EPRI Protection Settings Evaluation Tool (PSET)

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Protection Settings Evaluation Tool (PSET)

Software

Intended use:

- Automatically assess the protection performance and identify misoperations, uncleared faults, and near-misses
- Use Web Browser/Excel/Access interface to report, track and trend over time

Requires network model with at least some protection relays in CAPE or ASPEN

Project Task Timeline

2015: Initial version of CAPE macro

2016: ASPEN macro, add near-miss to CAPE macro, basic database, case studies

2017: Optimize macros for speed, add new study scenarios, develop advanced trending database, case studies

2018: Further simulations, case studies

The Problem – Protection Misoperations

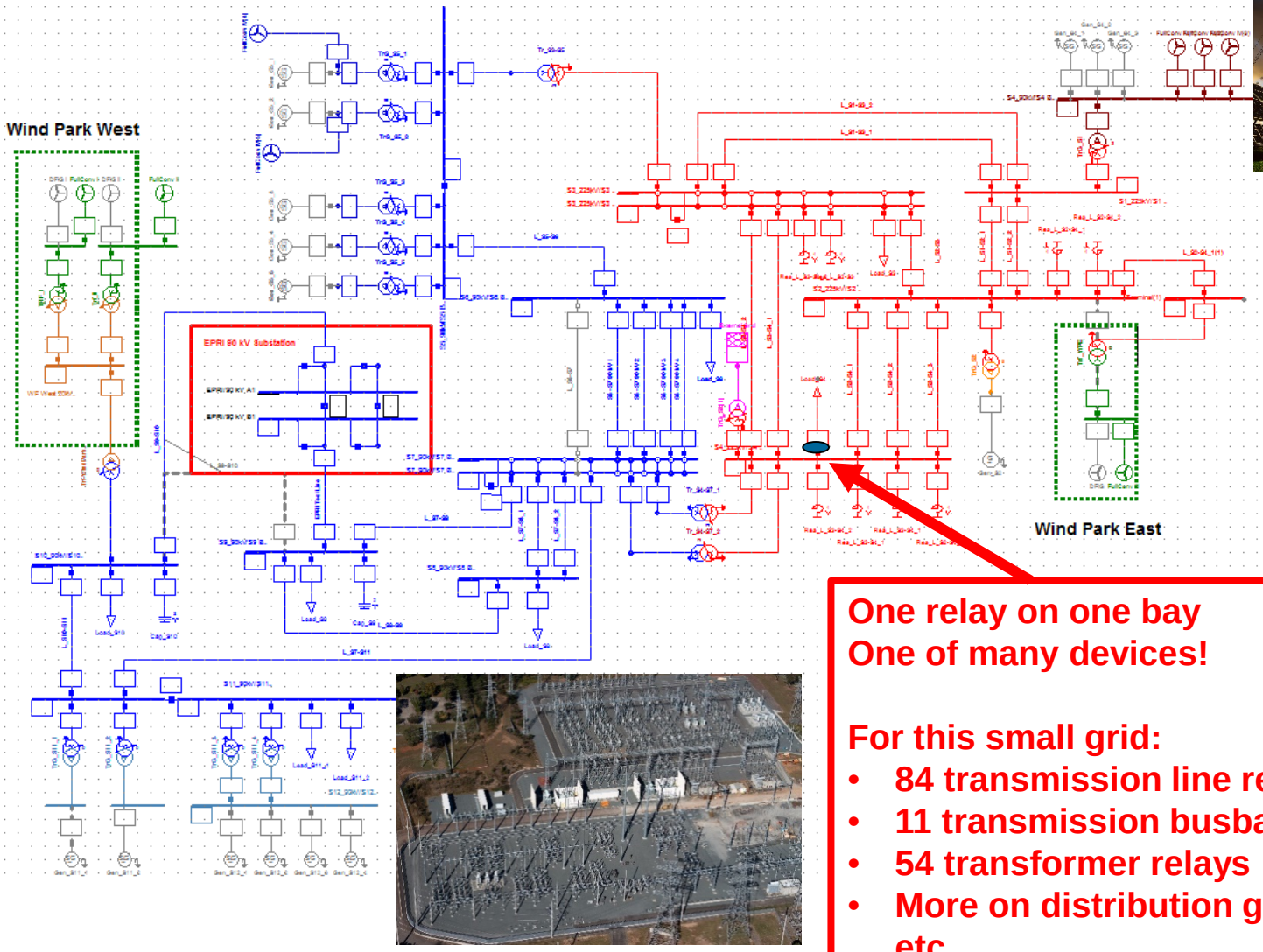
NERC Stats

- Misoperations occur in roughly 1 in 10 faults
- Approximately 29% of protection misoperations are due to settings, logic or design errors.
- NERC Events Analysis determined that incorrect ground instantaneous overcurrent settings on 115 kV and 230kV systems are a leading cause of relay misoperations.

Trends

- Misoperations tend to be more commonly associated with numerical relays. Number of numerical relays increasing.
- Significant changes to the system (generation retirements, etc.) are occurring quickly and can impact the performance of protection systems.
- Industry is losing P&C expertise at a rapid pace.

Grid Scenarios for Relay Settings



One relay on one bay
One of many devices!

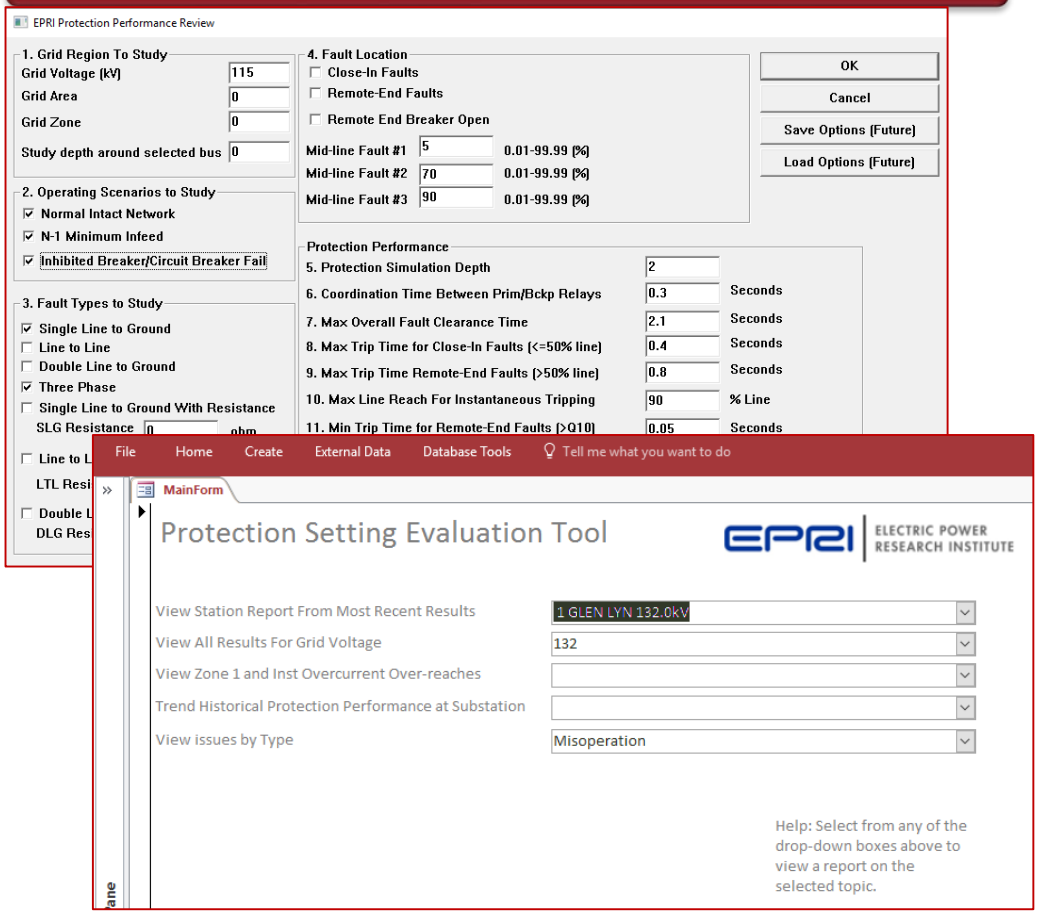
For this small grid:

- **84 transmission line relays**
- **11 transmission busbar protection**
- **54 transformer relays**
- **More on distribution grid, generators etc**

Relays commissioned at different times
Settings based on different grid scenarios
Settings often not kept in a centralised DB

Protection Settings Evaluation Tool (PSET)

Implemented using both CAPE and OneLiner



- Evaluate coordination of protection near a busbar, in a grid area or across whole grid
  - Applies multiple fault types across all lines in study area
- Flags relay misoperations, fast/slow trips, uncleared faults
- View results in web browser & store in database for simple reporting, trending over time
- Use database to track performance. Flag when grid changes cause relays to become miscoordinated.

