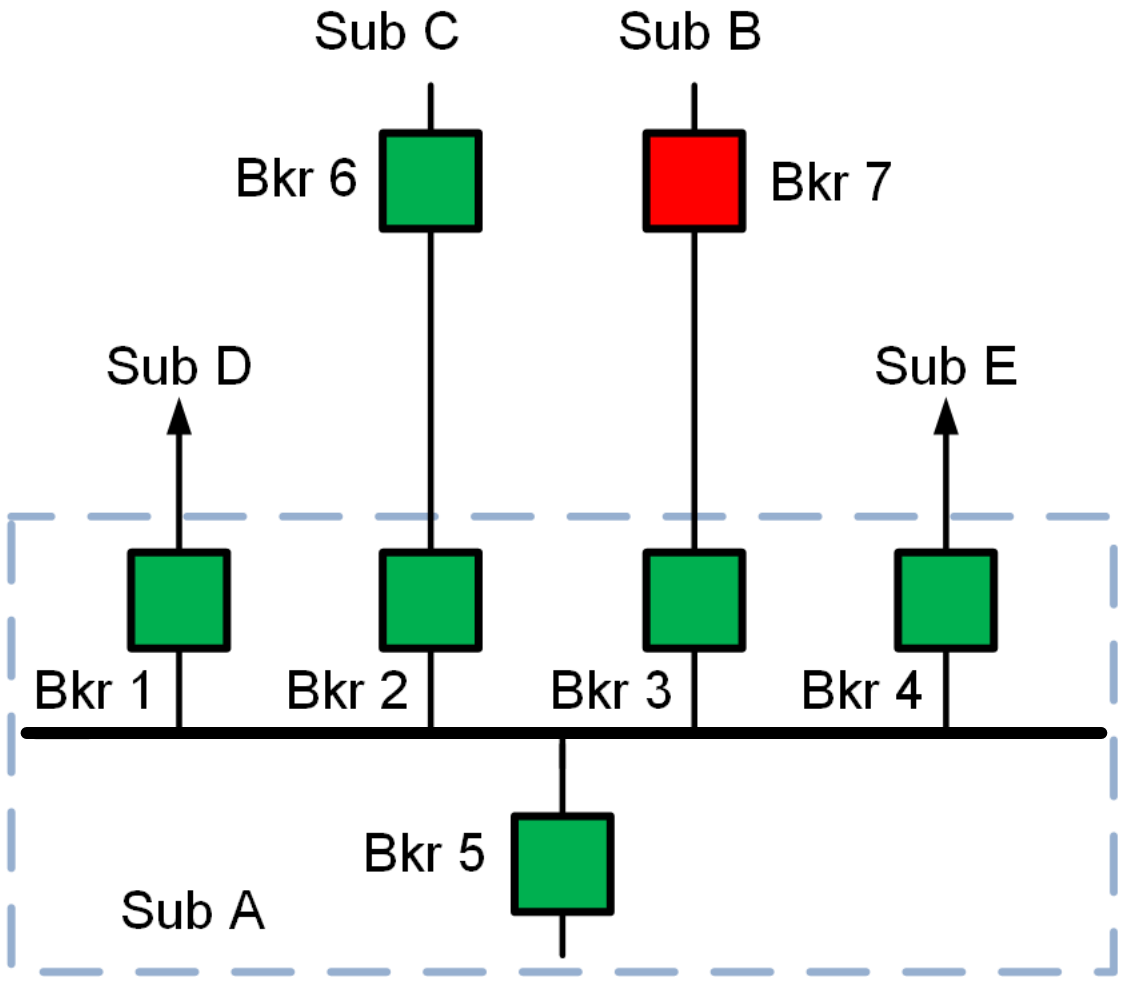
Time	Event
16:37:00.5165	Sub A–Sub B line fault
16:37:00.5270	Sub A–Sub B line relays trip
16:37:00.9546	87B1 trips Sub A bus
16:37:00.9850	Bkr 1, Bkr 2, Bkr 4, Bkr 5 52As begin deasserting
16:37:01.6553	Sub B Bkr 7 recloses
17:05:21.2273	87B2 attempts to trip Sub A bus

~28 min



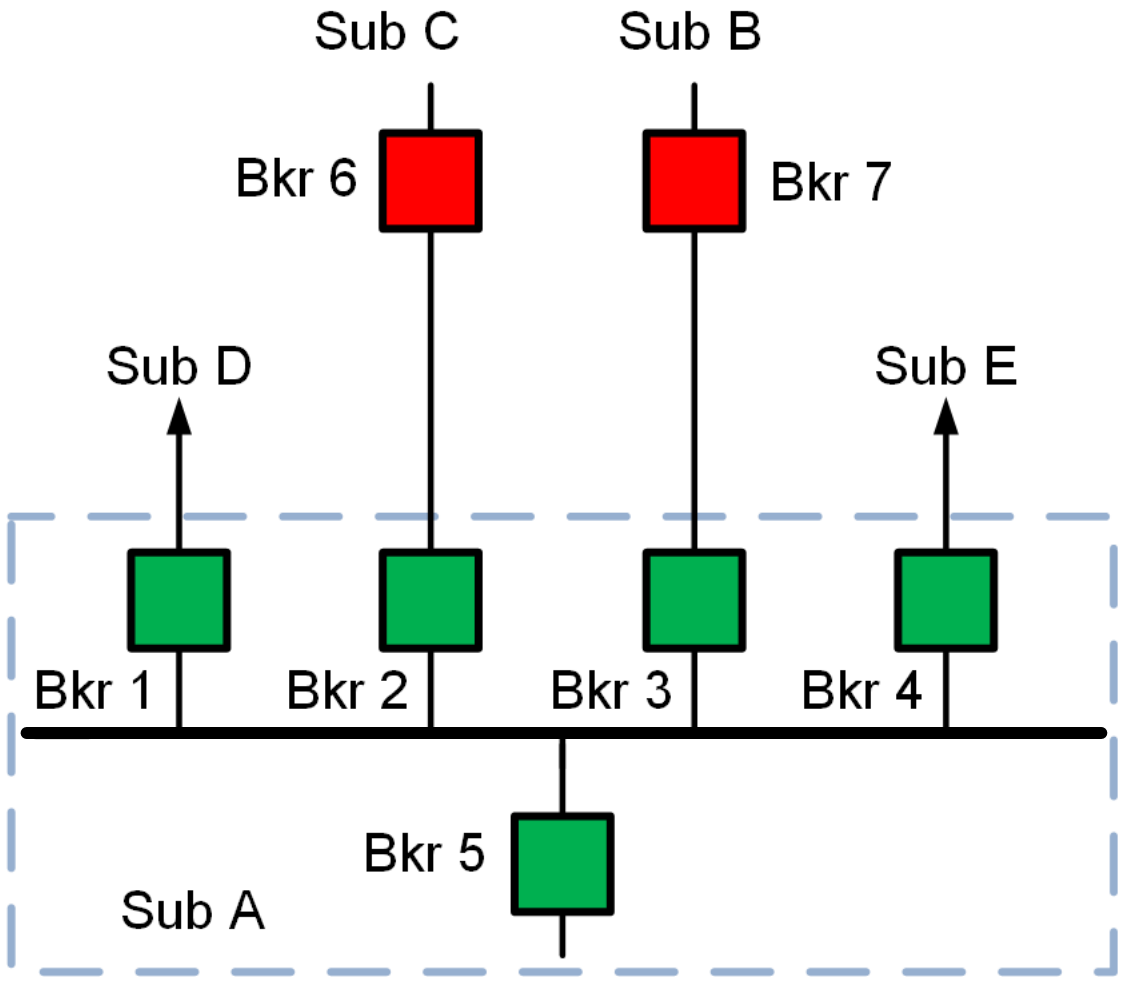
Sequence of Events – Sub C Bkr 6 trips

Time	Event
16:37:00.5165	Sub A–Sub B line fault
16:37:00.5270	Sub A–Sub B line relays trip
16:37:00.9546	87B1 trips Sub A bus
16:37:00.9850	Bkr 1, Bkr 2, Bkr 4, Bkr 5 52As begin deasserting
16:37:01.6553	Sub B Bkr 7 recloses
17:05:21.2273	87B2 attempts to trip Sub A bus
17:05:21	Sub C Bkr 6 trips



Sequence of Events – Sub C Bkr 6 recloses

Time	Event
16:37:00.5165	Sub A–Sub B line fault
16:37:00.5270	Sub A–Sub B line relays trip
16:37:00.9546	87B1 trips Sub A bus
16:37:00.9850	Bkr 1, Bkr 2, Bkr 4, Bkr 5 52As begin deasserting
16:37:01.6553	Sub B Bkr 7 recloses
17:05:21.2273	87B2 attempts to trip Sub A bus
17:05:21	Sub C Bkr 6 trips
17:05:22	Sub C Bkr 6 recloses



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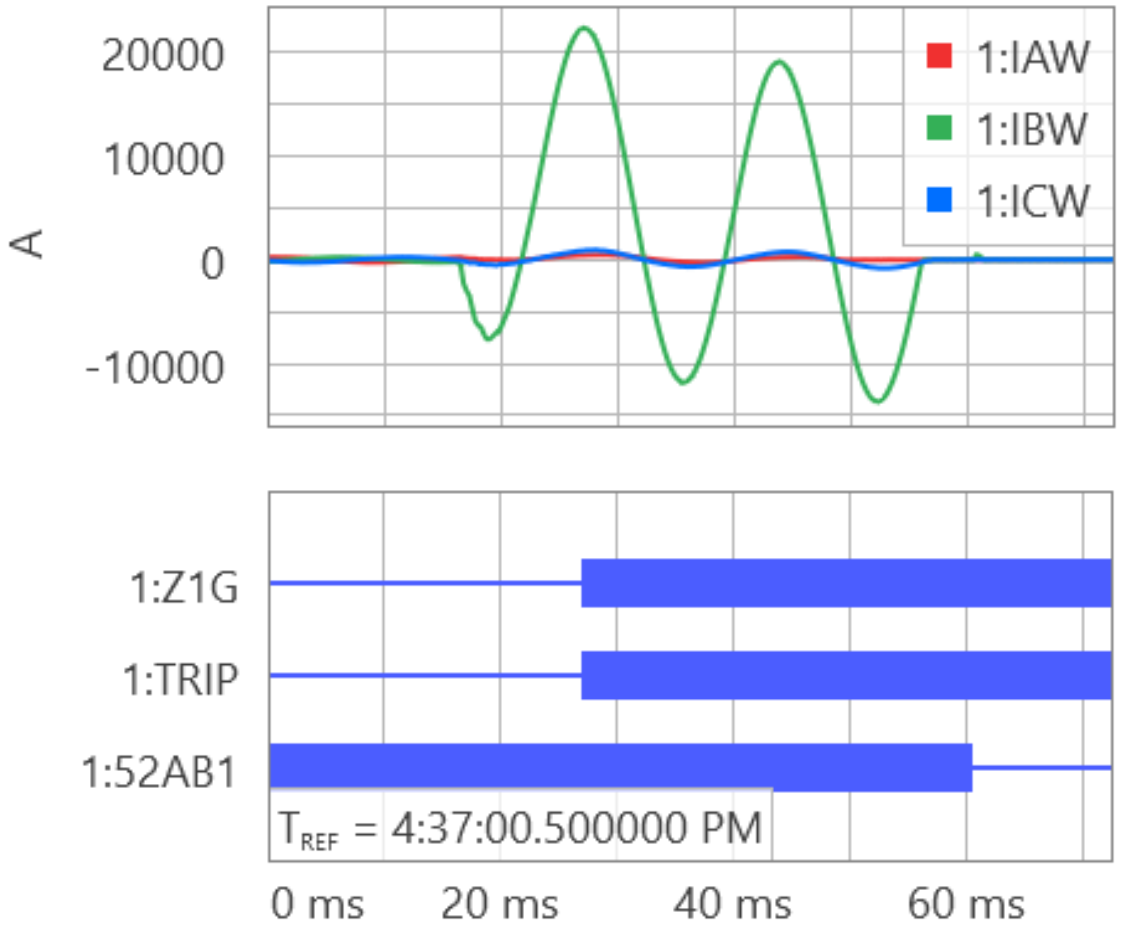
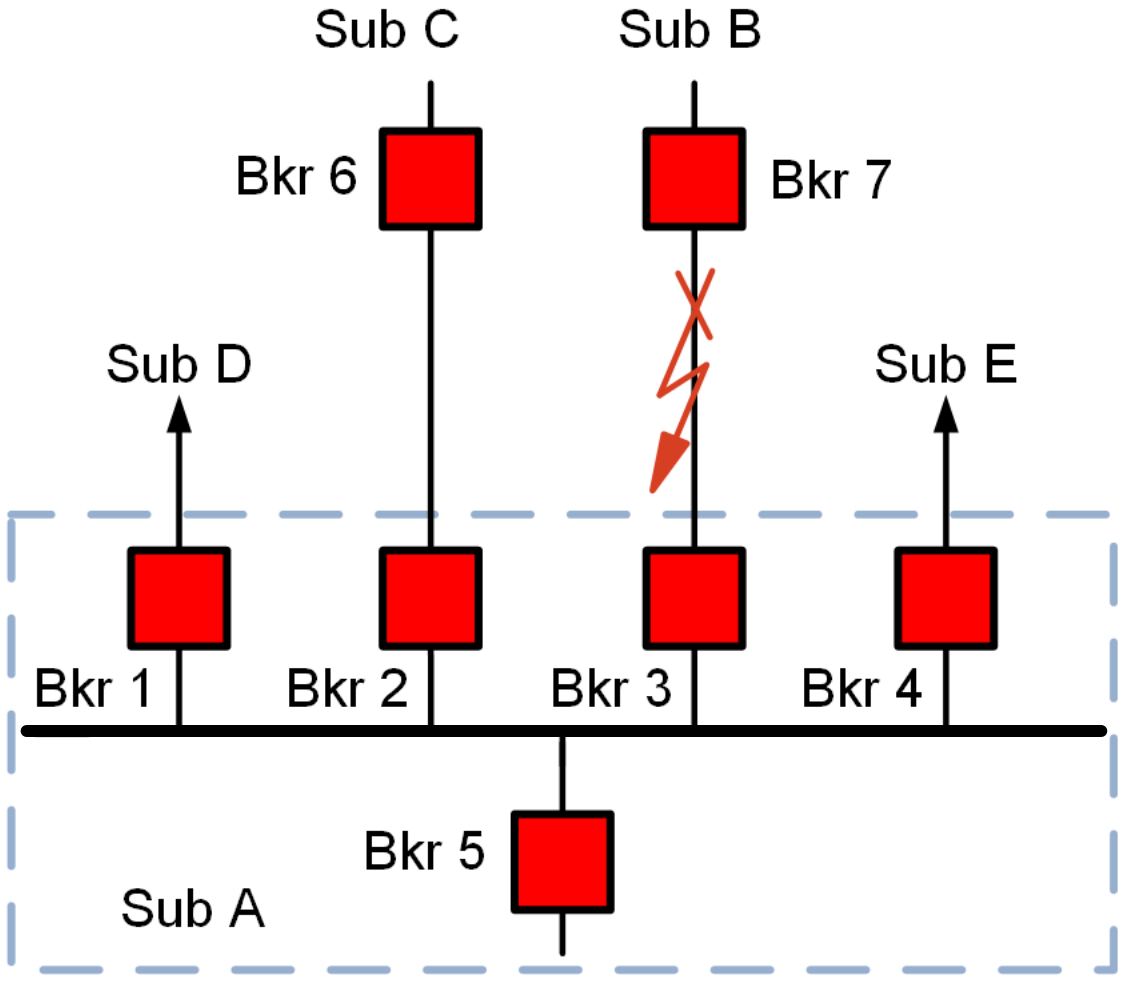
Initial BG fault on Sub A–Sub B line





