POWERFACTORY

PowerFactory 2021

Technical Reference

Series Reactor

ElmSind

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

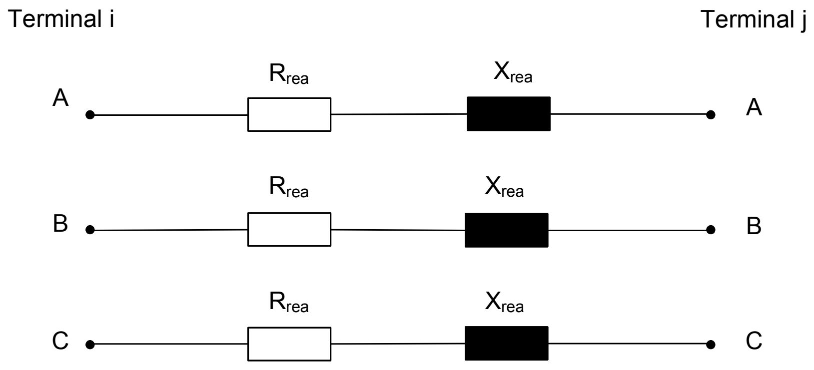

Figure 1.1: Three Phase Model

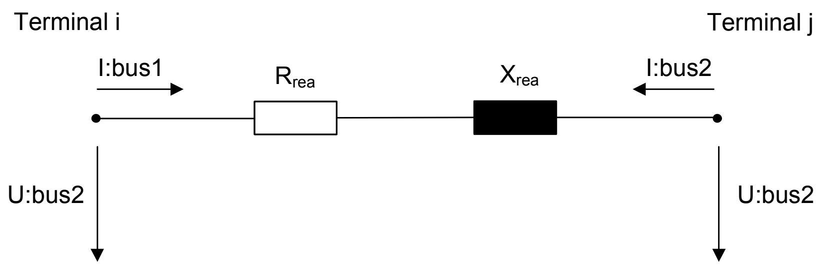

Figure 1.2: Single Phase Model

The series reactor can be used to limit the short-circuit current.

A three phase and single phase model is available.

1.1 Input Parameter

The positive sequence resistance and the reactance of the reactor can be entered at different input options (only for system type: AC and AC/BI):

- Short-circuit voltage *uk* in % and copper losses in kW or real part of the short-circuit voltage in %
- Impedance (magnitude) in Ohm and copper losses in kW or real part of the short-circuit voltage in %
- Reactance X and Resistance R in Ohm
- Inductance L in mH and Resistance in Ohm

The negative sequence impedance is equal to the positive sequence one.

For the three-phase model, the zero sequence impedance can be defined through the *R0toR1* and *X0toX1* parameters.

For a DC series reactor, only the Inductance L in mH and Resistance in Ohm can be entered. Other input options are not supported.

Parameter	Description	Unit	Symbol
xrea	Reactance, X	Ohm	X_{rea}
lrea	Inductance, L	mH	L_{rea}
rrea	Resistance, R	Ohm	R_{rea}
Zd	Impedance (absolute) Zd	Ohm	Z_{rea}
uk	Short-Circuit Voltage uk	%	uk
ukr	Short-Circuit Voltage (Re(uk)) ukr	%	ukr
Pcu	Copper Losses	kW	P_{cu}

Table 1.1: Impedance parameter

1.1.1 Input mode of the rating parameter

For the definition of the rating parameter they 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 reactor is the rated current calculated as:

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

for an AC single phase reactor:

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

for an AC/BI single phase reactor:

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

and for a DC single phase reactor:

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

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.

1.1.2 Base impedance Z_{base}

The base impedance for the short-circuit voltage is dependent on the system type and the no. of phases of the model.

