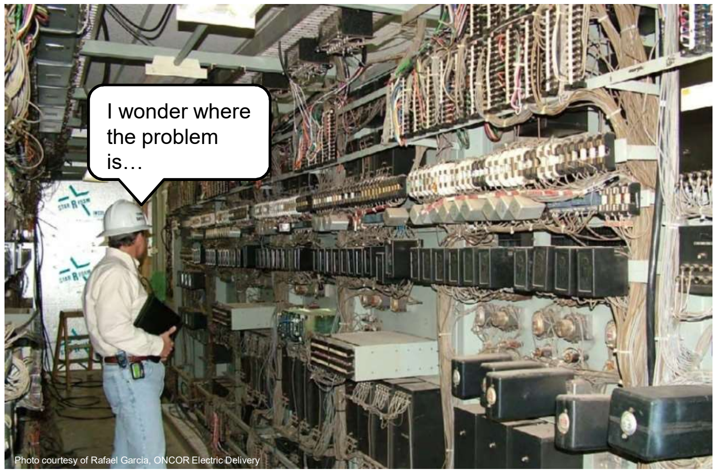
Hands On Relay School 2019

Event Analysis

Ahhh, the Good Old Days…

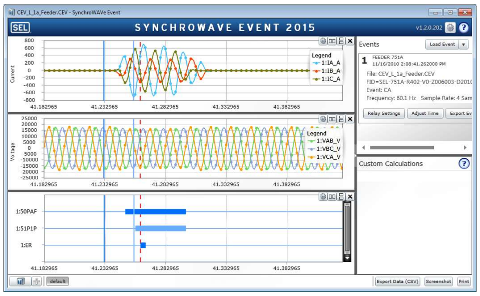


In the aftermath of the Northeast Blackout of 2003, congressional action granted the Federal Energy Regulatory Commission (FERC) and the North American Electric Reliability Corporation (NERC) the power to implement mandatory and enforceable reliability standards. Whether these efforts and their costs are improving power reliability is debatable; recent misoperation statistics are level and generally show no improvement. In 2010, NERC revitalized its event analysis program; however, the industry lacks safe harbor guarantees that self-reported information will not be used to punish and fine the reporters. The North American Transmission Forum (NATF) promotes the idea that the candid exchange of information is the key to improving reliability; however, it is a members-only group, exclusive of manufacturers, regulators, and other key stakeholders. Individual utilities work on root-cause analysis and improving their own processes; however, sharing lessons learned with others in an efficient way is difficult. Following outages, especially at industrial plants, the threat of lawsuits further hinders the sharing of information.

Significant improvements in reliability will likely not occur until the industry emulates models such as those provided by the Commercial Aviation Safety Team (CAST) and the nuclear power and healthcare industries. Rather than blaming individuals, collaborative expert system-think teams inclusive of all stakeholders focus on human factors, system issues, and improvements. CAST, in particular, has amazing results: an 83 percent reduction in the fatal accident rate over 10 years as well as improved productivity (lowered costs), all without a single new regulation.

What Is an Event Report?

- Snapshot of the power system
- Trip or trigger prompts data capture
- Includes:
  - Date and time stamp
  - Sampled analog inputs
  - Status of inputs and outputs
  - State of relay elements and logic
  - Relay settings



Analysis of event reports and SER data can provide the root cause of protection system operations so that you can identify if equipment can quickly be restored or if testing and repairs are required.

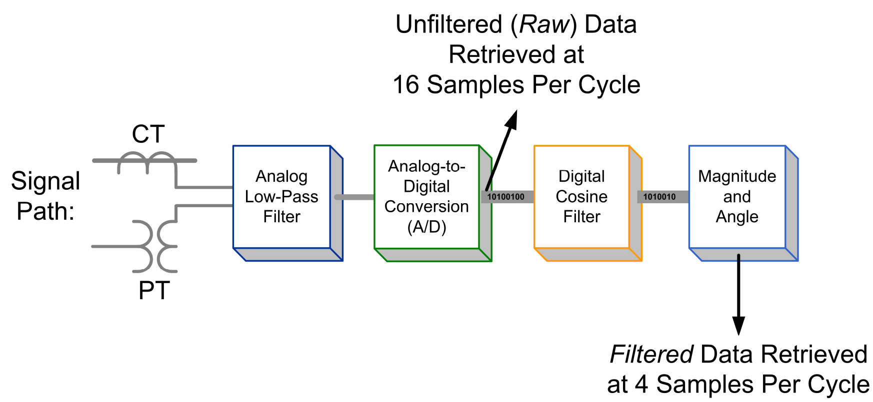
You will want to analyze event reports frequently and use them as a tool to improve protection and maintain vital equipment.

The relay captures 15 or 64 cycles of event data and creates an event report, which includes four sections:

- Analog values of current and voltage (translated into waveforms)
- Digital states of the protection and control elements and digital inputs/outputs
- Event summary (trip type, date, and time)
- Settings in service at the time of the event

