# *Using SYNCHROWAVE Event to Model Transformer Differential With Harmonic Restraint and Blocking*

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## Introduction

Percentage-restrained differential (87R) protection is a popular algorithm used in SEL transformer relays. The basic implementation of 87R compares a pickup threshold for the summation of an operate quantity to a restraint quantity scaled by a slope value. SEL relays improve on this by providing harmonic restraint and harmonic blocking methods to keep the relay secure during transformer energization. It is important to be able to model this algorithm, in its simplest form as well as with harmonic restraint and blocking, to analyze relay differential element operation after an event.

This application guide shows how you can use the custom calculation engine in SEL-5601-2 SYNCHROWAVE® Event Software to model the 87R element (including harmonic restraint and blocking) in the SEL-387 Current Differential and Overcurrent Relay, SEL-787 Transformer Protection Relay, and SEL-487E Transformer Protection Relay. You can use the resulting graphs to understand and validate relay operation after a fault. You can also use these to compare the performance of harmonic blocking versus harmonic restraint for a given fault as well as simulate the effect of proposed settings changes.

This application guide only models harmonic restraint and blocking using the second and fourth harmonics, which are traditionally used to detect transformer magnetizing inrush. It does not include fifth harmonic blocking, dc ratio blocking, or waveshape recognition methods.

## Background

Consider the concept of current differential protection as Kirchhoff's current law—the current entering the zone of protection must equal the current leaving the zone of protection. If this is not the case, there must be another path (such as a fault) inside the defined differential protection zone through which current can flow. In a percentage-restrained differential relay, CTs for all current infeeds to and outfeeds from the protected equipment are brought into the relay, and the measured currents are used to calculate the operate (IOP) and restraint (IRT) quantities, as shown in *Figure 1*. The operate quantity is a measure of the difference current into the zone while the restraint quantity is a measure of the total current the zone detects. The relay calculates operate and restraint values independently for each phase.

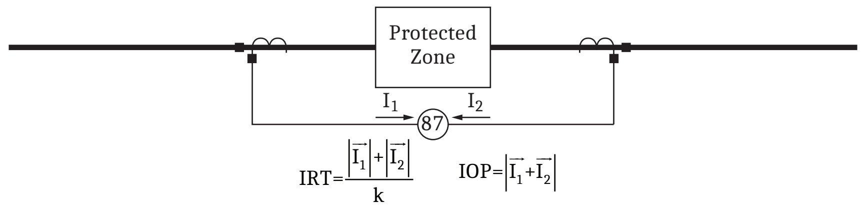


**Figure 1 Operate and Restraint Calculations for a Percentage-Restrained Differential Relay**

For load conditions or external faults, the relay should ideally calculate a value for restraint current that is relative to the magnitude of the through-current and a value of operate current equal to zero. For internal faults, the relay should calculate values for both restraint and operate that are relative to the magnitude of the fault current.

We can then use these operate and restraint values to plot a point on a percentage-restrained differential characteristic, as shown in *Figure 2*. The X-axis is the restraint current and the Y-axis is the operate current, each in per-unit tap. The percentage-restrained characteristic consists of a minimum operate current and a slope value, both of which can be set in the relay. Relay designs can have single slopes, dual slopes, or adaptive slopes, but the idea behind them is the same. If the calculated values of operate (y component) and restraint (x component) cause the rectangular coordinate point (restraint, operate) to fall above the slope line, the relay operates. If the point falls below the line, the relay restrains. For more information on percentage-restrained differential characteristics, as well as how transformer relays compensate winding currents to arrive at the operate and restraint values, see [1], [2], and [3].

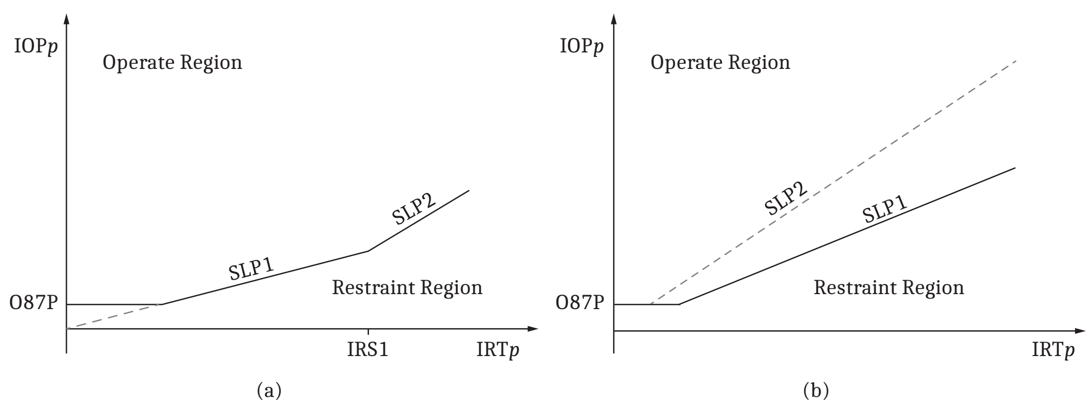


**Figure 2 Percentage-Restrained Characteristic for (a) Single-/Dual-Slope and (b) Adaptive-Slope Relays**

A few different settings in SEL relays define the 87R characteristics in *Figure 2*. The O87P setting defines the minimum value of operate current that the relay must detect in order to operate. For relays that operate on a single- or dual-slope characteristic (*Figure 2[a]*), the SLP1 and SLP2 settings define these two slope values, with the IRS1 setting defining the point on the restraint axis where SLP2 becomes active. Although Slope 1 intersects the origin, Slope 2 does not. The y-intercept of Slope 2 is a function of the SLP1, SLP2, and IRS1 settings. For relays that operate on an adaptive slope characteristic (*Figure 2[b]*), the relay switches between SLP1 and SLP2 dynamically according to whether it has detected an internal or external fault. The selected slope intersects the origin and is active for the entire restraint region.

