Tools and Strategies for Reliability Improvement

Brian Bertini, Mikaela Mohaupt, Ryan Rausch

May 15, 2024

Powering Business Worldwide

Causes of Electric Fau

- EPRI study found that:
  - 1% Snow & ice
  - 3% Vehicle
  - 4% Dig-ins
  - 6% Wind
  - 8% Animals
  - 13% Equipment Fai
  - 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.

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

Powering Business Worldwide

Reliability definitions

SAIFI = System Average Interruption Frequency Index

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

where λ_i is the failure rate and N_i is the number of customers for location i.

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

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?

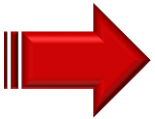
- Fast trip operation **clears temporary faults** before they become permanent faults
- Faults that would have been **permanent** with a **fuse** become **temporary** with a **recloser**

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

Powering Business Worldwide

Three-Phase Reclosers

	**W/WV Family** • Self-contained, oil-insulated three-phase recloser • Oil-interrupting (W) or vacuum-interrupting (VW) • Hydraulically or electronically controlled (WE/VWE)	**Ratings** • 15kV, 27kV, 38kV • 560A cont. • 8kA or 12kA interrupt
	**Three-Phase NOVA** • Solid insulation 3 phase recloser • Mechanical gang operated phases • Vacuum interrupters fully encapsulated • Magnetic actuators	**Ratings** • 15kV, 27kV, 38kV • 630A/800Acont. • 12.5kA or 16kA interrupt
 	**Triple-Single (TS) NOVA** • NOVA Three-Tank, Triple-Single Recloser • Offers additional overcurrent protection flexibility with single or three-phase trip modes	**Ratings** • 15kV, 27kV, 38kV • 400A/630A/800A cont. • 8kA, 12.5kA or 16kA interrupt
	**Single-Triple-Single (STS) NOVA** • Triple-single functionality in a single-tank design • Mechanisms are independent • Less cabling and no junction box	**Ratings** • 15kV, 27kV, 38kV • 630A/800Acont. • 12.5kA or 16kA interrupt
	**NOVA NX-T & NX-STS** • Next generation NOVA • Replaces TS and STS • Numerous enhancements	**Ratings** • 15kV, 27kV, 38kV • 630A/800Acont. • 12.5kA or 16kA interrupt

NOVA NX Platform

NOVA NX-STS

NOVA NX-T

Powering Business Worldwide

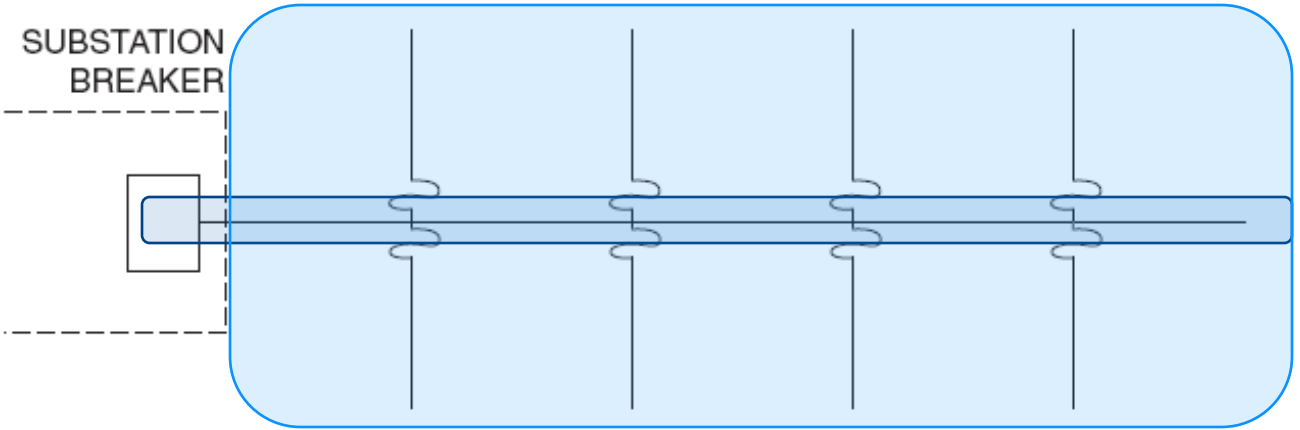
Operation Sequence Selection

- 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

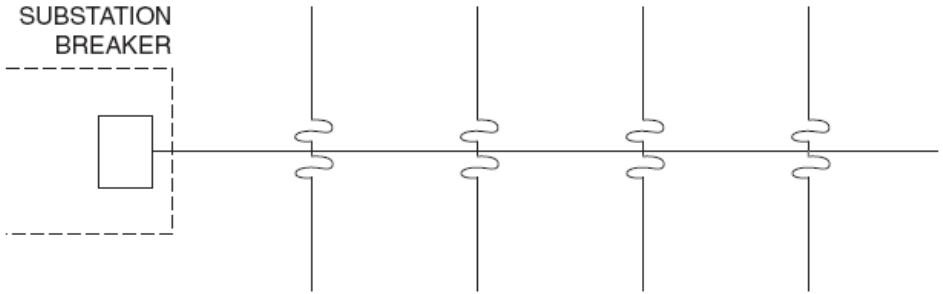
Substation breaker protecting the 3-phase feeder main

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



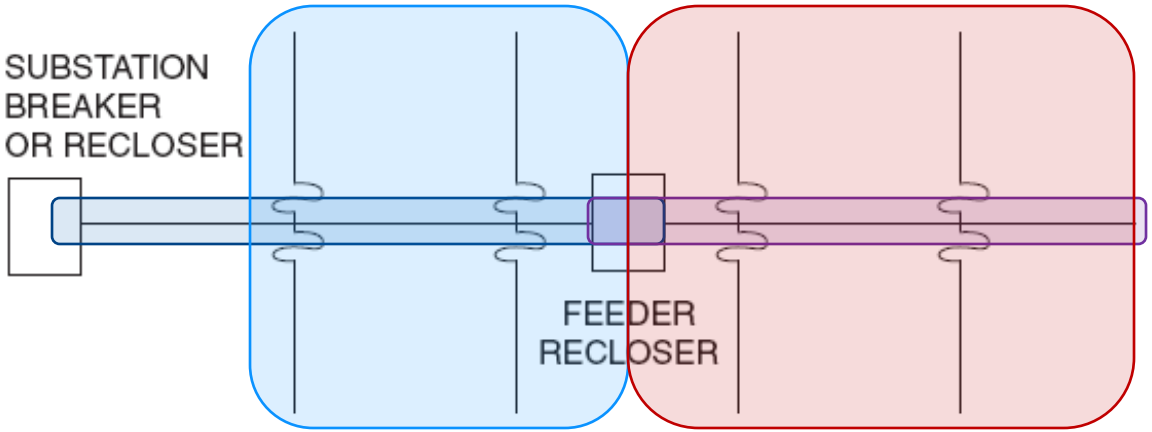
Example feeder

- 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 hr / 1000 = 2 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