Z_{base} is for a three phase reactor:

$$Z_{base} = \frac{U_r^2}{S_r} \qquad in\ Ohm$$

for an AC single phase reactor:

$$Z_{base} = \frac{U_r^2}{3 \cdot S_r} \qquad in\ Ohm$$

and for an AC/BI single phase reactor:

$$Z_{base} = \frac{U_r^2}{4 \cdot S_r} \qquad in\ Ohm$$

where:

- U_r : Rated Voltage (Line-Line) in kV
- S_r : Rated Power in MVA

1.1.3 Short-circuit voltage *uk* $<=>$ Impedance Z_{rea} relation

$$Z_{rea} = \frac{uk}{100\%} \cdot Z_{base} \qquad in\ Ohm$$

where:

- Z_{rea} : Impedance magnitude in Ohm
- uk : Short-circuit voltage in %
- Z_{base} : Base impedance in Ohm, see 1.1.2

1.1.4 Copper Losses *Pcu* $<=>$ Short-circuit voltage *ukr*, real part relation

$$ukr = \frac{P_{cu}}{S_r \cdot 1000} \cdot 100 \qquad in\ \%$$

where:

- ukr : Short-circuit voltage, real part in %
- P_{cu} : Copper Losses in kW
- S_r : Rated Power in MVA

1.1.5 Reactance X_{rea} $<=>$ Inductance L_{rea} relation

$$L_{rea} = \frac{X_{rea}}{2 \cdot \pi \cdot f_{nom}} \cdot 1000 \qquad in\ mH$$

where:

- L_{rea} : Inductance in mH
- X_{rea} : Reactance in Ohm
- f_{nom} : Nominal frequency of the grid in Hz

1.1.6 Resistance R_{rea} $<=>$ Copper Losses *Pcu* , Short-circuit voltage *ukr*, real part relation

$$R_{rea} = \frac{ukr}{100\%} \cdot Z_{base} = \frac{P_{cu}}{S_r \cdot 1000} \cdot Z_{base} \qquad in\ Ohm$$

where:

- R_{rea} : Resistance of the reactor in Ohm
- P_{cu} : Copper Losses in kW
- S_r : Rated Power of the reactor in MVA
- ukr : Short-circuit voltage, real part in %
- Z_{base} : Base impedance in Ohm, see 1.1.2

1.1.7 Reactance X_{rea} $<=>$ short-circuit voltage, *uk* and *ukr*, Impedance Z_{rea}

$$X_{rea} = \frac{\sqrt{uk^2 - ukr^2}}{100\%} \cdot Z_{base} = \sqrt{Z_{rea}^2 - R_{rea}^2} \qquad in\ Ohm$$

where:

- uk : Short-circuit voltage, magnitude in %
- ukr : Short-circuit voltage, real part in %
- Z_{rea} : Impedance magnitude in Ohm
- X_{rea} : Reactance in Ohm
- Z_{base} : Base impedance in Ohm, see 1.1.2

2 Load flow Analysis

The series reactor is completely considered in the Load Flow calculation. A warning message will be printed on the output window if the rated voltage differs more than 10% as the nominal voltage of the bus bars. An error message will be printed on the output window if the rated voltages differs more than 50%.

2.1 AC-Model

For the Load Flow calculation the reactor is modelled by its nominal frequency behaviour:

$$
\begin{aligned}
U_{bus1} - U_{bus2} &= I_{bus1} \cdot (Rrea + j \cdot Xrea) \\
I_{bus1} + I_{bus2} &= 0
\end{aligned}
$$

For an unbalanced load flow calculation, the above equations refer to the positive and negative sequence. Similar equations are valid for the zero sequence. The positive (negative) and zero sequence models of the three-phase series reactor are shown in Figures 2.1 and 2.2.

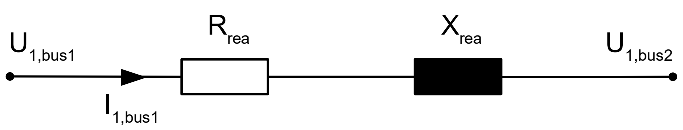

Figure 2.1: Positive and negative sequence model

Figure 2.2: Zero sequence model

The input signals *Rin* and *Xin* are available to be used with QDSL models. If these signals are connected, their value will be used in the calculations instead of *Rrea* and *Xrea*.

2.1.1 Calculation Quantities

Loading

The loading of the reactor 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 reactor for terminal 1 in kA
- $I_{nom(bus2)}$ is nominal current of the reactor 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 $I_{nom(bus1)} = I_{nom(bus2)} = I_r$ (see 1.1.1).

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 reactor:

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

  - AC single phase reactor:

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

  - AC/BI single phase reactor:

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

- 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 reactor is considered for the DC Load Flow:

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

where ϕ_{bus1} is the voltage angle on terminal 1, ϕ_{bus2} angle on terminal 2.

