POWERFACTORY

PowerFactory 2021

Technical Reference

Series Capacitor

ElmScap

PF2021

POWER SYSTEM SOLUTIONS

MADE IN GERMANY

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Contents

1 General Description

PowerFactory provides both an AC and a DC series capacitor model. The AC series capacitor model may be used for various applications which require the connection of the series capacitance to an AC terminal, such as:

- Series compensation of transmission lines
- Filter capacitance

The DC series capacitor model may be used for applications which require connection to a DC terminal, such as:

- Detailed voltage source converter modelling
- FACTS controller modelling

Losses are modelled as a conductance in parallel with the capacitor.

The model uses a nonlinear resistance in parallel with the capacitance for modelling protection of series capacitances by a MOV-bypass. Under normal operating conditions, it is assumed that the parallel resistance has no influence on the capacitance. It is therefore only considered in EMT simulations.

The rated voltage and rated current (or rated power) can be specified, as well as a *Thermal Rating*. The *System Type* can be set to either *AC* or *DC* and the *Phases* to either *1* or *3*. The three-phase model is illustrated in Figure 1.1, and the single-phase model is illustrated in Figure 1.2.

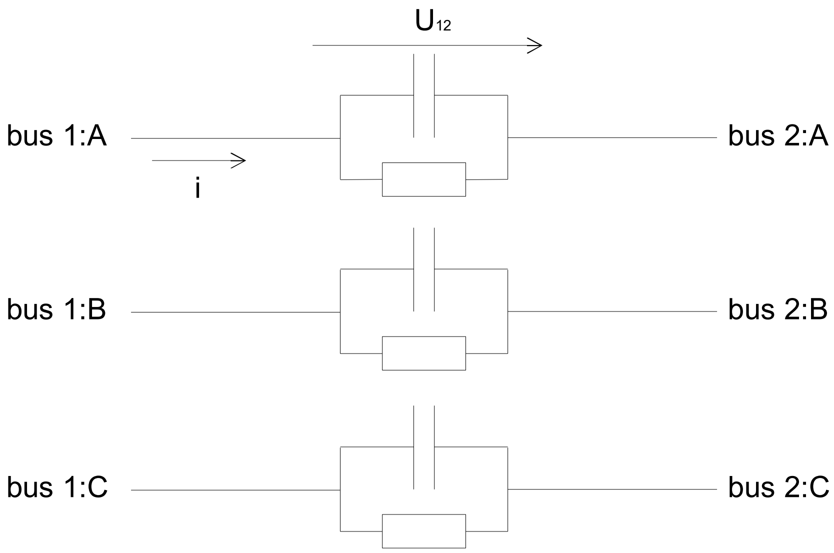

Figure 1.1: Three-phase model

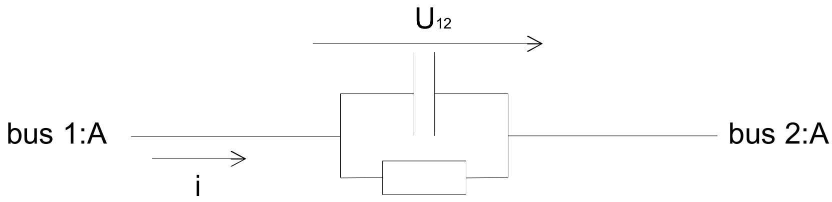

Figure 1.2: Single-phase model

1.1 Input Parameter

1.1.1 Admittance

The series capacitor is modelled with a capacitance in parallel with a conductance, representing the losses.

Capacitance The capacitance of the capacitor can be entered with different input options (only for system type: AC and AC/BI):

- Capacitance in F
- Suscepteance in S
- Reactance in Ohm

When using the three-phase model in conjunction with the *Unbalanced* option on the *Load Flow* tab of the series capacitor element dialog, the user may specify a susceptance on a per-phase basis. In this case, all balanced calculation methods are using the average capacitance of the the three phase as positive sequence capacitance $C_{cap} = 1/3(C_{a,cap} + C_{b,cap} + C_{c,cap})$.

For a DC series capacitor, only the Capacitance C in F can be entered. Other input options are not supported.