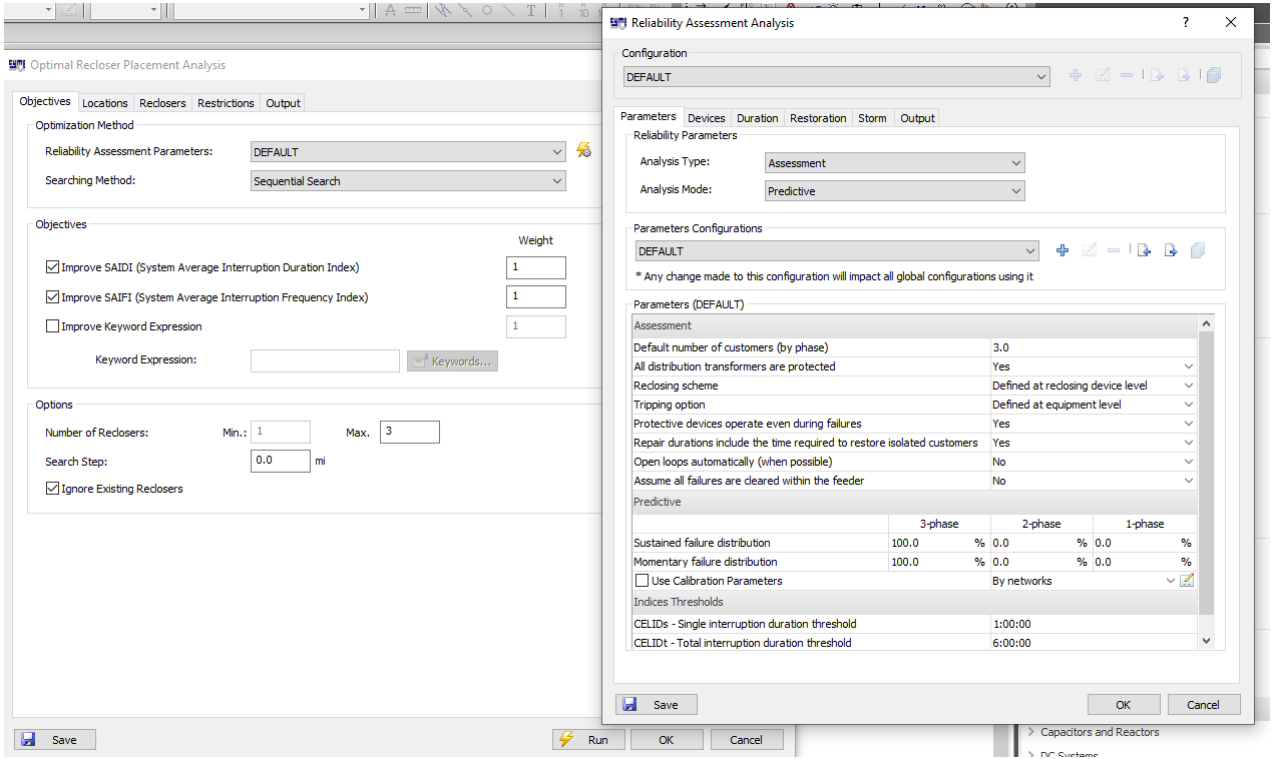
1,000 customers
2 outages/year, 60 minutes each

