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Using Custom Calculations in SYNCHROWAVE® Event to Apply Transformer Compensation Matrices

Ariana Hargrave, Matt Watkins, and Sundaravaradan Navalpakkam Ananthan

INTRODUCTION

References [1] and [2] explain how transformer protective relays use matrices to compensate for the phase shift across a transformer before calculating operate and restraint quantities. Being able to see these compensated currents is useful during commissioning testing, as well as troubleshooting after an event occurs. For example, many transformer relay misoperations are caused by incorrect compensation settings. These mistakes can be easily detected during commissioning (or by using pre-fault data after a trip) by looking at the compensated currents and verifying that the phasors on either side of the transformer are 180 degrees out of phase from each other before the fault.

The challenge is that these compensated current signals are not available in metering or event reports from existing SEL relays. Furthermore, some relays such as the SEL-387 Current Differential and Overcurrent Relay and the SEL-787 Transformer Protection Relay separate all of the useful signals into two separate event reports. The winding event report contains the winding currents, while the differential event report contains the operate and restraint quantities. This can prove troublesome if an engineer or technician forgets to download both event report types after a fault. Sometimes a user only downloads the winding event report, so looking at the operate and restraint currents requires another trip to the substation for the differential event report.

This application guide shows how the custom calculation engine in SEL-5601-2 SYNCHROWAVE® Event Software can be used to mimic the relay algorithm and plot the compensated currents and operate and restraint quantities by using a compressed filtered winding event report from an SEL-387, SEL-487E, SEL-587, or SEL-787 relay.

BACKGROUND

The concept of current differential protection is simple, but it is more complicated when the zone of protection includes a transformer. The turns ratio and winding connections of a transformer make it so that the current entering the transformer is not the same as the current leaving the transformer, even under normal conditions. Although the current transformer (CT) ratios do most of the work in making the current magnitudes similar on either side, a $\sqrt{3}$ magnitude difference and a phase shift remain because of the effect of a delta-wye transformer connection.

Traditionally, this magnitude difference and phase shift were compensated for by using external CT connections. Modern microprocessor-based relays can use wye-connected CTs and implement this compensation mathematically inside the relay.

The way a microprocessor-based relay compensates for the differences in magnitude and angle across a transformer is simple. The relay measures the current phasors from the CTs and applies a tap scaling factor to each winding measurement to make up for differences in magnitudes and to

get both winding currents on the same base. Tap settings correspond to how much secondary current the relay sees on each winding for full through-load conditions. After the relay scales each winding input by the corresponding tap setting, it applies a compensation matrix to compensate for the phase shift across the transformer. After applying the compensation matrices to a two-winding transformer, the currents on each winding should have the same magnitude and be 180 degrees out of phase for normal through-load conditions or external faults. Note that the 180-degree difference is because of the common practice of wiring CTs in wye, looking into the zone of protection.

The relay then uses these compensated currents to calculate operate and restraint quantities, which are described in [2]. *Figure 1* shows an example of how a transformer current differential relay compensates the currents it measures on each winding by magnitude and angle to make up for the magnitude and angle differences across the transformer. The original phase currents (IAW1, IBW1, and so on), as well as the resulting operate and restraint quantities (calculated by the 87 element), are available in relay metering and event reports. However, the compensated currents (I1W1C, I2W1C, and so on) are not.

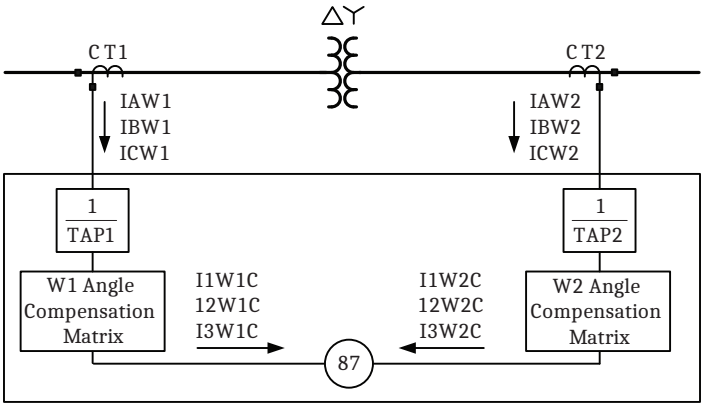

Figure 1 Relay Compensation of Magnitude and Angle

SOLUTION

SYNCHROWAVE Event is powerful event visualization and analysis software that can aid in the process of visualizing the compensated currents. The ability to create custom calculations makes it possible to model various relay algorithms and display the results graphically. Custom calculations included with SYNCHROWAVE Event calculate compensated currents and operate and restraint quantities by using a compressed filtered winding event report from any SEL transformer relay.

To use the custom calculations, perform the following steps:

Step 1. Open a compressed filtered winding event report in SYNCHROWAVE Event (version 1.7 or later).

Step 2. Select the **Import calculations** icon (shown in *Figure 2*) at the top right of the custom calculations window. Open the **AG2015-26** folder. Select the appropriate calculations file based on your relay type. Select **Open**.

NOTE: The calculations are also available for download on the SEL website (AG2015-26.zip).

