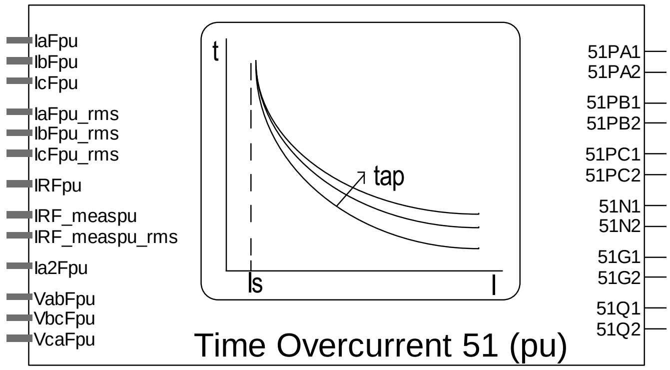
Protection: Time overcurrent relay functions



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1 Introduction

This device uses data entered on the Relay “Overcurrent functions” tab.
The time overcurrent relay function reproduces the ANSI standards 51P, 51N, 51Q, 51G, 50P, 50N, 50Q and 50G, the IEC PTOC and PIOC standards and some manufacturer standards.

The inputs are:

1. the current phasors with phasor or rms options
2. the residual current (IRF) which is 3 times the zero-sequence current
3. the residual current measured from the ground CT (phasor or rms options)
4. the negative sequence current (Ia2)
5. the phasors of line-to-line voltages, utilized in the voltage restraint function

The above inputs are used in this module (Time Overcurrent 51 functions) when the related functions are enabled on the mask.
The outputs are the tripping requests for each element following the standards (see Section 3).

2 Input data, Overcurrent tab

- **Manufacturer**: selection of manufacturer.
- **Enable time overcurrent relay**: enable the overcurrent functions. If unchecked, the Instantaneous Overcurrent (IOC) and Time Overcurrent (TOC) functions are disabled and provide zero output.
- **Enable voltage restraint**: The voltage restraint is a function which changes the value of the pickup current of the TOC according to the levels of line-to-line voltages. It is applicable only to phase elements.
  If the box is checked it is possible to enter data when it is not otherwise.
  - **Number of points**: number of points to define the curve. The limit is 100.
  - **Table**: defines the curve as a lookup table. The first column is the line-to-line voltage in per unit (AB for phase A element, BC for phase B element and CA for phase C element). The second column is the coefficient that multiplies the pickup current setting to provide the actual pickup current of the element. Linear interpolation is used.

  The above two settings are disabled (not used) when Manufacturer data is selected (see Manufacturer dropdown menu). The manufacturer curves are preset as explained is Section 3.7.

The overcurrent relay monitors the phase currents, the residual (Neutral, 3 times zero-sequence current) current, the negative sequence current and the ground current. For each protection, 2 levels of settings are available. For each level:

- **Checkbox for enabling the level**: If checked, the level is enabled. If level 1 is unchecked, level 2 is unchecked automatically. The list of output function flags is shown near the level. These flags can be used in the tripping logic specified in the following tab.
- **Type of value**: phasor or rms. The first option “phasor” uses Discrete Fourier Transform to extract phasor magnitude (fundamental frequency), whereas the second option “rms” uses the actual rms calculator. All values are in pu.
- **I_{pkp}**: Pickup current in per unit. When the current reaches this threshold the timer determined by the inverse curve starts.
- **Type of curve**: Select the type of time curve. The available options depend on the selected Manufacturer (see Section 3) dropdown. If no Manufacturer is selected, then all standard curves are available. Also, depending on the Manufacturer, some additional data, like the “Reset time dial” has to be entered.
  If “Build your own curve” is selected:
  - **Number of points**: number of points to define the curve. The limit is 100.
  - **Table**: defines the time curve as a lookup table. The first column is the ratio of the actual current divided by the pickup current. The second column is the tripping time in seconds.
    Linear interpolation is performed when the input is in the range of entered data.
    A reset curve can be defined by putting negative tripping times for the ratio values between 0 and 1.
  - **Time dial**: Extra coefficient that multiplies the time points of the curve.