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 reactor I_r (see 1.1.1).
$U_{n(bus1)}, U_{n(bus2)}$ 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:

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

- if the continuous rating is entered in %:

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

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 reactor is a closed circuit, hence only the resistance is considered:

$$U_{bus1} - U_{bus2} = I_{bus1} \cdot Rrea \qquad (1)$$
$$I_{bus1} + I_{bus1} = 0 \qquad (2)$$

2.3.1 Calculation Quantities

Loading

The loading of the reactor is calculated as follows:

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

- $I_{nom(bus1)}$ is nominal current of the reactor for terminal 1 in $[kA]$
- $I_{nom(bus2)}$ is nominal current of the reactor for terminal 2 in $[kA]$
- I_{bus1} : DC current at terminal 1
- I_{bus2} : DC current at terminal 2

If no thermal rating object is defined, the nominal currents are equal to the rated current of the reactor $I_{nom(bus1)} = I_{nom(bus2)} = I_r$(see 1.1.1).

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

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

Table 2.3: Losses Quantities, DC-model

3 Short-circuit Analysis

The Short-Circuit model of the series capacitance is fully compatible to the load flow model.

4 RMS Simulation

4.1 AC-Model

The RMS-simulation model of the series reactor is fully compatible to the load flow model.

The calculation quantity $Inom$ is set according to 2.1.1. The $loading$ is calculated accordingly. The rated current as base for the p.u. current is I_r (see 1.1.1).

4.2 DC-Model

In DC circuits, network transients are considered as well. The series reactor is hence modelled by the differential equation of a resistance in series with a inductance:

$$
\begin{aligned}
U_{bus1}(t) - U_{bus2}(t) &= R_{rea} \cdot I_{bus1}(t) + L_{rea} \cdot \frac{d(I_{bus1}(t))}{dt} \\
I_{bus1} + I_{bus2} &= 0
\end{aligned}
$$

5 EMT Simulation

5.0.1 AC-Model without Saturation

The series reactor is modelled by the differential equation of a resistance in series with an inductance. However, since the positive sequence impedance is in general different than the zero sequence impedance, a coupling between the three phases exists:

$$
\begin{aligned}
U_{bus1:A}(t) - U_{bus2:A}(t) = {} & R_s \cdot I_{bus1:A}(t) + R_m \cdot I_{bus1:B}(t) + R_m \cdot I_{bus1:C}(t) + \\
& L_s \cdot \frac{d(I_{bus1:A}(t))}{dt} + L_m \cdot \frac{d(I_{bus1:B}(t))}{dt} + L_m \cdot \frac{d(I_{bus1:C}(t))}{dt}
\end{aligned}
$$

$$
\begin{aligned}
U_{bus1:B}(t) - U_{bus2:B}(t) = {} & R_m \cdot I_{bus1:A}(t) + R_s \cdot I_{bus1:B}(t) + R_m \cdot I_{bus1:C}(t) + \\
& L_m \cdot \frac{d(I_{bus1:A}(t))}{dt} + L_s \cdot \frac{d(I_{bus1:B}(t))}{dt} + L_m \cdot \frac{d(I_{bus1:C}(t))}{dt}
\end{aligned}
$$

$$
\begin{aligned}
U_{bus1:C}(t) - U_{bus2:C}(t) = {} & R_m \cdot I_{bus1:A}(t) + R_m \cdot I_{bus1:B}(t) + R_s \cdot I_{bus1:C}(t) + \\
& L_m \cdot \frac{d(I_{bus1:A}(t))}{dt} + L_m \cdot \frac{d(I_{bus1:B}(t))}{dt} + L_s \cdot \frac{d(I_{bus1:C}(t))}{dt}
\end{aligned}
$$

$$I_{bus1:A}(t) + I_{bus2:A}(t) = 0$$
$$I_{bus1:B}(t) + I_{bus2:B}(t) = 0$$
$$I_{bus1:C}(t) + I_{bus2:C}(t) = 0$$

where:

$$R_s = \frac{R_{rea} \cdot R0toR1 + 2 \cdot R_{rea}}{3}$$
$$R_m = \frac{R_{rea} \cdot R0toR1 - R_{rea}}{3}$$
$$L_s = \frac{L_{rea} \cdot L0toL1 + 2 \cdot L_{rea}}{3}$$
$$L_m = \frac{L_{rea} \cdot L0toL1 - L_{rea}}{3}$$

5.0.2 AC-Model with Saturation

The saturation of the reactance can be simulated in the EMT model.

