Voltage Potential Device Impact on Negative Sequence Directionality

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Chronology of Events

- On 7/25/16, at 06:58:57.634, a utility experienced a disturbance event on a transmission line.
  - Fault type was A phase to Ground.
  - Fault location was about 3 miles from one end of a 9-mile long line.
  - Fault duration was four cycles.

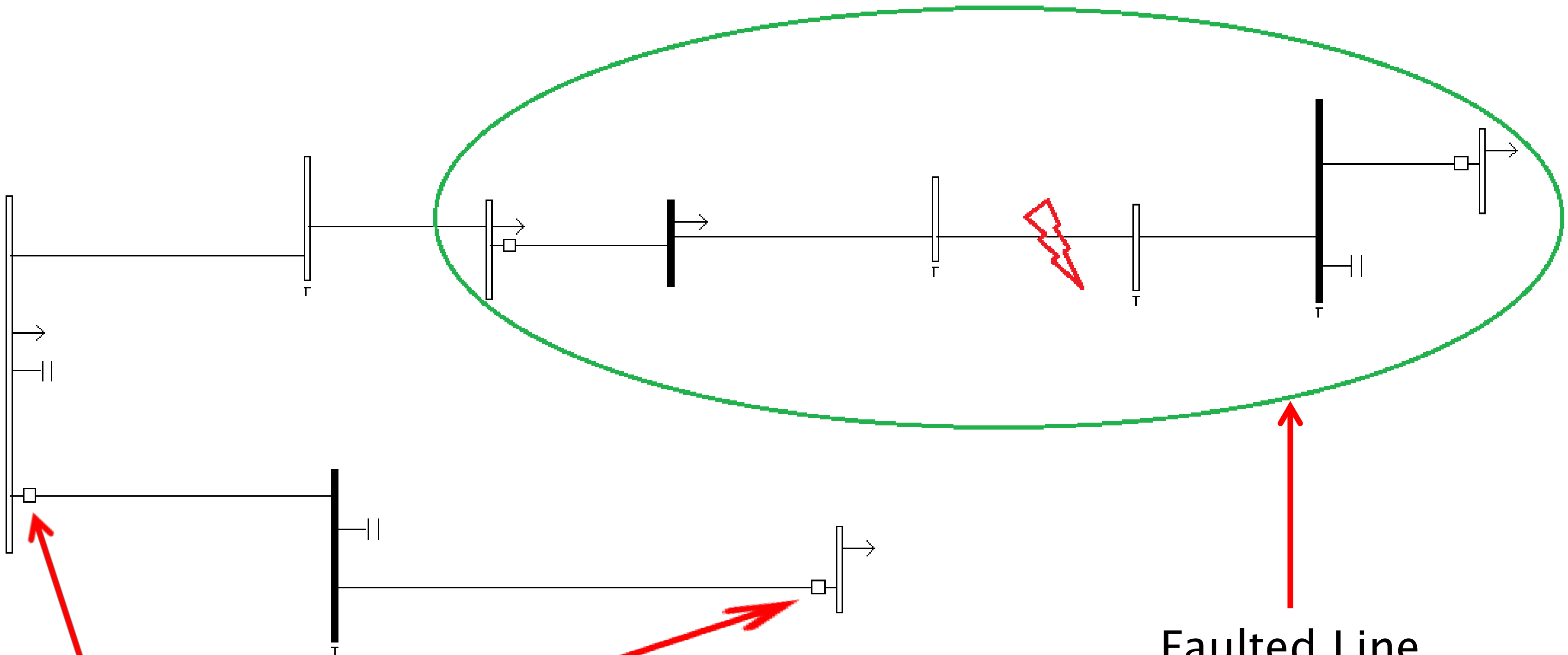
- At the same time, a nearby line operated at both ends.
  - There was no fault on nearby line.
  - Fault appeared to be reverse-looking, to one of the ends that misoperated.
  - Fault appeared to be forward-looking, to the other end that misoperated.

Protection Scheme Used

- For both of the lines in question, the communication protection scheme being utilized was the Directional Comparison Blocking (DCB) Scheme.

