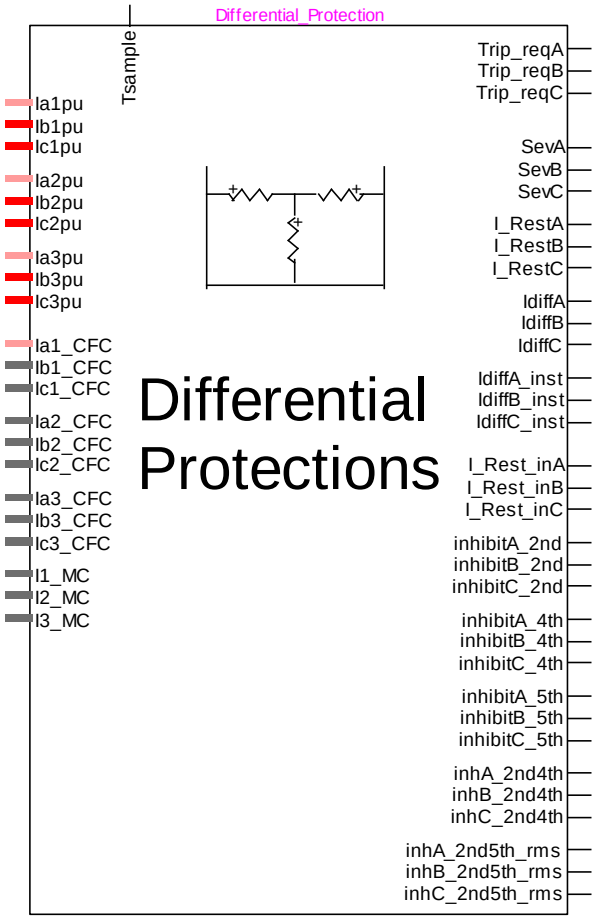
Protection: Differential functions



Henry Gras, Jean Mahseredjian, 9/1/2017 3:17:00 PM

1 Introduction

This function follows the ANSI standard 87 – differential.
The differential protection can use up to 3 CT inputs. Two different shapes of 2-slope characteristics and restraint options are available. This relay has harmonic inhibit/restraint options and external fault detection logic for certain manufacturers.

The differential element also has the option to remove the zero-sequence component of the currents.

2 Input data common for every manufacturer

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

$$I_{res} = MAX\left(\left|I_i\right|\right)_{i=inputs} \quad (1)$$

    where I_i are the currents of the inputs for each phase.
  - If "SUM(|I|)": the restraint current I_{res} is:

$$I_{res} = \sum_{i=inputs} \left(\left|I_i\right|\right) \quad (2)$$

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

$$I_{res} = \frac{1}{2} \sum_{i=inputs} \left(\left|I_i\right|\right) \quad (3)$$

- **Characteristic:** Select the type of characteristic.
  - 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)

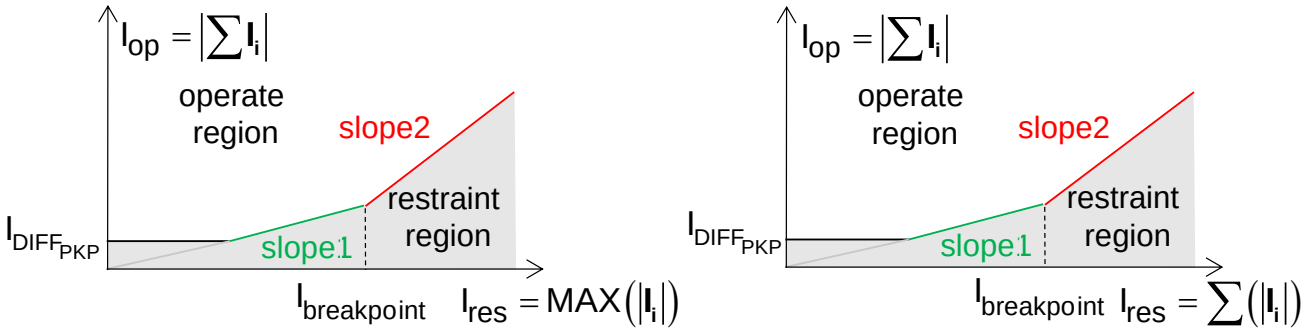


Figure 2-1: Continuous characteristic, two types of restraint quantities.

