POWERFACTORY

PowerFactory 2021

Technical Reference

Filter/Shunt

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PF2021

POWER SYSTEM SOLUTIONS

MADE IN GERMANY

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1 General Description

All the internal p.u. voltages and fluxes available as result variables (such as p.u. voltage/flux of an inductor or p.u. voltage of a capacitor) are based on the busbar nominal voltage $U_{bus,nom}$, and not on the shunt element rated voltage. All internal p.u. currents available as result variables (such as p.u. current through an inductor or resistor) are based on the following base current:

$$I_{base} = \frac{1MVA}{\sqrt{3} \cdot U_{bus,nom}}$$

In case of single phase shunts (technology: 1PH PH-N and 1PH PH-E) the base of p.u. voltages is the corresponding line-ground voltage of the busbar (for system type AC/BI: $U_{bus,nom}/2$).

1.1 R-L Shunt

The R-L shunt is a reactance/inductance and a resistance in series. To define the reactance/inductance and the resistance there are two input modes:

a) Design Parameter: the parameters are defined with the rated reactive power or the rated current and a quality factor
b) Layout Parameter: the parameters are defined with the reactance or inductance and the resistance in Ohm

When the technology is 3PH-'YN', the zero sequence impedance can be defined through the *R0toR1* and *X0toX1* parameters, available on the *Zero Sequence/Neutral Conductor* tab of the *Basic Data* page.

1.1.1 Common Relations

Relation between the reactance X_{rea} and the inductance L_{rea}

The inductance L_{rea} is calculated:

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

X_{rea}: Reactance in Ohm
f_{nom}: Nominal Frequency in Hz of the grid

1.1.2 Technology: 3PH-'D'

Model

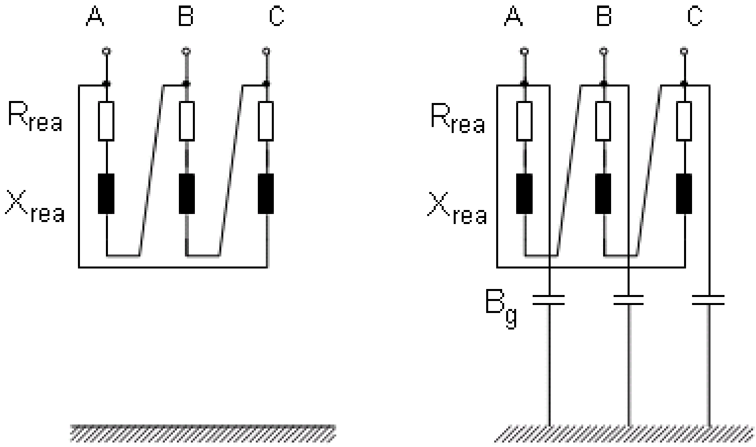

Figure 1.1: Model for the 3PH-'D' technology with and without susceptance to ground

The 3PH-'D' model is a 3-phase shunt in delta connection. Additionally it is possible to enter a susceptance to ground (Bg) in μS.

X_{rea}, R_{rea} $<$-$>$ Q_{rea} **relation**

$$X_{rea} = 3 \cdot \frac{U_r^2}{Q_{rea}} \quad and \quad R_{rea} = \frac{X_{rea}}{qf_{rea}} \qquad \text{in Ohm}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{rea}: Rated Reactive Power, L in Mvar
q_{frea}: Quality Factor (at fn, nominal frequency) for a quality factor of zero (=0) the resistance is set to zero (=0)

Q_{rea}, I_{rea} $<$-$>$ **relation**

The relation between the reactive power in Mvar of the shunt and the rated current, L in A is the following:

$$Q_{rea} = \frac{I_{rea} \cdot \sqrt{3} \cdot U_r}{1000} \qquad \text{in Mvar}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
I_{rea}: Rated Current, L in A

1.1.3 Technology: 3PH-'YN', 3PH-'Y'

Model

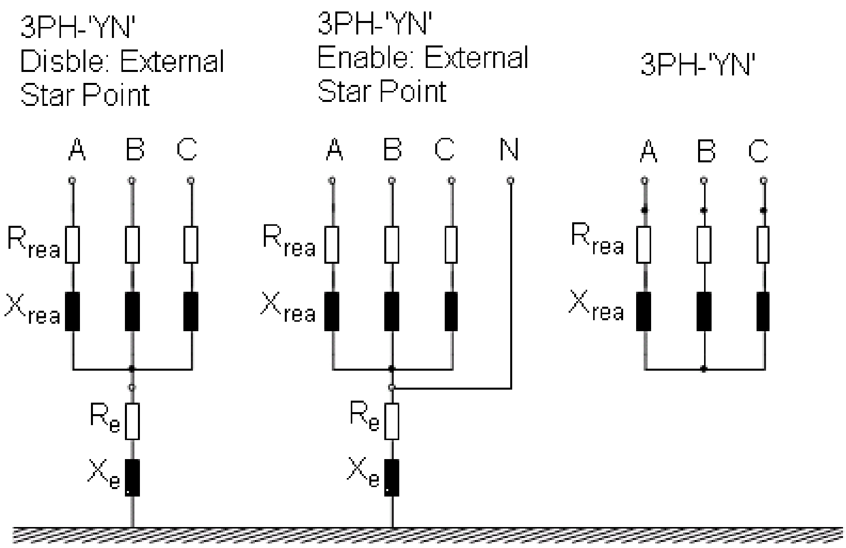

Figure 1.2: Models for the 3PH-'YN' and 3PH-'Y' technology

For the 3PH-'YN' technology it is possible to connect the star point to the neutral wire (enable option: External Star Point) and to setup if the internal grounding impedance star point is 'connected', 'connected (Petersen Coil)' or 'disconnected'. For a 'connected' star point a grounding reactance (Xe) and grounding resistance (Re) in Ohm is considered. For a 'disconnected' internal star point the grounding reactance and resistance is neglected (-> isolated star point). For the 3PH-'Y' technology it's further possible to enter a susceptance to ground (Bg) in μS.

X_{rea}, R_{rea} $<$-$>$ Q_{rea} **relation**

$$X_{rea} = 3 \cdot \frac{U_r^2}{Q_{rea}} \quad and \quad R_{rea} = \frac{X_{rea}}{qf_{rea}} \qquad \text{in Ohm}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{rea}: Rated Reactive Power, L in Mvar
q_{frea}: Quality Factor (at fn, nominal frequency) for a quality factor of zero (=0) the resistance is set to zero (=0)

Q_{rea}, I_{rea} $<$-$>$ **relation**

The relation between the reactive power in Mvar of the shunt and the rated current, L in A is the following:

$$Q_{rea} = \frac{I_{rea} \cdot \sqrt{3} \cdot U_r}{1000} \qquad \text{in Mvar}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
I_{rea}: Rated Current, L in A

1.1.4 Technology: 2PH-'YN'

Model

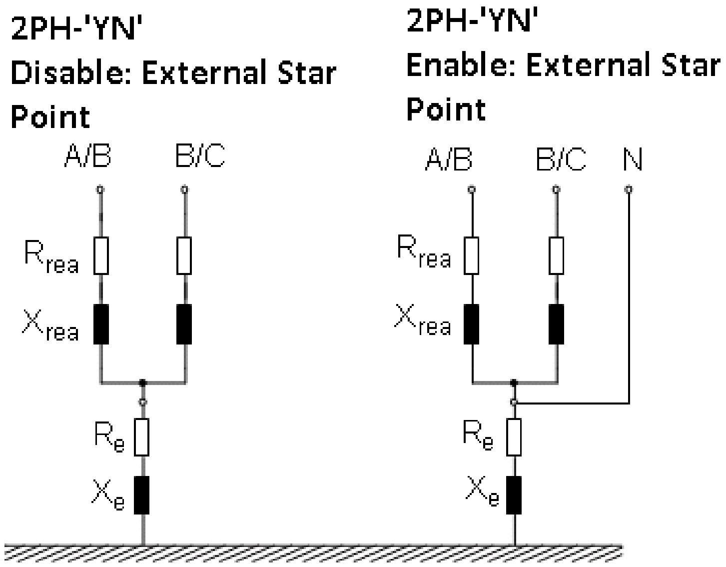

Figure 1.3: Model for the 2PH-'YN' technology

For the 2PH-'YN' technology it is possible to connect the star point to the neutral wire (enable option: External Star Point). For a 'connected' or 'connected (Petersen Coil)' internal star point grounding reactance (Xe) and a grounding resistance (Re) is considered. For a 'disconnected' star point the grounding reactance and resistance is neglected (-> isolated star point).

X_{rea}, R_{rea} <-> Q_{rea} relation

$$X_{rea} = \frac{2 \cdot U_r^2}{3 \cdot Q_{rea}} \quad and \quad R_{rea} = \frac{X_{rea}}{qf_{rea}} \qquad \text{in Ohm for shunts with } AC \text{ system type}$$

$$X_{rea} = \frac{U_r^2}{2 \cdot Q_{rea}} \qquad \text{in Ohm for shunts with } AC/BI \text{ system type}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{rea}: Rated Reactive Power, L in Mvar
q_{frea}: Quality Factor (at fn, nominal frequency) for a quality factor of zero (=0) the resistance is set to zero (=0)

Q_{rea}, I_{rea} <-> relation

The relation between the reactive power in Mvar of the shunt and the rated current, L in A is the following:

$$Q_{rea} = \frac{2 \cdot I_{rea} \cdot U_r}{\sqrt{3} \cdot 1000} \qquad \text{in Mvar for shunts with } AC \text{ system type}$$

$$Q_{rea} = \frac{I_{rea} \cdot U_r}{1000} \qquad \text{in Mvar for shunts with } AC/BI \text{ system type}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
I_{rea}: Rated Current, L in A

1.1.5 Technology: 1PH PH-PH

Model

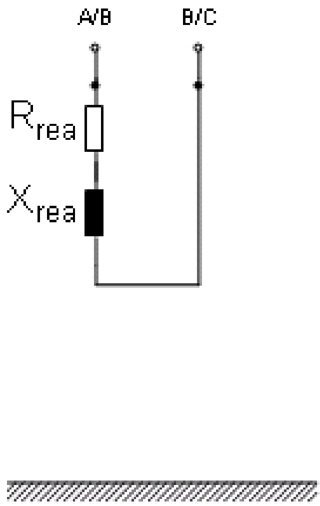

Figure 1.4: Model for the 1PH PH-PH technology

The 1PH PH-PH model is a single phase shunt connected between two phases (A-B, B-C or A-C). Additionally it is possible to enter a susceptance to ground Bg in μS.