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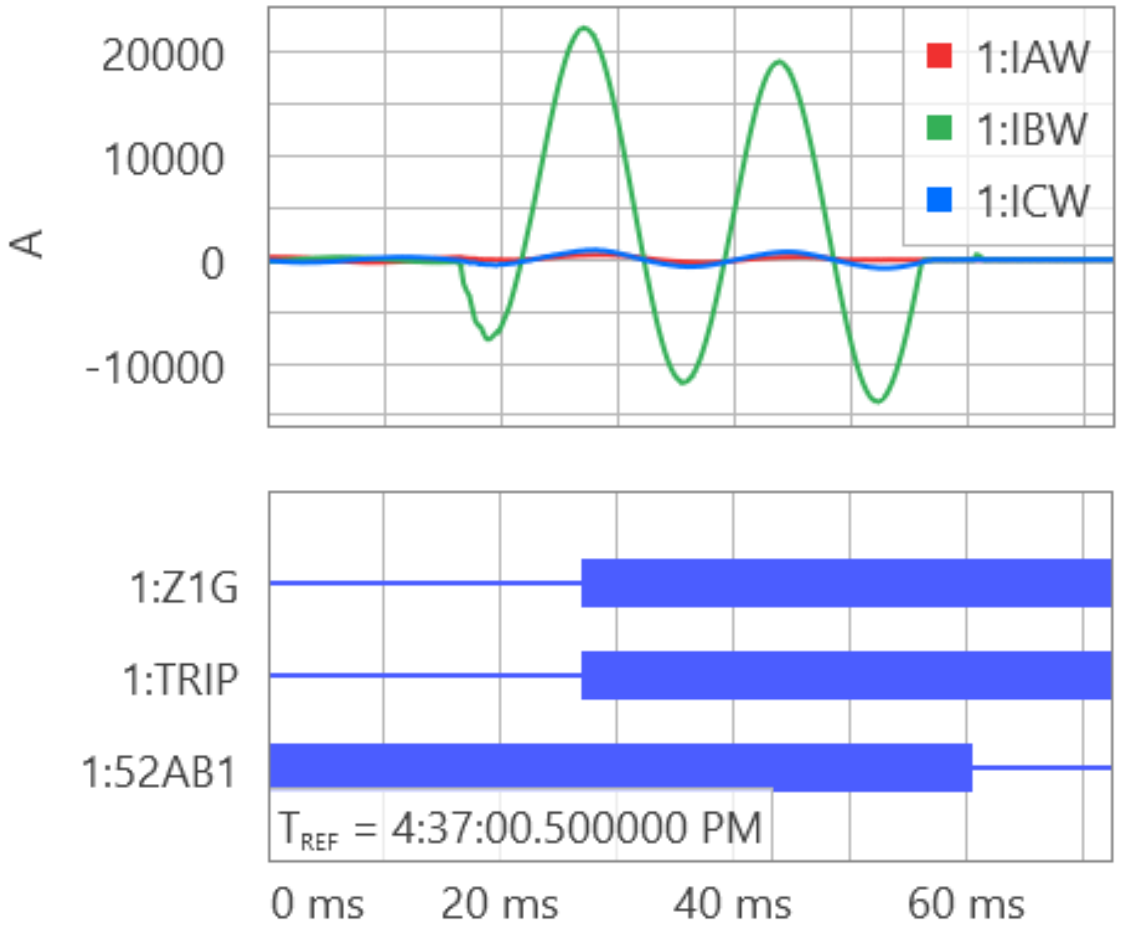
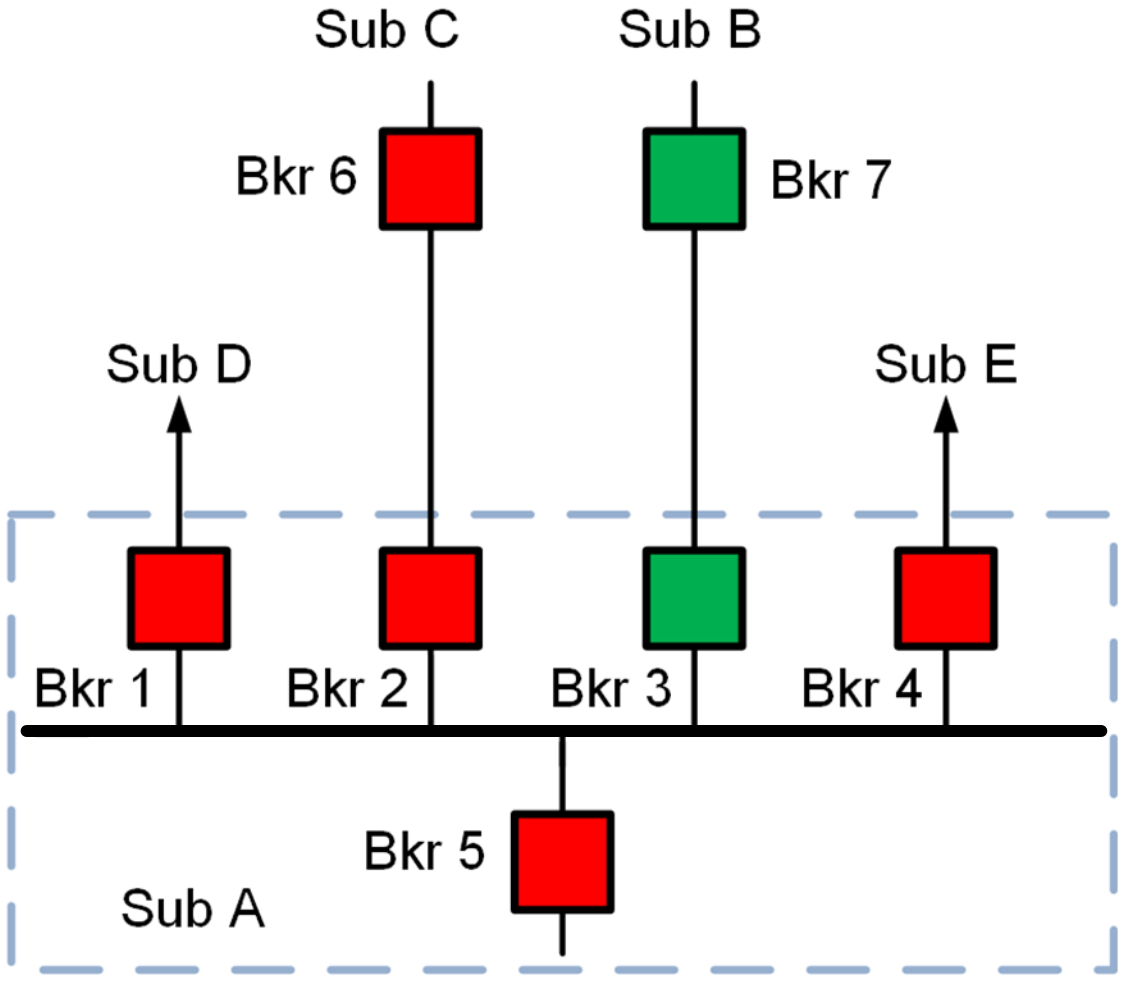
Initial BG fault on Sub A–Sub B line





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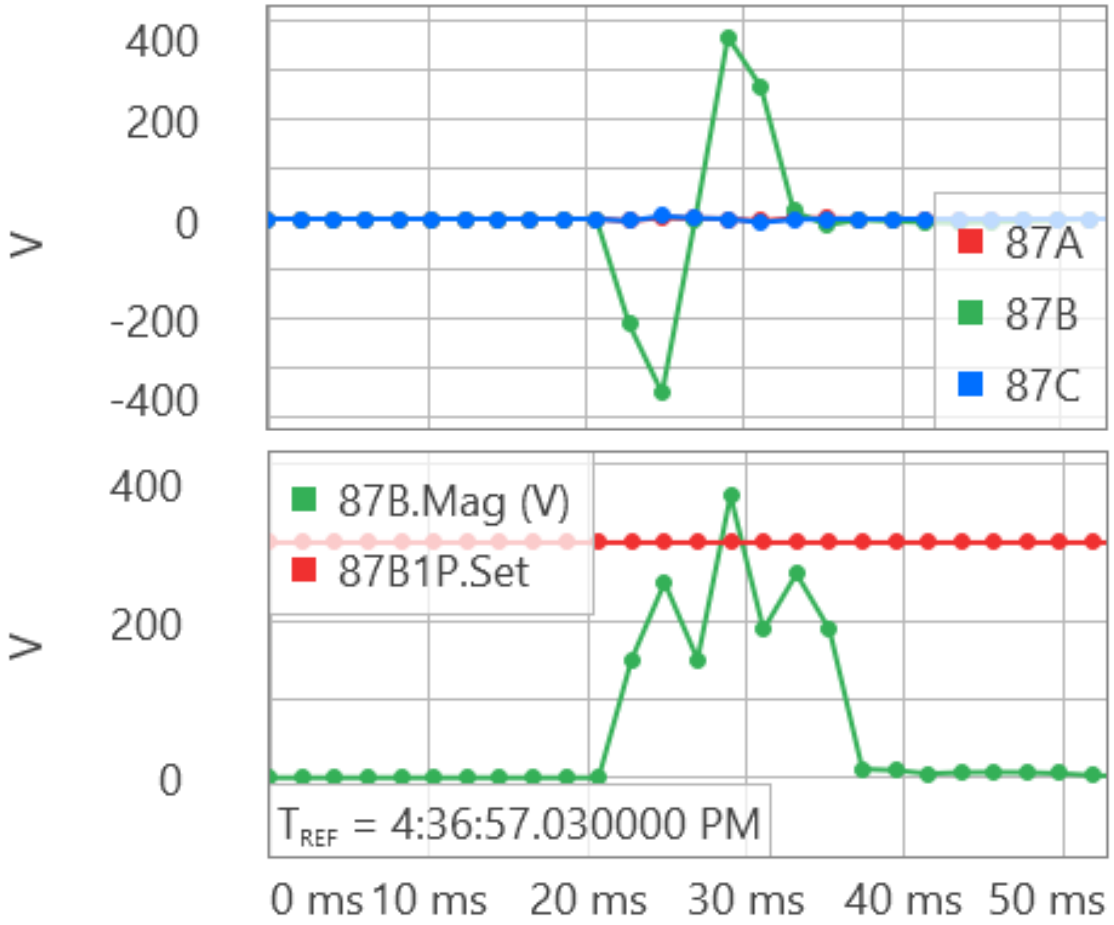
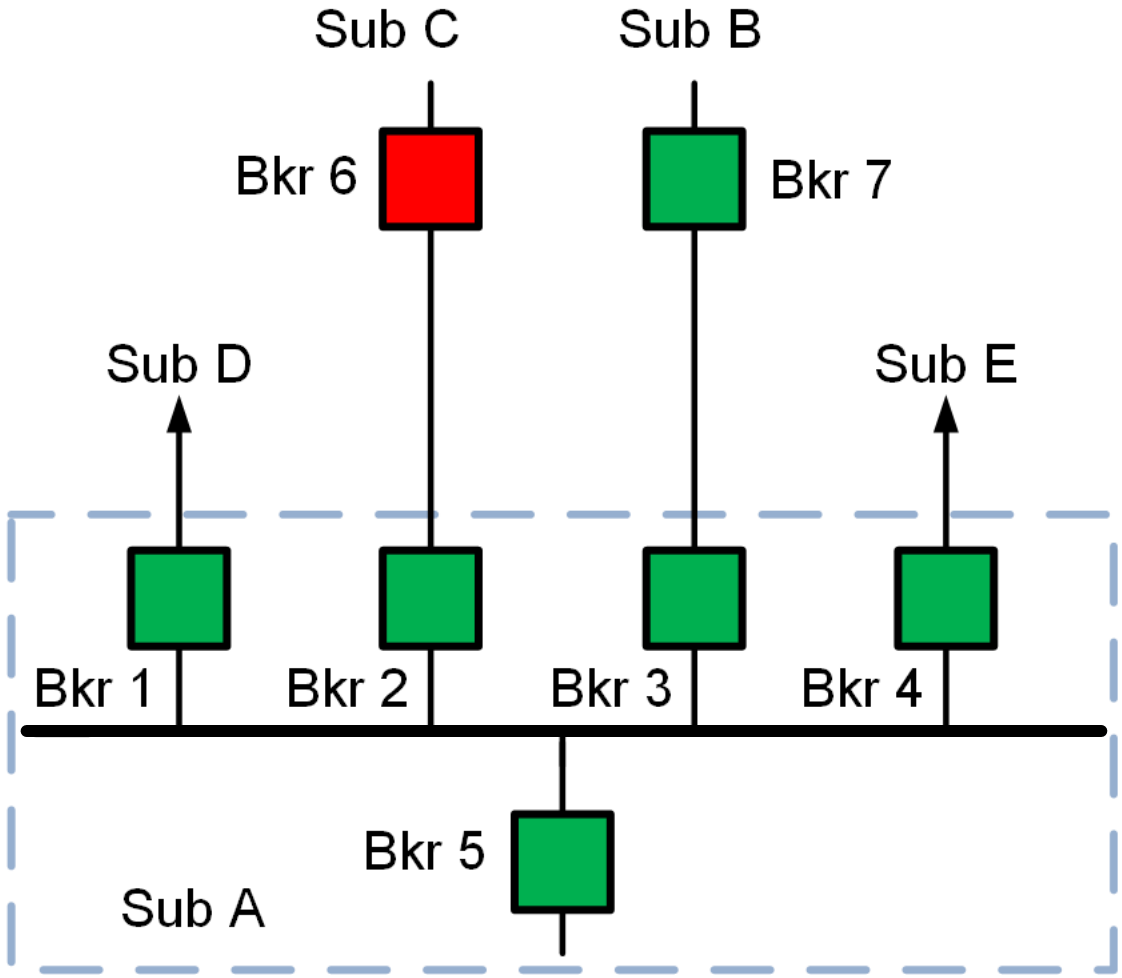
High-impedance bus differential relay trips Sub A bus





