Advanced Event Analysis Tutorial

Part 1: Questions

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***Abstract*—Event reports continue to be an invaluable feature in microprocessor-based relays. Some events are relatively straightforward to analyze, and others require experience and considerable knowledge of the power system and protective relay system in order to find root cause. This session provides several advanced real-world event examples, time to evaluate them, and solutions.**

I. Introduction

The event reports provided in this session are from real-world applications. They have been edited only to the extent that the owner involved is not revealed. They provide us the opportunity to learn and improve our power system. We want to thank the engineers and technicians who share information and what they know for the benefit of our industry.

We provide a number of example case studies. These come from a wide variety of power system and protection applications and include distribution, transmission, transformer, and bus event examples.

In each case, we provide some or all of the following:

- A brief introduction to the application and problem.
- The event reports required to solve the problem.
- The instruction manual for the product involved.
- References for future reading and further instruction.

Students are required to use their own personal computer with SEL Compass®, ACSELERATOR QuickSet® SEL-5030 Software, and ACSELERATOR Analytic Assistant® SEL-5601 Software installed. These programs are available for download at no cost from www.selinc.com. It will also be helpful to have the instruction manuals available for the relays being applied in the example events.

Students are invited to answer the questions asked in this document. These questions are intended to guide analysis, keep the class efforts focused in the same direction, and highlight the main lesson points. Please document the solution to each case study in the format of a Microsoft® Word document with appropriate software screen captures and notes.

Some of the events highlight the need to capture certain event formats. For example, it is always recommended that users capture a filtered compressed format and unfiltered compressed or COMTRADE format for each event. In some cases, a traveling wave COMTRADE is required.

Finally, instructors are available to answer questions, share tips, and highlight lessons learned. Have fun!

II. Directional Element Operates for Reverse Fault

This event occurred on a 230 kV line protected with an SEL-311C Transmission Protection System. Direct tripping and a permissive overreaching transfer trip (POTT) scheme were employed with phase and ground protection elements. The relay produced a trip for an apparent reverse fault, as shown in Fig. 1.

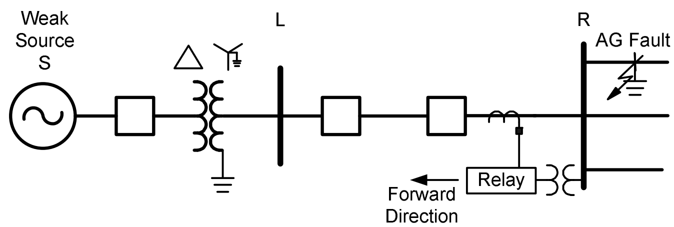

Fig. 1. One-line diagram of example system

First, consider the expected operation. For an external fault (reverse fault from the R terminal), no tripping would be expected. The L relays would likely detect a forward fault and send a permissive trip signal to the R terminal. The only possibility for a trip is if there were a protection or breaker failure to clear the fault from the protected line. However, what actually occurred is a trip at the R terminal.

Open the event labeled **2_EXAMPLE 2_311C.cev**. Also, in order to analyze the relay settings and logic, some familiarity with the relay and protection scheme is necessary.

II-a What relay elements are programmed to trip, and what tripping schemes are applied?

II-b What relay element or elements actually produced the trip condition?

II-c What type of fault occurred? Was the fault forward or reverse? Did the relay elements operate correctly?

II-d How was the directional element set? Did the relay use negative sequence, zero sequence, or both?

II-e Were the settings correctly applied?

III. High-Speed Zone 1 Trip for 345 kV Line Fault

In this example, an SEL-421 Protection, Automation, and Control System tripped at high speed for a line fault. The utilities involved considered this to be a correct operation. However, here we take the opportunity to analyze the event reports. What can we learn from a correct operation? The one-line diagram is shown in Fig. 2.