X_{rea}, R_{rea} $<->$ Q_{rea} **relation**

$$X_{rea} = \frac{U_r^2}{Q_{rea}} \quad and \quad R_{rea} = \frac{X_{rea}}{qf_{rea}} \qquad \text{in Ohm}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{rea}: Rated Reactive Power, L in Mvar
qf_{rea}: Quality Factor (at fn, nominal frequency) for a quality factor of zero (=0) the resistance is set to zero (=0)

Q_{rea}, I_{rea} $<->$ **relation**

The relation between the reactive power in Mvar of the shunt and the rated current, L in A is the following:

$$Q_{rea} = \frac{I_{rea} \cdot U_r}{1000} \qquad \text{in Mvar}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
I_{rea}: Rated Current, L in A

1.1.6 Technology: 1PH PH-E and 1PH PH-N

Model

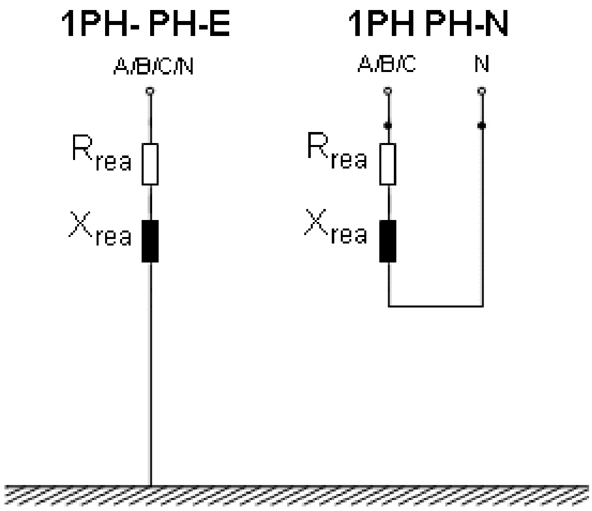

Figure 1.5: Model for the 1PH PH-E and 1PH PH-N technology

The 1PH PH-E technology can be used as grounding resistance, reactance to ground e.g. the neutral wire or a transformer star point.

X_{rea}, R_{rea} <-> Q_{rea} relation

$$X_{rea} = \frac{U_r^2}{3 \cdot Q_{rea}} \quad and \quad R_{rea} = \frac{X_{rea}}{qf_{rea}} \qquad \text{in Ohm for shunts with } AC \text{ system type}$$

$$X_{rea} = \frac{U_r^2}{4 \cdot Q_{rea}} \qquad \text{in Ohm for shunts with } AC/BI \text{ system type}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{rea}: Rated Reactive Power, L in Mvar
q_{frea}: Quality Factor (at fn, nominal frequency) for a quality factor of zero (=0) the resistance is set to zero (=0)

Q_{rea}, I_{rea} <-> relation

The relation between the reactive power in Mvar of the shunt and the rated current, L in A is the following:

$$Q_{rea} = \frac{I_{rea} \cdot U_r}{\sqrt{3} \cdot 1000} \qquad \text{in Mvar for shunts with } AC \text{ system type}$$

$$Q_{rea} = \frac{I_{rea} \cdot U_r}{2 \cdot 1000} \qquad \text{in Mvar for shunts with } AC/BI \text{ system type}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
I_{rea}: Rated Current, L in A

1.1.7 Technology: 2PH-'Y'

Model

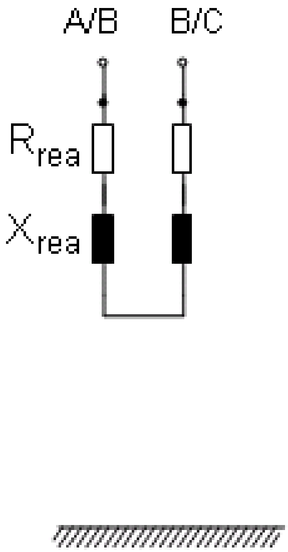

Figure 1.6: Model for the 2PH-'Y' technology

The 2PH-'Y' model is a two phase shunt connected at two phases (A or B and B or C) it is not recommended to connect the second phase at the neutral phase. Additionally it is possible to enter a susceptance to ground Bg in μS.

X_{rea}, R_{rea} <-> Q_{rea} relation

$$X_{rea} = \frac{U_r^2}{2 \cdot Q_{rea}} \quad and \quad R_{rea} = \frac{X_{rea}}{qf_{rea}} \qquad \text{in Ohm}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{rea}: Rated Reactive Power, L in Mvar

q_{frea}: Quality Factor (at fn, nominal frequency) for a quality factor of zero (=0) the resistance is set to zero (=0)

Q_{rea}, I_{rea} $<$-$>$ relation

The relation between the reactive power in Mvar of the shunt and the rated current, L in A is the following:

$$Q_{rea} = \frac{I_{rea} \cdot U_r}{1000} \qquad \text{in Mvar}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
I_{rea}: Rated Current, L in A

1.2 C Shunt

The C shunt is a pure capacitance. To define the susceptance/capacitance are two input modes available:

a) Design Parameter: the parameter are defined with the rated capacitive power or the rated current
b) Layout Parameter: the parameter are defined with the susceptance or capacitance.

When the technology is 3PH-'YN', the zero sequence admittance can be defined through the *G0toG1* and *B0toB1* parameters, available on the *Zero Sequence/Neutral Conductor* tab of the *Basic Data* page.

1.2.1 Common Relations

Relation between the susceptance B_{cap} and the capacitance C_{cap}

The capacitance C_{cap} is calculated:

$$C_{cap} = \frac{B_{cap}}{2 \cdot \pi \cdot f_{nom}} \qquad \text{Capacitance in } \mu\text{F}$$

B_{cap}: Susceptance in μS
f_{nom}: Nominal Frequency in Hz of the grid

Relation between the loss factor, tan(delta) $tandc$ and the parallel conductance G_p

$$G_p = B_{cap} \cdot tandc \qquad \text{Parallel conductance in } \mu\text{S}$$

B_{cap}: Susceptance in μS
$tandc$: Loss Factor, tan(delta)

1.2.2 Technology: 3PH-'D'

Model

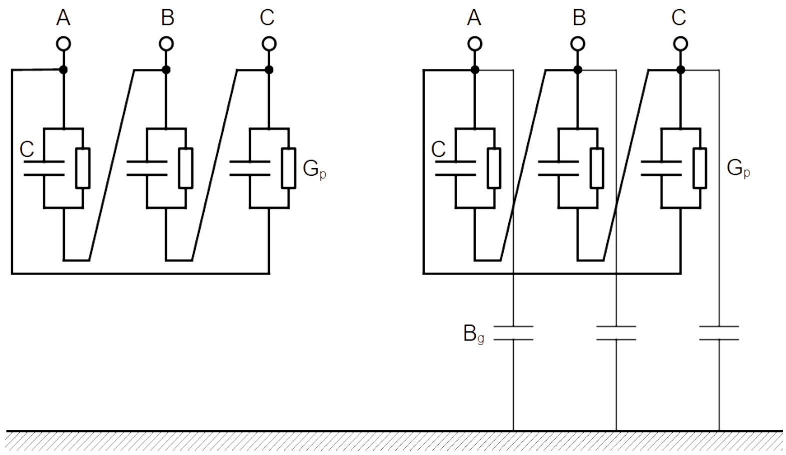

Figure 1.7: Model for the 3PH-'D' technology with and without susceptance to ground

The 3PH-'D' model is a 3-phase shunt in delta connection. Additionally it is possible to enter a susceptance to ground (Bg) in μS.

B_{cap} <-> Q_{cap} **relation**

$$B_{cap} = \frac{Q_{cap}}{3 \cdot U_r^2} \cdot 10^6 \qquad \text{in } \mu\text{S}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{cap}: Rated Capacitive Power in Mvar
B_{cap}: Susceptance in μS

Q_{cap} <-> I_{cap} **relation**

The relation between the capacitive power in Mvar of the shunt and the rated current, C in A is the following:

$$Q_{cap} = \frac{I_{cap} \cdot \sqrt{3} \cdot U_r}{1000} \qquad \text{in Mvar}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
I_{cap}: Rated Current, C in A

1.2.3 Technology: 3PH-'YN' and 3PH-'Y'

Model

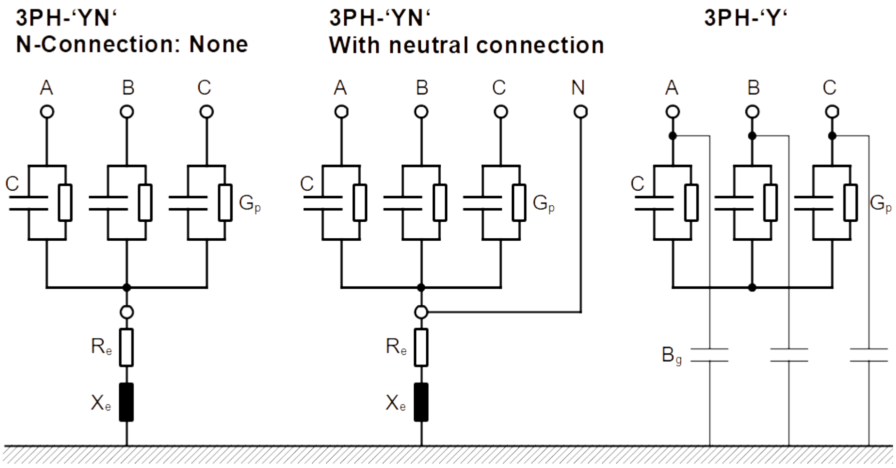

Figure 1.8: Models for the 3PH-'YN' and 3PH-'Y' technology

For the 3PH-'YN' technology it is possible to connect the star point to the neutral wire (enable option: External Star Point) and to setup if the internal grounding impedance star point is 'connected', 'connected (Petersen Coil)' or 'disconnected'. For a 'connected' star point a grounding reactance (Xe) and grounding resistance (Re) in Ohm is considered. For a 'disconnected' internal star point the grounding reactance and resistance is neglected (-> isolated star point). For the 3PH-'Y' technology it's further possible to enter a susceptance to ground (Bg) in μS.