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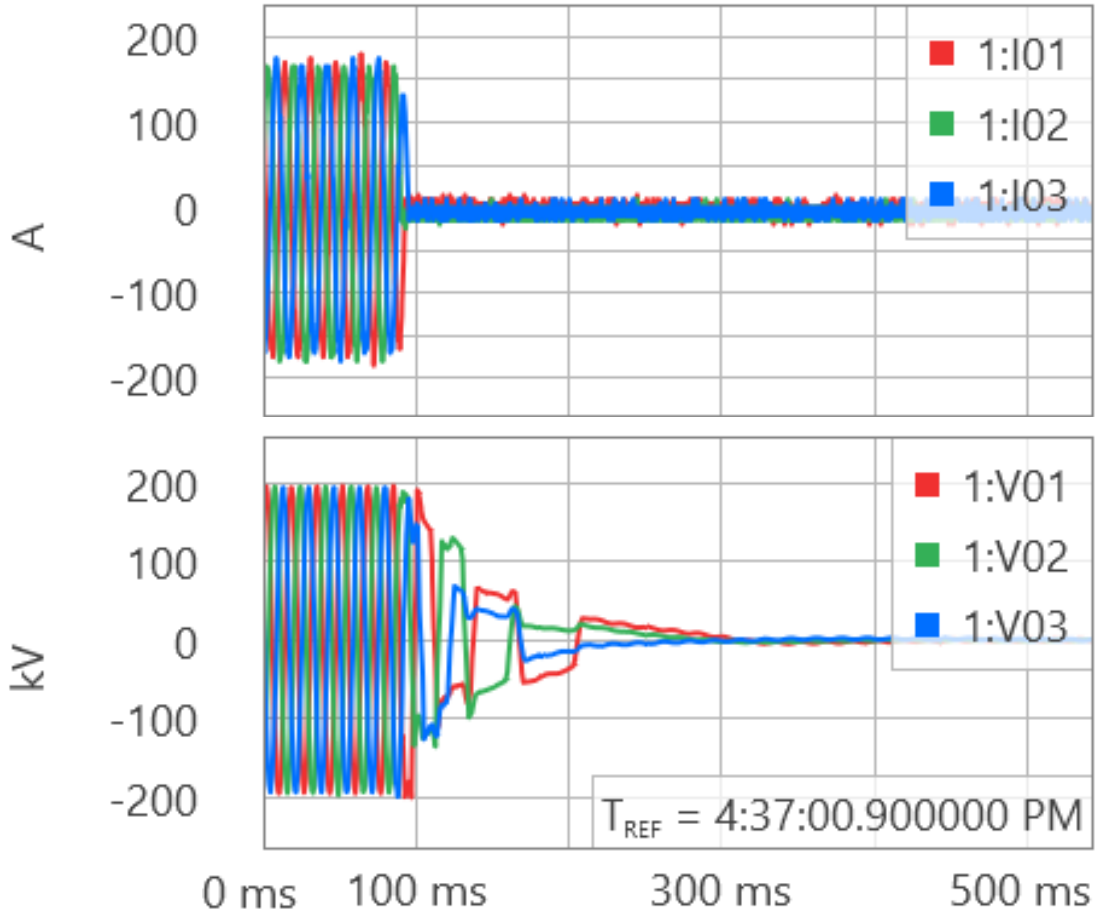
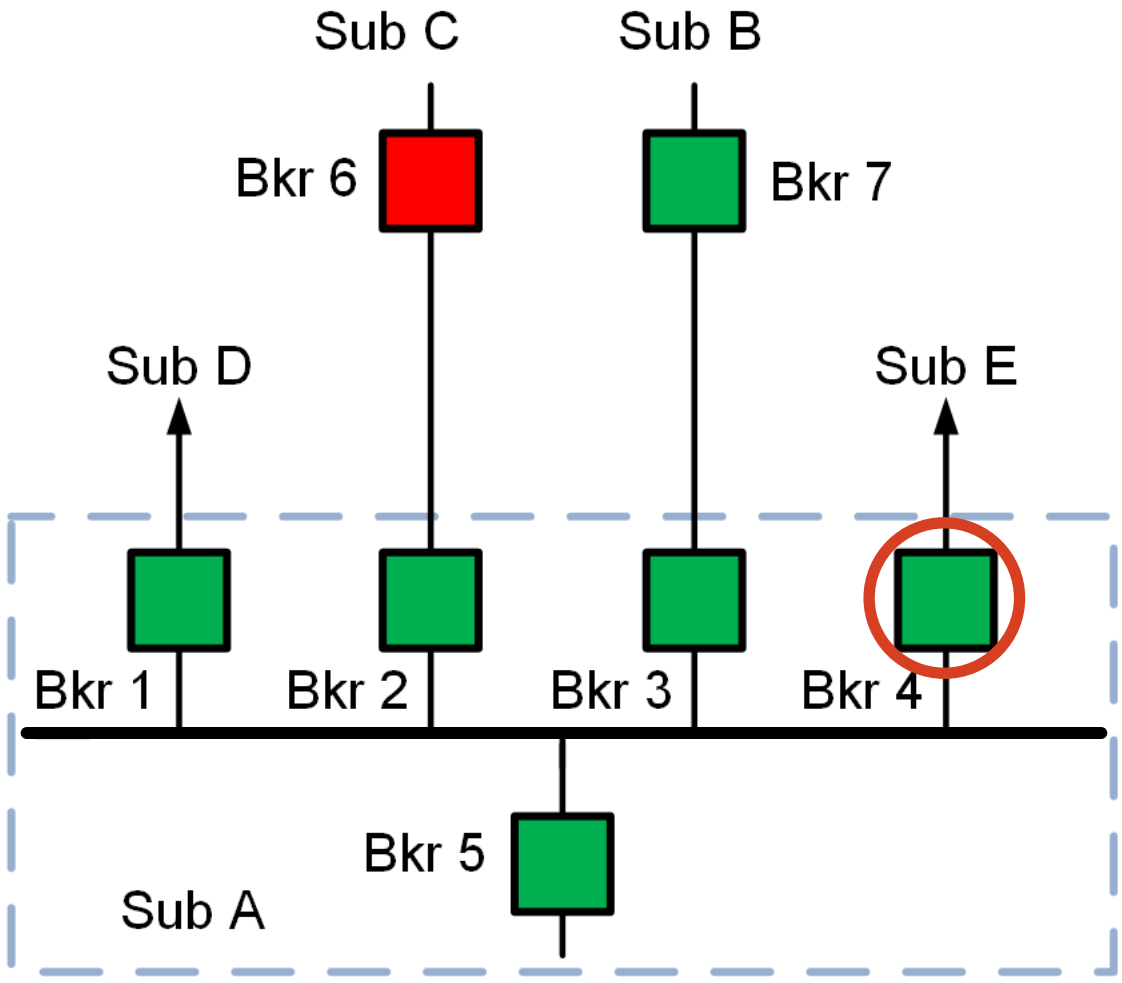
Percentage-restrained differential relay analysis





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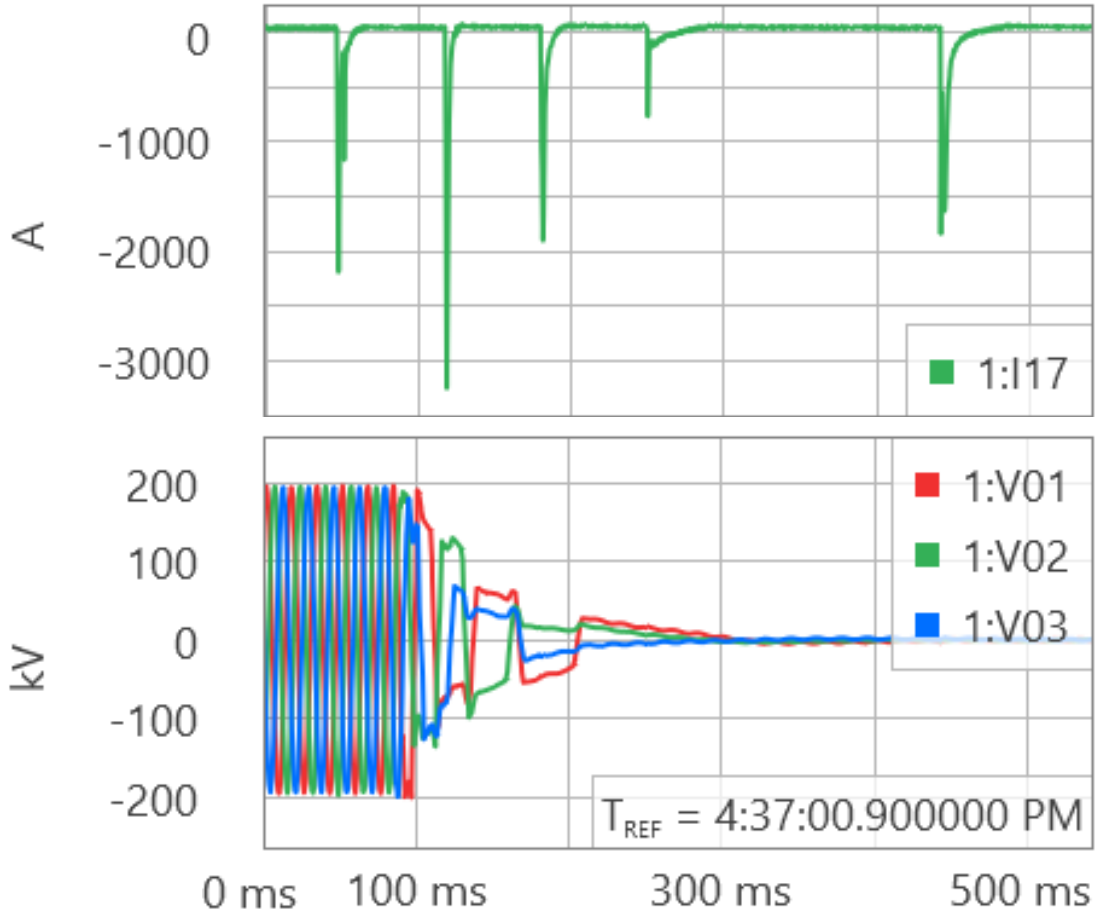
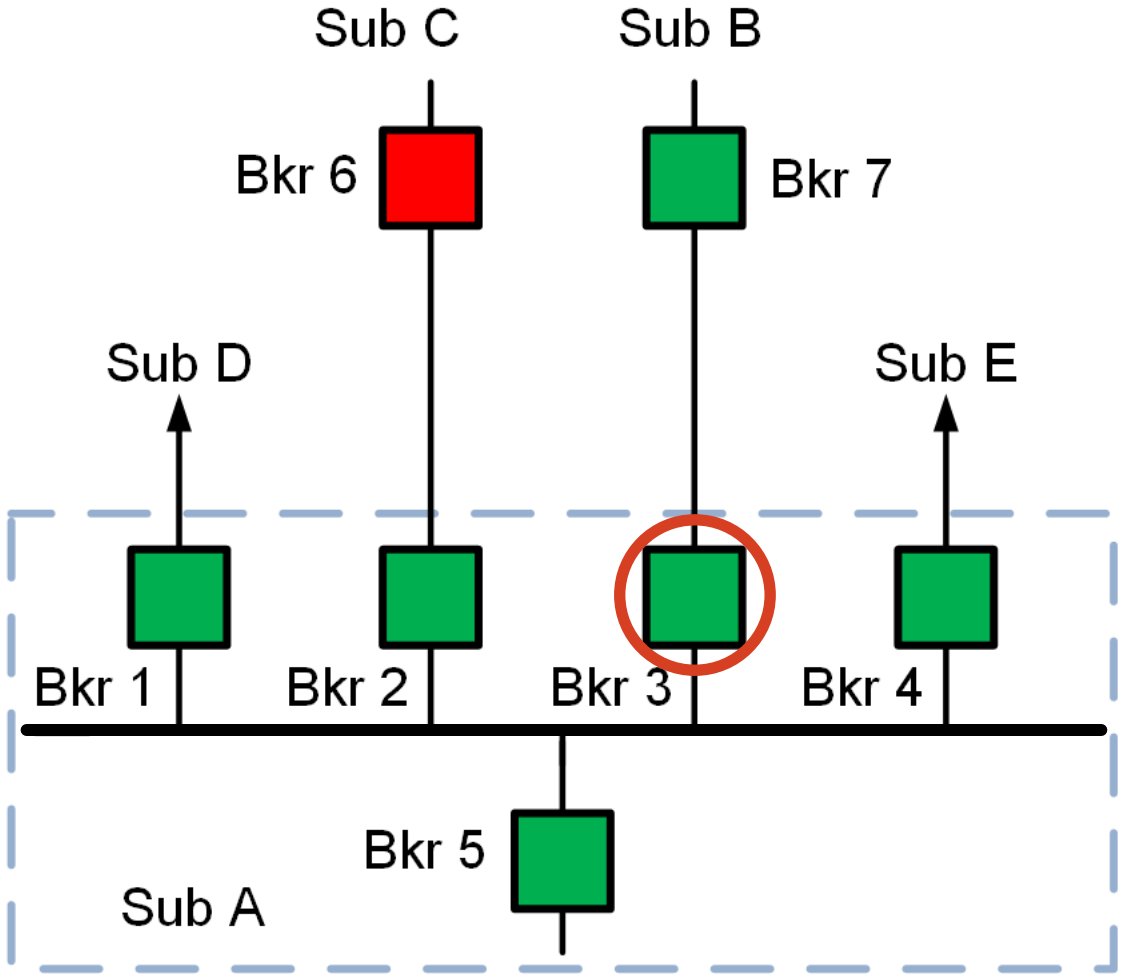
Percentage-restrained differential relay analysis – Bkr 3 currents





