

An aerial night view of a city skyline, likely New York City, featuring prominent skyscrapers like the Empire State Building. The image is overlaid with a white geometric network of lines and glowing nodes, suggesting a digital or interconnected theme.

# Tools and Strategies for Reliability Improvement

Brian Bertini, Mikaela Mohaupt, Ryan Rausch

May 15, 2024



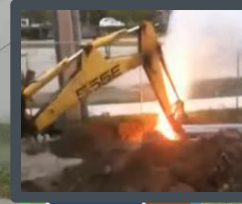
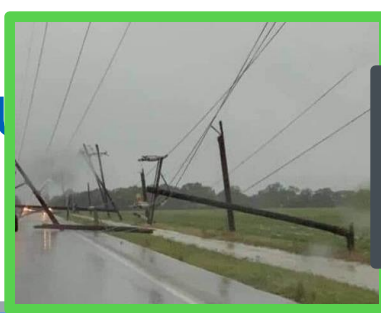
Powering Business Worldwide

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# Causes of Electric Failure

- EPRI study found that:

- 1% Snow & ice
- 3% Vehicle
- 4% Dig-ins
- 6% Wind
- 8% Animals
- 13% Equipment Failure
- 19% Lightning
- 19% Trees
- 27% Unknown



# Reliability definitions

SAIDI = System Average Interruption Duration Index

$$\text{SAIDI} = \frac{\sum U_i N_i}{N_T}$$

where  $N_i$  is the number of customers and  $U_i$  is the annual outage time for location  $i$ ,  
and  $N_T$  is the total number of customers served.

$$\text{SAIDI} = \frac{\text{sum of all customer interruption durations}}{\text{total number of customers served}}$$

# Reliability definitions

SAIFI = System Average Interruption Frequency Index

$$\text{SAIFI} = \frac{\sum \lambda_i N_i}{\sum N_i}$$

where  $\lambda_i$  is the failure rate and  $N_i$  is the number of customers for location  $i$ .

$$\text{SAIFI} = \frac{\text{total number of customer interruptions}}{\text{total number of customers served}}$$

IEEE 1366    sustained interruption > 5 minutes

Some utilities or public utility commissions  
sustained interruption > 1 or 2 minutes



## Improve SAIFI

- Reduce the number of interruptions with proactive maintenance and system hardening
- Reduce the number interruptions by turning sustained outages into momentary outages

## Improve SAIDI

- Reduce the number of interruptions
- Locate the fault faster and restore power to customers sooner

# **Reclosers**

# **Brian Bertini**

# What is a Recloser?

- Fast trip operation **clears temporary faults** before they become permanent faults
- Faults that would have been permanent with a fuse become **temporary** with a **recloser**

## Recloser

- Self-controlled device
- Automatically interrupts & recloses AC circuits
- Predetermined sequence of actions including
  - **Opening, Reclosing, Resetting, Holding closed, Locking out**



# Market trends affecting reclosers

- **Smart grid trends**

- **Distributed energy resources**

- Bi-directional power flow
    - Advanced protection schemes
    - Micro-grids

- **System automation**

- Volt/VAR optimization
    - More metering points

- **Grid modernization**

- System reliability
    - Reliable, maintenance-free solutions








- **Effects on utilities**

- Increased complexity
  - Higher system reliability
  - Resilience of distribution grids
  - Tightening O&M budgets
  - Staffing, expertise, and training constraints
  - Better grid efficiency
  - Better operating efficiency
  - Longer equipment lead-times
  - Increased material costs



# Three-Phase Reclosers

	<p><b>W/WV Family</b></p> <ul style="list-style-type: none"> <li>• Self-contained, oil-insulated three-phase recloser</li> <li>• Oil-interrupting (W) or vacuum-interrupting (VW)</li> <li>• Hydraulically or electronically controlled (WE/VWE)</li> </ul>	<p><b>Ratings</b></p> <ul style="list-style-type: none"> <li>• 15kV, 27kV, 38kV</li> <li>• 560A cont.</li> <li>• 8kA or 12kA interrupt</li> </ul>
	<p><b>Three-Phase NOVA</b></p> <ul style="list-style-type: none"> <li>• Solid insulation 3 phase recloser</li> <li>• Mechanical gang operated phases</li> <li>• Vacuum interrupters fully encapsulated</li> <li>• Magnetic actuators</li> </ul>	<p><b>Ratings</b></p> <ul style="list-style-type: none"> <li>• 15kV, 27kV, 38kV</li> <li>• 630A/800Acont.</li> <li>• 12.5kA or 16kA interrupt</li> </ul>
	<p><b>Triple-Single (TS) NOVA</b></p> <ul style="list-style-type: none"> <li>• NOVA Three-Tank, Triple-Single Recloser</li> <li>• Offers additional overcurrent protection flexibility with single or three-phase trip modes</li> </ul>	<p><b>Ratings</b></p> <ul style="list-style-type: none"> <li>• 15kV, 27kV, 38kV</li> <li>• 400A/630A/800A cont.</li> <li>• 8kA, 12.5kA or 16kA interrupt</li> </ul>
	<p><b>Single-Triple-Single (STS) NOVA</b></p> <ul style="list-style-type: none"> <li>• Triple-single functionality in a single-tank design</li> <li>• Mechanisms are independent</li> <li>• Less cabling and no junction box</li> </ul>	<p><b>Ratings</b></p> <ul style="list-style-type: none"> <li>• 15kV, 27kV, 38kV</li> <li>• 630A/800Acont.</li> <li>• 12.5kA or 16kA interrupt</li> </ul>
	<p><b>NOVA NX-T &amp; NX-STS</b></p> <ul style="list-style-type: none"> <li>• Next generation NOVA</li> <li>• Replaces TS and STS</li> <li>• Numerous enhancements</li> </ul>	<p><b>Ratings</b></p> <ul style="list-style-type: none"> <li>• 15kV, 27kV, 38kV</li> <li>• 630A/800Acont.</li> <li>• 12.5kA or 16kA interrupt</li> </ul>

# NOVA NX Platform



**NOVA NX-ST3**



**NOVA NX-T3**

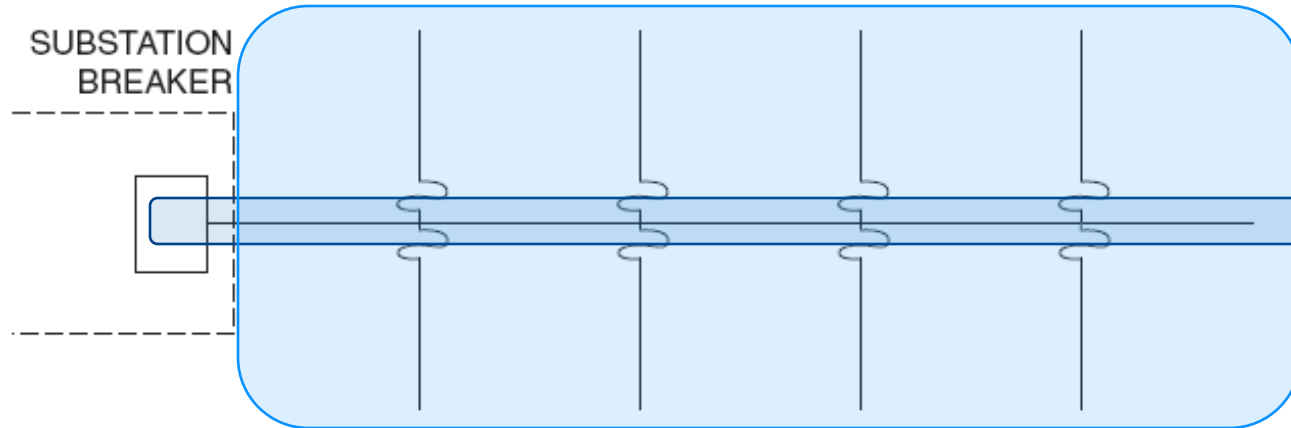
# Operation Sequence Selection

- The recloser's operation sequence determines the number of fast and delayed operations the unit will utilize
- Operation sequence combinations include:
  - Two Fast – Two Delayed
  - One Fast – Three Delayed
  - One Fast – Two Delayed
  - No Fast – All Delayed
- Selection of the correct operation sequence can be influenced by the following:
  - Coordinating with downline fuses
  - Impact of through-faults on substation equipment
  - Transient fault clearing
  - High side fuse coordination
  - Downline sectionalizer coordination
  - Momentary outage reduction

