POWERFACTORY

PowerFactory 2021

Technical Reference

Breaker/Switch

ElmCoup,StaSwitch,TypSwitch,EvtSwitch

PF2021

POWER SYSTEM SOLUTIONS

MADE IN GERMANY

Publisher:
DIgSILENT GmbH
Heinrich-Hertz-Straße 9
72810 Gomaringen / Germany
Tel.: +49 (0) 7072-9168-0
Fax: +49 (0) 7072-9168-88
info@digsilent.de

Please visit our homepage at:
https://www.digsilent.de

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1 General Description and Basic Data

1.1 Phase Nomenclature

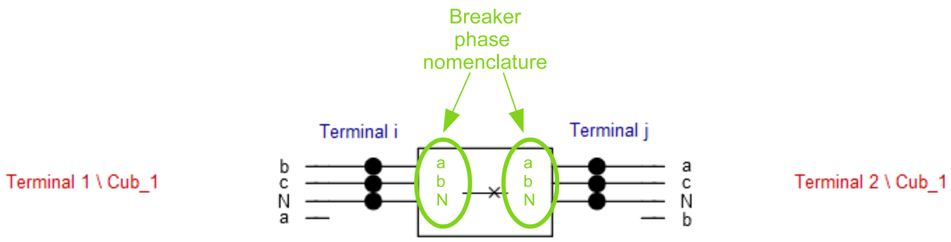

Figure 1.1: Breaker phase nomenclature.

Breakers can have a variable number of phases. The number of phases and neutral are defined on the basic data page. By clicking on "Figure" on the right, the detailed connections are shown. An example is given in Fig. 1.1, where a breaker is connected to phase b, c and neutral at Terminal 1 and to phase a, c and neutral at Terminal 2. Although this case seems unlikely, it is an example of the phase nomenclature being ambiguous, as it does not match for both terminals. Therefore, breakers define their own naming according to the number of phases, independent from the connected terminals. The phases are counted from a to c as usual. Hence, a breaker that is connected to two phases always defines the phases a and b, independent from the actual connection to the terminals. The neutral is named and counted separately. Regarding the example in Fig. 1.1, this means that the breaker defines phases a, b and neutral (N). This nomenclature is used in the following sections. See also Sec. 5.3.4 for an example to further clarify.

1.2 Equivalent Circuit

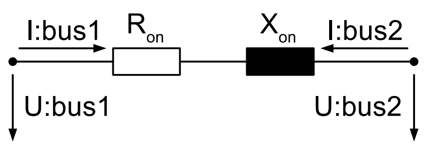

Figure 1.2: Single phase equivalent circuit.

When the breaker is closed, it connects each phase of the terminals with a series impedance consisting of R_{on} and X_{on} as depicted in Fig. 1.2. The values of the impedance are set in the type (TypSwitch) and are the same for all phases of the breaker. If the breaker is open, it is modelled by a zero admittance. If more complicated models are needed, this can be achieved by using other network elements in parallel.
Neglecting transients, the voltage difference between the two buses can be described by the phasor model:

$$U_{bus1}(t) - U_{bus2}(t) = I_{bus1}(t)(R_{on} + jX_{on}) \tag{1}$$

To improve performance, breakers are generally reduced in most simulations. This means that a closed breaker connecting two nodes will be merged to one node to reduce the total number of nodes. However, result variables, such as the current over the breaker, cannot be monitored in this case and the breaker impedance is neglected in simulations.
The model reduction of breakers can be prevented by setting "Detailed for calculation" on the basic data page. This should also be enabled if result variables of breakers are to be monitored.

1.3 Further Options

The breaker can be excluded from running arrangements of substations by enabling the check box. Switch events can be applied to breakers. They can affect all phases or a selection of phases only.
Switch events can only be applied to the neutral when the check box 'Switch interrupts neutral wire' on the basic data page of the target ElmCoup is set.

1.4 Input Parameters

Name	Unit	Description
on_off	-	Breaker is closed at beginning of simulation
idetail	-	Breaker is detailed for calculation - result variables are recorded
Switch Type	-	
Switch interrupts neutral wire	-	Events that are applied to the breaker incorporate the neutral wire
Excluded from running arrangement	-	Exclude breaker from running arrangement

Table 1.1: Input parameters of basic data page.