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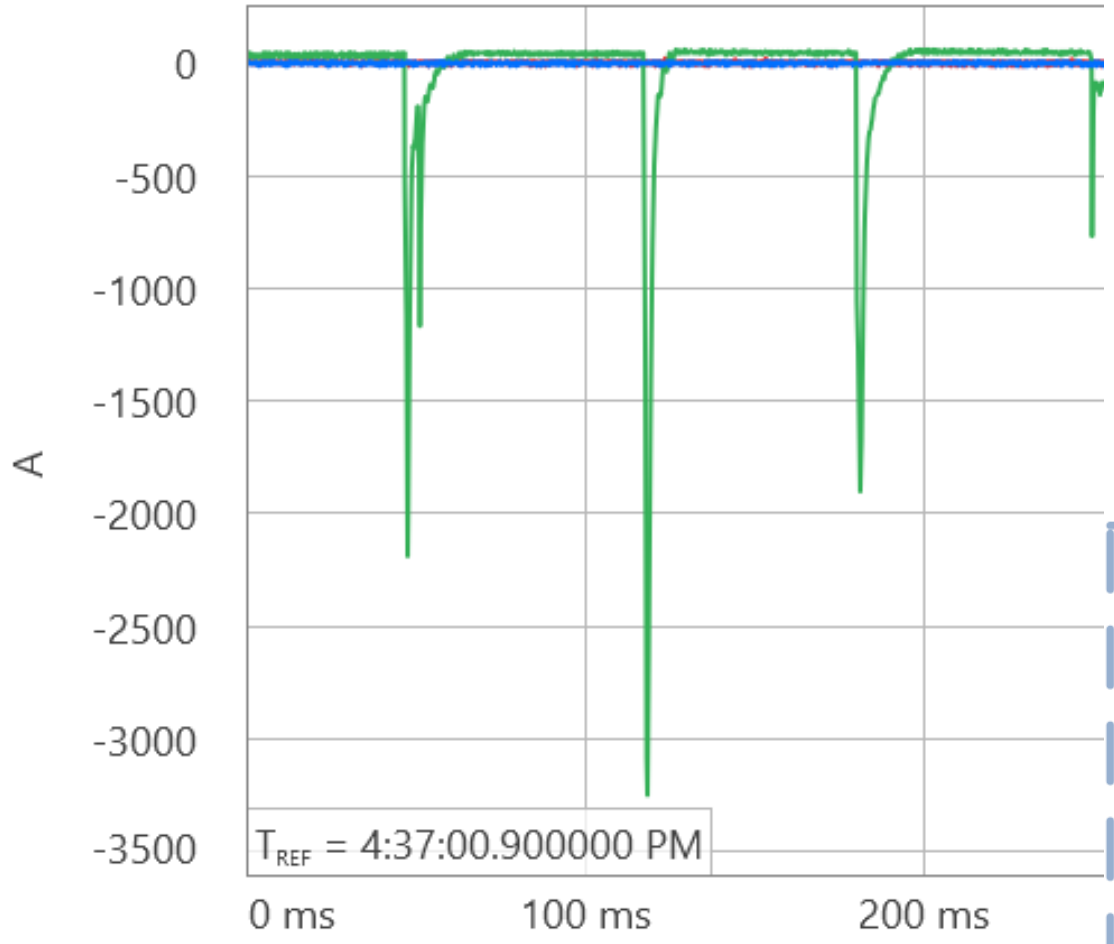
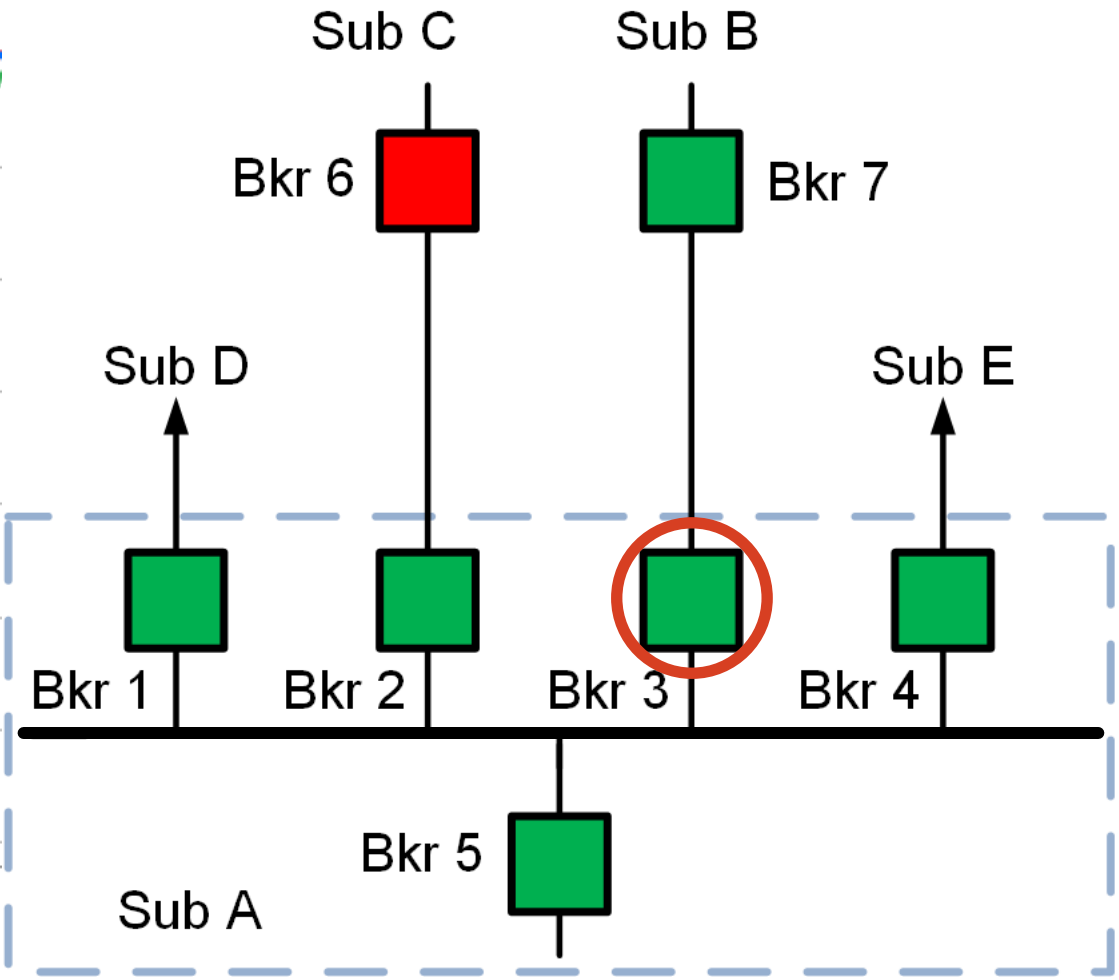
Is current flowing through open Bkr 3?





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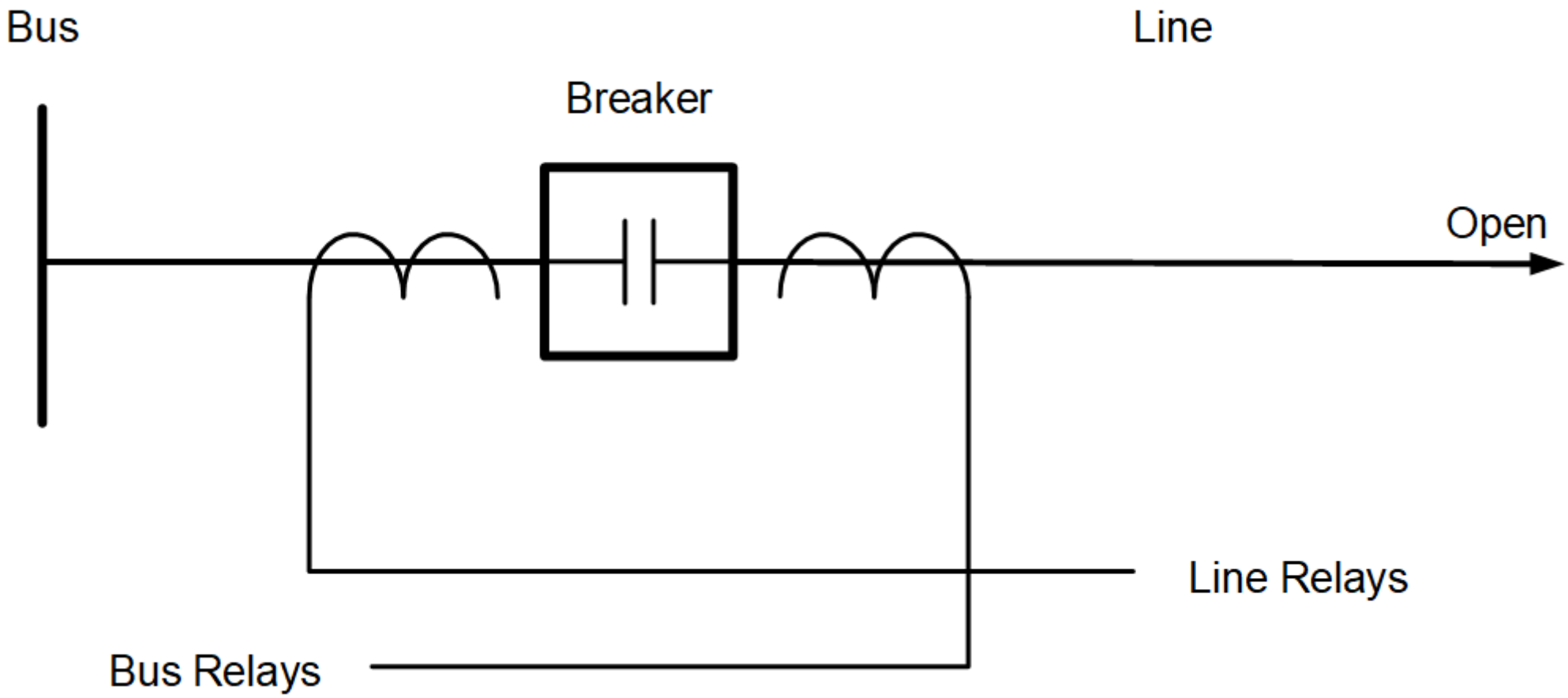

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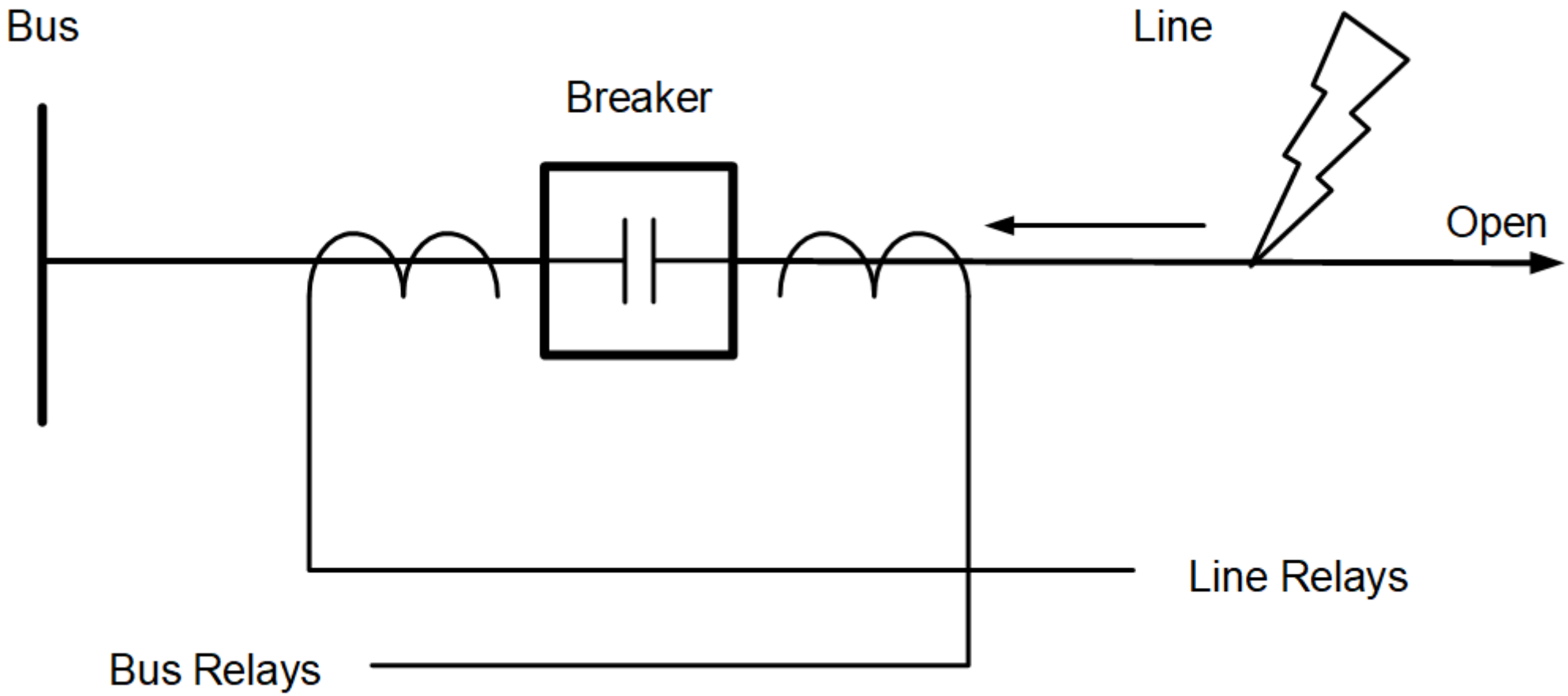

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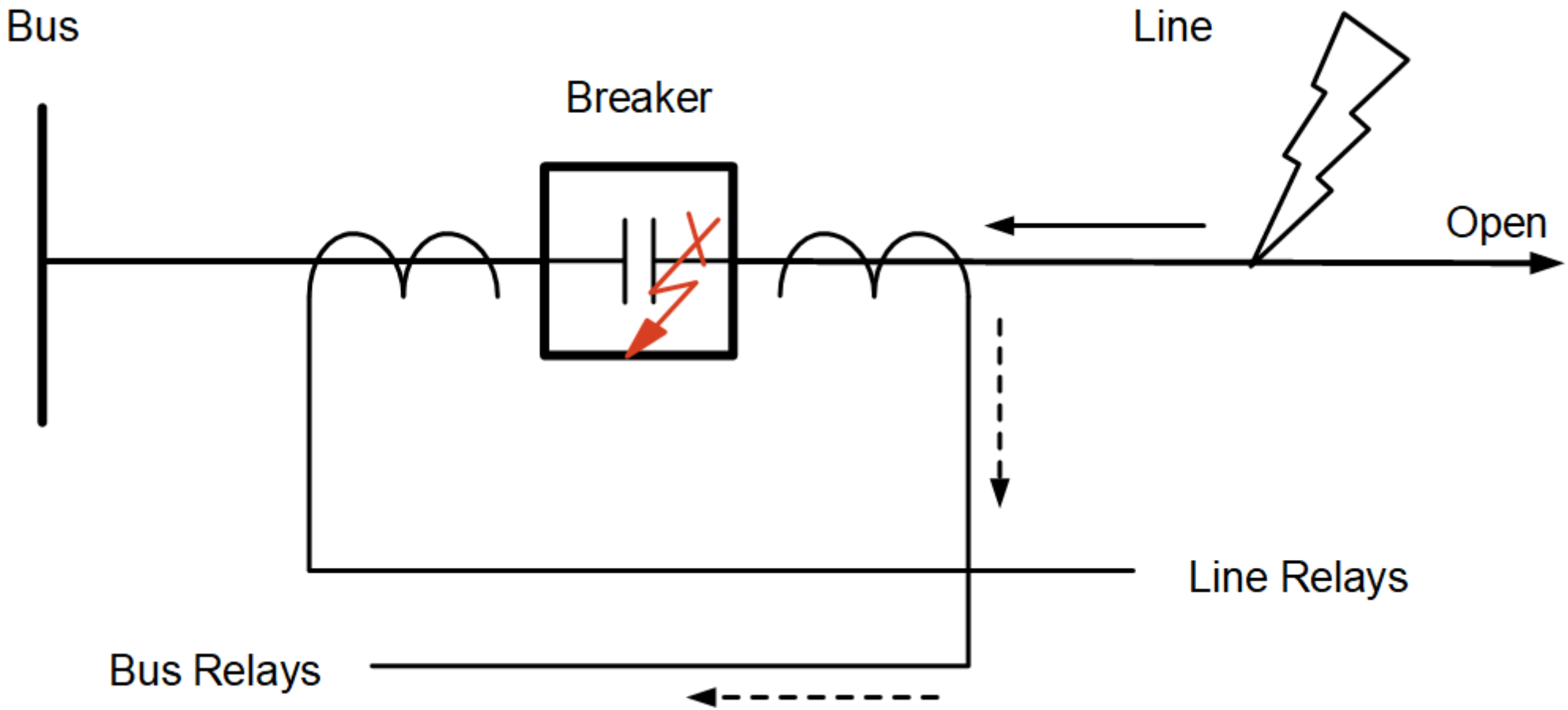
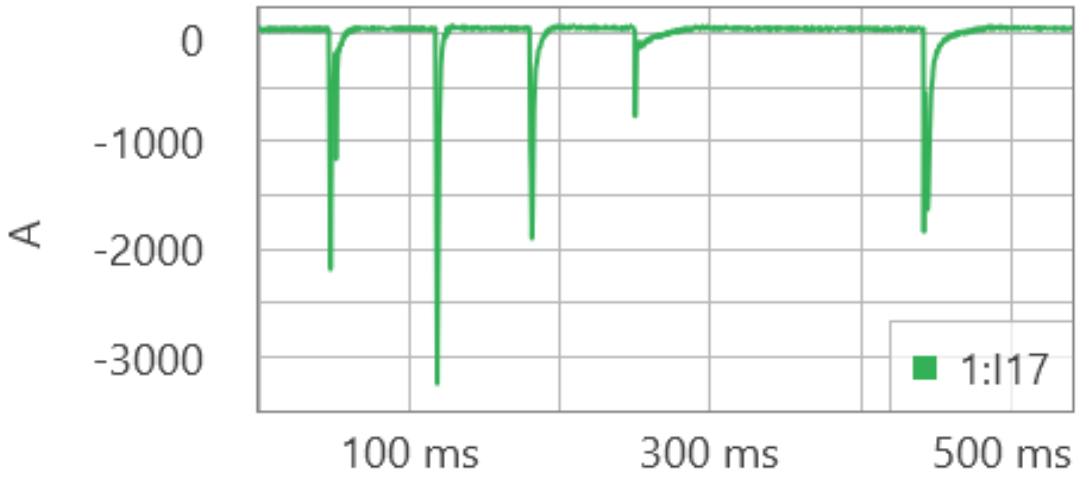


