Transformer Event Analysis

Exercise 3: SEL-487E Trips on External Fault

Introduction

A utility has a 6.9 kV generator connecting to a 40 MVA, 6.8/115/230 kV, generator step-up (GSU) transformer, as seen in Figure 1. An SEL-487E Transformer Protection Relay is used as the differential protection for the GSU transformer. The CTs are connected in wye with differential polarity and connected to the S, T, U, and W current channel inputs on the SEL-487E. The utility reports that there was an external fault on the station service (SS) transformer and the SEL-487E tripped unexpectedly. This exercise helps us determine why the relay operated, if there are any problems, and propose solutions.

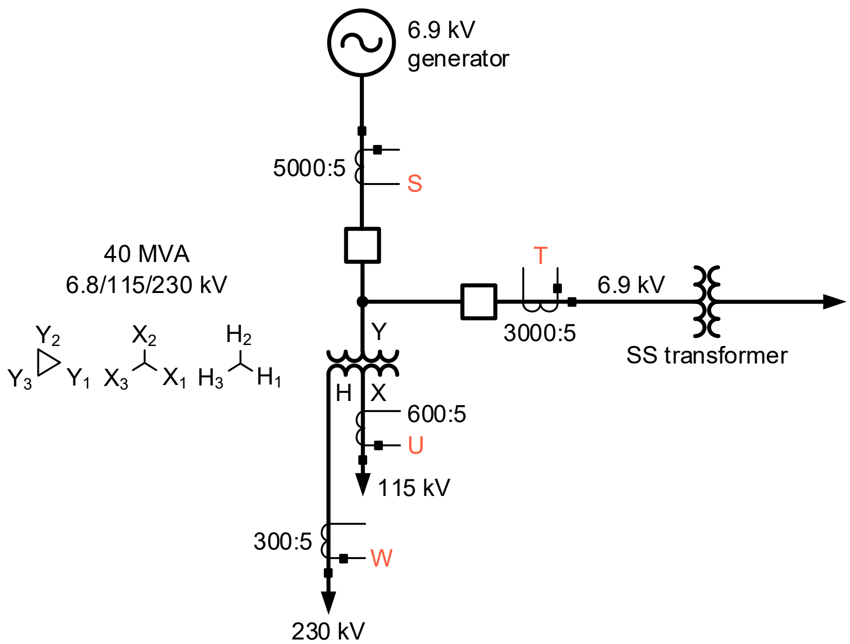

Figure 1 Transformer Installation

Resources available for this example:

- Event reports (Exercise 3 Filtered.CEV)
- SEL-5601-2 SYNCHROWAVE® Event Software
- SEL-487E instruction manual
- "Using Custom Calculations in SYNCHROWAVE Event to Apply Transformer Compensation Matrices" (AG2015-26) application guide
- "Beyond the Nameplate – Selecting Transformer Compensation Settings for Secure Differential Protection" technical paper

Questions and Answers

1. Open Exercise 3 Filtered.CEV. Is this a fault? Did the relay trip?

If we plot the S, T, U, and W current signals, we can see that the waveforms look like a fault. The customer reported that there was a fault on the station service transformer, which is on Terminal T of the relay. The relay's Terminal T shows fault current, which confirms that the fault is beyond the zone of protection for the differential on the GSU transformer. Based on the current magnitudes and angles on Terminal T, these currents look like an ACG fault. From the digital signal window, we can see that the relay tripped on percentage restrained differential (87R), specifically 87RA.

2. What operating characteristic does the 87R element use in the SEL-487E? What signals will we need to determine if the relay operated correctly based on this characteristic? What settings will we need, and what are they set to in the relay?

The SEL-487E uses a percentage restrained differential element with an adaptive slope (shown in Figure 2) to decide when to assert 87R. The 87R element asserts if the operate current is above the O87P setting and also falls above the slope line (IOP/IRT > SLP). This is done for each phase independently.