2 Load Flow Analysis

The equivalent circuit as described in Sec. 1.2 and Eq. 1 is used.

2.1 Calculation Quantities

2.1.1 Loading

The loading of the breaker is calculated as follows:

$$loading = max\left(\frac{|I_{bus1}|}{I_{nom(bus1)}}, \frac{|I_{bus2}|}{I_{nom(bus2)}}\right) \cdot 100 \qquad [\%]$$

where:

- $I_{nom(bus1)}$ is nominal current of the breaker for terminal 1 in kA
- $I_{nom(bus2)}$ is nominal current of the breaker for terminal 2 in kA
- I_{bus1} is magnitude of the current at terminal 1
- I_{bus2} is magnitude of the current at terminal 2

If no thermal rating object is defined, the nominal currents are equal to the rated current of the reactor $I_{nom(bus1)} = I_{nom(bus2)} = I_r$.

2.1.1.1 Losses

The losses are calculated as follows:

Quantity	Unit	Description	Value
$Ploss$	MW	Losses (total)	$= P_{bus1} + P_{bus2}$
$Qloss$	$Mvar$	Reactive-Losses (total)	$= Q_{bus1} + Q_{bus2}$
$Plossld$	MW	Losses (load)	$= Ploss - Plossnld$
$Qlossld$	$Mvar$	Reactive-Losses (load)	$= Qloss - Qlossnld$
$Plossnld$	MW	Losses (no load)	$= 0$
$Qlossnld$	$Mvar$	Reactive-Losses (no load)	$= 0$

Table 2.1: Losses Quantities, AC-model

2.1.2 Voltage Drop

Quantity	Unit	Description	Value
du	$p.u.$	Voltage Drop	$= \lvert\underline{u}_{bus1}\rvert - \lvert\underline{u}_{bus2}\rvert$
$dphiu$	deg	Voltage Drop Angle	$= \phi_{u,bus1} - \phi_{u,bus2}$

Table 2.2: Voltage Drop Quantities, AC-model

where $\underline{u}_{bus1}$ and $\underline{u}_{bus2}$ are the corresponding terminal voltages in p.u. based on the rated voltage of the terminal. $\phi_{u,bus1}$ and $\phi_{u,bus2}$ are the terminal voltage angles in degree.

3 Short-Circuit Analysis

The equivalent circuit as described in Sec. 1.2 and Eq. 1 is used.

4 RMS-Simulation

The equivalent circuit as described in Sec. 1.2 and Eq. 1 is used.

4.1 Switch Events

Breakers can change their state (open/close) during time domain simulations by applying switch events. Switch events can be created by clicking on the "Edit Simulation Events" button → New Object, then select "Switch Event" in the drop down list. The options on the basic data page apply to RMS- as well as EMT-simulations. The event can either apply to all phases of the breaker or to an individual selection of phases.
The neutral can only be triggered by a switch event when the check box 'Switch interrupts neutral wire' on the basic data page of the target ElmCoup is set.
The type of breaker action (open/close) and the event execution time are selected. For RMS-simulations, the event execution time is equivalent to the actual breaker action. For EMT-simulation, further options are available as described in Sec. 5.1.

4.2 Results Variables

Name	Unit	Description
closed	-	All phases of breaker are closed
closedPh	-	Specific phase is closed

Table 4.1: Results variables for EMT-simulation

5 EMT-Simulation

The equivalent circuit as described in Sec. 1 is used. The voltage difference between the buses is calculated as follows (similar for all phases):

$$U_{bus1}(t) - U_{bus2}(t) = I_{bus1}(t)R_{on} + L_{on}\frac{d(I_{bus1}(t))}{dt} \tag{2}$$