  - 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)

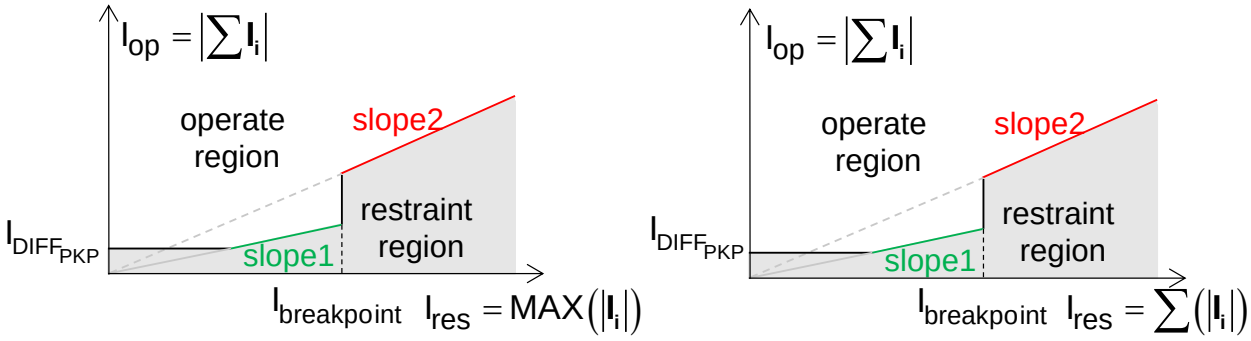


Figure 2-2 Discontinuous characteristic, two types of restraint quantities.

- **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).

- **Pickup delay:** Differential protection pickup delay. Apply to restrained and unrestrained differential protection.
- **$I_{DIFFunrestrained}$**: Unrestrained pickup differential current. If the differential current reaches this value, no matter what the restraint or the harmonic content are, the protection trips.
- **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, 4^{th}, 5^{th}, 2^{nd}+4^{th} or 2^{nd}+5^{th}.
  When a sum of harmonics is selected, their magnitudes are added together and compared to the threshold.
- **Harmonics restraint**: Enable and select the harmonics to consider to be part of the restraint current calculation. This option is valid with the **Manufacturer** SEL only. The only option for this version is 2^{nd}+4^{th}. In that case, the restraint current is:

$$I_{res} = \sum_{inputs} |I_i| + |I_{M2}| * \frac{100}{PCT2} + |I_{M4}| * \frac{100}{PCT4} \quad (4)$$

  where I_i are the currents of the inputs for each phase, PTC2 and PTC4 are the 2^{nd} and 4^{th} harmonic inhibition levels, and I_{M2} and I_{M4} are the levels of 2^{nd} and 4^{th} harmonics, respectively, in the differential current.
- **Enable phase compensation and zero-sequence removal:** Enable the zero-sequence removal in the current. Mimic the delta connection of the CTs.

3 Manufacturer architectures

3.1 Generic/GE

This architecture follows the information available in [1]. The operation and restraint quantities are calculated with the phasors from signal acquisitions.
The instantaneous differential current is also calculated with the value sampled from the CT inputs and whose phases have been corrected according to the transformer connection. The harmonic inhibit function is based on the instantaneous differential current.
A severity factor is calculated for each phase:

$$Sev = (I_{diff})^2 - 2 * \left(I_{DIFF_{pkp}}\right)^2 - (I_{res})^2 \quad (5)$$

where $I_{diff} = \left|\sum \mathbf{I}_i\right|$ is the differential current, I_{pkp} is the pickup current and I_{rest} is the restraint current defined above.

3.2 SEL

This architecture follows the information available in [2]. Its uses two differential elements in parallel:

- in the first one the operation and restraint quantities are calculated with instantaneous values from the sampler.
- In the second one, the same quantities are calculated with phasors.

The instantaneous value are used for Internal and External fault detection logics shown in Figure 3-1.

