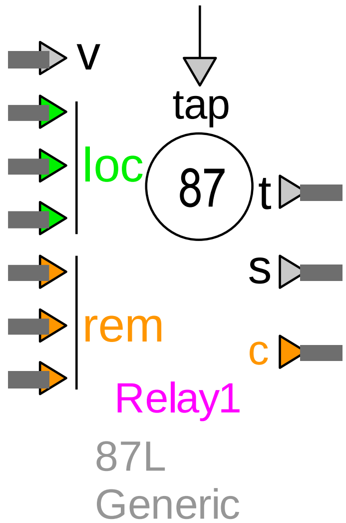
Protection: Line differential functions



Henry Gras, 6/19/2018 1:52:00 PM

1 Introduction

This relay device follows the ANSI standard 87L – line differential. It also contains zero-sequence and negative-sequence differential protections.

The relay device has 3 bundle inputs for local current transformers (CTs) and 3 bundle inputs for communication with remote relay devices. Therefore, line applications with up to 4 terminals can be studied. The required information is sent from a remote relay to the local one through the output bundle c. This communication port contains the instantaneous and phasor phase local differential currents as well as the sequence local differential currents, the local sequence and phase restraint currents, and some other signals required by certain manufacturer architectures.

This relay compensates the line charging current in the local differential current calculation. A bundle input is available to connect a local voltage measurement device (VT or CVT) in order to evaluate the charging current with the voltage variations.

Applications with in-zone transformer can also be studied. In that case, the phase shift and magnitude changes introduced by the transformer connection in the current are compensated.

2 Input data - common for every manufacturer

- **Enable differential protection**: Enable or disable the line differential protection function.
- **$I_{DIFFpkp}$**: Pickup differential current in pu, below this threshold, the element is disabled.
- **Restraint type:** Define how the restraint current is calculated.
  - If "MAX(|I|)": the restraint current I_{res} is:

$$I_{res} = MAX\left(|I_i|, I_{res_j}\right)_{i=local\,inputs,\,j=remote\,connections} \quad (1)$$

    where I_i are the currents from the local CTs and I_{res_j} are the local restraint currents of the line remote ends relays.
  - If "SUM(|I|)": the restraint current I_{res} is:

$$I_{res} = \sum_{i=local\,inputs}\left(|I_i|\right) + \sum_{j=remote\,connections}\left(I_{res_j}\right) \quad (2)$$

  - If "1/2SUM(|I|)": the restraint current I_{res} is:

$$I_{res} = \frac{1}{2}\left(\sum_{i=local\,inputs}\left(|I_i|\right) + \sum_{j=remote\,connections}\left(I_{res_j}\right)\right) \quad (3)$$

These equations apply for each phase restraint current calculation as well as for the zero-sequence and negative-sequence restraint current calculations.
For SEL manufacturer, see 3.1.

- **Characteristic:** Select the type of characteristic. It applies for the phases, the zero-sequence and the negative-sequence differential protections.
  - If "Continuous percent differential dual-slope" is selected, the characteristic has 2 slopes where the maximum operating current before tripping is continuous at the breaking point (see Figure 2-1)

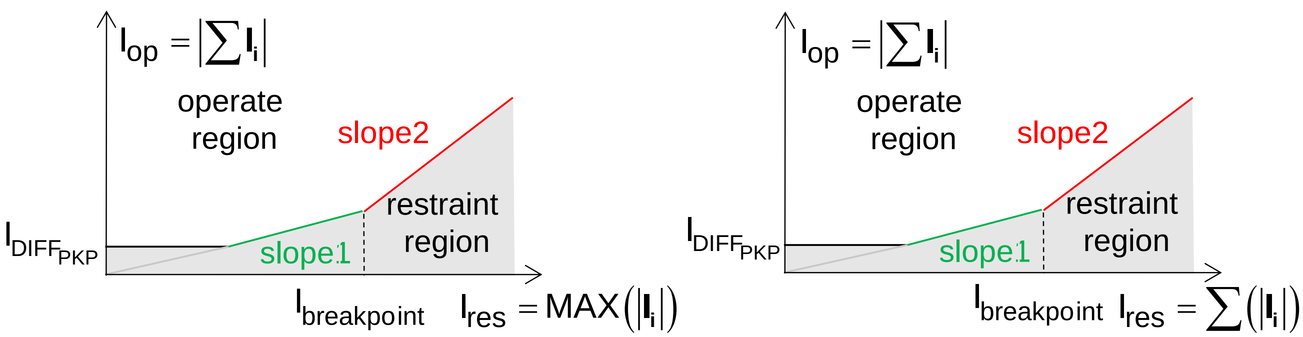


Figure 2-1: Continuous characteristic, two types of restraint quantities.

  - If "Discontinuous percent differential dual-slope" is selected, the characteristic has 2 slopes where the maximum operating current before tripping and the restraint current are always proportional (see Figure 2-2)