5.1 Switch Events

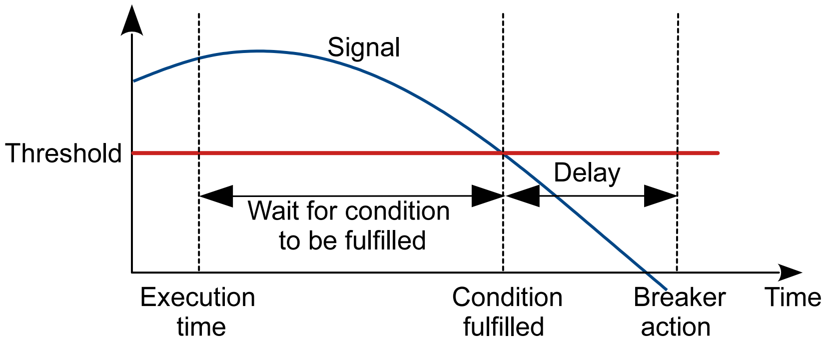

Figure 5.1: General process of EMT event.

The descriptions from Sec. 4.1 also apply to EMT-simulations. However, more options are available on the EMT page of the switch event and will be described in the following sections.
The general process of an event in the EMT-simulation is illustrated in Fig. 5.1. After the execution of the event, the breaker is waiting for some signal (current/voltage) condition to be fulfilled. In the example in Fig. 5.1, the condition is fulfilled, when the signal falls below a certain threshold. The actual breaker action (opening/closing) may then be delayed further. The delay may be caused by the reaction time of the breaker, for example. A closer look at this process is taken in the following sections. Examples are given in Sec. 5.3.

5.1.1 Opening events

There are generally three options for the condition to be fulfilled (referred to as 'Trigger opening at' in the switch event) for the opening event:

- Current zero crossing (default)
- Execution time
- Current threshold

The default condition is the current zero crossing. Opening at execution time means that the condition is fulfilled immediately at the event execution time specified on the basic data page and the ”Wait for condition to be fulfilled” time period in Fig. 5.1 is omitted. In this case, all the selected phases on the basic data page of the switch event are triggered simultaneously. The last condition is the definition of a current threshold, which is further explained in Sec. 5.1.4. Depending on the selected condition, further options become available which are elaborated in the following sections.

5.1.2 Closing events

Four general options for the condition exist for closing events:

- Execution time (default)
- Voltage zero crossing
- Voltage threshold
- Voltage maximum

The default selection is the closing at the event execution time specified on the basic data page, meaning that the condition is fulfilled immediately for all selected phases. The second option is the closing at the voltage zero crossing. The option voltage threshold is further explained in Sec. 5.1.4. The last option is to trigger the closing at the maximum voltage, which is described in Sec. 5.1.5.

5.1.3 Scheme

The scheme selection is available for opening and closing events, depending on the selected condition. There are three options:

- Phases evaluated separately
- Simultaneous
- Staggered

Phases evaluated separately means that the condition is evaluated for each phase separately and independently.
Simultaneous means that the condition is checked only for one specified phase, and this phase as well as all other phases depend on the fulfillment of the condition for this specific phase. A selection becomes active which defines the phase for which the condition is evaluated. For example, if phase b is selected for the trigger, phases a,b, c and neutral depend on the fulfillment of the condition for phase b. The neutral cannot be selected as a trigger.
When staggered is selected, the trigger condition is also evaluated for one of the phases only, similar to the previously explained option. However, the phases are not triggered simultaneously, but with a certain difference in time. The difference in time is defined individually for each phase and neutral. Concerning the phases, the time difference is relative to the preceding phase. For the neutral, the time difference is relative to the phase that triggers. For example, a three phase switch with neutral is triggered on phase b. The opening action of phase b is triggered at the instant the condition is fulfilled. The next phase in row is phase c. Hence, the dialogue ’phase c after’ defines the time difference for the switch action of phase c relative to phase b. The last phase is phase a. The dialogue ’phase a after’ defines the time difference for the switch action of phase a relative to the preceding phase, i.e. phase c (not phase b). ’Neutral after’ defines the difference in time between the phase that triggers (phase b in this case) and the neutral.