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

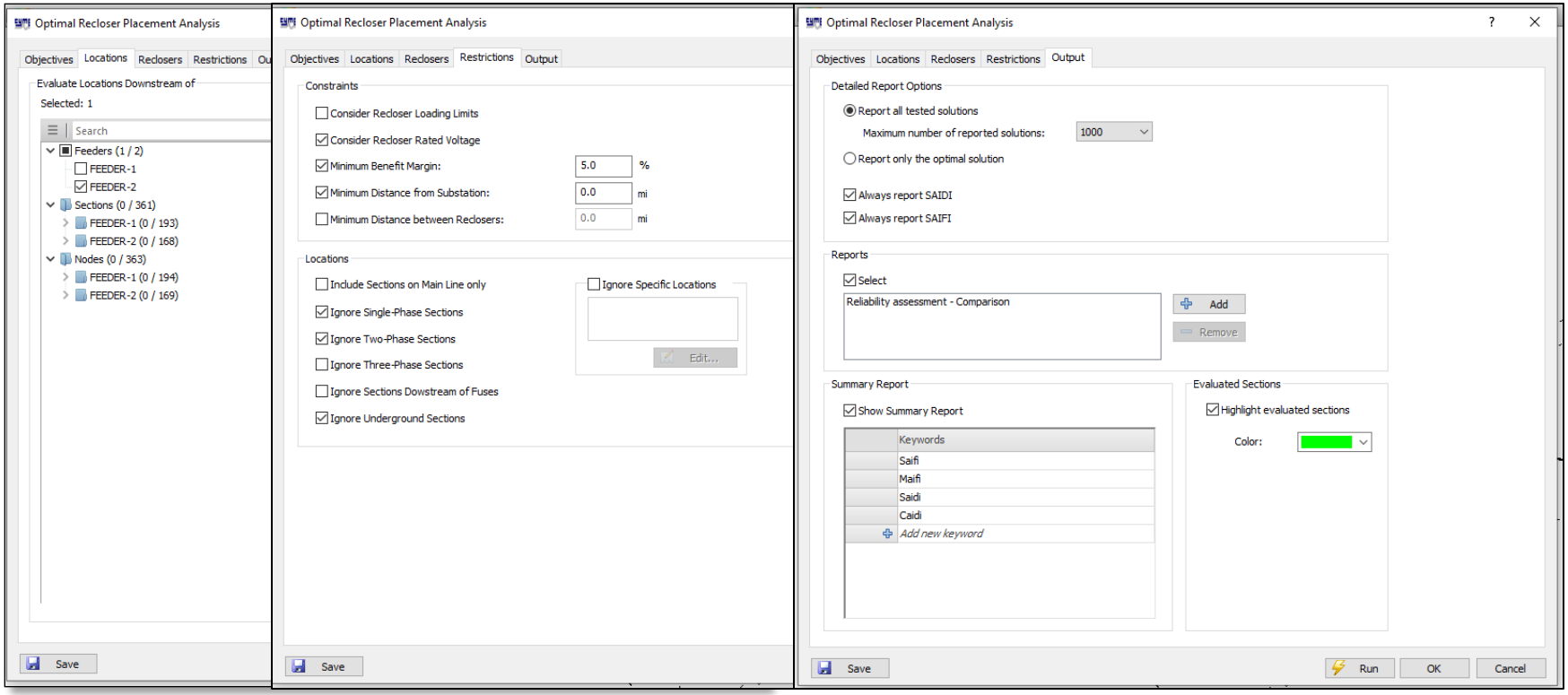
Mikaela Mohaupt

CYME Optimal Recloser Placement - Parameters

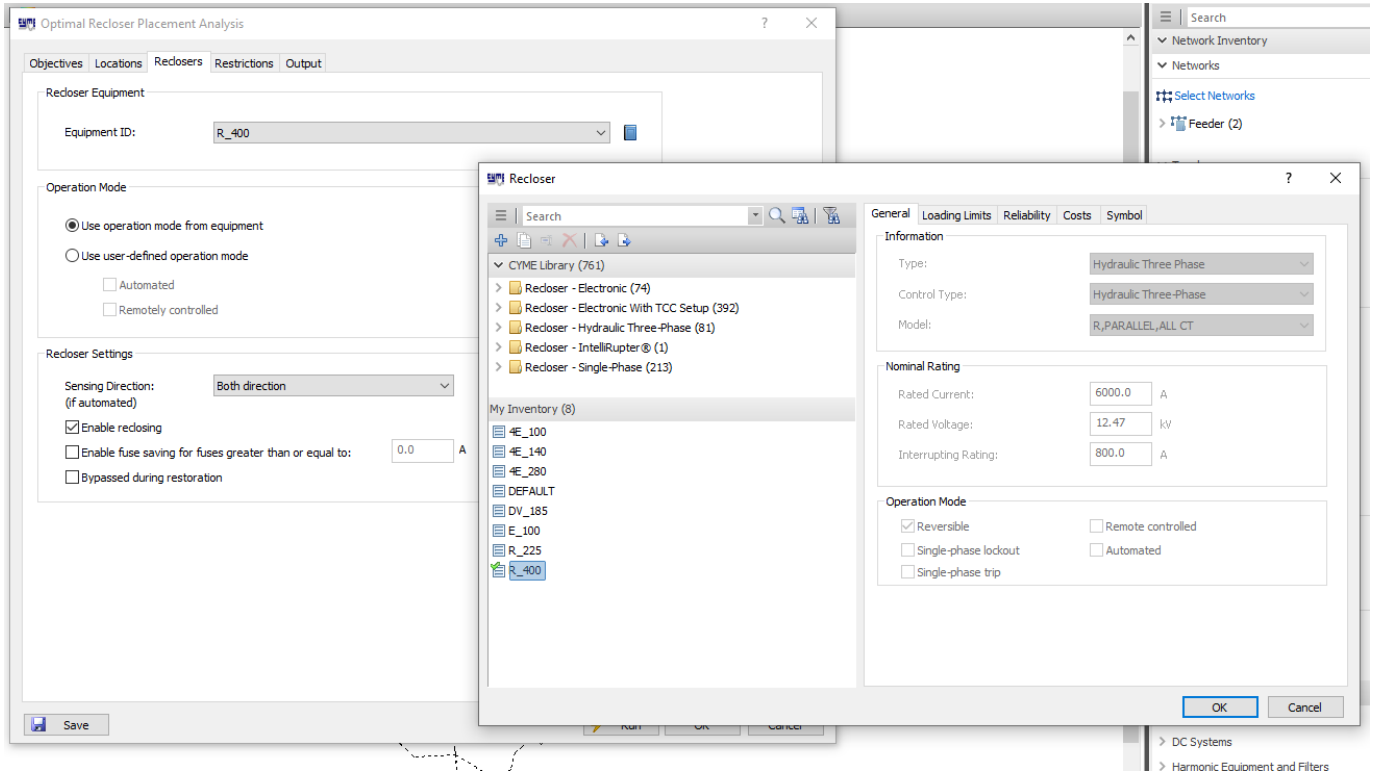


- Reliability Assessment Module required so recloser can improve quality.

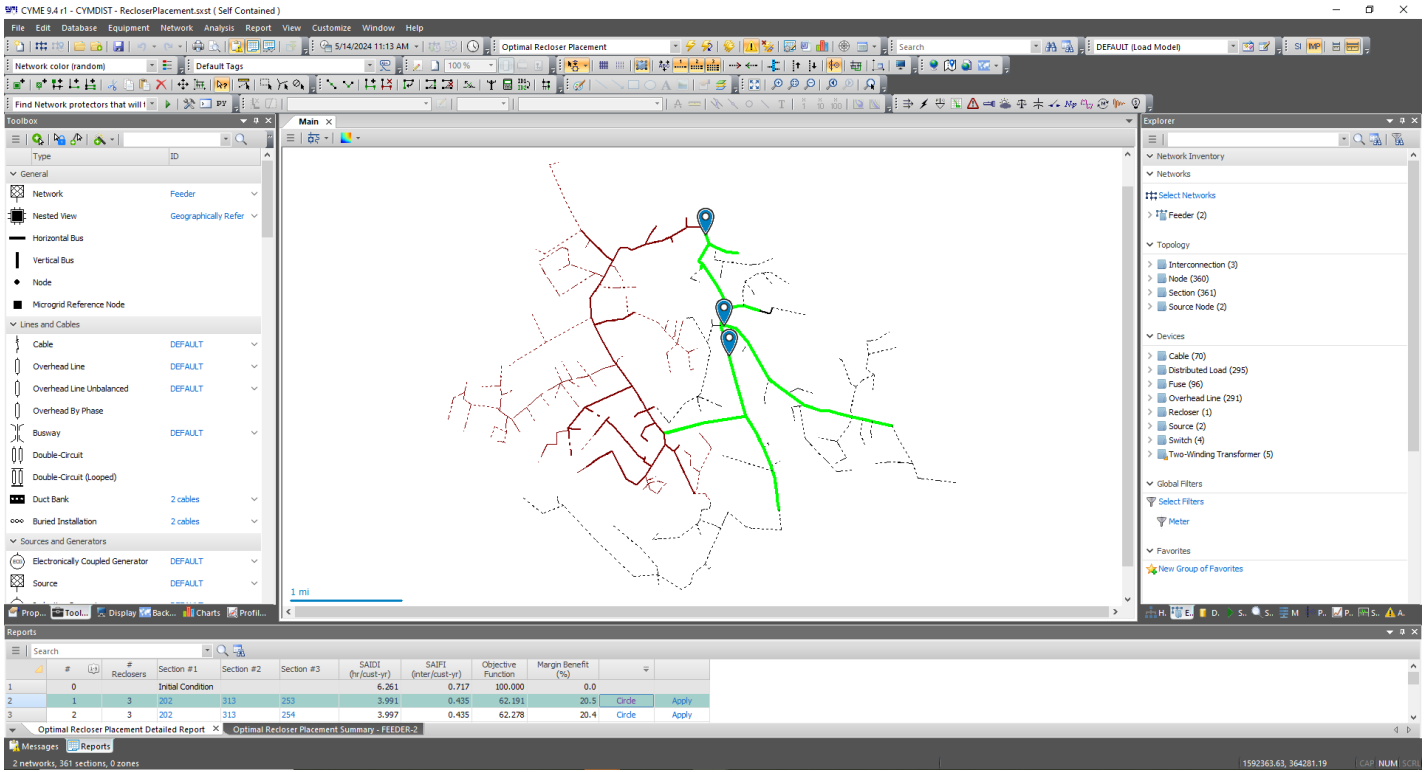
CYME Optimal Recloser Placement - Parameters



CYME Optimal Recloser Placement - Parameters



CYME Optimal Recloser Placement - Results



Powering Business Worldwide

CYME Optimal Recloser Placement - Results

Reports

Search

	#	# Reclosers	Section #1	Section #2	Section #3	SAIDI (hr/cust-yr)	SAIFI (inter/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	253	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	254	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	255	4.015	0.438	62.580	20.0	Circle	Apply
21	4	3	202	313	261	4.049	0.442	63.152	19.2	Circle	Apply
22	5	3	202	313	258	4.049	0.442	63.157	19.2	Circle	Apply
23	6	3	202	313	262	4.055	0.443	63.253	19.1	Circle	Apply

Optimal Recloser Placement Detailed Report | Optimal Recloser Placement Summary - FEEDER-2

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
Search Method	**Sequential Search**
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)