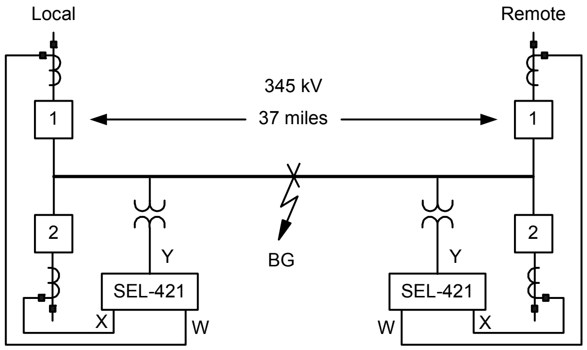

Fig. 2. One-line diagram of example system

In this section, we have the following three events:

- Local SEL-421 compressed filtered event at 8 samples per cycle.
- Local SEL-421 COMTRADE unfiltered event.
- Remote SEL-421 filtered event at 4 samples per second (not compatible with ACSELERATOR Analytic Assistant).

Each event has useful data that we can use to evaluate the protection system performance. First, open the local compressed filtered event **3_421_LOCAL.CEV**.

III-a What type of fault occurred?

III-b What protection schemes does the relay apply?

III-c What element within the relay caused the trip? How long did it take for the relay to operate? How long did the breaker(s) take to clear the fault?

III-d Did the relay and protection system operate correctly and as expected?

III-e Open the local COMTRADE event **HR_10003_421_LOCAL.DAT**. Evaluate the unfiltered currents and voltages before, during, and after the fault. What observations can we make, and are there any concerns?

III-f Evaluate the DCB scheme. What inputs and outputs were assigned for the DCB scheme? Did the local inputs and outputs assert as expected?

III-g Open the remote event **3_421_REMOTE.txt**. Did the remote SEL-421 send a block signal? What could have caused the local SEL-421 BT input to assert?

IV. Traveling Wave Fault Location

The SEL-411L Advanced Line Differential Protection, Automation, and Control System now has the ability to provide traveling wave (TW) fault location, which measures the time that high-frequency transients produced by faults are sensed at each end of the line. The TW-based fault locating function uses the internal protection elements, the communications channel to the remote terminal, and Global Positioning System-based (GPS-based) time synchronization. The TW fault locator uses conventional current transformer (CT) measurements.

Although the fault location estimate can be provided automatically from each end, it is useful to be able to evaluate and calculate the estimate using event reports.

For this example, we examine an actual BG fault on a 72.77-mile 161 kV line in an area of rough terrain in the western part of the United States. The actual line data, event information, and traveling wave calculation details are described in [1]. The basic formula for calculating fault location is shown in (1).

$$\text{TWFL} = \frac{\text{LL} + (\text{TwaveA} - \text{TwaveB}) \cdot c \cdot \text{LPVEL}}{2} \tag{1}$$

where:

TWFL is the TW-based fault location from local Terminal A.

LL is the line length.

TwaveA is the TW arrival time recorded at Terminal A.

TwaveB is the TW arrival time recorded at Terminal B.

c is the speed of light.

LPVEL is the propagation velocity of the TW in per unit (pu) of the speed of light.

From [1], the TW propagation velocity is a key parameter in the fault location calculation and is typically obtained from line parameter estimation programs. We can also estimate propagation velocity using TW measurements with the following:

- Local TW information recorded during line or reactor energization tests.
- Local and remote TW information recorded during external faults.

Open the event reports titled **4_TW_10002_LOCAL.DAT** and **4_TW_10002_REMOTE.DAT** to find the precise time of the transient of the fault. Using the zoom-in feature of ACSELERATOR Analytic Assistant and selecting **Line and Points** in the **Style** selection, we can view the peak of the local and remote waveforms. We can select the peak point on the given phase to give us the time stamp.

IV-a What is the time stamp for each event?

IV-b Calculate TWFL using the observed times and remaining parameters, which are the following:

- LPVEL = 0.98821 (setting determined from system test).
- c = 186282.39705 miles per second.
- LL = 72.77 miles.

V. Transformer Differential Operation

A fault on a distribution feeder produced an undesired operation on a transformer differential relay. Fig. 3 shows the system one-line diagram.