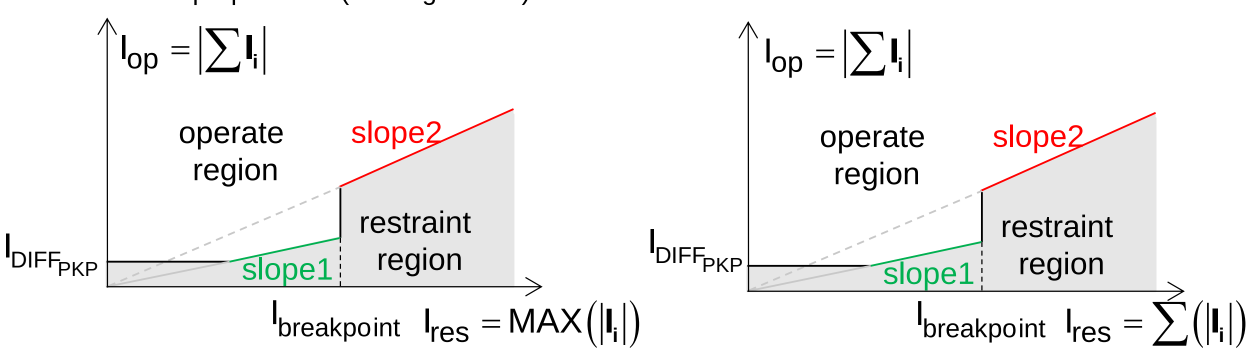


Figure 2-2 Discontinuous characteristic, two types of restraint quantities.

- **Slope 1**: Value of the first slope of the characteristic in %
- **Slope 2**: Value of the second slope of the characteristic in %
- $I_{breakpoint}$: Threshold of restraint current to go from slope 1 to slope 2 (see Figure 2-1 and Figure 2-2).
- **Harmonics inhibit**: Enable and select the harmonics for inhibition. If the ratio between the selected harmonic and the fundamental in the differential current is reached, the protection is blocked. The options are 2nd, 4th, 5th, 2nd+4th or 2nd+5th.
  When a sum of harmonics is selected, their magnitudes are added together and compared to the threshold.
- **Harmonics restraint**: This option is valid with the SEL Manufacturer (see 3.1).
- **Enable phase compensation and zero-sequence removal:** Enable the zero-sequence removal in the current. Mimic the delta connection of the CTs.

3 Manufacturer specific architectures

3.1 SEL

The line differential protection architecture when SEL manufacturer is selected follows the description in [1].

- **Harmonics restraint**: Enable and select the harmonics to consider to be part of the restraint current calculation. The only option for this version is 2nd+4th. In that case, the restraint current is:

$$I_{res} = I_{res_{Trad}} + |I_{M2}|\frac{100}{PCT2} + |I_{M4}|\frac{100}{PCT4} \quad (4)$$

  where $I_{res_{Trad}}$ is the restraint current calculated as in applications without in-zone transformer, PTC2 and PTC4 are the 2nd and 4th harmonic inhibition levels, I_{M2} and I_{M4} are the levels of 2nd and 4th harmonics, respectively, in the differential current. The restraint current calculation scheme for each phase is detailed in Figure 3-4.
- **87LPU**: High set differential current pickup for in-zone transformer applications. Above this value, the relay trips regardless of the harmonics blocking or restraint. Therefore, this setting has to be set above the maximum inrush current of the in-zone transformer.
- **Charging current high-frequency restraint:** The charging current is evaluated by the relay based on the line fundamental frequency impedance. Therefore, for high frequencies, an error in the compensation is made. In order to avoid spurious tripping, the high frequency content of the differential current is added to the restraint current using the scheme of the following figure:

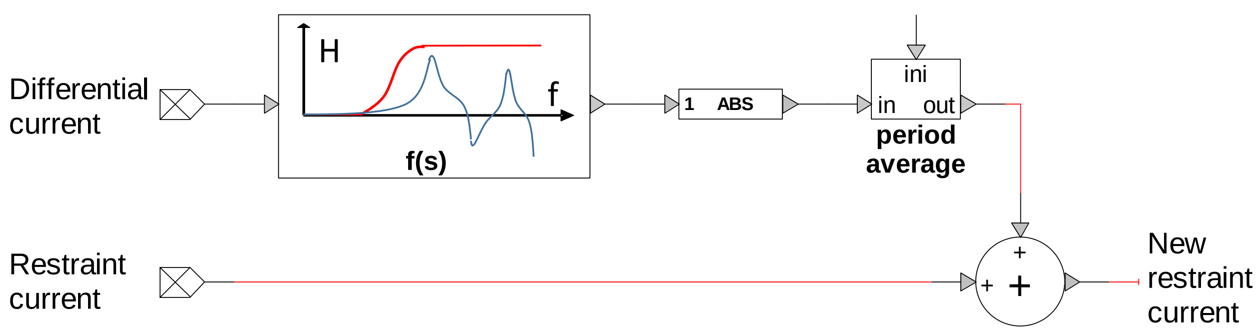


Figure 3-1: Augmentation of the restraint current with the high frequency content in the differential current.

- **Band-pass frequency:** Band-pass frequency of the high-pass filter transfer function of Figure 3-1.
- **External fault detection:** In order to differentiate external and internal faults and avoid tripping for external faults causing high saturations of the CTs, detection logics for DC and AC paths are applied on each phase. The detection logic schemes are shown in Figure 3-2 and Figure 3-3 and more information can be found in [1]. An external fault (EFD flag) is declared if, for one of the phases, the

AC-logic detection of the local relay or of any of the line remote-end relays are true. Therefore, the local external fault detection flag is communicated between relays through the **signal1 of the output bundle c.**