EATON
Powering Business Worldwide

FLISR
Brian Bertini

FLISR – The Backbone of Feeder Automation

F ault

L ocation

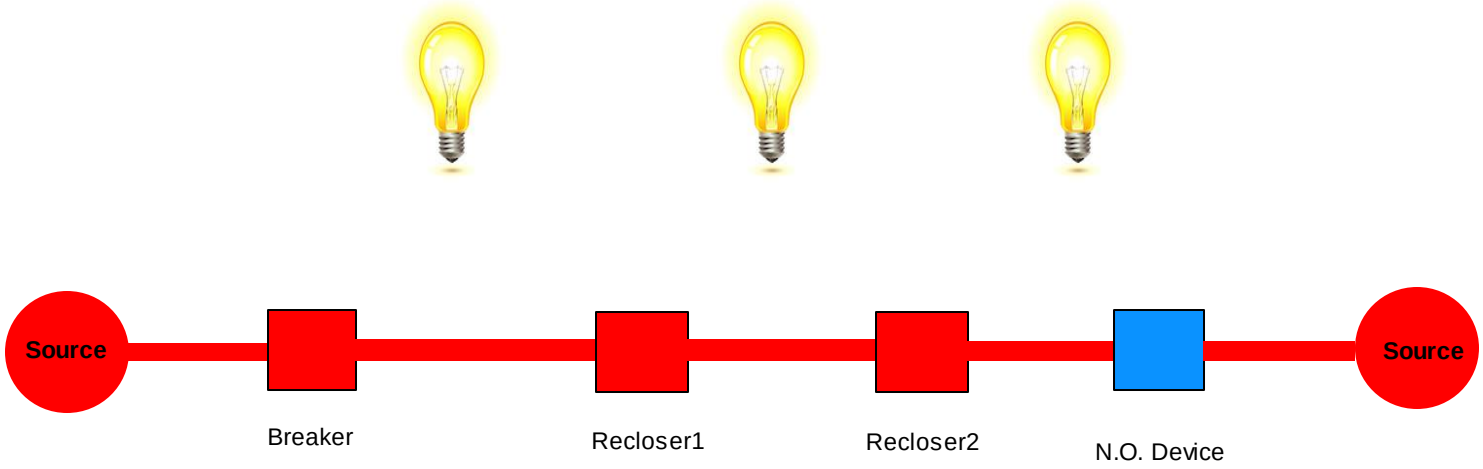
I solation

S ervice

R estoration

Powering Business Worldwide

FLISR Basics



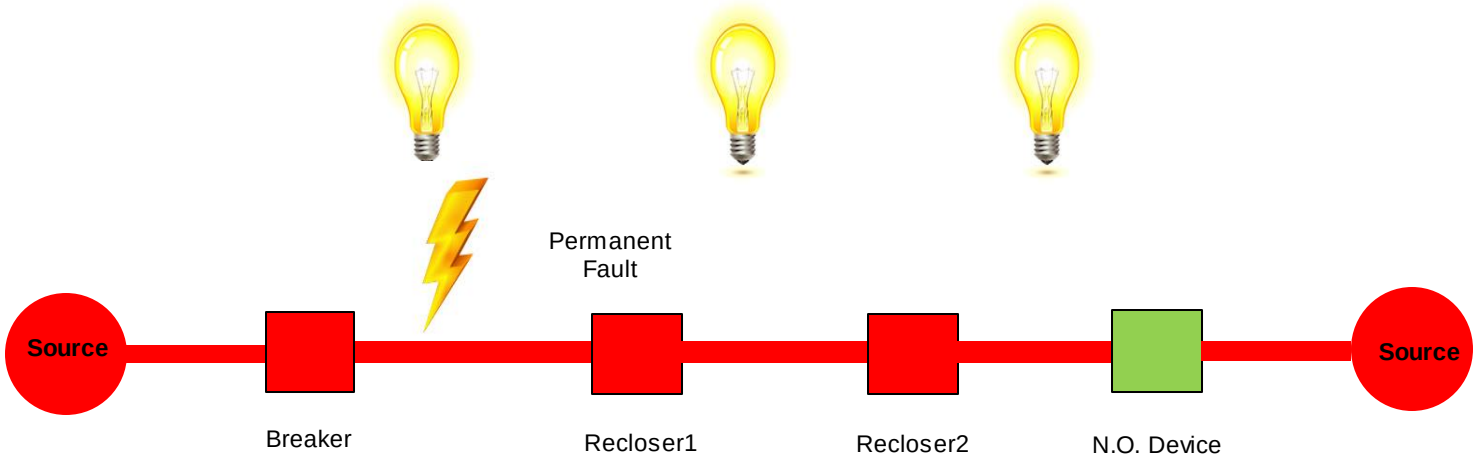
Zone 1
Customer

Zone 2
Customer

Zone 3
Customer

Powering Business Worldwide

FLISR Basics



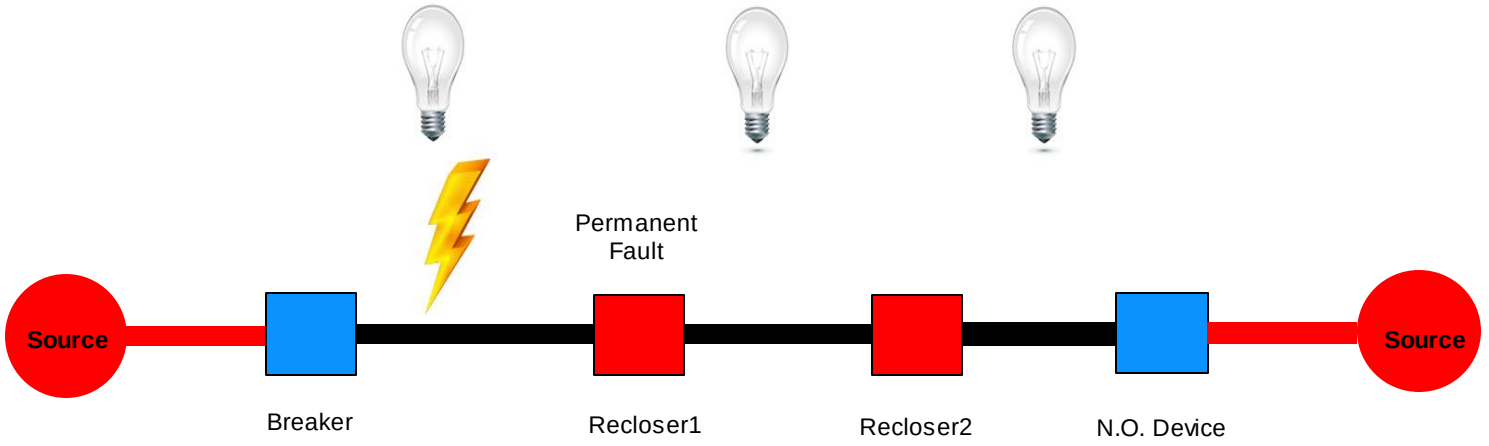
Zone 1
Customer

Zone 2
Customer

Zone 3
Customer

Powering Business Worldwide

FLISR Basics



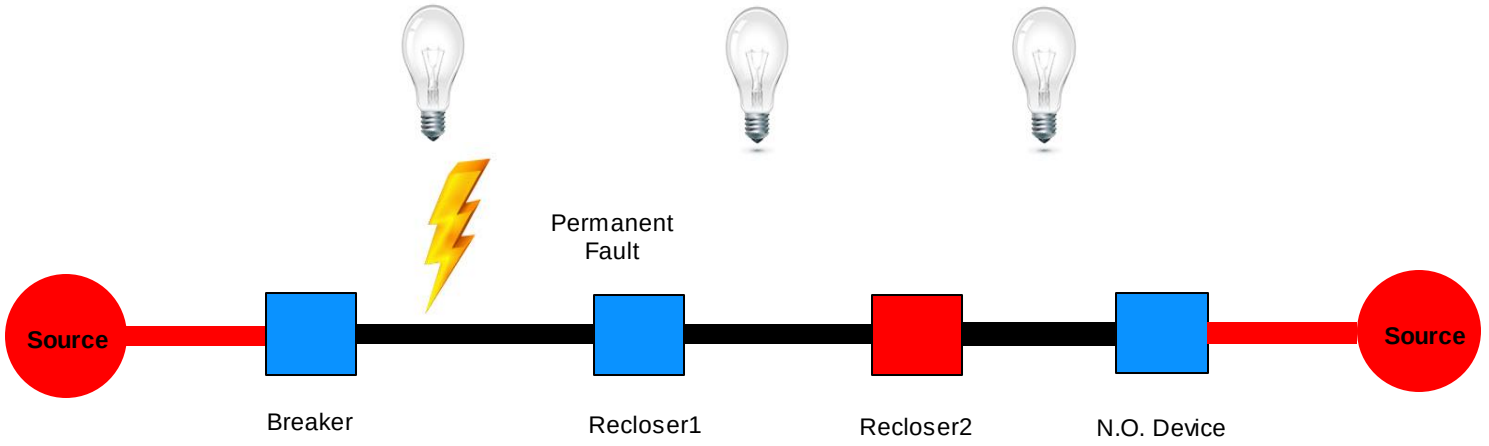
Zone 1
Customer

Zone 2
Customer

Zone 3
Customer

Powering Business Worldwide

FLISR Basics



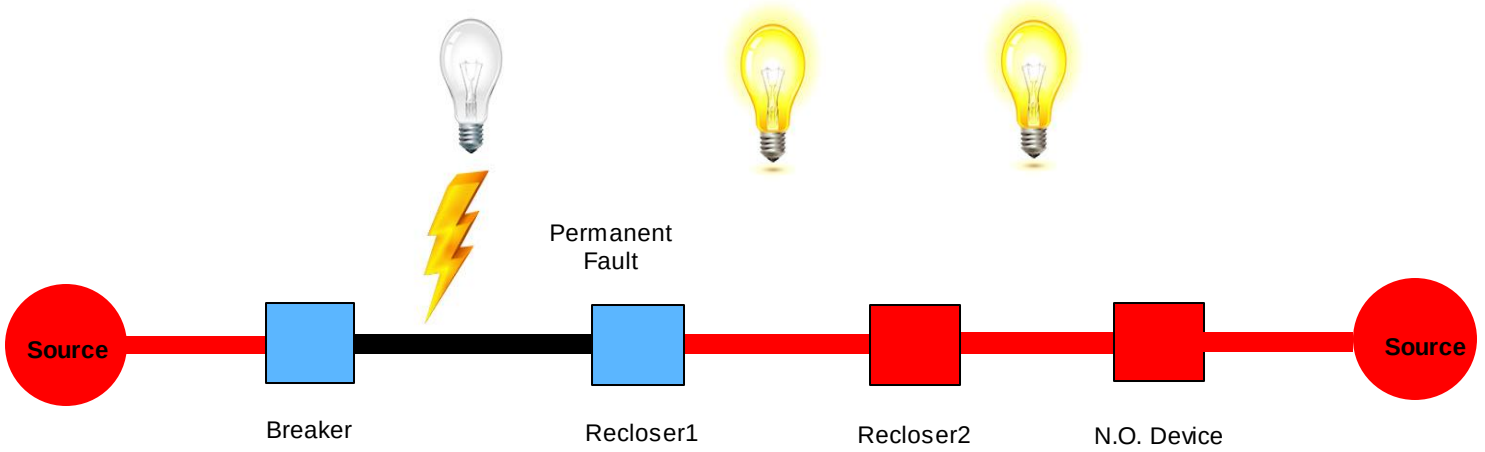
Zone 1
Customer

Zone 2
Customer

Zone 3
Customer

Powering Business Worldwide

FLISR Basics



Zone 1
Customer

Zone 2
Customer

Zone 3
Customer

Powering Business Worldwide

Reliability as a function of devices per feeder with FLISR

