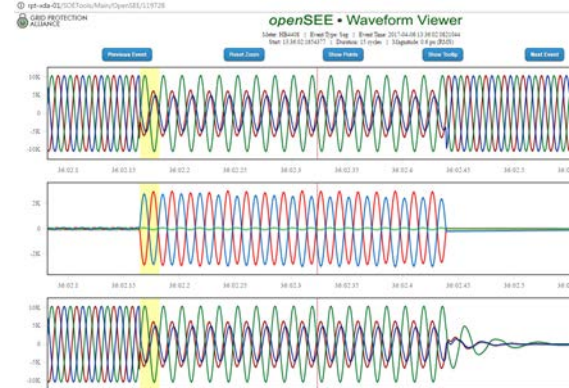




epri

Smart Grid

DISCOVER MORE NOW



Progress Update

Sequence Of Events SOE Dashboard

April 25, 2018

Presented by: Bob Hay – PE

EPRI – Knoxville, TN



hayrw@epb.net

Agenda

- So what's the Smart Grid DA problem?
- EPB Visualization Goals
- SOE Dashboard Solution
- Links to specialized analysis and measurements
- Looking Ahead



Problem: Distribution Events Produce 'an Ocean' of Data

- It takes too long (aka: costs too much) to analyze using traditional sequence of events logs
 - Retrieved and formatted by hand (80%)
 - New information triggers re-work
 - Analysis reports filed and forgotten
- DMEs produce files
 - Unmanageable quantity



“Ocean of data” example

- One device, one lockout investigation
 - ➔ Percent of data that has value: 0.005%
 - ➔ Once summarized, it takes minutes to review what happened
- The incident that prompted a quest for SOE
 - 70 IRs produced 1Gig in 30 seconds
 - “How many engineers does it take to figure out what 70 IntelliRupters® did in 30 seconds?”

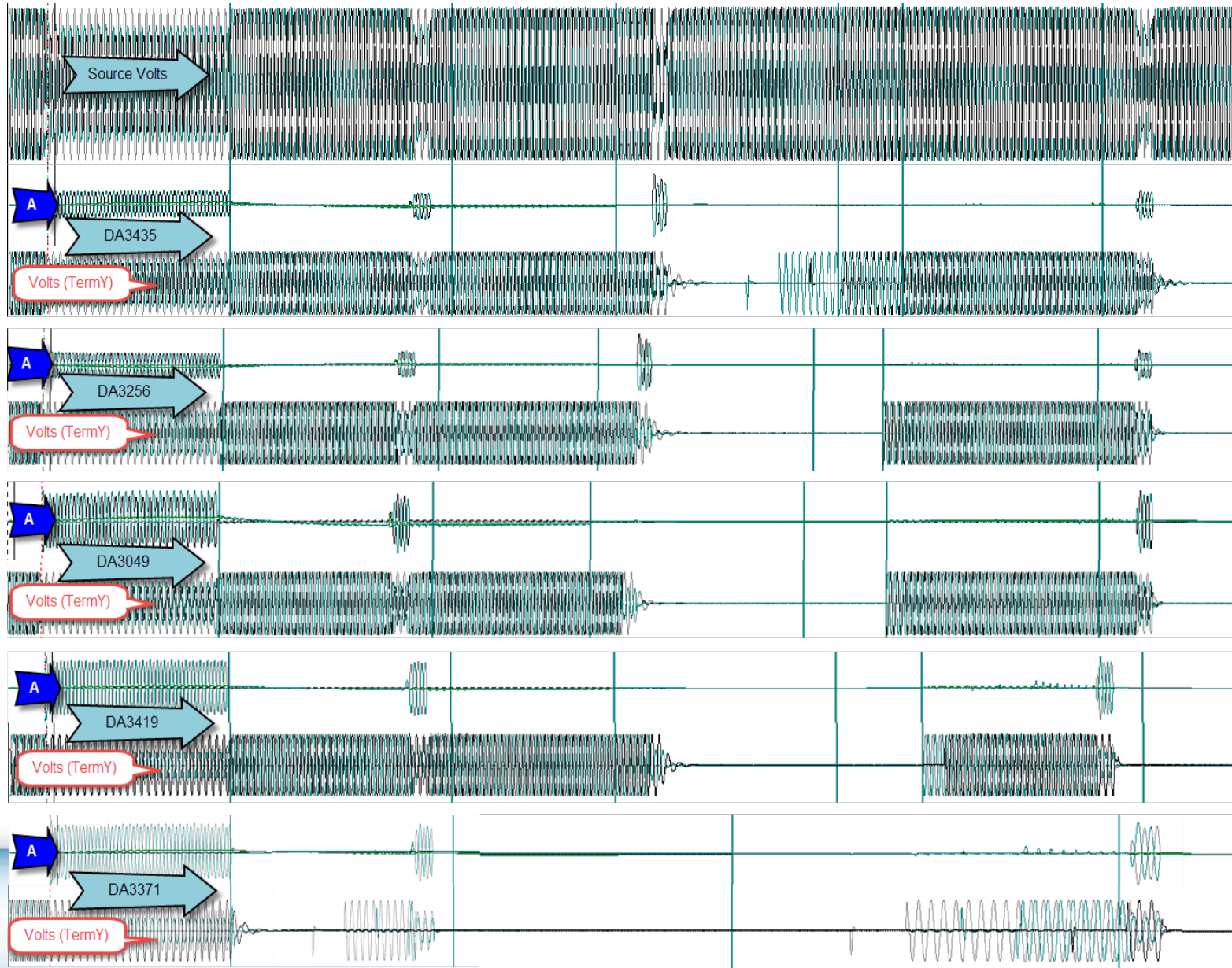


EPB Visualization Goals

- “Three mouse clicks” to visualization
- Common SOE time line (all circuit sensors)
 - Multiple devices recording the same event
 - Ability to see an entire sequence on one screen
- “Speed of Thought” Dashboard
 - One mouse click: useful data ready for review
- Automatic classification of waveforms
- To be the first to use a waveform dashboard that “every utility wants to have”