Parameter	Description	Unit	Symbol
For Balanced *option:*			
ccap	Capacitance, C	F	C_{cap}
bcap	Susceptance, B	S	B_{cap}
xcap	Reactance 1/B	Ohm	X_{cap}
For Unbalanced *option:*			
ccap_a	Capacitance, C, phase A	F	$C_{a,cap}$
ccap_b	Capacitance, C, phase B	F	$C_{b,cap}$
ccap_c	Capacitance, C, phase C	F	$C_{c,cap}$
bcap_a	Susceptance, B, phase A	S	$B_{a,cap}$
bcap_b	Susceptance, B, phase B	S	$B_{b,cap}$
bcap_c	Susceptance, B, phase C	S	$B_{c,cap}$
xcap_a	Reactance 1/B, phase A	Ohm	$X_{a,cap}$
xcap_b	Reactance 1/B, phase B	Ohm	$X_{b,cap}$
xcap_c	Reactance 1/B, phase C	Ohm	$X_{c,cap}$

Table 1.1: Suceptance, Capacitance parameter

Losses Losses in the series capacitor can be modelled as a conductance in parallel with the capacitor. The conductance is defined directly (parameter *gcap*) if the system type is DC and through the *Loss factor, tan(delta)* parameter (*tandc*) for system type AC and AC/BI. The relation between conductance used in the calculations, susceptance and loss factor is:

$$gcap = bcap \cdot tandc$$

for *Balanced* option, and:

$$gcap\_a = bcap\_a \cdot tandc$$
$$gcap\_b = bcap\_b \cdot tandc$$
$$gcap\_c = bcap\_c \cdot tandc$$

for *Unbalanced* option.

1.1.2 Zero Sequence Admittance

A zero sequence admittance can be defined through the parameters *G0/G1 ratio* and *B0/B1 ratio*. The zero sequence admittance is considered only in unbalanced calculations. The definition of the zero sequence admittance is supported only for the *Balanced* input mode option and for system type AC. The zero sequence conductance and susceptance are given as:

$$G_{0,cap} = G0toG1 \cdot G_{cap}$$
$$B_{0,cap} = B0toB1 \cdot B_{cap}$$

1.1.3 Input mode of the rating parameter

For the definition of the rating parameter there are two different input modes available:

a) Rated Voltage in kV and Rated Power in MVA

b) Rated Voltage in kV and Rated Current in kA

For a three phase capacitor the rated current is calculated as:

$$I_r = \frac{S_r}{\sqrt{3} \cdot U_r} \qquad in\ kA$$

for an AC single phase capacitor:

$$I_r = \frac{\sqrt{3} \cdot S_r}{U_r} \qquad in\ kA$$

for an AC/BI single phase capacitor:

$$I_r = \frac{2 \cdot S_r}{U_r} \qquad in\ kA$$

and for a DC single phase capacitor:

$$I_r = \frac{S_r}{U_r} \qquad in\ kA$$

where:

Parameter	**Description**	**Unit**	**Symbol**
ucn	Rated Voltage (Line-Line)	kV	U_r
Sn	Rated Power	MVA	S_r
Curn	Rated Current	kA	I_r
systp	System Type (AC, DC, AC/BI)		

Table 1.2: Rating parameter

The rated current I_r is the base for p.u. current quantities.

1.1.4 Susceptance B_{cap} $<=>$ Capacitance C_{cap} $<=>$ Reactance relation

$$B_{cap} = 2 \cdot \pi \cdot f_{nom} \cdot C_{cap}$$
$$X_{cap} = 1/B_{cap}$$

where:

- C_{cap} : Capacitance in F
- B_{cap} : Susceptance in S
- X_{cap} : Reactance in Ohm
- f_{nom} : Nominal frequency of the grid in Hz

2 Load Flow Analysis

2.1 AC Model

In all steady-state analysis functions the capacitance is modelled by its nominal frequency behaviour.

In case of a balanced load flow:

$$\underline{I}_{bus1} = (G_{cap} + jB_{cap}) \cdot \underline{U}_{12} \tag{1}$$

$$\underline{I}_{bus1} + \underline{I}_{bus2} = 0 \tag{2}$$

In case of an unbalanced load flow and with the *Balanced* input option:

$$\begin{aligned}
\underline{I}_{1,bus1} &= (G_{cap} + jB_{cap}) \cdot \underline{U}_{1,12} \\
\underline{I}_{1,bus1} + \underline{I}_{1,bus2} &= 0 \\
\underline{I}_{2,bus1} &= (G_{cap} + jB_{cap}) \cdot \underline{U}_{2,12} \\
\underline{I}_{2,bus1} + \underline{I}_{2,bus2} &= 0 \\
\underline{I}_{0,bus1} &= (G_{0,cap} + jB_{0,cap}) \cdot \underline{U}_{0,12} \\
\underline{I}_{0,bus1} + \underline{I}_{0,bus2} &= 0
\end{aligned}$$

where $\underline{I}_{1,bus1}$, $\underline{I}_{2,bus1}$ and $\underline{I}_{0,bus1}$ are the positive, negative and zero sequence current at bus 1; $\underline{I}_{1,bus2}$, $\underline{I}_{2,bus2}$ and $\underline{I}_{0,bus2}$ are the positive, negative and zero sequence current at bus 2; $\underline{U}_{1,12}$, $\underline{U}_{2,12}$ and $\underline{U}_{0,12}$ are the positive, negative and zero sequence voltage difference between bus 1 and bus 2.