Relay Signal Path

Data Retrieved at Different Points



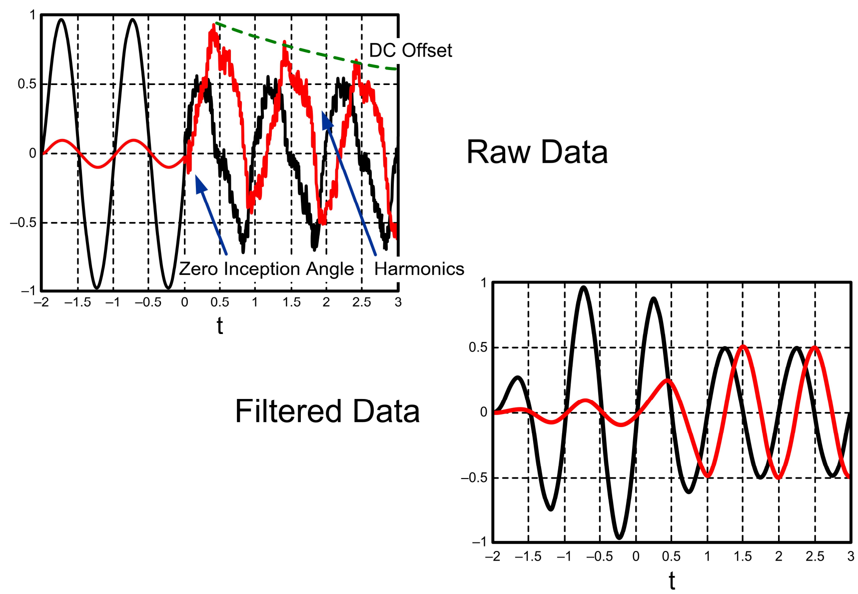
The relay can retrieve two types of event data: either 4 samples/cycle filtered data or 16 samples/cycle unfiltered (raw) data.

The data are retrieved at different points in relay processing, as shown above in the data path for the voltage and current input signals.

After the currents and voltages are reduced to acceptable levels by the instrument transformers, the signals are filtered with an analog low-pass filter, which rejects higher harmonics. Then it is digitized and refiltered with a digital cosine filter. Numerical operating quantities are then calculated from the processed waveforms.

Filtered data are useful in calculations of fault data. They are the data that the relay uses in the protection algorithms. Filtered data are not the sampled waveform, but a mathematically manipulated waveform.

Waveforms



The raw voltage and current waveforms generated during a power system fault are illustrated on the slide. These waveforms are the result of a fault on the power system at the end of the line with no fault resistance. An inception angle of zero gives a full dc offset. The post-fault data are corrupted with noise, dc, and 2nd, 3rd, and 5th harmonics.

The filtered quantities should look clean without any harmonics, dc offset, or noise. The relay operates on filtered quantities. Analysis of these quantities will yield proper current and voltage phasors.

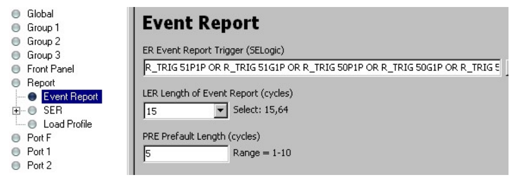
You will want to choose filtered event data for most of your event reporting needs because these are the signals the relay's protection elements work from. The raw event reports, however, can also be useful since this unfiltered data shows what the relay actually "sees" from the power system. Raw event reports will show conditions such as:

- CT saturation
- Decaying dc offset (the difference between the symmetrical wave and the actual current wave during a transient condition)
- Power system harmonics (signals with atypical frequencies, creating waveform distortions)
- Input contact bounce

Raw event reports display one extra cycle of data at the beginning of the report.

Event Report Settings

- ER trigger logic
  - Elements other than trip conditions
  - Use rising-edge operators to prevent long-term Event Trigger equation assertion



- LER specifies the length of reports
  - Default 15-cycle length allows the relay to store 23 reports
  - The 64-cycle length allows the relay to store 7 reports
  - WARNING! Changing the LER setting will *erase* stored event report data. Save existing data before changing the LER
- PRE specifies prefault cycle length

You can specify the length of event reports as either 15 or 64 cycles of event data in the LER setting.

However, changing the LER setting will erase stored event report data. You must save all existing event records before changing this setting.

The event report length also affects storage capacity: the default length of 15 cycles allows the relay to store up to 23 reports. The 64-cycle length allows only 7 reports to be stored due to the higher resolution and more detailed data capture.

The PRE prefault length setting determines how many cycles of data will precede the event report trigger point. Prefault data can be helpful in determining what was happening prior to the event.

Elements in the programmable ER logic will trigger event reports for conditions other than trip conditions, such as external RTD warnings or alarms. An event report is automatically generated when trip equation elements assert. Thus, any Relay Word bit that causes a trip does not have to be entered in the ER setting.

It is important to always use the R_TRIG rising-edge operator with all word bits used in the ER equation. A word bit that remains asserted in the ER equation will not allow future assertions of the ER equation. It is the assertion of the ER equation that triggers event recording. If the ER equation remains asserted, no other word bit activity in the ER equation results in event data capturing.

Event Report Viewers

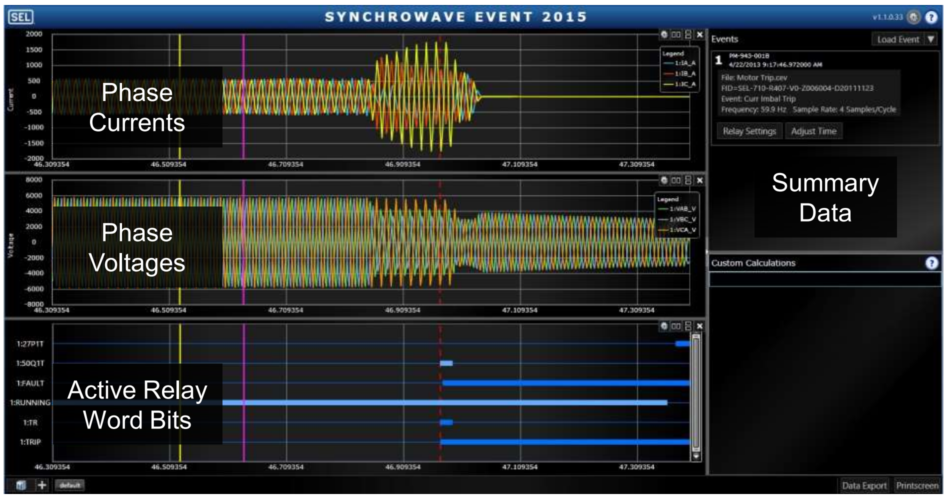
1. SYNCHROWAVE® Event 2015
   SEL-5601-2015 Software
2. ACSELERATOR Analytic Assistant®
   SEL-5601 Software