Smart Grid Analysis Need

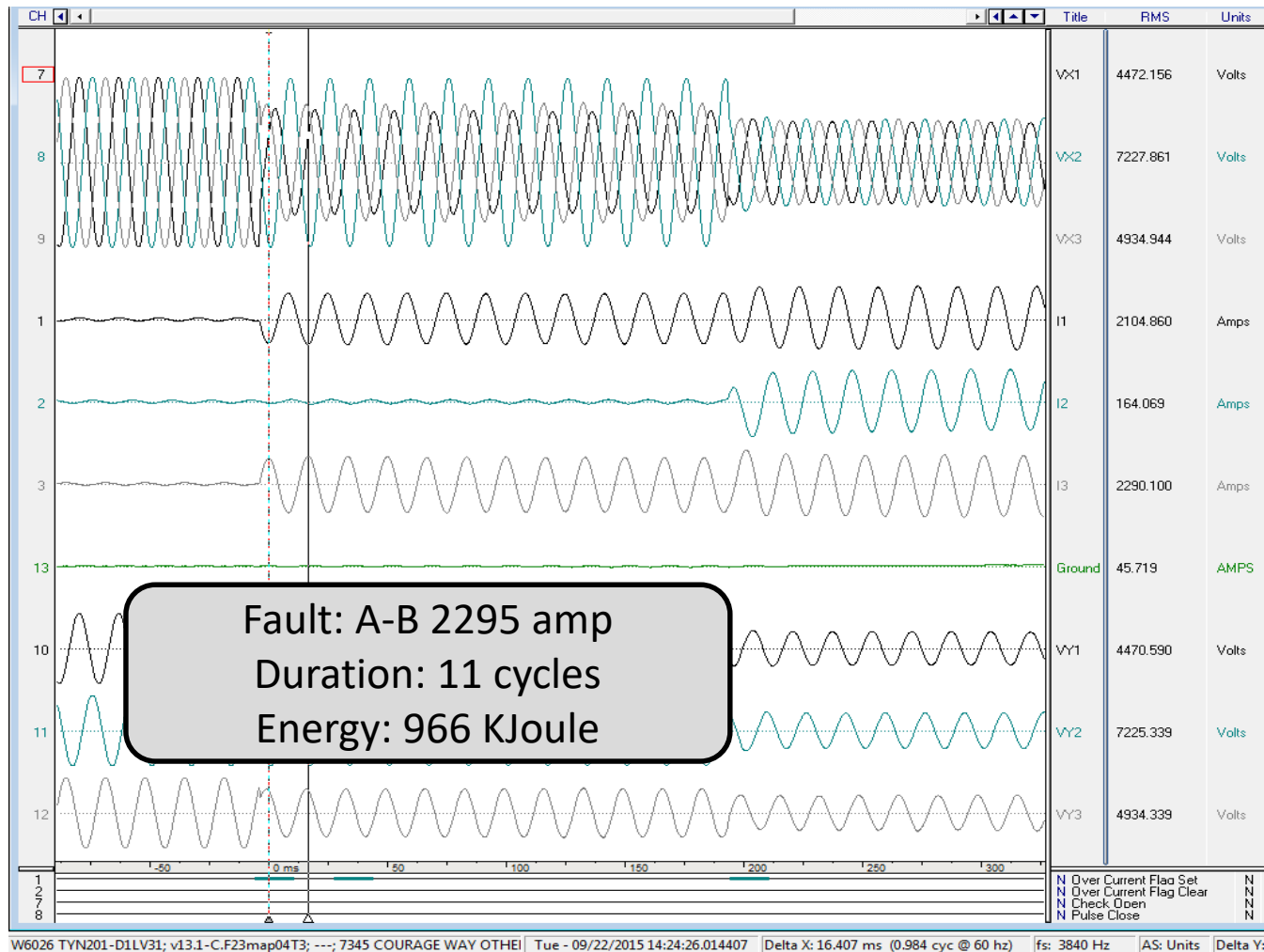


Identifying Useful Data

- “Useful data” rather than “interesting data”
 - Doug Dorr EPRI / DMD
- Points in time with “distinct” transitions
- Image of the disturbance
- Simple text with data point measurements
 - Faults: Let-Through-Energy (amps squared seconds)
 - Voltage: severity

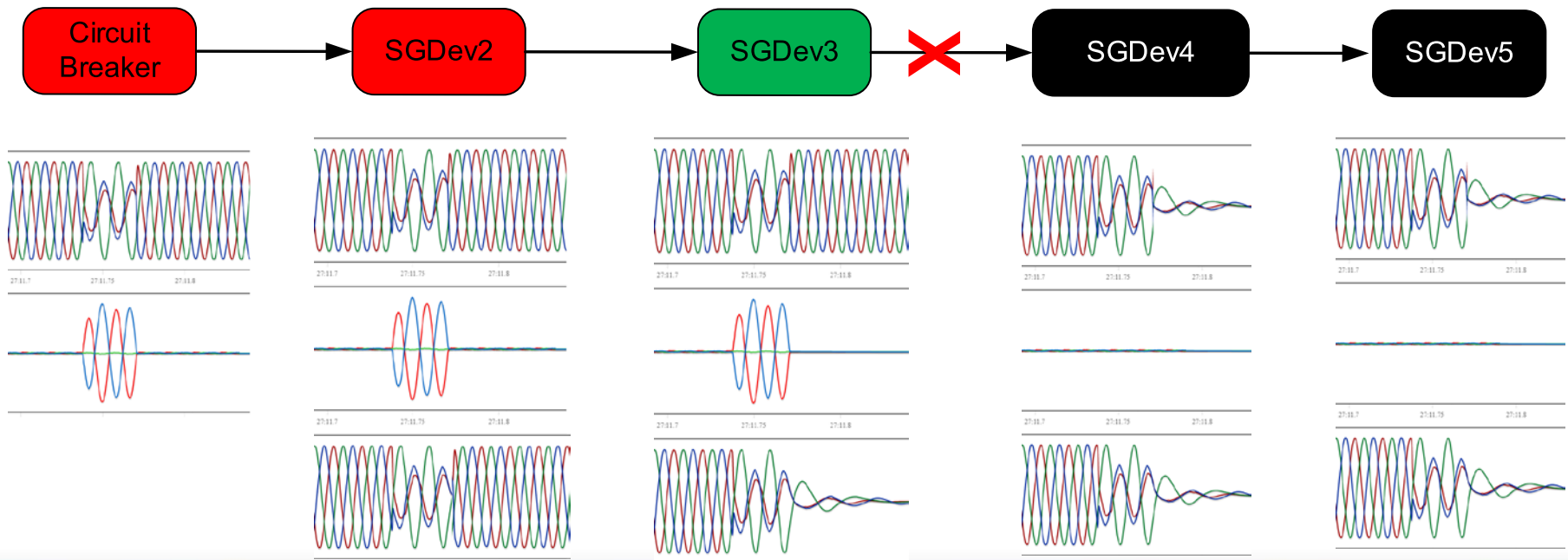


Useful Data: text and image



L-L Fault on Main Line

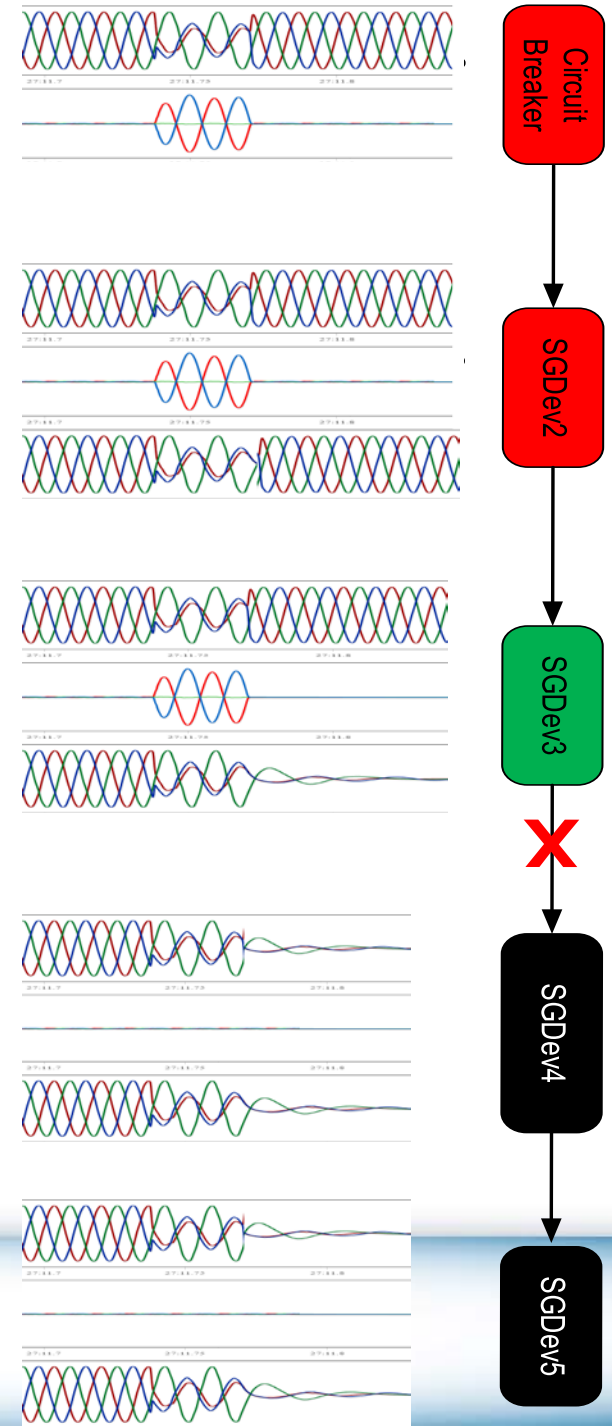
- Dev#3 (green line recloser) clears fault
- 4 distinct waveform patterns captured by 5 devices
- Difficult to align time in your mind