  If “Definite time” is selected:
  - **Time dial**: tripping time in seconds
  - **Reset time dial**: reset time in seconds
  - **Time dial**: time multiplier. See above usage for “Build your own curve” and “Definite time”. See section 3 for predefined curves.
- **Reset Time dial**: See above usage for “Build your own curve” and “Definite time”. See section 3 for predefined curves. For some “Type of curve” selections this value is predefined.
- **Reset:** if it is set to Instantaneous, “Reset Time dial” is the delay in seconds after which the (time-overcurrent) TOC element is reset when the current drops below the pickup current.
  If it is set to “Time”, when the measured current is below the pickup current, a memory effect is considered and the TOC is reinitialized following a timing defined by a reset function associated to each curve (see Section 3).

For the sample data shown in Table 2-1, both tripping and reset characteristics are defined. For example: after an overcurrent, if the current ratio is 3, the tripping time is 3.647s; if the ratio is 0.5, the reset time is 38.8 s.

Table 2-1 Sample user-defined curve ("Build your own curve" option)

	I / Ipkp	t (s)
1	0.1	-29.393
2	0.3	-31.978
3	0.5	-38.8
4	0.6	-45.469
5	0.7	-57.059
6	0.8	-80.833
7	0.9	-153.158
8	0.95	-298.46
9	0.98	-734.8
10	0.99999999	-1e5
11	1	1e5
12	1.1	134.407
13	1.5	22.682
14	2	9.522
15	3	3.647
16	4	2.002
17	5	1.297
18	6	1.297
19	7	0.709
20	8	0.569
21	9	0.474
22	10	0.407

- **Instantaneous function**: enable the instantaneous tripping function (ANSI function 50). As soon as the measured current is above the pickup current, a timer is launched. When the timer reaches the defined "Delay**"** input associated with the function, the tripping request is sent and held during a time defined by the "Reset Delay" option. If the measured current goes above the pickup current before the tripping request is sent, the timer is reset to zero.
- **I_{inst}**: pickup current for the instantaneous overcurrent element (in per unit).
- **Delay**: delay in seconds for a tripping request flag to rise after the measured current is above the pickup current.
- **Reset delay**: Delay in seconds for the function to be reinitialized after a tripping request flag is raised and the overcurrent condition is eliminated.

For the neutral and negative sequence elements only:

- **K**: Positive restraint current coefficient. Used to restraint a small portion of the positive sequence current magnitude to the current that is compared to the pickup current for the instantaneous overcurrent functions of level 1 and 2.
  For the neutral elements, the input current of the IOC is:
  $$I_{op} = 3I_0 - KI_1 \quad (1)$$
  where the subscripts 0 and 1 designate zero-sequence and positive-sequence, respectively.
  For the negative sequence (2) elements, the input current of the IOC is:
  $$I_{op} = I_2 - KI_1 \quad (2)$$

3 Predefined curves

In the following equation, $t_{tripping}$ is the tripping time, t_{reset} is the reset time, Tap is the "Time dial" (input data), t_r is the "Reset delay" (input data), I is the actual current input of the TOC element and I_{pkp} is the pickup current (input data).

3.1 IEEE/ANSI curves

Mathematical functions:

$$t_{tripping} = Tap\left[\frac{A}{\left(\frac{I}{I_{pkp}}\right)^{C} - 1} + B\right] \tag{3}$$

$$t_{reset} = Tap\frac{t_r}{1 - \left(\frac{I}{I_{pkp}}\right)^{2}} \tag{4}$$

The "Reset delay" (t_r) input is defined by the ANSI standard and disabled in the mask. The various parameters for the above equations are defined in Table 3-1.