## The Standard Equation

To determine whether a given point has fallen above the slope line, the relay calculates a standard threshold that is equal to the restraint scaled by the slope. If the operate quantity exceeds this threshold, the relay operates. The equation for comparing the operate quantity with the standard threshold is shown in *Equation 1*. The relay performs this calculation every processing interval on a per-phase basis. In addition to meeting this condition, the operate current also must exceed the O87P setting to operate. This comparison is the basis for the 87R element in SEL relays.

$$\mathrm{IOP}p > \frac{\mathrm{SLP}}{100} \bullet \mathrm{IRT}p + \mathrm{b}$$

**Equation 1**

where $p$ = Phase A, B, C or 1, 2, 3 depending on the relay.

For relays that operate on an adaptive slope or a single-slope characteristic, b = 0.

For relays that operate on a dual-slope characteristic, the "b" term is used to account for the fact that the SLP2 line does not intersect the origin. In these cases,

$\mathrm{b} = 0$ when the relay is working on SLP1 (IRT$p$ < IRS1)

$\mathrm{b} = \mathrm{IRS1} \bullet \dfrac{\mathrm{SLP1} - \mathrm{SLP2}}{100}$ when the relay is working on SLP2 (IRT$p \geq$ IRS1)

## Harmonic Restraint and Blocking

SEL relays employ both harmonic blocking and harmonic restraint algorithms to prevent misoperation during inrush conditions. When a transformer is energized, a large amount of current enters the transformer to magnetize the core without leaving the zone of protection. If this is not accounted for properly, the relay can misoperate because of the false operate current that it measures. These magnetization inrush currents contain high amounts of even-harmonic content, and these even harmonics can be used to identify inrush and prevent misoperation. Harmonic restraint and harmonic blocking algorithms use the second and fourth harmonic content of the energization waveform to make the 87R element more secure during inrush. SEL relays always require the use of either harmonic blocking or restraint in the 87R function, so we must supplement the standard equation with these functions to model relay operation correctly.

## Harmonic Restraint

Harmonic restraint starts with the standard equation (*Equation 1*) and the minimum operating current requirement (O87P) but modifies the equation slightly. The algorithm adds a percentage of the measured second and fourth harmonic content of the differential (operate) current to the restraint threshold. This effectively moves the slope line up (by making the y-intercept a larger number), resulting in the need for more operate current to exceed the threshold. This is shown in *Figure 3* for the dual-slope characteristic. The PCT2 and PCT4 settings, respectively, define the amount of second and fourth harmonic content that is added to the restraint threshold.

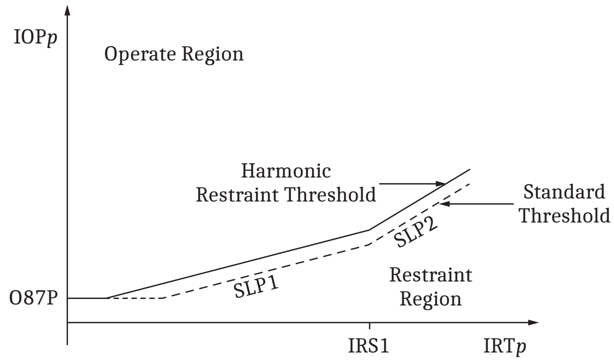


**Figure 3 Harmonic Restraint Moves Threshold Up**

*Equation 2* shows the addition of the second and fourth harmonics to the restraint threshold. Notice that this is a modification of the standard equation in *Equation 1*. We add another term, "c," which is a measure of the second and fourth harmonics present in the operate current, scaled by the PCT2 and PCT4 settings. The $IOPp_{2H}$ and $IOPp_{4H}$ terms are the second and fourth harmonic content of the operate current in per-unit tap. The relay calculates this equation independently and raises the restraint threshold independently for each phase. Note that the measured harmonics are not the harmonics of the system in general, but rather of the operate current created by the magnetizing inrush within the differential zone.

$$\mathrm{IOP}p > \frac{\mathrm{SLP}}{100} \bullet \mathrm{IRT}p + \mathrm{b} + \mathrm{c}$$

$$\mathrm{c} = \left(\mathrm{IOP}p_{2\mathrm{H}} \bullet \frac{100}{\mathrm{PCT2}}\right) + \left(\mathrm{IOP}p_{4\mathrm{H}} \bullet \frac{100}{\mathrm{PCT4}}\right)$$

**Equation 2**

where $p$ = Phase A, B, C or 1, 2, 3 depending on the relay.

Note that implementation of *Equation 2* inverts the effect of the PCT2 and PCT4 settings. In other words, increasing the PCT2 and PCT4 settings actually *decreases* the amount of harmonics added to the restraint threshold, making the relay *less* secure.

Harmonic restraint logic, shown in *Figure 4* for A-phase, is performed on a per-phase basis.