To view the saved events stored in a compressed format, you will need SYNCHROWAVE® Event 2015 SEL-5601-2015 Software or ACSELERATOR Analytic Assistant Software.

Open an event by double-clicking on a saved event file (.CEV extension)

SYNCHROWAVE Event 2015 Analysis

Default View



When you open an event report for the first time, the default view includes the three phase currents, three phase voltages, and active Relay Word bits. Manipulation is required for additional analysis.

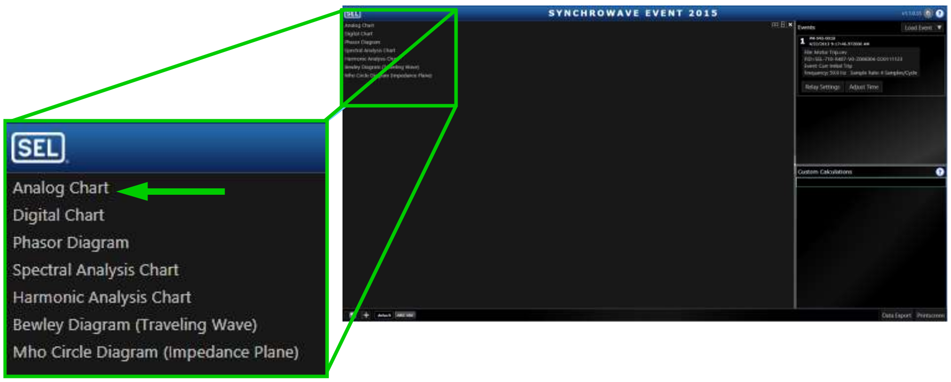
SYNCHROWAVE Event 2015 Analysis

Split Windows to Add More Charts

Split the chart vertically

SYNCHROWAVE Event 2015 Analysis

Select Different Types of Charts