Table 3-1 Predefined coefficients, ANSI functions for some manufacturers

Curve Name	A	B	C	t_r	**Manufacturers**
IEEE Extremely inverse	28.20	0.1217	2.000	29.10	Generic, ABB, General Electric, SEL
IEEE Very inverse	19.61	0.4910	2.000	21.60	Generic, ABB, General Electric, SEL
IEEE Moderately inverse	0.0515	0.1140	0.02000	4.850	Generic, ABB, General Electric, SEL
IEEE Normal inverse	0.0086	0.0185	0.02000	0.4600	ABB
US Inverse	5.950	0.1800	2.000	5.950	Generic, ABB, General Electric
US Short time inverse	0.16758	0.11858	0.02000	2.261	ABB
IEEE Long time extremely inverse	64.07	0.2500	2.000	30.00	ABB
IEEE Long time very inverse	28.55	0.7150	2.000	13.46	ABB
IEEE Long time inverse	0.02000	0.1850	0.08600	4.6	ABB
U1 Moderately inverse	0.01040	0.0226	0.02000	1.080	SEL
U2 Inverse	5.9500	0.18000	2.000	5.950	SEL
U3 Very inverse	0.09630	3.8800	2.000	3.880	SEL
U4 Extremely inverse	5.6400	0.02434	2.000	5.640	SEL
U5 Short-time inverse	0.003420	0.00262	0.02000	0.323	SEL

For the IEEE I^2t selection ("Type of curve"):

$$t_{tripping} = Tap\frac{100}{\left(\frac{I}{I_{pkp}}\right)^{2}} \tag{5}$$

$$t_{reset} = Tap \frac{100}{\left[\frac{t_r}{1-\left(\frac{I}{I_{pkp}}\right)^2}\right]^{-2}} \quad (6)$$

3.2 IEC curves

Mathematical function:

$$t_{tripping} = Tap\left[\frac{K}{\left(\frac{I}{I_{pkp}}\right)^E - 1}\right] \quad (7)$$

$$t_{reset} = \left[\frac{t_r}{1-\left(\frac{I}{I_{pkp}}\right)^2}\right] \quad (8)$$

The value of "Reset delay" (t_r) must be defined by the user.

Table 3-2 IEC curves

Name of the curve	K	E	Manufacturers
IEC Normal Inverse/Curve A	0.140	0.0200	*Generic, ABB, General Electric*
IEC Very inverse/Curve B	13.5	1.00	*Generic, ABB, General Electric*
IEC Extremely inverse/IEC Curve C	80.0	2.00	*Generic, ABB, General Electric*
IEC Short Inverse	0.0500	0.0400	*Generic, ABB, General Electric*
IEC Long inverse	120	1.00	*Generic, ABB, General Electric*
IEC Inverse	0.020	0.140	*Generic, ABB, General Electric*

For the *General Electric option the* t_r is defined as below:

Table 3-3 Predefined coefficients of the IEC reset functions, General Electric

Name of the curve	t_r	Manufacturers
IEC Normal Inverse/Curve A	9.70	GE
IEC Very inverse/Curve B	43.2	GE
IEC Extremely inverse/IEC Curve C	52.8	GE
IEC Short Inverse	0.500	GE

For the SEL option data is given in Table 3-4.

Table 3-4: Predefined coefficients of the IEC functions, SEL

Name of the curve	K	E	t_r	Manufacturers
C1 standard inverse	0.140	0.0200	13.5	SEL
C2 Very Inverse	13.5	1.00	47.3	SEL
C3 Extremely inverse	80.0	2.00	80	SEL
C4 Long-Time inverse	0.0500	0.0400	120	SEL
C5 Short-Time Inverse	120	1.00	4.85	SEL

3.3 General Electric

3.3.1 GE IAC curves

Mathematical expression:

$$t_{tripping} = Tap\left[A + \frac{B}{\frac{I}{I_{pkp}} - C} + \frac{D}{\left(\frac{I}{I_{pkp}} - C\right)^2} + \frac{E}{\left(\frac{I}{I_{pkp}} - C\right)^3}\right] \tag{9}$$

$$t_{reset} = Tap\left[\frac{t_r}{1 - \left(\frac{I}{I_{pkp}}\right)^2}\right] \tag{10}$$

Table 3-5: Predefined coefficients of the IAC functions used by the manufacturer *General Electric*