Lightning strike report

- Initial BG fault 16:37:00.5165
- 5 high-frequency current transients 16:37:00.946 to 16:37:01.400



Lightning strike time	Approximate distance from Sub A (mi)	Approximate distance from line (ft)	
16:37:00	0.625	NA	
16:37:00	0.606	341	1
16:37:00	0.890	156	2
16:37:00	0.890	65	3
16:37:00	0.890	40	4
16:37:00	1.004	0	5
16:37:00	0.871	176	6
16:37:00	0.871	NA	
16:37:01	0.890	252	7
16:37:01	0.890	77	8

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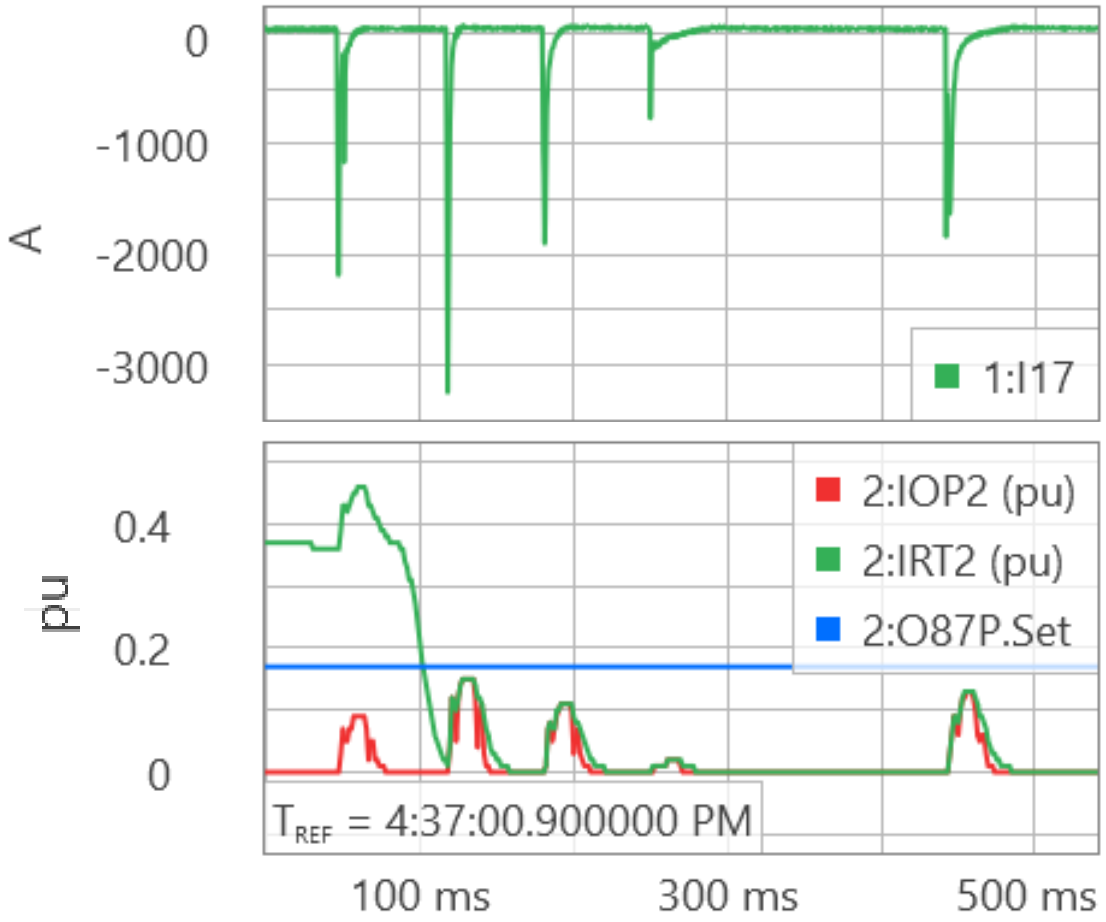
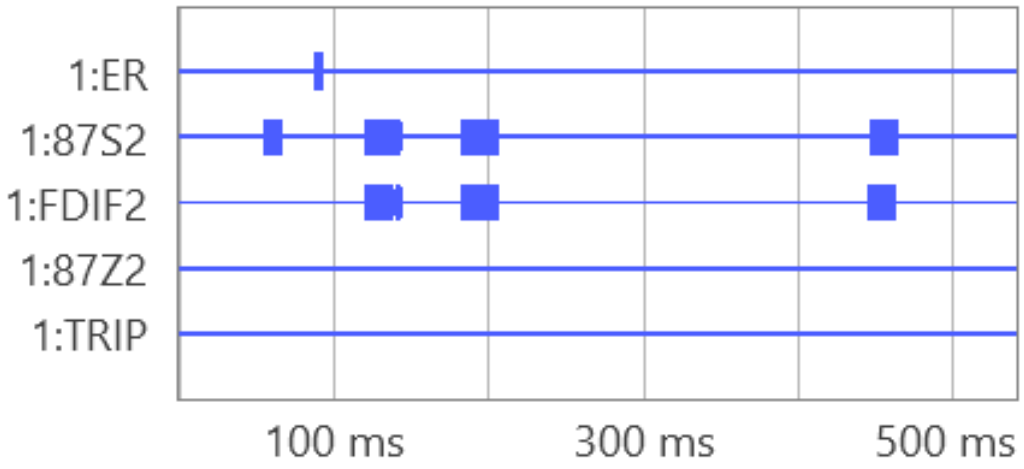
Percentage-restrained differential relay analysis





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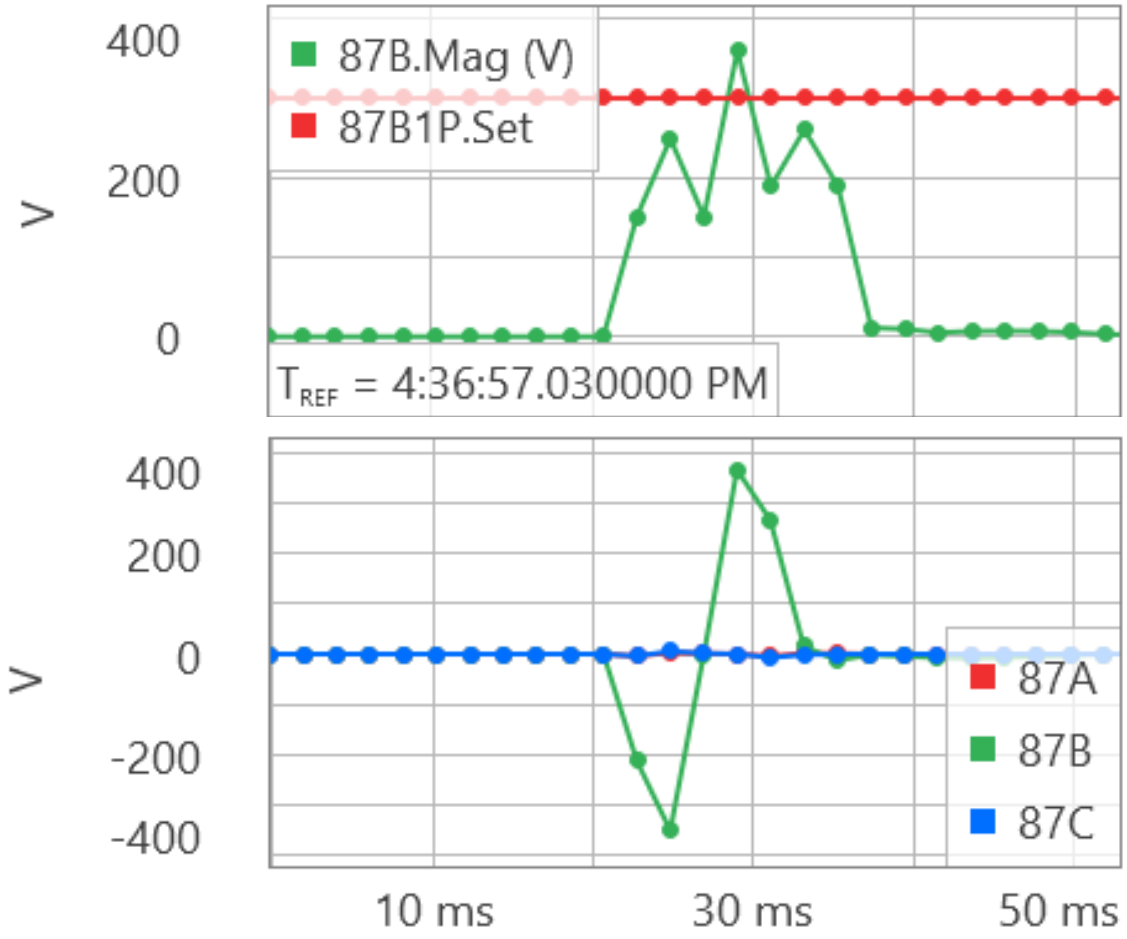
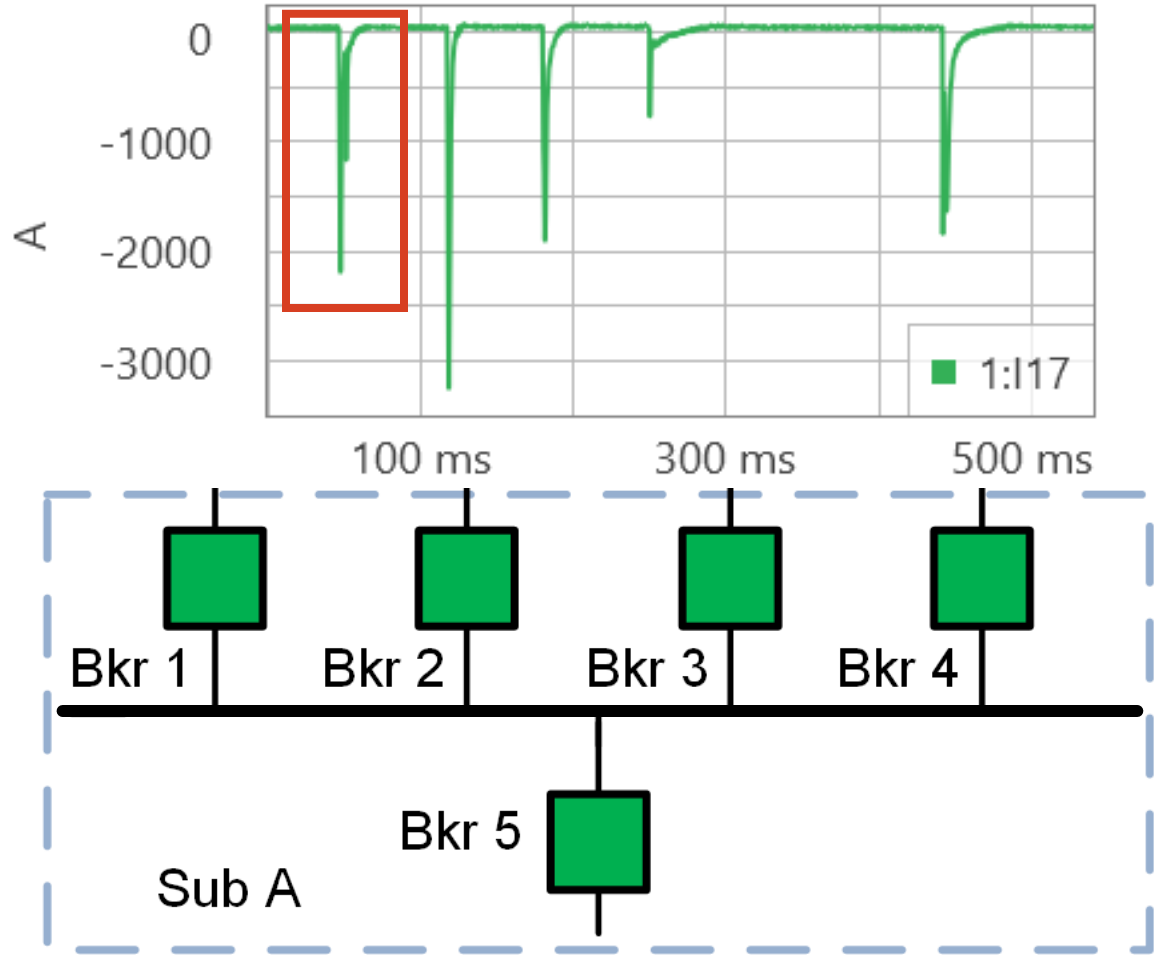
High-impedance bus differential relay trips Sub A bus