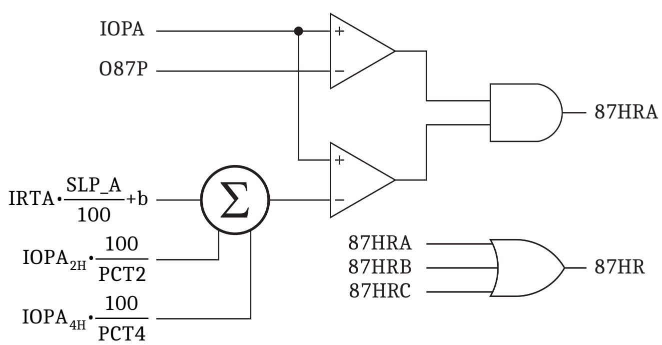


**Figure 4 Harmonic Restraint Logic for A-Phase**

## Harmonic Blocking

Harmonic blocking uses the standard equation (*Equation 1*) with the minimum operating current requirement (O87P) and also checks the harmonic content of the differential (operate) current in parallel with this. If the ratio of the second-harmonic content of the operate current ($IOPp_{2H}$) to the fundamental (50 or 60 Hz) component of the operate current ($IOPp_{1H}$) exceeds the PCT2 threshold, the relay blocks an operation declared by the standard equation. This is similar for the fourth harmonic, as shown in *Equation 3*. Harmonic blocking logic is shown in *Figure 5* for A-phase.

$$\frac{IOPp_{2H}}{IOPp_{1H}} \bullet 100 > PCT2$$
$$\frac{IOPp_{4H}}{IOPp_{1H}} \bullet 100 > PCT4$$

**Equation 3**

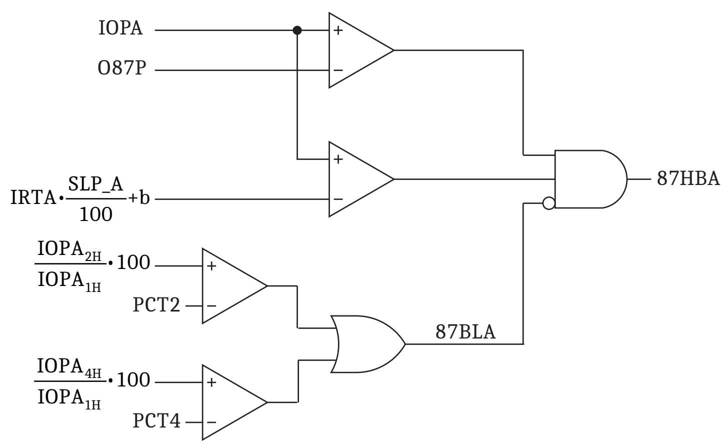


**Figure 5 Harmonic Blocking Logic for A-Phase**

Harmonic blocking is implemented in one of two ways: independent or common. Independent harmonic blocking treats each phase independently, meaning increased harmonics on a single phase only block operation of the 87R element on that phase. Common (or “cross”) harmonic blocking allows increased harmonics on a single phase to block all of the 87R elements. *Figure 6* shows independent and common harmonic blocking.

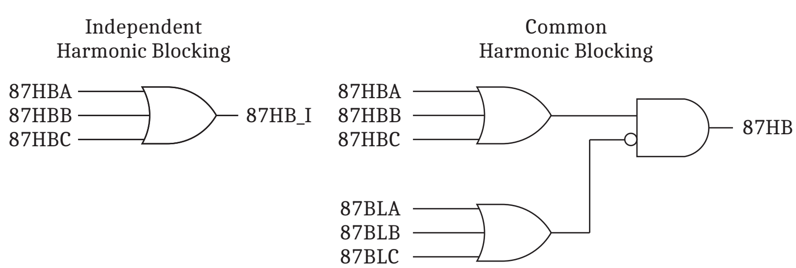


**Figure 6 Independent and Common Harmonic Blocking**

*Figure 7* shows the final output of the 87R function. In the SEL-387, the 87R output is an exclusive OR combination of the harmonic restraint, common harmonic blocking, and independent harmonic blocking functions. In the SEL-487E and SEL-787 relays, the 87R output is an OR combination of the harmonic restraint and common harmonic blocking functions.

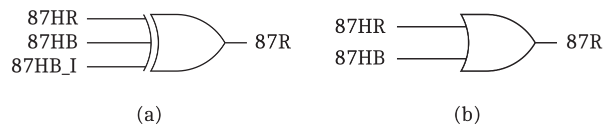


**Figure 7 Final Output of 87R Function in (a) SEL-387 and (b) SEL-487E / SEL-787 Relays**

For more information about harmonic restraint and harmonic blocking, see [4]. The logic diagrams in this section are generalized to show the concepts. Although very similar, there are slight variations in the way each relay implements these algorithms as well as the names of the signals and Relay Word bits. The instruction manual for each individual relay has specifics on each implementation. Consult these manuals ([5], [6], and [7]) as necessary.

## Solution

SYNCHROWAVE Event is a powerful event visualization and analysis software tool that can aid in the process of visualizing the 87R element and how harmonic restraint and blocking affect its operation. The ability to create custom calculations makes it possible to model these relay algorithms and display the results graphically. Custom calculations included with SYNCHROWAVE Event will model harmonic restraint and blocking in an SEL-387, SEL-487E, or SEL-787. The event reports from the SEL-587 Current Differential Relay do not contain the required harmonic data for these calculations, so that relay is excluded.

To use the custom calculations, perform the following steps:

Step 1. Download the appropriate event report type from the relay in question at the sample rate shown in *Table 1*.

**Table 1 Event Report Needed for Each Relay Type**

| Relay Type | Event Report Type | Sample Rate |
|---|---|---|
| SEL-387 | Differential | 8 samples/cycle |
| SEL-787 | Differential | 4 samples/cycle |
| SEL-487E | Compressed Event (*.CEV) | 8 samples/cycle |

Step 2. Open the event report in SYNCHROWAVE Event (version 1.7 or greater).

Step 3. Select the “Import calculations” icon (shown in *Figure 8*) at the top right of the custom calculations window. Open the **AG2020-28** folder. Select the appropriate calculations file based on your relay type. The options are **AG2020-28 SEL-387.txt**, **AG2020-28 SEL-487E.txt**, or **AG2020-28 SEL-787.txt**. Then select **Open**.