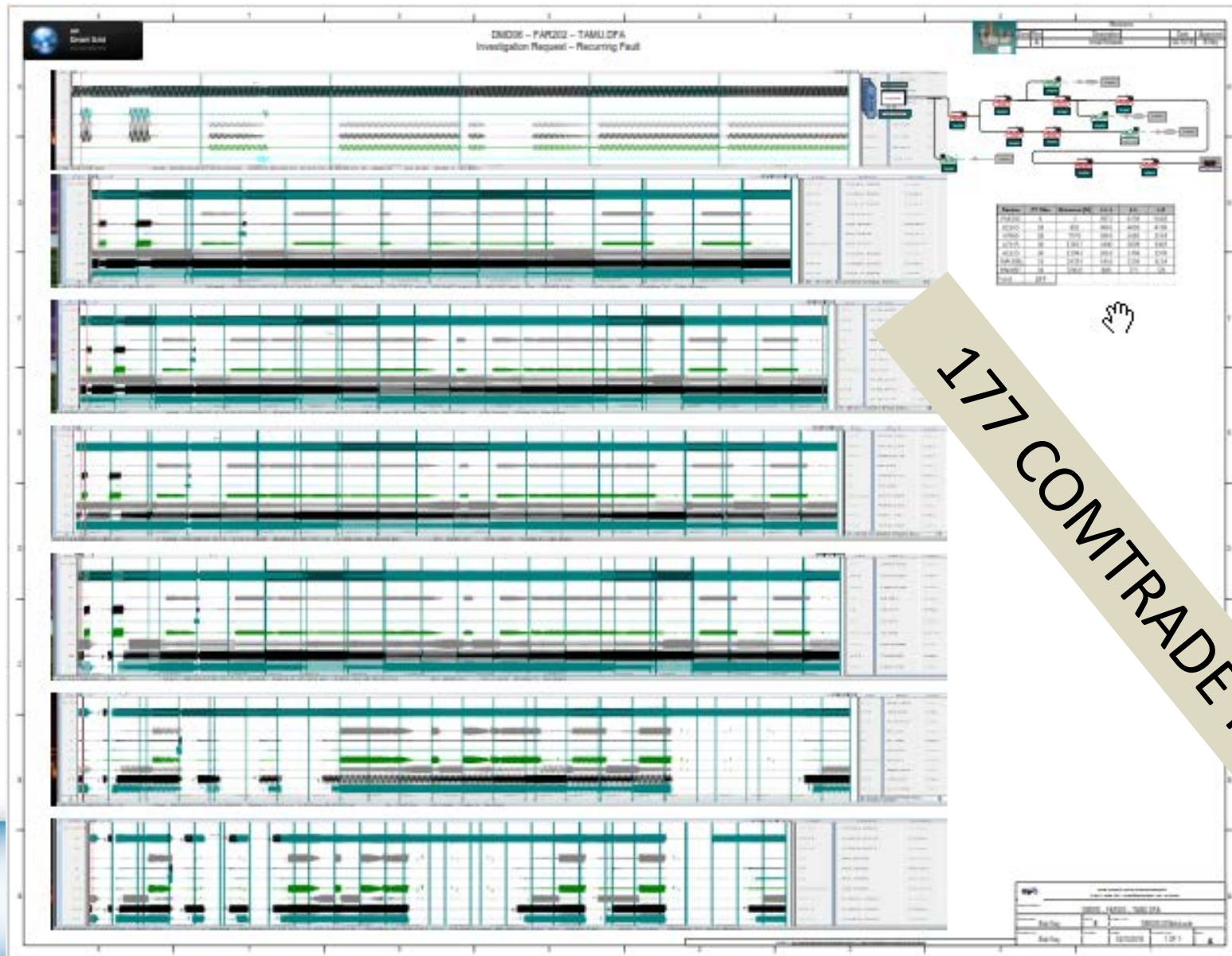
Same L-L Fault, Simple Case

Aggregation Benefits

- common time line
- sensors in “AFC” descending order
- easy to see time gaps
- see in seconds what many sensors recorded, this example
 - 27 voltage sensors
 - 15 current sensors
 - 5 comtrade files



DA Reality: Labor = 5 hours



SOE Dashboard Solution

- Summary page with incident counts
- Easily navigate across time
- Aggregated Device Common View
 - Devices ordered from substation to the fault
 - Circuit is a collection of sensors
 - Compress time to fit on one screen
 - One click link to OpenSEE
- Business value: hours of “analysis prep” reduced to a few mouse clicks



SOE Summary: Getting Started

SOE Tools

HomeSummarySettingsConsoleHelp

Log Out

Filter

Record Limits:

All

Search Levels:

Circuit

Filter Text:

Start Date:

12/19/2016 00:00

Time Context:

Months

Number of Buckets:

17

<< Step < Nudge																					Nudge > Step >>				
Volt Class	Circuit	Device	12/2016	1/2017	2/2017	3/2017	4/2017	5/2017	6/2017	7/2017	8/2017	9/2017	10/2017	11/2017	12/2017	1/2018	2/2018	3/2018	4/2018	5/2018	Total	LTE	PQS	CT Files	SOE
12	FAR202	11		20	7	37	31	66	31	28	50	123	22	32	18	26	20	10	29		550	37255031	6.09	1070	3854
12	AMZ202	3		21	8	9	11	20	24	16	4	15	6	1	3	4	4		2		148	36024731	1.87	182	424
46	MOC421	1		1		2	1	6	1			4			1		2				18	19814703	0.00	45	129
12	API203	6		26	23	25	21	15	26	18	4	52	3	4	19	4	8				248	16746242	3.82	542	2547
12	PAL201	6		6		11	30	60	22	15	44	89	16	10	7	10	5	10			335	14050716	3.79	593	2180
12	FAR203	5		9	14	28	34	58	10	15	35	74	8	7	21	5	28	2	7		355	13592389	5.77	638	2210
12	PAL202	6			4	21	22	55	42	54	50	126	42	51	22	6	14	1	10		520	11775328	7.83	1209	4722
46	MOC411	1				1	1	2	5	1	1	1	2								14	7995707	0.00	15	47
12	API211	5		5	5	15	10	14	25	5	10	9	5		5						108	7062135	3.26	153	579
12	API201	5		7	8	8	17	17	17	15	6	5		8	4	4		11	4		131	4027484	2.23	251	849
12	API207	4		34		8	14	7		8	12	4	8	14	8	4	9		6		136	2782062	4.13	266	897
12	API205	6		26	6	19	25	18	16	20	14	10	8	14	17		6	4	8		211	2492032	0.53	308	1199
12	API209	5		2	4	3	5		2		10		6					2	7		41	1795158	0.66	41	121

Navigate Time Efficiently

SOE Tools Home **Summary** Settings Console Help [Log Out](#)

Filter

Record Limits: All Start Date: 04/02/2018 00:00

Search Levels: Device Time Context: Days

Filter Text: FAR202 Number of Buckets: 5

04/02/2018 04/03/2018 04/04/2018 04/05/2018 04/06/2018 04/07/2018

<< Step < Nudge

Volt Class	Circuit	Device							Total	LTE	PQS	CT Files	SOE
12	FAR202	FAR202-A1133			2				2	327961	3.81	14	44
12	FAR202	FAR202-A7006			2				2	397300	2.18	15	30
12	FAR202	FAR202-A7115			2				2	407703	3.12	14	31
12	FAR202	FAR202-B1143			2				2	402782	0.10	6	16
12	FAR202	FAR202-FAR202			2				2	406620	0.00	6	26
12	FAR202	FAR202-HN4097			4				4	36605	6.09	26	174
12	FAR202	FAR202-SM1020			2				2	62017	2.93	24	142