SYNCHROWAVE Event 2015 Analysis

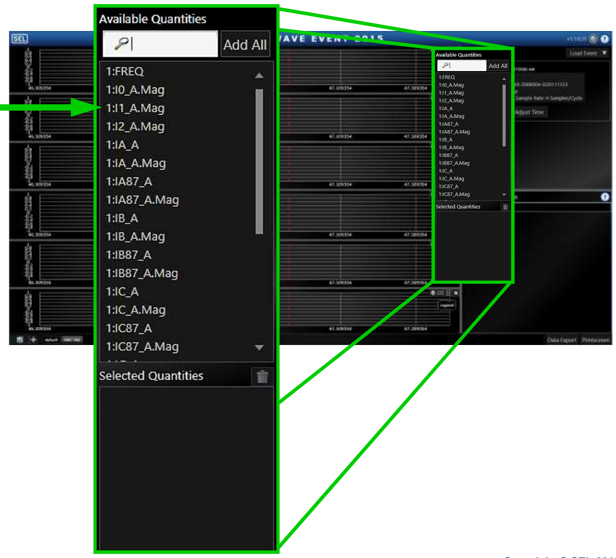
Define Signals in a Chart

Click the gear to define signals

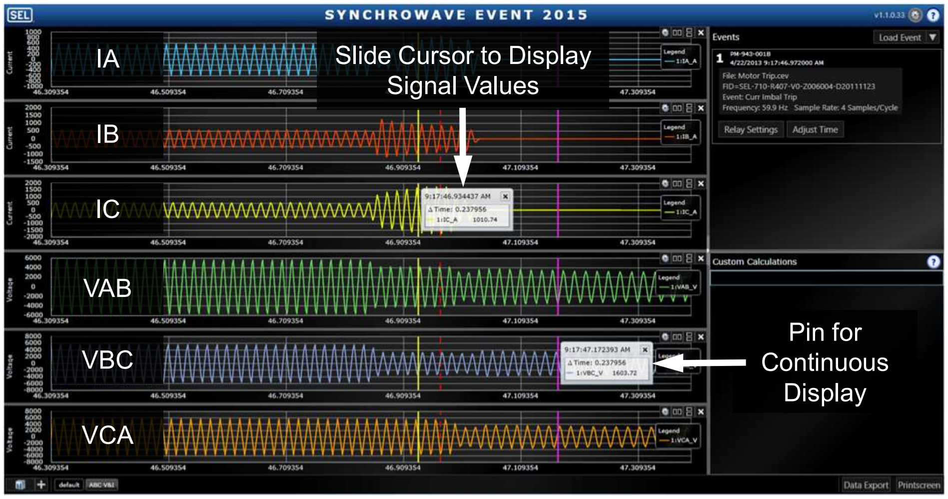
SYNCHROWAVE Event 2015 Analysis

Define Signals in a Chart

Select or search for signals



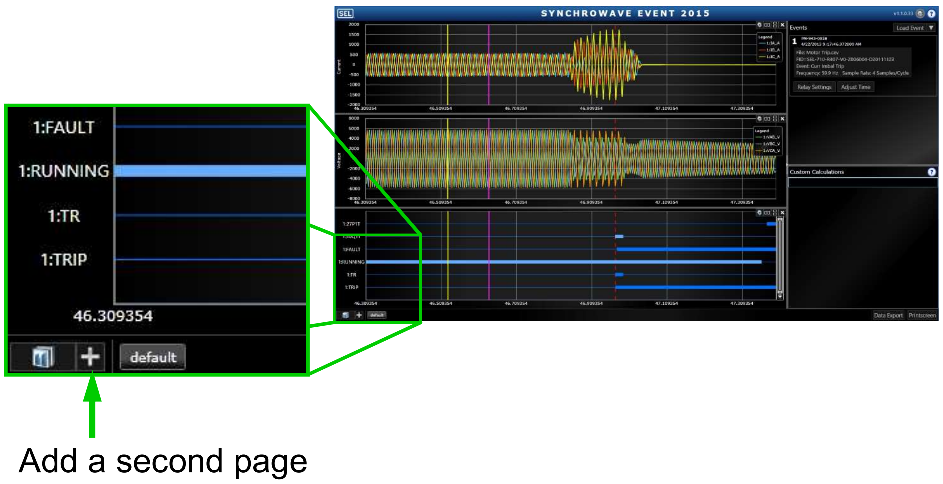
SYNCHROWAVE Event 2015 Analysis



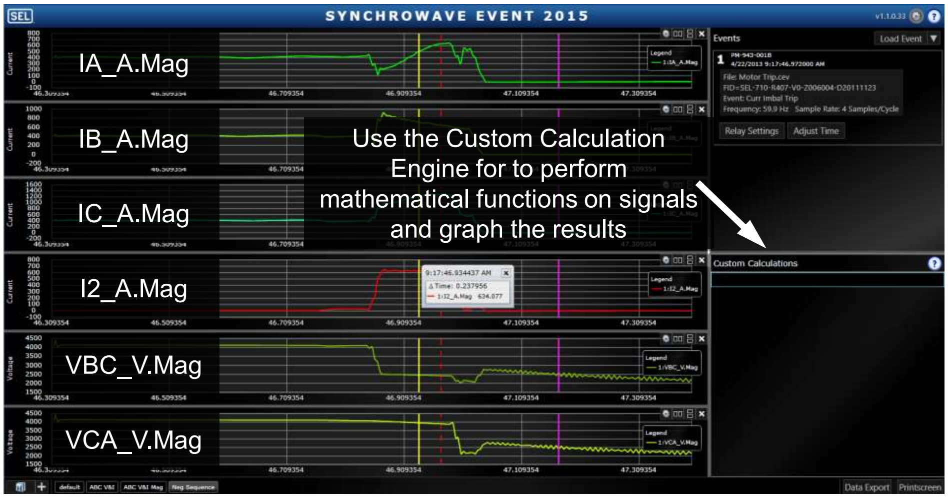
Cursors can be slid along the waveform to provide a value for a specific sample point. Multiple cursors can be added to provide time-difference references. The cursor location values can be pinned to keep them displayed. Hover over a cursor to display the time between two cursors in seconds or cycles.