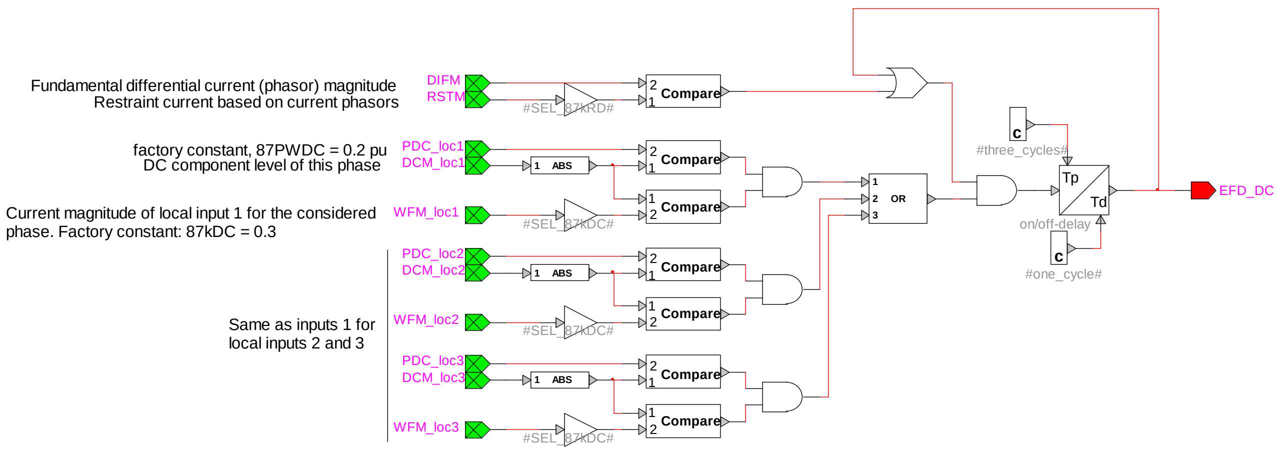


Figure 3-2 External fault detection for the DC path and for each phase.

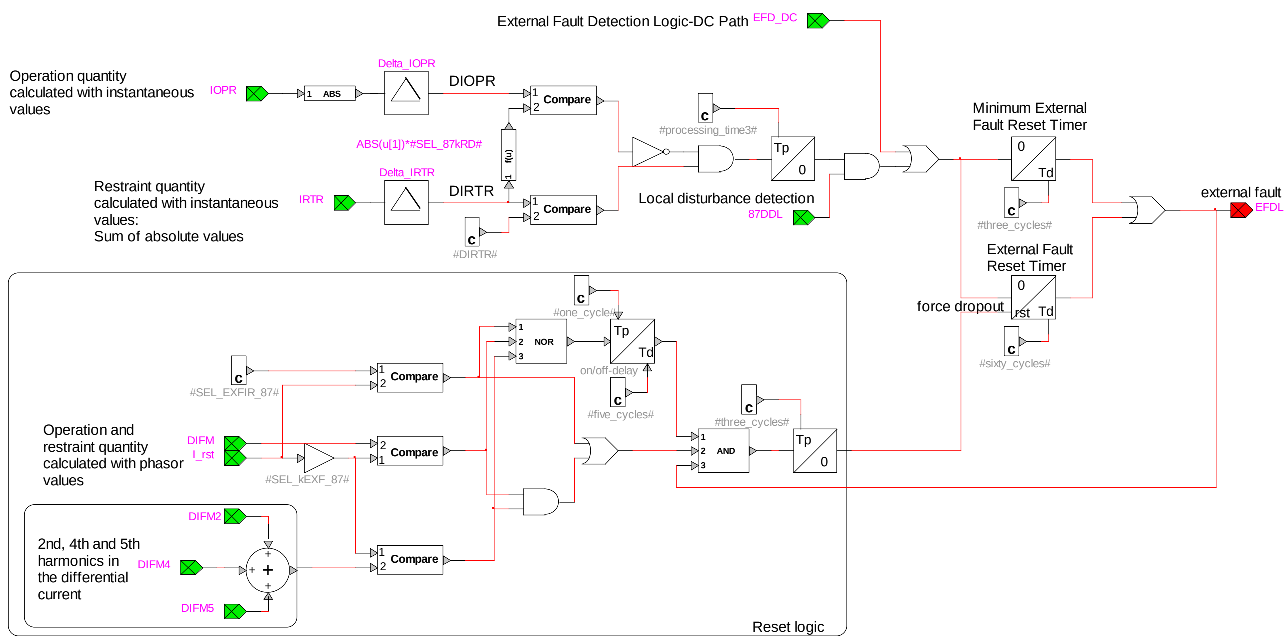


Figure 3-3 External fault detection for the AC path and for each phase.

When the external fault detection flag (EFD) is off, the restraint currents are calculated as explained in chapter 2. When EFD is on, in order to avoid tripping due to CT saturations, the sum of the magnitudes of the 2nd, 4th and 5th harmonics in the differential current multiplied by a factory factor equal to 2 is added to the differential current (see 87APA in Figure 3-4).

For the zero-sequence and the negative-sequence restraint currents, the maximum of the phases 87H (see Figure 3-4) multiplied by a factory factor equal to 0.33 is added (see Figure 3-5).

<u>Note:</u> in [1], when EFD is asserted, the relay algorithms can be switched to an 'Extended Security' mode. This status is not modelled in this version.