In case of an unbalanced load flow and with the *Unbalanced* input option:

$$\begin{aligned}
\underline{I}_{a,bus1} &= (G_{a,cap} + jB_{a,cap}) \cdot \underline{U}_{a,12} \\
\underline{I}_{b,bus1} &= (G_{b,cap} + jB_{b,cap}) \cdot \underline{U}_{b,12} \\
\underline{I}_{c,bus1} &= (G_{c,cap} + jB_{c,cap}) \cdot \underline{U}_{c,12} \\
\underline{I}_{a,bus1} + \underline{I}_{a,bus2} &= 0 \\
\underline{I}_{b,bus1} + \underline{I}_{b,bus2} &= 0 \\
\underline{I}_{c,bus1} + \underline{I}_{c,bus2} &= 0
\end{aligned}$$

2.1.1 Calculation Quantities

Loading

The loading of the capacitor 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 capacitor for terminal 1 in kA
- $I_{nom(bus2)}$ is nominal current of the capacitor 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 capacitor $I_{nom(bus1)} = I_{nom(bus2)} = I_r$ (see 1.1.3).

If a thermal rating object is used, the nominal currents are calculated using the parameter $ContRating$ and $U_{n(bus1)}$, $U_{n(bus2)}$ (nominal voltage in kV of the connected terminal 1 and 2) as:

- if the continuous rating is entered in MVA:
  - 3-phase capacitor:

$$I_{nom(bus1)} = ContRating/\left(\sqrt{3} \cdot U_{n(bus1)}\right) \qquad [kA]$$
$$I_{nom(bus2)} = ContRating/\left(\sqrt{3} \cdot U_{n(bus2)}\right) \qquad [kA]$$

  - AC single phase capacitor:

$$I_{nom(bus1)} = ContRating \cdot \sqrt{3}/U_{n(bus1)} \qquad [kA]$$
$$I_{nom(bus2)} = ContRating \cdot \sqrt{3}/U_{n(bus2)} \qquad [kA]$$

  - AC/BI single phase capacitor:

$$I_{nom(bus1)} = ContRating \cdot 2/U_{n(bus1)} \qquad [kA]$$
$$I_{nom(bus2)} = ContRating \cdot 2/U_{n(bus2)} \qquad [kA]$$

- if the continuous rating is entered in kA:

$$I_{nom(bus1)} = I_{nom(bus2)} = ContRating \qquad [kA]$$

- if the continuous rating is entered in %:

$$I_{nom(bus1)} = I_{nom(bus2)} = ContRating/100 \cdot I_r \qquad [kA]$$

The nominal currents are generally the same ($I_{nom(bus1)} = I_{nom(bus2)}$), but not if the reactor is connected between different voltage levels ($U_{n(bus1)} \neq U_{n(bus2)}$).

For an unbalanced load flow calculation the highest current of all phases is used.

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

Voltage Drop

Quantity	Unit	Description	Value
du	$p.u.$	Voltage Drop	$= \lvert\underline{u}_{bus1}\rvert - \lvert\underline{u}_{bus2}\rvert$
$dupc$	$\%$	Voltage Drop	$= du \cdot 100$
$dphiu$	deg	Voltage Drop Angle	$= \phi_{u,bus1} - \phi_{u,bus2}$
$du1$	$p.u.$	Positive Sequence Voltage Drop	$= \lvert\underline{u1}_{bus1}\rvert - \lvert\underline{u1}_{bus2}\rvert$
$du1pc$	$\%$	Positive Sequence Voltage Drop	$= du1 \cdot 100$
$dphiu1$	deg	Positive Sequence Voltage Drop Angle	$= \phi_{u1,bus1} - \phi_{u1,bus2}$

Table 2.2: Voltage Drop Quantities, AC-model

where u_{bus1} and u_{bus2} are the amplitudes of the corresponding terminal voltage in p.u. based on the rated voltage of the terminal. $\phi_{u,bus1}$ and $\phi_{u,bus2}$ the terminal voltage angle in deg. For an unbalanced load flow du, $dupc$, and $dphiu$ are available per phase (e.g. $c:dupc:B$).

2.2 AC model for linear DC Load Flow

Only the 3-phase series capacitor is considered for the DC Load Flow:

$$(\phi_{bus1} - \phi_{bus2})/X_{cap} = P_{bus1}$$
$$P_{bus1} + P_{bus2} = 0$$

where $X_{cap} = -1/B_{cap}$ and ϕ_{bus1} is the voltage angle on terminal i, ϕ_{bus1} angle on terminal j.