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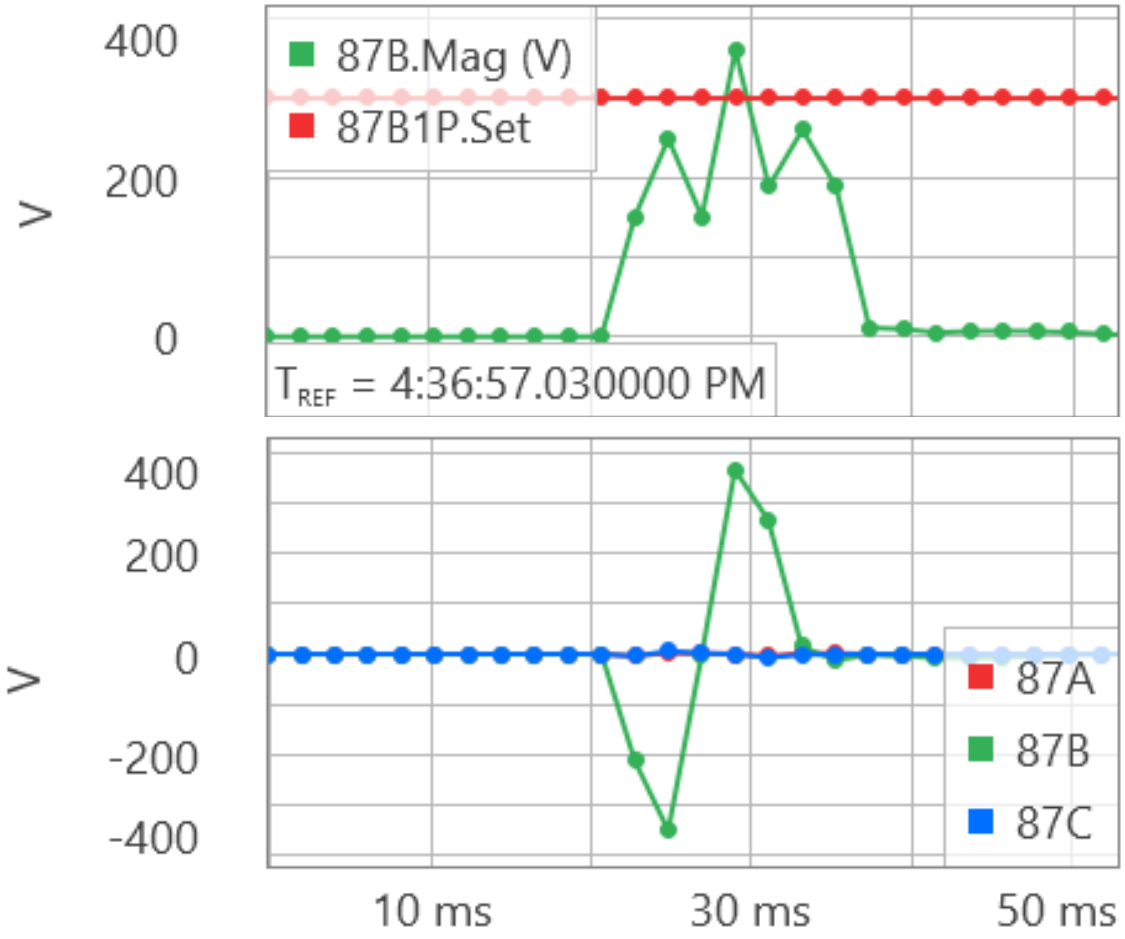
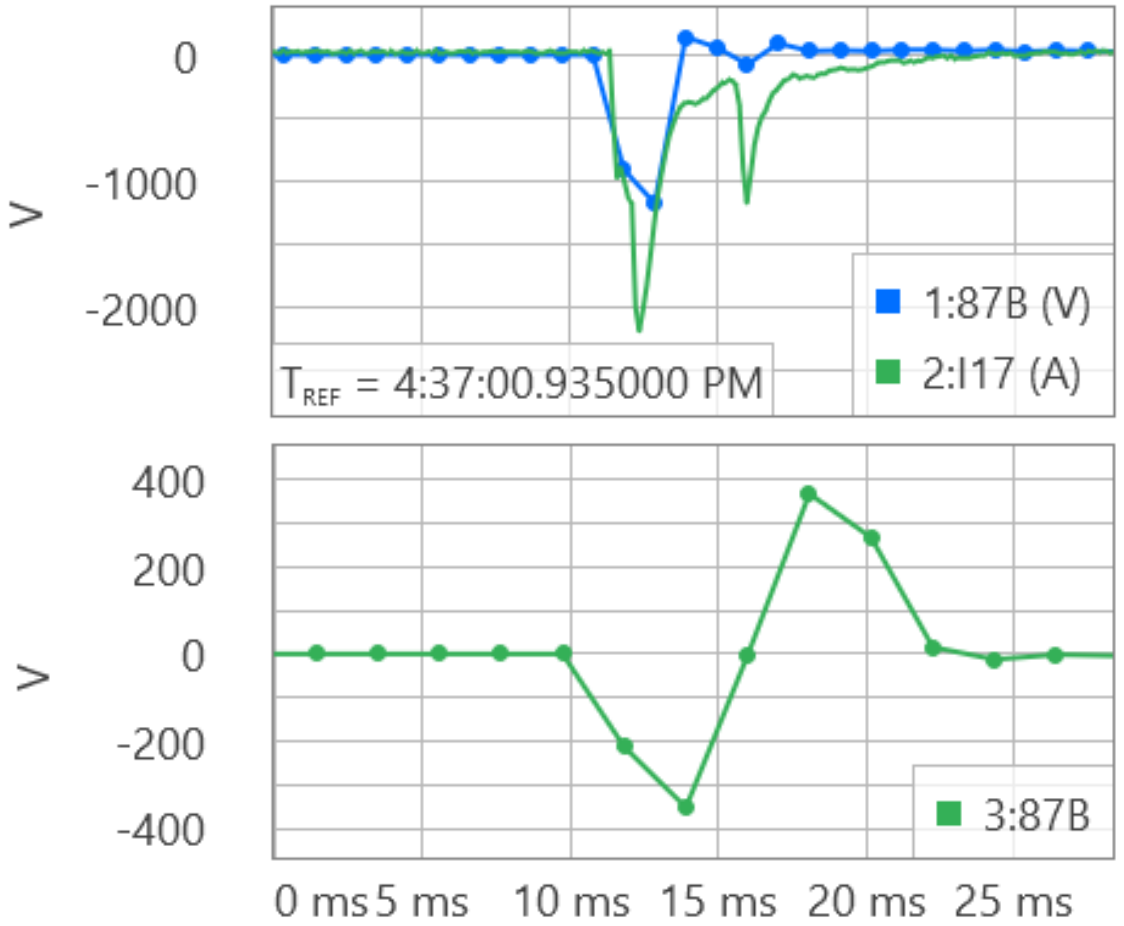
High-impedance bus differential relay trips Sub A bus





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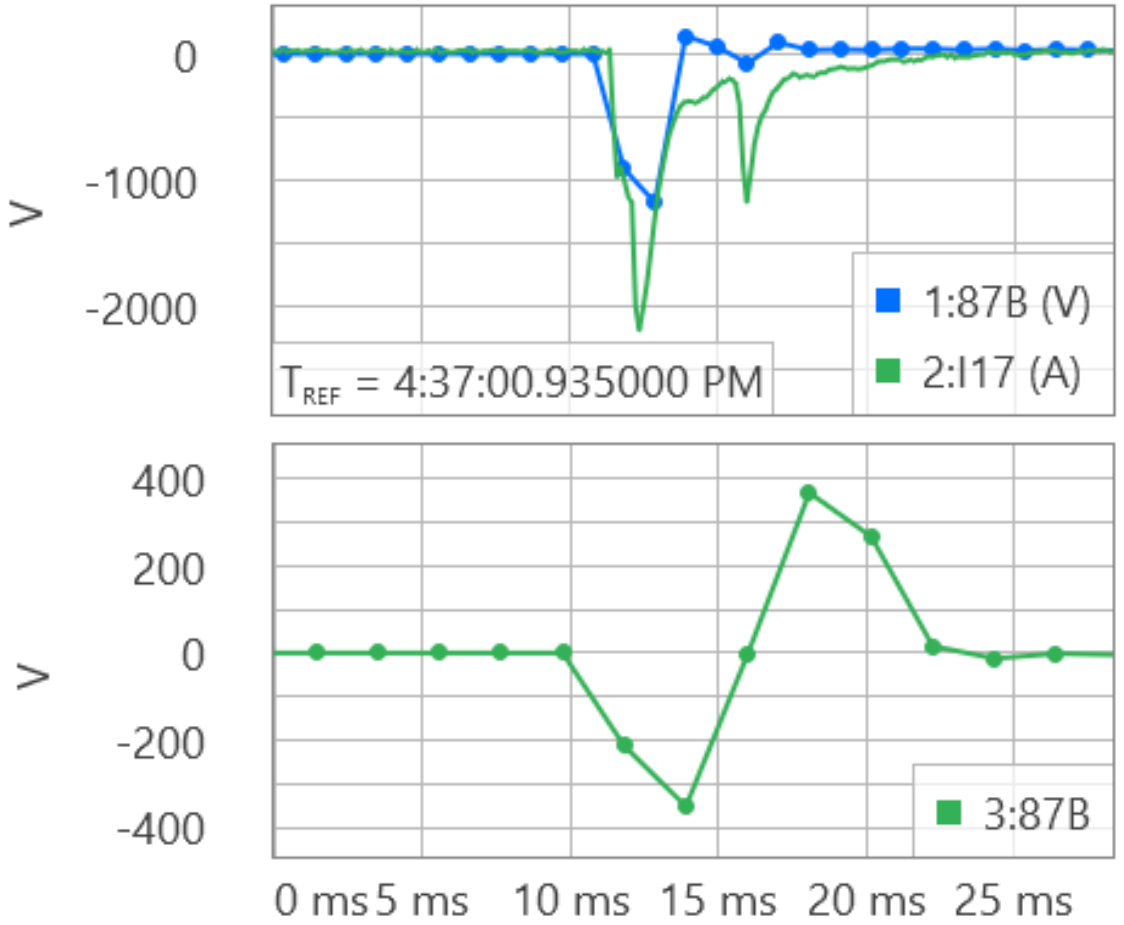
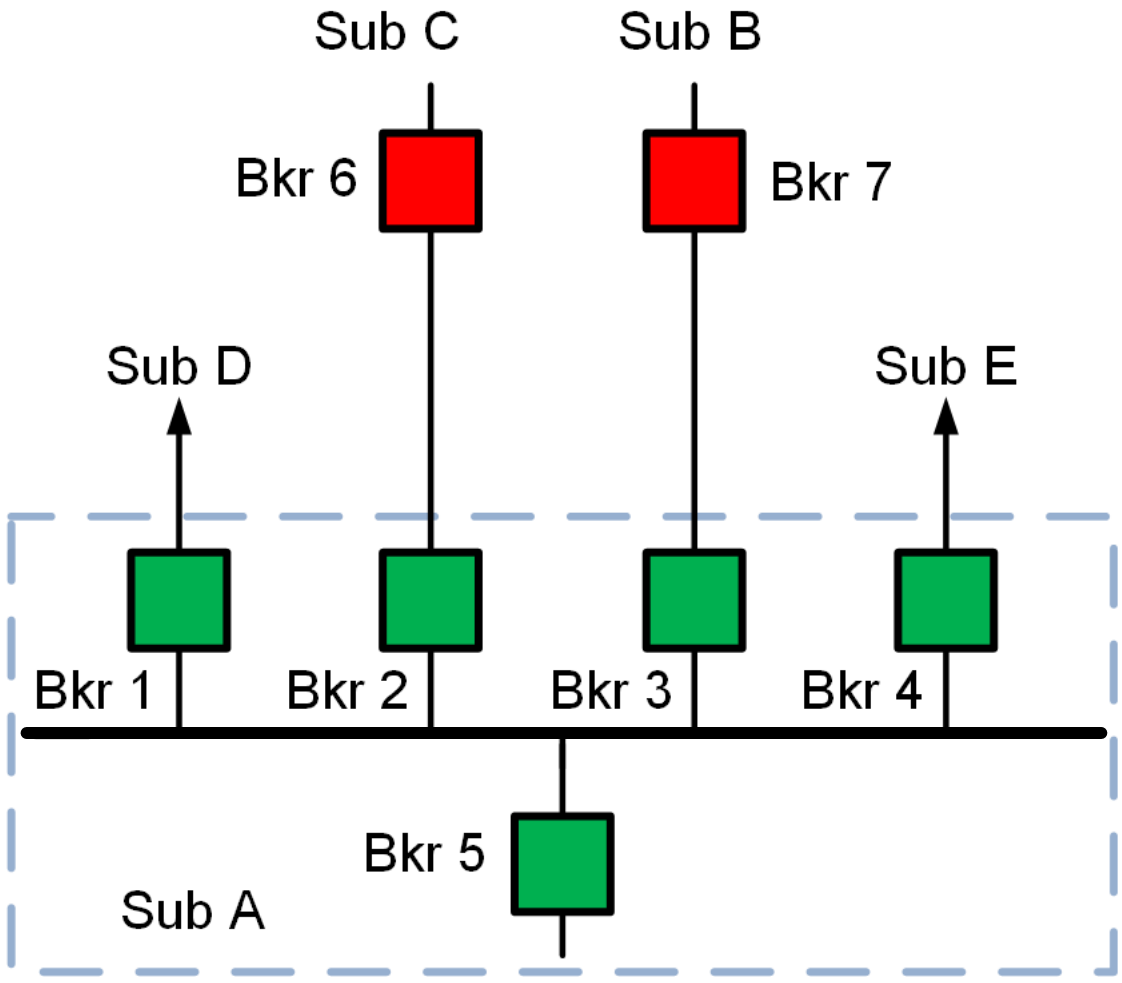
High-impedance bus differential relay trips Sub A bus

- Identify two unfiltered points
- Pass them through a half-cycle cosine filter at 16 samples per cycle (8 points), resulting in
  - 9 sample output at 16 samples per cycle
  - 5 sample output when downsampled to 8 samples per cycle

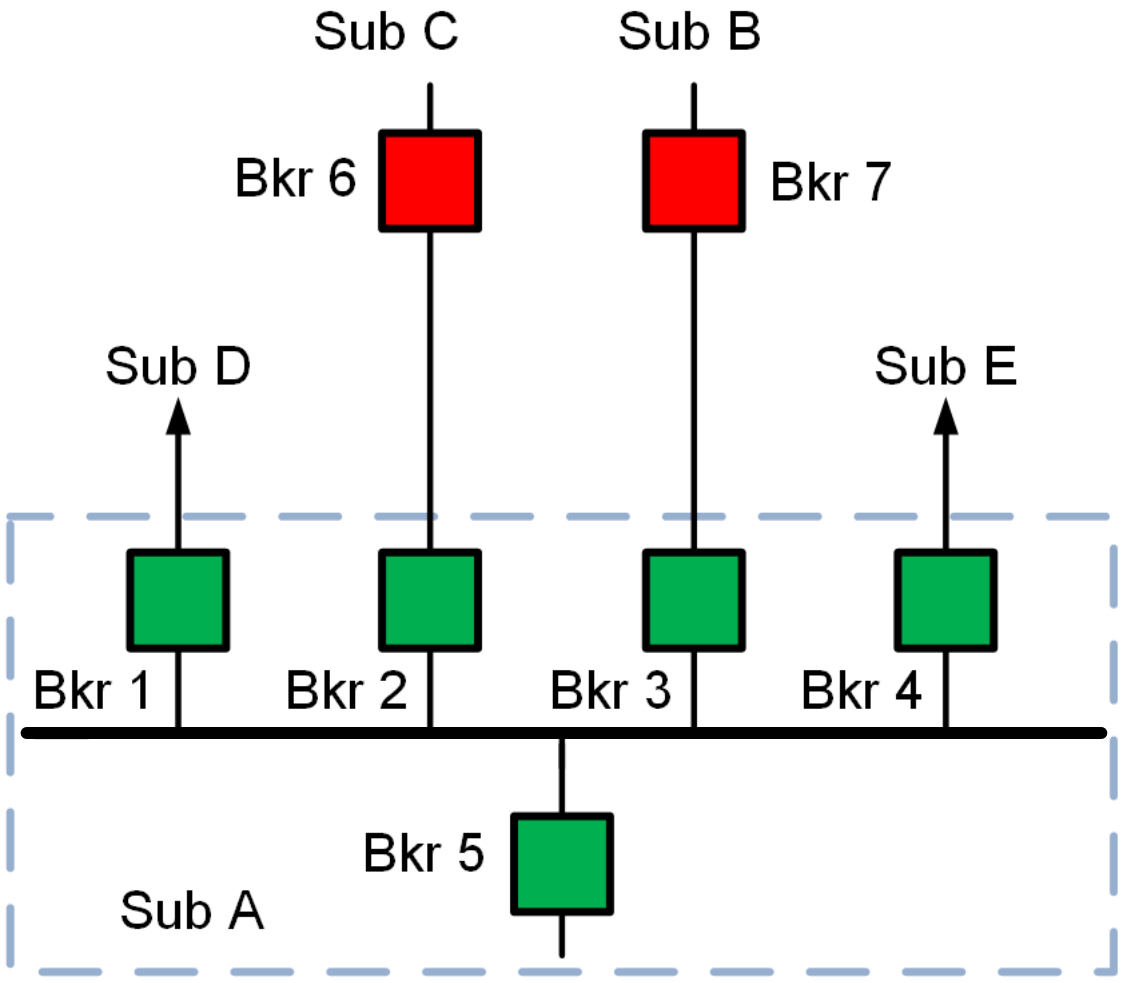


Sub B Bkr 7 recloses successfully

- 1 second after initial BG fault, Sub B Bkr 7 recloses
- Sub B supplies 42 A charging current
- Bkr 3 is able to withstand nominal voltage