5.1.4 Threshold

The condition can be defined as an absolute threshold of the signal, which is illustrated in Fig. 5.2. The evaluation can be limited to the positive or the negative half wave. It can be selected

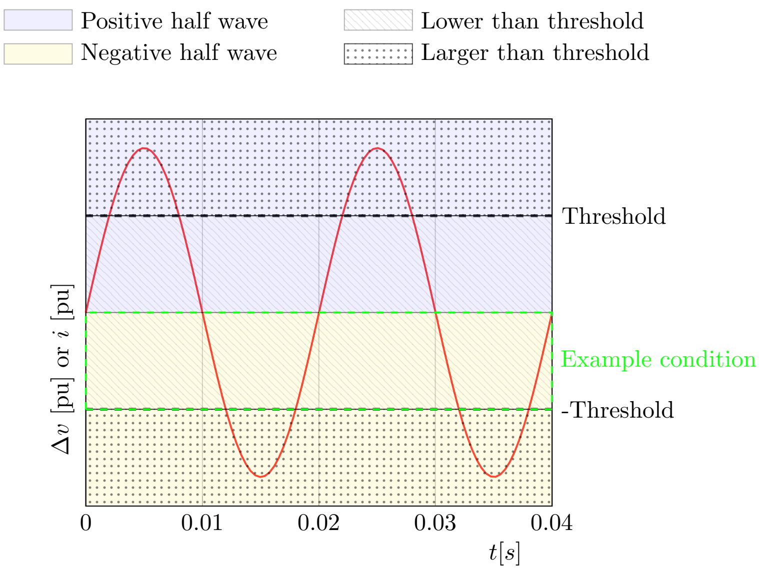

Figure 5.2: Threshold conditions.

whether the condition is fulfilled when the absolute value of the signal is larger or lower than the threshold. In Fig. 5.2 an example condition is marked for the settings ”Consider only negative half wave” and ”Lower than threshold”. Note that ”Lower than threshold” refers to the absolute value. See also the example in Sec. 5.3.3.

5.1.5 Maximum

The condition is fulfilled at the maximum absolute value of the signal. It can be selected which half waves are considered, similar to Fig. 5.2. For example, if ’Consider negative half wave only’ is selected, the switch action will actually be triggered at the minimum of the signal. This option should only be used when the signal is free of harmonics, as results may not turn out as expected when harmonics are present, due to local maxima.

5.1.6 Delay

The delay after the condition is met, as exemplified in Fig. 5.1, can originate from the target element (ElmCoup), its type (TypSwitch) and also the relative phase delay of the scheme (staggered phases, see Sec. 5.1.3). For the element, the delay is defined in the ”Scatter” option on the EMT page for each phase. For the type, the delay is defined on the basic data page as the ”Breaker opening time” and therefore applies to all phases.

The delays of ElmCoup, TypSwitch and EvtSwitch (in ’Scheme’: ’Staggered phases’) are accumulated. The delay of the type (’Breaker opening time’) is only relevant for opening events, while it is ignored for closing events.

5.2 Transient Recovery Voltage Envelope

It is possible to define a transient recovery voltage (TRV) envelope, which can be added to plots of opening events. The breaker TRV envelope can be defined on the EMT page of the TypSwitch on the advanced tab. In order to log the data of the TRV envelope, the option must be set on the EMT page of the ElmCoup. The envelope can either be logged only for the first opening event of a breaker or for all opening events. The latter means that the envelope is restarted at every opening event. The calculation parameters for the positive and negative TRV envelope can then be selected for EMT simulations and used for illustration in plots.

5.3 Examples

The following sections provide examples for the various options of switching events.

5.3.1 Example: Open at Current Zero Crossing without Delay

The breaker is opened at the zero crossing of the current. No delay is applied.

5.3.1.1 Relevant Input Data

ElmCoup:

- Basic data: No. of Phases = 3; No. of Neutrals = 1; Switch interrupts neutral wire = true
- Simulation EMT: Scatter phase a = 0 ms; Scatter phase b = 0 ms; Scatter phase c = 0 ms; Scatter neutral = 0 ms;

TypSwitch:

- Basic data: Breaker opening time = 0 s;

EvtSwitch:

- Basic data: Execution Time = 0 s; Action = Open; All phases = true;
- Simulation EMT: Trigger opening at = Current zero crossing; Scheme = Phases evaluated separately;

5.3.1.2 Simulation

The simulation outcome is shown in Fig. 5.3. After the event is executed at $t = 0$ s, the phases open (current is zero) separately one after another at their current zero crossing.