The model supports the following options:

- Linear: no saturation considered
- Two slope: the saturation curve is approximated by a two linear slopes
- Polynomial: the saturation curve is approximated by a polynom of user-defined order. The polynom fits asymptotically into the piecewise linear definition.
- Current/Flux peak values: the user inputs current-flux peak values as a sequence of points and selects among a piecewise-linear or spline interpolation.
- Current/Voltage RMS values: the user inputs current-voltage RMS values as a sequence of points. Piecewise-linear interpolation is always used.

Linear
The input parameters are listed in Table 5.1.

Parameter	Description	Unit	Symbol
xreapu	Magnetizing reactance for unsaturated conditions. In p.u. values, the linear reactance is equal to the reciprocal of the magnetizing current (reactive part of the exciting current).	p.u.	l_{unsat}

Table 5.1: Basic data of the linear characteristic

No saturation is considered. In this case, the current is proportional to the flux:

$$i_M = \frac{\psi_M}{l_{unsat}}$$

Where:

- i_M is the magnetizing current in p.u.
- ψ_M is the magnetizing flux in p.u.

The p.u. values used for the definition of the saturation characteristic of the positive sequence model are referred to the same base quantities mentioned in 5.0.2.

Two slope
Figure 5.1 shows the magnetizing current-flux curves for the two slope and polynomial characteristics. The input parameters of the two slope saturation characteristic are listed in Table 5.2.

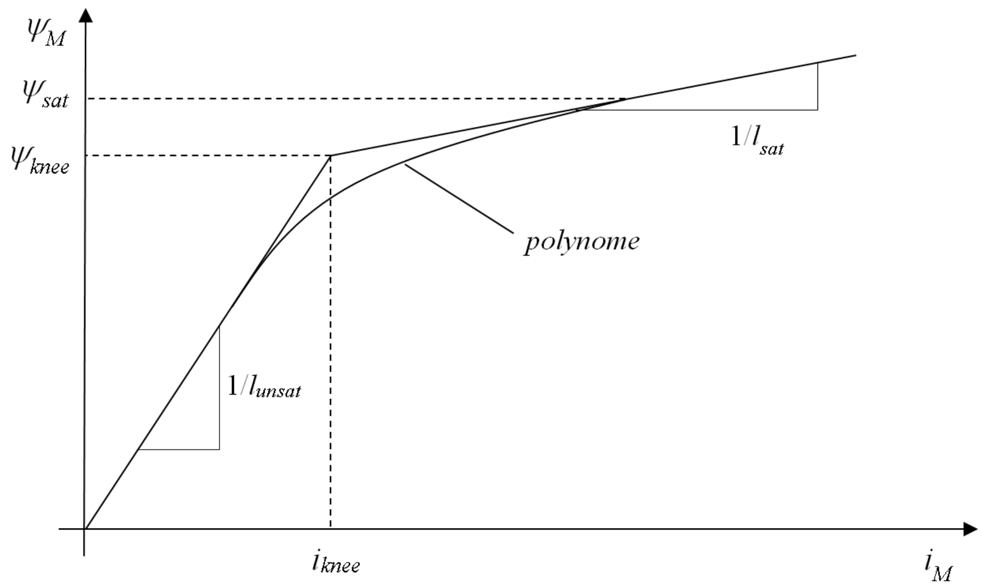

Figure 5.1: Two slope and polynomial saturation curves

Parameter	Description	Unit	Symbol
psi0	Knee-point Flux of asymptotic piece-wise linear characteristic. Typical value around 1.1 to 1.2 times the rated flux.	p.u.	ψ_{knee}
xreapu	Magnetizing reactance for unsaturated conditions. In p.u. values, the linear reactance is equal to the reciprocal of the magnetizing current (reactive part of the exciting current).	p.u.	l_{unsat}
xmair	Magnetizing reactance for saturated conditions.	p.u.	l_{sat}

Table 5.2: Basic data of the two-slope saturation characteristic

In the case of the two slope curve, the series reactor saturation is approximated by two linear slopes, which are separated by the value of the knee flux. The first slope is given by the linear reactance, while the second is given by the saturated reactance. The saturated reactance value is fairly low compared with the unsaturated reactance.

$$
\begin{aligned}
i_M &= \frac{\psi_M}{l_{unsat}} && \text{for } \psi_M \leq \psi_{knee} \\
i_M &= \frac{1}{l_{sat}}(\psi_M - \psi_{knee}) + i_{knee} && \text{for } \psi_M > \psi_{knee} \\
i_{knee} &= \frac{\psi_{knee}}{l_{unsat}}
\end{aligned}
$$

Where

- i_M is the magnetizing current in p.u.
- ψ_M is the magnetizing flux in p.u.