Sub A tripped again by 87B2 relay



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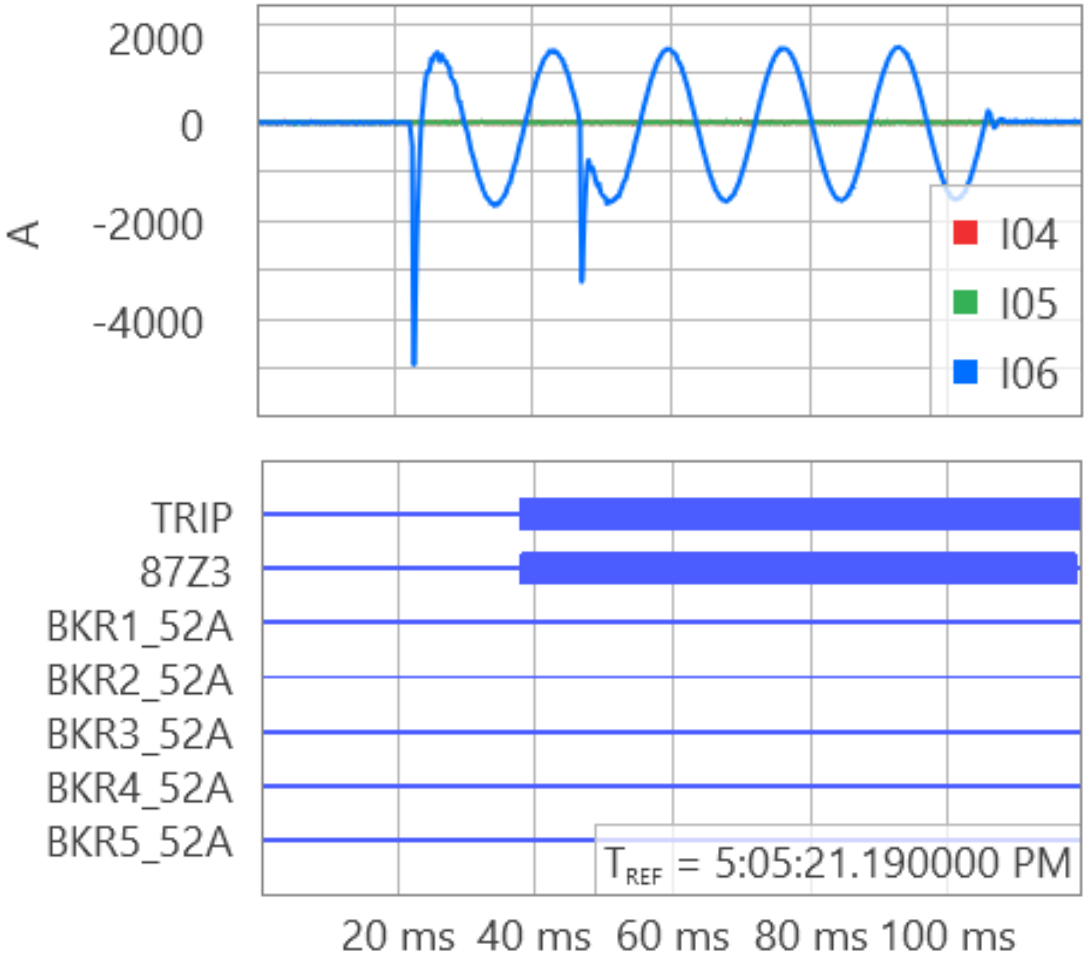
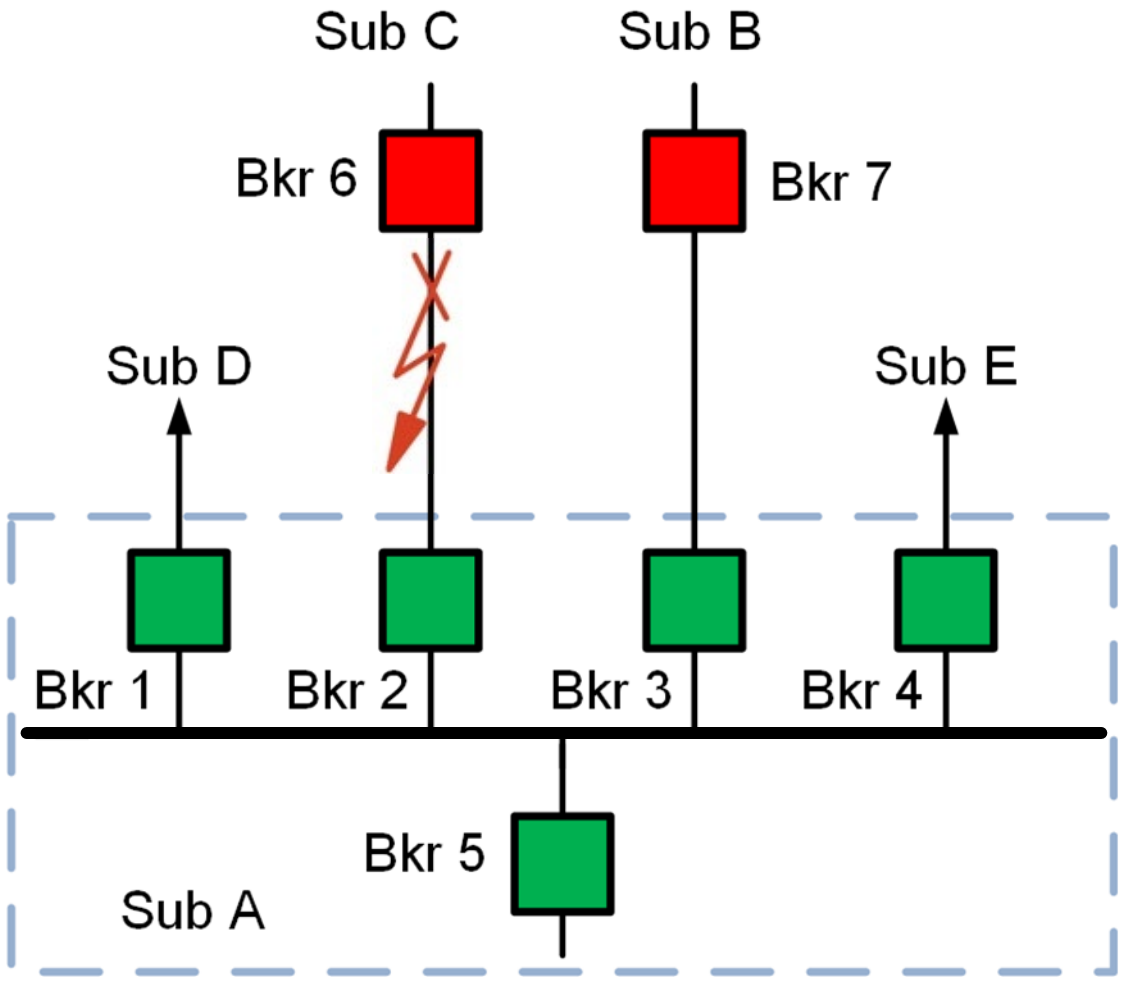
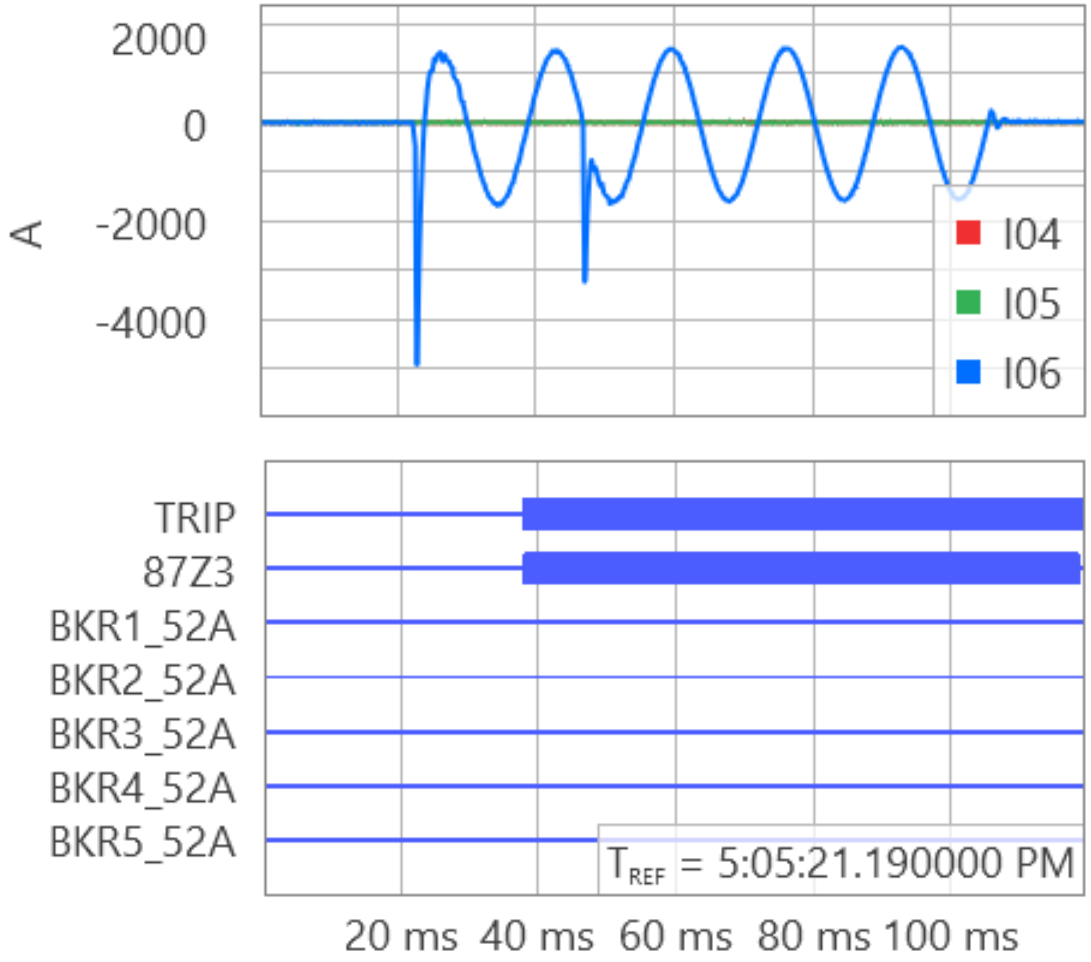
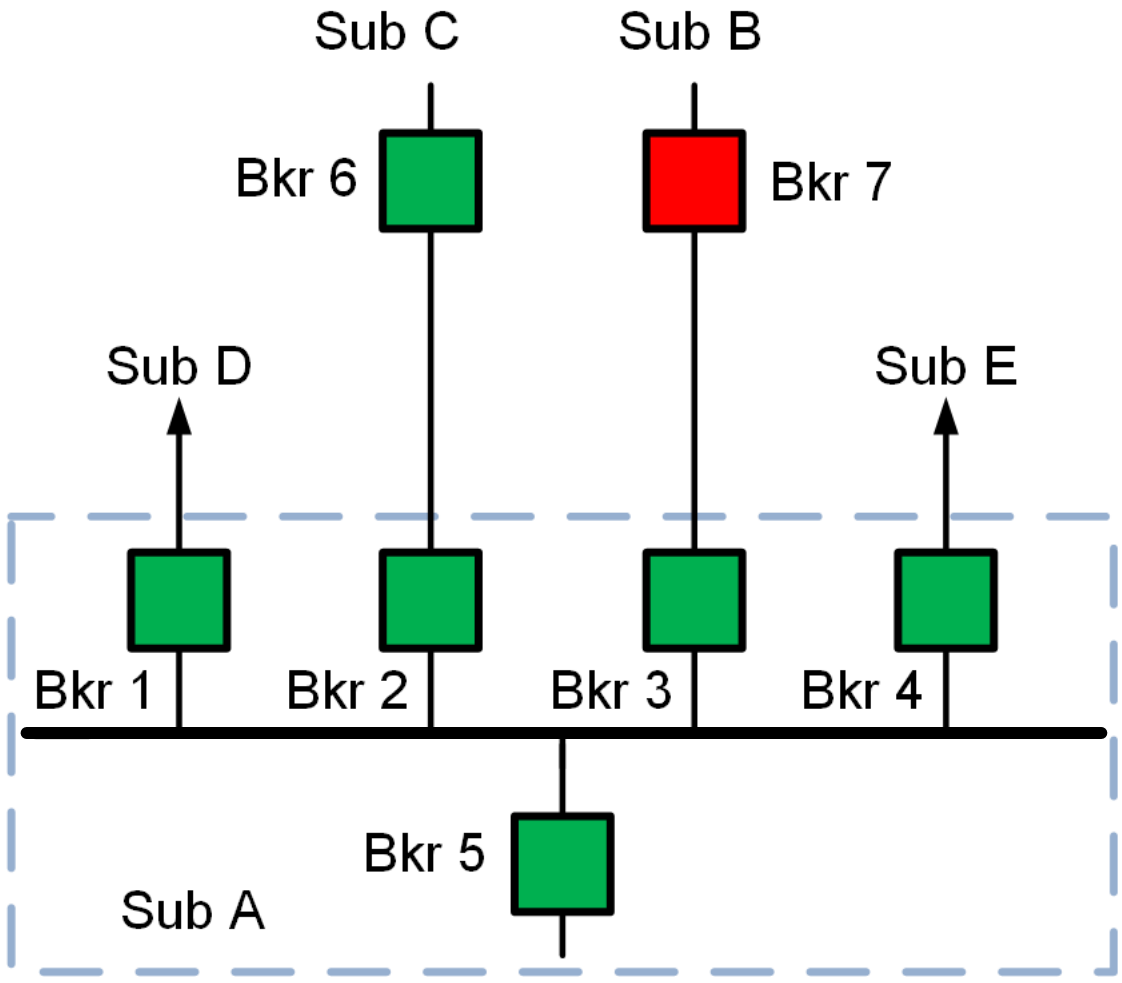
Percentage-restrained bus differential relay trip