Proactively identify & avert potential misoperations!

What does PSET Analyze?

Examines local protection relays after short circuit simulated and again after each circuit breaker trips open

Was the fault isolated?

- Did each relay trip correctly and quickly?
- Did any relay over-reach?
- Were any relays miscoordinated?
- Was any relay close to misoperation (near miss)?

Has Protection Performance Changed Since the Last Time the Tool was Run?

Define Fault Study and Protection Criteria - CAPE

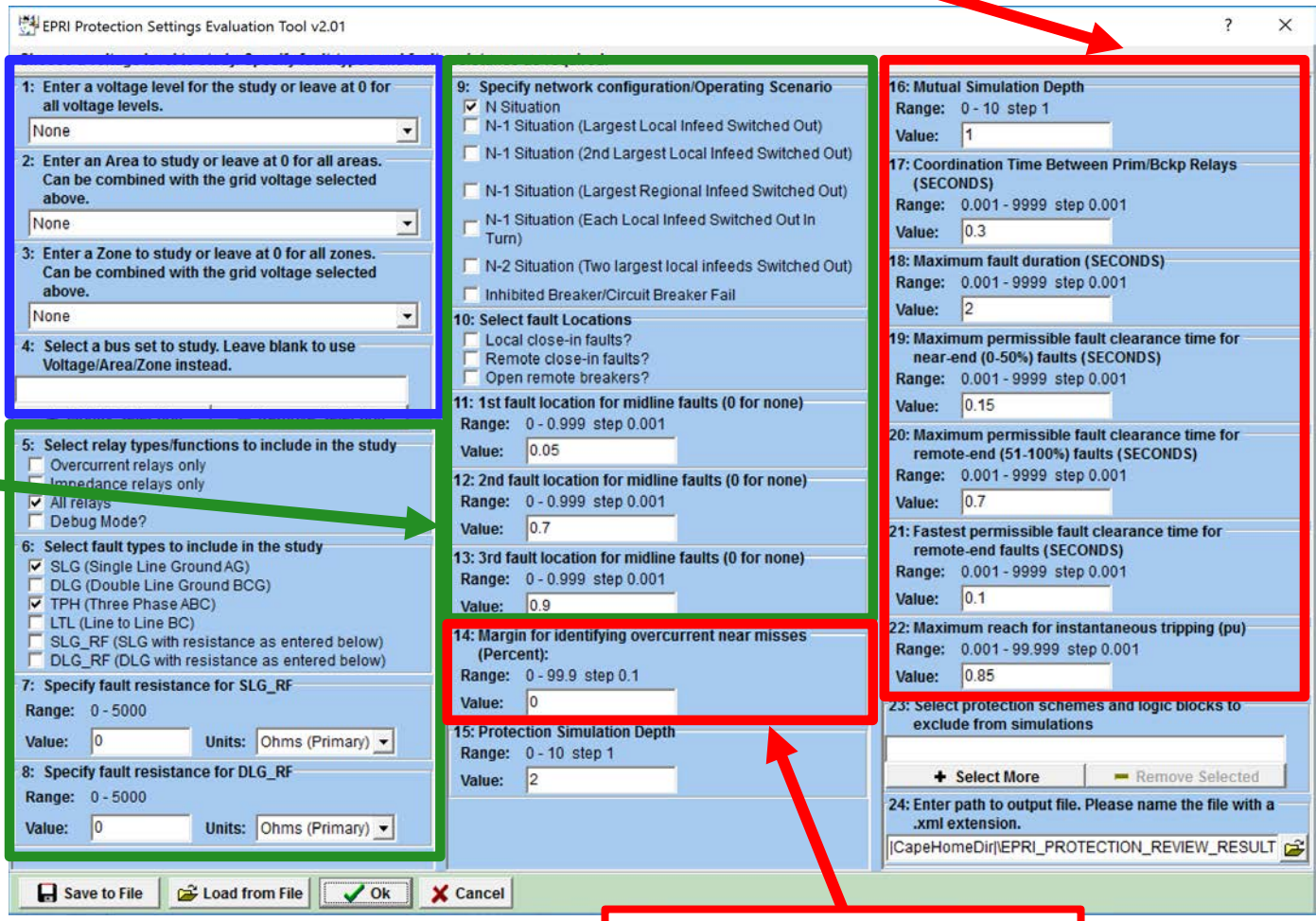
Define protection performance requirements

Study all of a grid voltage level, area/zone, or all lines within X buses of the selected busbar

Study various fault scenario combinations:

- **Grid scenarios**
- **Fault Types**
- **Fault Locations**

Selecting all the options means 10,000s of fault simulations!



Identify Near-Misses

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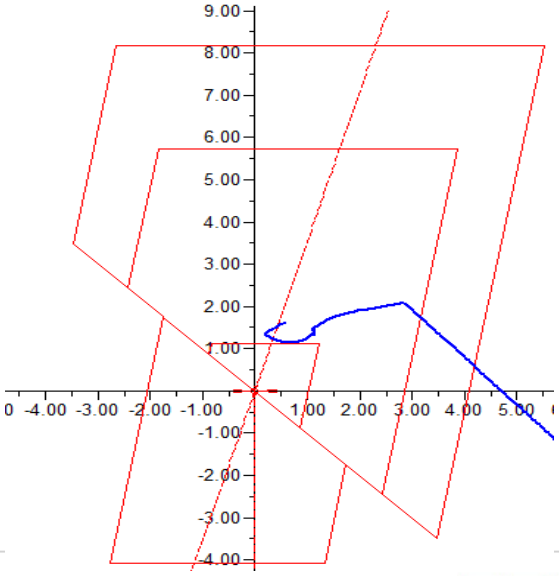
Identifying Protection Misoperation Near Misses

Simulations never 100% accurate

Fault current in practice is greater or less than simulation

- Trip setting=1000A, but what if fault current is 999A or 1001A?
- “Near-miss” feature identifies settings with small margin



CAPE/ASPEN Macros – Results – Web Browser

- Output file in XML file format
- Can open in a Web Browser, Excel, Access etc
- High-level results per fault; hover mouse over a fault and a box pops up with specific relay op details
- Just click CTRL-O from Internet Explorer, FireFox, or Excel and select the XML file

EPRI Protection Settings Evaluation Tool 2017 (BETA) Results	
Results Created:	29-Aug-17 11:02:31
Database:	C:\Program Files (x86)\ASPEN\1LPFv14\SAMPLE30.OLR
Network Study Date:	29-08-2017
Studied Grid Voltage:	132
Studied Grid Area:	0
Studied Grid Zone:	0
Studied Busbar:	

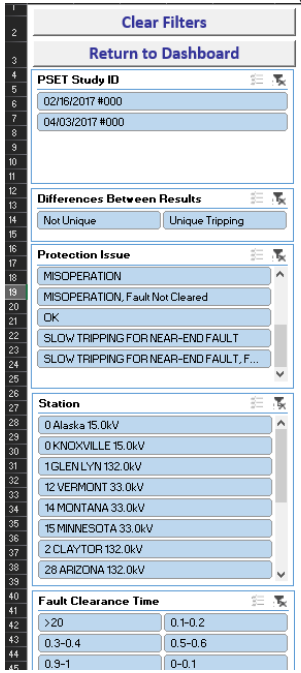
Fault Number	From Station	To Station	Voltage (kV)	Circuit ID	Distance To Fault	Fault Type	Contingency	Outage(s)	Fault Clearance Time (Seconds)	Test Result
1	2 CLAYTOR 132.0kV	1 GLEN LYN 132.0kV	132	1	5	SINGLE_LINE_GROUND, R=0 (ohm)	Normal state with intact network		9999.000	Inst Over-reach Misoperation, Fault Not Cleared
2	1 GLEN LYN 132.0kV	2 CLAYTOR 132.0kV	132	1	5	SINGLE_LINE_GROUND, R=0 (ohm)	Normal state with intact network		9999.000	MISOPERATION, Fault Not Cleared
3										
4										
5										
6										
7										Cleared
8	1 GLEN LYN 132.0kV	2 CLAYTOR 132.0kV	132	2	5	SINGLE_LINE_GROUND, R=0 (ohm)	Normal state with intact network		9999.000	MISOPERATION, Fault Not Cleared
9	2 CLAYTOR 132.0kV	1 GLEN LYN 132.0kV	132	2	70	SINGLE_LINE_GROUND, R=0 (ohm)	Normal state with intact network		9999.000	MISOPERATION, Fault Not Cleared
10	1 GLEN LYN 132.0kV	2 CLAYTOR 132.0kV	132	2	70	SINGLE_LINE_GROUND, R=0 (ohm)	Normal state with intact network		9999.000	Inst Over-reach Misoperation, Fault Not Cleared