5.3.2 Example: Open at Current Zero Crossing with Delays

This example is analogous to the previous in Sec. 5.3.1, except that there are delays and only phase a and c are switched.

5.3.2.1 Relevant Input Data

ElmCoup:

- Basic data: No. of Phases = 3; No. of Neutrals = 1; Switch interrupts neutral wire = true

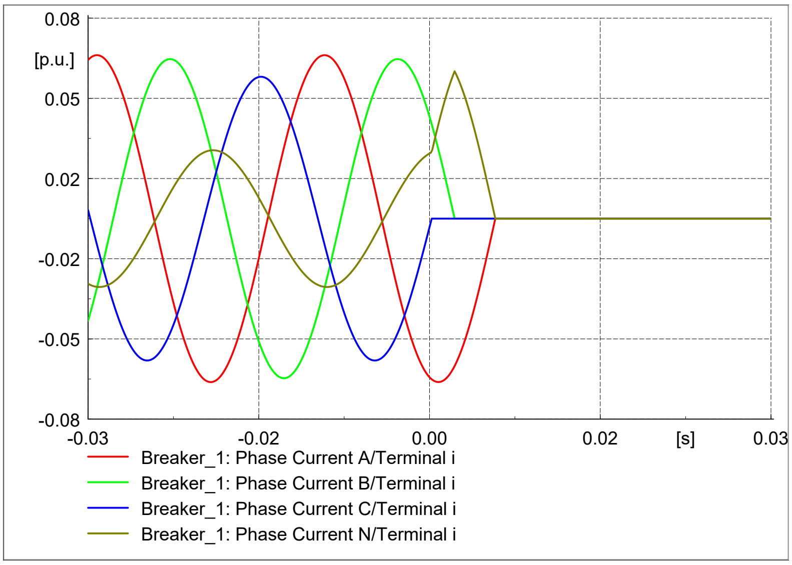

Figure 5.3: Open at current zero crossing without delays.

- Simulation EMT: Scatter phase a = 2 ms; Scatter phase b = 0 ms; Scatter phase c = 0 ms; Scatter neutral = 0 ms;

TypSwitch:

- Basic data: Breaker opening time = 0.001 s;

EvtSwitch:

- Basic data: Execution Time = 0 s; Action = Open; All phases = false; Phase a = true; Phase b = false; Phase c = true; Neutral = false;
- Simulation EMT: Trigger opening at = Current zero crossing; Scheme = Phases evaluated separately;

5.3.2.2 Simulation

The simulation outcome is shown in Fig. 5.4. The event is executed at $t = 0$ s. Because of the delay, phases do not close exactly at their zero crossing. For phase c, the delay is 1 ms, due to the 'Breaker opening time' of the TypSwitch (Scatter in ElmCoup is zero for phase c). Note that this opening also affects the current of the other phases. For phase a, the delay is the sum of 'Breaker opening time' of the TypSwitch and the Scatter of the ElmCoup (1 ms + 2 ms = 3 ms). Phase b and neutral are not included in the switch event, which is why they never open.

5.3.3 Example: Close at Voltage Threshold without Delay

The breaker is closed when the absolute voltage across phase c of the breaker exceeds a certain threshold during the negative half wave. All phases are closed simultaneously and no delays are applied.