Name of the curve	A	B	C	D	E	t_r	Manufacturers
GE IAC Extremely inverse	0.0040	0.6379	0.6200	1.7872	0.2461	6.008	*General Electric*
GE IAC Very Inverse	0.0900	0.7955	0.1000	-1.2885	7.9586	4.678	*General Electric*
GE IAC Inverse	0.2078	0.8630	0.800	-0.4180	0.1947	0.990	*General Electric*
GE IAC Short Inverse	0.0428	0.0609	0.6200	-0.0010	0.0221	0.222	*General Electric*

3.3.2 GE Ground

Mathematical expression:

$$t_{tripping} = \frac{Tap}{\sqrt{\frac{I}{I_{pkp}}} - 1} \tag{11}$$

$$t_{reset} = t_r \tag{12}$$

3.4 Definite time

$$t_{tripping} = Tap \tag{13}$$

$$t_{reset} = t_r \tag{14}$$

3.5 RI inverse characteristic

For Generic and ABB:

$$t_{tripping} = Tap\left[\frac{1}{0.339 - \frac{0.236}{I/I_{pkp}}}\right] \quad (15)$$

$$t_{reset} = t_r \quad (16)$$

3.6 Logarithmic inverse characteristic

For Generic and ABB:

$$t_{tripping} = 5.8 - 1.35\ln\left(\frac{I/I_{pkp}}{Tap}\right) \quad (17)$$

$$t_{reset} = t_r \quad (18)$$

3.7 Restraint voltage

For General Electric, the preset curve lookup table is shown below.

Table 3-6 Predefined lookup table, restraint voltage curve, General Electric

	V (pu)	Multiplier
1	0	0.1
2	0.1	0.1
3	0.9	0.9
4	0.9000001	1
5	1	1

4 Flags

These flags are available in the tripping function, the output bundle and scopes of the relay:

- 51_PA_1: Overcurrent on phase A with the setting of level 1
- 51_PA_2: Overcurrent on phase A with the setting of level 2
- 51_PB_1: Overcurrent on phase B with the setting of level 1
- 51_PB_2: Overcurrent on phase B with the setting of level 2
- 51_PC_1: Overcurrent on phase C with the setting of level 1
- 51_PC_2: Overcurrent on phase C with the setting of level 2
- 51_N_1: Overcurrent on the calculated residual current ($3I_0$) with the setting of level 1
- 51_N_2: Overcurrent on the calculated residual current ($3I_0$) with the setting of level 2
- 51_Q_1: Overcurrent on the negative sequence with the setting of level 1. The same as 46_1.
- 51_Q_2: Overcurrent on the negative sequence with the setting of level 2. The same as 46_2.
- 51_G_1: Overcurrent on the measured residual current (input pin Ig_sec) with the setting of level 1
- 51_G_2: Overcurrent on the measured residual current (input pin Ig_sec) with the setting of level 2

In the tripping logic expressions in the tab Tripping Logic, the flags listed above are OR combinations between the flags from the time and the instantaneous overcurrent functions. In the output bundle S, they are separate. When the user enters 51_PA_1, both IOC (50L_1A) and TOC (51_PA_1) protection flags are selected with an OR gate.

The following flags are available only in the output bundle:

- 50L_1A: Instantaneous overcurrent on phase A with the setting of level 1
- 50L_2A: Instantaneous overcurrent on phase A with the setting of level 2

- 50L_1B: Instantaneous overcurrent on phase B with the setting of level 1
- 50L_2B: Instantaneous overcurrent on phase B with the setting of level 2
- 50L_1C: Instantaneous overcurrent on phase C with the setting of level 1
- 50L_2C: Instantaneous overcurrent on phase C with the setting of level 2
- 50N1: Instantaneous overcurrent on the calculated residual current ($3I_0$) with the setting of level 1
- 50N2: Instantaneous overcurrent on the calculated residual current ($3I_0$) with the setting of level 2
- 50Q1: Instantaneous overcurrent on the negative sequence with the setting of level 1. The same as 46i_1.
- 50Q2: Instantaneous overcurrent on the negative sequence with the setting of level 2. The same as 46i_2.
- 50G1: Instantaneous overcurrent on the measured residual current (input pin Ig_sec) with the setting of level 1
- 50G2: Instantaneous overcurrent on the measured residual current (input pin Ig_sec) with the setting of level 2

5 Modifications

The TOC and IOC elements are updated automatically. For example, for memory usage and computational speed considerations, if “Enable time overcurrent relay” is unchecked, the subcircuits associated to these functions (TOC and IOC) 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 below).