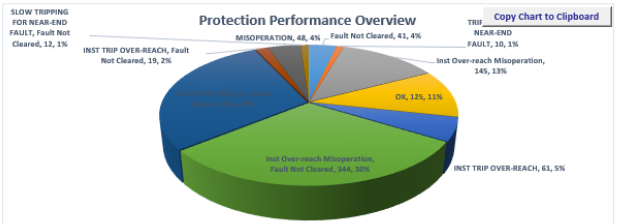
Station	Circuit Breaker	Voltage (kV)	Circuit ID	Tripping Relay	Tripping Element	Trip time (Seconds)	Test Result
6 NEVADA 132.0kV	2 CLAYTOR 132.0kV	132		NV-G2 (B)	Ground Overcurrent	0.064	MISOPERATION
8 REUSENS 132.0kV	6 NEVADA 132.0kV	132		RE-G1 (B)	Ground Overcurrent	1.319	MISOPERATION
7 OHIO 132.0kV	6 NEVADA 132.0kV	132		OH-P1 (B)	Phase Overcurrent	0.756	MISOPERATION
7 OHIO 132.0kV	6 NEVADA 132.0kV	132		OH-G1 (B)	Ground Overcurrent	1.008	MISOPERATION
6 NEVADA 132.0kV	10 NEW HAMPSHR 33.0kV	33		NE-NH01 (B)	Ground Overcurrent	0.995	MISOPERATION

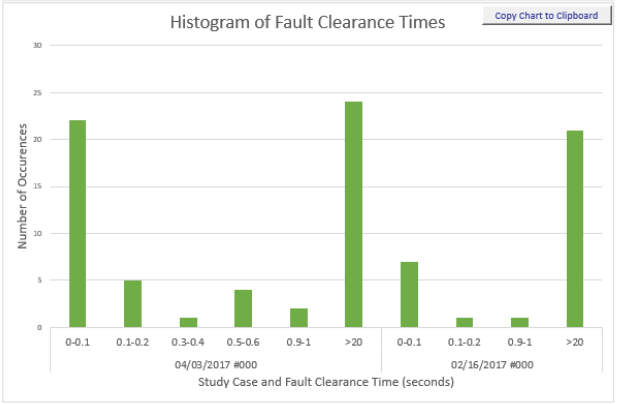
CAPE/ASPEN Macros – Results – New Excel Interface

2017 - New Excel Sheet Interface

- Presents high level overview of latest or historical simulation run
- Compare sets of results; e.g. this week vs last month/last year
- Easy to filter results by station, fault clearance issue etc. Report instantly updates
- Identify changes since last run – flag new misoperations, miscoordinations, uncleared faults that weren't an issue the last time you ran the tool
- Track/trend fault clearance times
- Present high level statistics and graphs on fault clearance times and issue type







Copy Results Table

RELAY OPERATIONS

PSET Study ID	Faulted Circuit	Clearance Time	Protection Performance Assessment	Tripped Element	Tripping Element	Trip Time
04/03/2017 #000	2 CLAYTOR 132.0kV 1 GLEN LYN 132.0kV 1 13:	0.05	Inst Over-reach Misoperation	1 GLEN LYN 132.0kV 2 CLAYTOR 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
				2 CLAYTOR 132.0kV 1 GLEN LYN 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
				6 NEVADA 132.0kV 2 CLAYTOR 132.0kV	Ground Overcurr	0.032
						0.050
			OK	1 GLEN LYN 132.0kV 2 CLAYTOR 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
				2 CLAYTOR 132.0kV 1 GLEN LYN 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
	1 GLEN LYN 132.0kV 2 CLAYTOR 132.0kV 1 13:	0.05	Inst Over-reach Misoperation	1 GLEN LYN 132.0kV 2 CLAYTOR 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
				2 CLAYTOR 132.0kV 1 GLEN LYN 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
				6 NEVADA 132.0kV 2 CLAYTOR 132.0kV	Ground Overcurr	0.037
						0.033
			OK	1 GLEN LYN 132.0kV 2 CLAYTOR 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
				2 CLAYTOR 132.0kV 1 GLEN LYN 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
			INST TRIP OVER-REACH	1 GLEN LYN 132.0kV 2 CLAYTOR 132.0k'	Phase Overcurre	0.017
				2 CLAYTOR 132.0kV 1 GLEN LYN 132.0k'	Phase Overcurre	0.017
	2 CLAYTOR 132.0kV 1 GLEN LYN 132.0kV 2 13	0.05	Inst Over-reach Misoperation	6 NEVADA 132.0kV 2 CLAYTOR 132.0kV	Ground Overcurr	0.032
						0.050
				1 GLEN LYN 132.0kV 2 CLAYTOR 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
				2 CLAYTOR 132.0kV 1 GLEN LYN 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
			OK	1 GLEN LYN 132.0kV 2 CLAYTOR 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
				2 CLAYTOR 132.0kV 1 GLEN LYN 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
	1 GLEN LYN 132.0kV 2 CLAYTOR 132.0kV 2 13	0.05	Inst Over-reach Misoperation	6 NEVADA 132.0kV 2 CLAYTOR 132.0kV	Ground Overcurr	0.037
						0.033
				1 GLEN LYN 132.0kV 2 CLAYTOR 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
				2 CLAYTOR 132.0kV 1 GLEN LYN 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
			OK	1 GLEN LYN 132.0kV 2 CLAYTOR 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
				2 CLAYTOR 132.0kV 1 GLEN LYN 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
			INST TRIP OVER-REACH	1 GLEN LYN 132.0kV 2 CLAYTOR 132.0k'	Phase Overcurre	0.017

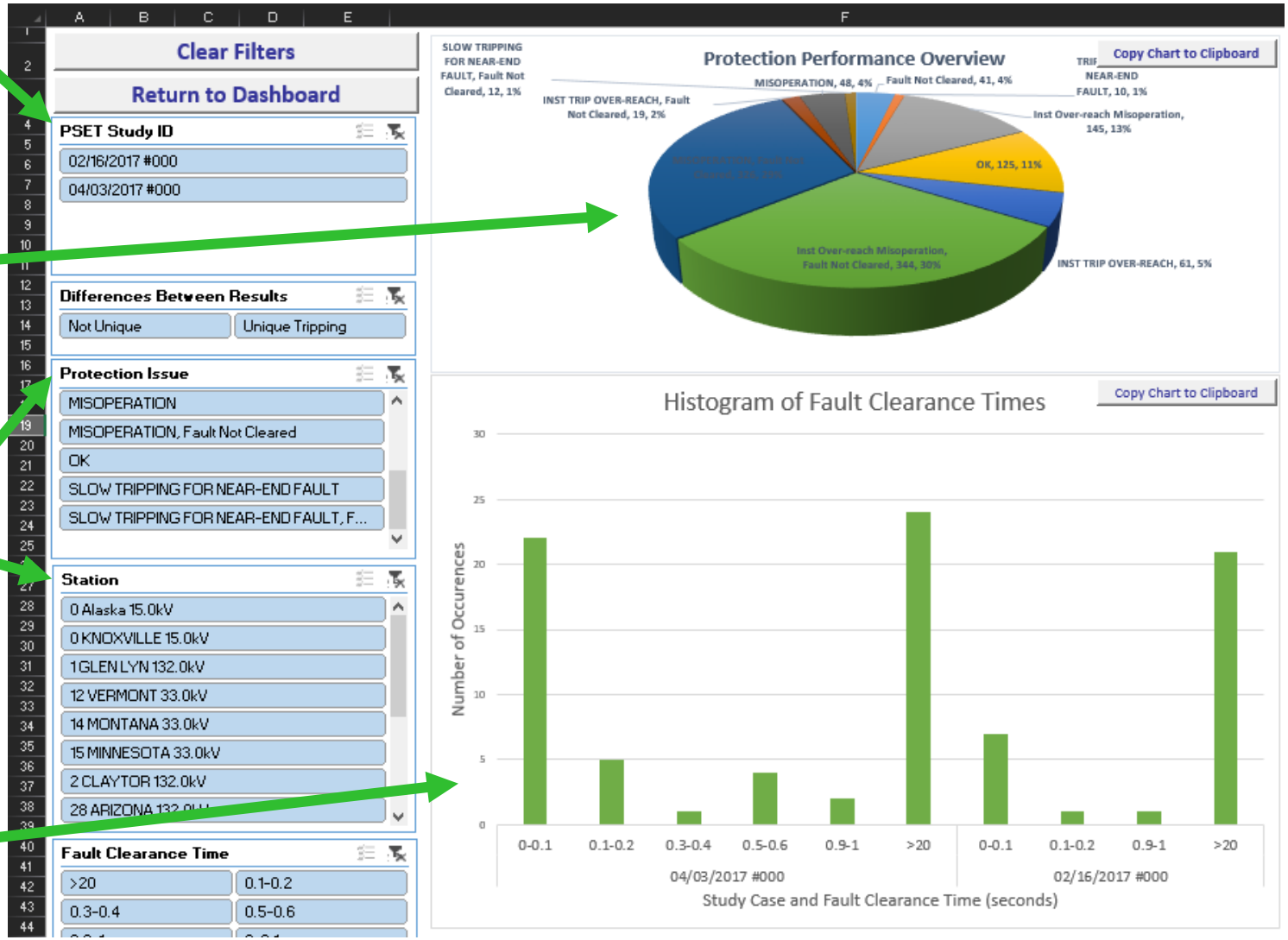
CAPE/ASPEN Macros – Results – New Excel Interface