B_{cap} <-> Q_{cap} relation

$$B_{cap} = \frac{Q_{cap}}{U_r^2} \cdot 10^6 \qquad \text{in } \mu\text{S}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{cap}: Rated Capacitive Power in Mvar
B_{cap}: Susceptance in μS

Q_{cap} <-> I_{cap} relation

The relation between the capacitive power in Mvar of the shunt and the rated current, C in A is the following:

$$Q_{cap} = \frac{I_{cap} \cdot \sqrt{3} \cdot U_r}{1000} \qquad \text{in Mvar}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
I_{cap}: Rated Current, C in A

1.2.4 Technology: 2PH-'YN'

Model

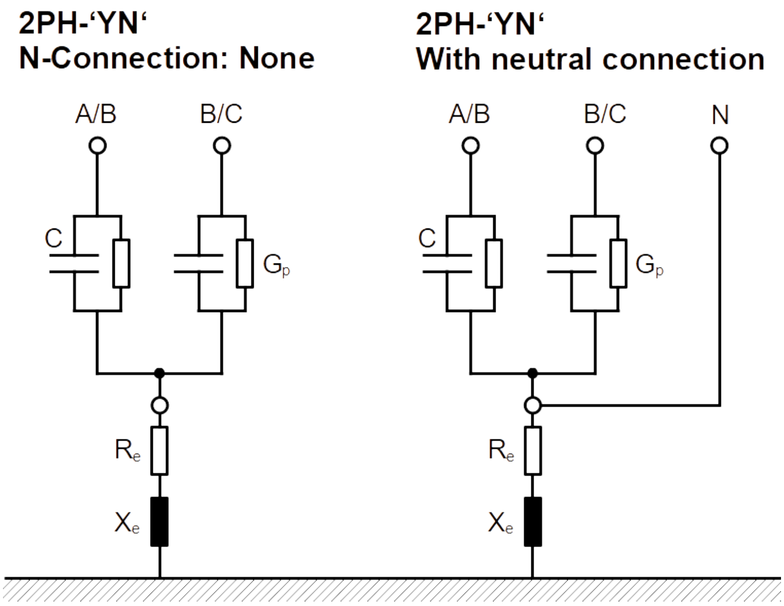

Figure 1.9: Models for the 2PH-'YN' technology

For the 2PH-'YN' technology it is possible to connect the star point to the neutral wire (enable option: External Star Point). For a 'connected' or 'connected (Pertersen Coil)' internal star point grounding reactance (Xe) and a grounding resistance (Re) is considered. For a 'disconnected' star point the grounding reactance and resistance is neglected (-> isolated star point).

B_{cap} <-> Q_{cap} relation

$$B_{cap} = \frac{3 \cdot Q_{cap}}{2 \cdot U_r^2} \cdot 10^6 \qquad \text{in } \mu\text{S for shunts with } AC \text{ system type}$$

$$B_{cap} = \frac{2 \cdot Q_{cap}}{U_r^2} \cdot 10^6 \qquad \text{in } \mu\text{S for shunts with } AC/BI \text{ system type}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{cap}: Rated Capacitive Power in Mvar
B_{cap}: Susceptance in μS

Q_{cap} <-> I_{cap} relation

The relation between the capacitive power in Mvar of the shunt and the rated current, C in A is the following:

$$Q_{cap} = \frac{2 \cdot I_{cap} \cdot U_r}{\sqrt{3} \cdot 1000} \qquad \text{in Mvar for shunts with } AC \text{ system type}$$

$$Q_{cap} = \frac{I_{cap} \cdot U_r}{1000} \qquad \text{in Mvar for shunts with } AC/BI \text{ system type}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
I_{cap}: Rated Current, C in A

1.2.5 Technology: 1PH PH-PH

Model

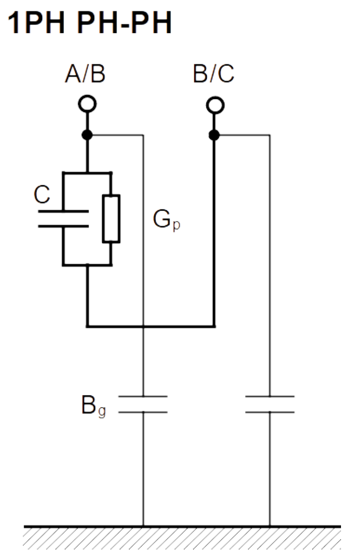

Figure 1.10: Model for the 1PH PH-PH technology

The 1PH PH-PH model is a single phase shunt connected between two phases (A-B, B-C or A-C). Additionally it is possible to enter a susceptance to ground Bg in μS.

B_{cap} <-> Q_{cap} relation

$$B_{cap} = \frac{Q_{cap}}{U_r^2} \cdot 10^6 \qquad \text{in } \mu\text{S}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{cap}: Rated Capacitive Power in Mvar
B_{cap}: Susceptance in μS

Q_{cap} <-> I_{cap} relation

The relation between the capacitive power in Mvar of the shunt and the rated current, C in A is the following:

$$Q_{cap} = \frac{I_{cap} \cdot U_r}{1000} \qquad \text{in Mvar}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
I_{cap}: Rated Current, C in A

1.2.6 Technology: 1PH PH-E and 1PH PH-N

Model

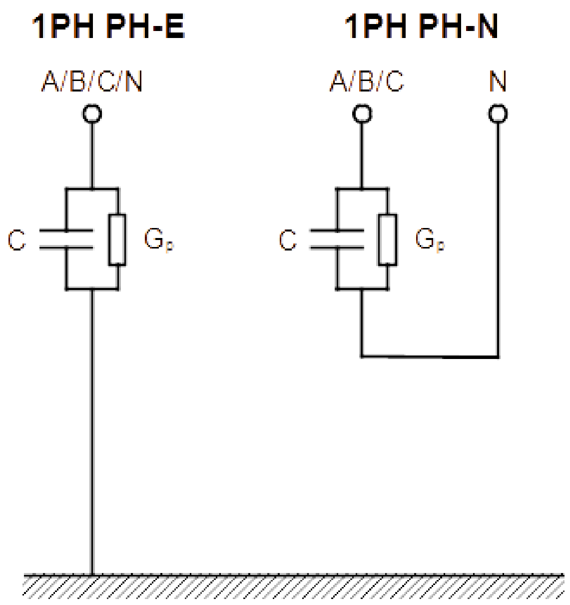

Figure 1.11: Model for the 1PH PH-E and 1PH PH-N technology

The 1PH PH-E technology can be used as grounding resistance, reactance to ground e.g. the neutral wire or a transformer star point.

B_{cap} <-> Q_{cap} **relation**

$$B_{cap} = \frac{3 \cdot Q_{cap}}{U_r^2} \cdot 10^6 \qquad \text{in } \mu\text{S for shunts with } \textit{AC} \text{ system type}$$

$$B_{cap} = \frac{4 \cdot Q_{cap}}{U_r^2} \cdot 10^6 \qquad \text{in } \mu\text{S for shunts with } \textit{AC/BI} \text{ system type}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{cap}: Rated Capacitive Power in Mvar
B_{cap}: Susceptance in μS

Q_{cap} <-> I_{cap} **relation**

The relation between the capacitive power in Mvar of the shunt and the rated current, C in A is the following:

$$Q_{cap} = \frac{I_{cap} \cdot U_r}{\sqrt{3} \cdot 1000} \qquad \text{in Mvar for shunts with } \textit{AC} \text{ system type}$$

$$Q_{cap} = \frac{I_{cap} \cdot U_r}{2 \cdot 1000} \qquad \text{in Mvar for shunts with } \textit{AC/BI} \text{ system type}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
I_{cap}: Rated Current, C in A

1.2.7 Technology: 2PH-'Y'

Model

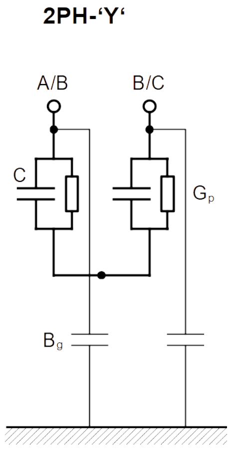

Figure 1.12: Model for the 2PH-'Y' technology

The 2PH-'Y' model is a two phase shunt connected at two phases (A or B and B or C) it is not recommended to connect the second phase at the neutral phase. Additionally it is possible to enter a susceptance to ground Bg in μS.