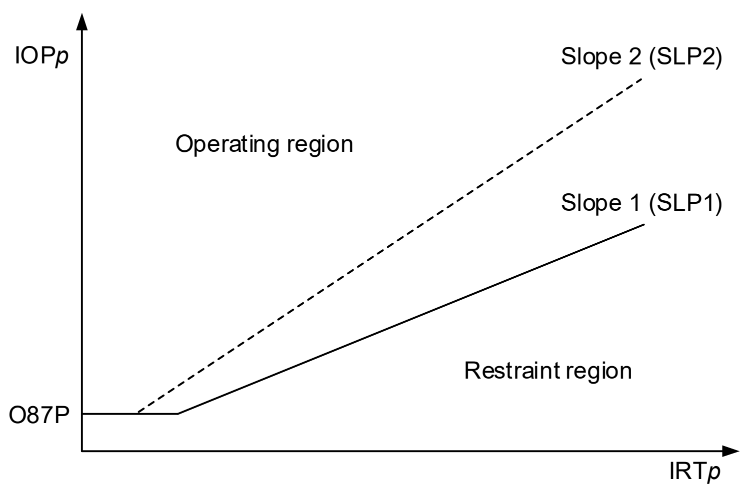

Figure 2 87R Operating Characteristic

The SEL-487E dynamically switches between SLP1 and SLP2 based on whether it has detected an internal or external fault. SLP2 is active when the relay goes into high-security mode for an external fault, indicated by the assertion of CONA, CONB, or CONC.

To know if the relay operated correctly, we need to know which slope was active as well as the operate and restraint currents for each phase. We will also need to know the settings for O87P (0.3), SLP1 (12.5%), and SLP2 (25%).

3. Was the relay in high-security mode? Which slope was the relay using for the 87R?

The relay was not in high-security mode. CONA, CONB and CONC were all at zero. Therefore, the SEL-487E was using SLP1 (12.5%) when this trip occurred. Page 172 of the SEL-487E instruction manual explains the CON Relay Word bits.

4. Plot and compare the operate and restraint quantities for each phase. Does the operation of 87RA make sense?

Figure 3 Operate and Restraint Quantities

For an 87R element to assert, two things must be true:

1. IOP must be above the O87P setting (0.30)
2. IOP/IRT must be greater than the SLP1 setting (12.5%)

As seen in the oscillography in Figure 3, IOPB and IOPC do not meet Condition 1 since they fall below the O87P threshold of 0.30. Thus, 87RB and 87RC remained deasserted.

If we look at the two conditions for A-phase:

1. IOPA is 0.31, which is greater than O87P threshold of 0.30.
2. IOPA/IRTA = 0.31 / 0.41 = 75%, which is above the SLP1 setting of 12.5%.

The operation makes sense based on the signals that the relay saw.

5. Do the IOP and IRT quantities look correct for an external fault on the station service transformer?

No, the relay should ideally see zero operate current for an external fault.

6. Are the winding compensation settings correct for the installation? Use AG2015-26 to plot the compensated current phasors and confirm. Hint: Terminals W and T do not have pre-fault current, so they cannot be used to validate compensation before the fault. Compare Terminal S and Terminal U only; determine what Terminal W and Terminal T should be by comparing them to S and U.

The compensation settings in the relay are shown in Figure 4. Matrix 0 is used for the delta side, and Matrix 11 is used for the wye side. Per the rules in Section V of the "Beyond the Nameplate" technical paper, this is correct for this transformer installation.

ICOM := Y	TSCTC := 0	TTCTC := 0	TUCTC := 11
TWCTC := 11	MVA := OFF	TAPS := 7.53	TAPT := 12.55

Figure 4 Compensation Settings

We can confirm this is correct by using AG2015-26 to plot the Terminal S and Terminal U currents before and after compensation. Notice that after compensation, they are 180 degrees out of phase as expected.

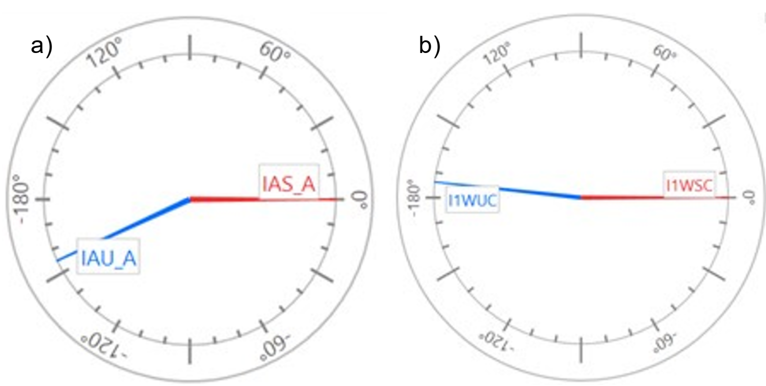

Figure 5 A-Phase Currents Before Compensation (a) and After Compensation (b)

Based on the one-line diagram of the system (see Figure 1), Terminal T should have the same compensation as Terminal S. Likewise, Terminal W should have the same compensation as Terminal U. The compensation settings are correct.

7. Since we were not able to use pre-fault current to verify the angles of Terminal T or Terminal W, we need to ensure that these angles look correct during the fault. Compare the angle of Terminal T to Terminal S during the fault, using the faulted phases. What should this angle be? What is it actually?