SYNCHROWAVE Event 2015 Analysis

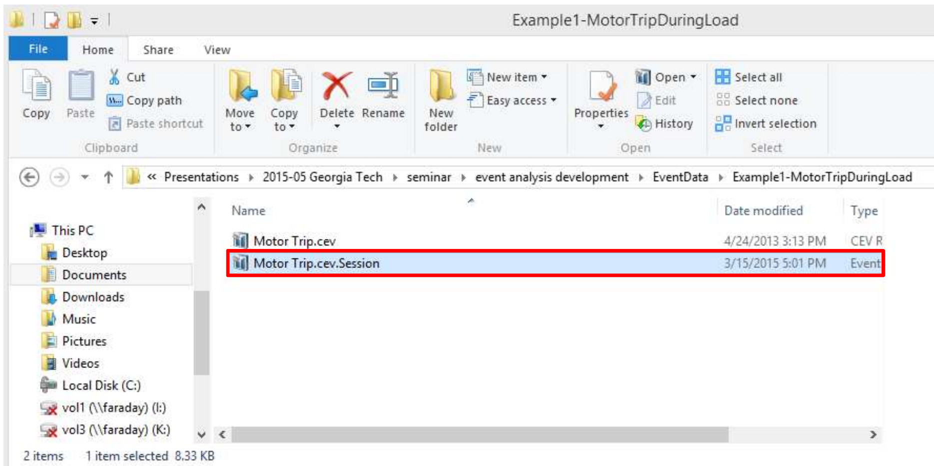
Add Tabs for More Space



SYNCHROWAVE Event 2015 Analysis

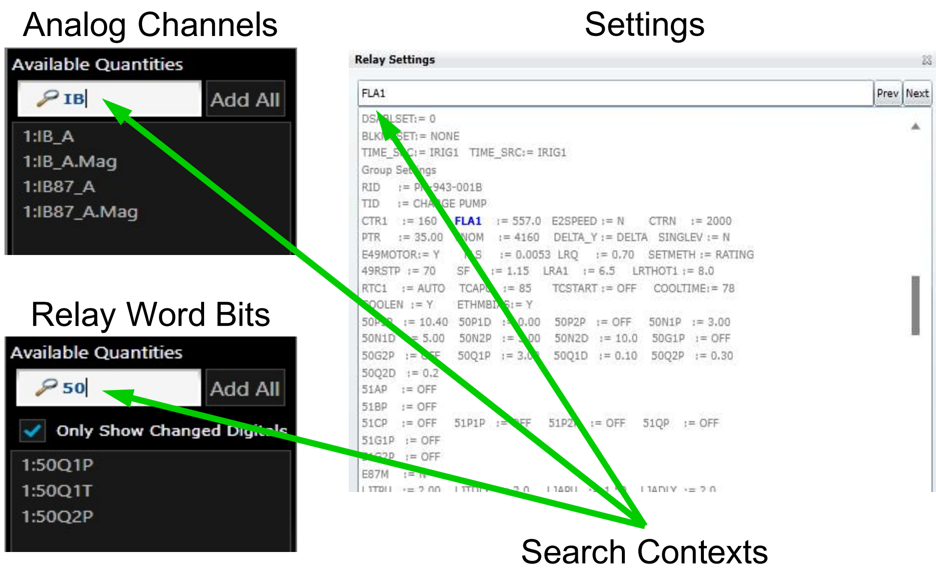


Session File Automatically Stores Analysis Work



All work is stored automatically in a session file in the event report folder. If you close the event and then re-open it later, the previous analysis work will be preserved. Session files can be centrally stored and used later as templates to simplify the event analysis for similar relay applications.

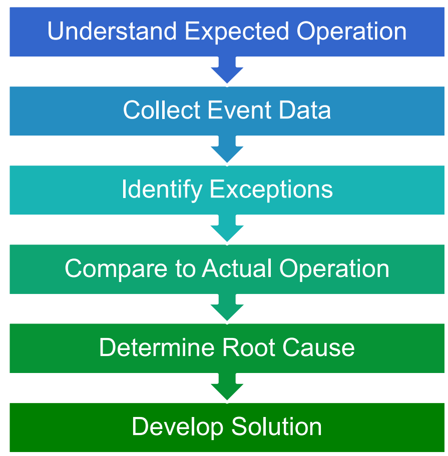
Search Tools Speed Up Analysis



Finding specific event information can be tedious. Powerful search tools help sift through the relay settings, analog channels, and digital channels to find specific event information quickly.

Analysis Process

- Do not guess
- Get the data you need
- Collect event data using the following event retrieval steps



Before analyzing the details of any event report, start with a basic understanding of what happened or what should have happened. This generally involves reviewing the relay settings and logic, obtaining the relay history report, and gathering any other information that may be helpful (known fault location, targets from other relays, breaker operations, SCADA, and personnel records).

It is important to review normal system operations, in order to more easily recognize problems and trends of failure.

Rather than guessing what occurred, retrieve the event data provided in the relay, and use the analysis process to determine root cause.

Analysis Hint

To determine expected operation, focus on TRIP and CLOSE outputs and logic

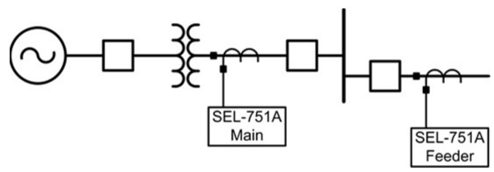
- Find TR logic, decipher elements used, and research elements
- Do not waste time researching unused elements

It can be very helpful to obtain a dc control schematic using settings in the protective relay to understand the use of inputs and outputs. Normally, outputs connected to a breaker will be controlled by the TRIP and CLOSE logic. These logic equations are functions of elements inside the relay. Relays contain many of these elements, many of which may not be related to the event. Save time by researching only the elements that are present in the TRIP logic.

Example Event

Known Information

- Two SEL-751A Relays: Main and feeder are fed from an upstream transformer
- Line-to-line fault is suspected (C to A)
- Main relay tripped; feeder relay is not tripped

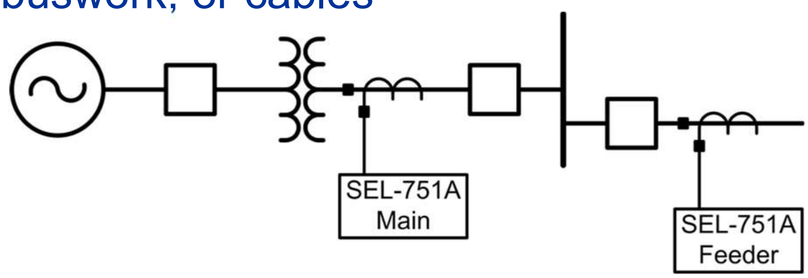


In this example event, the customer believed that a line-to-line fault (C-phase-to-A-phase fault) caused events to be generated in both the main and feeder SEL-751A Relays. A schematic of the system is provided on the next slide. Upon inspection of the transformer, buswork, and cables, no fault evidence was found. SEL was contacted to identify what caused the event and why the main relay tripped the breaker but the feeder relay did not. The event reports from both relays were provided, along with the settings from each during the time of the event.

One-Line Diagram

What Happened?