1

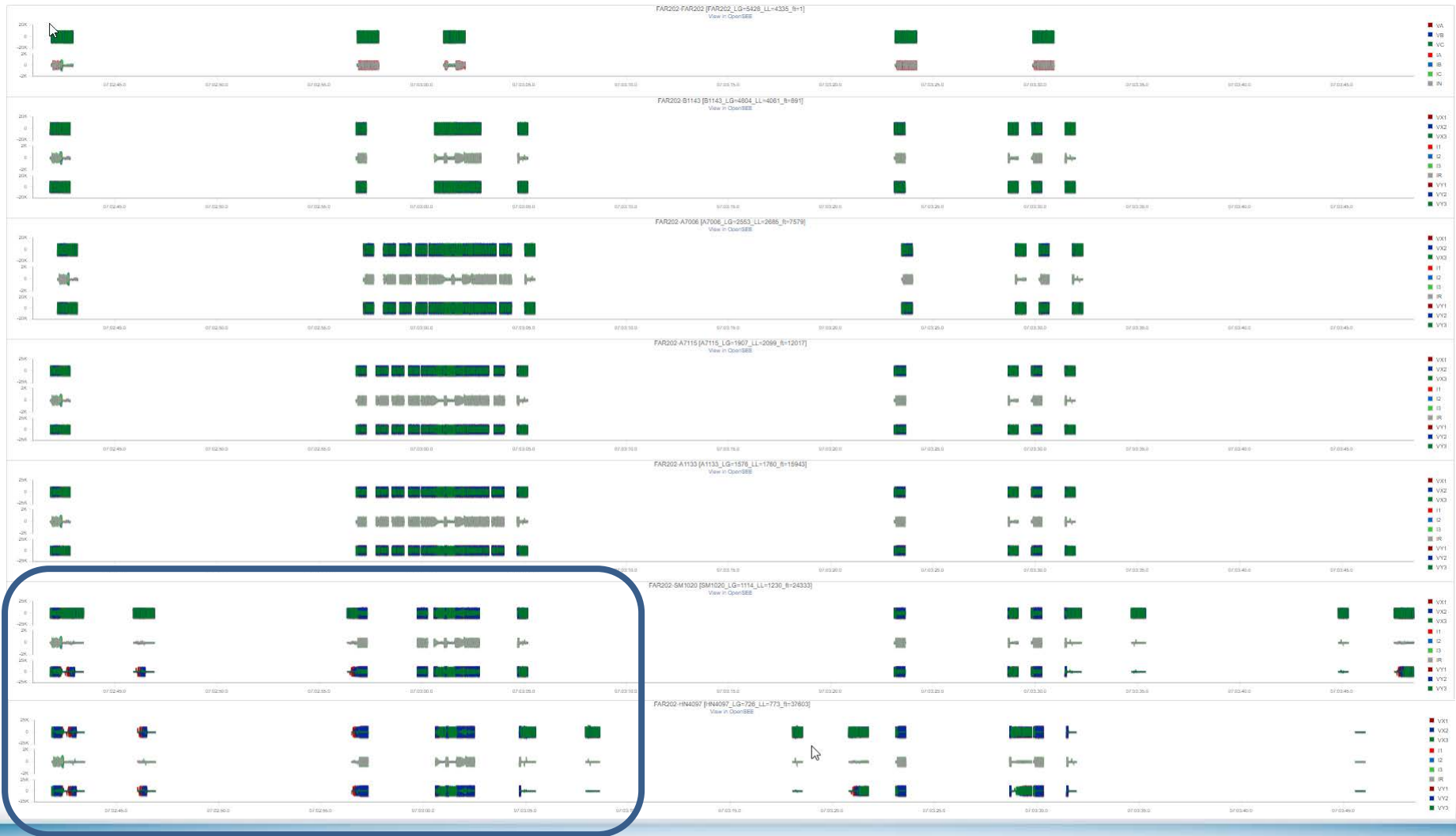
Quick time scan: Two Big SOE

SOE Tools													
Home Summary Settings + Console Help													
Log Out													
Incidents													
Records: 16													
Search													
Date/Time	System	Circuit	Device	Type	A	C	B	G	LTE	PQS	Duration	SOE Data	
04/04/2018 01:15:55.000	12	FAR202	FAR202-A1133	CN	137	1621	147	1607	327961	0.2	81.1	A	M
04/04/2018 01:15:55.000	12	FAR202	FAR202-SM1020		65	78	125	136		0.5	79.4	A	M
04/04/2018 01:15:55.000	12	FAR202	FAR202-HN4097		43	40	72	77		0.5	78.9	A	M
04/04/2018 01:15:55.000	12	FAR202	FAR202-B1143	CN	116	1502	166	1502	402782	0.1	75.5	A	M
04/04/2018 01:15:55.000	12	FAR202	FAR202-A7006	CN	105	1510	149	1487	397300	0.2	118.9	A	M
04/04/2018 01:15:55.000	12	FAR202	FAR202-A7115	CN	114	1731	138	1690	407703	0.2	74.8	A	M
04/04/2018 01:15:55.212	12	FAR202	FAR202-FAR202	CN	122	1491	146	1492	406620	0.0	63.7	A	M
04/04/2018 07:02:41.000	12	FAR202	FAR202-FAR202	ACB	756	832	883	647	65460	0.0	2995.3	A	M
04/04/2018 07:02:41.000	12	FAR202	FAR202-A7115	BN	758	846	854	721	48086	3.1	3000.0	A	M
04/04/2018 07:02:41.000	12	FAR202	FAR202-B1143	BN	771	868	869	697	37719	0.0	3057.5	A	M
04/04/2018 07:02:41.000	12	FAR202	FAR202-A1133	BN	761	845	855	733	48963	3.8	3057.4	A	M
04/04/2018 07:02:41.000	12	FAR202	FAR202-SM1020	ACB	718	859	852	670	62017	2.9	4051.0	A	M
04/04/2018 07:02:41.000	12	FAR202	FAR202-HN4097	CB	702	839	856	650	36605	6.1	3903.8	A	M
04/04/2018 07:02:42.000	12	FAR202	FAR202-A7006	BN	762	848	856	712	36678	2.2	3019.2	A	M
04/04/2018 08:04:08.561	12	FAR202	FAR202-HN4097		1	1	0	1		0.0	31.0	A	M
04/04/2018 10:06:23.000	12	FAR202	FAR202-HN4097		95	118	204	158		0.1	117.6	A	M