# Reliability example feeder

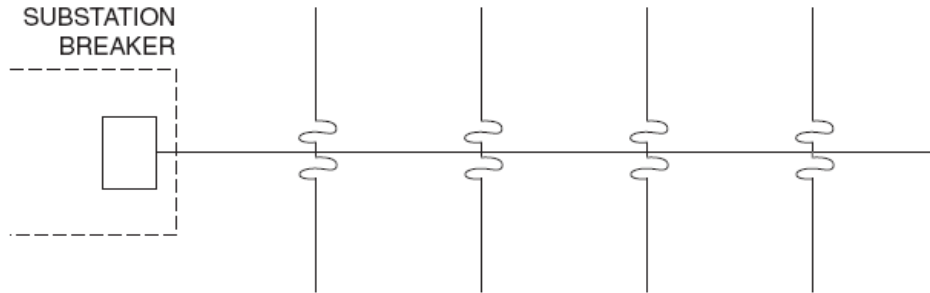
## Substation breaker protecting the 3-phase feeder main

- 1,000 customers
- 1 zone of protection on the 3-phase main (1,000 customers per zone)
- 2 permanent outages/year, 1 hour each



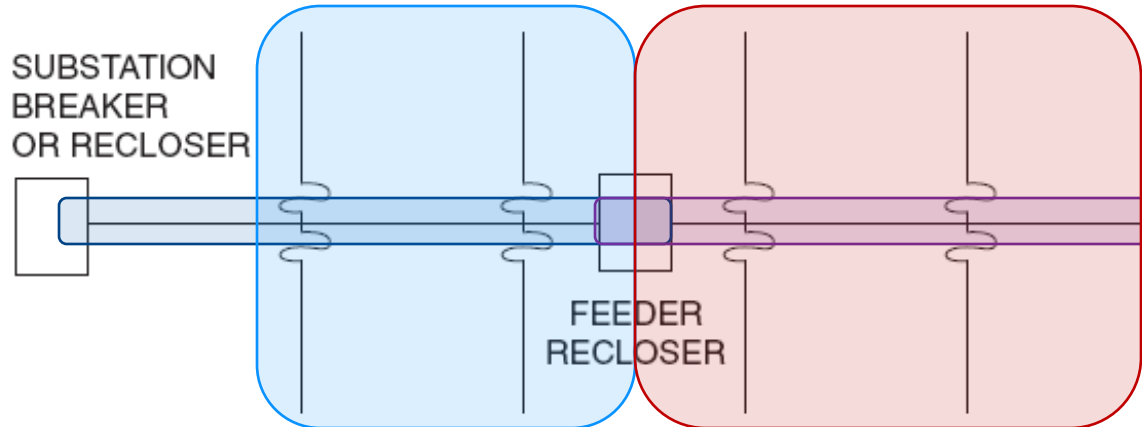
# Example feeder

- Substation Breaker Only
  - 1000 Customers
  - 1 Zone of protection on the 3-phase main (1000 customers per zone)
  - 2 Permanent outages/year, 1 hour each
  - SAIFI =  $2000 / 1000 = 2$
  - SAIDI =  $2000 \text{ hr} / 1000 = 2 \text{ hr}$  or 120 minutes



# Example feeder – Adding a device

- Add midline recloser
  - 1,000 customers
  - 2 zones (500 customers per zone)
  - 2 outages/year, 60 minutes each
    - (1 up-line and 1 down-line from midline recloser)
  - SAIFI = 1,500 / 1,000 = 1.5 (better)
  - SAIDI = 1,500 hours / 1,000 = 1.5 hours or 90 minutes (better)



# Reliability as a function of devices per feeder

1,000 customers

2 outages/year, 60 minutes each

Devices	SAIFI	SAIDI	Reliability % Improvement
1	2	120	Base Case
2	1.5	90	25%
3	1.33	80	11%
4	1.25	75	7.75%
5	1.2	72	4%
6	1.167	70	2.8%
7	1.14	68.6	2%
8	1.125	67.5	1.6%



# **CYME Optimal Recloser Placement Module Mikaela Mohaupt**



# CYME Optimal Recloser Placement - Parameters

- Reliability Assessment Module required so recloser can improve quality.

# CYME Optimal Recloser Placement - Parameters

The image displays three screenshots of the 'Optimal Recloser Placement Analysis' software interface, showing different configuration tabs.

**Left Screenshot (Objectives Tab):** Shows the 'Evaluate Locations Downstream of' section with 'Selected: 1'. A tree view on the left lists 'Feeder (1 / 2)' with sub-items 'FEEDER-1' and 'FEEDER-2', 'Sections (0 / 361)' with sub-items 'FEEDER-1 (0 / 193)' and 'FEEDER-2 (0 / 168)', and 'Nodes (0 / 363)' with sub-items 'FEEDER-1 (0 / 194)' and 'FEEDER-2 (0 / 169)'. A 'Save' button is at the bottom.

**Middle Screenshot (Constraints Tab):** Shows the 'Constraints' section with the following settings:

- Consider Recloser Loading Limits
- Consider Recloser Rated Voltage
- Minimum Benefit Margin: 5.0 %
- Minimum Distance from Substation: 0.0 mi
- Minimum Distance between Reclosers: 0.0 mi

The 'Locations' section has:

- Include Sections on Main Line only
- Ignore Single-Phase Sections
- Ignore Two-Phase Sections
- Ignore Three-Phase Sections
- Ignore Sections Downstream of Fuses
- Ignore Underground Sections

An 'Ignore Specific Locations' dialog box is open, showing an empty list and an 'Edit...' button. A 'Save' button is at the bottom.

**Right Screenshot (Detailed Report Options Tab):** Shows the 'Detailed Report Options' section with:

- Report all tested solutions (Maximum number of reported solutions: 1000)
- Report only the optimal solution
- Always report SAIDI
- Always report SAIFI

The 'Reports' section has:

- Select
- Reliability assessment - Comparison (with '+ Add' and '- Remove' buttons)

The 'Summary Report' section has:

- Show Summary Report
- Keywords table with entries: Salfi, Maifi, Saifi, Caidi, and '+ Add new keyword'

The 'Evaluated Sections' section has:

- Highlight evaluated sections
- Color: Green (dropdown menu)