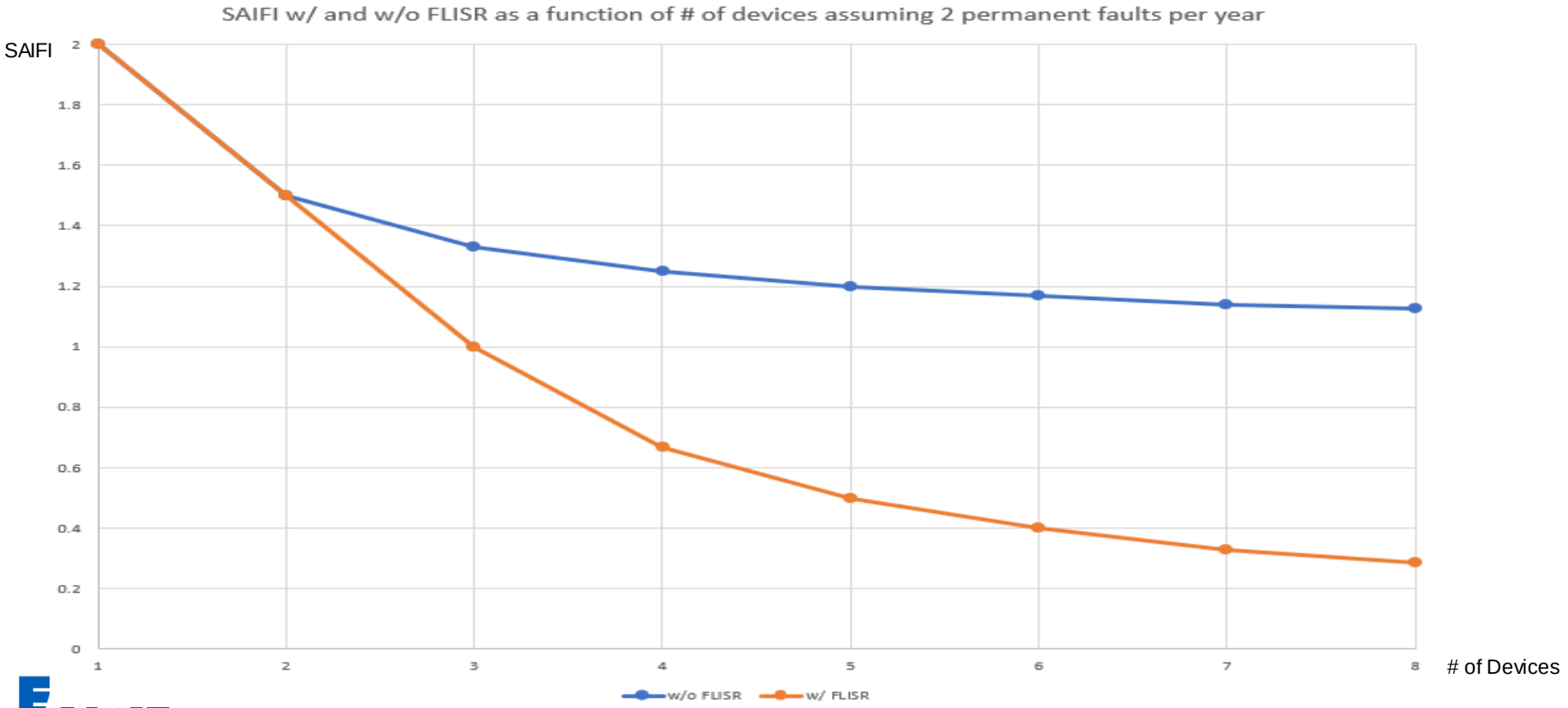
1000 Customers
2 Outages/year, 60 minutes each outage

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

Powering Business Worldwide

SAIFI with and without FLISR



Powering Business Worldwide

Fault Indicators
Ryan Rausch

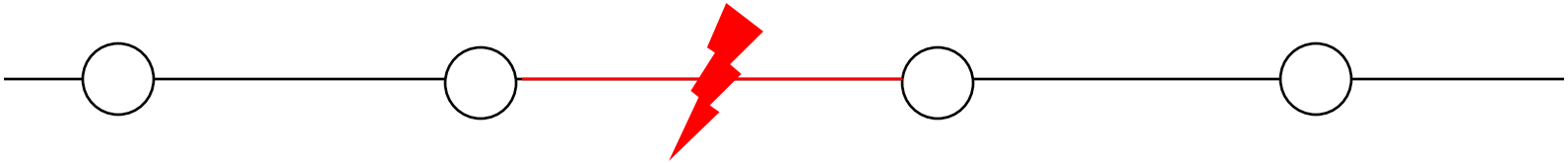
The role of fault indicators

- 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

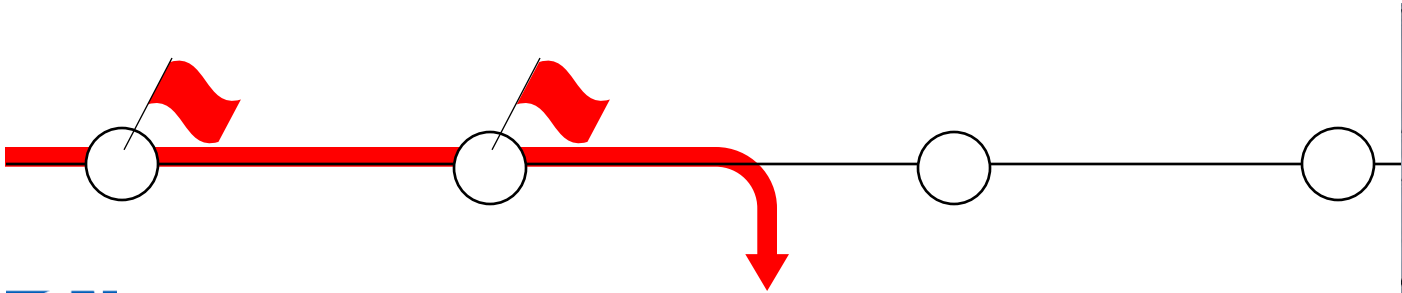
Powering Business Worldwide

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



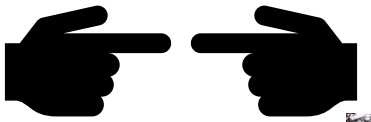
Communicating Fault Indicators

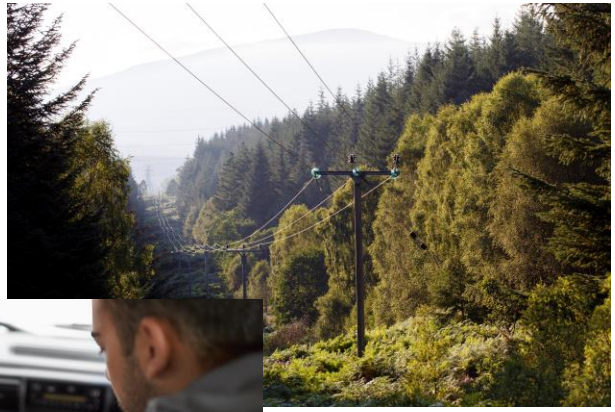
- Communications provide visibility at the control center for a more holistic view of the event
  - Aggregation of fault indicator statuses
  - Timestamping for multiple-fault events
- Enables targeted dispatching of crews
  - Smaller sections to patrol
  - Plan ahead for feeder splits or obstacles