SOE Dashboard: SOE #1



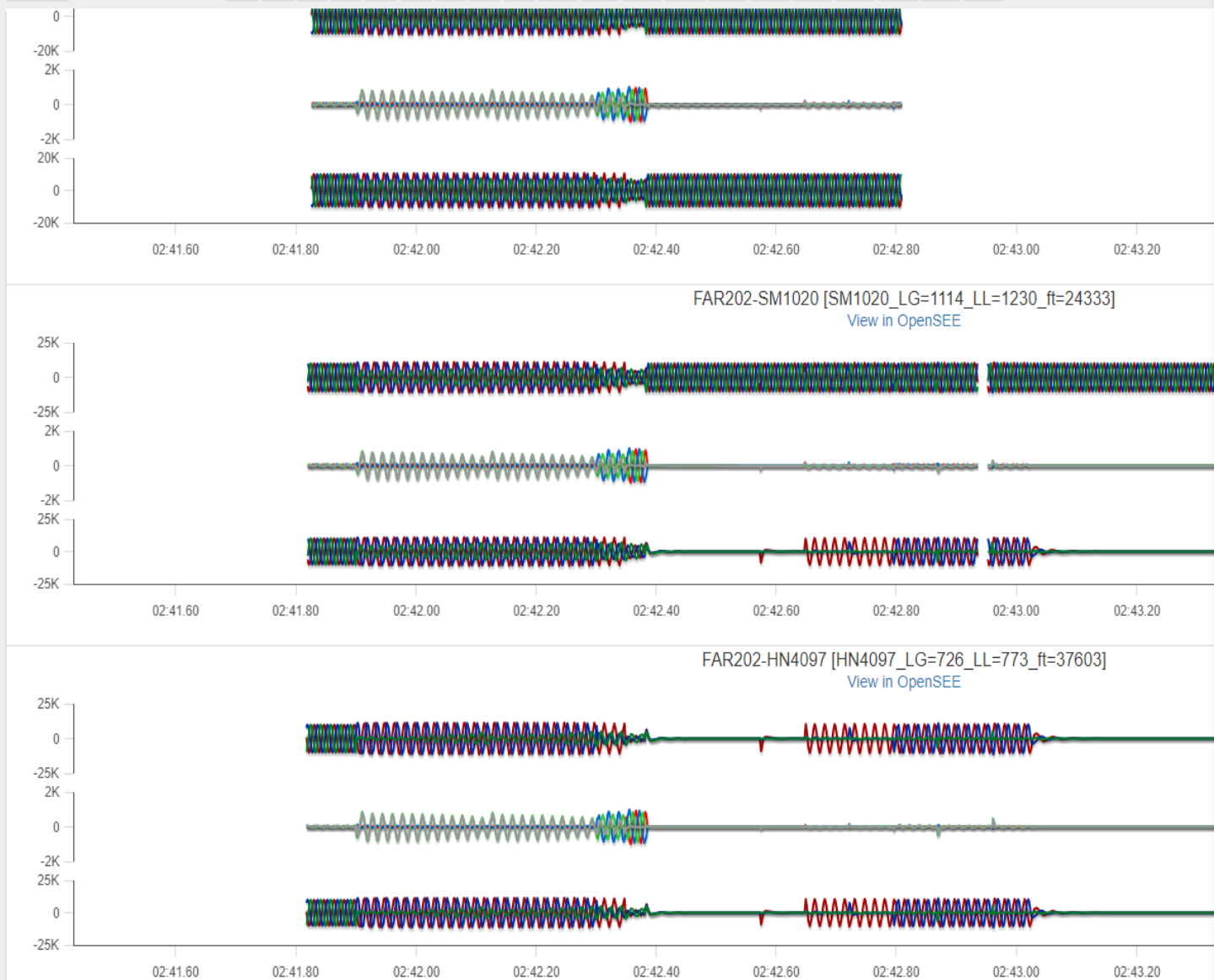
SOE #2 -- 5 hours later



Looks Like Miscoordination

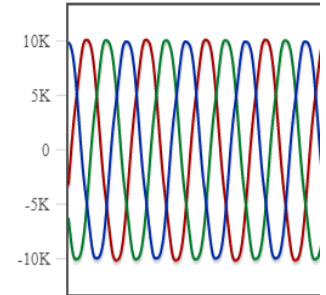


Confirmed: Miscoordination



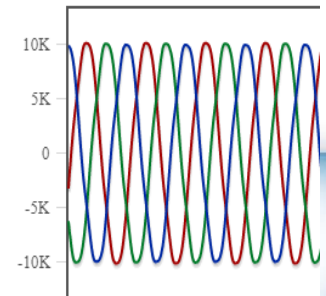
GRID PROTECTION
ALLIANCE

Reset Zoom



2018-04-04 07:02:42.3168640	
VXA:	-6643.07
VXC:	2890.63
VXB:	1123.05
IA:	-530.13
IC:	-28.59
IB:	147.58
IA RMS:	580.75
IB RMS:	703.27
VYA:	-6650.39
VYC:	2893.07
VYB:	1110.84

02:41.85



What We Learned in Minutes

With the dashboard rendering

- Recording device L-L AFC is 1230 amps
- CEC shift setting: 822 amps (phase)
- Measured actual: 859 amps
- Mis-coordination confirmed in minutes due to the simple navigation around the event



This Makes Me Dizzy

Waveform links:

J13028 initial - <http://rpt-xda-01/PQdashboard/openSEE.aspx?eventid=237968&faultcurves=1>

J12009 initial - <http://rpt-xda-01/PQdashboard/openSEE.aspx?eventid=237953&faultcurves=1>

J13028 (J12009 opens) - <http://rpt-xda-01/PQdashboard/openSEE.aspx?eventid=237979&faultcurves=1>

J12009 (J12009 opens) - <http://rpt-xda-01/PQdashboard/openSEE.aspx?eventid=237959&faultcurves=1>

J13028 (J13028 opens) - <http://rpt-xda-01/PQdashboard/openSEE.aspx?eventid=237984&faultcurves=1>

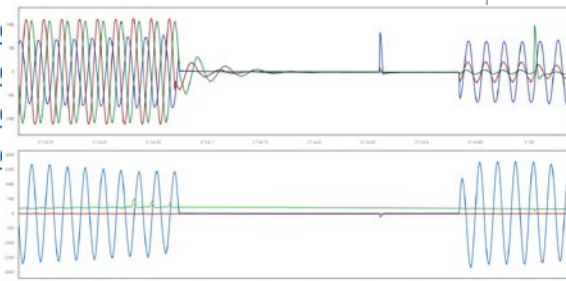
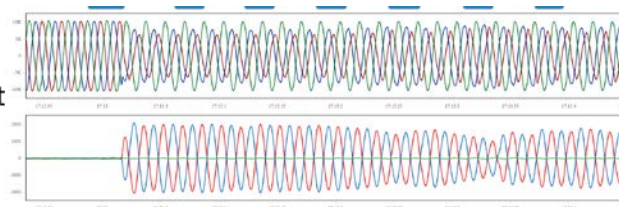
J12009 (J13028 opens) - <http://rpt-xda-01/PQdashboard/openSEE.aspx?eventid=237961&faultcurves=1>

Fault Magnitude: 1400/1400 A-A/B RMS

Duration: 51 cycles

Waveform Observations: A-B phase L-L fault

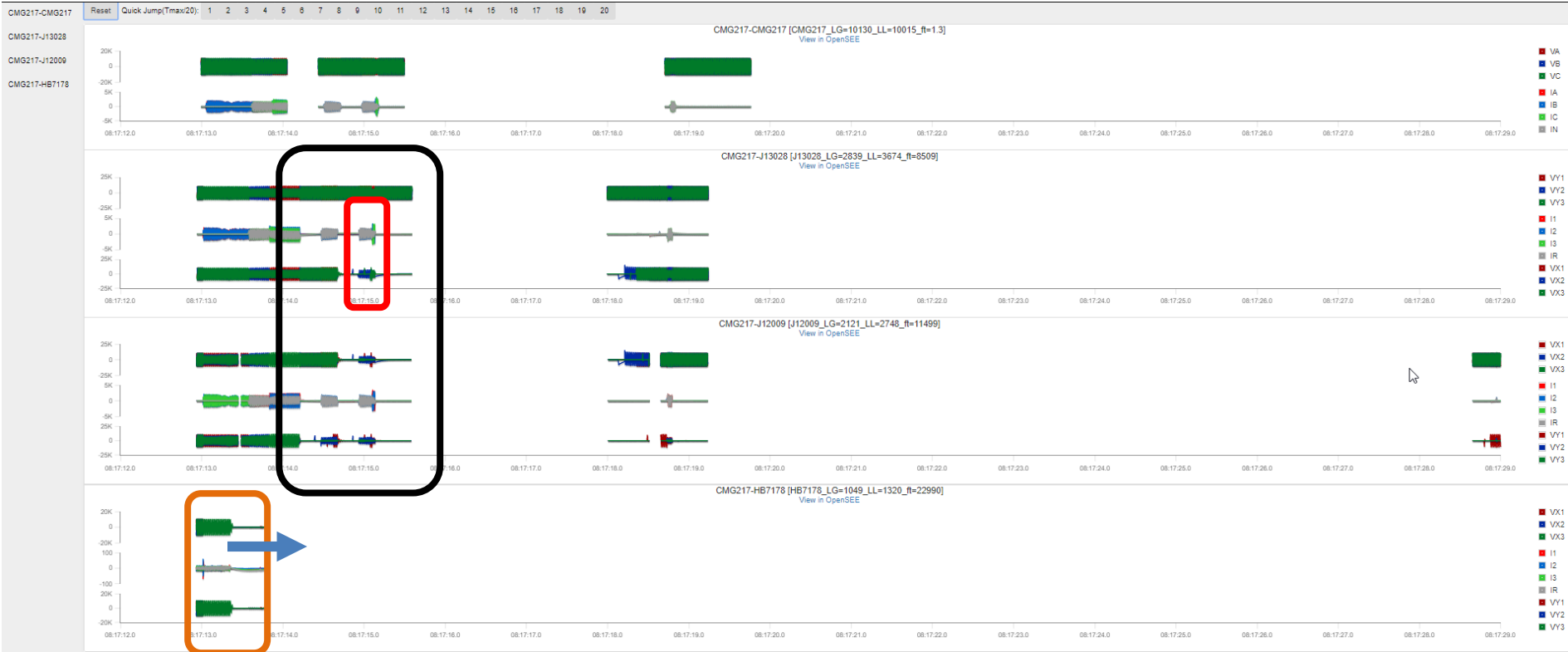
Incident or event: PCR J13028 operation



I started looking into this because our trouble was between J12009 and HB7178 but we opened back to J13028. Looking at the curves, we have a 2LL fault on A and B phase which quickly becomes a 3LL fault. Eventually A phase breaks in the clear and we go back to a 2LL fault but now with B and C phase. After 51 cycles we finally open up on PCR J12009. Then the first odd thing happens. While J12009 is attempting to reclose we open on J13028. According to PQM we also lose the source side voltage on J13028, however, the CMG 217 breaker is the next upstream device and it never opens. I'm guessing it's just showing the wrong side of the PCR. Next, the J12009 PCR closes in, with the J13028 PCR open (can see this in SCADA and in the curves as the J12009 sees bad fault current as well during the J13028 reclose). This appears to be the cause of the J13028 PCR failing its reclose as it still sees the fault through the J12009. The J12009 PCR finally opens again, which allows the J13028 PCR to successfully close, thus isolating the fault.