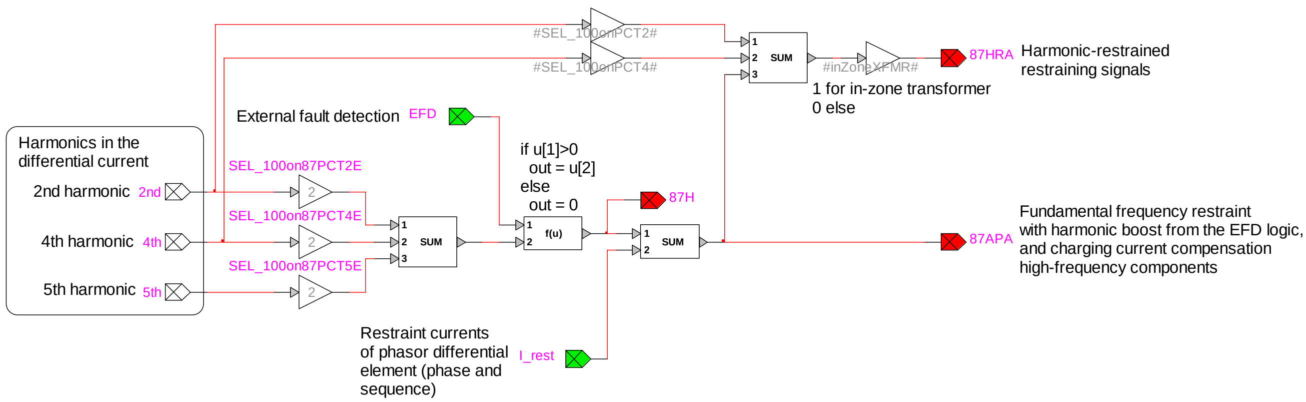


Figure 3-4: Restraint current calculation of each phase.

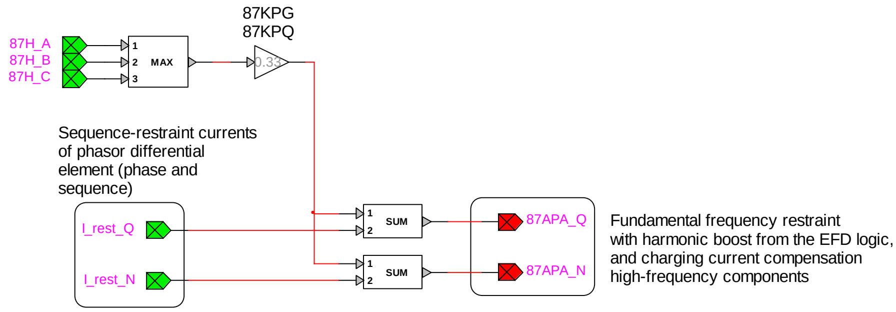


Figure 3-5: Restraint current calculation of zero-sequence and negative-sequence.

- **87kRD**: see Figure 3-2 and Figure 3-3. SEL factory constant.
- **87kDC**: see Figure 3-2. SEL factory constant.
- **87PWDC**: see Figure 3-2. SEL factory constant.
- **87PWDC**: see Figure 3-2. SEL factory constant.
- **DIRTR**: see Figure 3-3. Threshold of restraint current increase over a cycle for external fault detection.
- **87kEXF:** see Figure 3-3. SEL factory constant.
- **87EXFIR:** see Figure 3-3. SEL factory constant.

Generalized Alpha Plane: The Generalized alpha plane theory is described in [1] (see Figure 3-6)**.** It is applied to each phase differential and restraint currents (calculated in Figure 3-4 and Figure 3-5 schemes), as well as to the zero-sequence and negative-sequence differential and restraint currents. When the inputs are such that the locus is inside the Alpha Plane, the tripping is blocked.

For in-zone transformer applications, a second Alpha Plane is applied using the restraint current calculated in (4). See Figure 3-8 for the tripping logic of the SEL line differential element. In this figure, 87DD is the disturbance detection logic flag which is detailed in Figure 3-9. More information can be found in [1].

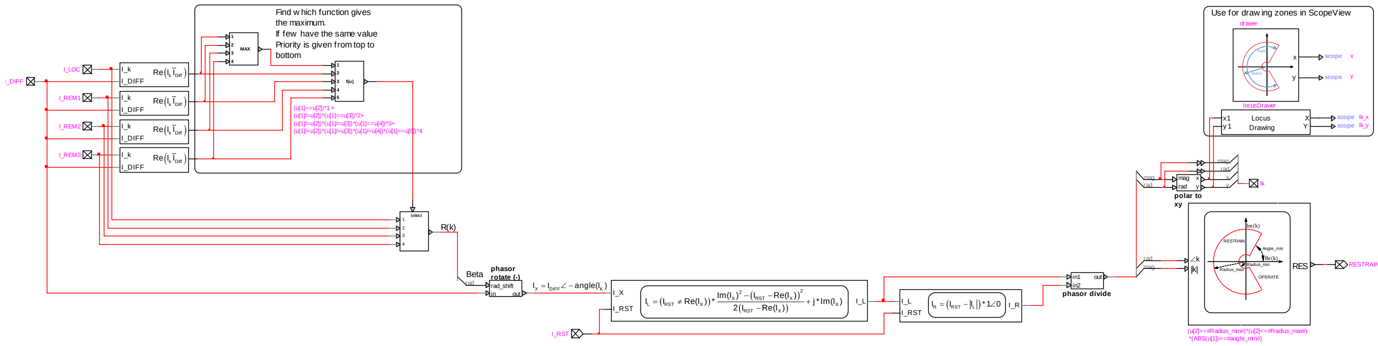


Figure 3-6: Generalized Alpha Plane scheme.