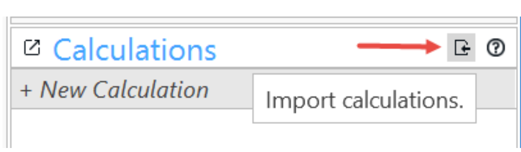


**Figure 8 Import Calculations in SYNCHROWAVE Event**

NOTE: The calculations are also available for download on the SEL website (AG2020-28.zip).

Step 4. When the calculations have been imported, only the settings you can modify are displayed in the custom calculations window. The rest of the code is hidden and should not be modified. By default, these user settings are set to AUTO, which pulls the settings from the event report. If you want to manually adjust these settings to see how the relay would have performed with different settings, substitute the new setting in place of AUTO. For example, change the SLP1_USER setting from AUTO to 30 to see how the relay would respond when using a slope of 30 instead of the setting presently in the event report. The following sections explain the resulting signals that can be plotted and used in the software, along with specific directions for each relay type.

## SEL-387

The SEL-387 can use either a single- or dual-slope characteristic, as shown in *Figure 2(a)*. The settings engineer must select whether the relay uses either harmonic restraint or harmonic blocking. Selection of both is not possible. For harmonic blocking, the relay supports either independent harmonic blocking or common harmonic blocking. As shown in *Table 2*, the relay settings HRSTR and IHBL determine which algorithm the relay uses.

**Table 2 Determining the Harmonic Restraint/Harmonic Blocking Algorithm Used in the SEL-387**

| Harmonic Restraint[a] (HRSTR) | Independent Harmonic Blocking (IHBL) | Algorithm Used by Relay |
|---|---|---|
| Grayed out/missing or N | N | Common Harmonic Blocking |
| Grayed out/missing or N | Y | Independent Harmonic Blocking |
| Y | Grayed out/missing | Harmonic Restraint |

[a] Harmonic restraint is unavailable in the SEL-387-0.

To model harmonic restraint and harmonic blocking, first obtain an 8 sample/cycle differential event report from the SEL-387. The differential event report contains the operate and restraint quantities as well as the second harmonic component of the operate current for each phase in multiples of tap. Fourth harmonic content is not included in the event report, and any analysis done without it will be an approximation.

Open an SEL-387 differential event report and import the calculations from AG2020-28 SEL-387.txt as explained previously. Manually adjust the user settings if desired, or leave them as AUTO to pull the settings from the event report. In addition to relay settings, the user settings include a setting called INOM_USER that defines the nominal current rating of the CT inputs (defaults to 5 A nominal) for the relay. There are also three variables (4TH_HARM_1, 4TH_HARM_2, and 4TH_HARM_3) that allow you to add fourth harmonic content if it can be obtained from another source. Finally, plot and compare the appropriate signals shown in *Table 3* to model the respective algorithm.

NOTE: There are two conditions that can cause the code to flag an error. You can clear both of these errors by opening the AG2020-28 SEL-387.txt file in Notepad and editing the code in the "Definitions" section. The first error occurs when the relay is set to only use a single slope (SLP2 = OFF), causing IRS1 to be missing from the settings. For this case, add a "#" in front of the first instance of the IRS1 equation to comment it out. Then remove the "#" that exists in front of the second instance of the IRS1 equation and save your changes. The second error occurs when the relay is set to not use the fourth harmonic (E87*n* = Y instead of Y1), causing PCT4 to be missing from the settings. For this case, add a "#" in front of the first instance of the PCT4 equation to comment it out. Then remove the "#" that exists in front of the second instance of the PCT4 equation and save your changes. The errors in SYNCHROWAVE Event will clear.

**Table 3 SEL-387 Signals to Compare Based on Algorithm**

| Algorithm | Operating Quantities | Compare to Threshold | Result | Relay Word Bits |
|---|---|---|---|---|
| Harmonic Restraint | IOP1<br>IOP2<br>IOP3 | HR_thresh_1<br>HR_thresh_2<br>HR_thresh_3 | Individual 87R*p* bits assert if IOP*p* exceeds HR_thresh_*p*. Any of these will assert 87R. | 87R1[a]<br>87R2[a]<br>87R3[a] |
| Independent Harmonic Blocking | IOP1<br>IOP2<br>IOP3 | S_thresh_1<br>S_thresh_2<br>S_thresh_3 | Individual 87R*p* bits assert if IOP*p* exceeds S_thresh_*p*. Any of these can assert 87R. | 87R1[a]<br>87R2[a]<br>87R3[a] |
| | 2H_1<br>2H_2<br>2H_3<br>4H_1<br>4H_2<br>4H_3 | PCT2<br>PCT2<br>PCT2<br>PCT4<br>PCT4<br>PCT4 | Individual 87BL*p* bits assert if 2H_*p* exceeds PCT2 or 4H_*p* exceeds PCT4. Each bit will block the corresponding 87R*p* from asserting, which can block 87R from asserting. | 87BL1[b]<br>87BL2[b]<br>87BL3[b] |
| Common Harmonic Blocking | IOP1<br>IOP2<br>IOP3 | S_thresh_1<br>S_thresh_2<br>S_thresh_3 | Individual 87R*p* bits assert if IOP*p* exceeds S_thresh_*p*. Any of these can assert 87R. | 87R1[a]<br>87R2[a]<br>87R3[a] |
| | 2H_1<br>2H_2<br>2H_3 | PCT2<br>PCT2<br>PCT2 | Individual 87BL*p* bits assert if 2H_*p* exceeds PCT2. If any of these bits assert, they will block 87R from asserting. | 87BL1[b]<br>87BL2[b]<br>87BL3[b] |

[a] When comparing signals to thresholds to validate relay operation, note that the SEL-387 has a built-in security delay of 1.25 cycles before the 87R*p* Relay Word bits are allowed to assert.