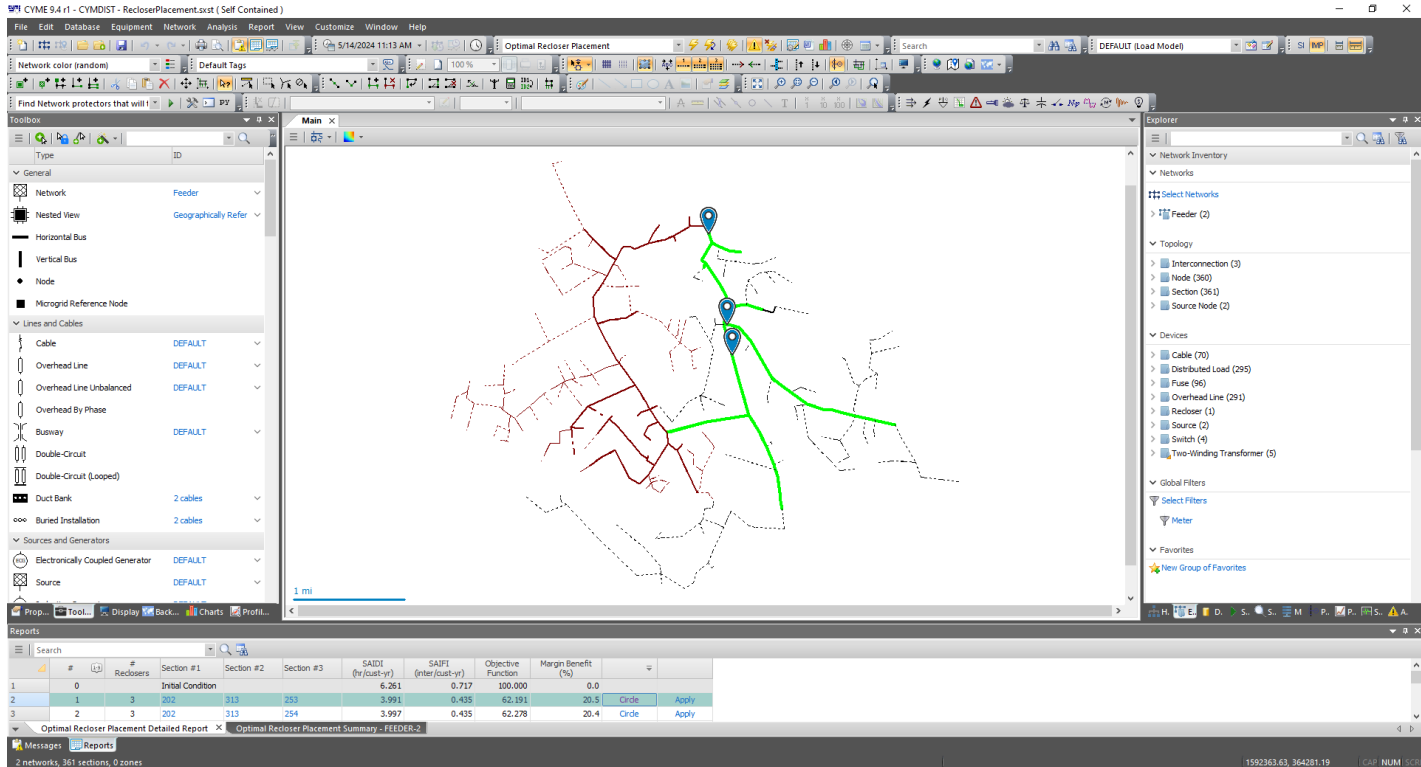
'Save', 'Run', 'OK', and 'Cancel' buttons are at the bottom.

# CYME Optimal Recloser Placement - Parameters

The screenshot displays the 'Optimal Recloser Placement Analysis' software interface. The main window has tabs for 'Objectives', 'Locations', 'Reclosers', 'Restrictions', and 'Output'. The 'Reclosers' tab is active, showing 'Recloser Equipment' with 'Equipment ID' set to 'R\_400'. Below this, 'Operation Mode' options include 'Use operation mode from equipment' (selected), 'Use user-defined operation mode', 'Automated', and 'Remotely controlled'. 'Recloser Settings' include 'Sensing Direction' set to 'Both direction', 'Enable reclosing' checked, and 'Enable fuse saving for fuses greater than or equal to' set to '0.0 A'. A 'Save' button is at the bottom left.

A 'Recloser' dialog box is open in the foreground, showing a tree view of the 'CYME Library (761)' with categories like 'Recloser - Electronic (74)', 'Recloser - Electronic With TCC Setup (392)', 'Recloser - Hydraulic Three-Phase (81)', 'Recloser - IntelliRupter® (1)', and 'Recloser - Single-Phase (213)'. The 'My Inventory (8)' list includes '4E\_100', '4E\_140', '4E\_280', 'DEFAULT', 'DV\_185', 'E\_100', 'R\_225', and 'R\_400' (highlighted). The 'General' tab is selected, showing 'Information' (Type: Hydraulic Three Phase, Control Type: Hydraulic Three-Phase, Model: R\_PARALLEL\_ALL CT), 'Nominal Rating' (Rated Current: 6000.0 A, Rated Voltage: 12.47 kV, Interrupting Rating: 800.0 A), and 'Operation Mode' (Reversible checked, Single-phase lockout and Single-phase trip unchecked, Remote controlled and Automated unchecked). 'OK' and 'Cancel' buttons are at the bottom right.

# CYME Optimal Recloser Placement - Results



# CYME Optimal Recloser Placement - Results

#	# Reclosers	Section #1	Section #2	Section #3	SAIDI (hr/cust-yr)	SAIFI (int/cust-yr)	Objective Function	Margin Benefit (%)		
1	48	1	202		6.261	0.717	100.000	45.0	Circle	Apply
2	49	1	213		6.307	0.724	100.866	44.5	Circle	Apply
3	50	1	214		6.388	0.735	102.241	43.8	Circle	Apply
4	51	1	236		6.667	0.750	105.556	42.0	Circle	Apply
5	52	1	218		6.737	0.759	106.721	41.3	Circle	Apply
6	53	1	219		6.852	0.773	108.654	40.3	Circle	Apply
7	54	1	220		6.873	0.776	108.990	40.1	Circle	Apply
8	55	1	313		8.011	0.916	127.859	29.7	Circle	Apply
9	56	1	314		8.611	0.991	137.880	24.2	Circle	Apply
10	57	1	253		8.769	1.013	140.651	22.7	Circle	Apply
11	58	1	254		8.818	1.019	141.468	22.2	Circle	Apply
12	19	2	202	313	4.954	0.554	78.201	21.8	Circle	Apply
13	59	1	255		8.897	1.029	142.786	21.5	Circle	Apply
14	60	1	258		8.993	1.041	144.400	20.6	Circle	Apply
15	1	3	202	313	3.991	0.435	62.191	20.5	Circle	Apply
16	61	1	261		9.013	1.043	144.725	20.4	Circle	Apply
17	2	3	202	313	3.997	0.435	62.278	20.4	Circle	Apply
18	62	1	315		9.030	1.044	144.880	20.3	Circle	Apply
19	63	1	262		9.057	1.049	145.458	20.0	Circle	Apply
20	3	3	202	313	4.015	0.438	62.580	20.0	Circle	Apply
21	4	3	202	313	4.049	0.442	63.152	19.2	Circle	Apply
22	5	3	202	313	4.049	0.442	63.157	19.2	Circle	Apply
23	6	3	202	313	4.055	0.443	63.253	19.1	Circle	Apply

Reports

Search

## Optimal Recloser Placement Summary Network: FEEDER-2

Study Parameters	
Study Name	RecloserPlacement.sxst
Date	05/14/2024
Time	11:09 AM
Project Name	New
<b>Search Method</b>	<b>Sequential Search</b>
Improve SAIDI	Yes
Improve SAIFI	Yes
Improve Keyword Expression	No
Ignore Existing Reclosers	Yes

Optimal Solution	
Section #1	202
Section #2	313
Section #3	253

Keyword	Initial	Final	
SAIFI	0.71708	0.43478	(int/cust-yr)
MAIFI	0.62537	0.35999	(int/cust-yr)
SAIDI	6.26110	3.99149	(h/cust-yr)
CAIDI	8.73132	9.18048	(h/cust-int)

# **FLISR**

# **Brian Bertini**



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# FLISR – The Backbone of Feeder Automation