2.2.1 Calculation Quantities

Loading

The loading of the reactor is calculated as follows:

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

where:

- P_{bus1} : Active power at terminal 1
- P_{bus2} : Active power at terminal 2
- $P_{nom(bus1)}$: Nominal power at terminal 1
- $P_{nom(bus2)}$: Nominal power at terminal 2

The nominal power is determined as follow when no thermal rating object is defined:

- $P_{nom(bus1)} = \sqrt{3} \cdot U_{n(bus1)} \cdot I_r$

- $P_{nom(bus2)} = \sqrt{3} \cdot U_{n(bus2)} \cdot I_r$

with the rated current of the capacitor I_r (see 1.1.3).
$U_{n(bus1)}$, $U_{n(bus2)}$ is the nominal voltage in kV of the connected terminals.

If a thermal rating object is used, the nominal power is calculated using the parameter $ContRating$ and $U_{n(bus1)}$ and $U_{n(bus2)}$ (nominal voltage in kV of the connected terminal 1 and 2) as:

- if the continuous rating is entered in MVA:

$$P_{nom(bus1)} = P_{nom(bus2)} = ContRating \qquad [MW]$$

- if the continuous rating is entered in kA:

$$\begin{aligned} P_{nom(bus1)} &= \sqrt{3} \cdot U_{n(bus1)} \cdot ContRating \qquad [MW] \\ P_{nom(bus2)} &= \sqrt{3} \cdot U_{n(bus2)} \cdot ContRating \qquad [MW] \end{aligned}$$

- if the continuous rating is entered in %:

$$\begin{aligned} P_{nom(bus1)} &= \sqrt{3} \cdot U_{n(bus1)} \cdot ContRating/100 \cdot I_r \qquad [MW] \\ P_{nom(bus2)} &= \sqrt{3} \cdot U_{n(bus2)} \cdot ContRating/100 \cdot I_r \qquad [MW] \end{aligned}$$

The nominal powers are generally the same ($P_{nom(bus1)} = P_{nom(bus2)}$), but not if the reactor is connected between different voltage levels ($U_{n(bus1)} \neq U_{n(bus2)}$).

Losses

Losses are not calculated in the linear DC Load Flow.

2.3 DC Model

Under DC-conditions, a capacitance represents an open-circuit, hence:

$$I_{bus1} = G_{cap} \cdot U_{12} \tag{3}$$

2.3.1 Calculation Quantities

Loading

The loading of the capacitor 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 capacitor for terminal 1 in kA
- $I_{nom(bus2)}$ is nominal current of the capacitor 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 capacitor $I_{nom(bus1)} = I_{nom(bus2)} = I_r$ (see 1.1.3).

If a thermal rating object is used, the nominal currents are calculated using the parameter $ContRating$ and $U_{n(bus1)}$, $U_{n(bus2)}$ (nominal voltage in kV of the connected terminal 1 and 2) as:

- if the continuous rating is entered in MVA:

$$I_{nom(bus1)} = ContRating/U_{n(bus1)} \qquad [kA]$$
$$I_{nom(bus2)} = ContRating/U_{n(bus2)} \qquad [kA]$$

- if the continuous rating is entered in kA:

$$I_{nom(bus1)} = I_{nom(bus2)} = ContRating \qquad [kA]$$

- if the continuous rating is entered in %:

$$I_{nom(bus1)} = I_{nom(bus2)} = ContRating/100 \cdot I_r \qquad [kA]$$

The nominal currents are generally the same ($I_{nom(bus1)} = I_{nom(bus2)}$), but not if the reactor is connected between different voltage levels ($U_{n(bus1)} \neq U_{n(bus2)}$).

Losses

The losses are calculated according to Table 2.1.

3 Short-Circuit Analysis

3.1 AC Model

In all steady-state analysis functions the capacitance is modelled by its nominal frequency behaviour as described by (2).

The series capacitor is bypassed for the calculation of the R/X ratio in the following cases:

- When the equivalent frequency method is used by the calculation (see ***Note*** below).
- When using the *ANSI* method:
    1. If the parameter *X/R Calculation* on the *Advanced Options* tab (as shown in the Short-Circuit command dialog in Figure 3.1) is set to *Separate R and X*;
    2. If the parameter *X/R Calculation* on the *Advanced Options* tab is set to *complex*, then the bypassing is dependent upon the setting of the *Bypass Series Capacitance* option, explained in item 3., below;
    3. If the parameter *Bypass Series Capacitance* (also on the *Advanced Options* tab) is set to:

- *All currents*
- *LV & Interrupting & 30 cycle current* (bypass only in calculation of these kinds of current values)
- *30 cycle currents* (bypass only in calculation of these kinds of current values)

Note: the equivalent frequency method is used by the calculation when the user has selected the *Method* on the *Basic Options* tab of the Short-Circuit command to be one of:

- *VDE0102* or *IEC60909* and has set the *Using Method* option (on the *Advanced Options* tab) for the calculation of the peak short-circuit current, ip, to either *C(1)* or *C(012)*; and the peak breaking current, ib, to *C* or *C'*; or
- *complete* and has set the *Using Method* option (on the *Advanced Options* tab) for the calculation of the peak short-circuit current, ip, the peak breaking current, ib, and the dc short-circuit current, idc, to either *C(1)* or *C(012)*.