User can view results from one or more past studies

Pie chart showing main protection issues

Easily filter results to look at particular stations or examine particular issues

Present spread of trip times for all faults



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CAPE/ASPEN Macros – Results – New Excel Interface

By clicking on filters shown in previous slide, the main table automatically and instantaneously updates

Results shown here are just faults on lines connected to Glen Lyn 132 kV

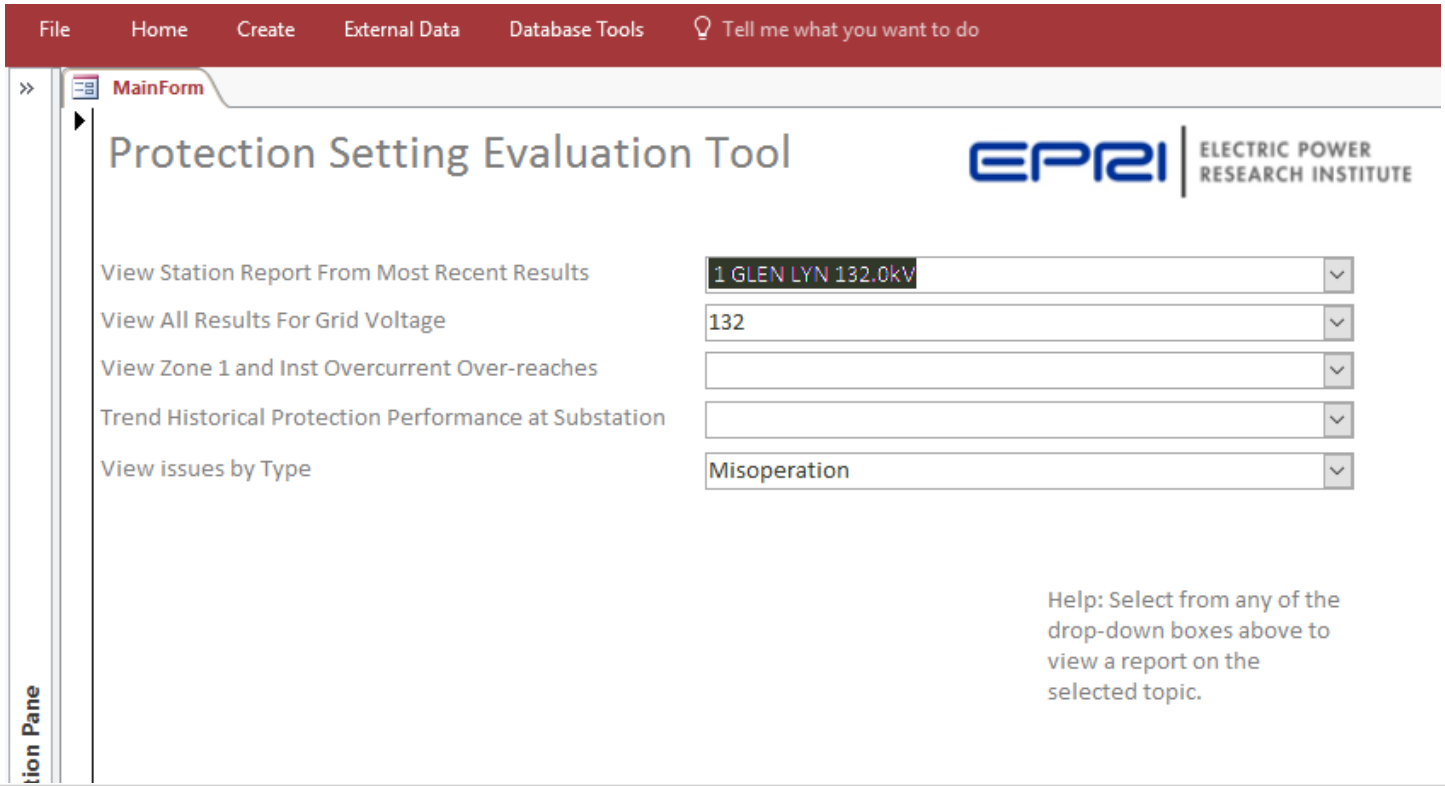
Copy Results Table

RELAY OPERATIONS

PSET Study ID	Faulted Circuit	Clearance Time	Protection Performance Assessment	Tripped Element	Tripping Element	Trip Time
04/03/2017 #000	1 GLEN LYN 132.0kV 2 CLAYTOR 132.0kV 1 13:	0.05	Inst Over-reach Misoperation	1 GLEN LYN 132.0kV 2 CLAYTOR 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
				2 CLAYTOR 132.0kV 1 GLEN LYN 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
				6 NEVADA 132.0kV 2 CLAYTOR 132.0kV	Ground Overcurr	0.037
						0.033
			OK	1 GLEN LYN 132.0kV 2 CLAYTOR 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
				2 CLAYTOR 132.0kV 1 GLEN LYN 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
			INST TRIP OVER-REACH	1 GLEN LYN 132.0kV 2 CLAYTOR 132.0k'	Phase Overcurre	0.017
				2 CLAYTOR 132.0kV 1 GLEN LYN 132.0k'	Phase Overcurre	0.017
	1 GLEN LYN 132.0kV 2 CLAYTOR 132.0kV 2 13	0.05	Inst Over-reach Misoperation	6 NEVADA 132.0kV 2 CLAYTOR 132.0kV	Ground Overcurr	0.037
						0.033
				1 GLEN LYN 132.0kV 2 CLAYTOR 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
				2 CLAYTOR 132.0kV 1 GLEN LYN 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
			OK	1 GLEN LYN 132.0kV 2 CLAYTOR 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
				2 CLAYTOR 132.0kV 1 GLEN LYN 132.0k'	Phase Overcurre	0.017
			INST TRIP OVER-REACH	1 GLEN LYN 132.0kV 2 CLAYTOR 132.0k'	Phase Overcurre	0.017
				2 CLAYTOR 132.0kV 1 GLEN LYN 132.0k'	Phase Overcurre	0.017
	1 GLEN LYN 132.0kV 3 TEXAS 132.0kV 1 132	9999	Inst Over-reach Misoperation, Fault Not Cleared	6 NEVADA 132.0kV 2 CLAYTOR 132.0kV	Ground Overcurr	0.080
						0.557
				2 CLAYTOR 132.0kV 1 GLEN LYN 132.0k'	Phase Overcurre	0.017
					Ground Overcurr	0.017
				5 FIELDALE 132.0kV 2 CLAYTOR 132.0k	Ground Overcurr	6.786
				8 REUSENS 132.0kV 6 NEVADA 132.0kV	Ground Overcurr	1.361
						1.142
				7 OHIO 132.0kV 6 NEVADA 132.0kV	Phase Overcurre	0.720
						0.656
						0.565
					Ground Overcurr	0.909
						0.541
			MISOPERATION, Fault Not Cleared	6 NEVADA 132.0kV 2 CLAYTOR 132.0kV	Ground Overcurr	0.462
				5 FIELDALE 132.0kV 2 CLAYTOR 132.0k	Ground Overcurr	6.786
				8 REUSENS 132.0kV 6 NEVADA 132.0kV	Ground Overcurr	1.239
				7 OHIO 132.0kV 6 NEVADA 132.0kV	Phase Overcurre	0.611
						0.596
						0.550