The p.u. values used for the definition of the saturation characteristic of the positive sequence model are referred to the same base quantities mentioned in 5.0.2.

Polynomial

Figure 5.1 shows the magnetizing current-flux curves for the polynomial characteristic. The input parameters are listed in Table 5.3.

Parameter	Description	Unit	Symbol
psi0	Knee-point Flux of asymptotic piece-wise linear characteristic. Typical value around 1.1 to 1.2 times the rated flux.	p.u.	ψ_{knee}
xreapu	Magnetizing reactance for unsaturated conditions. In p.u. values, the linear reactance is equal to the reciprocal of the magnetizing current (reactive part of the exciting current).	p.u.	l_{unsat}
xmair	Magnetizing reactance for saturated conditions.	p.u.	l_{sat}
ksat	Saturation exponent of polynomial representation. Typical values are 9,13,15. The higher the exponent the sharper the saturation curve.	-	k_{sat}

Table 5.3: Basic data of the polynomial saturation characteristic

In the polynomial type, the saturation is also represented by two linear slopes, but smoothed by a polynomial function, in which the higher the exponent is, the sharper the saturation becomes.

$$
\begin{aligned}
i_M &= \frac{\psi_M}{l_{unsat}} \cdot \left\{ 1 + \left(\frac{\psi_M}{\psi_0} \right)^{k_{sat}} \right\} && \text{for } \psi_M \leq \psi_{sat} \\
i_M &= \frac{1}{l_{sat}} (\psi_M - \psi_{sat}) + i_{knee} && \text{for } \psi_M > \psi_{sat} \\
\psi_{sat} &= \frac{k_{sat}+1}{k_{sat}} \cdot \psi_{knee} \\
i_{knee} &= \frac{\psi_{knee}}{l_{unsat}}
\end{aligned}
$$

Where

- i_M is the magnetizing current in p.u.
- ψ_M is the magnetizing flux in p.u.
- ψ_0 is a parameter automatically calculated, so that the polynomial characteristic fits the saturated reactance in full saturation and transits steadily into the piece-wise linear characteristic at the knee flux point, in p.u.

This polynomial characteristic is always inside the corresponding linear representation. In full saturation the polynomial characteristic is extended linearly. Compared to the two-slope curve, it does not contain a singular point at the knee flux and therefore its derivative (magnetizing voltage) is continuously defined.

The p.u. values used for the definition of the saturation characteristic of the positive sequence model are referred to the same base quantities mentioned in 5.0.2.

Current/Flux peak values
The user defines the saturation curve in terms of measured current-flux values and select between a *piecewise linear* or *spline* interpolation.

The current-flux values in the table are peak values in p.u.

The p.u. values used for the definition of the saturation characteristic of the positive sequence model are referred to the same base quantities mentioned in 5.0.2.

Current/Voltage RMS values
The saturation curve can also be defined in terms of measured current-voltage RMS values. With this option the user does not have to convert the RMS current values to peak values, as required in the previous option. The conversion to peak current values is handled internally in *PowerFactory* and a current-voltage peak values table is then used in the simulation.

The user can also specify a value for the final slope of the converted current-voltage peak values used in the simulation, by defining the saturated reactance. If the final slope is not defined, this is assumed to be equal to the slope of the last segment of the curve. Since the conversion between RMS and peak current values is non-linear, the slope of the last segment of the current-voltage (converted to peak values) curve is generally not known. The final slope defined by the saturated reactance is not considered if higher than the slope of the last segment of the current-voltage (converted to peak values) curve.

The current-voltage in the table are enetered by the user as RMS values in p.u.