**F**ault

**L**ocation

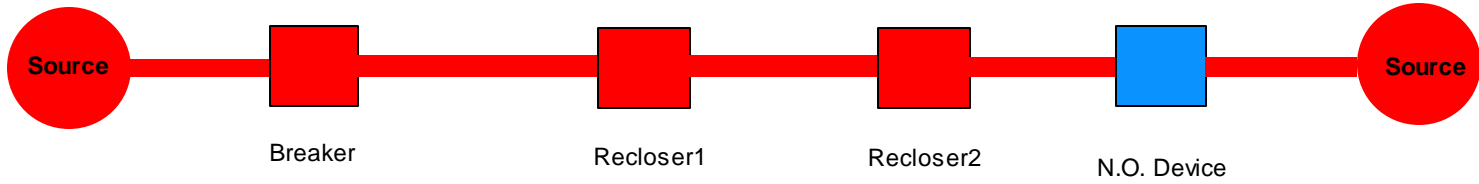
**I**solation

**S**ervice

**R**estoration



# FLISR Basics



Zone 1  
Customer



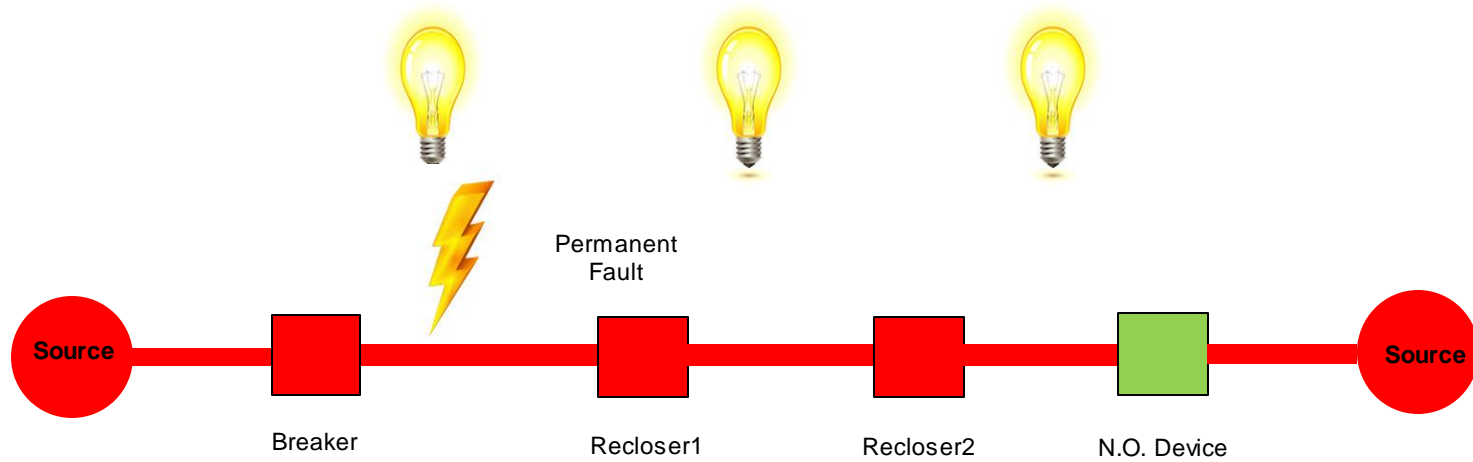
Zone 2  
Customer



Zone 3  
Customer



# FLISR Basics



Zone 1  
Customer



Zone 2  
Customer

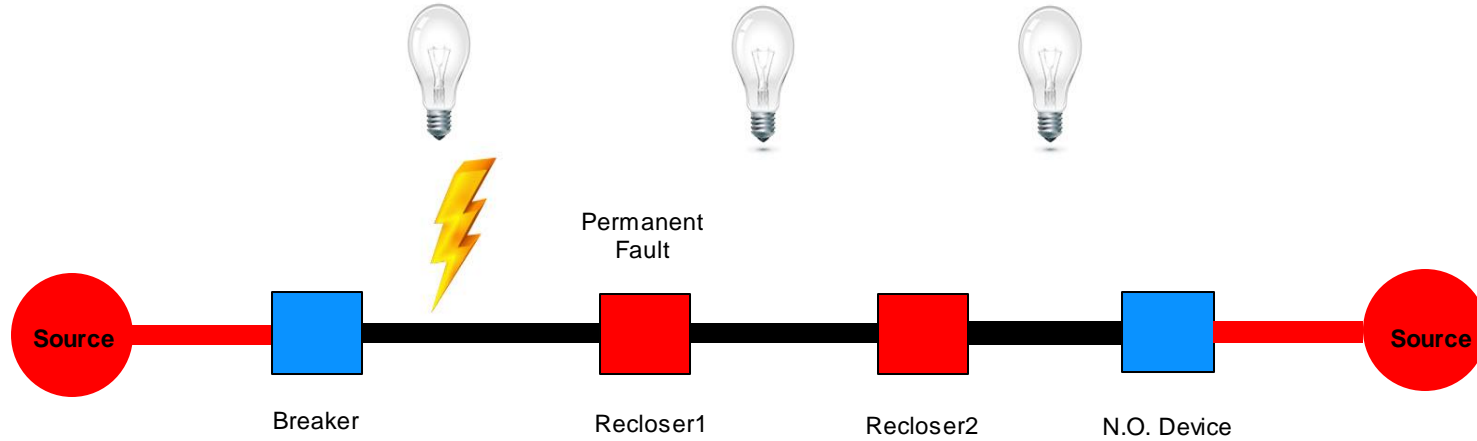


Zone 3  
Customer



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# FLISR Basics



Zone 1  
Customer

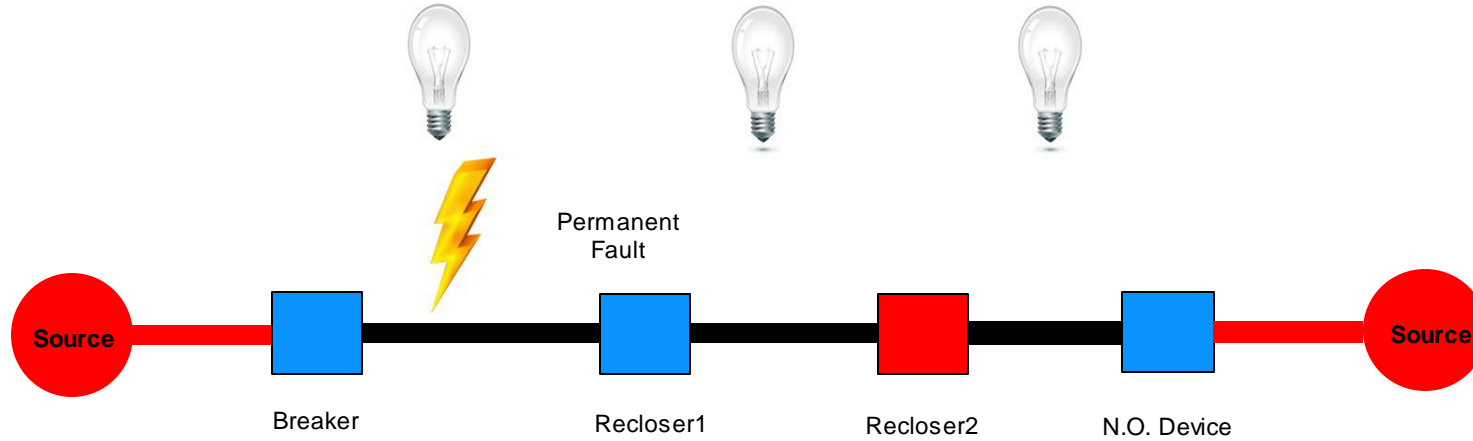


Zone 2  
Customer



Zone 3  
Customer

# FLISR Basics



Zone 1  
Customer



Zone 2  
Customer

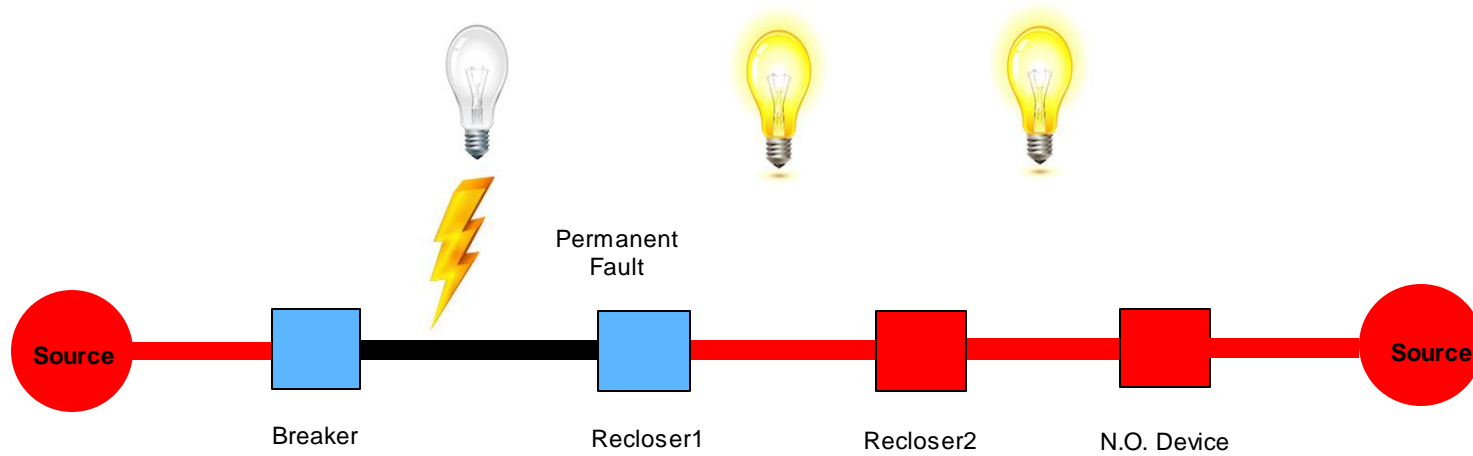


Zone 3  
Customer



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# FLISR Basics



Zone 1  
Customer



Zone 2  
Customer



Zone 3  
Customer

# Reliability as a function of devices per feeder with FLISR

1000 Customers  
2 Outages/year, 60 minutes each outage

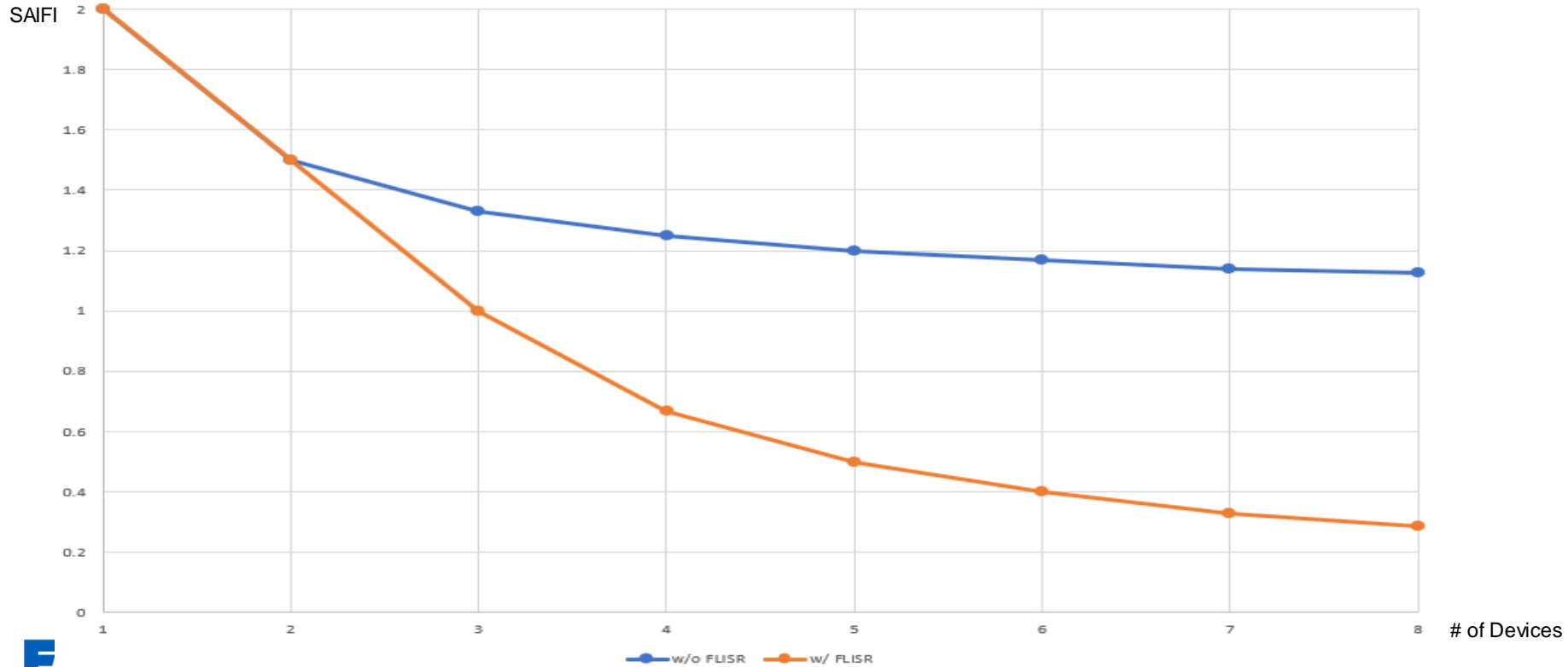