CAPE/ASPEN Macros – Results – Access Database

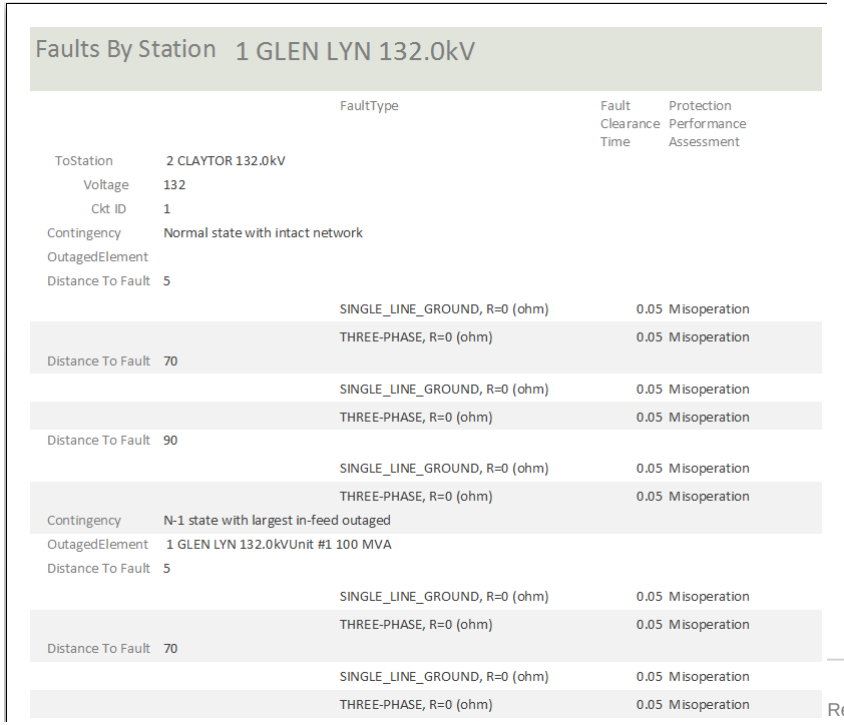
- Output file in XML file format; Can also import into an Access Database
- Store protection assessment results
- Easily create custom reports for trending over time, audit reports etc
- Basic version complete in 2016, advanced version with tracking/trending/auditing in 2017



CAPE/ASPEN Macros – Results – Access Database

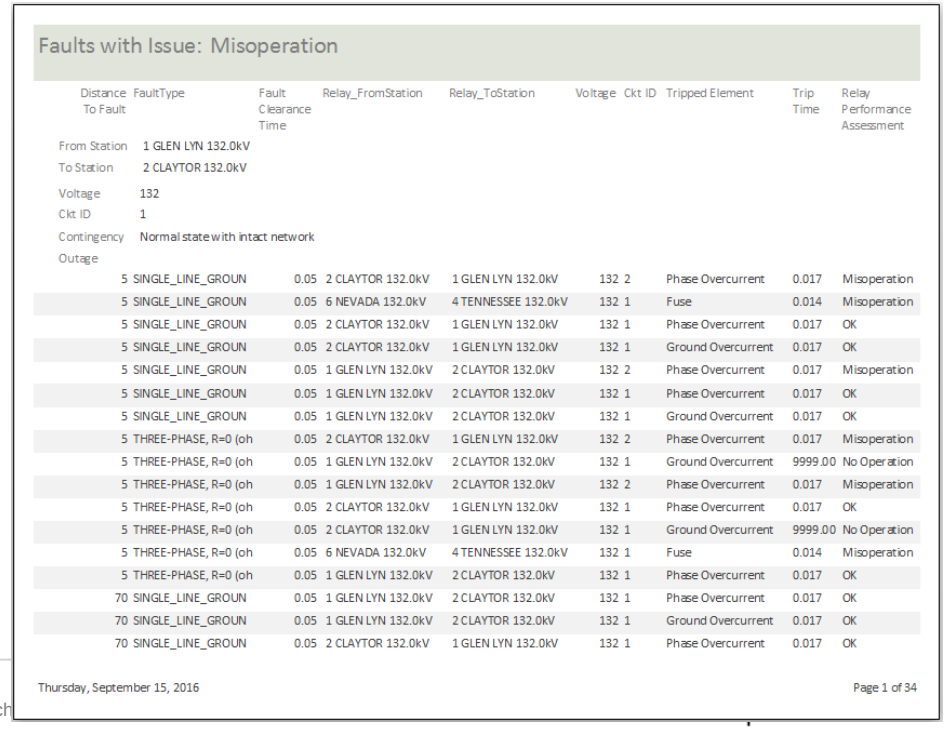
Quickly Generate Reports such as:

- View all Zone 1/Overcurrent over-reaches
- View protection performance near a line or a station
- Trend over time, find where protection performance across the grid has improved or new issues have arisen e.g.
  - New issues flagged this month that weren't there last month or 2017 vs 2016
- Study future grids and see if new issues arise in coming year with the commissioning of new lines, commissioning/de-commissioning of generators



Faults By Station 1 GLEN LYN 132.0kV

		FaultType	Fault Clearance Time	Protection Performance Assessment
ToStation	2 CLAYTOR 132.0kV			
Voltage	132			
Ckt ID	1			
Contingency	Normal state with intact network			
OutagedElement				
Distance To Fault	5			
		SINGLE_LINE_GROUND, R=0 (ohm)	0.05	Misoperation
		THREE-PHASE, R=0 (ohm)	0.05	Misoperation
Distance To Fault	70			
		SINGLE_LINE_GROUND, R=0 (ohm)	0.05	Misoperation
		THREE-PHASE, R=0 (ohm)	0.05	Misoperation
Distance To Fault	90			
		SINGLE_LINE_GROUND, R=0 (ohm)	0.05	Misoperation
		THREE-PHASE, R=0 (ohm)	0.05	Misoperation
Contingency	N-1 state with largest in-feed outaged			
OutagedElement	1 GLEN LYN 132.0kVUnit #1 100 MVA			
Distance To Fault	5			
		SINGLE_LINE_GROUND, R=0 (ohm)	0.05	Misoperation
		THREE-PHASE, R=0 (ohm)	0.05	Misoperation
Distance To Fault	70			
		SINGLE_LINE_GROUND, R=0 (ohm)	0.05	Misoperation
		THREE-PHASE, R=0 (ohm)	0.05	Misoperation



Faults with Issue: Misoperation

Distance To Fault	FaultType	Fault Clearance Time	Relay_FromStation	Relay_ToStation	Voltage	Ckt ID	Tripped Element	Trip Time	Relay Performance Assessment
From Station	1 GLEN LYN 132.0kV								
To Station	2 CLAYTOR 132.0kV								
Voltage	132								
Ckt ID	1								
Contingency	Normal state with intact network								
Outage									
5	SINGLE_LINE_GROUN	0.05	2 CLAYTOR 132.0kV	1 GLEN LYN 132.0kV	132	2	Phase Overcurrent	0.017	Misoperation
5	SINGLE_LINE_GROUN	0.05	6 NEVADA 132.0kV	4 TENNESSEE 132.0kV	132	1	Fuse	0.014	Misoperation
5	SINGLE_LINE_GROUN	0.05	2 CLAYTOR 132.0kV	1 GLEN LYN 132.0kV	132	1	Phase Overcurrent	0.017	OK
5	SINGLE_LINE_GROUN	0.05	2 CLAYTOR 132.0kV	1 GLEN LYN 132.0kV	132	1	Ground Overcurrent	0.017	OK
5	SINGLE_LINE_GROUN	0.05	1 GLEN LYN 132.0kV	2 CLAYTOR 132.0kV	132	2	Phase Overcurrent	0.017	Misoperation
5	SINGLE_LINE_GROUN	0.05	1 GLEN LYN 132.0kV	2 CLAYTOR 132.0kV	132	1	Phase Overcurrent	0.017	OK
5	SINGLE_LINE_GROUN	0.05	1 GLEN LYN 132.0kV	2 CLAYTOR 132.0kV	132	1	Ground Overcurrent	0.017	OK
5	THREE-PHASE, R=0 (oh	0.05	2 CLAYTOR 132.0kV	1 GLEN LYN 132.0kV	132	2	Phase Overcurrent	0.017	Misoperation
5	THREE-PHASE, R=0 (oh	0.05	1 GLEN LYN 132.0kV	2 CLAYTOR 132.0kV	132	1	Ground Overcurrent	9999.00	No Operation
5	THREE-PHASE, R=0 (oh	0.05	1 GLEN LYN 132.0kV	2 CLAYTOR 132.0kV	132	2	Phase Overcurrent	0.017	Misoperation
5	THREE-PHASE, R=0 (oh	0.05	2 CLAYTOR 132.0kV	1 GLEN LYN 132.0kV	132	1	Phase Overcurrent	0.017	OK
5	THREE-PHASE, R=0 (oh	0.05	2 CLAYTOR 132.0kV	1 GLEN LYN 132.0kV	132	1	Ground Overcurrent	9999.00	No Operation
5	THREE-PHASE, R=0 (oh	0.05	6 NEVADA 132.0kV	4 TENNESSEE 132.0kV	132	1	Fuse	0.014	Misoperation
5	THREE-PHASE, R=0 (oh	0.05	1 GLEN LYN 132.0kV	2 CLAYTOR 132.0kV	132	1	Phase Overcurrent	0.017	OK
70	SINGLE_LINE_GROUN	0.05	1 GLEN LYN 132.0kV	2 CLAYTOR 132.0kV	132	1	Phase Overcurrent	0.017	OK
70	SINGLE_LINE_GROUN	0.05	1 GLEN LYN 132.0kV	2 CLAYTOR 132.0kV	132	1	Ground Overcurrent	0.017	OK
70	SINGLE_LINE_GROUN	0.05	2 CLAYTOR 132.0kV	1 GLEN LYN 132.0kV	132	1	Phase Overcurrent	0.017	OK