- Main relay tripped the breaker
- Feeder relay did not trip breaker
- No faults were found on the transformer, buswork, or cables

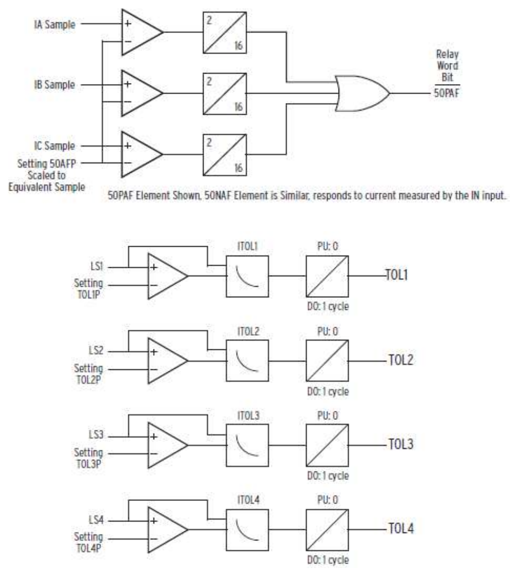


Understand Expected Operation

- OUT101 of each relay trips the appropriate breaker
- Settings in both relays reveal
  - OUT101 = TR
  - TR = instantaneous overcurrent (50), time-overcurrent (51), and arc-flash elements (50PAF, 50NAF, and TOL1 through TOL4)

It is known (or can be observed from system schematics) that OUT101 of each relay trips its respective breaker. Inspection of the settings inside each relay shows that OUT101 operates upon the assertion of the TR SELOGIC® control equation, which is a function of instantaneous overcurrent (50), time-overcurrent (51), and arc-flash elements. The typical installation of arc-flash detection requires both overcurrent and arc-flash light sensors.

Understand Expected Operation

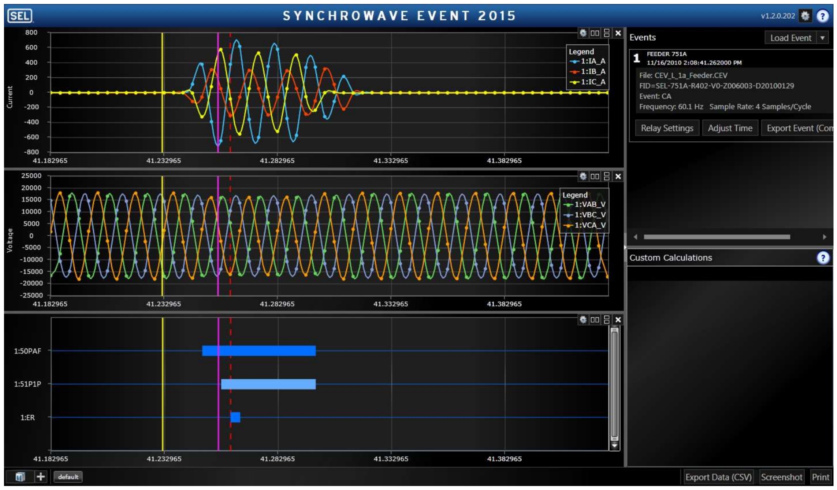


Logic diagrams are available in the instruction manual

To understand the operation of the elements in the TR equation, reference the instruction manual. The instruction manual includes logic diagrams, descriptions, and an explanation of related settings.

Collect Events and Other Information

Feeder Relay Filtered Event



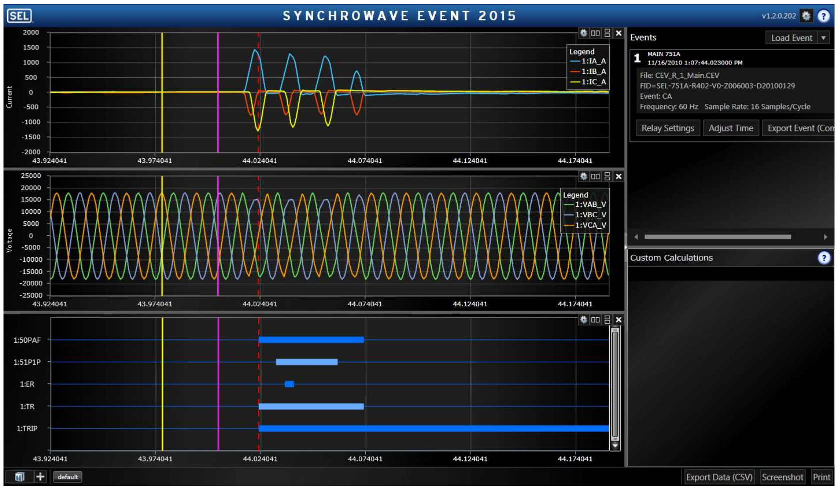
Is this a fault?

This slide shows the filtered event report from the feeder relay.

Does this look like a fault? It may be hard to tell from this information. Notice the decaying magnitudes of the phase currents. Also notice that the fault currents are fairly low for a fault condition. Knowing that this relay is close to a transformer leads to a suspicion of transformer inrush. You may need to obtain an unfiltered event report to get more information.

Collect Events and Other Information

Main Relay Unfiltered (Raw) Event



Is this a fault?

This slide shows the raw (unfiltered) event report seen by the main relay. This slide makes it more obvious that you are looking at transformer inrush instead of a fault.

Not a Fault

- Decaying dc offset in phase currents
  - Harder to see in the filtered (feeder) event
  - Easier to see in the unfiltered (main) event
- Transformer inrush
  - Neither relay should trip
  - Arc-flash overcurrent element is likely to assert but should not trip without light