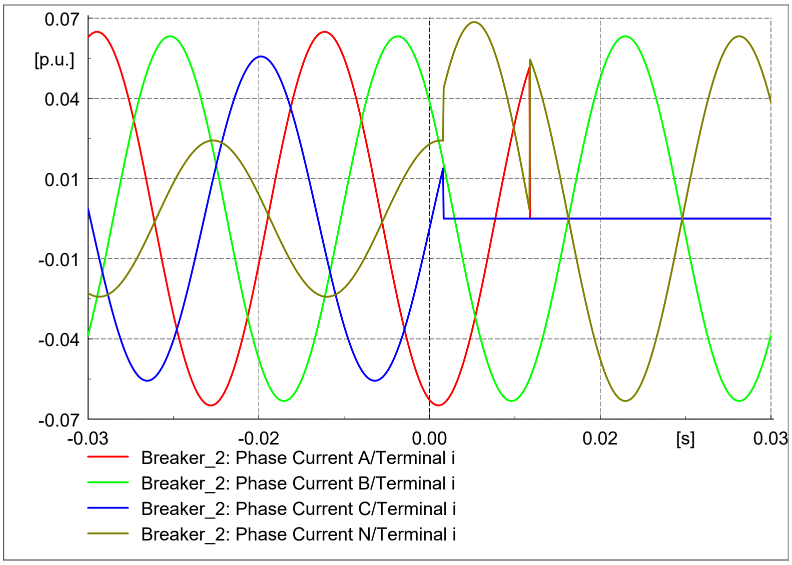

Figure 5.4: Open at current zero crossing wit delays.

5.3.3.1 Relevant Input Data

ElmCoup:

- Basic data: No. of Phases = 3; No. of Neutrals = 1; Switch interrupts neutral wire = true
- Simulation EMT: Scatter phase a = 0 ms; Scatter phase b = 0 ms; Scatter phase c = 0 ms; Scatter neutral = 0 ms;

TypSwitch:

- Basic data: Breaker opening time = 0.002 s;

EvtSwitch:

- Basic data: Execution Time = 0 s; Action = Close; All phases = true;
- Simulation EMT: Trigger opening at = Voltage threshold; Scheme = All phases simultaneously & Trigger on = phase c; Consider half wave = Negative only; Amplitude threshold = 0.635 p.u. (57 kV); Larger or lower than threshold = Larger;

5.3.3.2 Simulation

The simulation results are given in Fig. 5.5. The event is executed at $t = 0$ s. The moment the absolute value of the voltage difference between the terminals on phase c (phase that triggers) of the breaker exceeds 57 kV (i.e becomes larger than the threshold) during the negative half wave, all phases close simultaneously. Note that the non-zero 'Breaker opening time' does not affect closing events.

5.3.4 Example: Close at Voltage Maximum wit Delays for 2-phase Breaker with Neutral

The breaker has only two phases and a neutral. Note how the internal phase nomenclature of the breaker differs from the terminals. The conditions is fulfilled when the voltage of phase b reaches its maximum.

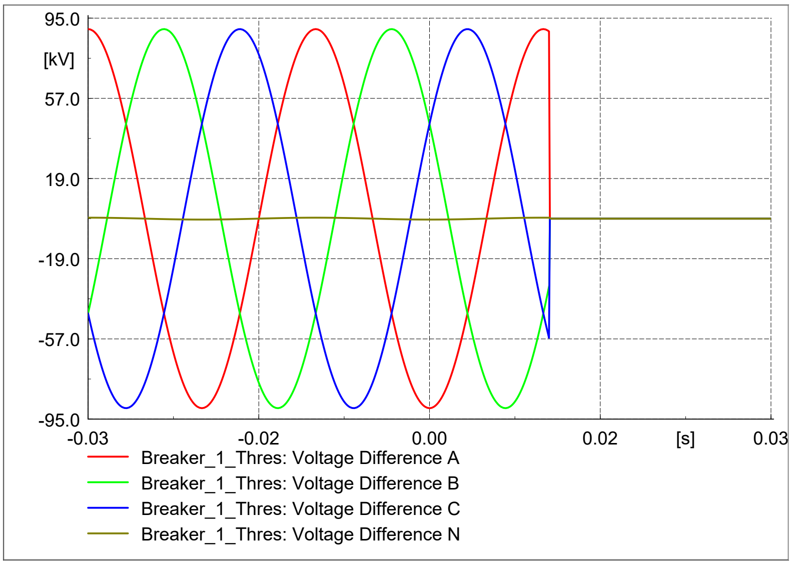

Figure 5.5: Close at voltage threshold without delays.