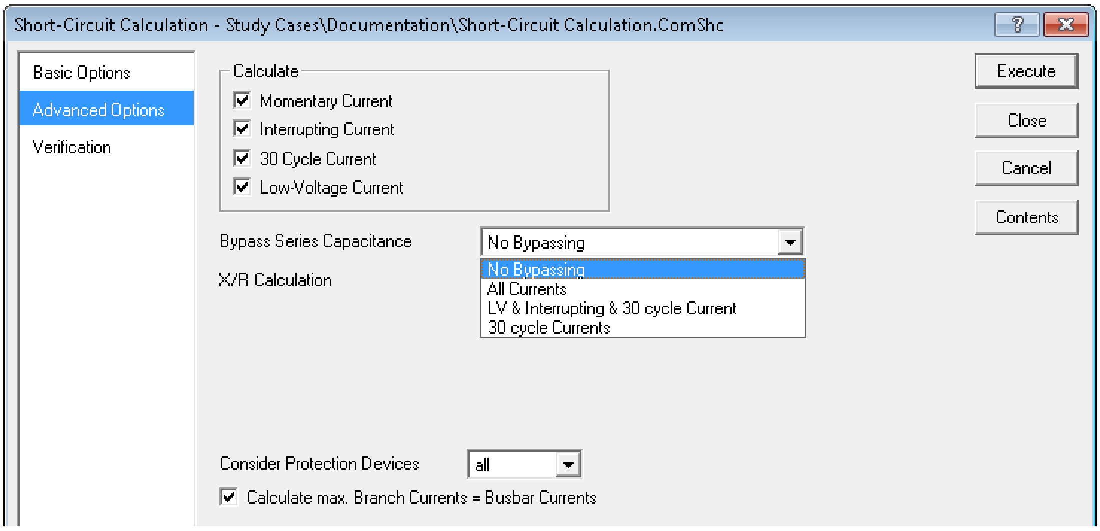

Figure 3.1: ANSI Short-Circuit calculation (*Advanced Options* tab)

4 RMS-Simulation

4.1 AC Model

The RMS-simulation and the Load Flow calculation both use the same circuit model representation of the series capacitance. Please refer to Section 2.1.

4.2 DC Model

In DC circuits, network transients are taken into consideration. The series capacitance is therefore modelled by the differential equation of a capacitance and a conductance in parallel:

$$i(t) = G \cdot u_{12}(t) + C \cdot \frac{du_{12}(t)}{dt} \tag{4}$$

5 EMT-Simulation

5.1 AC Model

5.1.1 Without Metal Oxide Varistor Protection

For EMT simulation, without any Metal Oxide Varistor (MOV) protection, the series capacitance is modelled by the differential equation of a capacitance and a conductance in parallel:

$$i(t) = G \cdot u_{12}(t) + C \cdot \frac{du_{12}(t)}{dt} \tag{5}$$

5.1.2 With Metal Oxide Varistor Protection

When the option *Metal Oxide Varistor* is selected, a nonlinear resistance can be defined which represents the protection of series capacitances by the MOV. The nonlinear resistance is entered by a voltage-current characteristic table. The entire characteristic is then approximated using cubic splines. The corresponding equivalent circuit diagram is shown in Figure 5.1. An example of a typical MOV characteristic is shown in Figure 5.2.

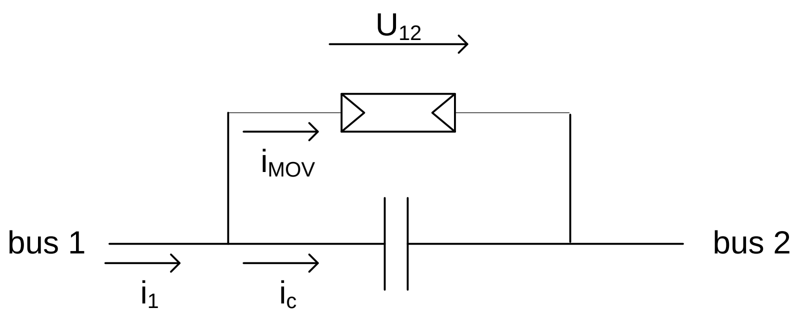

Figure 5.1: Series capacitance with MOV protection. The parallel conductance, not shown in the figure, is also included in the model