- **Radius:** Alpha plane radius (see Figure 3-7)
- **Angle:** Alpha plane angle (see Figure 3-7)

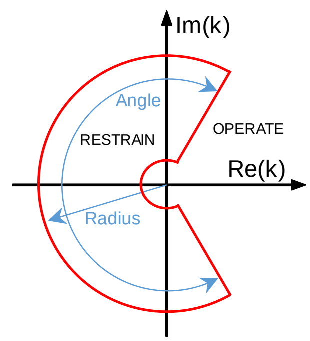


Figure 3-7: Generalized Alpha Plane parameters

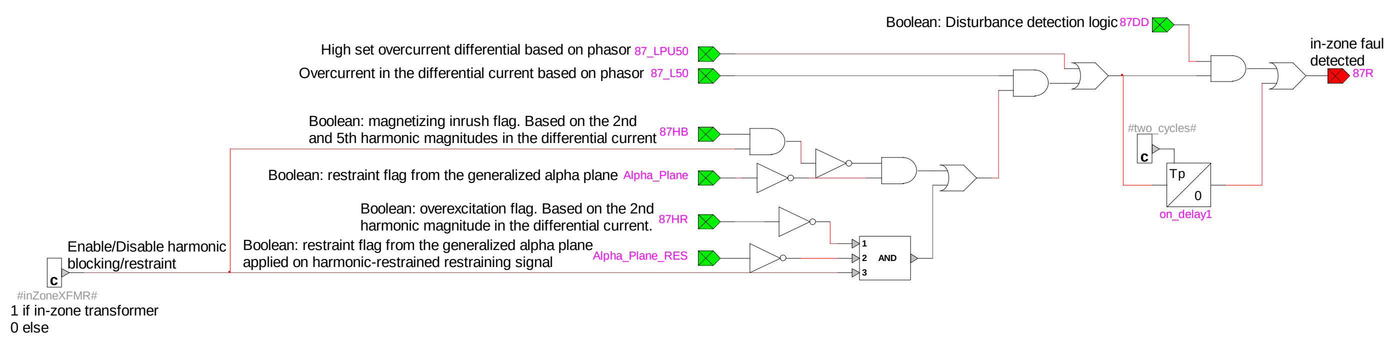


Figure 3-8: SEL line differential protection function tripping logic.

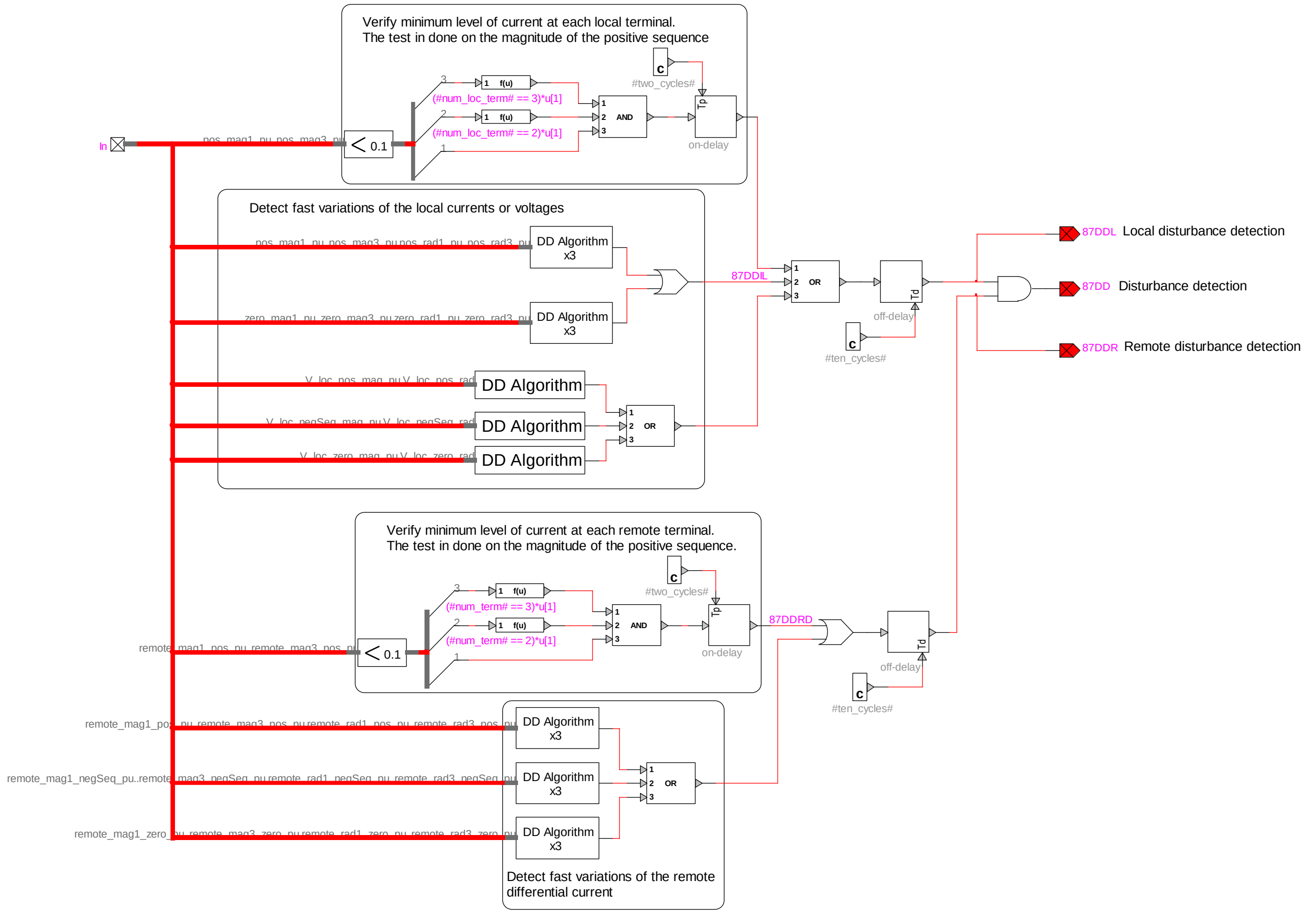


Figure 3-9: Disturbance detection logic

- **Scope Alpha Planes:** Scope the trajectories of the current ratios in Alpha Planes.
- **Open Alpha Planes scopes:** Display the trajectories of the Alpha Plane current ratios for the 3 phases, the zero-sequence and the negative-sequence in complex planes in ScopeView (see Figure 3-10). The simulation must have been previously ran with **Scope Alpha Planes** checked.
  On the locus trajectories, discontinuities are marked at every cycle in order to give an information on how fast the locus is moving (see Figure 3-11). When the locus reaches a steady-state, its size increases.