Devices	SAIFI	SAIDI	Reliability % Improvement
1	2	120	Base Case
2	1.5	90	25%
3	1	60	33%
4	0.667	40	33%
5	0.5	30	25%
6	0.4	24	20%
7	0.33	20	16.7%
8	0.285	17.1	14.3%

Used as a midline device  
Used as an open device



# SAIFI with and without FLISR

SAIFI w/ and w/o FLISR as a function of # of devices assuming 2 permanent faults per year



# Fault Indicators

## Ryan Rausch



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# The role of fault indicators

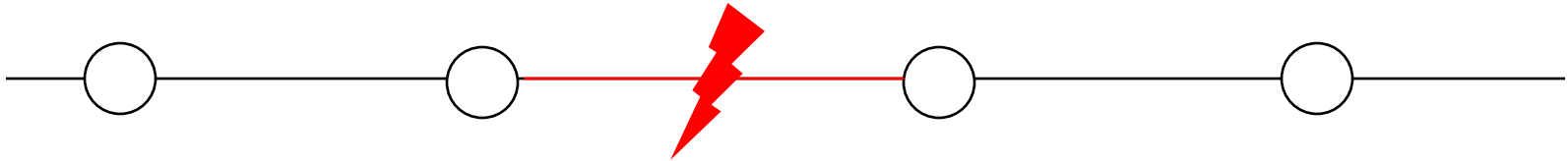


- You can eliminate some customer interruptions through reclosing
- Even after reclosing fails to clear the fault, you can eliminate more customer interruptions with timely isolation and service restoration through FLISR
- Ultimately, with a permanent fault there is an interruption to some section(s) of the feeder
  - We can still improve SAIDI by finding the fault faster and quickly dispatching trouble crews...using fault indicators