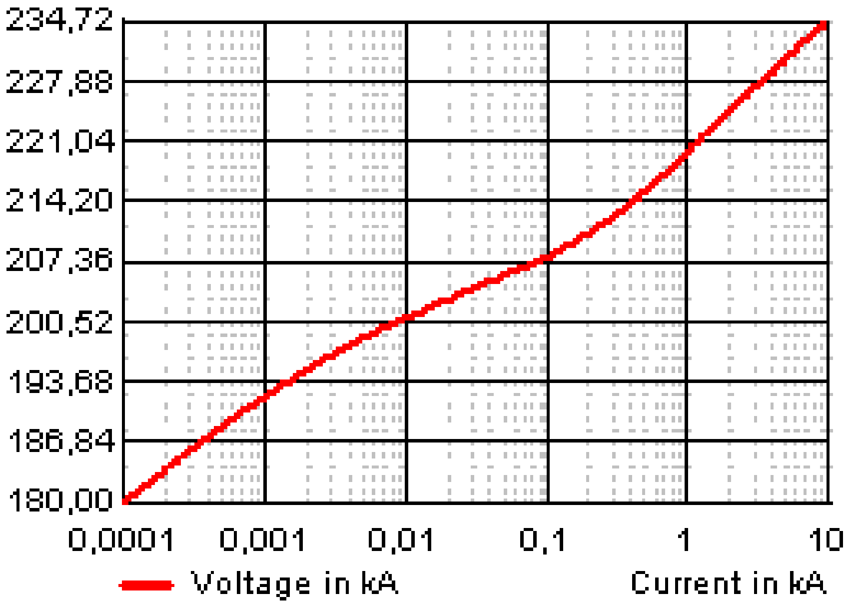

Figure 5.2: Typical MOV characteristic

The model equations of the series capacitance with MOV protection are:

$$i_{MOV}(t) = f(u_{12}(t)) \tag{6}$$

$$i_c(t) = G \cdot u_{12} + C \cdot \frac{du_{12}}{dt} \tag{7}$$

$$i_1 = i_{MOV} + i_c \tag{8}$$

The dissipated MOV energy is calculated as follows:

$$p_{MOV}(t) = i_{MOV}(t) \cdot u_{MOV}(t) \tag{9}$$

$$E_{MOV}(t) = \int_{tstart}^{t} p_{MOV}(\tau) d\tau \tag{10}$$

5.1.3 Spark Gap

The series capacitor model for EMT simulations allows the definition of a protection spark gap, via the selection of the *Spark Gap* option. Once this option is selected, the resistance and reactance of the damping circuit can be defined. The spark gap model with optional parallel MOV surge arrester is shown in Figure 5.3.

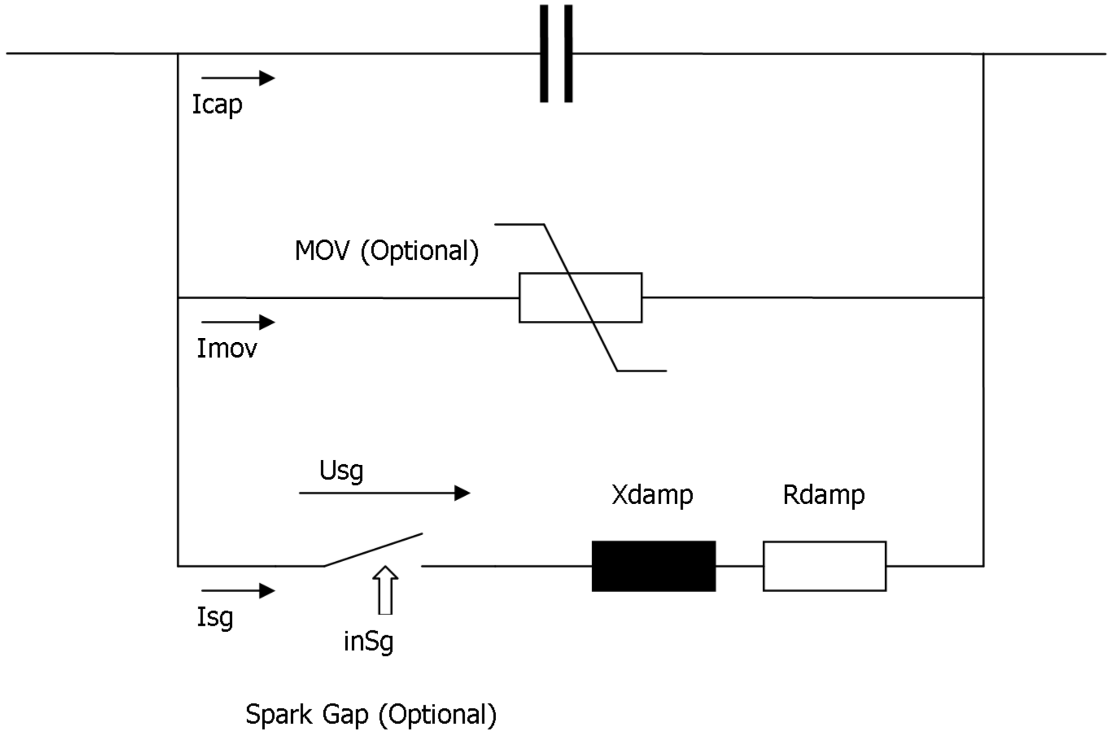

Figure 5.3: Spark gap model. The parallel conductance, not shown in the figure, is also included in the model

External Tripping
When the option *Built-In Tripping Unit* is deactivated, the spark gap can be triggered via the use of input signals *inSg_A*, *inSg_B* and *inSg_C* (defined in Table A.1) using either a parameter event (*EvtParam*) defined for the EMT simulation, or via an external DSL controller. The surge arrester is described in detail in the *PowerFactory* Surge Arrester Technical Reference document.