[b] For any of the harmonic blocking bits to assert, IOP*p* must also be greater than IOP_min. This ensures that the relay does not make decisions on very small current values. In the SEL-387, IOP_min = 0.05 • INOM/2.

*Figure 9* shows an example of analyzing an event from an SEL-387 with common harmonic blocking enabled. For common harmonic blocking, *Table 3* instructs us to compare the IOP*p* quantities versus the S_thresh_*p* quantities and explains that the 87R*p* bits assert if an operate quantity exceeds its threshold. These signals are shown on the left side of *Figure 9*. Here you can see that the third element (C-phase) is the only one where the operate quantity exceeds the threshold and that the corresponding 87R3 element asserts 1.25 cycles after this occurs.

Next, *Table 3* instructs us to compare the 2H_*p* quantities versus the PCT2 threshold and explains that the 87BL*p* bits assert if the corresponding 2H_*p* quantity exceeds the threshold. These signals are shown on the right side of *Figure 9*, and you can see that the 87BL*p* bits assert during the times when the 2H_*p* signals exceed the PCT2 threshold. However, because the harmonic blocking bits were not asserted when 87R3 asserted, they could not prevent the operation of 87R.

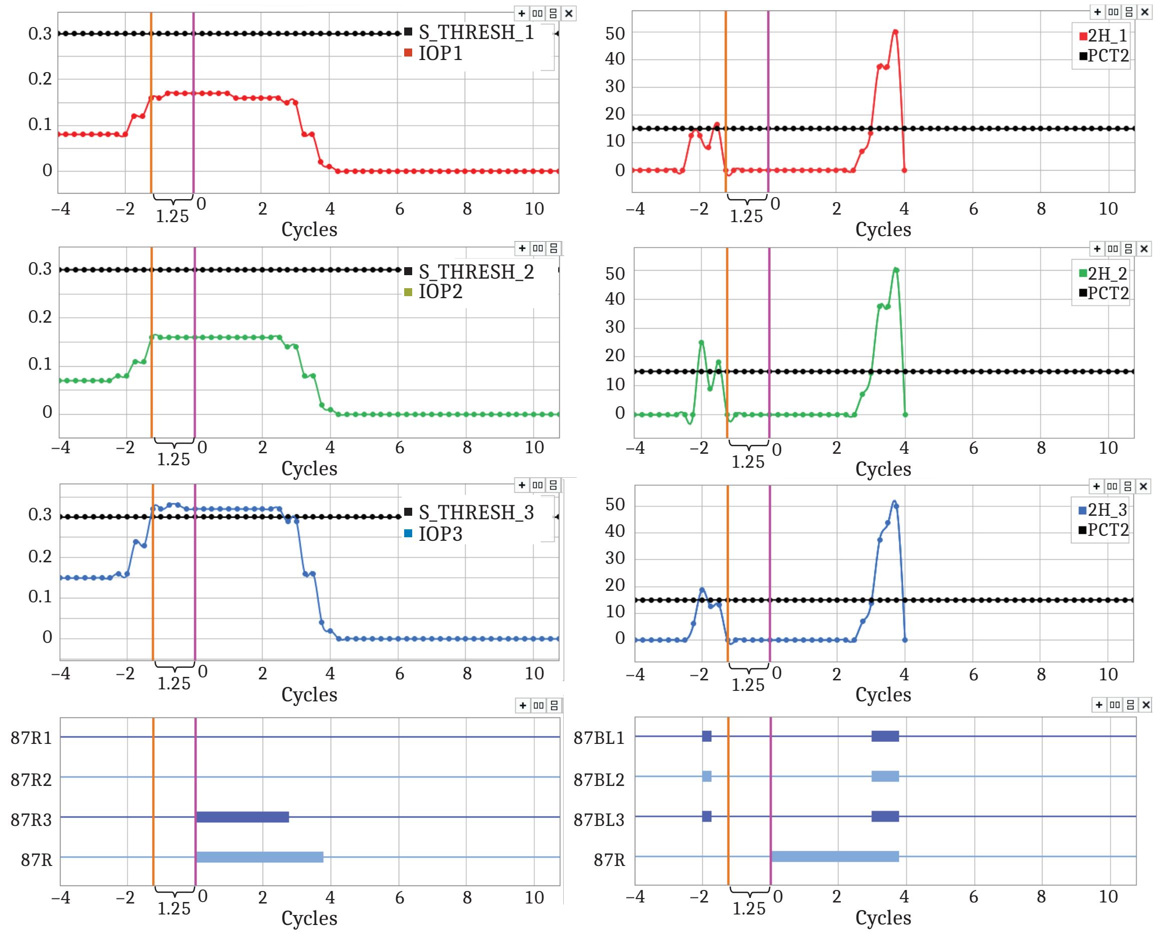


**Figure 9 Analyzing Common Harmonic Blocking in the SEL-387**

## SEL-787

The SEL-787 uses a dual-slope characteristic, as shown in *Figure 2(a)*. The IRS1 setting determines the transition point between SLP1 and SLP2, with one exception. When the transformer breaker is open, and for 10 cycles after the transformer is energized, the relay asserts the INR*p* Relay Word bit to put the relay in high-security mode. When the INR*p* bit is asserted, the relay uses SLP2 for the entire restraint axis.

The SEL-787 supports harmonic restraint and common harmonic blocking. You must select whether you want the relay to use harmonic restraint (HRSTR = Y), common harmonic blocking (HBLK = Y), or both.

To model harmonic restraint and blocking, first obtain a 4 sample/cycle differential event report from the SEL-787. The differential event report contains the operate and restraint quantities as well as the second harmonic component of the operate current for each phase in multiples of tap. Fourth harmonic content is not included in the event report, and any analysis done without it will be an approximation.