We know the fault current coming from the generator is going through Terminal S CTs (i.e., into the polarity dot of the CT) and going out on Terminal T CTs (i.e., out of the polarity dot of the CT). Therefore, Terminal S and T currents on the faulted phases (A and C) should be 180 degrees out of phase with one another for the external fault on the station service transformer.

To determine if this expectation matches reality, plot A-phase of Terminal S compared to A-phase of Terminal T, as well as C-phase of Terminal S compared to C-phase of Terminal T. We can see that these currents are not 180 degrees out of phase with each other—instead, they are in phase. It looks like the Terminal T CTs may have been wired with incorrect polarity.

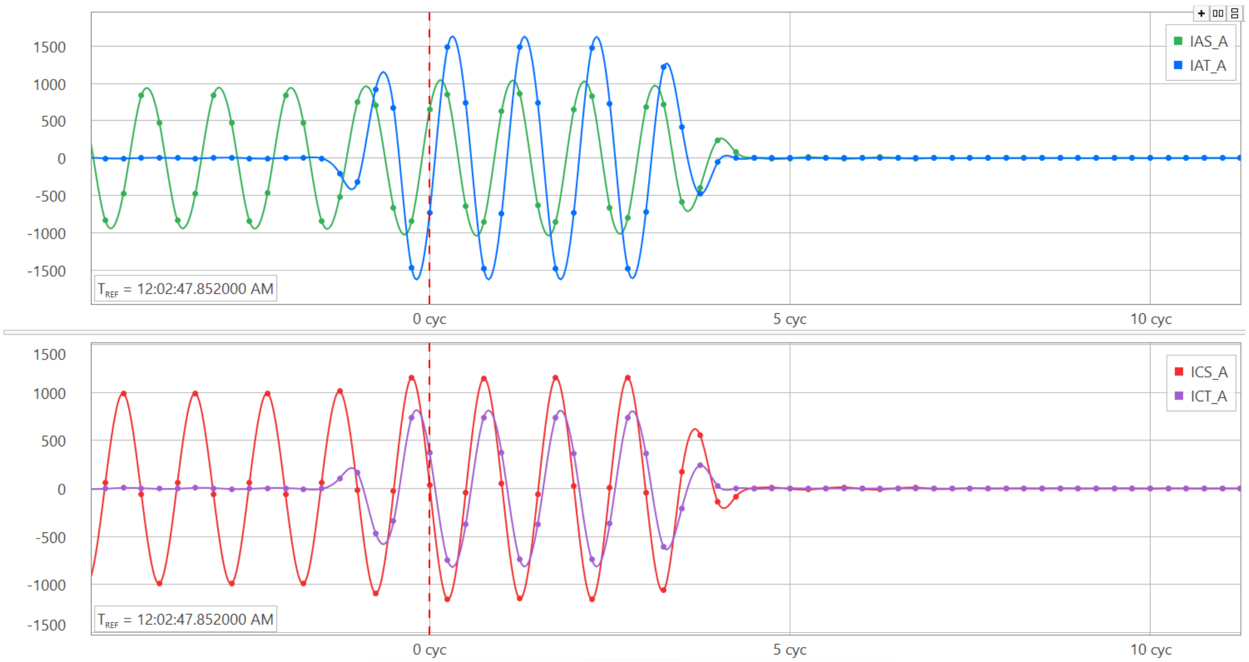

Figure 6 Incorrect Polarity at Terminal T CTs

8. Use AG2015-26 to plot the calculated operate and restraint currents for each phase (IOPnCALC vs. IRTnCALC). These should match your results from Question 4. Simulate a polarity swap on Terminal T CTs by adding a negative sign where the phasor signals for Terminal T are defined (shown in Figure 7). Are the new IOPnCALC vs. IRTnCALC plots correct?

IAT_ACalc.phasor = -IAT_A.Phasor*CT2CONFIG
IBT_ACalc.phasor = -IBT_A.Phasor*CT2CONFIG
ICT_ACalc.phasor = -ICT_A.Phasor*CT2CONFIG

Figure 7 Phasor Signals for Terminal T in Custom Calculations

Once the polarity of Terminal T is inverted, the operate currents for all three phases drop to zero. This is correct and would have prevented the relay from operating for this external fault.

9. What is the proposed solution?

Swap the polarity of the CTs connected to Terminal T of the relay. An alternative solution is to keep the existing wiring and use compensation settings to balance the differential by setting TTCTC = 6 (instead of 0). It should be noted, however, that the wiring should always match the drawings, which it currently does not. Fixing the wiring is the preferred solution.