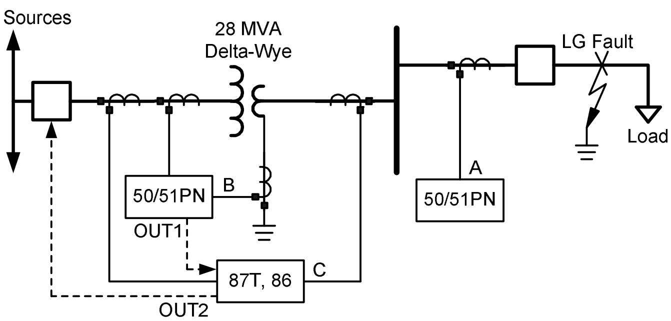

Fig. 3. System one-line diagram

In order to analyze this event, it is first important to understand the following expected operation:

- The recloser (A) should operate first.
- The transformer backup overcurrent relay (B) should operate second.
  - The relay protects the transformer based on the damage curve.
  - The relay coordinates with the downstream recloser control.
  - The output from B is connected as an input on Relay C, which acts as a lockout relay.
- The transformer differential relay (C) 87T should restrain.

The following actually occurred:

- A line-to-ground fault occurred on the feeder.
- Recloser A did not trip.
- The high-side circuit switcher did trip.
- The substation and all load were de-energized.

In order to find root cause, we will analyze the event reports. Open the events **5_YELLOW Event Files 587 2-4-12.CEV** and **5_YELLOW Event Files 551 2-4-12.CEV**.

V-a Where was the fault (internal to the transformer or external to the protection zone)? Did Relay B operate? Based solely on the event reports and the one-line diagram, what observations can we make?

V-b What problems, settings, wiring, testing, and so on contributed to these misoperations?

VI. Bus Differential Relay Application

Fig. 4 shows the one-line diagram of a 138 kV bus protected by a high-impedance bus differential scheme. The bus has two line sources, two transformers feeding radial load, a surge arrester, and a capacitor bank. The capacitor bank is manually controlled (energized and de-energized) by system operators to adjust the system voltage.

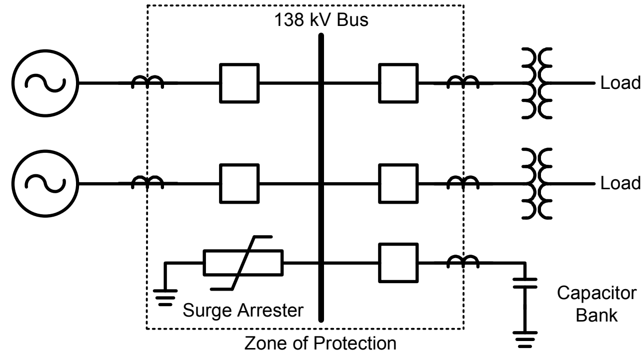

Fig. 4. One-line diagram of bus differential zone of protection

In a high-impedance bus differential scheme, the paralleled output of all of the CTs is connected through a large resistor (2,000 ohms in the SEL-587Z High-Impedance Differential Relay). The CTs are selected to be the same ratio (in this case, all CTs are 2000:5). If an unbalance current flows, such as for an internal fault, a voltage is developed across that resistor and the relay compares the voltage to a predefined threshold. The threshold is typically set to withstand an external fault if one CT completely saturates.

On one occasion, the high-impedance bus differential operated when the capacitor bank was de-energized. To evaluate this event, open the event files **6_SEL_587Z FILTERED.CEV** and **6_SEL_587Z RAW.CEV**.

See [2] for more background on this event.

VI-a What element produced the trip? How was the element set?

VI-b There were no other faults on the system at the time of the trip. The trip was directly related to the de-energization of the capacitor bank. What is the possible cause of the trip?

VI-c If the root cause is the conduction of the surge arrester, what protection measures can be taken?