Base Quantities
The p.u. values used for the definition of the saturation characteristic of the positive sequence model are referred to the following bases quantities:

- U_{base} in kV is the Rated Voltage of the series reactor
  - for 3-phase reactor $U_{base} =$ *ucn*
  - for AC single phase reactor $U_{base} =$ *ucn*$/\sqrt{3}$
  - for AC/BI single phase reactor $U_{base} =$ *ucn*$/2$
- S_{base} is the Rated Power of the series reactor (*Sn*) in MVA
- I_{base} in A:
  - for 3-phase reactor $I_{base} = \sqrt{2} \cdot \dfrac{S_{base}}{\sqrt{3} \cdot U_{base}} \cdot 1000$
  - for AC single phase reactor $I_{base} = \sqrt{2} \cdot \dfrac{S_{base} \cdot \sqrt{3}}{U_{base}} \cdot 1000$
  - for AC/BI single phase reactor $I_{base} = \sqrt{2} \cdot \dfrac{S_{base} \cdot 2}{U_{base}} \cdot 1000$
- Ψ_{base} in $V \cdot s$:
  - for 3-phase reactor $\Psi_{base} = \sqrt{2} \cdot \dfrac{U_{base}/\sqrt{3}}{2\pi f} \cdot 1000$
  - for AC single phase reactor $\Psi_{base} = \sqrt{2} \cdot \dfrac{U_{base}}{2\pi f} \cdot 1000$
  - for AC/BI single phase reactor $\Psi_{base} = \sqrt{2} \cdot \dfrac{U_{base}}{2\pi f} \cdot 1000$

- L_{base} in H: $L_{base} = \left(\frac{U_{base}^2}{S_{base}}\right) \cdot \frac{1}{2\pi f}$

Ignoring the Saturation

The saturation is ignored when any of the following conditions are met:

- The reactance *xrea* is zero
- It is a DC reactor
- The input signal *Xin* is connected

Considerations for 3-Limb Core

For a 3-limb core, the zero sequence flux follows a path in the air and the corresponding reactance does not saturate. Therefore, the per-phase flux values to consider for saturation are calculated solely from the $\alpha - \beta$ flux components (ψ_0 is ignored in the transformation):

$$\begin{bmatrix} \psi_{M:A} \\ \psi_{M:B} \\ \psi_{M:C} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & 1 \end{bmatrix} \times \begin{bmatrix} \psi_\alpha \\ \psi_\beta \\ 0 \end{bmatrix}$$

To the phase currents calculated given the above fluxes, a zero-sequence current component is added, given in p.u. by:

$$i_0 = \frac{\psi_0}{2\pi f \cdot l_{rea,unsat} \cdot X0toX1}$$

Considerations for 5-Limb Core

For a 5-limb core, the zero sequence flux follows the same path in the iron core as the positive sequence. Therefore, it is assumed that positive and zero sequence reactances saturate in the same way. The per-phase per unit flux values are calculated from the $\alpha - \beta$ flux components:

$$\begin{bmatrix} \psi_{M:A} \\ \psi_{M:B} \\ \psi_{M:C} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & 1 \end{bmatrix} \times \begin{bmatrix} \psi_d \\ \psi_q \\ \psi_0 \end{bmatrix}$$

The zero-sequence current in p.u. is given by:

$$i_0 = 0$$

Equations

The magnetizing currents in p.u. are calculated according to the type of saturation selected:

$$i_{M:A}(t) = f(\psi_{M:A})$$
$$i_{M:B}(t) = f(\psi_{M:B})$$
$$i_{M:C}(t) = f(\psi_{M:C})$$

The equations for voltage and current per phase in actual values are given by:

$$I_{bus1:A}(t) = (i_{M:A} + i_0) \cdot I_{base}$$
$$I_{bus1:B}(t) = (i_{M:B} + i_0) \cdot I_{base}$$
$$I_{bus1:C}(t) = (i_{M:C} + i_0) \cdot I_{base}$$
$$U_{bus1:A}(t) - U_{bus2:A}(t) = R_{rea:r} \cdot I_{bus1:A}(t) + \frac{1}{2\pi f} \cdot \frac{d(\Psi_{bus1:A}(t))}{dt}$$
$$U_{bus1:B}(t) - U_{bus2:B}(t) = R_{rea:s} \cdot I_{bus1:B}(t) + \frac{1}{2\pi f} \cdot \frac{d(\Psi_{bus1:B}(t))}{dt}$$
$$U_{bus1:C}(t) - U_{bus2:C}(t) = R_{rea:t} \cdot I_{bus1:C}(t) + \frac{1}{2\pi f} \cdot \frac{d(\Psi_{bus1:C}(t))}{dt}$$
$$I_{bus1:A}(t) + I_{bus2:A}(t) = 0$$
$$I_{bus1:B}(t) + I_{bus2:B}(t) = 0$$
$$I_{bus1:C}(t) + I_{bus2:C}(t) = 0$$