B_{cap} <-> Q_{cap} relation

$$B_{cap} = \frac{2 \cdot Q_{cap}}{U_r^2} \cdot 10^6 \qquad \text{in } \mu\text{S}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{cap}: Rated Capacitive Power in Mvar
B_{cap}: Susceptance in μS

Q_{cap} <-> I_{cap} relation

The relation between the capacitive power in Mvar of the shunt and the rated current, C in A is the following:

$$Q_{cap} = \frac{I_{cap} \cdot U_r}{1000} \qquad \text{in Mvar}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
I_{cap}: Rated Current, C in A

1.3 R-L-C Shunt

The R-L-C shunt is a reactance/inductance, a resistance and a susceptance/capacitance in series. To define the reactance/inductance, the resistance and the susceptance/capacitance there are two input modes:

a) Design Parameter: the parameters are defined with the rated reactive power (L-C) or the rated current (L-C), the degree of inductance or the resonance frequency or the tuning order and the quality factor at nominal frequency (at fn) or the quality factor at resonance frequency (at fr)
b) Layout Parameter: the parameters are defined with the reactance (in Ohm) or inductance (in mH), the susceptance (in S) or capacitance (in μF) and the resistance in Ohm

1.3.1 Common Relations

Relation between the susceptance B_{cap} and the capacitance C_{cap}

The capacitance C_{cap} is calculated:

$$C_{cap} = \frac{B_{cap}}{2 \cdot \pi \cdot f_{nom}} \qquad \text{Capacitance in } \mu\text{F}$$

B_{cap}: Susceptance in μS
f_{nom}: Nominal Frequency in Hz of the grid

Relation between the reactance X_{rea} and the inductance L_{rea}

The inductance L_{rea} is calculated:

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

X_{rea}: Reactance in Ohm f_{nom}: Nominal Frequency in Hz of the grid

Relation between Degree of Inductance, Resonance Frequency and Tuning Order

$$f_{res} = \frac{f_{nom}}{\sqrt{P_{grad}/100}} \qquad \text{Resonance Frequency in Hz}$$

$$n_{res} = \frac{f_{res}}{f_{nom}} \qquad \text{Tuning Order}$$

p_{grad}: Degree of Inductance in %
f_{nom}: Nominal Frequency of the grid in Hz
f_{res}: Resonance Frequency in Hz
n_{res}: Tuning Order

Relation between Quality Factor (at f_{nom}) and Quality Factor (at f_{res})

$$g_{reaf0} = g_{rea} \cdot n_{res} = g_{rea} \cdot \frac{f_{res}}{f_{nom}}$$

g_{rea}: 'Quality Factor at fnom', at nominal frequency
g_{reaf0}: 'Quality Factor at fres' at resonance frequency
n_{res}: Tuning Order

Rated Capacitive Power Q_{cap} and Rated Reactive Power, L-C Q_{tot}

The rated capacitive power can be calculated according to following additional equations:

$$Q_{cap} = Q_{tot} \cdot (1 - p_{grad}/100) = Q_{tot} \cdot \left(1 - \frac{1}{n_{res}^2}\right) = Q_{tot} \cdot \left(1 - \left(\frac{f_{nom}}{f_{res}}\right)^2\right) \qquad \text{in Mvar}$$

Q_{cap}: 'Rated Capacitive Power, C' in Mvar
Q_{tot}: 'Rated Reactive Power, L-C' in Mvar
p_{grad}: Degree of Inductance in %
f_{nom}: Nominal Frequency of the grid in Hz
f_{res}: Resonance Frequency in Hz
n_{res}: Tuning Order

Rated Reactive Power Q_{cea} and Rated Reactive Power, L-C Q_{tot}

The rated reactive power can be calculated according to following additional equations:

$$Q_{rea} = Q_{tot} \cdot (100/p_{grad} - 1) = Q_{tot} \cdot (n_{res}^2 - 1) = Q_{tot} \cdot \left(\left(\frac{f_{res}}{f_{nom}}\right)^2 - 1\right) \qquad \text{in Mvar}$$

Q_{rea}: 'Rated Reactive Power, L' in Mvar
Q_{tot}: 'Rated Reactive Power, L-C' in Mvar
p_{grad}: Degree of Inductance in %
f_{nom}: Nominal Frequency of the grid in Hz
f_{res}: Resonance Frequency in Hz
n_{res}: Tuning Order

Resonance Frequency f_{res}

Resonance Frequency is calculated:

$$f_{res} = \frac{1}{2 \cdot \pi \cdot \sqrt{L_{rea} \cdot 10^{-3} \cdot C_{cap} \cdot 10^{-6}}} \qquad \text{in Hz}$$

L_{rea}: Inductance in mH
C_{cap}: Capacitance in μF

Relation between Inductance L_{rea}, Resonance Frequency f_{res} and Capacitance C_{cap}

The inductance L_{rea} can be calculated according to following equation:

$$L_{rea} = \frac{10^3}{(2 \cdot \pi \cdot f_{res})^2 \cdot C_{cap} \cdot 10^{-6}} \qquad \text{in mH}$$

C_{cap}: Capacitance in μF
f_{res}: Resonance Frequency in Hz

1.3.2 Technology: 3PH-'D'

Model

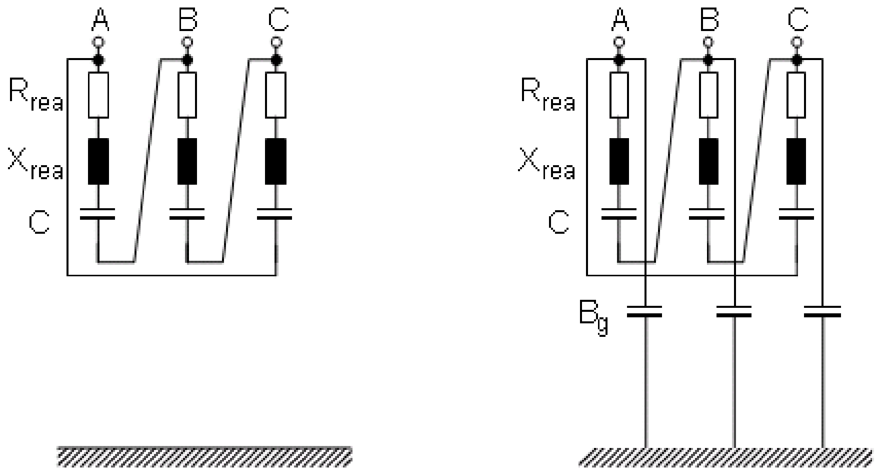

Figure 1.13: Model for the 3PH-'D' technology with and without susceptance to ground

The 3PH-'D' model is a 3-phase shunt in delta connection. Additionally it is possible to enter a susceptance to ground (Bg) in μS.

Q_{cap} <-> B_{cap} relation

$$B_{cap} = \frac{Q_{cap}}{3 \cdot U_r^2} \cdot 10^6 \qquad \text{in } \mu\text{S}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{cap}: Rated Capacitive Power (3phase) in Mvar
B_{cap}: Susceptance in μS

X_{rea}, R_{rea} <-> Q_{rea} **relation**

$$X_{rea} = 3 \cdot \frac{U_r^2}{q_{rea}} \quad and \quad R_{rea} = \frac{X_{rea}}{qf_{rea}} \qquad \text{in Ohm}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{rea}: Rated Reactive Power of the reactor in Mvar
X_{rea}: Reactance in one phase in mH

1.3.3 Technology: 3PH-'YN' and 3PH-'Y'

Model

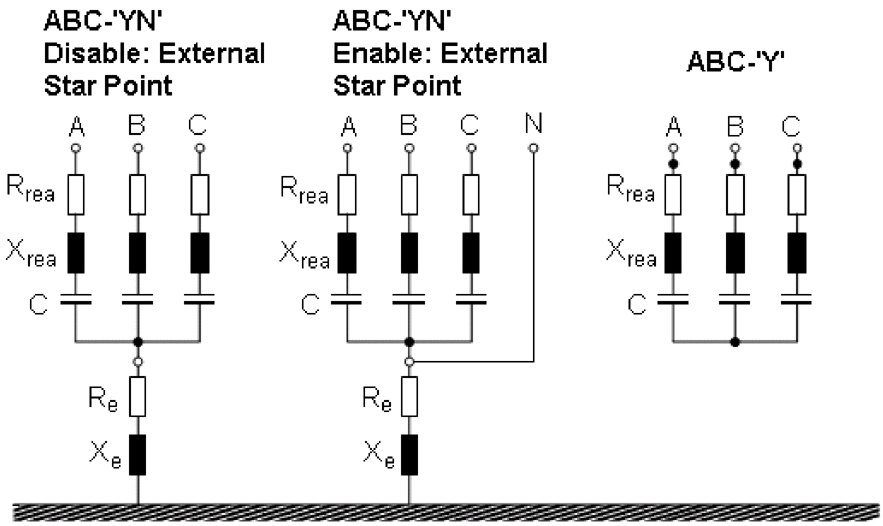

Figure 1.14: Model for the 3PH-'YN' and 3PH-'Y' technology

For the 3PH-'YN' technology it is possible to connect the star point to the neutral wire (enable option: External Star Point) and to setup if the internal grounding impedance star point is 'connected', 'connected (Petersen Coil)' or 'disconnected'. For a 'connected' star point a grounding reactance (Xe) and grounding resistance (Re) in Ohm is considered. For an 'disconnected' internal star point the grounding reactance and resistance is neglected (-> isolated star point). The 3PH-'Y' technology it is further possible to enter a susceptance to ground (Bg) in μS.

Q_{cap} <-> B_{cap} **relation**

$$B_{cap} = \frac{Q_{cap}}{U_r^2} \cdot 10^6 \qquad \text{in } \mu\text{S}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{cap}: Rated Capacitive Power (3phase) in Mvar
B_{cap}: Susceptance in μS

X_{rea}, R_{rea} <-> Q_{rea} relation

$$X_{rea} = \frac{U_r^2}{Q_{rea}} \quad and \quad R_{rea} = \frac{X_{rea}}{qf_{rea}} \qquad \text{in Ohm}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{rea}: Rated Reactive Power of the reactor in Mvar
qf_{rea}: Quality Factor (at fn, nominal frequency) for a quality factor of zero (=0) the resistance is set to zero (=0)

1.3.4 Technology: 2PH-'YN'

Model

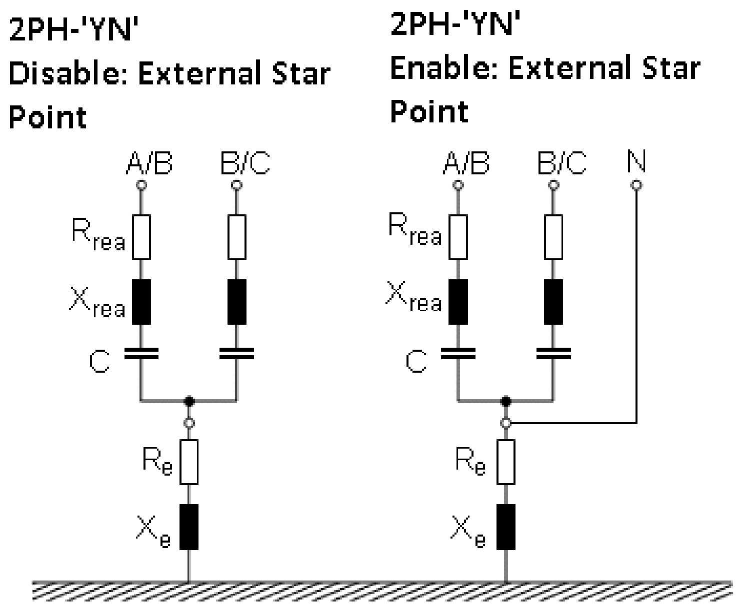

Figure 1.15: Model for the 2PH-'YN' technology

For the 2PH-'YN' technology it is possible to connect the star point to the neutral wire (enable option: External Star Point). For a 'connected' or 'connected (Pertersen Coil)' internal star point grounding reactance (Xe) and a grounding resistance (Re) is considered. For a 'disconnected' star point the grounding reactance and resistance is neglected (-> isolated star point).