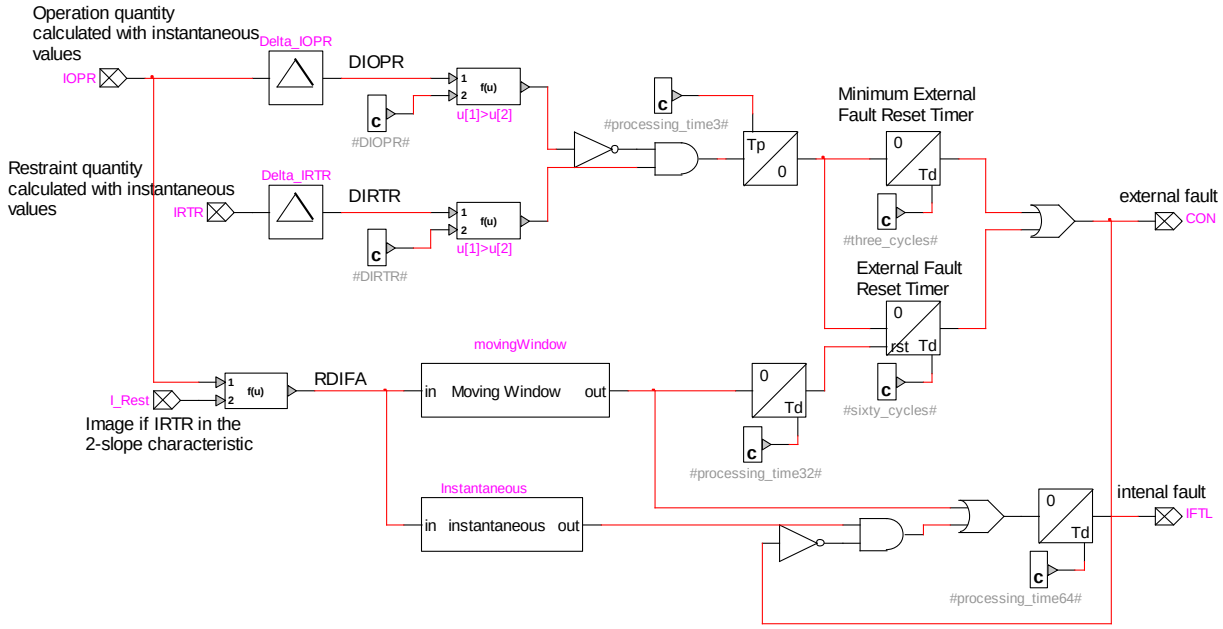


Figure 3-1 Internal and external detection logics for SEL.

In Figure 3-1, the moving window is a function that returns true if the input is true for at least 2 periods. Instantaneous is the same for a delay of a quarter cycle. Delta_IOPR and Delta_IRTR are differential functions. The harmonic inhibit option is also based on the instantaneous differential current. The final tripping decision is based on the differential element using phasors, and is supervised by the harmonic inhibit functions and the internal and external detection logics. The Figure 3-2 presents this logic.