Hysteresis

Hysteresis can also be modelled whenever saturation is modelled. Please, refer to the three-phase 2-winding transformer model technical reference for further details related to modelling of hysteresis.

5.0.3 DC-Model

The series reactor is modelled by the differential equation of a resistance in series with an inductance:

$$U_{bus1}(t) - U_{bus2}(t) = R_{rea} \cdot I_{bus1}(t) + L_{rea} \cdot \frac{d(I_{bus1}(t))}{dt}$$
$$I_{bus1}(t) + I_{bus2}(t) = 0$$

6 Harmonics/Power Quality Model

Frequency-dependent characteristics may be defined for the following parameters (parameter names follow in parentheses): R ($rrea$) and L ($lrea$), R0 and L0.

If the characteristic for the zero sequence parameter R0 is not defined, the parameter is considered equal to the corresponding positive sequence parameter R (as defined through its characteristic) times R0toR1 parameter.

If the characteristic for the zero sequence parameter L0 is not defined, the parameter is considered equal to the corresponding positive sequence parameter L (as defined through its characteristic) times X0toX1 parameter.

Note: For absolute characteristics, the values defined in the element (not in the characteristic) will be used at the fundamental frequency.

where

$$R_{rea} = f(rrea, \omega_n \cdot h)$$
$$X_{rea} = f(lrea, \omega_n \cdot h)$$

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

and

$$U_{bus1} - U_{bus2} = I_{bus1} \cdot (Rrea + j \cdot Xrea)$$
$$I_{bus1} + I_{bus2} = 0$$

A Parameter Definitions

Parameter	Description	Unit
loc_name	Name	
outserv	Out of Service	
ucn	Rated voltage	kV
Sn	Rated power	MVA
Curn	Rated current	kA
pRating	Thermal rating	
systp	System type	
nphases	Phases	
uk	Short-circuit voltage	%
Zd	Absolute impedance	Ohm
lrea	Inductance	mH
xrea	Reactance	Ohm
Pcu	Copper losses	kW
ukr	Short-circuit voltage	%
rrea	Resistance	Ohm
maxLoad	Thermal load limit	%
iAstabint	A-stable integration algorithm	
psi0	Knee flux	p.u.
xmair	Saturated reactance	p.u.
ksat	Saturation exponent	
satcur	Current (peak)	p.u.
satflux	Flux (peak)	p.u.
iInterPol	Interpolation	
smoothfac	Smoothing factor	%
Inom	Rated current	kA
xreapu	Linear reactance	p.u.

Table A.1: Series Reactor Parameters

B Signal Definitions

B.0.4 AC-Model

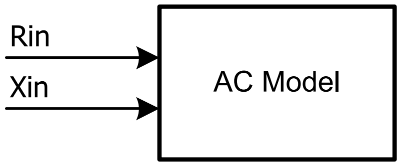

Figure B.1: Input/Output Definition of AC Series Reactor Model (RMS/EMT-Simulation)

Name	Description	Unit	Type	Model
Rin	Resistance Input	Ohm	IN	RMS, EMT
Xin	Reactance Input	Ohm	IN	RMS, EMT

Table B.1: Input/Output signals

B.0.5 DC-Model

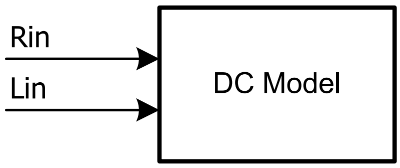

Figure B.2: Input/Output Definition of DC Series Reactor Model (RMS/EMT-Simulation)

Name	Description	Unit	Type	Model
Rin	Resistance Input	Ohm	IN	RMS, EMT
Lin	Inductance Input	H	IN	RMS, EMT

Table B.2: Input/Output signals

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