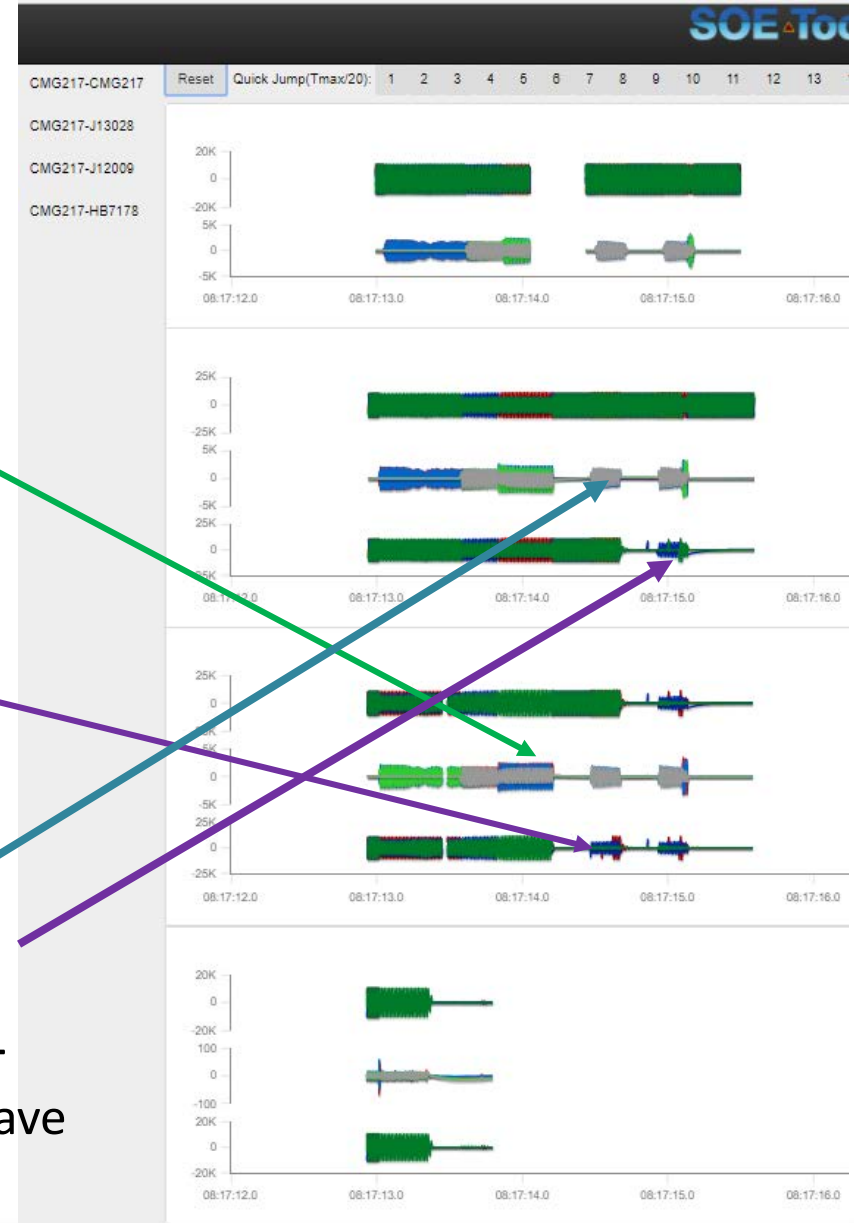
This doesn't seem like proper coordination. My guess is maybe the J13028 opened because of possible conductor slap, but I'm not seeing conductor slap in the curves. Every fault I see appears downstream of J12009. Seems like it would be worth someone taking a look at this.

SOE in Seconds!



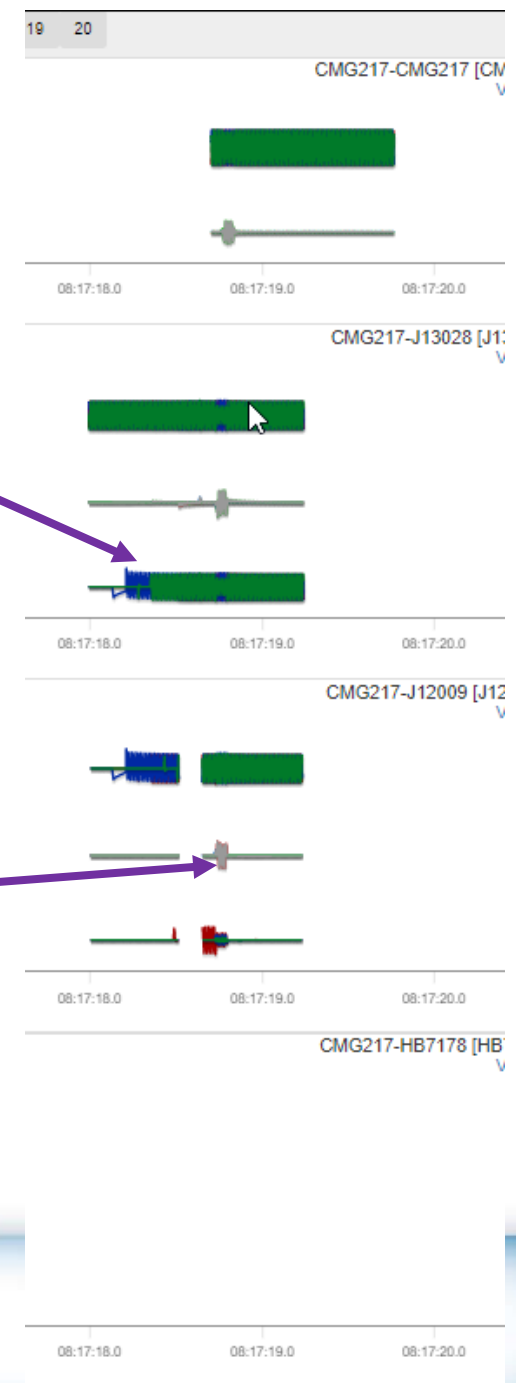
Part 1

- CMG217 Time Gap
- J12009 trips on fault (correct)
 - Evolves to L-L-L
- J12009 pulse close
 - L-L Fault returns
- J13028
 - Conductor Slap? Notch Trip?
 - Over-reach trip?
- J13028 pulse test / aborts on L-L
 - If J12009 were open, this would have been a successful test



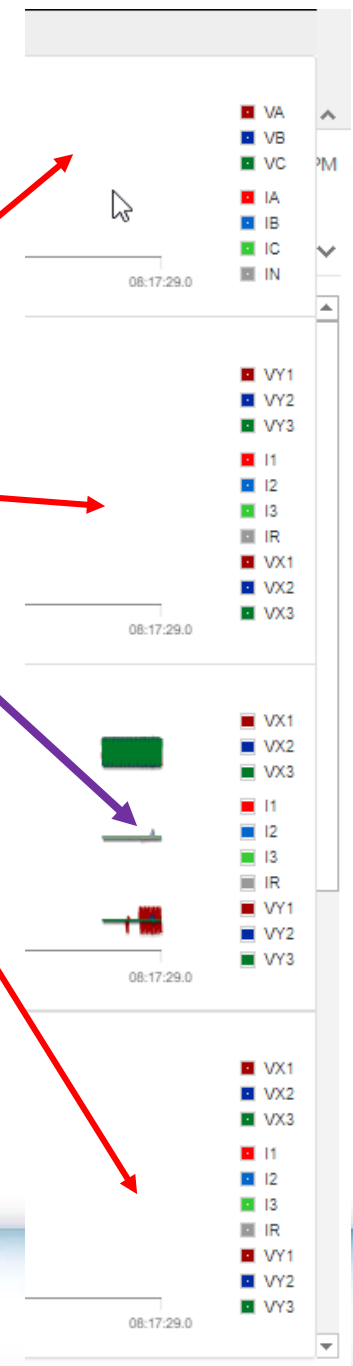
Part #2

- EPB uses a three test to lockout reclose sequence
 - 0.18 sec / 3 sec / 10 sec
- J13028 pulse tests (after 3 seconds)
 - It's successful because J12009 tripped on the pulse test sequence (of J13028) in Part #1
 - “successful reclose #2”
- J12009 pulse tests because source returned
 - L-L fault detected, aborts the reclose
 - Reclose attempt #2 failed
 - Wait 10 seconds