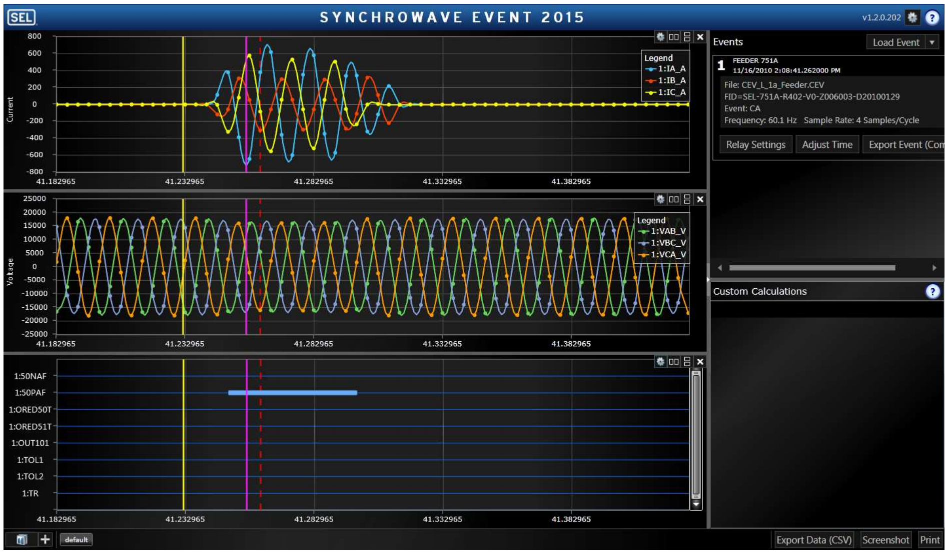
Generally, you do not want the relay to trip during transformer inrush. Even more so, you would not expect an arc-flash element to cause the trip because these elements are typically programmed to require both overcurrent and light from an arc flash.

Investigate Settings and Schematics

- Use what you know to work backward
  - Breaker opens when OUT101 asserts
  - OUT101 asserts when TR asserts
  - TR asserts from either 50, 51, or arc-flash elements
    - Feeder: TR = ORED50T OR ORED51T OR (50PAF AND TOL1) OR (50NAF AND TOL1) OR (50PAF AND TOL2) OR (50NAF AND TOL2)
    - Main: TR = ORED50T OR ORED51T OR (50PAF AND TOL1) OR (50NAF AND TOL1) OR (50PAF AND TOL2) OR (50NAF AND TOL2) OR (50PAF OR 50NAF AND TOL3) OR IN302
- Use software to view the state of each element during an event

The breaker opens when OUT101 operates. OUT101 operates when the TR equation asserts, which is a function of the 50, 51, and arc-flash elements. Look at the logical value of each element in the TR equation during the event using event analysis software (ACSELERATOR Analytic Assistant) to determine which element caused the trip.

Feeder Relay



Starting with the feeder relay, notice that the breaker did not trip because OUT101 did not operate. OUT101 did not operate because the TR equation did not assert. The TR equation did not assert because the combination of logical expressions did not evaluate to a logical 1. Although 50PAF did assert, TOL1 or TOL2 would also have to assert in order to make TR equal to a logical 1.

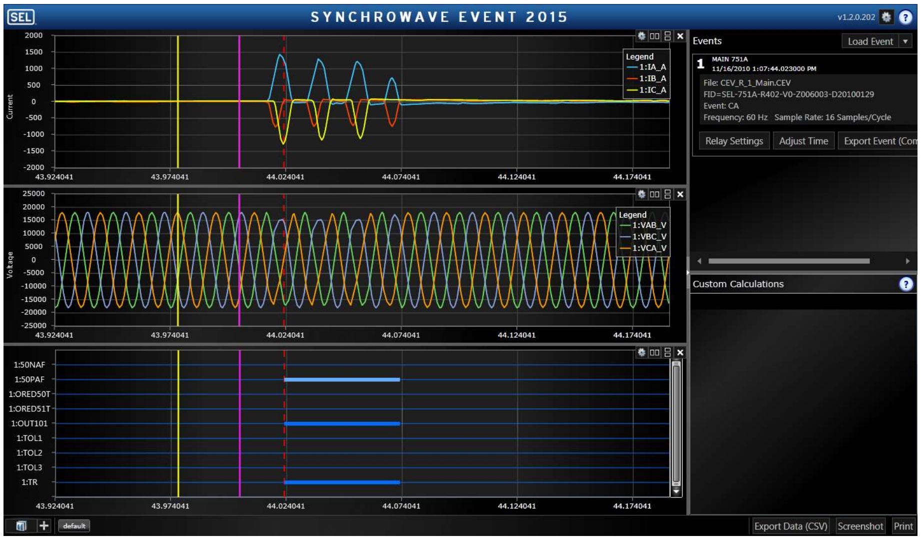
Compare Operation to Expectations

Feeder Relay

- 50PAF asserted but not TOL1 or TOL2
  - Overcurrent but no light = no trip
  - 50PAF = 1, TOL1 = 0, TOL2 = 0
- TR did not assert (expected); would need 50PAF = 1 and either TOL1 = 1 or TOL2 = 1 to trip for arc flash
- OUT101 did not assert (expected)
- Relay operated as expected

When inspecting the operation of the feeder relay, you can see that the arc-flash overcurrent element asserted but the light elements did not (as expected). Because the overcurrent elements and light elements are combined together with AND, the relay did not trip. The feeder relay operated as expected.

Main Relay



Observing the event from the main relay, notice that OUT101 operated at the same time the TR equation asserted. It is also shown that TR asserted at the same time 50PAF asserted.

What is 50PAF? It is an instantaneous overcurrent element for arc flash. Reference the instruction manual for more information. The instruction manual also explains settings associated with this element and how to implement it for tripping. Notice that TOL1, TOL2, and TOL3 (the light elements) are all deasserted during the course of the event. Again, reference the instruction manual for more information.

Compare Operation to Expectations

Main Relay

- 50PAF asserted but not TOL1, TOL2, or TOL3
  - Overcurrent but no light = no trip
  - 50PAF = 1, TOL1 = 0, TOL2 = 0, TOL3 = 0
- TR asserted; is not supposed to assert unless overcurrent and light are present
- OUT101 asserted to trip the breaker; this was expected because TR asserted
- Why did TR assert?

