POWERFACTORY

PowerFactory 2021

Technical Reference

Common Result Variables for Terminals and Elements

Load Flow Calculation

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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Contents

1 General Description

This document describes the common variables available for monitoring in *PowerFactory* for the terminals and for the single- and multiple-port elements (primary equipment). These are the parameters that can be selected to be displayed in the result boxes and in the flexible data page of the elements, which are not specific to a certain element.

Variables starting with capital letters are expressed in absolute values and variables starting with a lower case letters are expressed in per unit values.

1.1 Terminals

For the terminals (*ElmTerm*) only the set *Currents, Voltages and Powers* displays common result variables that can be monitored after a calculation. The identification name of a result variable contains the letter m to denominate that it is a common monitoring variable (in opposite to c which stands for calculation variable), a semicolon and the name of the variable. For example, the result variable *Voltage, Magnitude* has the following identification name $m{:}u$.

For the unbalanced representation, the phase result variables get a slightly different identification name where the name of the phase is added. For example: $m{:}u{:}A$.

1.2 Elements (single and multiple port)

For the single- and multiple-port elements (ex.: *ElmSym*, *ElmLne*, *ElmTr3*, etc.), there are two sets containing common result variables that can be monitored after a calculation:

- *Currents, Voltages and Powers*
- *Bus Results*

1.2.1 Currents, Voltages and Powers

The identification name of the variables available in this set is similar to the one used for the terminals with the difference that for the elements also the connection point name is added.

For example $m{:}i1{:}\_LOCALBUS$ is the magnitude of the positive-sequence current of the connected element. If the result variable is shown for a certain type of an element, the real connection point name is used. For example $m{:}i1{:}bushv$ is the magnitude of the positive-sequence current flowing through the HV connection of a transformer and $m{:}i1{:}busi$ is the magnitude of the positive-sequence current flowing through the connection '$busi$' of a line.

For the unbalanced representation, the phase result variables get a slightly different identification name where the name of the phase is added. For example: $m{:}i1{:}\_LOCALBUS{:}A$, $m{:}i1{:}bushv{:}\ A$, $m{:}I{:}bus1{:}A$.

The result variables available for the elements in $p.u.$ values are based on the element (not on the terminal). Due to this, the same variable for a port element and a terminal may have a different value. For example, if the nominal voltage of an element differs from the nominal voltage of a terminal, the positive sequence voltage magnitude $m{:}u$ will have a different value compared to $m{:}u$ of a terminal.

1.2.2 Bus Results

The result variables available in the *Bus Results* set for the terminals are actually the variables from the connected terminal i.e. they are the same as the variables available in the *Currents, Voltages and Powers* set from the terminals.

There are two differences regarding the identification name:

- the letter 'n' is used to denominate that this is a node (terminal) variable
- the connection-point name is also used

The result variables in $p.u.$ values from this set are based on the terminal. Please note that if for example for a certain element $n{:}u1{:}bus1$ and $m{:}u1{:}bus1$ are displayed, the result will be different if the nominal voltage of the element differs from the nominal voltage of the terminal.

2 Balanced Load Flow calculation

The balanced load flow calculations uses positive sequence network representation which is valid for balanced symmetrical networks. The resulting quantities are positive sequence quantities.

For DC terminals and elements, the variables displaying imaginary values are zero.

2.1 Result variables for terminals

As described in Section 1.2.2, the result variables from the *Bus Results* set from the port elements are equivalent to the result variables from the *Currents, Voltages and Currents* set for the terminals.

The result variables available for terminals after a balanced Load Flow calculation are presented in the following sub chapters.

2.1.1 Voltage related variables for terminals

The voltage related variables for the terminals are all based on the positive-sequence, phase to ground complex voltage $\underline{u}$ resulting from the balanced load flow. The relationship between the absolute and per unit value voltage is $\underline{U} = \underline{u} \cdot U_{base}$ where the base voltage is $U_{base} = uknom/\sqrt{3}$ where $uknom$ is the nominal line to line voltage of the terminal.

Table 2.1: Voltage related variables for terminals

Name	**Unit**	**Description**
$u1$	$p.u.$	Positive-Sequence Voltage, Magnitude
$u1r$	$p.u.$	Positive-Sequence Voltage, Real-Part
$u1i$	$p.u.$	Positive-Sequence Voltage, Imaginary-Part
u	$p.u.$	Voltage, Magnitude
ur	$p.u.$	Voltage, Real Part
ui	$p.u.$	Voltage, Imaginary Part
U	kV	Line-Ground Voltage, Magnitude
Ul	kV	Line-Line Voltage, Magnitude
$phiu$	deg	Voltage, Angle
$phiurel$	deg	Voltage, Relative Angle
$u1pc$	$\%$	Voltage, Magnitude
upc	$\%$	Voltage, Magnitude
du	$\%$	Voltage Deviation

The result variables from Table 2.1 are calculated as follows:

- $u1$ is obtained as the magnitude of the complex voltage $\underline{u}$ as:

$$u1 = \sqrt{\underline{u}.r^2 + \underline{u}.i^2}$$

- $u1r$ is obtained from the complex voltage $\underline{u}$ as:

$$u1r = \underline{u}.r$$

- $u1i$ is obtained from the complex voltage $\underline{u}$ as:

$$u1i = \underline{u}.i$$

- u is equal to the positive sequence voltage magnitude:

$$u = u1$$

- ur is obtained as:

$$ur = u1r$$

- ui is obtained as:

$$ui = u1i$$

- U is obtained as:

$$U = u \cdot uknom/\sqrt{3}$$

  where $uknom$ is the nominal voltage of the terminal.