Q_{cap} <-> B_{cap} relation

$$B_{cap} = \frac{3 \cdot Q_{cap}}{2 \cdot U_r^2} \cdot 10^6 \qquad \text{in } \mu\text{S for shunts with } AC \text{ system type}$$

$$B_{cap} = \frac{2 \cdot Q_{cap}}{U_r^2} \cdot 10^6 \qquad \text{in } \mu\text{S for shunts with } AC/BI \text{ system type}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{cap}: Rated Capacitive Power, C in Mvar
B_{cap}: Susceptance in μS

X_{rea}, R_{rea} <-> Q_{rea} relation

$$X_{rea} = \frac{2 \cdot U_r^2}{3 \cdot Q_{rea}} \quad and \quad R_{rea} = \frac{X_{rea}}{qf_{rea}} \qquad \text{in Ohm for shunts with } AC \text{ system type}$$

$$X_{rea} = \frac{U_r^2}{2 \cdot Q_{rea}} \qquad \text{in Ohm for shunts with } AC/BI \text{ system type}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{rea}: Rated Reactive Power, L in Mvar qf_{rea}: Quality Factor (at fn, nominal frequency) for a quality factor of zero (=0) the resistance is set to zero (=0)

1.3.5 Technology: 1PH PH-PH

Model

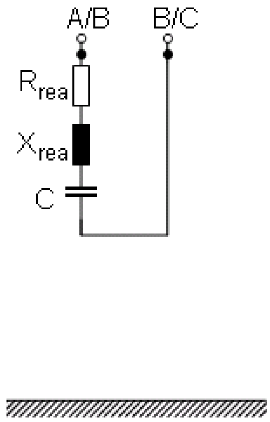

Figure 1.16: Model for the 1PH PH-PH technology

The 1PH PH-PH model is a single phase shunt connected between two phases (A-B, B-C or A-C). Additionally it is possible to enter a susceptance to ground Bg in μS.

Q_{cap} <-> B_{cap} relation

$$B_{cap} = \frac{Q_{cap}}{U_r^2} \cdot 10^6 \qquad \text{in } \mu\text{S}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{cap}: Rated Capacitive Power, C in Mvar
B_{cap}: Susceptance in μS

X_{rea}, R_{rea} <-> Q_{rea} **relation**

$$X_{rea} = \frac{U_r^2}{Q_{rea}} \quad and \quad R_{rea} = \frac{X_{rea}}{qf_{rea}} \qquad \text{in Ohm}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{rea}: Rated Reactive Power of the reactor in Mvar qf_{rea}: Quality Factor (at fn, nominal frequency) for a quality factor of zero (=0) the resistance is set to zero (=0)

1.3.6 Technology: 1PH PH-E and 1PH PH-N

Model

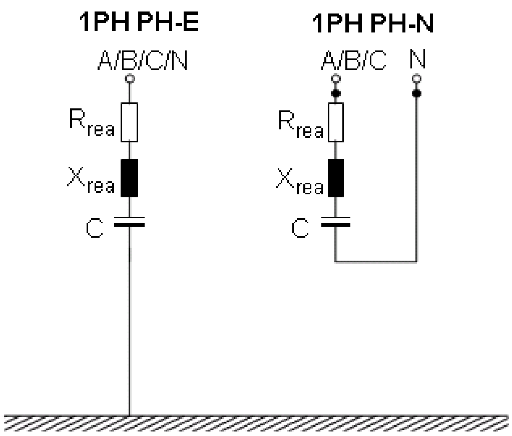

Figure 1.17: Model for the 1PH PH-E and 1PH PH-N technology

The 1PH PH-E technology can be used as grounding resistance, reactance to ground e.g. the neutral wire or a transformer star point.

Q_{cap} <-> B_{cap} **relation**

$$B_{cap} = \frac{3 \cdot Q_{cap}}{U_r^2} \cdot 10^6 \qquad \text{in } \mu\text{S for shunts with } AC \text{ system type}$$

$$B_{cap} = \frac{4 \cdot Q_{cap}}{U_r^2} \cdot 10^6 \qquad \text{in } \mu\text{S for shunts with } AC/BI \text{ system type}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{cap}: Rated Capacitive Power, C in Mvar
B_{cap}: Susceptance in μS

X_{rea}, R_{rea} <-> Q_{rea} **relation**

$$X_{rea} = \frac{U_r^2}{3 \cdot Q_{rea}} \quad and \quad R_{rea} = \frac{X_{rea}}{qf_{rea}} \qquad \text{in Ohm for shunts with } AC \text{ system type}$$

$$X_{rea} = \frac{U_r^2}{4 \cdot Q_{rea}} \qquad \text{in Ohm for shunts with } AC/BI \text{ system type}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{rea}: Rated Reactive Power, L in Mvar
qf_{rea}: Quality Factor (at fn, nominal frequency) for a quality factor of zero (=0) the resistance is set to zero (=0)

1.3.7 Technology: 2PH-'Y'

Model

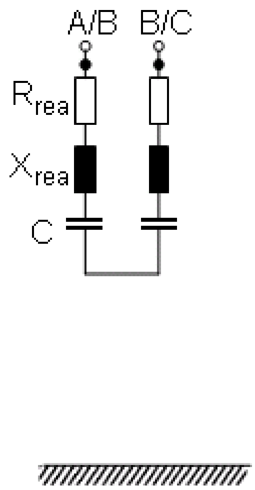

Figure 1.18: Model for the 2PH-'Y' technology

The 2PH-'Y' model is a two phase shunt connected at two phases (A or B and B or C) it is not recommended to connect the second phase at the neutral phase. Additionally it is possible to enter a susceptance to ground Bg in μS.

Q_{cap} <-> B_{cap} relation

$$B_{cap} = \frac{2 \cdot Q_{cap}}{U_r^2} \cdot 10^6 \qquad \text{in } \mu\text{S}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{cap}: Rated Capacitive Power, C in Mvar
B_{cap}: Susceptance in μS

X_{rea}, R_{rea} <-> Q_{rea} relation

$$X_{rea} = \frac{U_r^2}{2 \cdot Q_{rea}} \quad and \quad R_{rea} = \frac{X_{rea}}{qf_{rea}} \qquad \text{in Ohm}$$

U_r: Rated Line-Line voltage of the shunt/filter in kV ($U_r = ushnm$)
Q_{rea}: Rated Reactive Power of the reactor in Mvar qf_{rea}: Quality Factor (at fn, nominal frequency) for a quality factor of zero (=0) the resistance is set to zero (=0)

1.4 R-L-C, Rp Shunt

The R-L-C, Rp shunt is a reactance/inductance, a resistance and a susceptance/capacitance in series with an additional resistance in parallel to the R-L impedance. To define the reactance/inductance, the resistance and the susceptance/capacitance there are two input modes:

a) Design Parameter: the parameter are defined with the rated reactive power (L-C) or the rated current (L-C), the degree of inductance or the resonance frequency or the tuning order and the quality factor at nominal frequency (at fn) or the quality factor at resonance frequency (at fr)
b) Layout Parameter: the parameter are defined with the reactance (in Ohm) or inductance (in mH), the susceptance (in μS) or capacitance (in μF) and the resistance in Ohm

The parallel resistance Rp can be entered in the layout parameter frame in Ohm and is independent on the input option. If the parallel resistance Rp is equal zero (Rp = 0) the parallel resistance is not considered (equal to G = 0).

1.4.1 Common Relations

All common relations are similar/equal to those used by the R-L-C shunt. See section 1.3.1.

1.4.2 Technology: 3PH-'D'

Model

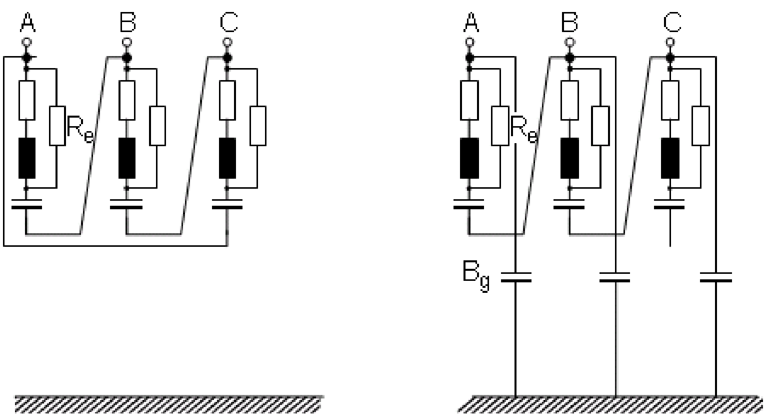

Figure 1.19: Model for the 3PH-'D' technology with and without susceptance to ground

The 3PH-'D' model is a 3-phase shunt in delta connection. Additionally it is possible to enter a susceptance to ground (Bg) in S.

All relations are similar/equal to those used by the R-L-C shunt. See section 1.3.2.