Typical installations require two things to trip for arc flash: a lot of current and a lot of light. Therefore, if 50PAF asserted, TOL1, TOL2, or TOL3 would also have to be asserted. This was not true for the event. To find out why, inspect the TR equation in the main relay.

Use the Instruction Manual to Find Root Cause

Table 4.34 SELOGIC Control Equation Operators (Listed in Operator Precedence)

Operator	Function	Function Type (Boolean and/ or Mathematical)
( )	parentheses	Boolean and Mathematical (highest precedence)
–	negation	Mathematical
NOT	NOT	Boolean
R_TRIG	rising-edge trigger/detect	Boolean
F_TRIG	falling-edge trigger/detect	Boolean
* /	multiply divide	Mathematical
+ -	add subtract	Mathematical
<, >, <=, >=	comparison	Boolean
= <>	equality inequality	Boolean
AND	AND	Boolean
OR	OR	Boolean (lowest precedence)

- Verify logic equations
- Note order of operations: AND comes before OR

First, review the information on SELOGIC control equations in the instruction manual, such as the table shown on this slide that indicates the order of operations.

Root Cause Found

- Main relay: Mistake was made
  - TR = …OR (50PAF OR 50NAF AND TOL3) OR…
    - Relay reads this as 50PAF OR (50NAF AND TOL3)
    - Intention was to have (50PAF OR 50NAF) AND TOL3
  - TR asserts when 50PAF asserts; the presence of light is not necessary
- Feeder relay: Mistake was not made

This slide shows one section of the TR equation in the main relay. The user who entered the expression had a different interpretation of the expression than the relay did because ANDs are evaluated before ORs. Therefore, the presence of light was not necessary, and the relay tripped the breaker as soon as 50PAF asserted.

Benefits of Analysis

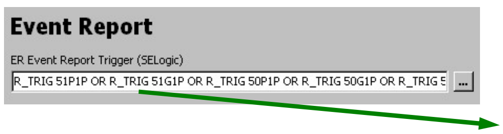
- Understand the system better
- Verify correct relay operation and the cause of a misoperation
- Identify importance of proper testing during commissioning

After finding root cause, the solution should be implemented and tested. Through the process of event analysis and troubleshooting, you can get a better understanding of your system, verify relay operation, find the cause of a misoperation, and correct settings or wiring errors when necessary. Proper testing during commissioning is important and can help reduce the frequency of unexpected operations, as well as limit the amount of time necessary to determine root cause.

Five Things to Remember About Event Data

1. The event report of interest may not be the newest event
2. The relay does not need to trip to generate an event report

Use the ER equation to trigger non-trip events



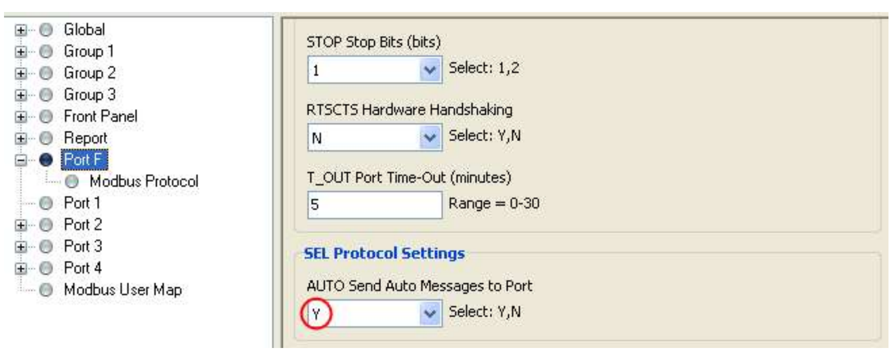
The relay generates an event report on the *rising edge* of the phase or ground time-overcurrent element.

The ER Trigger equations use the R_TRIG logic operator, which will momentarily assert an element on its rising edge.

Five Things to Remember About Event Data

3. Download event data *soon:* Event report storage is limited

4. Download both filtered and raw data
   – Filtered is best for standard protection analysis
   – Raw is needed to see inrush, CT saturation, and harmonics



Five Things to Remember About Event Data

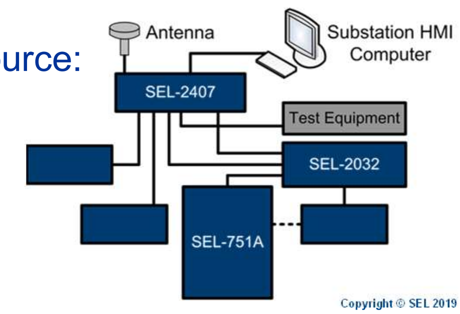
5. Event retrieval of combined or correlated relay events requires *highly accurate* time synchronization

   – System-wide event analysis is greatly simplified with time synchronization

   – Connect a relay time source:

   ▪ IRIG-B input signal

   ▪ GPS clock



One-millisecond resolution is required to accurately align event data. Most alternate time-synchronization methods (manual relay, computer clock settings, or SCADA protocols) do not meet event data time accuracy requirements.

The SEL-751 has three different physical interfaces to provide demodulated IRIG-B time-code input for time synchronization. If the relay has multiple options for IRIG-B input, only one input can be used at a time. Refer to the SEL-751 Instruction Manual for more information.

For more information on event report analysis, see the technical paper "Forward to the Basics: Selected Topics in Distribution Protection" by Lee Underwood and David Costello, on your Student CD and available at selinc.com.

Generator Event

Mystery Event

Mystery Event