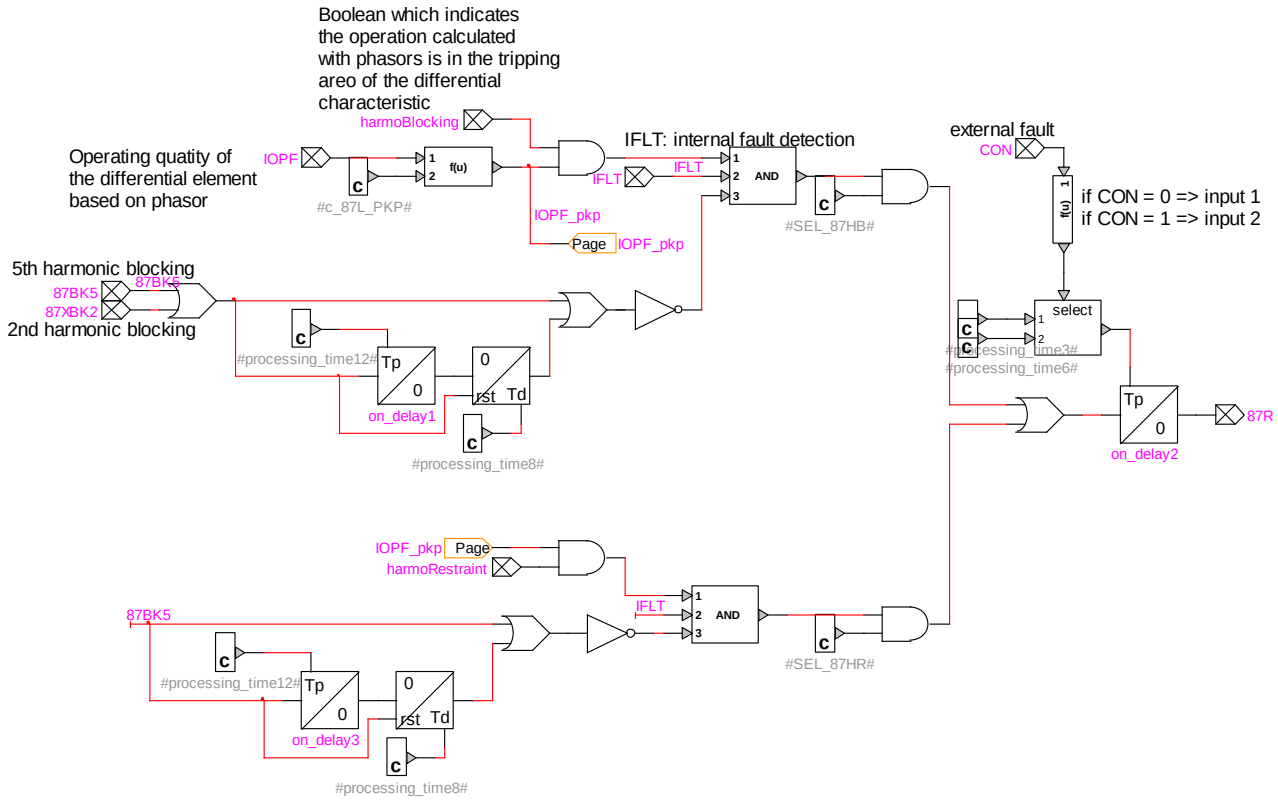


Figure 3-2 Tripping logic of the differential element of SEL.

4 Flags available in the tripping function and the output bundle of the relay

- 87_P*k*: Differential current detected on phase k, K=A, B, C
- 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 Flags available in the output bundle of the relay

- Idiffk*:* Differential current calculated by the differential element based on phasors calculations for phase k, k=A, B or C
- Trip_req*k*: Differential current detected on phase k, k=A, B, C
- I_Restk: restraint current calculated by the differential element based on phasors calculations for phase k, k=A, B or C
- Restraint_quantity_*k*: Restraint quantity on phase k, k=A, B, C. Image of the restraint current on the y-axis of the percentage restraint characteristic.
- 87G*i*_diff: Winding *i, i=1, 2 or 3,* differential current calculated by the differential element based on phasors calculations.
- 87G*i*_trip: Tripping signal due to ground differential current on winding *i, i=1, 2 or 3,*.
- 87G*i*_rest: Winding *i, i=1, 2 or 3,* restraint current calculated by the differential element based on phasors calculations.
- Restraint_quantity_G*i*: Restraint quantity on winding *i* ground current. Image of the restraint current on the y-axis of the percentage restraint characteristic.
- 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: 5h 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.
- I*k_h:* Harmonic *h* in the differential current calculated by the differential element based on phasors calculations for phase k, k=A, B or C

6 Scopes

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

- 87_P*k*: Differential current detected on phase k, k=A, B, C
- 87G*i*: Tripping signal due to ground differential current on winding *i, i=1, 2 or 3,*.
- diff_P*k:* Differential current calculated by the differential element based on phasors calculations for phase *k, k*=A, B or C
- diff_G*i*: Winding *i, i=1, 2 or 3,* differential current calculated by the differential element based on phasors calculations.
- rest_P*k*: restraint quantity calculated by the differential element based on phasors calculations for phase *k, k*=A, B or C.
- rest_G*i*: Winding *i, i=1, 2 or 3,* restraint current calculated by the differential element based on phasors calculations.
- rest_quantity_*k*: Restraint quantity on phase *k*, k=A, B, C. Image of the restraint current on the y-axis of the percentage restraint characteristic.
- rest_quantity_G*i*: Restraint quantity on winding *i* ground current. Image of the restraint current on the y-axis of the percentage restraint characteristic.
- Sev*k*: Severity coefficient calculated by (5). Only for manufacturers *Generic* and *General Electric.*
- 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: 5h 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.
- Idiff_*k_h:* Harmonic *h* in the differential current calculated by the differential element based on phasors calculations for phase k, k=A, B or C

7 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.