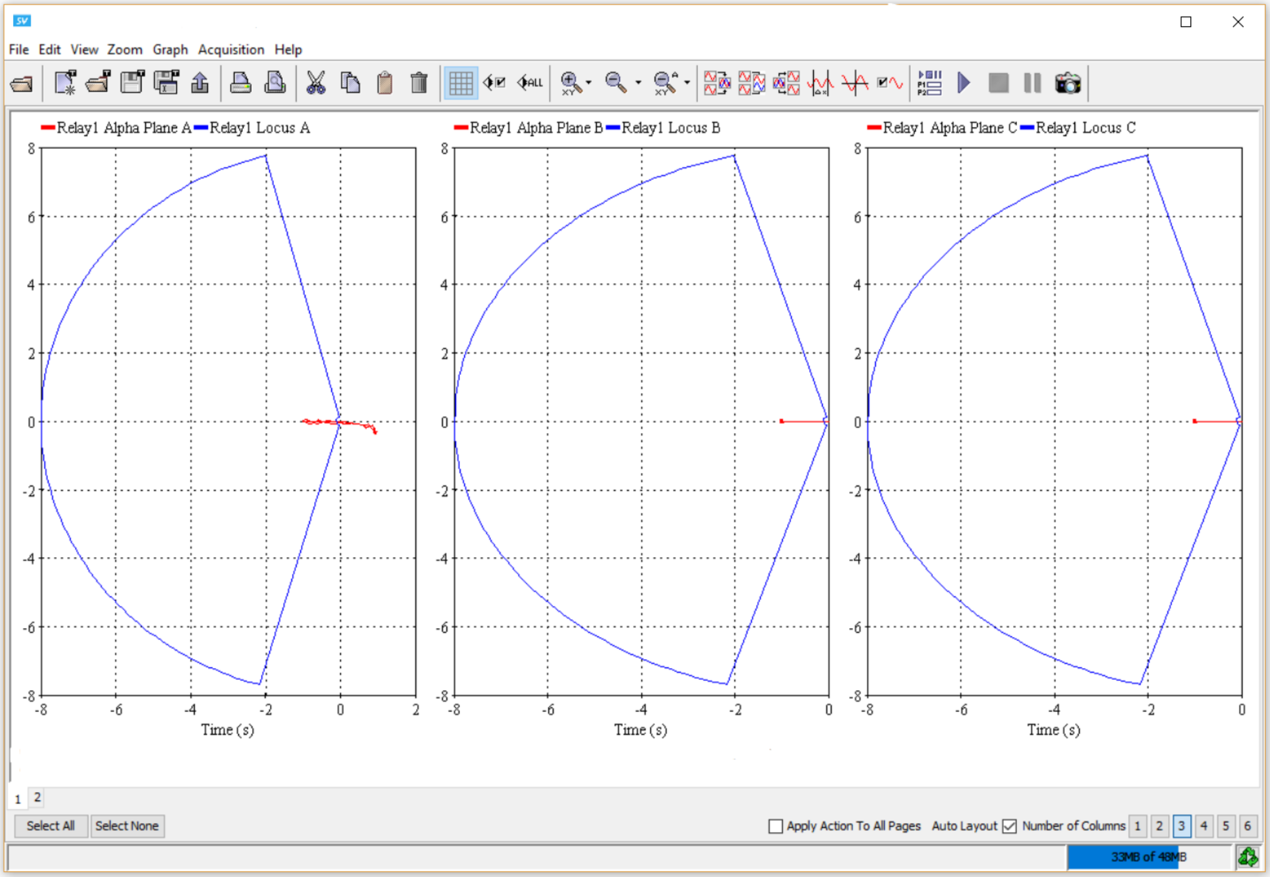


Figure 3-10: Alpha planes in ScopeView

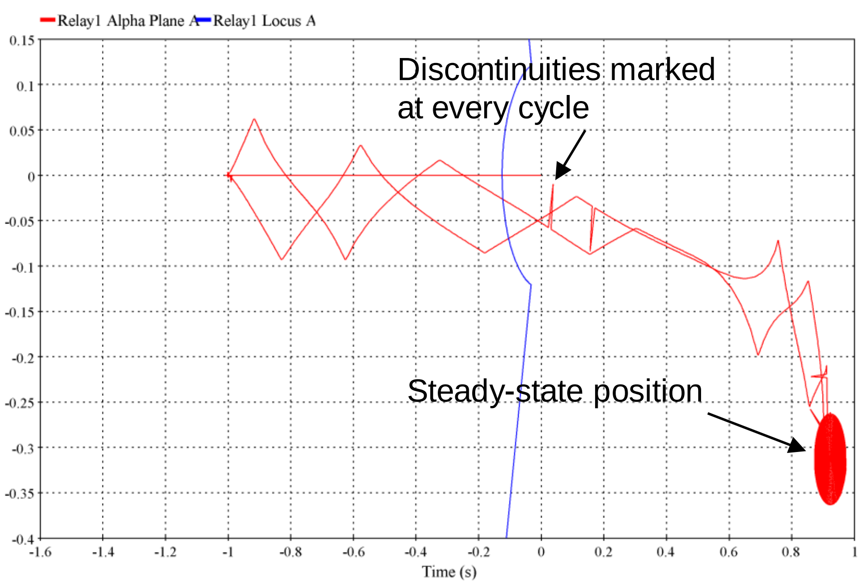


Figure 3-11: Current ratio locus trajectory in the complex plane

4 Flags available in the tripping function

- **87_P*k***: Differential current detected on phase k, k=A, B, C.
- **87_P**: Phase differential current on detected one of the phases.
- **87_Q**: Negative-sequence differential current detected.
- **87_N**: Zero-sequence differential current detected.
- **INH_k_2ND**: 2nd harmonic detection and inhibition for phase k, *k= A, B or C*
- **INH_2ND**: 2nd harmonic detection and inhibition in one of the 3 phases.
- **INH_k_4TH**: 4th harmonic detection and inhibition for phase k, *k= A, B or C*
- **INH_4TH**: 4th harmonic detection and inhibition in one of the 3 phases.
- **INH_k_2ND4TH**: harmonic detection and inhibition for the sum of the magnitudes of the 2nd and 4th harmonics for phase k, *k= A, B or C*
- **INH_2ND4TH**: harmonic detection and inhibition for the sum of the magnitudes of the 2nd and 4th harmonics in one of the 3 phases.
- **INH_k_5TH**: 5th harmonic detection and inhibition for phase k, *k= A, B or C*
- **INH_5TH**: 5th harmonic detection and inhibition in one of the 3 phases.
- **INH_k_2ND5TH**: harmonic detection and inhibition for the sum of the magnitudes of the 2nd and 5th harmonics for phase k, *k= A, B or C*
- **INH_2ND5TH**: harmonic detection and inhibition for the sum of the magnitudes of the 2nd and 5th harmonics in one of the 3 phases.

5 Signals available as scopes or in the output bundle S

The following scopes are located in the subcircuit: *RelayName/Control/Console*

- **87_N:** Zero-sequence pickup current detected.
- **87_Q:** Negative-sequence pickup current detected.
- **87_*k*:** Differential current detected on phase *k, k*=A, B or C.
- **I_diff_*k*_fund:** Phase *k* differential current based on fundamental frequency phasor calculation, *k*=A, B or C.
- **I_diff_loc_*k*_mag:** Phase *k* local differential current magnitude based on fundamental frequency phasor calculation, *k*=A, B or C.
- **I_diff_loc_*k*_ang:** Phase *k* local differential current angle based on fundamental frequency phasor calculation, *k*=A, B or C.
- **I_diff_loc_*negSeq*_mag:** Negative-sequence local differential current magnitude.
- **I_diff_loc_ *negSeq* _ang:** Negative-sequence local differential current angle.
- **I_diff_loc_*zero*_mag:** Zero-sequence local differential current magnitude.
- **I_diff_loc_ *zero* _ang:** Zero-sequence local differential current angle.