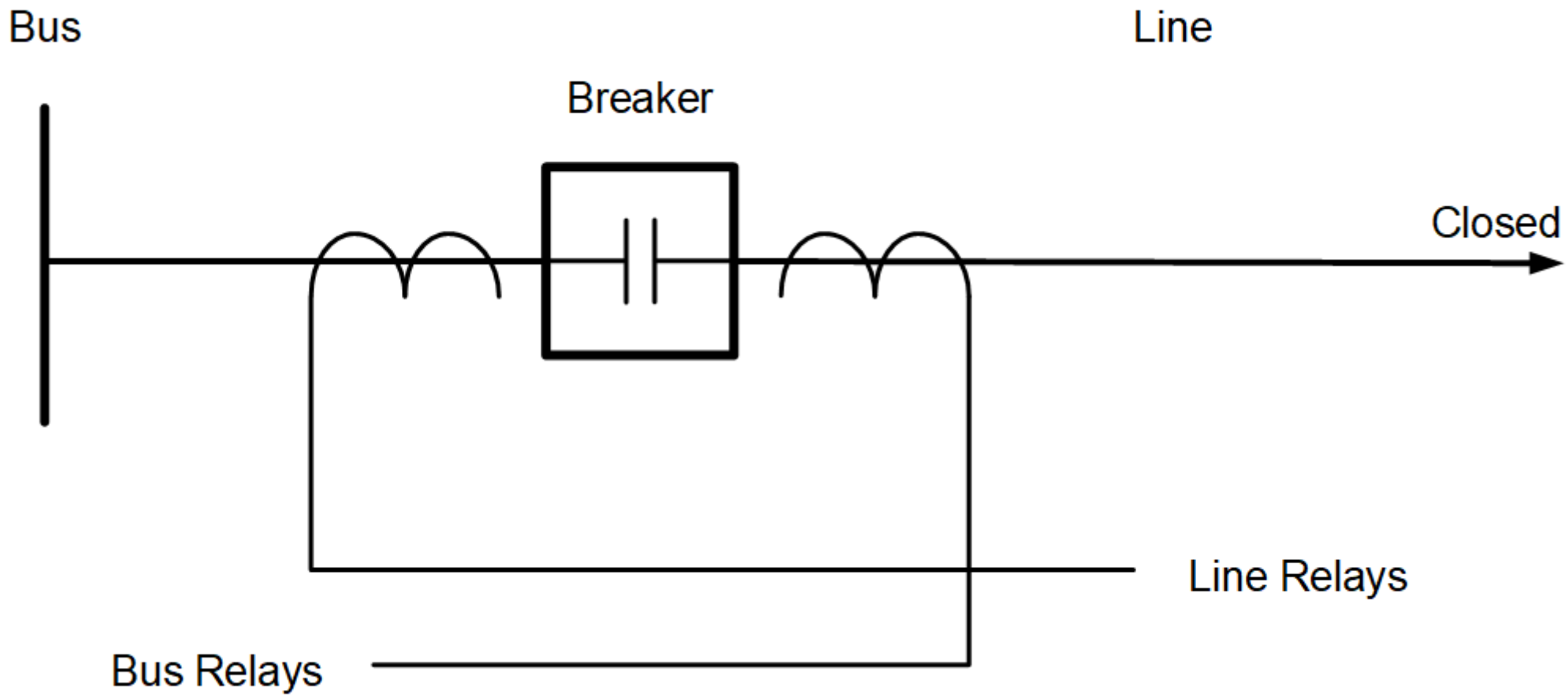


Percentage-restrained bus differential relay trip

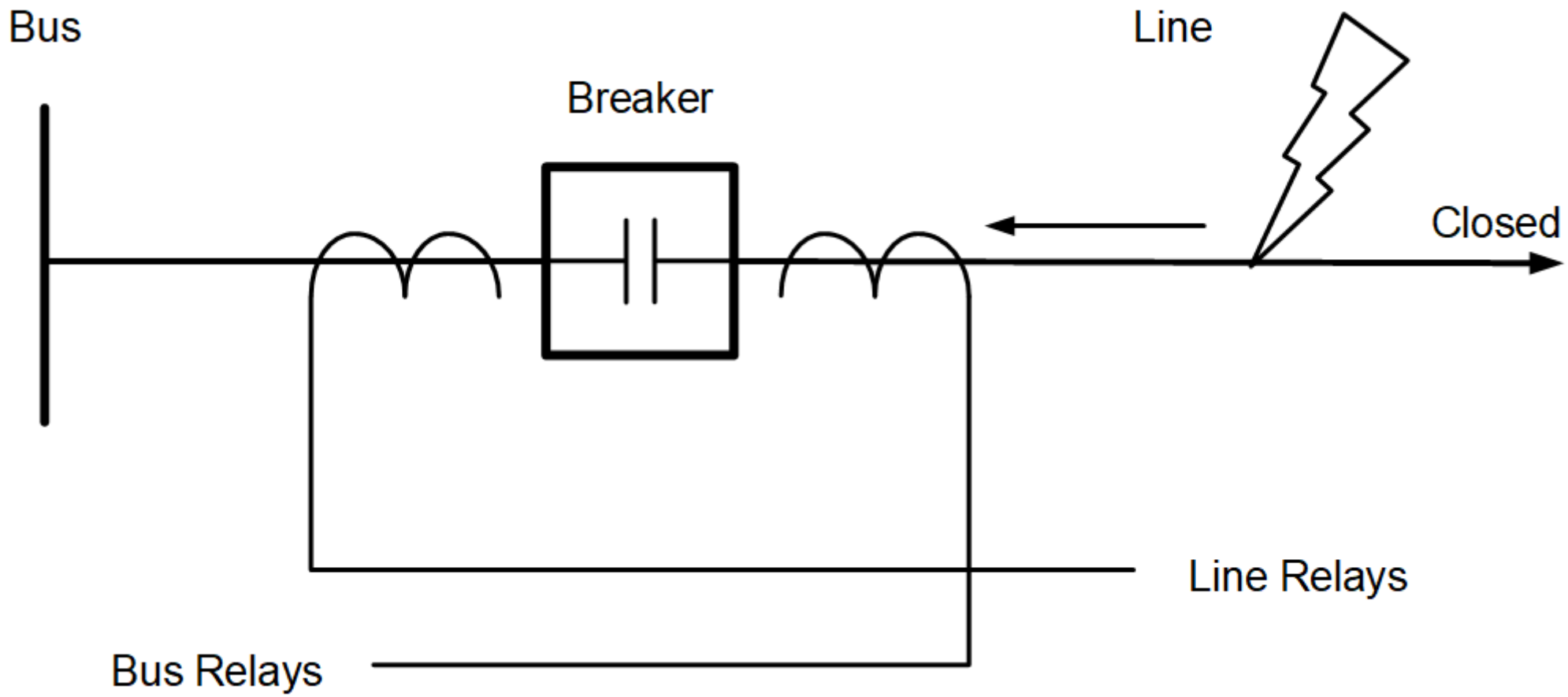




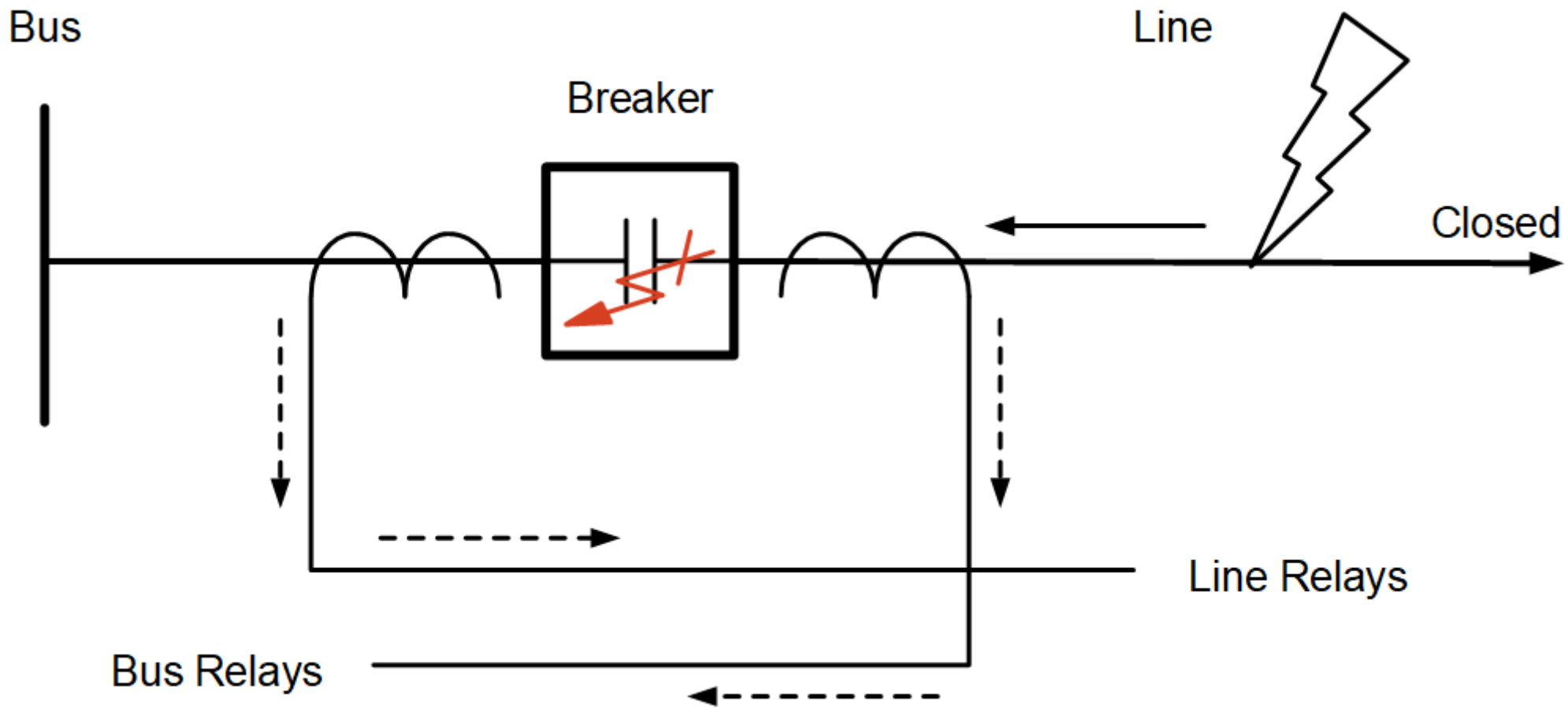
Is current flowing through open Bkr 2?



Is current flowing through open Bkr 2?



Is current flowing through open Bkr 2?



Lightning strike report

- First high-frequency current transient that initiated the fault was at 17:05:21.2128
- Second high-frequency current transient that occurred during fault was at 17:05:21.2371

Lightning strike time	Approximate distance from Sub A (mi)	Approximate distance from line (ft)
17:05:21	3.84	417
17:05:21	3.84	103
17:05:22	NA	NA

Event analysis conclusions

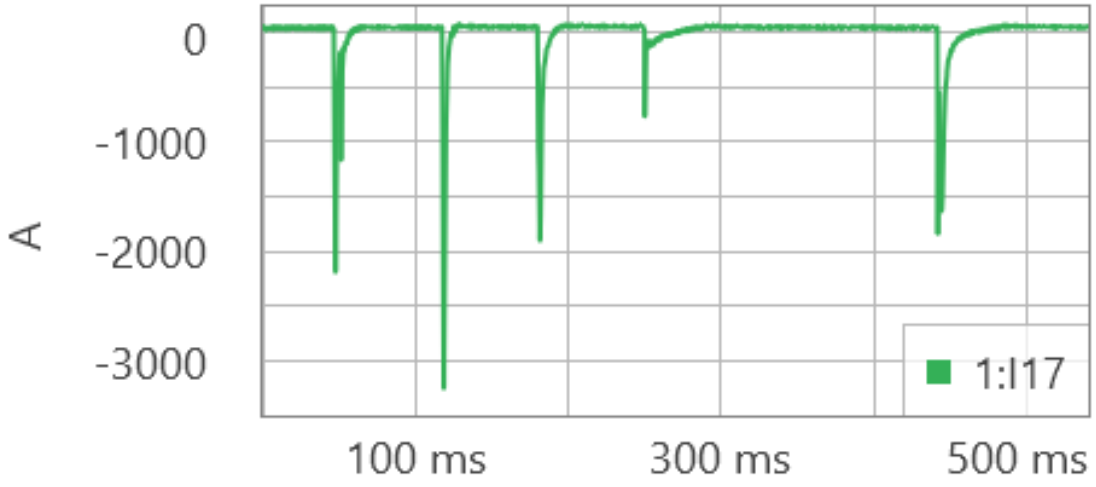
Three separate faults and relay responses

- Initial Sub A–Sub B line BG fault occurred
- Bkr 3 internal flashover (caused Sub A bus to be cleared)
- Bkr 2 internal flashover (fault occurred)

Breaker inspection results

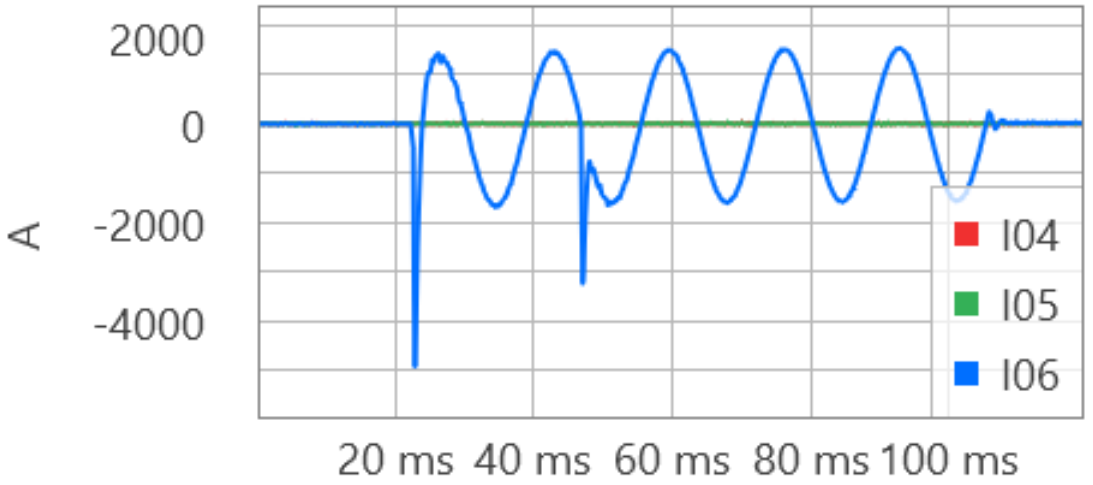
Bkr 3

- Gas sample was normal
- No damage was visible



Bkr 2

- Gas sample indicated problem
- Arcing marks were visible
- Breaker sustained 1,062 A rms fault current



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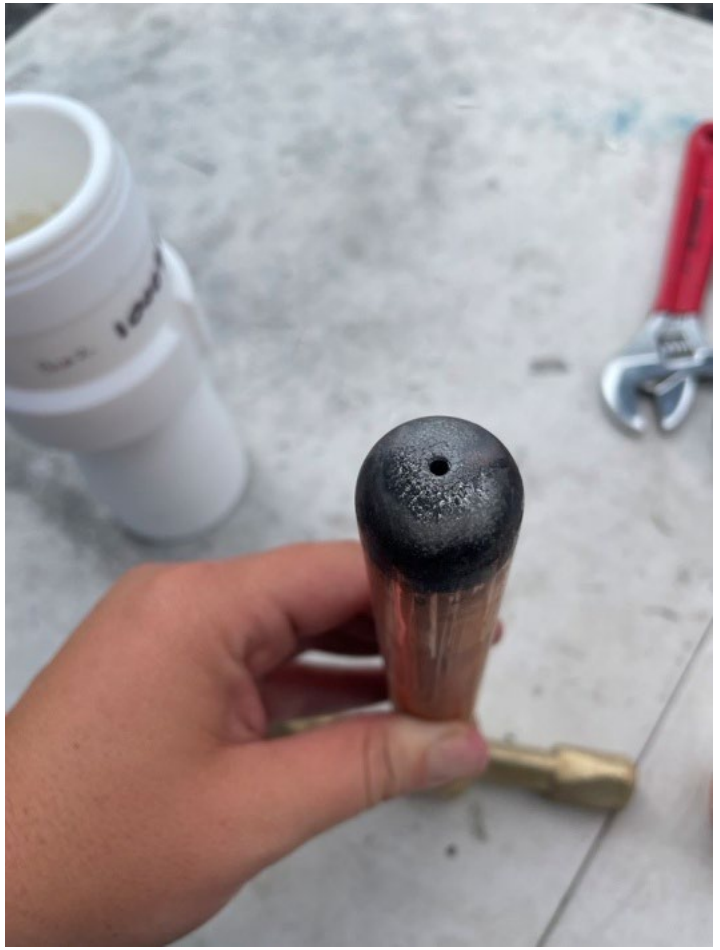
Bkr 2 damage



Lessons learned

- Preventative actions
  - Add shield wires
  - Add surge arrestors at 230 kV level
- Benefit of multiple operating principles
- Depth of event analysis
  - Low- and high-resolution relay event reports
  - Lightning strike reports

Questions?