5.3.4.1 Relevant Input Data

ElmCoup:

- Basic data: No. of Phases = 2; No. of Neutrals = 1; Switch interrupts neutral wire = true
- Simulation EMT: Scatter phase a = 0 ms; Scatter phase b = 2 ms; Scatter neutral = 2 ms;

TypSwitch:

- Basic data: Breaker opening time = 0.002 s;

EvtSwitch:

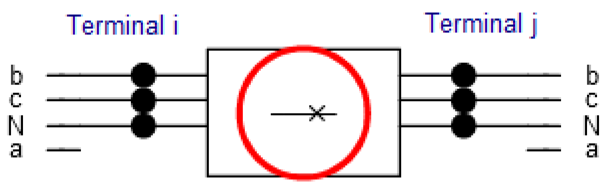

Figure 5.6: Phase connections of breaker.

- Basic data: Execution Time = 0 s; Action = Close; All phases = true;
- Simulation EMT: Trigger opening at = Voltage maximum; Scheme = Staggered Phases & Trigger on = phase b & Second phase 'a' after = 1 ms & Neutral delay = 3 ms; Consider half wave = Positive only;
- The two phases and the neutral are connected as depicted in Fig. 5.7. As described in Sec. 1.1, the breaker defines its own phase nomenclature, i.e. the phase connected to phase b of the terminals is renamed phase a and the phase that is connected to phase c is renamed phase b according to the internal nomenclature of the breaker. The name of the connected neutral is not changed.

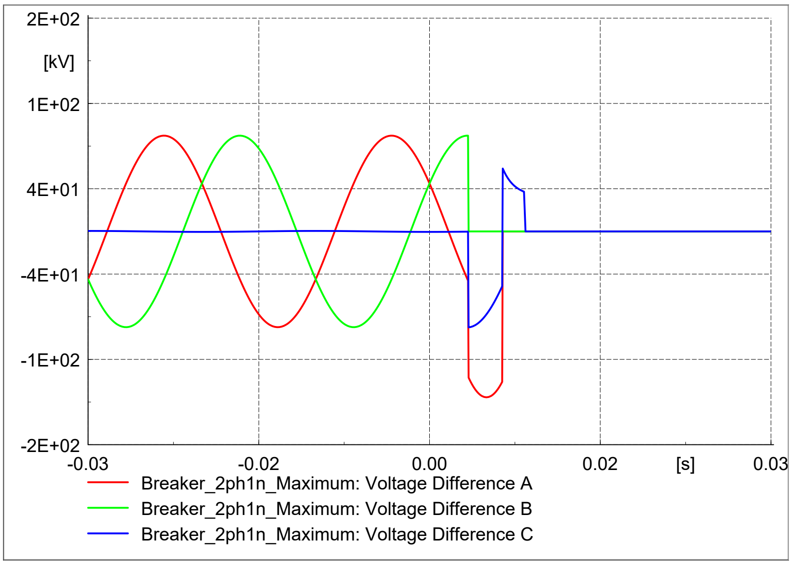

Figure 5.7: Close at voltage maximum without delays.

5.3.4.2 Simulation

The simulation results are illustrated in Fig. 5.7. The event is executed at $t = 0$ s. The closing condition is fulfilled when phase b (breaker nomenclature) reaches its maximum on the positive half wave. Phase b is then closed immediately, as it is the phase that triggers and as it has no delays. Phase a (breaker nomenclature) is closed with a delay. The delay is the sum of the delay due to the 'Scheme' of the EvtSwitch (Second phase 'a' after = 1 ms) and the 'Scatter' of the ElmCoup (Phase a = 2 ms), i.e. the accumulated delay is 3 ms. Note that the non-zero 'Breaker opening time' does not affect closing events. The neutral closes with a delay of 5 ms, which is the sum of the delay due to the 'Scheme' (Neutral delay = 3 ms) and the 'Scatter' (Neutral = 2 ms). Note that the neutral is labelled 'C' in Fig. 5.7, because of the nomenclature used in plots.