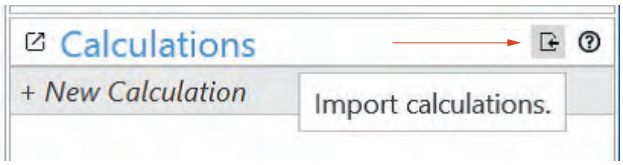

Figure 2 Import Calculations in SYNCHROWAVE Event

Step 3. When the calculations have been imported, SYNCHROWAVE Event only displays the settings you can modify in the Calculations window. The rest of the code is hidden and should not be modified. Set the user settings as desired, and the software will mimic the relay algorithm to calculate the compensated currents and operate and restraint quantities. The resulting compensated current signals, as well as the operate and restraint quantities calculated by the code, are shown in *Table 1*. These signals can be plotted in SYNCHROWAVE Event to aid in event analysis.

Table 1 Names of Calculated Signals

Relay Type	Maximum Windings	Compensated Currents (n = winding)	Operate Quantities	Restraint Quantities
SEL-387A	2	I1W*n*C I2W*n*C I3W*n*C	IOP1 IOP2 IOP3	IRT1 IRT2 IRT3
SEL-387E	3	I1W*n*C I2W*n*C I3W*n*C	IOP1 IOP2 IOP3	IRT1 IRT2 IRT3
SEL-387	4	I1W*n*C I2W*n*C I3W*n*C	IOP1 IOP2 IOP3	IRT1 IRT2 IRT3
SEL-487E	5	I1W*n*C I2W*n*C I3W*n*C	IOP1Calc IOP2Calc IOP3Calc	IRT1Calc IRT2Calc IRT3Calc
SEL-587	2	I1W*n*C I2W*n*C I3W*n*C	IOP1Calc IOP2Calc IOP3Calc	IRT1Calc IRT2Calc IRT3Calc
SEL-787	2	I1W*n*C I2W*n*C I3W*n*C	IOP1 IOP2 IOP3	IRT1 IRT2 IRT3
SEL-787-3S/3E	3	I1W*n*C I2W*n*C I3W*n*C	IOP1 IOP2 IOP3	IRT1 IRT2 IRT3
SEL-787-4X	4	I1W*n*C I2W*n*C I3W*n*C	IOP1 IOP2 IOP3	IRT1 IRT2 IRT3

NOTES AND TIPS

Consider the following when applying the methods in this application guide to transformer relay event reports:

- When you import the calculations, be sure to select the file that matches your relay type. Although all SEL transformer relays perform differential protection similarly, there are slight variations in each relay that are accounted for in the various files.

- If a winding is not enabled, the corresponding settings associated with that winding may not be present in the event report. For example, if only the first two windings are being used in the differential in a relay that supports three windings, the settings corresponding to the third winding (such as the Winding 3 TAP setting and Winding 3 CT connection compensation setting) may not be present in the event report. In such cases, disable the unused winding by using the E87W*x* setting (E87T*x* for SEL-487E) in the User Settings. When a winding is disabled, it is removed from the calculations for operate and restraint. Although the compensated currents for the disabled winding will still be calculated, they should be ignored.
- If internal CT connection compensation is disabled, use 0 as the compensation matrix settings for all the windings.
- Never set a TAP setting to 0 in the code. Doing so will cause a divide-by-zero error and the code will not function correctly. If a winding is unused, set the TAP setting to any number other than 0 and disable the winding using the appropriate E87W*x* (or E87T*x*) user setting.
- Note that if harmonic restraint is enabled, the operate and restraint quantities calculated by the algorithm are the values before the harmonics have been added. This matches the operate and restraint quantities in the relay differential event report. To analyze an event with harmonics, see [3].
- For the SEL-587 relay, the operate and restraint quantities calculated by the code are the actual values used by the relay. However, these quantities will not match the operate and restraint quantities in the relay's event report. The SEL-587 relay multiplies the operate and restraint quantities by TAP1 before recording them in the event report.

Conclusion

This application guide shows how the custom calculations engine in SYNCHROWAVE Event can be used to simulate transformer compensation and operate and restraint calculations in SEL transformer relays.

References

[1] IEEE C37.91-2008, *IEEE Guide for Protecting Power Transformers*.

[2] B. Edwards, D.G. Williams, A. Hargrave, M. Watkins, and V.K. Yedidi "Beyond the Nameplate–Selecting Transformer Compensation Settings for Secure Differential Protection," presented at the 70th Annual Georgia Tech Protective Relaying Conference, April 2016. Available: selinc.com.

[3] A. Hargrave, M. Taberer, "Using Synchrowave Event to Model Transformer Differential with Harmonic Restraint and Blocking," SEL Application Guide (AG2020-28), 2020. Available: selinc.com.

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Schweitzer Engineering Laboratories, Inc.
2350 NE Hopkins Court
Pullman, WA 99163-5603 U.S.A.
Tel: +1.509.338.3838
Fax: +1.509.332.7990
Internet: selinc.com/support
Email: info@selinc.com

SCHWEITZER ENGINEERING LABORATORIES, INC.
2350 NE Hopkins Court • Pullman, WA 99163-5603 U.S.A.
Tel: +1.509.332.1890 • Fax: +1.509.332.7990
selinc.com • info@selinc.com