Part #3

- J12009 10 second timer expires
 - Pulse test / faulted / abort test
 - LOCKED OUT
- Note: other devices are not recording
 - pulse energy so low the fault current did not trigger pickup – no COMTRADE files generated
- Even though J12009 mis-operated due to over-reach during conductor slap detection, a small number of customers experienced a 3 second outage
- Otherwise, the fault isolated correctly



Business Value

- Reduce review time from hours to minutes
- Tedious assessment (what just happened) is easier to visualize
- New tools allow a user to visualize
 - “hundred plus” comtrade files (one PC screen)
 - 45 sensors (30 second time window)
 - vs. 9 sensors (limited to ½ second window)
- Quickly eliminate unnecessary analysis
- Focus on events that require detail investigation



Speed of Thought Example

Filter

Record Limits:

All

Start Date:

07/16/2017 00:00

Search Levels:

Circuit

Time Context:

Days

Filter Text:

Number of Buckets:

30

<< Step

< Nudge

Volt Class	Circuit	Device	07/16/2017	07/17/2017	07/18/2017	07/19/2017	07/20/2017	07/21/2017	07/22/2017	07/23/2017	07/24/2017	07/25/2017	07/26/2017	07/27/2017	07/28/2017	07/29/2017	07/30/2017	07/31/2017	08/01/2017	08/02/2017	08/03/2017	08/04/2017	08/05/2017	08/06/2017	08/07/2017	08/08/2017	08/09/2017	08/10/2017	08/11/2017	08/12/2017	08/13/2017	08/14/2017	08/15/2017	Total	CT Files	SOE
12	FAR202	3		2		2														2		1											7	7	18	
12	FAR203	1											2																				2	2	2	
12	PAL201	2			2							2																					4	4	4	
12	PAL202	5		17	6	28														4		1					3						59	196	826	

⏮

⏪

1

⏩

⏭

Nudge >

Step >>

Mouse Click 1



Speed of Thought: Proof of Concept

Incidents

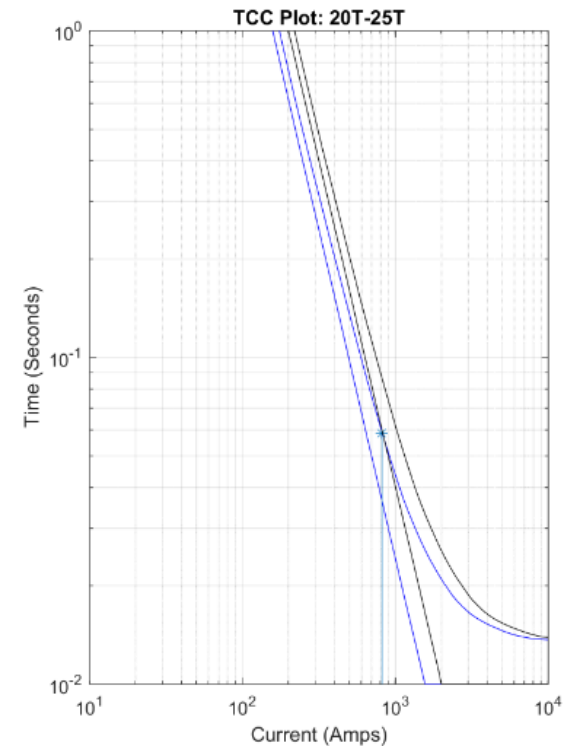
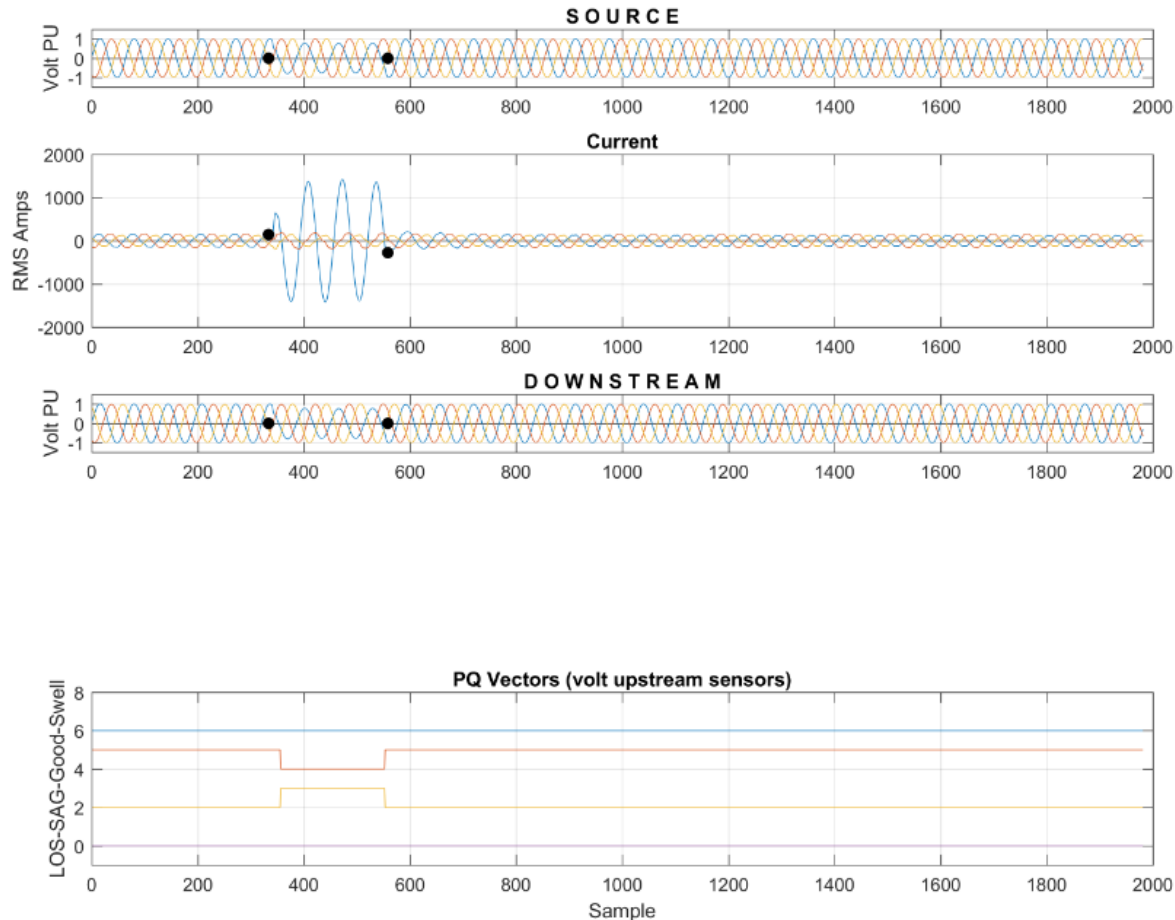
Records:

Search												Clear Sort	
Date/Time	System	Circuit	Device	Type	A	C	B	G	Duration	SOE Data			
07/21/2017 13:40:46.000	12	PAL202	PAL202-B4167	ABN	2029	174	2131	1712	92.6	A	W		
07/21/2017 13:40:46.000	12	PAL202	PAL202-B4096	ABN	2125	346	2279	1704	81.5	A	W		
07/21/2017 13:40:46.000	12	PAL202	PAL202-B3956	ABN	2009	165	2365	1722	142.0	A	W		
07/21/2017 13:40:46.000	12	PAL202	PAL202-B4552	ABN	2097	122	2517	1670	80.8	A	W		
07/21/2017 13:40:46.000	12	PAL202	PAL202-B3246	ABN	2047	131	2450	1642	84.8	A	W		
07/21/2017 13:42:09.000	12	PAL202	PAL202-B3246	ABN	2047	226	2355	1790	2120.6	A	W		
07/21/2017 13:42:09.000	12	PAL202	PAL202-B4552	ABN	2066	78	2368	1739	93.7	A	W		
07/21/2017 13:42:09.000	12	PAL202	PAL202-B4552	ABN	1984	87	2103	1790	1800.0	A	W		
												Export CSV	
												1 of 4	

Mouse Click 2



MATLAB: Measure Useful Data



Eng Review - Looking For: FaultClearedByDownstream
Device: A8162 --- SOE Event ID: 182566
RMS between dots: 817 Amp
Samples: 333 to 558
Duration: 3.52 cycles
Possible fuse: 20T or 25T
Let-through energy: 39110.68 (A²s)
Date: 11/01/2018 Time: 13:07:11.896000
PNG File Name: A8162-7006066-LF-182566.png



MATLAB Useful Data

Eng Review - Looking For: FaultClearedByDownstream

Device: A8162 --- SOE Event ID: 182566

RMS between dots: 817 Amp

Samples: 333 to 558

Duration: 3.52 cycles

Possible fuse: 20T or 25T

Let-through energy: 39110.68 (A²)s

Date: 11/01/2018 Time: 13:07:11.896000

PNG File Name: A8162-7006066-LF-182566.png



Measured Data Business Value

Engineer time reduced: 20 min to “1” click

Eng Review - Looking For: FaultClearedByDownstream

Device: K6319 --- SOE Event ID: 182001

RMS between dots: 2165 Amp

Samples: 362 to 915

Duration: 8.64 cycles

Possible fuse: 80T or 100T

Let-through energy: 675009.23 (A²)s

Date: 02/01/2018 Time: 09:33:01.218000

PNG File Name: K6319-7006006-LF-182001.png



Useful Data Logged

	D	E	F	G	H	I	J	K	L	M
1	startSample	endSample	Magnitude RMS	UnitAmps	DurationSec	Cycles	FusePredicted	LTE	UnitsKA^2sec	PngFileName
2	336	576	1041	Amps	0.063	3.75	30T	67.69	KA^2sec	A8162-7007001-v2x-96720.png
3	336	576	1041	Amps	0.063	3.75	30T	67.69	KA^2sec	A8162-7007002-v2x-96092.png
4	284	512	1075	Amps	0.059	3.56	30T	68.63	KA^2sec	A7178-7007003-v2x-96095.png
5	284	512	1075	Amps	0.059	3.56	30T	68.63	KA^2sec	A7178-7007004-v2x-96718.png
6	336	512	1429	Amps	0.046	2.75	30T	93.58	KA^2sec	A9036-7007005-v2x-96978.png
7	942	955	136	Amps	0.003	0.2		0.06	KA^2sec	A9036-7007006-v2x-100020.png
8	341	354	281	Amps	0.003	0.2		0.27	KA^2sec	A9036-7007007-v2x-100034.png
9	341	354	281	Amps	0.003	0.2		0.27	KA^2sec	A9036-7007008-v2x-100034.png
10	360	768	2457	Amps	0.106	6.38	80T-100T	641.27	KA^2sec	A9036-7007009-v2x-100049.png
11	316	329	282	Amps	0.003	0.2		0.27	KA^2sec	A9036-7007010-v2x-100084.png
12	335	377	1270	Amps	0.011	0.66	15T	17.64	KA^2sec	A9036-7007011-v2x-100111.png
13	340	350	1	Amps	0.003	0.16		0	KA^2sec	A5056-7007012-v2x-98276.png
14	299	534	1807	Amps	0.061	3.67	50T	199.89	KA^2sec	A9015-7007013-v2x-98294.png
15	355	512	1331	Amps	0.041	2.45	30T	72.41	KA^2sec	A8162-7007014-v2x-101561.png
16	326	480	1349	Amps	0.04	2.41	30T	72.97	KA^2sec	A7178-7007015-v2x-101556.png
17	334	345	6	Amps	0.003	0.17		0	KA^2sec	A8162-7007016-v2x-101567.png



Looking Ahead

- Auto-classification of distribution electrical disturbances
 - Faults, PQ events, Pulse tests, Switching
- Add 'one click' link between PQD and SOE
- Add some PQD features to SOE dashboard
- Trend the “useful data”
 - Recurring event dashboard
 - Anomaly detection
 - Artifact analysis (harmonics, CAP, ferroresonance)
 - Predicting failure / asset health
- Solution available to support large sensor deployments



Problems Mitigated with SOE Dash

- Can see the whole SOE picture instead of one comtrade file at a time
- Can navigate between devices efficiently
- Devices recording the same event don't all record the same number of comtrade files
 - Time gaps are easy to identify
- Clocks not is sync, now obvious
- Human brain can process 177 COMTRADE files





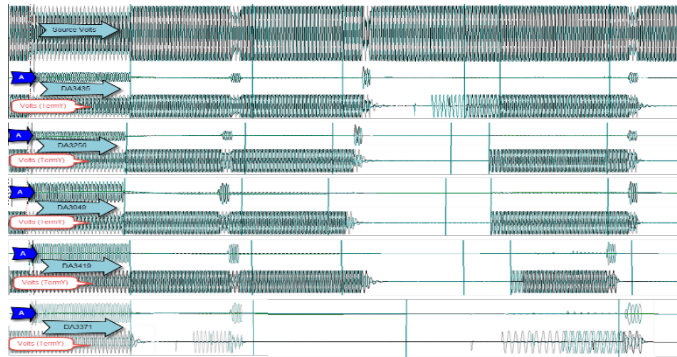
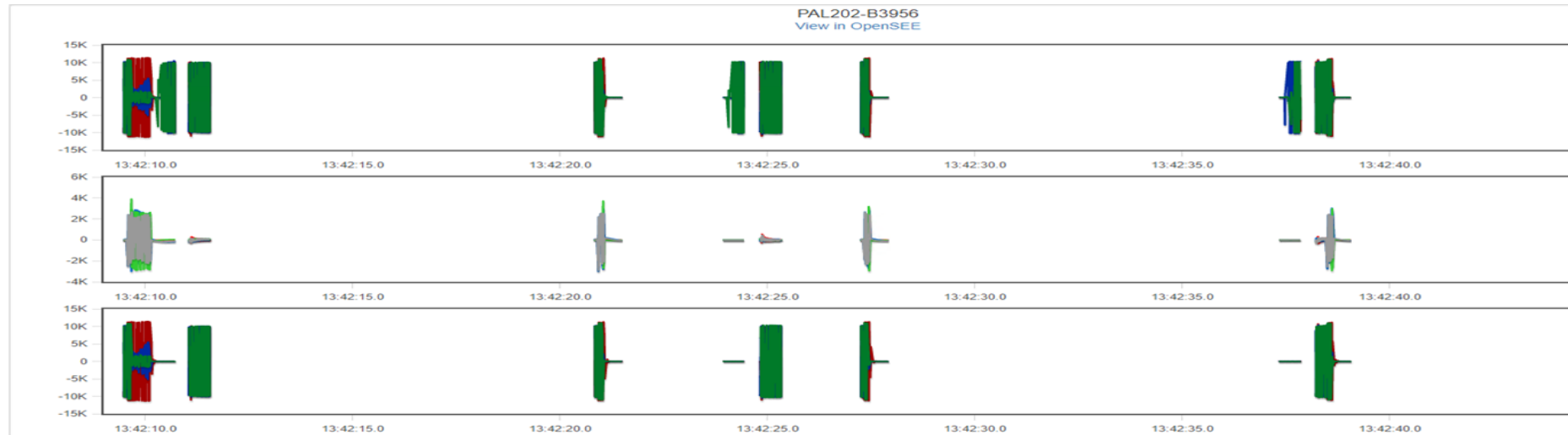
epb

Smart Grid

DISCOVER MORE NOW

SOE Analysis Engine

➔ Discover More Now ➔



Modified original for illustration: add date range and data detail