Open an SEL-787 differential event report and import the calculations from AG2020-28 SEL-787.txt as explained previously. Manually adjust the user settings if desired, or leave them as AUTO to pull the settings from the event report. Enter the four TAP settings at the very top manually; you cannot set these to AUTO. In addition to relay settings, the user settings include a setting called INOM_USER that defines the nominal current rating of the CT inputs (defaults to 5 A nominal) for the relay. There are also three variables (4TH_HARM_1, 4TH_HARM_2, 4TH_HARM_3) that allow you to add fourth harmonic content if it can be obtained from another source. Finally, plot and compare the appropriate signals shown in *Table 4* to model the respective algorithm.

**Table 4 SEL-787 Signals to Compare**

| Algorithm | Operating Quantities | Compare to Threshold | Result | Relay Word Bits |
|---|---|---|---|---|
| Harmonic Restraint | IOP1<br>IOP2<br>IOP3 | HR_thresh_1<br>HR_thresh_2<br>HR_thresh_3 | Individual 87HR*p* bits assert if IOP*p*_pu exceeds HR_thresh_*p*. Any of these will assert 87HR and 87R. | 87HR1[a]<br>87HR2[a]<br>87HR3[a] |
| Harmonic Blocking | IOP1<br>IOP2<br>IOP3 | S_thresh_1<br>S_thresh_2<br>S_thresh_3 | Individual 87R*p* bits assert if IOP*p*_pu exceeds S_thresh_*p*. Any of these can assert 87HB and 87R. | 87R1[a]<br>87R2[a]<br>87R3[a] |
| | 2H_1<br>2H_2<br>2H_3 | PCT2<br>PCT2<br>PCT2 | Individual 2_4HB*p* bits assert if 2H_*p* exceeds PCT2. If any of these bits assert, they will block 87HB and 87R from asserting.[b] | 2_4HB1[c]<br>2_4HB2[c]<br>2_4HB3[c] |

[a] When comparing signals to thresholds to validate relay operation, note that the SEL-787 has a built-in security delay of as long as 1.25 cycles before the 87R*p* and 87HR*p* Relay Word bits are allowed to assert.

[b] 87BL*p* also blocks 87HB and 87R from asserting.

[c] For any of the harmonic blocking bits to assert, IOP*p* must also be greater than IOP_min. This ensures that the relay does not make decisions on very small current values. In the SEL-787, IOP_min = 0.05 •INOM/minimum TAP.

*Figure 10* shows an example of analyzing an event from an SEL-787 with harmonic restraint enabled. For harmonic restraint, *Table 4* instructs us to compare the IOP*p* quantities versus the HR_thresh_*p* quantities and explains that the 87HR*p* bits assert if an operate quantity exceeds its threshold. These signals are shown in *Figure 10*. Here you can see that the operate quantities exceed the threshold for both the first and second elements (A-phase and B-phase), and that the corresponding 87HR1, 87HR2, 87HR, and 87R bits assert 0.5 cycles after this occurs.