- Ul is obtained as:

$$Ul = u \cdot uknom$$

- $phiu$ is obtained from the complex voltage $\underline{u}$ as:

$$phiu = \arctan\left(\frac{\underline{u}.i}{\underline{u}.r}\right) \cdot \frac{180}{\pi}$$

- $phiurel$ is obtained using the *Initial Angle of Bus Voltage* $phiini$ basic data parameter as:

$$phiurel = phiu - phiini \cdot \frac{180}{\pi}$$

- $u1pc$ is obtained as:

$$u1pc = u \cdot 100$$

- upc is obtained as:

$$upc = u \cdot 100$$

- du is obtained as:

$$du = upc - 100$$

2.1.2 Aggregated power variables for terminals

Table 2.2: Aggregated power variables for terminals

Name	**Unit**	**Description**
$Pgen$	MW	Generation, Active Power
$Qgen$	$Mvar$	Generation, Reactive Power
$Pmot$	MW	Motor Load, Active Power
$Qmot$	$Mvar$	Motor Load, Reactive Power
$Pload$	MW	General Load, Active Power
$Qload$	$Mvar$	General Load, Reactive Power
$Pcomp$	MW	Compensation (Losses)
$Qcomp$	$Mvar$	Compensation
$Pnet$	MW	External Networks, Active Power
$Qnet$	$Mvar$	External Networks, Reactive Power
$Pflow$	MW	Power Flow, Active Power
$Qflow$	$Mvar$	Power Flow, Reactive Power
$Pout$	MW	Outgoing Flow, Active Power
$Qout$	$Mvar$	Outgoing Power, Reactive Power
$Sout$	MVA	Outgoing Power, Apparent Power
$cosphiout$		Outgoing Power, Power Factor
$Pbalance$	MW	Active Power Balance (=0)
$Qbalance$	$Mvar$	Reactive Power Balance (=0)

The result variables from Table 2.2 are calculated as follows:

- $Pgen$ is the active power sum of all synchronous, asynchronous and static generators connected to the terminal. If generation is defined in the MV Load (*ElmLodmv*), the generated active power is also added to this sum.
- $Qgen$ is the reactive power sum of all synchronous, asynchronous and static generators connected to the terminal. If generation is defined in the MV Load (*ElmLodmv*), the generated reactive power is added to this sum.
- $Pmot$ is the active power sum of all synchronous and asynchronous motors connected to the terminal.
- $Qmot$ is the reactive power sum of all synchronous and asynchronous motors connected to the terminal.
- $Pload$ is the active power sum of all loads connected to the terminal.
- $Qload$ is the reactive power sum of all loads connected to the terminal.
- $Pcomp$ is the active power sum of all shunts and filters connected to the terminal.
- $Qcomp$ is the reactive power sum of all shunts and filters connected to the terminal.
- $Pnet$ is the active power sum of all external network elements connected to the terminal.
- $Qnet$ is the reactive power sum of all external network elements connected to the terminal.
- $Pflow$ is the sum of all active power flowing out of the terminal.
- $Qflow$ is the sum of all reactive power flowing out of the terminal.
- $Pout$ is the sum of all active power flowing out of the terminal.

- $Qout$ is the sum of reactive powers of all elements whose active power is flowing out of the terminal ($\sum Q$ if $P > 0$).
- $Sout$ is calculated as:

$$Sout = \sqrt{Pout^2 + Qout^2}$$

- $cosphiout$ is obtained as:

$$cosphiout = \arctan\left(\frac{Qout}{Pout}\right)$$

- $Pbalance$ is the sum of all active power at the terminal. This sum is always zero or near zero and is dependent on the maximum acceptable load flow error setting.
- $Qbalance$ is the sum of all reactive power at the terminal. This sum is always zero or near zero and is dependent on the maximum acceptable load flow error setting.

2.1.3 Low-voltage analysis related variables for terminals

Table 2.3: Low-voltage analysis related variables for terminals

Name	Unit	Description
$umin$	$p.u.$	Minimum Voltage
$Umin$	kV	Minimum Voltage (Line to Neutral)
$dumax$	$\%$	Maximum Voltage Drop along Feeder
$dUmax$	kV	Maximum Voltage Drop along Feeder
$dUlmax$	kV	Maximum Voltage Drop along Feeder (Line-Line)
$Ulmin$	kV	Minimum Voltage (Line to Line)

The result variables from Table 2.3 are calculated from a low-voltage load flow analysis where coincidence of low-voltage loads is considered.