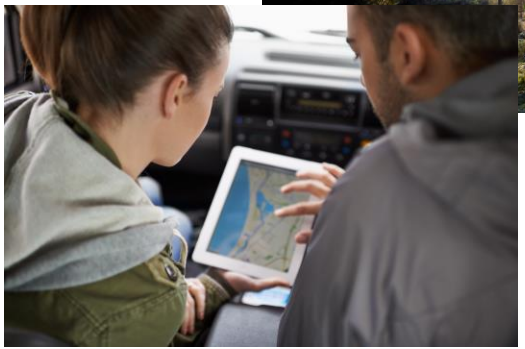
Powering Business Worldwide

Placement parameters

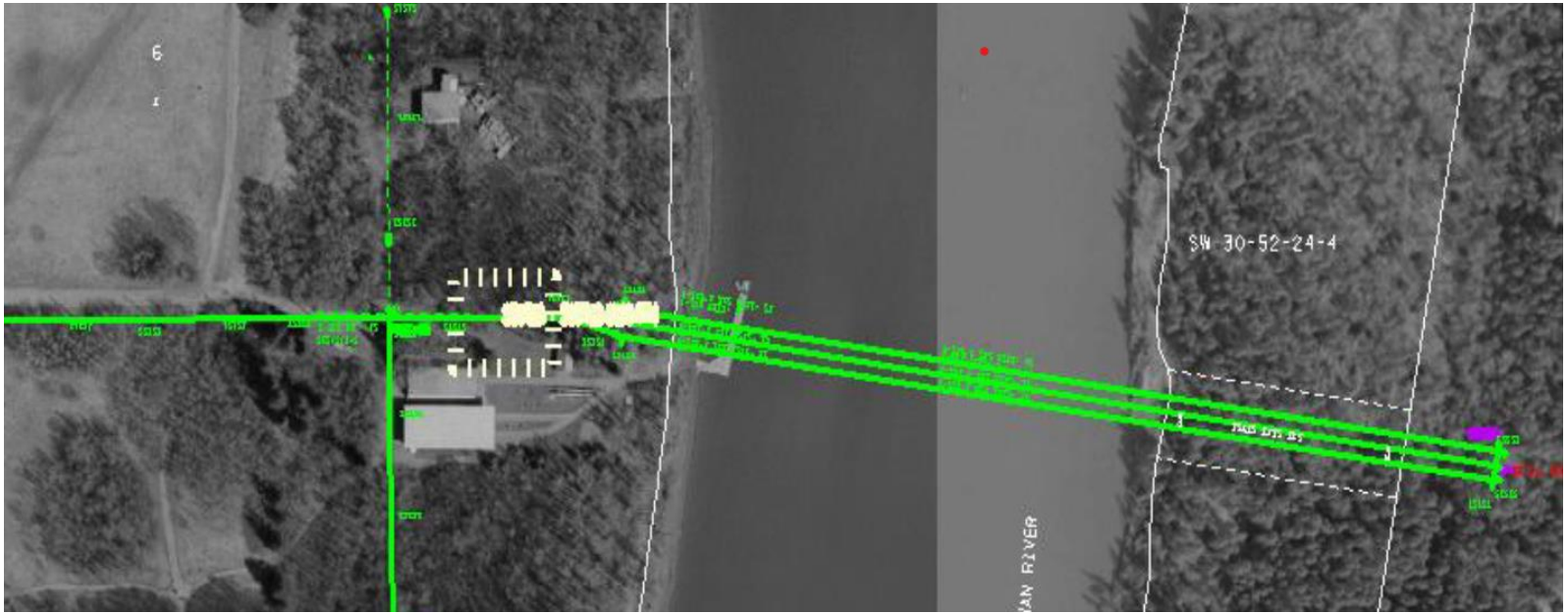
- Customers: sensitive or troublesome sites (not customer count)
- Patrol time: Eliminate sections with difficult terrain/environment
- Drive Time: Plan ahead for the optimal route
- Other Considerations: Line current, Signal level