Built-In Tripping Unit
By activating the option *Built-In Tripping Unit*, it is possible to specify when to trigger the spark gap, according to any of the following thresholds:

- Trip when Current value is above the specified value in kA
- Trip when Voltage value is above the specified value in kV. Available only for option *Metal Oxide Varistor* **deactivated**.
- Trip when Energy value is above the specified value in MW. Available only for option *Metal Oxide Varistor* **selected**.
- Trip when Power value is above the specified value in MW. Available only for option *Metal Oxide Varistor* **selected**.

Concurrent Tripping
The triggering of the models can be done concurrently by the built-in tripping conditions as well as by using the external signals.

5.2 DC Model

In DC systems, the EMT model is identical to the RMS model. The DC model does not consider nonlinear resistance.

6 Harmonics/Power Quality

6.1 Frequency-Dependent Characteristics

If the *Balanced* input option is used, frequency-dependent characteristics may be defined for the capacitance C ($ccap$), conductance G and zero sequence capacitance and conductance. If the *Unbalanced* input option is used, frequency-dependent characteristics may be defined for the capacitance C per-phase ($ccap\_a$, $ccap\_b$ and $ccap\_c$) and conductance per-phase.

Note: For absolute characteristics, the values defined in the element (not in the characteristic) will be used at the fundamental frequency. In addition, for an *Unbalanced* capacitor, only *relative* characteristics may be defined (i.e. not characteristics which are set to use *absolute* values).

The B_{cap} and G_{cap} used in the harmonics studies are calculated depending on the defined characteristic in case of *Balanced* input option as:

$$\begin{aligned}
B_{cap}(\omega_n \cdot h) &= f(ccap, \omega_n \cdot h) \\
G_{cap}(\omega_n \cdot h) &= f(bcap \cdot tandc, \omega_n \cdot h) \\
B_{0,cap}(\omega_n \cdot h) &= f(B_{cap}(\omega_n) \cdot B0toB1, \omega_n \cdot h) \\
G_{0,cap}(\omega_n \cdot h) &= f(G_{cap}(\omega_n) \cdot G0toG1, \omega_n \cdot h)
\end{aligned}$$

and in case of *Unbalanced* input option as:

$$\begin{aligned}
B_{a,cap}(\omega_n \cdot h) &= f(ccap_a, \omega_n \cdot h) \\
G_{a,cap}(\omega_n \cdot h) &= f(bcap_a \cdot tandc, \omega_n \cdot h) \\
B_{b,cap}(\omega_n \cdot h) &= f(ccap_b, \omega_n \cdot h) \\
G_{b,cap}(\omega_n \cdot h) &= f(bcap_b \cdot tandc, \omega_n \cdot h) \\
B_{c,cap}(\omega_n \cdot h) &= f(ccap_c, \omega_n \cdot h) \\
G_{c,cap}(\omega_n \cdot h) &= f(bcap_c \cdot tandc, \omega_n \cdot h)
\end{aligned}$$

where ω_n is the nominal fundamental frequency of the corresponding grid and h is the harmonic order.

In case of *Balanced* input option, the equations are:

$$\begin{aligned}
\underline{I}_{1,bus1} &= (G_{cap}(\omega_n \cdot h) + jB_{cap}(\omega_n \cdot h)) \cdot \underline{U}_{1,12} \\
I_{1,bus1} + I_{1,bus2} &= 0 \\
\underline{I}_{2,bus1} &= (G_{cap}(\omega_n \cdot h) + jB_{cap}(\omega_n \cdot h)) \cdot \underline{U}_{2,12} \\
I_{2,bus1} + I_{2,bus2} &= 0 \\
\underline{I}_{0,bus1} &= (G_{0,cap}(\omega_n \cdot h) + jB_{0,cap}(\omega_n \cdot h)) \cdot \underline{U}_{0,12} \\
I_{0,bus1} + I_{0,bus2} &= 0
\end{aligned}$$