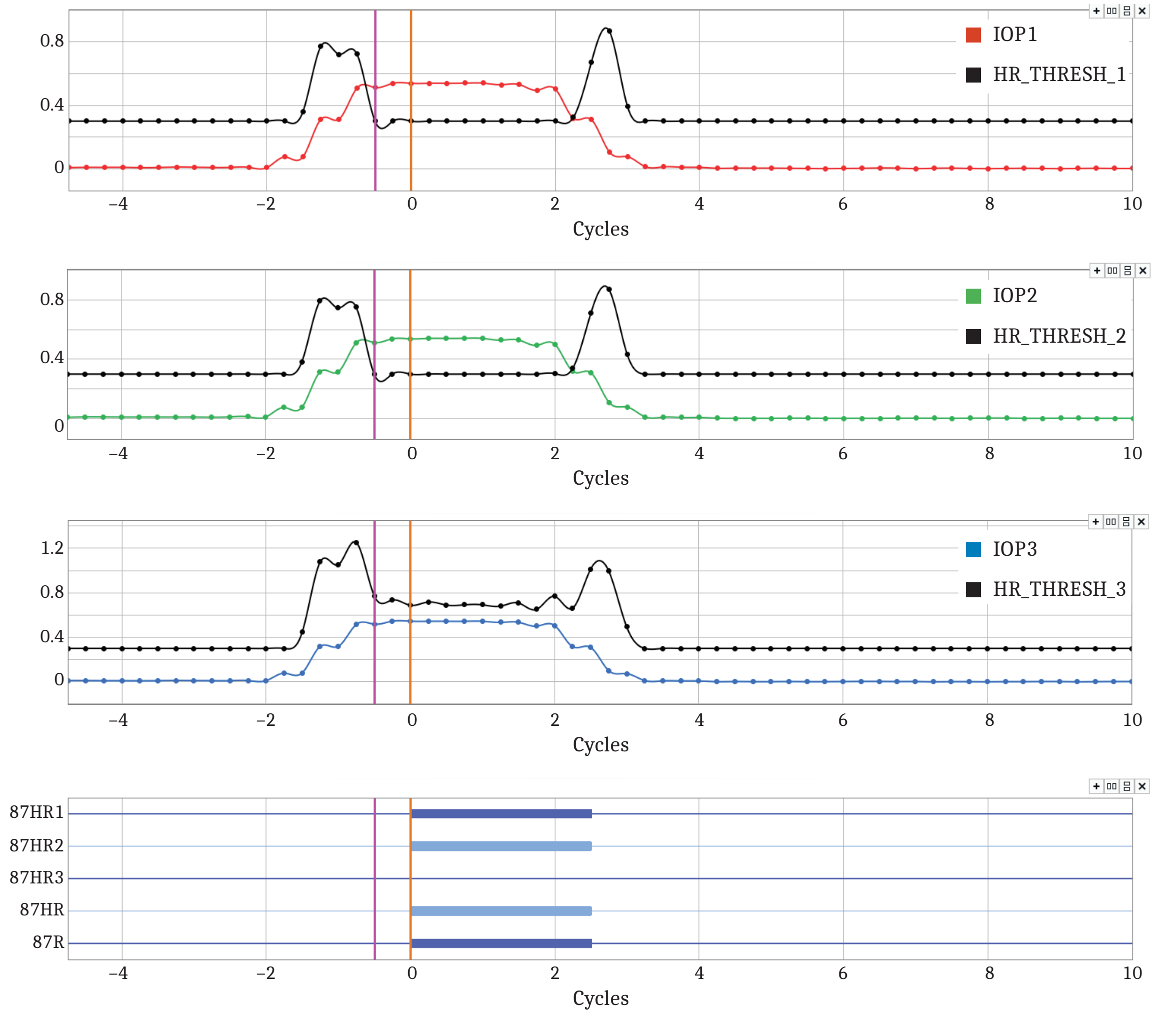


**Figure 10 Analyzing Harmonic Restraint in the SEL-787**

## SEL-487E

The SEL-487E uses an adaptive slope characteristic, as shown in *Figure 2(b)*. The relay supports harmonic restraint and common harmonic blocking. You must select whether you want the relay to use harmonic restraint (E87HR = Y), common harmonic blocking (E87HB = Y), or both. This application guide does not model waveshape blocking or unblocking functions. Consult the SEL-487E instruction manual for details on how the harmonic blocking and restraint elements are affected when waveshape functions are enabled (E87HB = E, E87HR = W, or E87UNB = Y).

To model harmonic restraint and blocking, first obtain an 8 sample/cycle compressed event report (*.CEV) from the SEL-487E. This event report contains the winding currents, the operate and restraint quantities, and the second and fourth harmonic quantities. The second harmonic quantities given in the event report signify the second harmonic content of the operate currents divided by the fundamental (50 or 60 Hz) content of the operate currents and multiplied by 100. This is similar for the fourth harmonic quantities.

**NOTE:** The SEL-487E uses the CON*p* bits (where *p* = A, B, or C) to control whether the active slope is SLP1 or SLP2. For the code to work correctly, the CON*p* bits must be included in the event reporting digitals via the relay settings *before an event occurs*. To do this in ACSELERATOR QuickSet® SEL-5030 Software, open the SEL-487E settings file and navigate to **Report** > **Event Reporting Digitals**. Then, navigate to **Relay Word Bits** > **Phase Differential Elements**, and move all of the Relay Word bits in that group to the right-hand (ERDG) column.

Open an SEL-487E compressed event report (*.CEV) and import the calculations from AG2020-28 SEL-487E.txt as explained previously. Manually adjust the user settings if desired, or leave them as AUTO to pull the settings from the event report. Plot and compare the appropriate signals shown in *Table 5* in your event report to model the respective algorithm.

In the case that the CON*p* bits were not added to the event reporting digitals before the event occurred, the code will flag an error. To clear this error, you must define which slope to use by setting the CON*p*_USER settings to FALSE (for SLP1) or TRUE (for SLP2). If the slope you select is not the same as what the relay was actually using during the event, the output of the calculations may not match the expected behavior shown in *Table 5*.

Once asserted, the 87*p*HR and 87*p*HB bits deassert at regular intervals. This is because of the behavior of the IFLT*p* Relay Word bit. See the SEL-487E instruction manual for a more detailed explanation.

**Table 5 SEL-487E Signals to Compare**

| Algorithm | Operating Quantities | Compare to Threshold | Result | Relay Word Bits |
|---|---|---|---|---|
| Harmonic Restraint | IOPA<br>IOPB<br>IOPC | HR_thresh_A<br>HR_thresh_B<br>HR_thresh_C | Individual 87*p*HR bits assert if IOP*p* exceeds HR_thresh_*p*. These will assert 87R*p* after a time delay of as long as 1 cycle. Any 87R*p* will assert 87R. | 87AHR[a, b]<br>87BHR[a, b]<br>87CHR[a, b] |
| Harmonic Blocking | IOPA<br>IOPB<br>IOPC | S_thresh_A<br>S_thresh_B<br>S_thresh_C | Individual 87*p*HB bits assert within 1 cycle[c] if IOP*p* exceeds S_thresh_*p*, and no blocking bits (below) have asserted. These will assert 87R*p* after a time delay of as long as 1 cycle. Any 87R*p* will assert 87R. | 87AHB[a, b]<br>87BHB[a, b]<br>87CHB[a, b] |
| | 2H_A<br>2H_B<br>2H_C<br>4H_A<br>4H_B<br>4H_C | PCT2<br>PCT2<br>PCT2<br>PCT4<br>PCT4<br>PCT4 | Individual 87*p*BK2 bits assert if 2H_*p* exceeds PCT2 or 4H_*p* exceeds PCT4. If any of these assert, they will block all 87*p*HB bits from asserting. | 87ABK2[a, d]<br>87BBK2[a, d]<br>87CBK2[a, d] |

[a] These Relay Word bits are not included by default in the event report. Adding the "Phase Differential Elements" Relay Word bits to the event reporting digitals as described previously ensures that they are included. If they are not in your event report, use the 87R*p* bits instead. The 87R*p* bits are an OR combination of 87*p*HR and 87*p*HB with a time delay of as long as 1 cycle.