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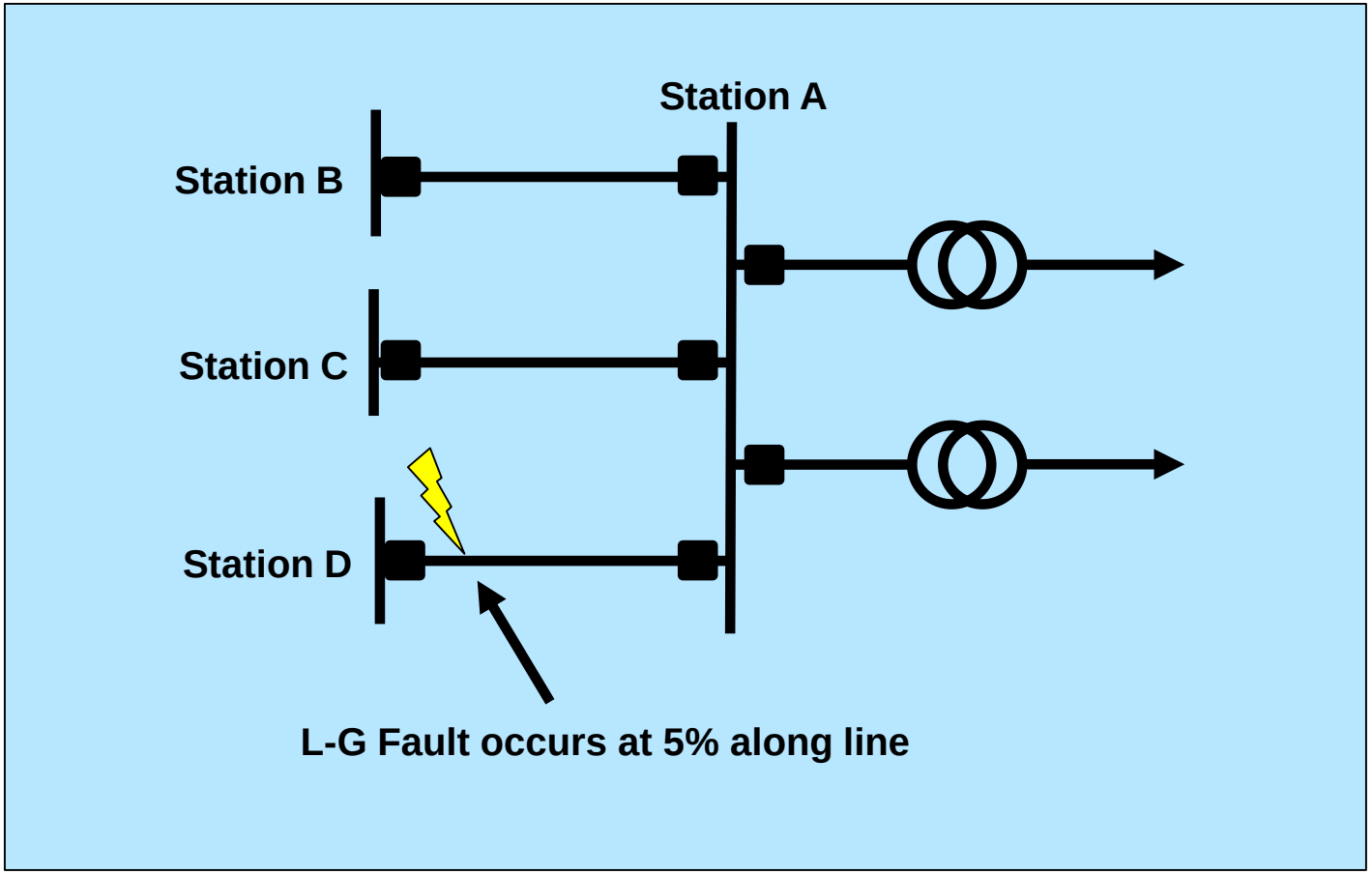
Summary of Protection Settings Evaluation Tool (PSET)

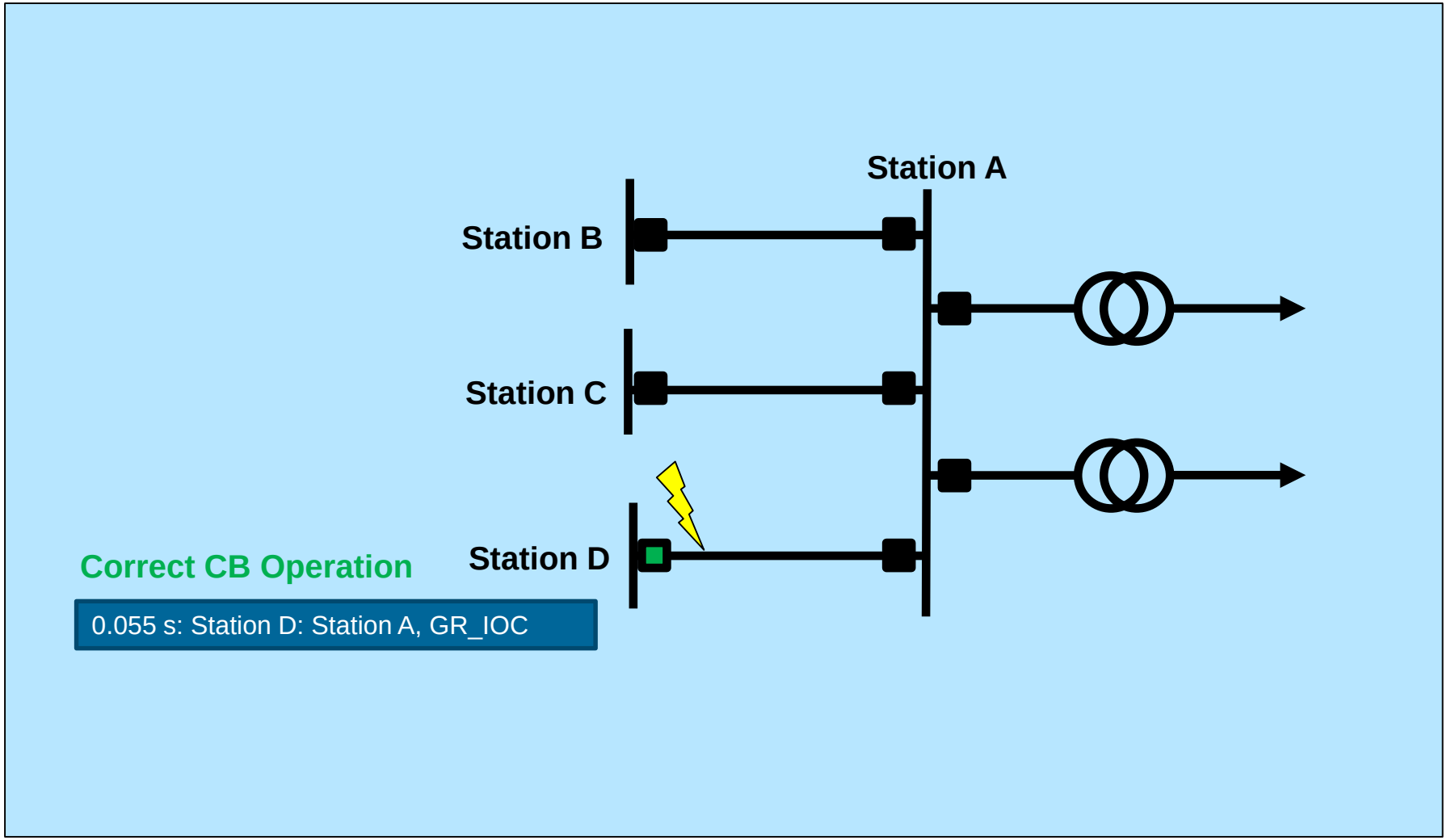
Problem	Protection becoming more numerous and complex: 10s to 100+s of settings
	Grid state (outages and generators) can have a massive impact on protection performance and coordination
	Relay settings calculated for credible grid states (N-1 etc) at that time
	Settings checked/revised at maintenance intervals like 3-7+ years
	10% of faults in US have at least one relay misoperation; 29% of misoperations due to relay configuration/settings issues
Solution	Automatically simulate multiple fault types at multiple locations along each transmission line across the grid and for each fault assess each relay tripping
	For each fault, look at trip times of each relay and identify if all protection relays near the fault meet set criteria. Did any relays over-reach or misoperate, was the fault cleared quickly?
	Engineers can't be expected to manually examine 1000s of results, so produce short, simple, easy to read report identifying issues - results file can be viewed in a webpage, Excel, or brought into an Access DB
	Automatically compare latest results with last week/month/year etc. Flag new protection issues which didn't exist the last time you ran the tool