River Crossing



Riser Pole Deployment

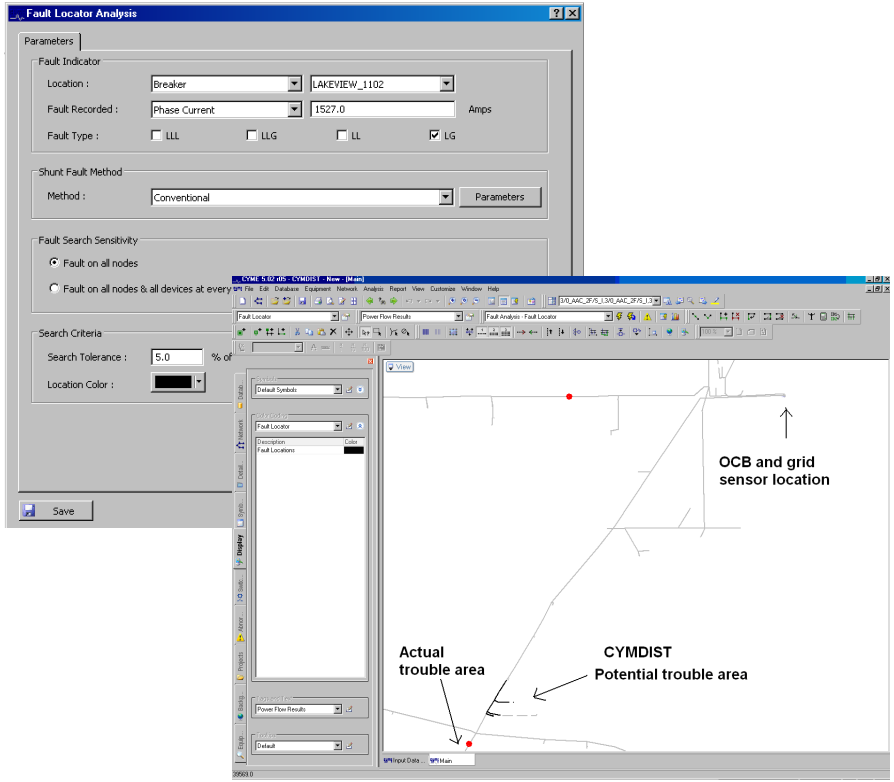
Powering Business Worldwide

Underground Deployment

Powering Business Worldwide

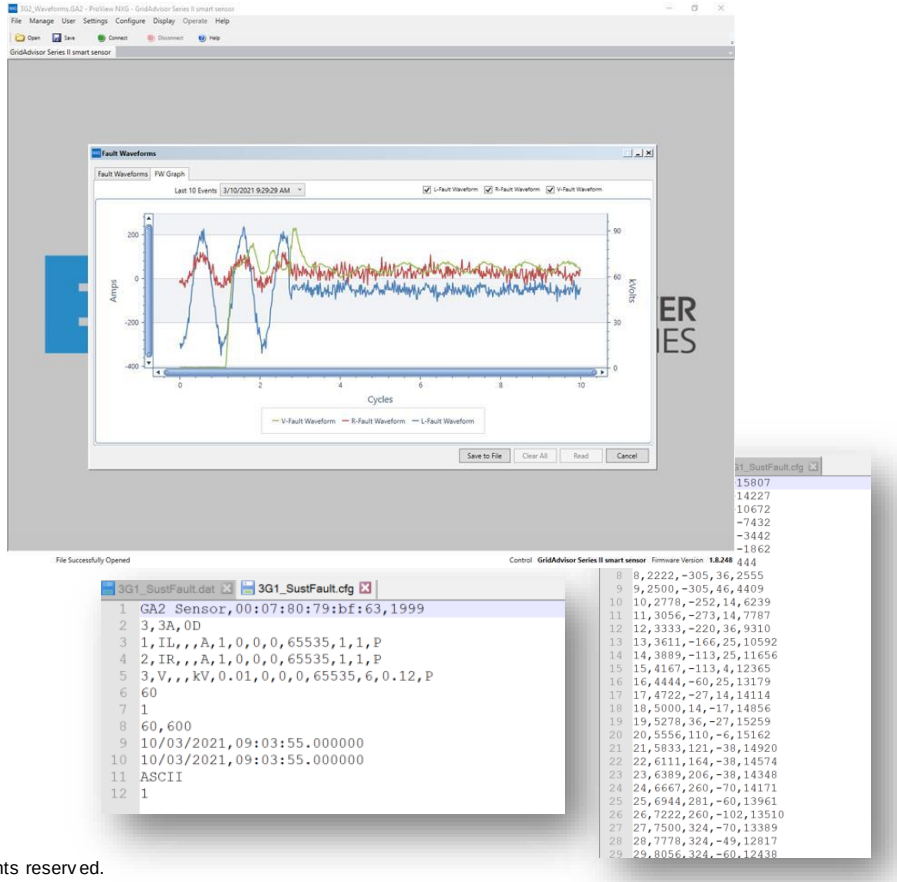
Fault Magnitude and Direction

- 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

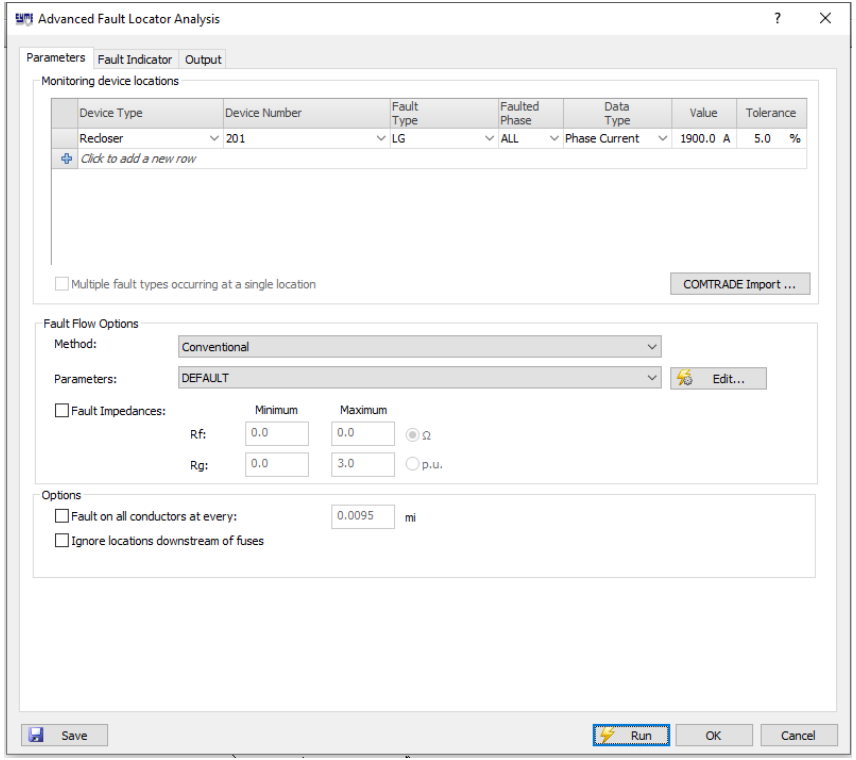


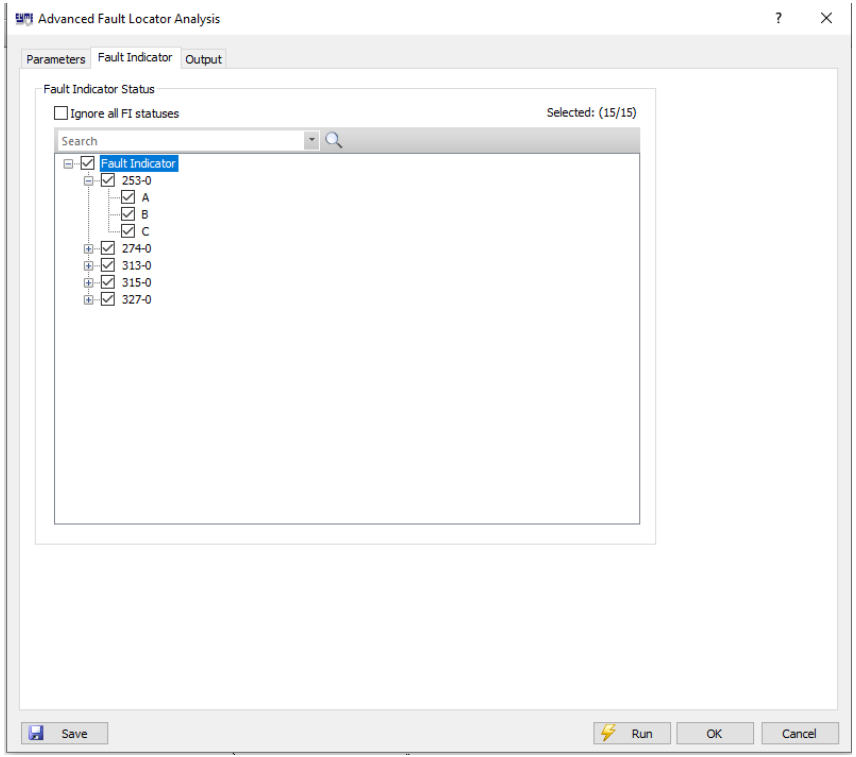
Powering Business Worldwide

Advanced Fault Locator in CYME

Mikaela Mohaupt

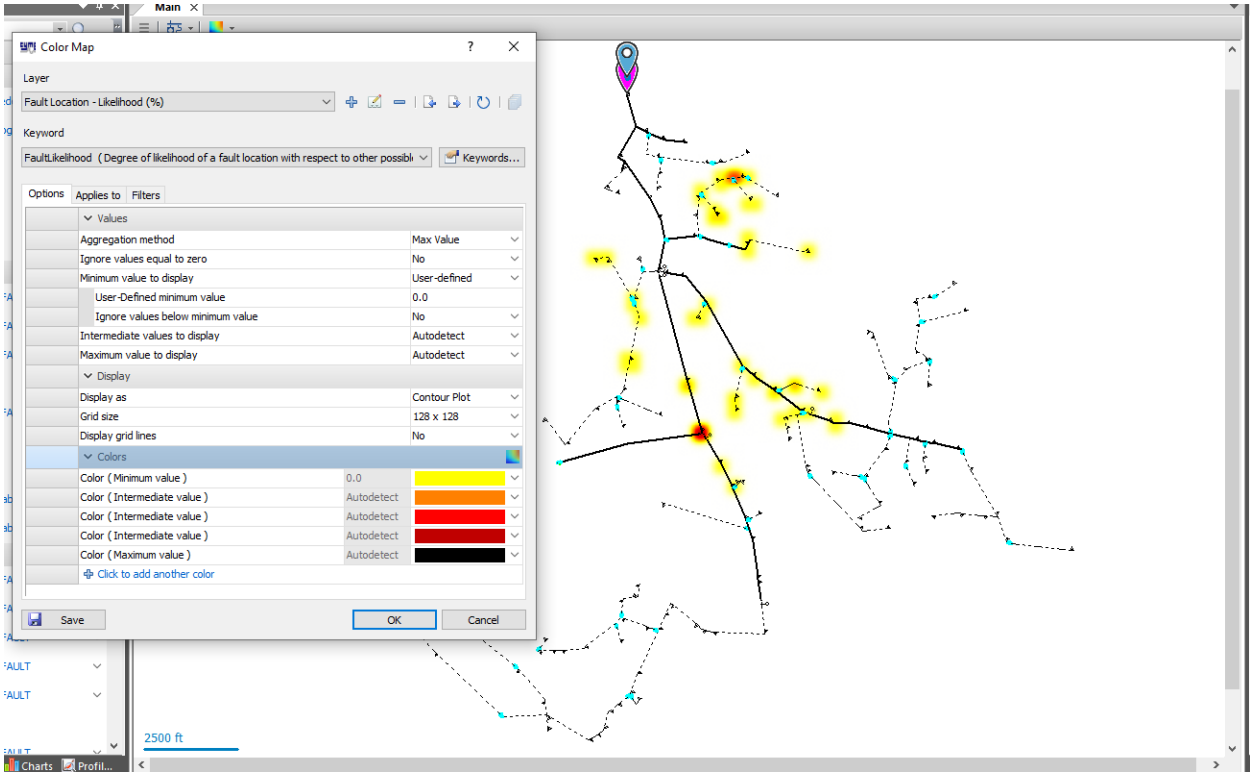
CYME Advanced Fault Locator - Parameters