- The elements that misoperated were part of that DCB scheme.
  - 67QG2S is a directional forward-looking element that will assert and cause the relay to send trip if no blocking signal is received.
  - IN105 is the input wired to be picked up if a blocking signal is present or being received from the remote end.

Topology of Area



Faulted Line Segment

Relays that misoperated

Relay Calculations

Based on the below equation, the relays at both ends calculated an impedance and declared the fault forward.

$$Z2c = \frac{Re[V_2 \bullet (1\angle Z1ANG \bullet I_2)^*]}{|I_2|^2}$$

$$= \frac{|V_2|}{|I_2|} \bullet \cos(\angle V_2 - \angle Z1ANG - \angle I_2)$$

Equation 6.3

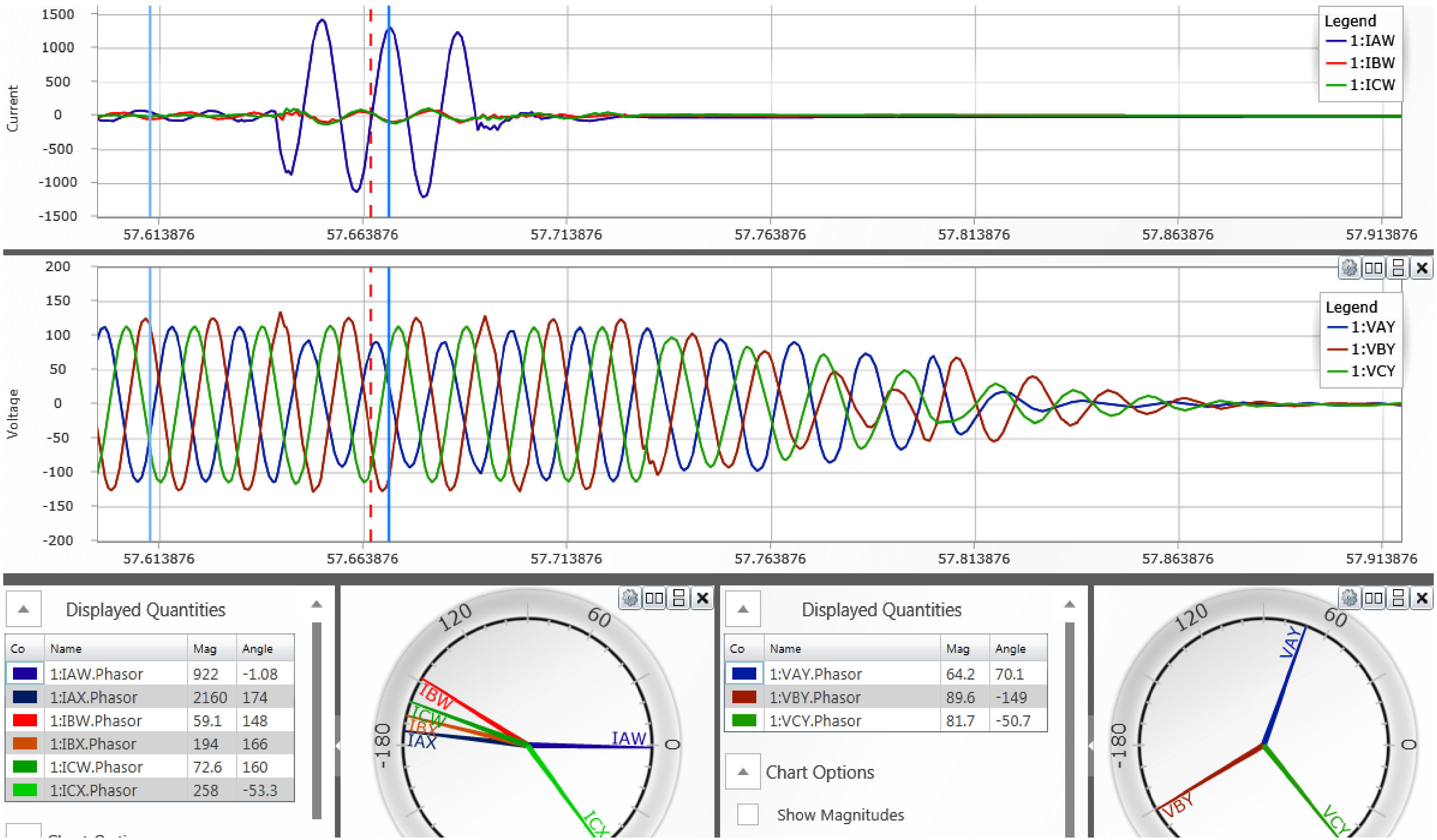
where:

V_2 = the negative-sequence voltage
I_2 = the negative-sequence current
Z1ANG = the positive-sequence line impedance angle
Re = the real part of the term in brackets, for example, (Re[A + jB] = A)
* = the complex conjugate of the expression in parentheses, $(A + jB)^* = (A - jB)$

The result of *Equation 6.3* is an impedance magnitude that varies with the magnitude and angle of the applied current. Normally, a forward fault results in a negative Z2c relay calculation.

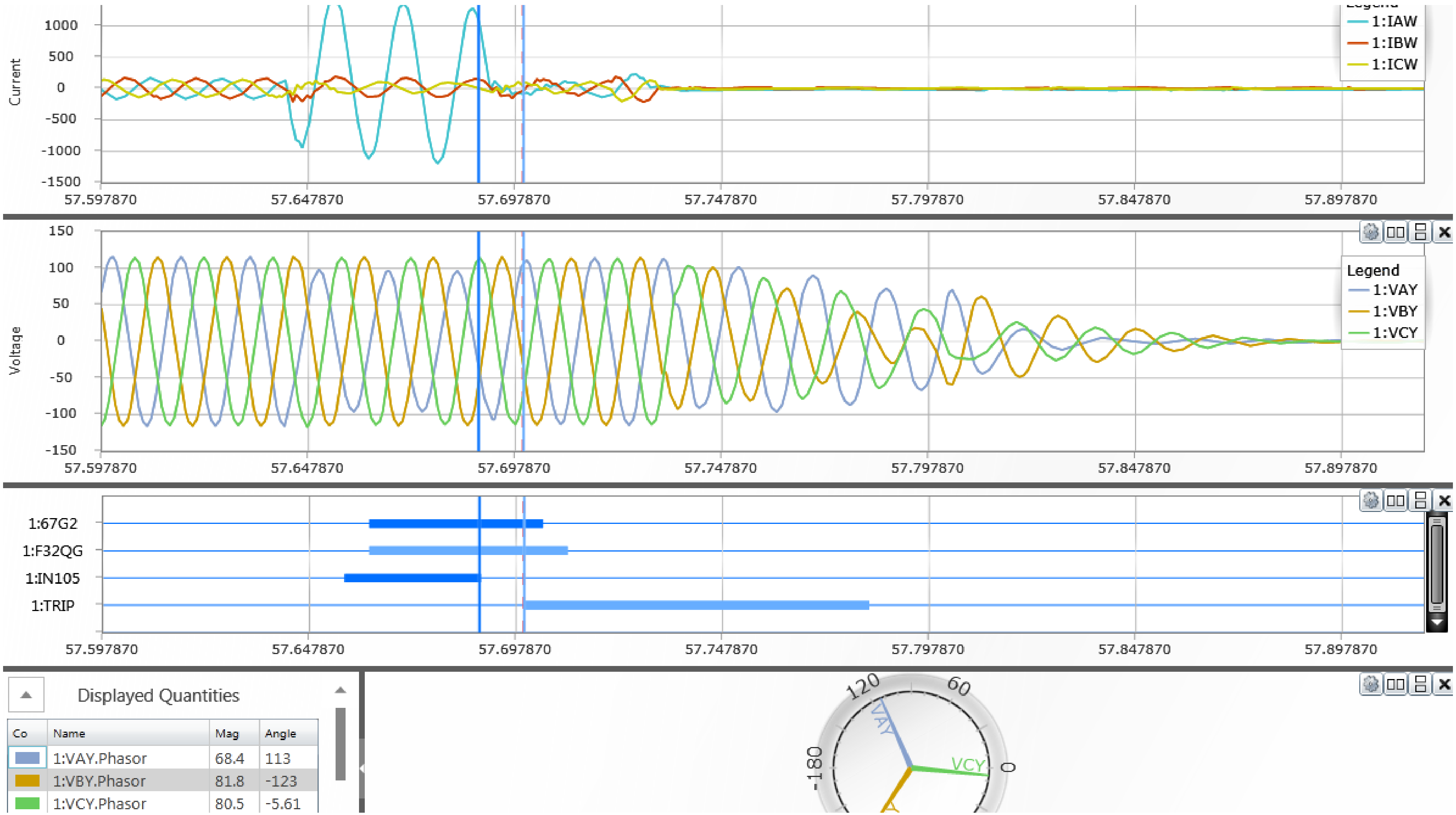
Relay Oscillography

The relay's measured quantities at one end of the line that misoperated are shown below.



Relay Oscillography (cont.)

Shown below is the relay's oscillography at the other end of the line that misoperated.

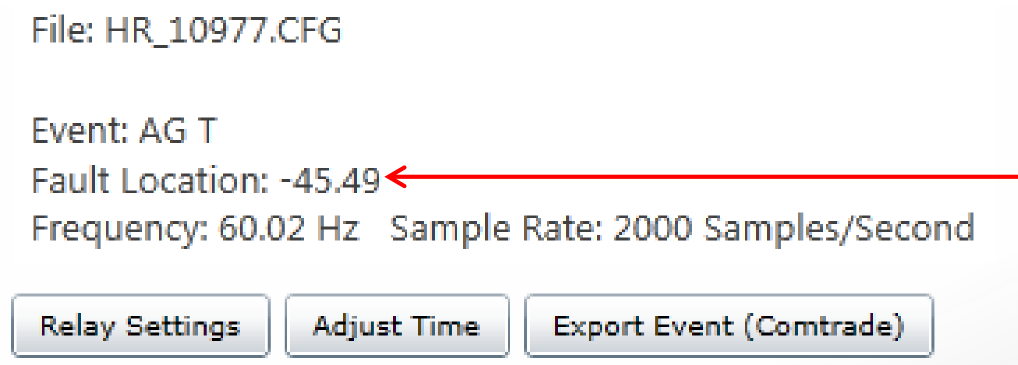


Revelations from Investigations

- Root cause of both relays that misoperated stemmed from a defective B-phase CCVT at one end.
  - Line that misoperated is short (1.5 miles). So voltage readings at both ends should be close in magnitude and phase.
  - When measurements were taken, B-phase CCVT at the end that should have been seeing fault as reverse was giving an inaccurate reading. (During the fault, relay measured 89kV, L-N on B-phase. Nominal voltage at 138kV, L-L should be about 81 kV, L-N and un-faulted phase voltage should only go up slightly during fault)
  - That inaccurate B-phase voltage reading resulted in the relay calculating an inaccurate V2 value that in turn gave a Z2c value that the relay saw as being in the forward region.

Revelations from Investigations (cont.)

- It is interesting to note that although relay with the defective CCVT calculated fault to be in forward region, the relay's "fault locator" algorithm calculated the fault to be in the reverse direction.



Relay Fault Location

Cascading Effect

- Because the communication protection schemes in the transmission network depend on receiving the correct information from the remote end, it is imperative to ensure that all equipment on which this information depends is operating correctly.
  - In this case, a defective CCVT at one end resulted in two relays misoperating.

Lessons Learned

- Consider feasibility of various mitigation possibilities:
  - Monitor the health of CCVT's to intercept the occurrence of misoperations using, for example, protective relays.
  - Changing out aging or defective equipment.

Lessons Learned (cont.)

- If a problem is detected on equipment on one phase, it is best to replace all three phases w/ the same make and manufacturer equipment to ensure similar performance characteristics.

References

- Schweitzer Engineering Laboratories SEL-421 Instruction Manual

- Zimmerman Karl and Costello David, "Fundamentals and Improvements for Directional Relays"

- Bogdan Kasztenny, Ian Stevens,

"Monitoring Ageing CCVTs,

Practical Solutions with Modern Relays to Avoid Catastrophic Failures"


Questions/ Comments?