- **I_diff_*negSeq*_mag:** Negative-sequence differential current magnitude.
- **I_diff_ *negSeq* _ang:** Negative-sequence differential current angle.
- **I_diff_*zero*_mag:** Zero-sequence differential current magnitude.
- **I_diff_ *zero* _ang:** Zero-sequence differential current angle.
- **I_rest_*k*:** Phase *k* restraint current based on fundamental frequency phasor calculation, *k*=A, B or C.
- **I_rest_loc_*k*:** Phase *k* local restraint current based on fundamental frequency phasor calculation, *k*=A, B or C.
- **I_rest_loc_negSeq***:* Negative-sequence local restraint current.
- **I_rest_loc_zero***:* Zero-sequence local restraint current.
- **I_rest_negSeq***:* Negative-sequence restraint current.
- **I_rest_zero***:* Zero-sequence restraint current.
- **Rest_quantity_*k*:** Restraint quantity on phase *k*. Image of the restraint current on the y-axis of the percentage restraint characteristic, *k*=A, B or C.
- **Rest_quantity_*negSeq*:** Negative-sequence restraint quantity. Image of the restraint current on the y-axis of the percentage restraint characteristic.
- **Rest_quantity_*zero*:** Zero-sequence restraint quantity. Image of the restraint current on the y-axis of the percentage restraint characteristic.

- **i_diff_*k*_inst:** Phase *k* instantaneous differential current, *k*=A, B or C.
- **i_diff_loc_*k*_inst:** Phase *k* local instantaneous differential current, *k*=A, B or C.
- **i_rest_inst_*k*:** Phase *k* instantaneous restraint current, *k*=A, B or C.
- **I_diff_*k*_2nd:** 2nd harmonic magnitude in the phase *k* differential current, *k*=A, B or C.
- **I_diff_*k*_4th:** 4th harmonic magnitude in the phase *k* differential current, *k*=A, B or C.
- **I_diff_*k*_5th:** 5th harmonic magnitude in the phase *k* differential current, *k*=A, B or C.
- **inhibit*k*_2ND**: 2nd harmonic detection and inhibition for phase k, *k= A, B or C*
- **inhibit*k*_4TH**: 4th harmonic detection and inhibition for phase k, *k= A, B or C*
- **inhibit*k*_5TH**: 5th harmonic detection and inhibition for phase k, *k= A, B or C*
- **inhibit*k*_2ND4TH**: harmonic detection and inhibition for the sum of the magnitudes of the 2nd and 4th harmonics for phase k, *k= A, B or C*
- **inhibit*k*_2ND5TH**: harmonic detection and inhibition for the sum of the magnitudes of the 2nd and 5th harmonics for phase k, *k= A, B or C*
- **INH_2ND5TH**: harmonic detection and inhibition for the sum of the magnitudes of the 2nd and 5th harmonics in one of the 3 phases.