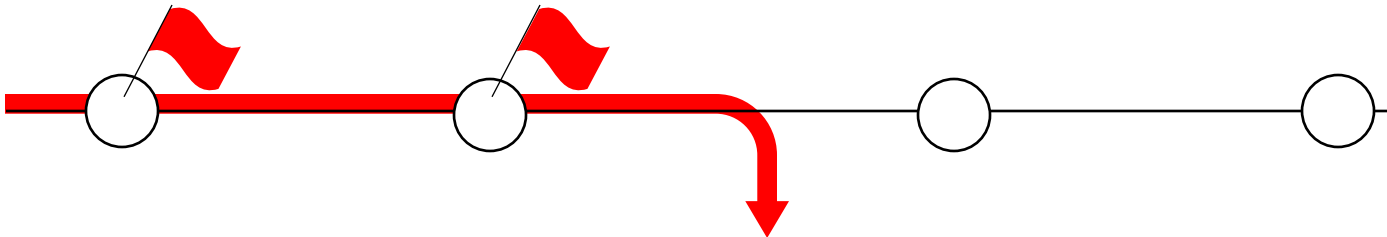


# Traditional Fault Location

- Basic premise: sectionalize the feeder and identify the faulted section

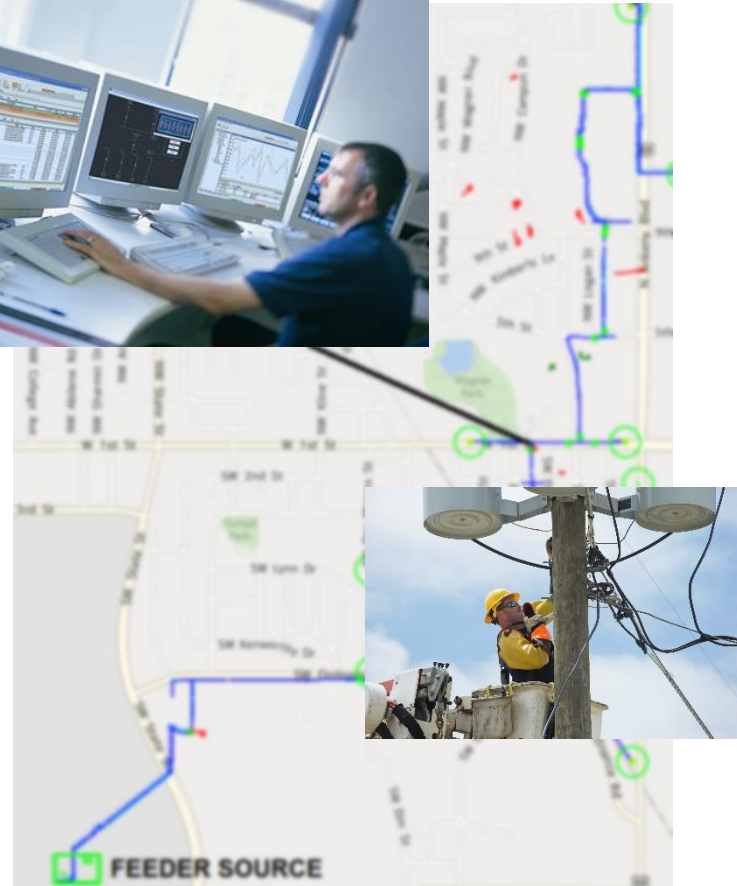


- One strategy is deploying fault indicators along the feeder to identify passage of fault current



# Communicating Fault Indicators

- Communications provide visibility at the control center for a more holistic view of the event
  - Aggregation of fault indicator statuses
  - Timestamping for multiple-fault events
- Enables targeted dispatching of crews
  - Smaller sections to patrol
  - Plan ahead for feeder splits or obstacles

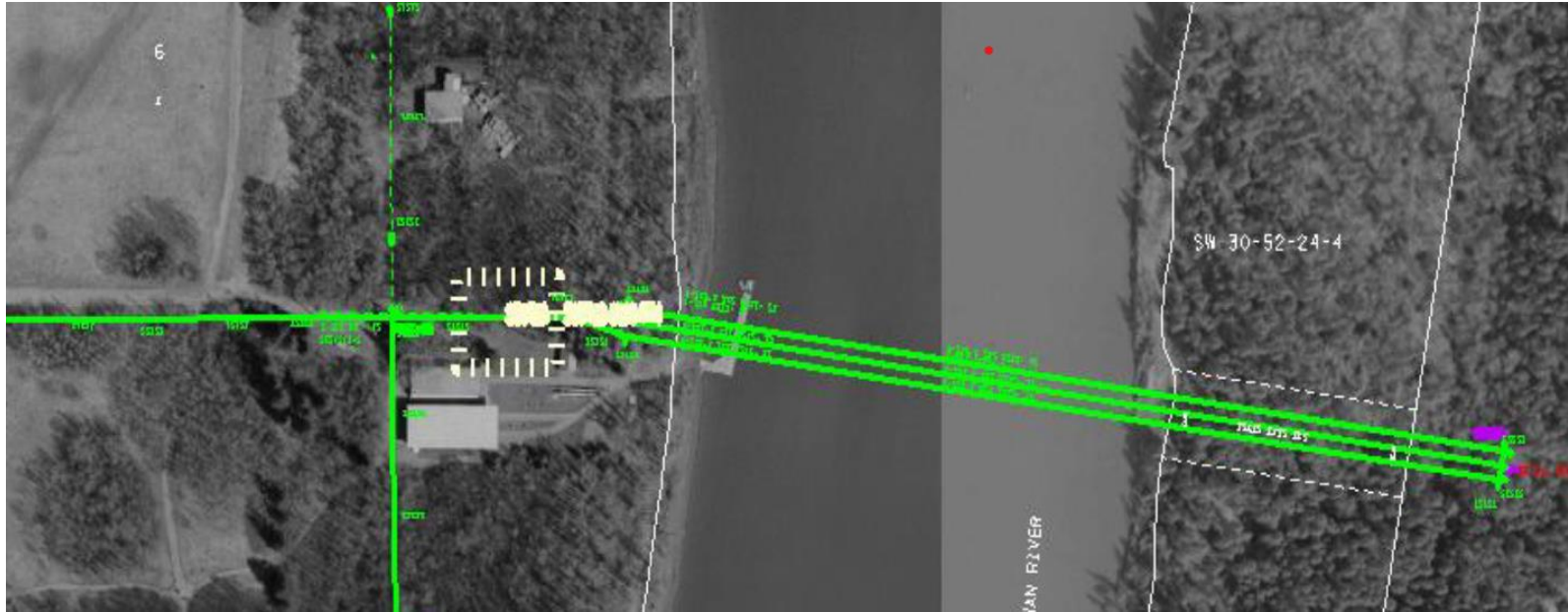


# Placement parameters

- Customers: sensitive or troublesome sites (not customer count)
- Patrol time: Eliminate sections with difficult terrain/environment
- Drive Time: Plan ahead for the optimal route
- Other Considerations: Line current, Signal level