VII. Restricted Earth Fault (REF) Element Trip

A large manufacturing facility experienced two critical transformer trips, which caused a loss of production while the trips were being investigated. The transformers were actually three single-phase, three-winding transformers connected in wye-wye-delta. A simplified three-line diagram is shown in Fig. 5. Fig. 6 shows a more detailed wiring diagram where we can see a spare transformer.

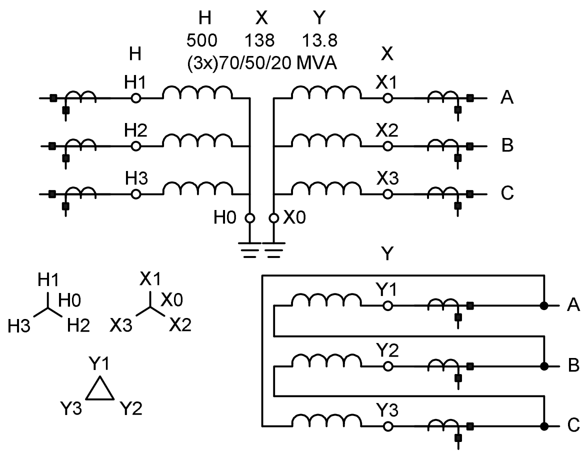

Fig. 5. Simplified three-line diagram

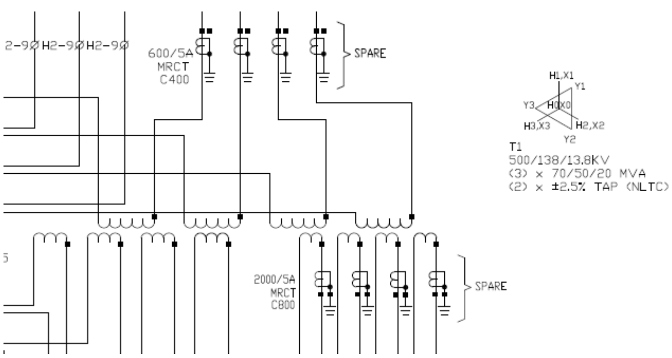

Fig. 6. Detailed screen capture shows single-phase transformers connected wye-wye-delta with spare transformer

The questions and discussion in this section follow a sequence of events that allow us to determine root cause. Open the event **7_CEV_S4_L30_1 initial trip.CEV**.

VII-a What elements were set to trip, and what element produced the first trip? How was the element set?

VII-b Open the event **7_CEV_S4_L15_1-trip after load.CEV**. What element produced the second trip?

VII-c What could have caused the trip?

VIII. Ground Directional Overcurrent Operates for Remote Fault

A line protective relay tripped for a remote AG bus fault and produced a Zone 1 target, which was deemed to be a misoperation. See Fig. 7.

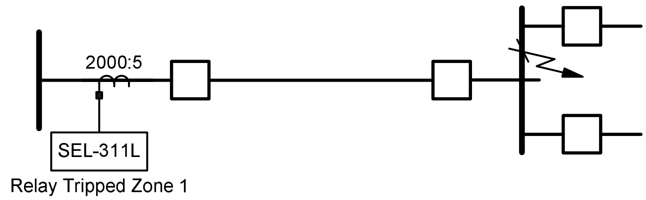

Fig. 7. One-line diagram shows Zone 1 trip for remote bus fault

The initial report from the field was that a Zone 1 distance element operated.

Open the event **8_311L_67G1 operation.cev**.

VIII-a What elements were set to trip, and what element produced the trip? How was the element set?

VIII-b What could have caused the unexpected rise in current? What actions can be taken to avoid this in the future?

IX. Line Current Differential Operates on Line Charging Current

A line current differential (87L) scheme operated for an out-of-section CA fault on the negative-sequence (87L2) element on a 5.6-mile 230 kV cable with no tapped load. By definition, this is an undesired operation. Fig. 8 shows a basic one-line diagram. Note that this line is radial with only tapped load and a reactor at Station G.

Open the event **SEL-311L_STATION G_LINE GH1.cev**.