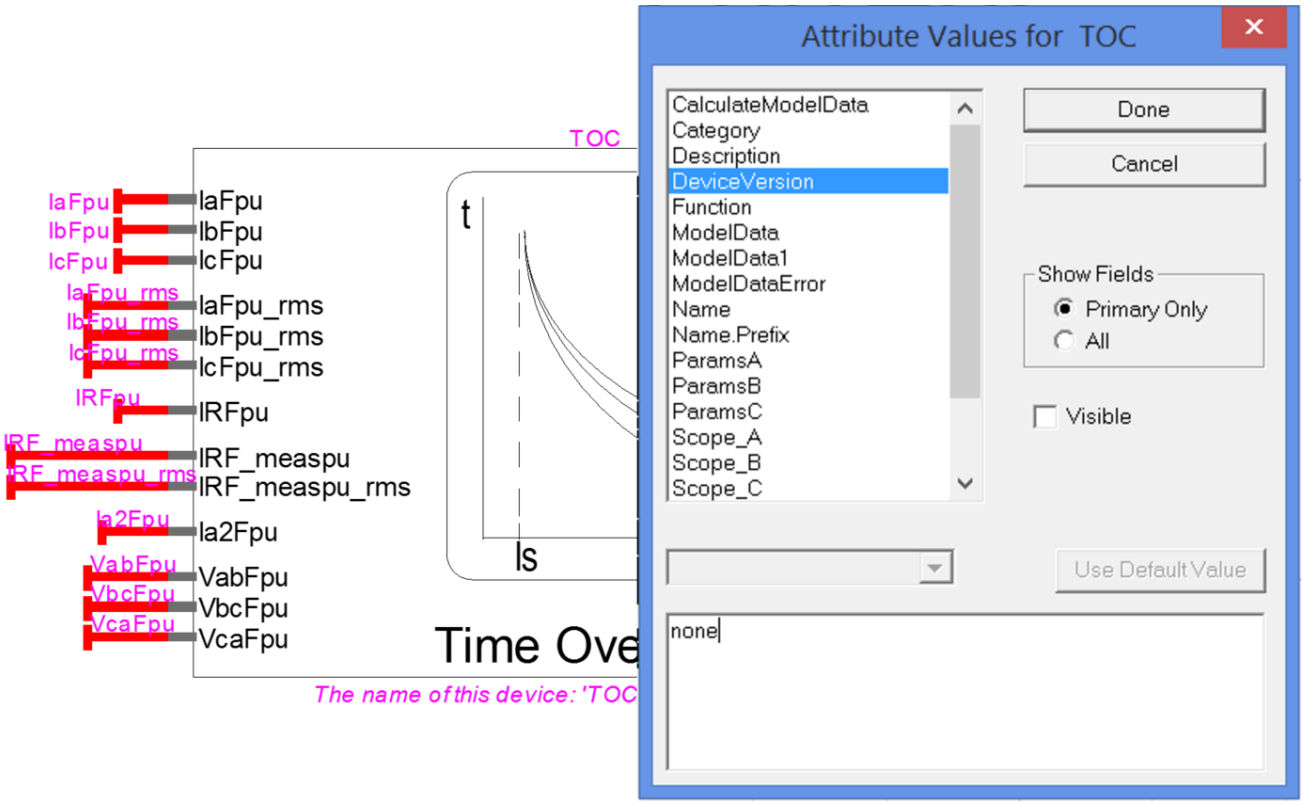


Figure 7-1 How to set the DeviceVersion attribute of the TOC element to allow modifications.

8 References:

[1] 745 Transformer Protection System Instruction Manuel, chapter 5.6 p5-45 – p5, Instruction Manual, GE Digital Energy, Revision 5.20.

[2] SEL-487E Relay – Current Differential and Voltage Protection, Section 4 p4.1 - p4.24, Instruction Manual, Schweitzer Engineering Laboratories.