[b] Once asserted, the 87pHR and 87pHB bits deassert at regular intervals. This is because of the behavior of the IFLTp Relay Word bit. See the SEL-487E instruction manual for a more detailed explanation

[c] This 1 cycle delay only exists if any 87*p*BK2 element is asserted for longer than 1.5 cycles.

[d] For any of the harmonic blocking bits to assert, IOP*p* must also exceed IOP_min. This ensures that the relay does not make decisions on very small current values. In the SEL-487E, IOP_min = 0.05.

*Figure 11* shows an example of analyzing an event from an SEL-487E with harmonic restraint enabled. For harmonic restraint, *Table 5* instructs us to compare the IOP*p* quantities versus the HR_thresh_*p* quantities and explains that the 87*p*HR bits assert if an operate quantity exceeds its threshold. These signals are shown in *Figure 11*. Here you can see that the operate quantity exceeds the threshold for the second element (B-phase) and asserts the corresponding 87BHR bit. The 87R bit asserts 1 cycle after this occurs.

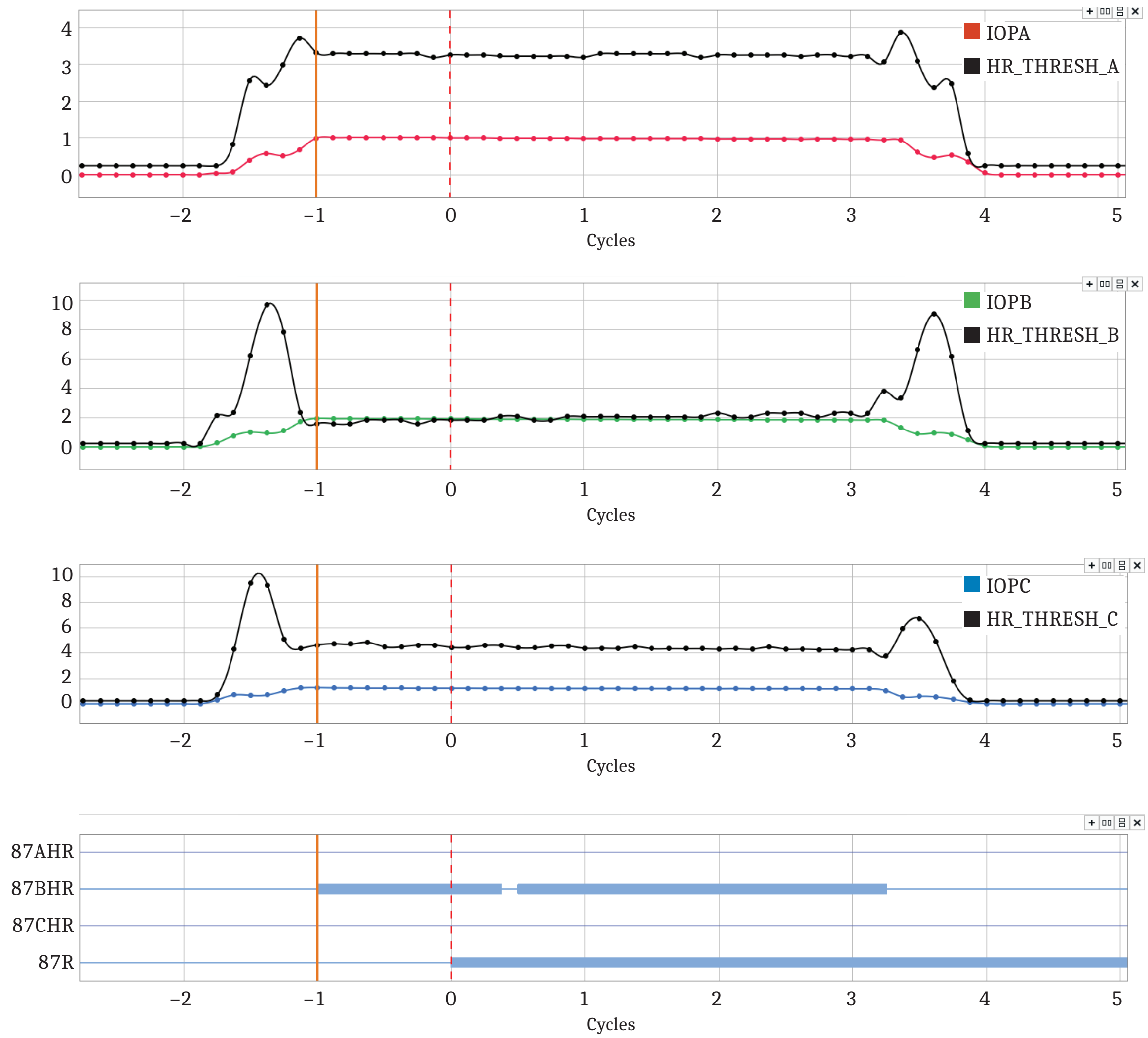


**Figure 11 Analyzing Harmonic Restraint in the SEL-487E**

## Conclusion

This application guide shows how the custom calculations engine in SYNCHROWAVE Event can be used to model the 87R element, along with harmonic blocking and restraint, in the SEL-387, SEL-787, and SEL-487E. Compare the operate quantities to the thresholds provided in the tables of this application guide to validate relay operation for harmonic restraint or harmonic blocking methods. It is also possible to alter the relay settings to see how the relay would have operated with different values.

## References


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[5] *SEL-387 Relay Current Differential Overcurrent Relay Instruction Manual*. Available at selinc.com/products/387/docs/.

[6] *SEL-787 Transformer Protection Relay Instruction Manual.* Available at selinc.com/products/787/docs/.

[7] *SEL-487E Transformer Protection Relay Instruction Manual*. Available at selinc.com/products/487E/docs/.


## Technical Support

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