In case of *Unbalanced* input option the equations are:

$$
\begin{aligned}
\underline{I}_{a,bus1} &= (G_{a,cap}(\omega_n \cdot h) + jB_{a,cap}(\omega_n \cdot h)) \cdot \underline{U}_{a,12} \\
\underline{I}_{b,bus1} &= (G_{b,cap}(\omega_n \cdot h) + jB_{b,cap}(\omega_n \cdot h)) \cdot \underline{U}_{b,12} \\
\underline{I}_{c,bus1} &= (G_{c,cap}(\omega_n \cdot h) + jB_{c,cap}(\omega_n \cdot h)) \cdot \underline{U}_{c,12} \\
\underline{I}_{a,bus1} + \underline{I}_{a,bus2} &= 0 \\
\underline{I}_{b,bus1} + \underline{I}_{b,bus2} &= 0 \\
\underline{I}_{c,bus1} + \underline{I}_{c,bus2} &= 0
\end{aligned}
$$

A Signals Definitions

Table A.1: Internal signals (EMT-Simulation)

Variable	Unit	I/O	Description	Symbol
Emov_a	MWs	STATE	MOV absorbed energy	
Emov_b	MWs	STATE	MOV absorbed energy	
Emov_c	MWs	STATE	MOV absorbed energy	
inSg_A		IN	Spark Gap	
inSg_B		IN	Spark Gap	
inSg_C		IN	Spark Gap	

B Parameter Definitions

Table B.1: Input parameters for series capacitor element

Parameter	Unit	Default Value	Description	Range	Symbol
loc_name			Name		
bus1			Terminal i (StaCubic)		
bus1_bar			Terminal i		
bus2			Terminal j (StaCubic)		
bus2_bar			Terminal j		
iZoneBus		0	Zone		
cpZone			Zone		
iAreaBus		0	Area		
cpArea			Area		
outserv		0	Out of Service	x≥0 and x≤1	
ucn	kV	1,	Ratings: Rated Voltage	x≥0	
Sn	MVA	1,732051	Ratings: Rated Power	x>0	
Curn	kA	1,	Ratings: Rated Current	x>0	
pRating			Thermal Rating (IntThrating)		
systp		AC	System Type	AC:DC	
nphases		3	Phases	1:3	
Inom	kA	1,	Rated Current		
i_sym		0	Balanced/Unbalanced	x=0 or x=1	
ccap	F	0,	Value: Capacitance, C	x≥0	C
bcap	S	0,	Value: Susceptance, B	x≥0	
xcap	Ω	0,	Value: Reactance 1/B	x≥0	
tandc		0,	Value: Loss Factor, tan(delta)	x≥0	
gcap	S	0,	Value: Conductance, G	x≥0	
bcap_a	S	0,	Value / Phase A: Susceptance, B	x≥0	
ccap_a	F	0,	Value / Phase A: Capacitance, C	x≥0	
xcap_a	Ω	#INF	Value / Phase A: Reactance 1/B	x≥0	
bcap_b	S	0,	Value / Phase B: Susceptance, B	x≥0	
ccap_b	F	0,	Value / Phase B: Capacitance, C	x≥0	
xcap_b	Ω	#INF	Value / Phase B: Reactance 1/B	x≥0	
bcap_c	S	0,	Value / Phase C: Susceptance, B	x≥0	
ccap_c	F	0,	Value / Phase C: Capacitance, C	x≥0	

xcap_c	Ω	#INF	Value / Phase C: Reactance 1/B	x≥0	
B0toB1		1,	Value: B0/B1 ratio	x≥0	
G0toG1		1,	Value: G0/G1 ratio	x≥0	
maxload	%	100,	Thermal Loading Limit: Max. Loading	x≥0	
iSparkGap		0	Spark Gap	x=0 or x=1	
Rdamp	Ω	0,	Spark Gap Damping Circuit: Resistance	x≥0	Rdamp
Xdamp	Ω	0,	Spark Gap Damping Circuit: Reactance	x≥0	Xdamp
i_enter		0	Metal Oxide Varistor	x=0 or x=1	
Im	kA	0,	Current		I_{MOV}
Vm	kV	0,	Voltage		

Table B.2: Input parameters for series capacitor element

Parameter	**Unit**	**Default Value**	**Description**	**Range**	**Symbol**
iInterPol		0	Interpolation	spline:-piecewise linear	
smoothfac	%	10,	Smoothing Factor	x≥0.0 and x≤100.0	
gnrl_modif		01.01.1970 01:00:00	Object modified		
gnrl_modby			Object modified by		
sernum			Serial Number		
manuf			Manufacturer		
constr		0	Year of Construction		
iComDate		01.01.1970 01:00:00	Commissioning Date		
chr_name			Characteristic Name		
for_name			Foreign Key		
dat_src		MAN	Data source		
doc_id			Additional Data ()		
pOwner			Owner (ElmOwner)		
pOperator			Operator (ElmOperator)		
desc			Description		
appr_status		Not Approved	Approval Information: Status		
appr_modif		01.01.1970 01:00:00	Approval Information: Modified		
appr_modby			Approval Information: Modified by		
cimRdfId			RDF ID		

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