5.3.5 Example: Close at Voltage Maximum wit Delays for 3-phase breaker with neutral

Similar to the example in Sec. 5.3.4, the condition is fulfilled when the voltage of phase b reaches its maximum. However, both half waves are considered, delays are applied and the breaker has three phases and a neutral.

5.3.5.1 Relevant Input Data

ElmCoup:

- Basic data: No. of Phases = 3; No. of Neutrals = 1; Switch interrupts neutral wire = true
- Simulation EMT: Scatter phase a = 2 ms; Scatter phase b = 2 ms; Scatter phase c = 2 ms; Scatter neutral = 2 ms;

TypSwitch:

- Basic data: Breaker opening time = 0.002 s;

EvtSwitch:

- Basic data: Execution Time = 0 s; Action = Close; All phases = true;
- Simulation EMT: Trigger opening at = Voltage maximum; Scheme = Staggered Phases & Trigger on = phase b & Second phase 'c' after = 1 ms & Third phase 'a' after = 3 ms & Neutral delay = 3 ms; Consider half wave = Positive and negative;

5.3.5.2 Simulation

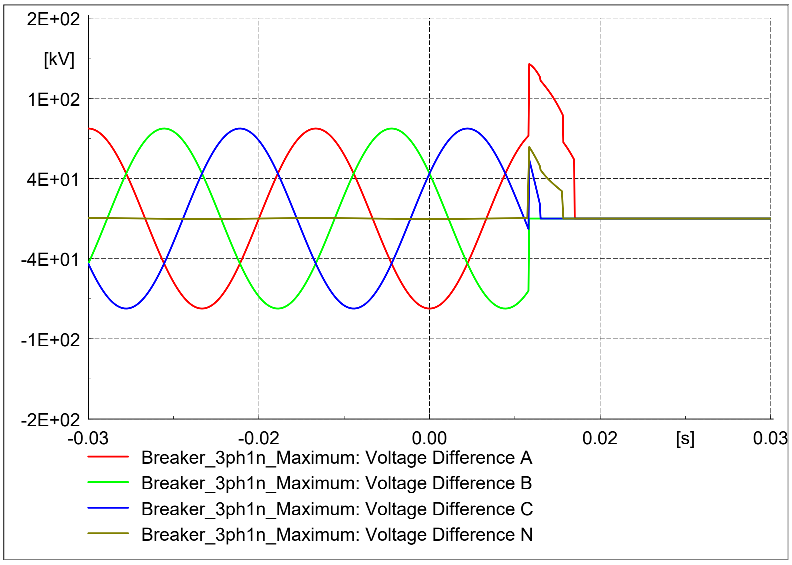

Figure 5.8: Close at voltage maximum with delays.

Simulation results are given in Fig. 5.8. The event is executed at $t = 0$ s. The condition is fulfilled for all phases when phase b reaches its maximum on th negative half wave. The 'Scatter' delays the opening of phase b by 2 ms. Next phase c is closed with a delay of 3 ms (due to stagger of 'Scheme' and 'Scatter', i.e. $1 + 2$ ms) after the condition was fulfilled. Phase a is the last in row and its delay is 6 ms (accumulated delay of phase c and a due to stagger and 'Scatter', i.e $1 + 3 + 2$ ms). The neutral is closed after 5 ms (due to stagger of 'Scheme' and 'Scatter', i.e. $3 + 2$ ms). Note that the delay of the stagger is not accumulated with the other phases. Note also that the non-zero 'Breaker opening time' does not affect closing events.

5.4 Input Parameters

Name	Unit	Description
Scatter Phase a/b/c/Neutral Switch Type	 ms -	 Delay of phase for switching events
Log TRV envelope		Log data of TRV envelope for post processing

Table 5.1: Input parameters of basic data page.

5.5 Results Variables

Name	Unit	Description
closed	-	All phases of breaker are closed
closedPh	-	Phase is closed
TRV_pos	kV	Positive TRV envelope
TRV_neg	kV	Negative TRV envelope

Table 5.2: Results variables for EMT-simulation