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

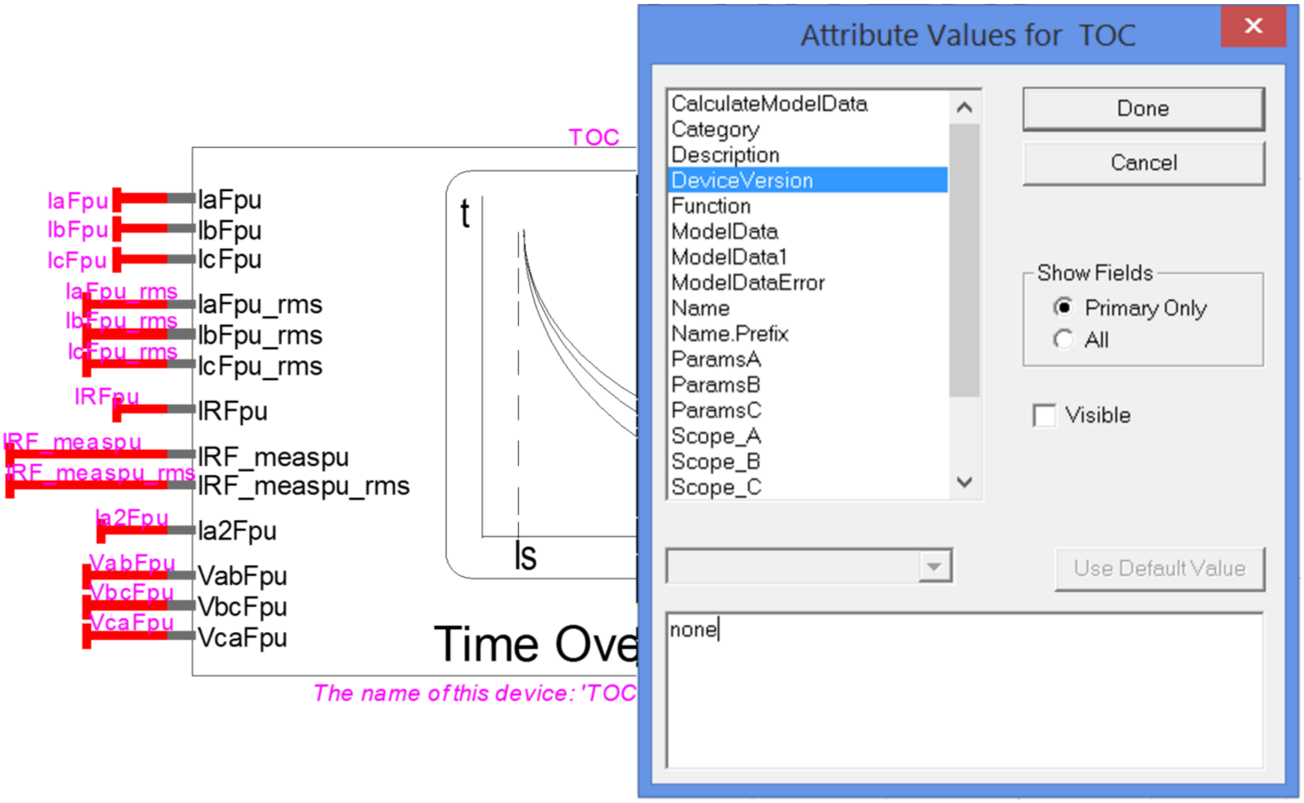

Figure 5-1 How to set the DeviceVersion attribute of the TOC element to allow user modifications.