1.4.3 Technology: 3PH-'YN' and 3PH-'Y'

Model

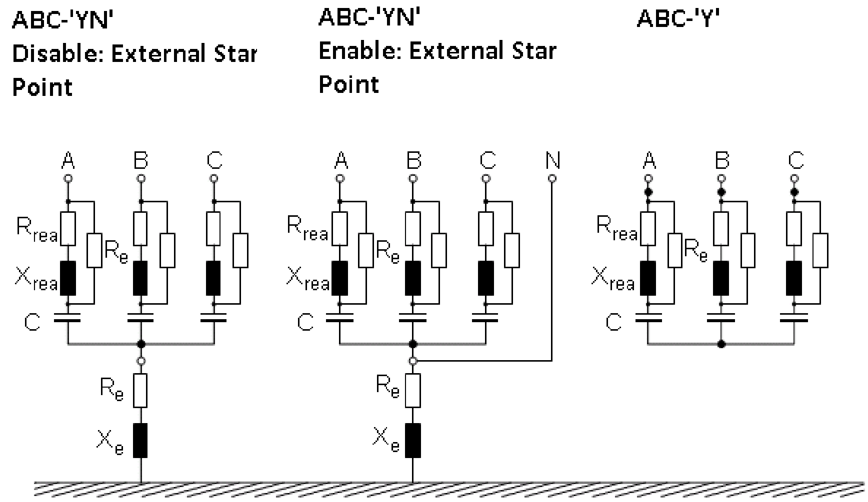

Figure 1.20: Models for the 3PH-'YN' and 3PH-'Y' technology

For the 3PH-'YN' technology it is possible to connect the star point to the neutral wire (enable option: External Star Point) and to setup if the internal grounding impedance star point is 'connected', 'connected (Petersen Coil)' or 'disconnected'. For a 'connected' star point a grounding reactance (Xe) and grounding resistance (Re) in Ohm is considered. For an 'disconnected' internal star point the grounding reactance and resistance is neglected (-> isolated star point). The 3PH-'Y' technology it is further possible to enter a susceptance to ground (Bg) in μS.

All relations are similar/equal to those used by the R-L-C shunt. See section 1.3.3.

1.4.4 Technology: 2PH-'YN'

Model

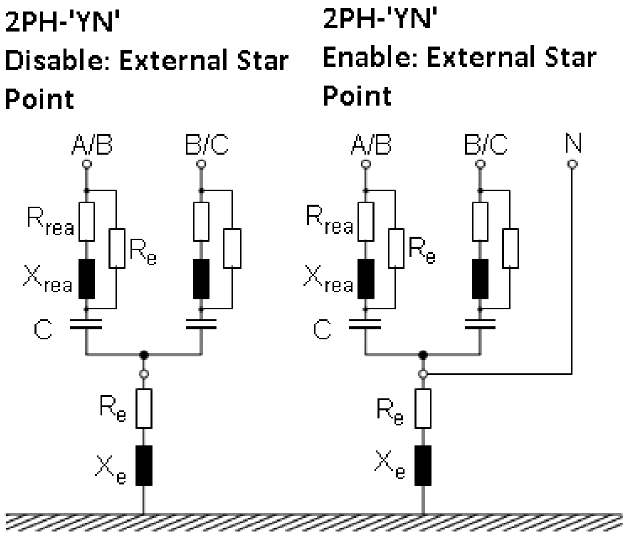

Figure 1.21: Model for the 2PH-'YN' technology

For the 2PH-'YN' technology it is possible to connect the star point to the neutral wire (enable option: External Star Point). For a 'connected' or 'connected (Petersen Coil)' internal star point grounding reactance (Xe) and a grounding resistance (Re) is considered. For a 'disconnected' star point the grounding reactance and resistance is neglected (-> isolated star point).

All relations are similar/equal to those used by the R-L-C shunt. See chapter 1.3.4.

1.4.5 Technology: 1PH PH-PH

Model

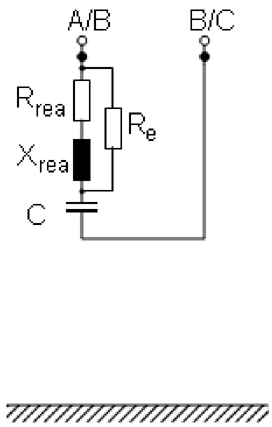

Figure 1.22: Model for the 1PH PH-PH technology

The 1PH PH-PH model is a single phase shunt connected between two phases (A-B, B-C or A-C). Additionally it is possible to enter a susceptance to ground Bg in μS.

All relations are similar/equal to those used by the R-L-C shunt. See section 1.3.5.

1.4.6 Technology: 1PH PH-E and 1PH PH-N

Model

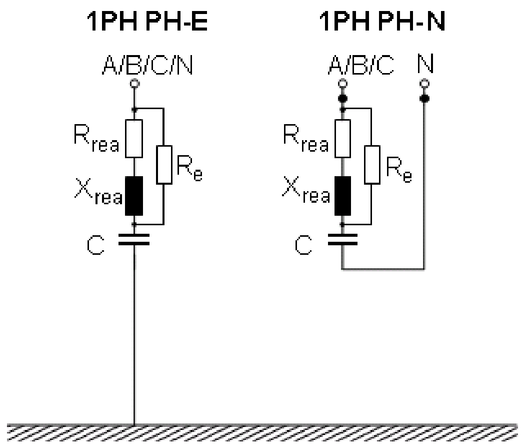

Figure 1.23: Model for the 1PH PH-E and 1PH PH-N technology

The 1PH PH-E technology can be used as grounding resistance, reactance to ground e.g. the neutral wire or a transformer star point.

All relations are similar/equal to those used by the R-L-C shunt. See chapter 1.3.6.

1.4.7 Technology: 2PH-'Y'

Model

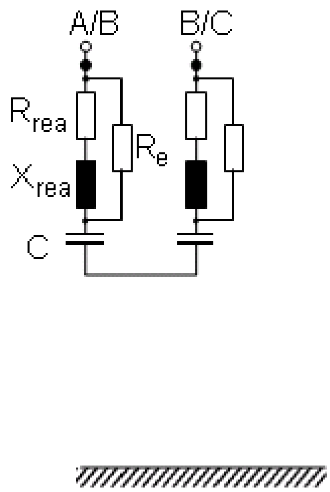

Figure 1.24: Model for the 2PH-'Y' technology

The 2PH-'Y' model is a two phase shunt connected at two phases (A or B and B or C). Connection of the second phase at the neutral phase is not recommended. In addition, it is possible to enter a susceptance to ground, Bg, in μS.

All relations are similar/equal to those used by the R-L-C shunt. See section 1.3.7.

1.5 R-L-C1-C2,Rp shunt

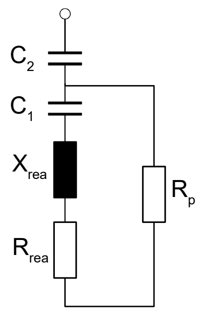

Figure 1.25: Model for the R-L-C1-C2,Rp shunt

The R-L-C1-C2,Rp shunt is only available in 3 phase technology.

All relations are similar/equal to those used by the R-L-C shunt. See sections 1.3.2 and 1.3.3.

1.6 Measurement table

Without the use of a measurement table the reactive power of the shunt can be varied only by constant discrete steps. Using a measurement table allows to specify the total reactive power versus number of steps. In this way, an effective varying reactive power per step can be used. A measurement table can be defined activating the checkbox "According to Measurement Report" in the *Basic Data* page. The possibility to use a measurement table only exists for C and R-L shunts with three-phase technology.

When using the measurement table, the internal calculation parameters of the shunt (e.g. the current through capacitors) refer to the sum of all steps. Without the use of a measurement table the internal calculation parameters are given for one step.

It is also possible to define the zero sequence impedance/admittance per step (only for technology 3PH-'YN').

Note: The values of the reactive power have to be in ascending or descending order

---

1.7 Internal Grounding Impedance

The internal grounding impedance can be defined on the *Zero Sequence/Neutral Conductor* tab of the *Basic Data* page, when the technology is 3PH-'YN' or 2PH-'YN'.

The configuration of the grounding can be selected as either *Per step* or *Common*, see Figure 1.26. The first option corresponds to the implementation in PowerFactory versions prior 2018.

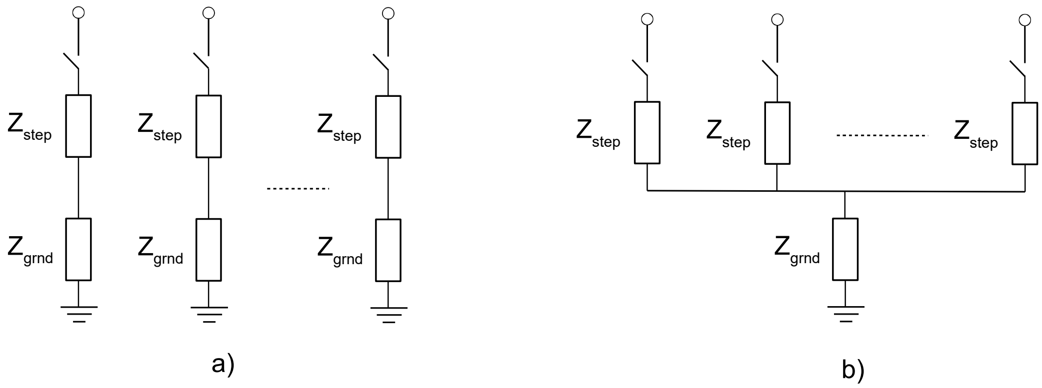

Figure 1.26: Grounding configuration: a) Per step, b) Common

2 Load Flow Analysis

An integrated shunt controller is available in *Load Flow* and can be activated by selecting the checkbox *Switchable* on the element *Load Flow* page. The controller can be configured to control voltage, reactive power or power factor. The internal logic for the different control modes is described in the next sections.