Together…Shaping the Future of Electricity

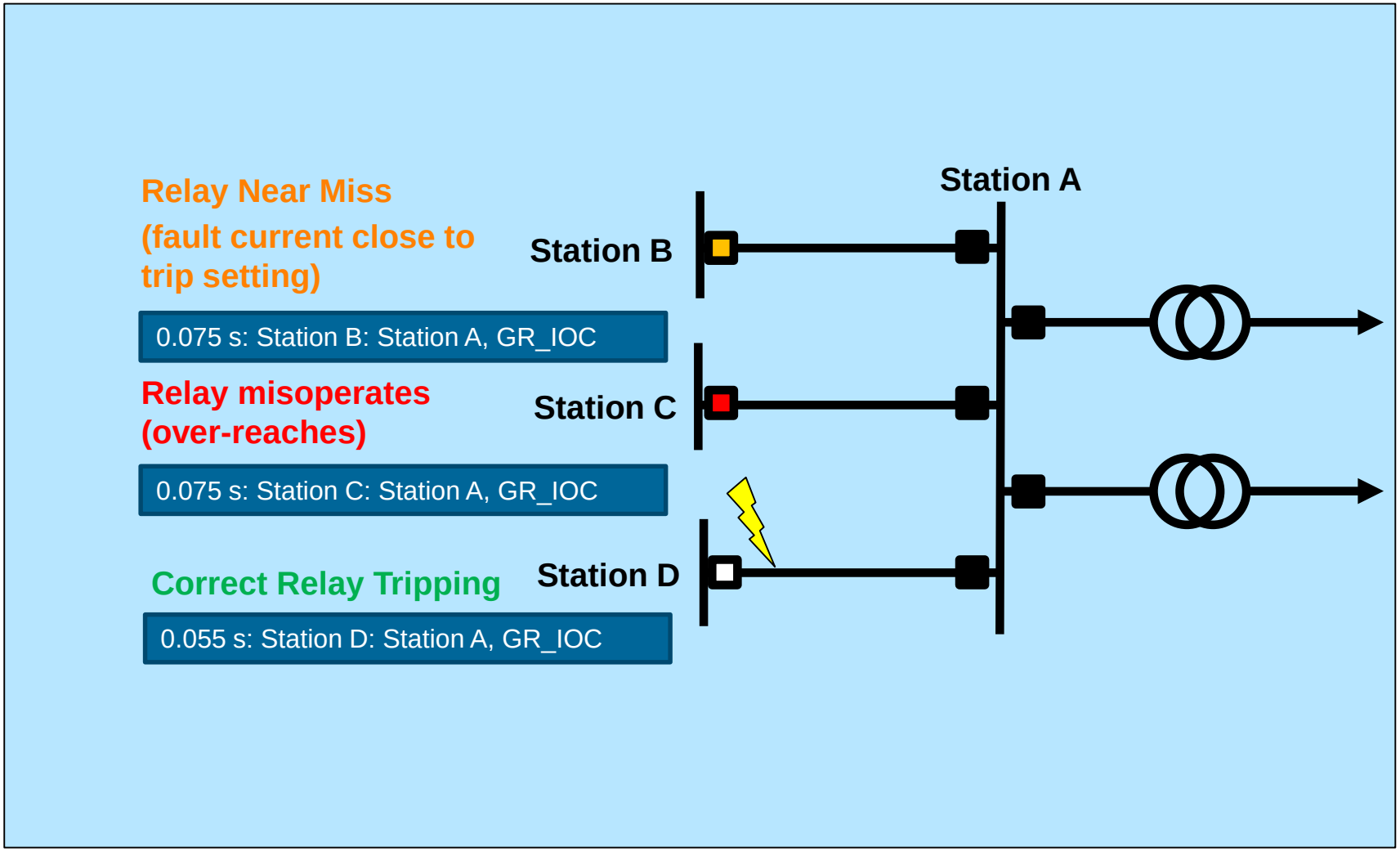
System Simulator Example: Fault Initiation (5% of Line)



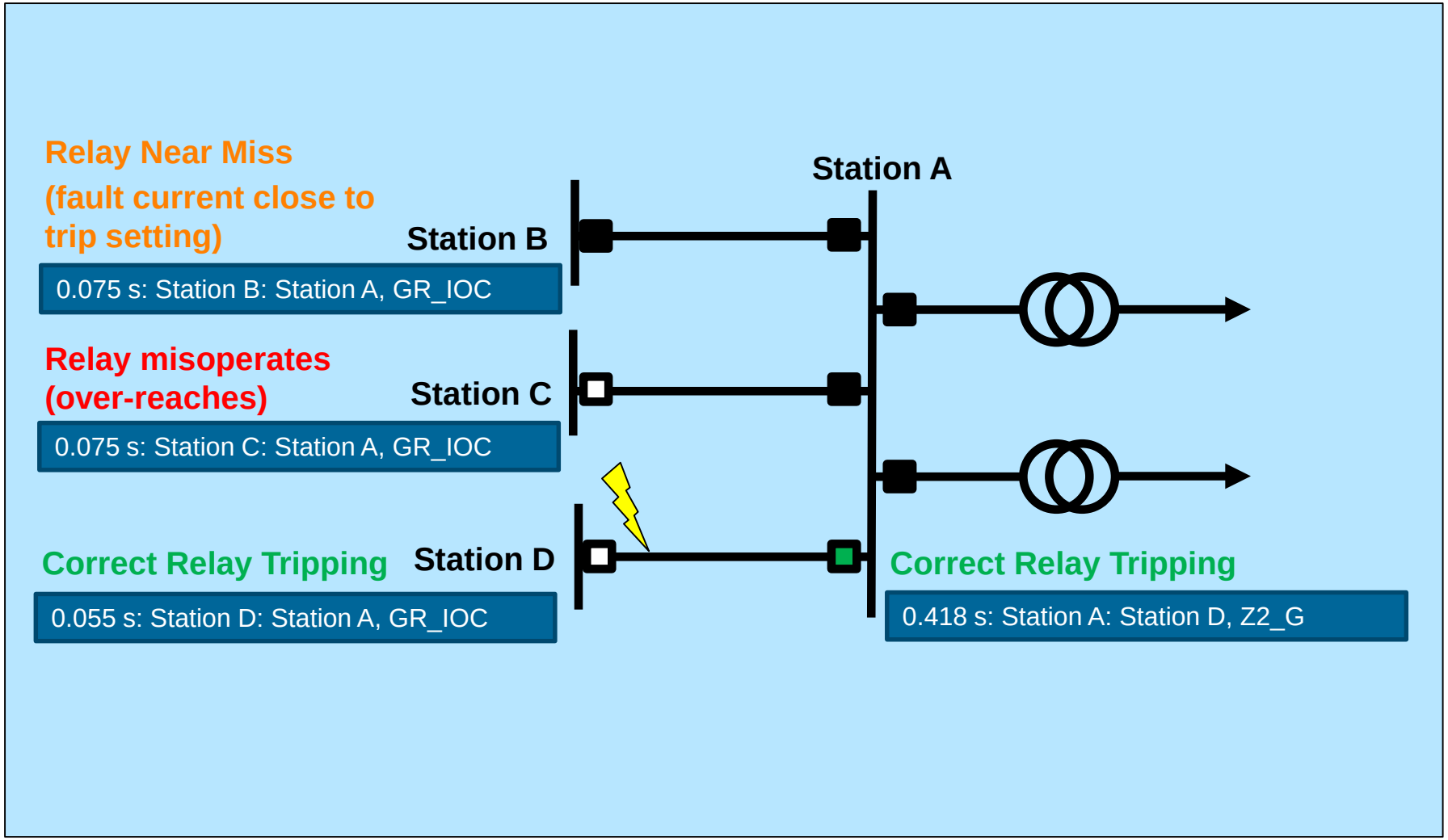
System Simulator Example: First PCB Opens