# River Crossing



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# Riser Pole Deployment



# Underground Deployment

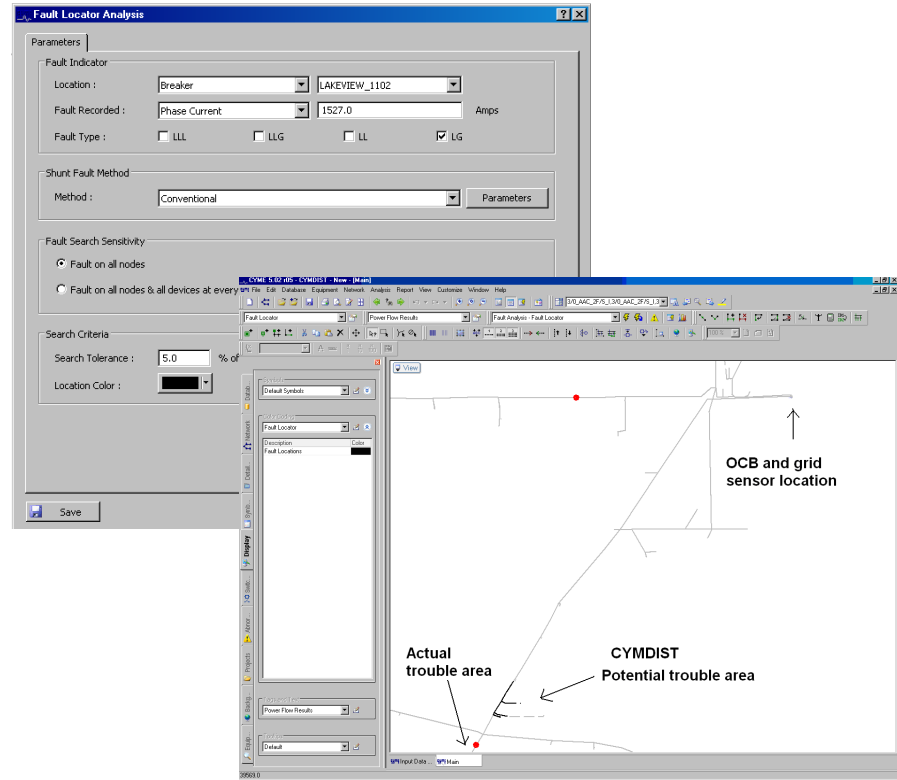


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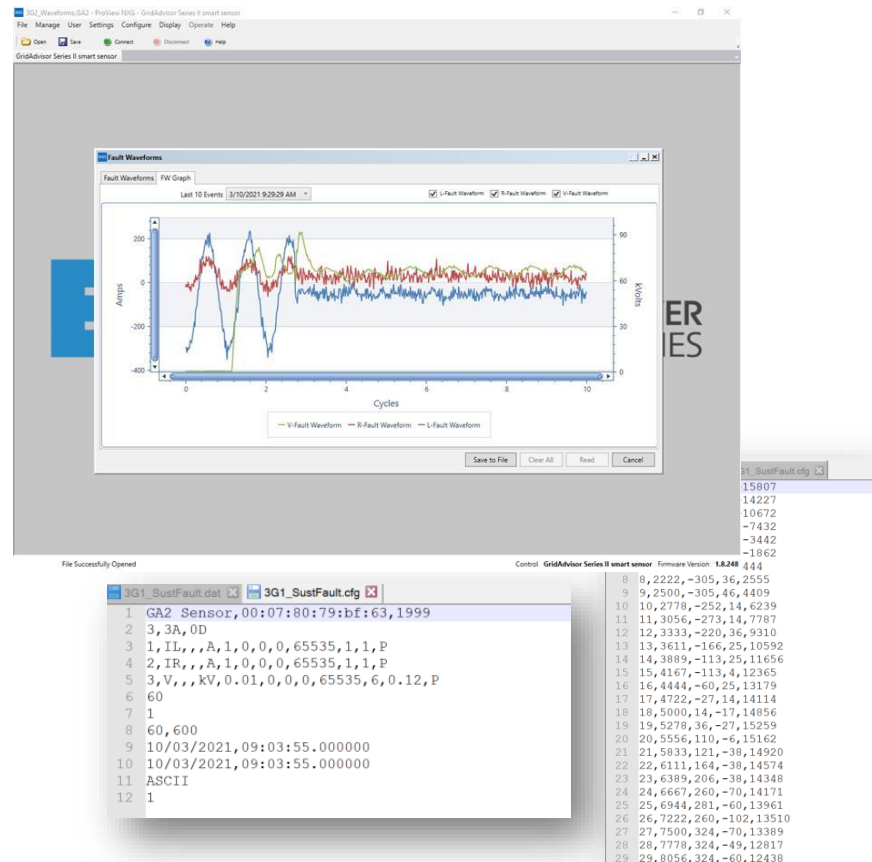
# Fault Magnitude and Direction

- Fault Current Magnitude
  - Pinpoint fault location with a distance to fault calculation
- Fault Direction
  - Networked feeders
  - Abnormal Feeder Configurations
  - Backfeed from DER



# Fault Waveforms

- Capture fault waveforms and store in non-volatile memory for later viewing
- Enable advanced post-analysis of events
- Export via COMTRADE format for viewing in viewing applications and analytics platforms





# **Advanced Fault Locator in CYME**

## **Mikaela Mohaupt**

# CYME Advanced Fault Locator - Parameters

Advanced Fault Locator Analysis

Parameters | Fault Indicator | Output

Monitoring device locations

Device Type	Device Number	Fault Type	Faulted Phase	Data Type	Value	Tolerance
Recloser	201	LG	ALL	Phase Current	1900.0 A	5.0 %

[Click to add a new row](#)

Multiple fault types occurring at a single location

COMTRADE Import ...

Fault Flow Options

Method: Conventional

Parameters: DEFAULT [Edit...](#)

Fault Impedances:

	Minimum	Maximum	
Rf:	0.0	0.0	<input checked="" type="radio"/> $\Omega$
Rg:	0.0	3.0	<input type="radio"/> p.u.

Options

Fault on all conductors at every: 0.0095 mi

Ignore locations downstream of fuses

Save Run OK Cancel

Advanced Fault Locator Analysis

Parameters | Fault Indicator | Output

Fault Indicator Status

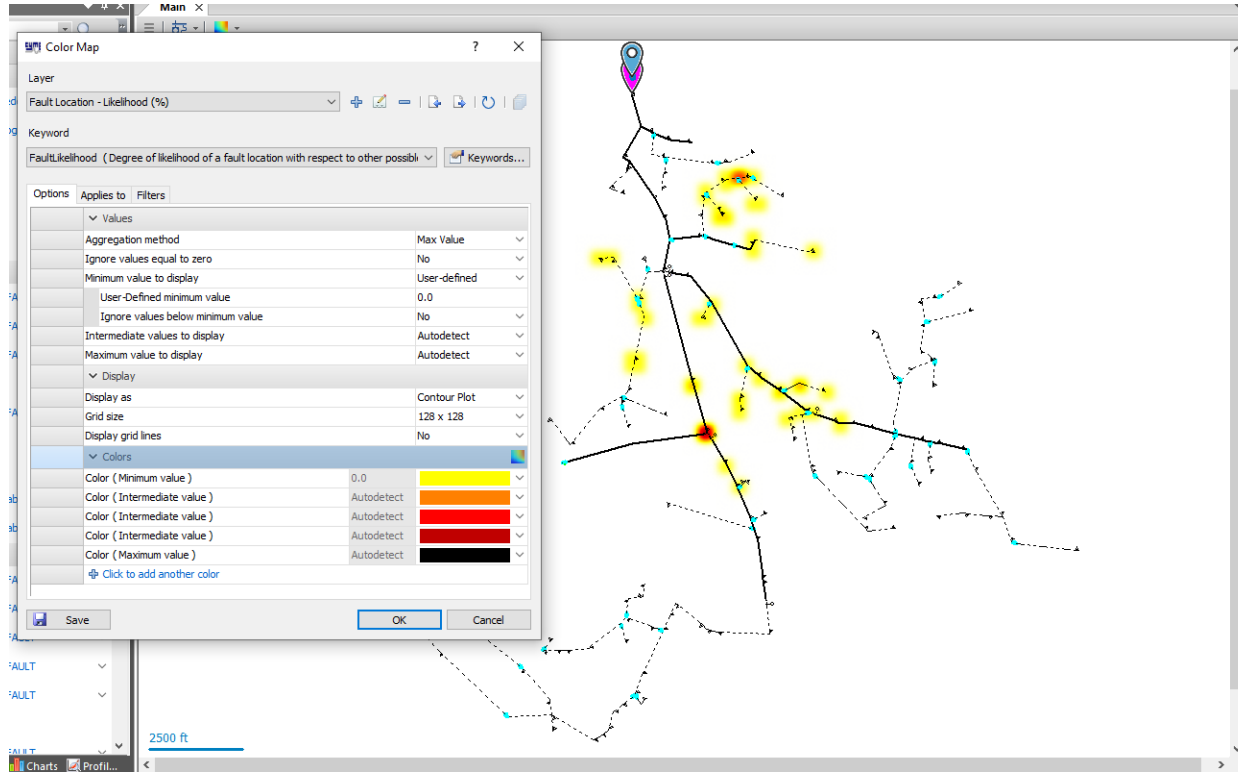
Ignore all FI statuses Selected: (15/15)

Search

- Fault Indicator
  - 253-0
    - A
    - B
    - C
  - 274-0
  - 313-0
  - 315-0
  - 327-0

Save Run OK Cancel

# CYME Advanced Fault Locator - Results



# **Preventative/Predictive Measures Ryan Rausch**



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Fault Indicators are not a control device...so how can they improve SAIFI?