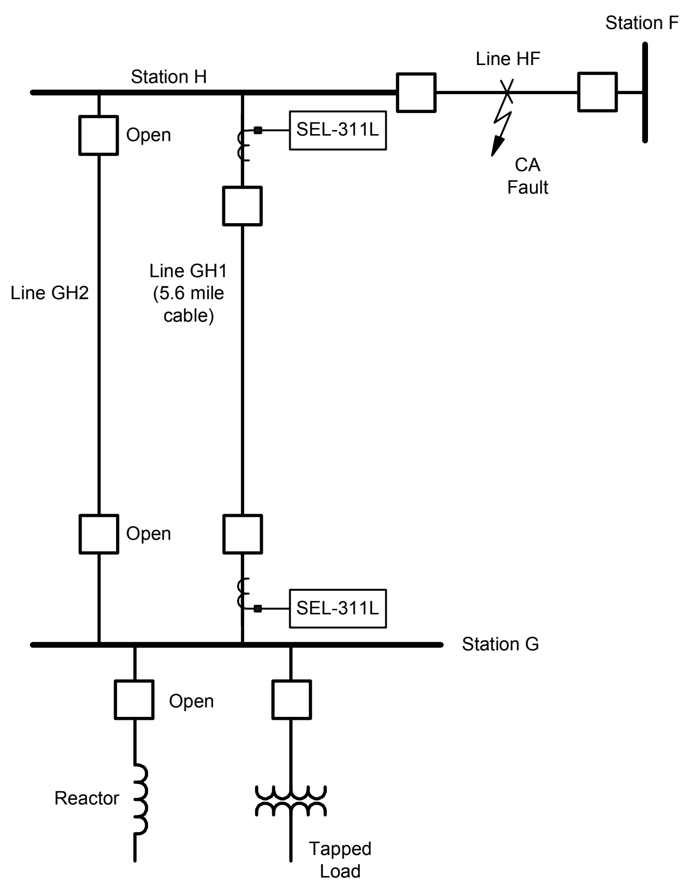

Fig. 8. Basic system one-line diagram

IX-a What elements were set to trip, and what element produced the trip? How was the element set?

IX-b Was there differential current in the prefault currents? What might have caused this?

IX-c What was the line charging current? What measures can be taken to prevent future operations? The events **SEL-411L STATION G LINE GH1_REPLAY.cev** and **SEL-411L STATION G LINE GH1_REPLAY_LINE CHARGING COMPENSATION ENABLED.cev** will be necessary to complete this exercise.

IX-d What measures can be taken to prevent future operations?

X. Acknowledgments

The author acknowledges the contributions of David Costello, Oskar Reynisson, Normann Fischer, Lee Underwood, Tony Lee, Bill Fleming, Mike Collum, Mangapathirao V. Mynam, and the many utility and industrial engineers who provided events and helped determine root cause of the events contained in this analysis.

XI. References

[1] S. Marx, B. K. Johnson, A. Guzmán, V. Skendzic, and M. V. Mynam, "Traveling Wave Fault Location in Protective Relays: Design, Testing, and Results," proceedings of the 16th Annual Georgia Tech Fault and Disturbance Analysis Conference, Atlanta, GA, May 2013.

[2] K. Koellner, O. Reynisson, and D. Costello, "High-Impedance Bus Differential Misoperation Due to Circuit Breaker Restrikes," proceedings of the 67th Annual Georgia Tech Protective Relaying Conference, Atlanta, GA, May 2013.

XII. Biography

Karl Zimmerman is a regional technical manager with Schweitzer Engineering Laboratories, Inc. in Fairview Heights, Illinois. His work includes providing application and product support and technical training for protective relay users. He is a senior member of the IEEE Power System Relaying Committee and chairman of Working Group D25, Distance Element Response to Distorted Waveforms. Karl received his BSEE degree at the University of Illinois at Urbana-Champaign and has over 20 years of experience in the area of system protection. He has authored over 25 papers and application guides on protective relaying and was honored to receive the 2008 Walter A. Elmore Best Paper Award from the Georgia Institute of Technology Protective Relaying Conference.