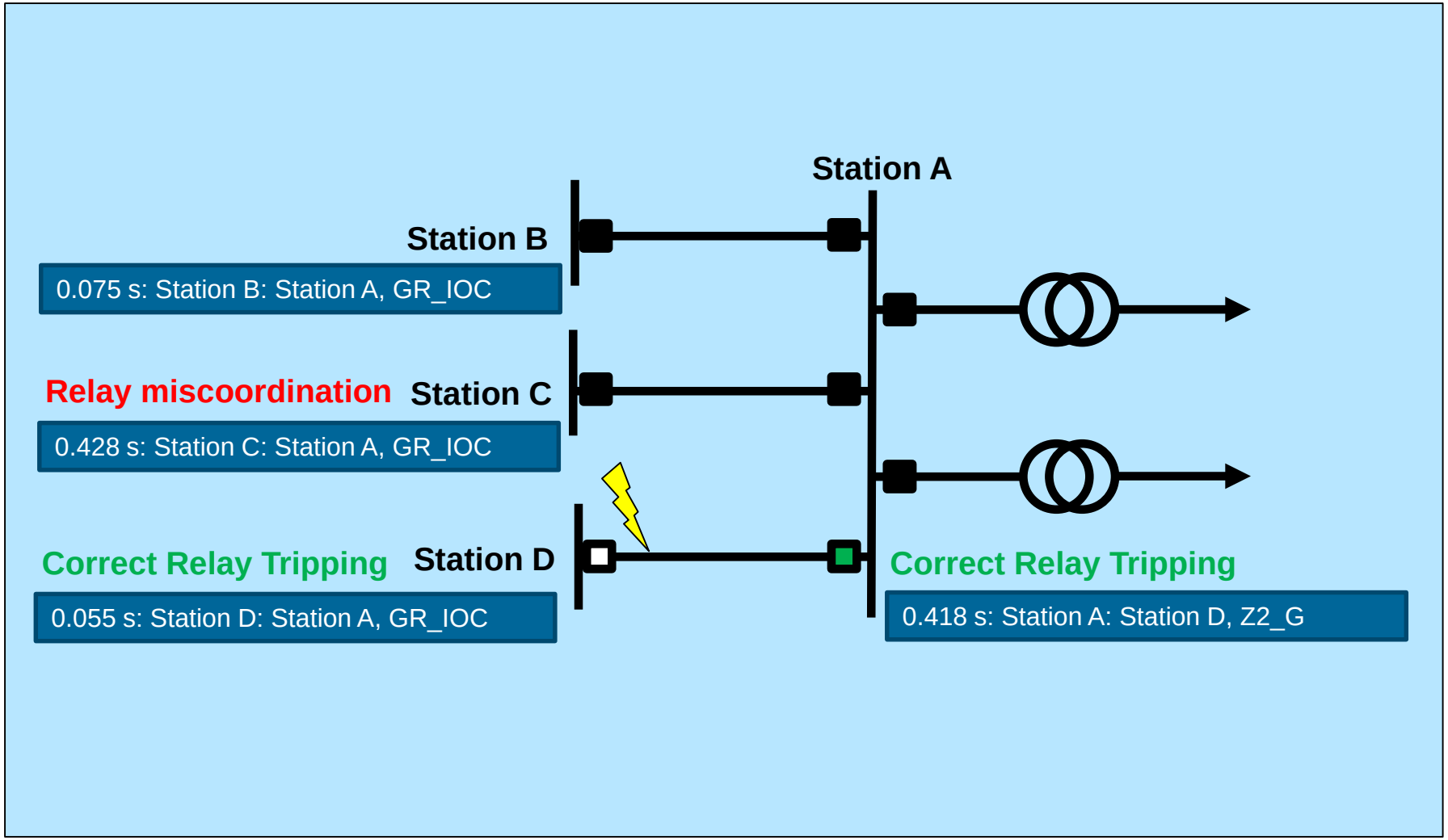
System Simulator Example: Second PCB Opens (Misoperation and Near Miss)



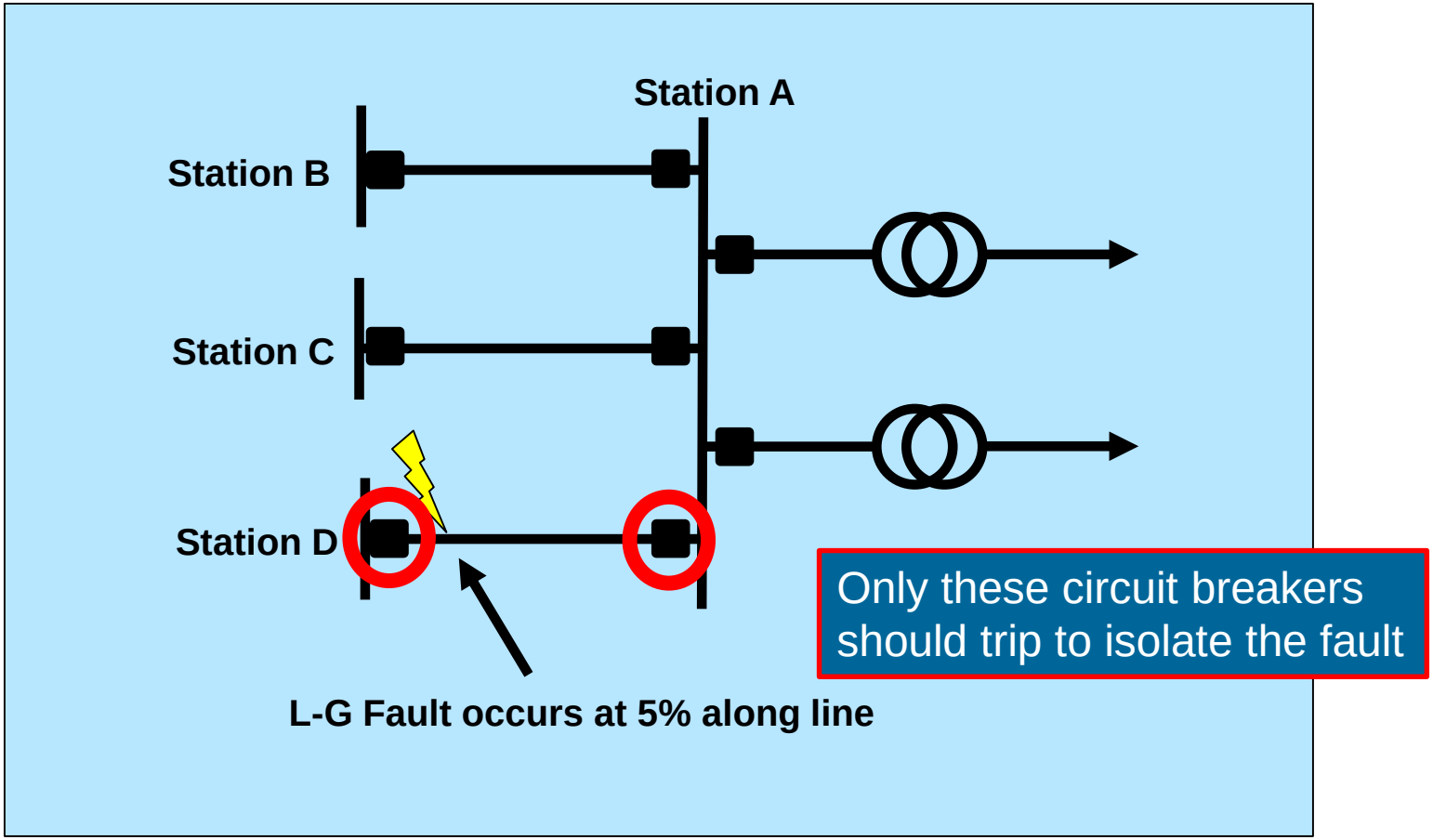
System Simulator Example: Third PCB Opens & Clears Fault



System Simulator Example: Miscoordination



System Simulator Example: Primary Protection



System Simulator Example: Backup Protection