2.0.1 Voltage Control

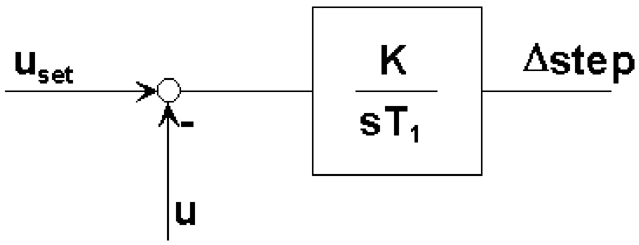

Figure 2.1: Voltage Control

u_{set}: voltage set point in p.u.
u: measured voltage in p.u.
$T1$: time constant $T1 = T_{ctrl}/(T_{minctrl} \times krelax)$
T_{ctrl}: controller Time Constant
K: controller Factor $K = 100\% \times ncapx \times K_{ctrl} \times orientation$
K_{ctrl}: Sensitivity dq/dv in p.u./%
$ncapx$: Max. no of steps
$orientation$: step orientation (+1 for capacitive shunts, -1 for inductive shunts)
$\Delta step$: step changes

$T_{minctrl}$: is the fastest controller time constant of all automatic adjusted tap-changer and shunts
$krelax$: is the min. controller relaxation factor parameter in the load-flow command ('Advanced Options' page)

u_{set}: is calculated from the upper and lower voltage limits according to following equation:

$$u_{set} = \frac{u_{set}(upper) + u_{set}(lower)}{2}$$

2.1 Reactive Power Control

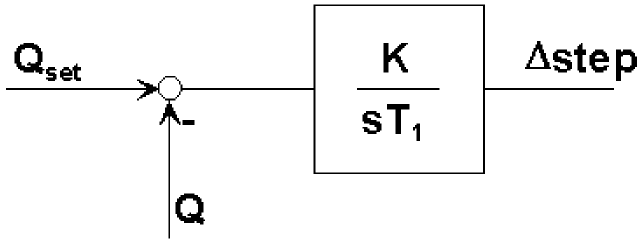

Figure 2.2: Reactive Power Control

Q_{set}: reactive power set point in Mvar
Q: measured reactive power in Mvar
$T1$: time constant $T1 = T_{ctrl}/(T_{minctrl} \times krelax)$
T_{ctrl}: Controller Time Constant
K: controller factor $K = ncapx/Qrmax \times orientation \times iQorientation$
$ncapx$: Max. no of steps
$Qrmax$: Max. rated reactive power in Mvar
$orientation$: step orientation (+1 for capacitive shunts, -1 for inductive shunts)
$iQorient$: Orientation of reactive power ('+Q' = 1 for '-Q' = -1)
$\Delta step$: step changes

$Tminctrl$: is the fastest controller time constant of all automatic adjusted tap-changer and shunts
$krelax$: is the min. controller relaxation factor parameter in the load-flow command ('Advanced Options' page)

Q_{set}: is calculated from the upper and lower reactive power limits according to following equation:

$$Q_{set} = \frac{Q_{set}(upper) + Q_{set}(lower)}{2} \quad in\ Mvar$$

Figure 2.3 explains the definition of the parameter $iQorient$.

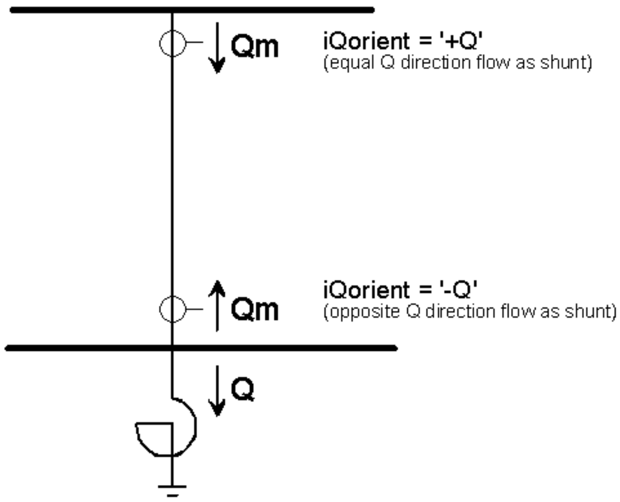

Figure 2.3: Reactive power orientation setting for reactive power and power factor control

2.2 Power Factor Control

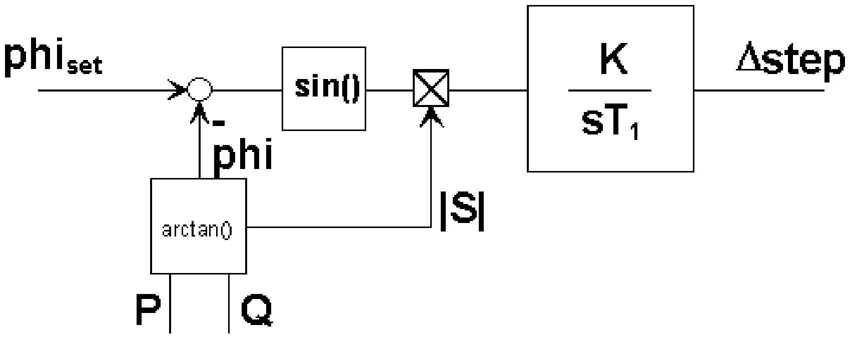

Figure 2.4: Power Factor Control

phi_{set}: power angle set point
Q: measured reactive power in Mvar
P: measured active power in MW
$|S|$: measured apparent power in MVA
phi: calculated power angle phi = arctan(Q/P)
$T1$: time constant $T1 = T_{ctrl}/(T_{minctrl} \times krelax)$
T_{ctrl}: Controller Time Constant
K: controller factor $K = ncapx/Qrmax \times orientation \times iQorientation$
$ncapx$: Max. no of steps
$Qrmax$: Max. rated reactive power in Mvar
$orientation$: step orientation (+1 for capacitive shunts, -1 for inductive shunts)
$iQorient$: Orientation of reactive power ('+Q' = 1 for '-Q' = -1)
$\Delta step$: step changes

$T_{minctrl}$: is the fastest controller time constant of all automatic adjusted tap-changer and shunts
$krelax$: is the min. controller relaxation factor parameter in the load-flow command ('Advanced Options' page)

phi_{set}: is calculated from the upper and lower power factor limits according to following equation:

$$phi_{set} = \frac{phi(upper) + phi(lower)}{2} \qquad in\ deg$$

Upper power angle:
For inductive power factor (ind.):

$$phi(upper) = arccos(pfsetp\_mx)$$

For capacitive power factor (cap.):

$$phi(upper) = \begin{cases} arccos(pfsetp\_mx) \geq 90° & \rightarrow & 360° - arccos(pfsetp\_mx) \\ arccos(pfsetp\_mx) \leq 90° & \rightarrow & -arccos(pfsetp\_mx) \end{cases}$$

Lower power angle:
For inductive power factor (ind.):

$$phi(lower) = arccos(pfsetp\_mn)$$

For capacitive power factor (cap.):

$$phi(lower) = \begin{cases} arccos(pfsetp\_mn) \geq 90° & \rightarrow & 360° - arccos(pfsetp\_mn) \\ arccos(pfsetp\_mn) \leq 90° & \rightarrow & -arccos(pfsetp\_mn) \end{cases}$$

If the lower power angle is greater than the upper power angle, the angles are swapped. If both angles are negative, the reactive power orientation $iQorient$ is multiplied by -1.

2.3 Calculation Quantities

The following calculation quantities are available.

2.3.1 Detailed Quantities

The p.u. voltage of the detailed quantities are base either on

- U_{ph-ph}, nominal line-line voltage of the connected busbar
- U_{ph-e}, nominal line-ground voltage of the connected busbar

Balanced load flow

Quantity	Unit	Description	Comment
uc	$p.u.$	Voltage across Capacitor	$=0$ for R-L shunt based on U_{ph-ph} for D-connections or U_{ph-e} for Y/YN-connections
Uc	kV	Voltage across Capacitor	$=0$ for R-L shunt
IL	A	Current through Inductor L	$=0$ for C shunt
IC	A	Current through Capacitor C	$=0$ for R-L shunt
IRp	A	Current through Rp	
PRp	kW	Losses in Rp	
PL	kW	Losses in Inductor (Rs)	$=0$ for C shunt
url	$p.u.$	Voltage across Inductor (Rs-L)	$=0$ for C shunt based on U_{ph-ph} for D-connections or U_{ph-e} for Y/YN-connections
Url	kV	Voltage across Inductor (Rs-L)	$=0$ for C shunt

Table 2.1: Detailed quantities for balanced load flow

The losses in Rp and the losses in the inductor (Rs) are calculated as follows:

$$PL = \Re\left((\underline{u}_{bus1} - \underline{u}_C) \cdot \underline{i}_L^*\right) \cdot 1000 \tag{1}$$

$$PRp = \Re\left((\underline{u}_{bus1} - \underline{u}_C) \cdot \underline{i}_{Rp}^*\right) \cdot 1000 \tag{2}$$

where

- $\underline{u}_{bus1}$ is the voltage in p.u. of the busbar
- $\underline{u}_C$ is the voltage across the capacitor in p.u
- $\underline{i}_L^*$ is the complex conjugate of current through inductor in p.u
- $\underline{i}_{Rp}^*$ is the complex conjugate of current through Rp in p.u

Unbalanced load flow

Quantity	Unit	Description	Comment
$ucph$	$p.u.$	Voltage across Capacitor (Phase Value)	$=0$ for R-L shunt based on U_{ph-ph} for D-connections or U_{ph-e} for Y/YN-connections
$Ucph$	kV	Voltage across Capacitor (Phase Value)	$=0$ for R-L shunt
$ILph$	A	Current through Inductor L (Phase Value)	$=0$ for C shunt
$ICph$	A	Current through Capacitor C (Phase Value)	$=0$ for R-L shunt
$IRpph$	A	Current through Rp (Phase Value)	
$urlph$	$p.u.$	Voltage across Inductor (Phase Value)	$=0$ for C shunt based on U_{ph-ph} for D-connections or U_{ph-e} for Y/YN-connections
$Urlph$	kV	Voltage across Inductor (Phase Value)	$=0$ for C shunt
uc	$p.u.$	Voltage across Capacitor (max abc)	Max. of all phase, $ucph$
Uc	kV	Voltage across Capacitor (max abc)	Max. of all phase, $Ucph$
IL	A	Current through Inductor (max abc)	Max. of all phase, $ILph$
IC	A	Current through Capacitor (max abc)	Max. of all phase, $ICph$
IRp	A	Current through Rp (max abc)	Max. of all phase, $IRpph$
url	$p.u.$	Voltage across Inductor (max abc)	Max. of all phase, url
Url	kV	Voltage across Inductor (max abc)	Max. of all phase, Url
PRp	kW	Losses in Rp	
PL	kW	Losses in Inductor (Rs)	

Table 2.2: Detailed quantities for unbalanced load flow

The losses in Rp and the losses in the inductor (Rs) are for a 3-phase shunt/filter calculated as follows:

- Technology 3PH-'D':

$$PL = \Re\left((\underline{u}_{ab} - \underline{u}_{C,ab}) \cdot \underline{i}^*_{L,a} + (\underline{u}_{bc} - \underline{u}_{C,bc}) \cdot \underline{i}^*_{L,b} + (\underline{u}_{ca} - \underline{u}_{C,ca}) \cdot \underline{i}^*_{L,c}\right) \cdot 1000/3$$
$$PRp = \Re\left((\underline{u}_{ab} - \underline{u}_{C,ab}) \cdot \underline{i}^*_{Rp,a} + (\underline{u}_{bc} - \underline{u}_{C,bc}) \cdot \underline{i}^*_{Rp,b} + (\underline{u}_{ca} - \underline{u}_{C,ca}) \cdot \underline{i}^*_{Rp,c}\right) \cdot 1000/3$$

- Technology 3PH-'Y' and 3PH-'YN':

$$PL = \Re\left((\underline{u}_{a} - \underline{u}_{C,a}) \cdot \underline{i}^*_{L,a} + (\underline{u}_{b} - \underline{u}_{C,b}) \cdot \underline{i}^*_{L,b} + (\underline{u}_{c} - \underline{u}_{C,c}) \cdot \underline{i}^*_{L,c}\right) \cdot 1000/3$$
$$PRp = \Re\left((\underline{u}_{a} - \underline{u}_{C,a}) \cdot \underline{i}^*_{Rp,a} + (\underline{u}_{b} - \underline{u}_{C,b}) \cdot \underline{i}^*_{Rp,b} + (\underline{u}_{c} - \underline{u}_{C,c}) \cdot \underline{i}^*_{Rp,c}\right) \cdot 1000/3$$

- Technology 2PH-'Y' and 2PH-'YN':

$$PL = \Re\left((\underline{u}_{a} - \underline{u}_{C,a}) \cdot \underline{i}^*_{L,a} + (\underline{u}_{b} - \underline{u}_{C,b}) \cdot \underline{i}^*_{L,b}\right) \cdot 1000/3$$
$$PRp = \Re\left((\underline{u}_{a} - \underline{u}_{C,a}) \cdot \underline{i}^*_{Rp,a} + (\underline{u}_{b} - \underline{u}_{C,b}) \cdot \underline{i}^*_{Rp,b}\right) \cdot 1000/3$$

- Technology 1PH PH-PH:

$$PL = \Re\left((\underline{u}_{ab} - \underline{u}_{C,ab}) \cdot \underline{i}^*_{L,a}\right) \cdot 1000/3$$
$$PRp = \Re\left((\underline{u}_{ab} - \underline{u}_{C,ab}) \cdot \underline{i}^*_{Rp,a}\right) \cdot 1000/3$$

- Technology 1PH-E and 1PH-N:

$$PL = \Re\left((\underline{u}_{a} - \underline{u}_{C,a}) \cdot \underline{i}^*_{L,a}\right) \cdot 1000/3$$
$$PRp = \Re\left((\underline{u}_{a} - \underline{u}_{C,a}) \cdot \underline{i}^*_{Rp,a}\right) \cdot 1000/3$$

where

- $\underline{u}_{a,b,c} = \underline{u}_{a,b,c;bus1} - \underline{u}_0$, busbar phase voltages minus zero-sequence voltage u_0
- $\underline{u}_{ab,bc,ca} = \underline{u}_{ab,bc,ca;bus1}$, are the busbar phase line to line voltages in p.u.
- $\underline{u}_{C;a,b,c}$ are the voltages across the capacitors in p.u
- $\underline{i}^*_{L;a,b,c}$ are the complex conjugate of current through inductors in p.u
- $\underline{i}^*_{Rp;a,b,c}$ are the complex conjugate of current through Rp in p.u

$\underline{u}_0$ is

- for a shunt/filter with neutral connection $\underline{u}_0 = u_{neutral}$
- for a 3-phase grounded shunt/filter $\underline{u}_0 = \underline{z}_e \cdot 3 \cdot \underline{i}_0$
- for a 3-phase ungrounded e.g. Y shunt/filter $\underline{u}_0 = \frac{1}{3} \cdot (\underline{u}_{a,bus1} + \underline{u}_{b,bus1} + \underline{u}_{c,bus1})$
- for a 2-phase grounded shunt/filter $\underline{u}_0 = \underline{z}_e \cdot 2 \cdot \underline{i}_0$
- for a 2-phase ungrounded e.g. Y shunt/filter $\underline{u}_0 = \frac{1}{2} \cdot (\underline{u}_{a,bus1} + \underline{u}_{b,bus1})$

and z_e is the p.u. grounding impedance (*Re*, *Xe*)

2.3.2 Losses

The active power flow of a shunt caused by the entered resistances are equal to the $Ploss$.

Quantity	Unit	Description	Value
$Ploss$	MW	Losses (total)	$= P$
$Qloss$	$Mvar$	Reactive-Losses (total)	$= 0$
$Plossld$	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 2.3: Losses Quantities

3 RMS Simulation

The integrated shunt controller is available also in *RMS Simulations* but only for 3PH-’D’, 3PH-’Y’ and 3PH-’YN’ technology.

4 EMT Simulation

The integrated shunt controller is not available in EMT simulations.

In EMT simulations it is possible to take into account saturation of the inductor. Saturation is modelled is a similar way as for the magnetizing impedance of a 2-winding transformer. More detailed information can be found in the 2-Winding Transformer Technical Reference.

However, notice that in the shunt the value of the *Linear reactance* refers to the value of the unsaturated inductance specified in the *Basic Data* page and it is always 1 p.u.

Attention must be paid when entering the current-flux (voltage) values of the saturation curve or the value of the knee point flux for a 2PH-'Y' ungrounded shunt with system type "AC" (and connected to a three-phase system). In this case the fluxes refer to one single impedance X_{rea}, see Figure 1.6. When all voltages over the shunt are at nominal value, the voltage over X_{rea} is equal to $\sqrt{3}/2$. Therefore the flux values defined for saturation must take this factor into account.

5 Harmonics/Power Quality

5.1 Parameter Frequency Dependency

Frequency-dependent characteristics may be defined for the parameters as listed in the following subsections.

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

5.1.1 R-L-C

Frequency-dependent parameters may optionally be defined for the following parameters (parameter names follow in parentheses): Rs ($rrea$), L ($rlrea$) and C ($ccap$).

5.1.2 R-L

Frequency-dependent parameters may optionally be defined for the following parameters (parameter names follow in parentheses): Rs ($rrea$) and L ($rlrea$).

5.1.3 C

Frequency-dependent parameters may optionally be defined for the following parameter (parameter name follows in parentheses): C ($ccap$).

5.1.4 R-L-C,Rp

Frequency-dependent parameters may optionally be defined for the following parameters (parameter names follow in parentheses): Rs ($rrea$), L ($rlrea$), C ($ccap$) and Rp ($rpara$).

5.1.5 R-L-C1-C2,Rp (Hipass Filter)

Frequency-dependent parameters may optionally be defined for the following parameters (parameter names follow in parentheses): Rs ($rrea$), L ($rlrea$), C1 ($c1$), C2 ($c2$) and Rp ($rpara$).

5.2 Result Variables

Different quantities relevant to harmonics calculations are available for each inductor, capacitor and parallel resistor as result variables. As an example, for inductor L the following result variables are defined:

- *url* (p.u.), Voltage across Inductor L (value at the output frequency)
- *ufn_rl* (p.u.), Fundamental Frequency Voltage across Inductor L (Rs-L)

- *uhrms_rl* (p.u.), Harmonic Voltage (rms) across Inductor L (Rs-L)
- *uha_rl* (p.u.), Harmonic Voltage (arith.) across Inductor L (Rs-L)
- *ut_rl* (p.u.), Total Voltage (u_fn+uhrms) across Inductor L (Rs-L)
- *Url* (kV), Voltage across Inductor L (value at the output frequency)
- *Ufn_rl* (kV), Fundamental Frequency Voltage across Inductor L (Rs-L)
- *Uhrms_rl* (kV), Harmonic Voltage (rms) across Inductor L (Rs-L)
- *Uha_rl* (kV), Harmonic Voltage (arith.) across Inductor L (Rs-L)
- *Ut_rl* (kV), Total Voltage (U_fn+Uhrms) across Inductor L (Rs-L)
- *IL* (A), Current through Inductor L (value at the output frequency)
- *Ifn_L* (A), Fundamental Frequency Current through Inductor L (Rs-L)
- *Ihrms_L* (A), Harmonic Current (rms) through Inductor L (Rs-L)
- *Irms_L* (A), RMS Value of Current through Inductor L (Rs-L)
- *PL* (kW), Losses in Inductor (Rs) (value at the output frequency)
- *Pfn_L* (kW), Fundamental Frequency Losses of Inductor (Rs)
- *Ph_L* (kW), Harmonic Losses of Inductor (Rs)
- *Pt_L* (kW), Total Losses of Inductor (Rs)

The *ufn_rl*, *Ufn_rl*, *Pfn_rl* and *Ifn_rl* parameters are the voltage, power and current values at fundamental frequency.

The *url*, *Url*, *PL* and *IL* parameters are the voltage, power and current values at the selected output frequency.

The remaining parameters are calculated as:

$$uhrms\_rl = \sqrt{\sum_{k=2}^{n} {url_k}^2}$$

$$uha\_rl = \sum_{k=2}^{n} url_k$$

$$ut\_rl = ufn\_rl + uhrms\_rl$$

$$Uhrms\_rl = \sqrt{\sum_{k=2}^{n} {Url_k}^2}$$

$$Uha\_rl = \sum_{k=2}^{n} Url_k$$

$$Ut\_rl = Ufn\_rl + Uhrms\_rl$$

$$Ihrms\_L = \sqrt{\sum_{k=2}^{n} {IL_k}^2}$$
$$Irms\_L = \sqrt{Ifn\_L^2 + Ihrms\_L^2}$$

$$Ph\_L = \sum_{k=2}^{n} PL_k$$
$$Pt\_L = Pfn\_L + Ph\_L$$

where n is the total number of harmonics which are being considered and the subscript k refers to the k_{th} harmonic.

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