# Momentary Faults

- Momentary Faults for SAIFI and Fire Mitigation: monitor high Momentary Fault Counts to prioritize vegetation management and feeder inspections

Filter

Name contains:

Use regular expressions

An advanced filter is currently defined for this view

Server Views - Analog Inputs (17 / 1779 Data Points)

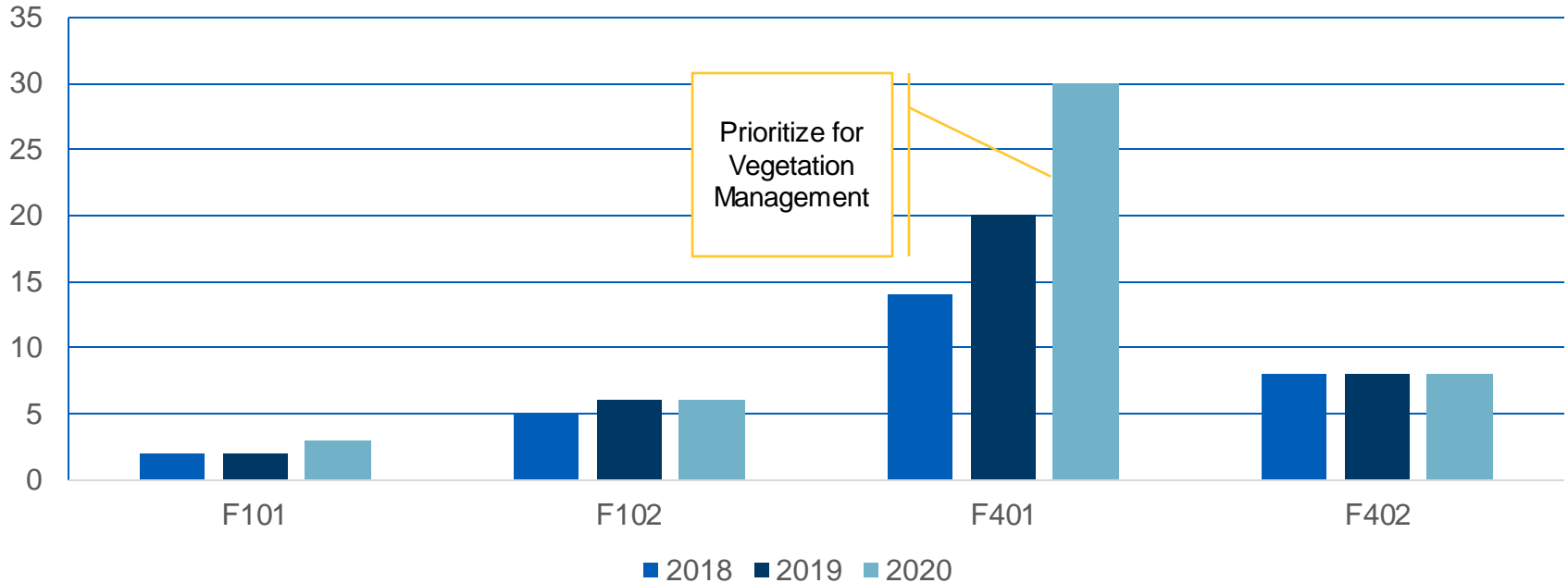
Typ	St	Counter	Name	Value	Description	D
		1	YGS_SS6-000780A4B5C8_MomCounts	12.0	Walker Art center: Momentary faults count	3/10
		1	YGS_SS6-000780A4B5C8_MomCounts	12.0	Walker Art center: Momentary faults count	3/10
		1	YGS_SS6-000780A4B5C7_MomCounts	12.0	Walker Art center: Momentary faults count	3/10
		1	YGS_SS7-000780345678_MomCounts	1.0	Hennepin Ave. and 36th: Momentary faults count	3/10
		1	YGS_SS7-000780123456_MomCounts	1.0	Hennepin Ave. and 36th: Momentary faults count	3/10
		1	YGS_SS9-000780A3B2C1_MomCounts	1.0	US Bank Stadium: Momentary faults count	3/10
		1	YGS_SS6-000780A3B2C2_MomCounts	1.0	US Bank Stadium: Momentary faults count	3/10
		1	YGS_SS7-000780234567_MomCounts	1.0	Hennepin Ave. and 36th: Momentary faults count	3/10
		1	YGS_SS1-000780A3B2C3_MomCounts	1.0	US Bank Stadium: Momentary faults	3/10

*Monitor this...*



# Momentary Faults

## Momentary Fault Counts by Feeder YoY



# Condition-based Maintenance

- Recloser Contact Lifecycle Monitoring
  - Deploy with hydraulic recloser assets to monitor remaining contact life and drive condition-based maintenance
  - Based on IEEE-defined recloser duty cycle test

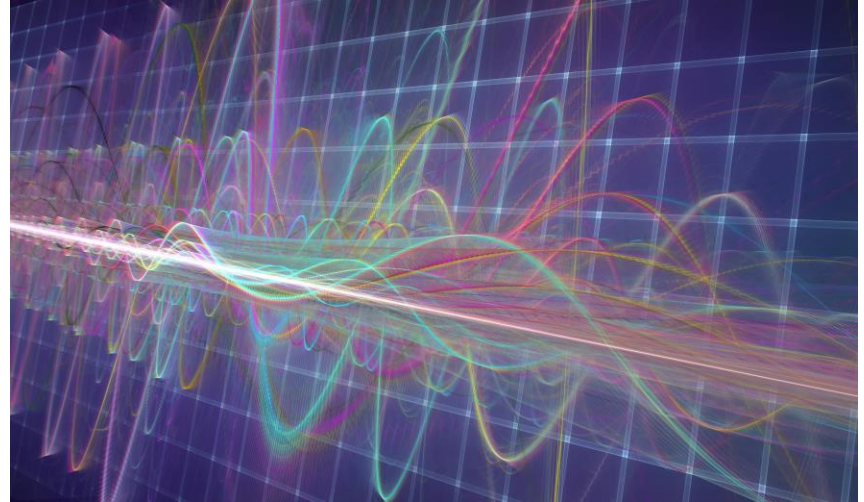


- Enter nameplate life rating (kA·s) and optionally de-rate remaining kA·s value
- Each fault event decrements remaining kA·s based on fault magnitude and number of operations
- DNP3 reporting of remaining life along with binary alarms



# Emerging Frontiers

- Enhanced sensing
  - Greater accuracy
  - Higher sampling rate
  - Digital signal processing
- New capabilities
  - Hi-Z and other fault algorithms
  - Early indicator recognition
  - Augmented sensing
  - Edge and cloud intelligence





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