Powering Business Worldwide

CYME Advanced Fault Locator - Results



Preventative/Predictive Measures

Ryan Rausch

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:

momcounts | Apply | Advanced >>

Use regular expressions

An advanced filter is currently defined for this view

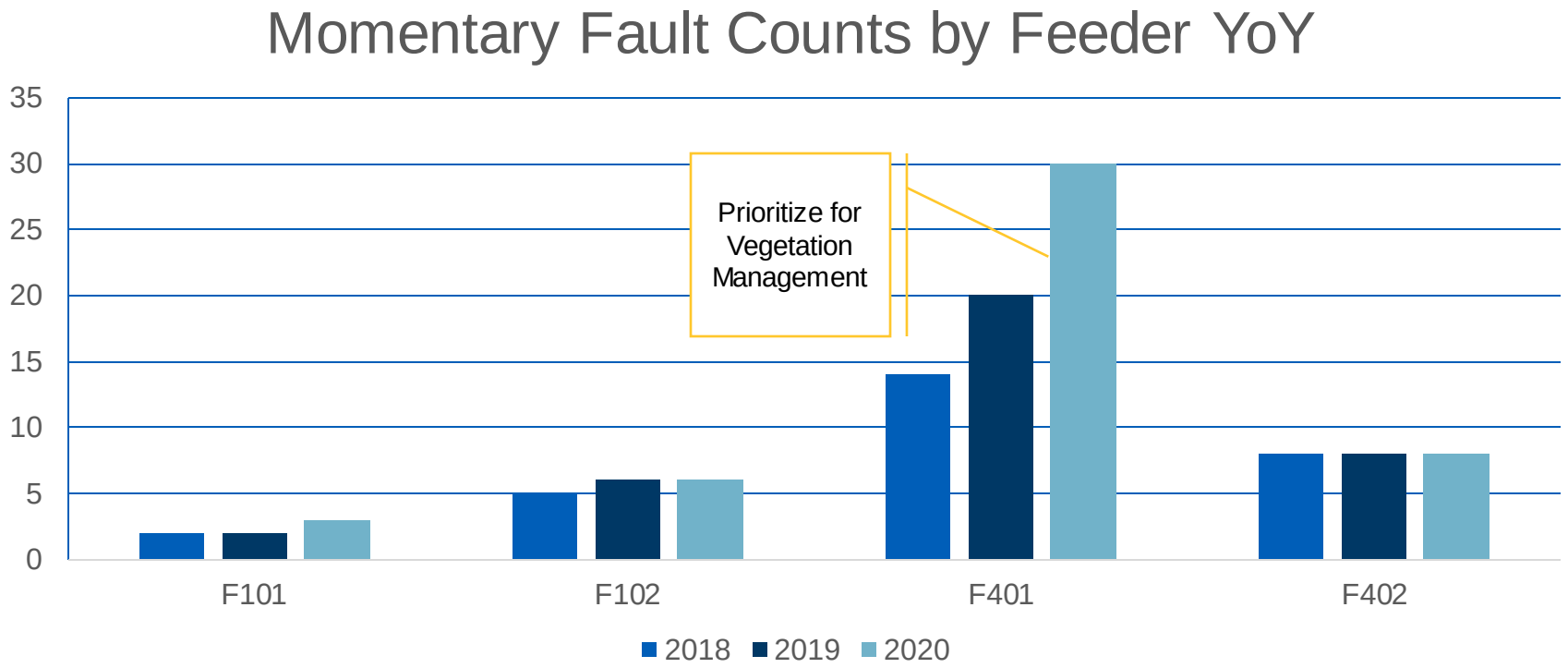
Server Views - Analog Inputs (17 / 1779 Data Points)

Typ	St	Counter	Name	Value	Description	D
		1	YGS_SS6-000780A4B5C8_MomCounts	12.0	Walker Art center: Momentary faults count	3/1
		1	YGS_SS6-000780A4B5C6_MomCounts	12.0	Walker Art center: Momentary faults count	3/1
		1	YGS_SS6-000780A4B5C7_MomCounts	12.0	Walker Art center: Momentary faults count	3/1
		1	YGS_SS7-000780345678_MomCounts	1.0	Hennepin Ave. and 36th: Momentary faults count	3/1
		1	YGS_SS7-000780123456_MomCounts	1.0	Hennepin Ave. and 36th: Momentary faults count	3/1
		1	YGS_SS9-000780A3B2C1_MomCounts	1.0	US Bank Stadium: Momentary faults count	3/1
		1	YGS_SS6-000780A3B2C2_MomCounts	1.0	US Bank Stadium: Momentary faults count	3/1
		1	YGS_SS7-000780234567_MomCounts	1.0	Hennepin Ave. and 36th: Momentary faults count	3/1
		1	YGS_SS1-000780A3B2C3_MomCounts	1.0	US Bank Stadium: Momentary faults	3/1

Monitor this…

Powering Business Worldwide

Momentary Faults



Powering Business Worldwide

Condition-based Maintenance

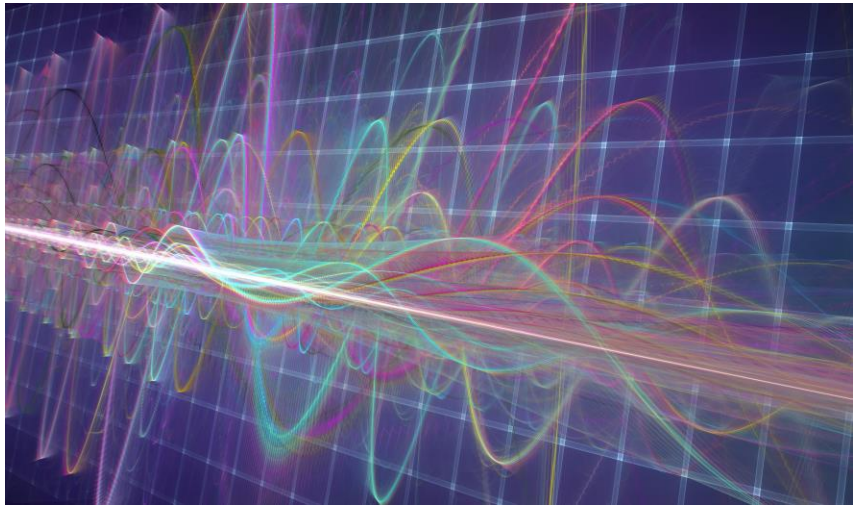
- Recloser Contact Lifecycle Monitoring
  - Deploy with hydraulic recloser assets to monitor remaining contact life and drive condition-based maintenance
  - Based on IEEE-defined recloser duty cycle test

- 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

Powering Business Worldwide

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



Eaton.com/WhatMatters