The following signals are only available as scopes

- **Icharging_*k***: Phasor of charging current evaluated on phase *k*, *k*=A, B or C.
- **Icharging_inst_*k***: Instantaneous value of charging current evaluated on phase *k*, *k*=A, B or C.
- **i_rest_inst_*k*:** Phase *k* instantaneous restraint current, *k*=A, B or C.
- **Scope Alpha Planes:** see chapter 3.1.

The following signals are only available in the output bundle S

- **Signal_*j***: Extra signals in the communication used by manufacturer algorithms (see chapter 3). If a signal is not used, users are free to pass signal through for customized architectures.

6 Modifications

The protection functions are updated automatically. For example, for memory usage and computational speed considerations, if an entire element is disabled, the subcircuits associated to its functions are replaced by empty subcircuits with the same inputs and outputs. The outputs will be forced to zero or one. When enabled, the subcircuits can take different architectures considering the user choices. Some elements can be excluded if not enabled in the mask.

The updates are performed immediately after entering the parameters and clicking the OK button. The user should wait for the completion of tasks.

If the user wants to modify the subcircuit manually (for example, when adding new scopes), using in the GUI, and avoid the automatic updates of contents, the attribute DeviceVersion has to be set to "none" as shown below. To access to this attribute, right click on the desired device, then go to Attributes and select DeviceVersion (see Figure below).

To allow the automatic updates again, just remove the "none" string.

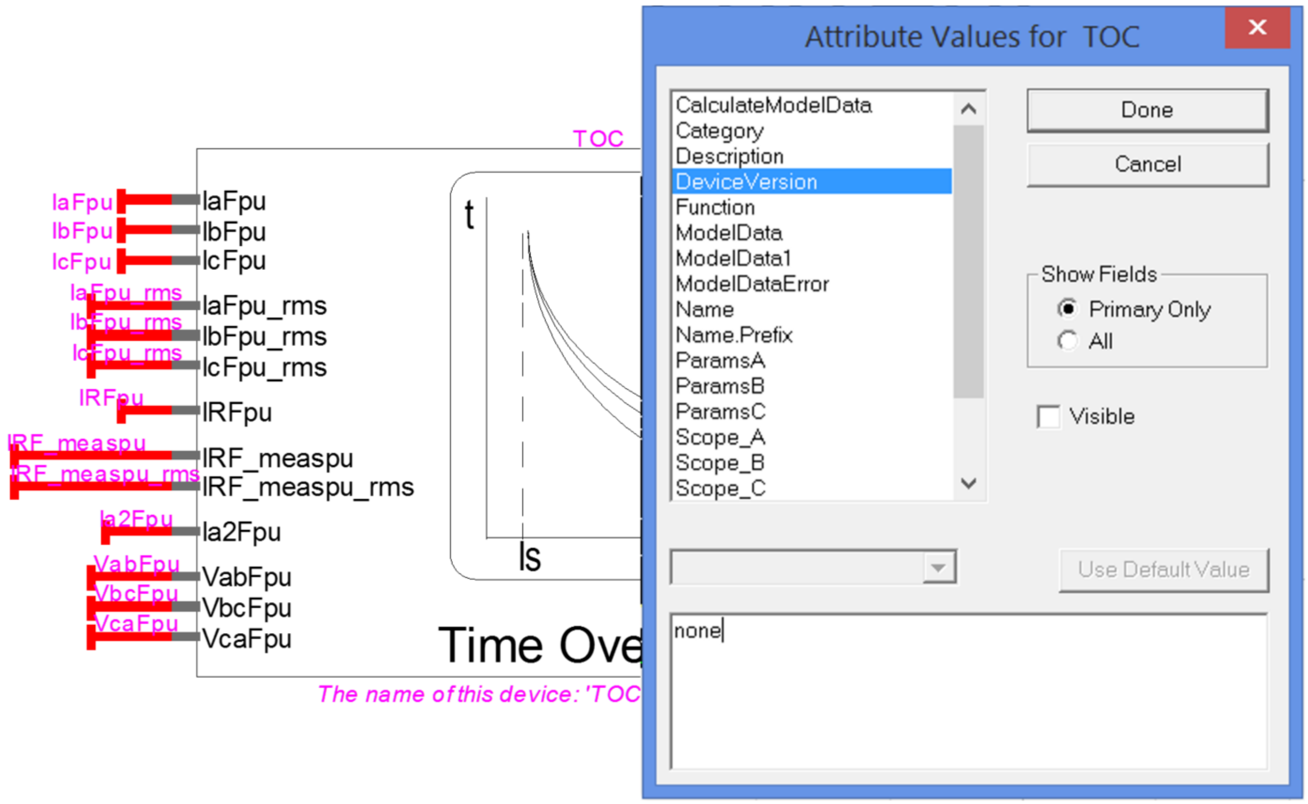


Figure 6-1 How to set the DeviceVersion attribute of the TOC element to allow modifications.

7 References:

[1] SEL-411L Relay – Protection and Automation System, Instruction Manual, Schweitzer Engineering Laboratories, 20170403.