2.1.4 Feeder losses variables for terminals

Table 2.4: Load flow, balanced, feeder losses variables (terminals)

Name	Unit	Description
$LossPdown$	MW	Losses, downstream
$LossQdown$	$Mvar$	Losses, downstream (Reactive Power)
$LossPdownload$	MW	Load losses, downstream
$LossQdownload$	$Mvar$	Load losses, downstream
$LossPdownnoload$	MW	No load losses, downstream
$LossQdownnoload$	$Mvar$	No load losses, downstream
du_feed	$\%$	Voltage difference relative to feeder begin

The result variables from Table 2.4 are calculated as follows:

- $LossPdown$ is the sum of active power load and no-load losses of all elements downward the feeder.

- $LossQdown$ is the sum of reactive power load and no-load losses of all elements downward the feeder.
- $LossPdownload$ is the sum of active power load losses of all elements downward the feeder.
- $LossQdownload$ is the sum of reactive power load losses of all elements downward the feeder.
- $LossPdownnoload$ is the sum of active power no-load losses of all elements downward the feeder.
- $LossQdownnoload$ is the sum of reactive power no-load losses of all elements downward the feeder.
- du_feed is obtained using the magnitude of the voltage where the feeder is defined u_{feeder} and the local positive sequence voltage magnitude:

$$du\_feed = (u_{feeder} - u) \cdot 100$$

2.2 Result variables for elements

The result variables available for single- and multiple-port elements after a balanced Load Flow calculation are presented in the following sub chapters.

2.2.1 Voltage related variables for elements

Similar as for the voltage related variables for the terminals, these variables are calculated from the same positive-sequence, phase to ground complex voltage $\underline{u}$ resulting from the balanced load flow.

For the element based variables, the relationship between the absolute and per unit value voltage is $\underline{U} = \underline{u} \cdot U_{base}$ where the base voltage is $U_{base} = U_{nom\_el}/\sqrt{3}$ where U_{nom_el} is the nominal line to line voltage of the element. Due to the change in base, the per unit values are multiplied with the factor $uknom/U_{nom\_el}$.

Table 2.5: Voltage related variables for elements

Name	Unit	Description
$u1$	$p.u.$	Positive-Sequence-Voltage, Magnitude
$u1r$	$p.u.$	Positive-Sequence Voltage, Real-Part
$u1i$	$p.u.$	Positive-Sequence Voltage, Imaginary-Part
$phiu1$	deg	Positive-Sequence-Voltage, Angle
u	$p.u.$	Voltage, Magnitude
ur	$p.u.$	Voltage, Real Part
ui	$p.u.$	Voltage, Imaginary Part
$U1$	kV	Line-Ground Positive-Sequence-Voltage, Magnitude
$U1l$	kV	Line-Line Positive-Sequence-Voltage, Magnitude

The result variables from Table 2.5 are calculated as follows:

- $u1$ is obtained from the complex voltage $\underline{u}$ as:

$$u1 = \sqrt{\underline{u}.r^2 + \underline{u}.i^2} \cdot \frac{uknom}{U_{nom\_el}}$$

where $uknom$ is the nominal voltage of the connected terminal and U_{nom_el} is the nominal voltage of the element.

- $u1r$ is obtained from the complex voltage $\underline{u}$ as:

$$u1r = \underline{u}.r \cdot \frac{uknom}{U_{nom\_el}}$$

- $u1i$ is obtained from the complex voltage $\underline{u}$ as:

$$u1i = \underline{u}.i \cdot \frac{uknom}{U_{nom\_el}}$$

- $phiu1$ is obtained from the complex voltage $\underline{u}$ as:

$$phiu = \arctan\left(\frac{\underline{u}.i}{\underline{u}.r}\right) \cdot \frac{180}{\pi}$$

- $phiurel$ is obtained using the *Initial Angle of Bus Voltage* $phiini$ basic data parameter as:

$$phiurel = phiu - phiini \cdot \frac{180}{\pi}$$

- u is equal to the positive sequence voltage magnitude:

$$u = u1$$

- ur is obtained as:

$$ur = u1r$$

- ui is obtained as:

$$ui = u1i$$

- $U1$ is obtained as:

$$U1 = u \cdot U_{nom\_el} / \sqrt{3}$$

- $U1l$ is obtained as:

$$U1l = u \cdot U_{nom\_el}$$

2.2.2 Current related variables for elements

The current related variables for the elements are all based on the positive-sequence complex current resulting from the balanced load flow. The relationship between the absolute and per unit value current is $\underline{I} = \underline{i} \cdot I_{nom\_el}$ where $I_{nom\_el} = \frac{MVA_{el}}{\sqrt{3} \cdot U_{nom\_el}}$ is the nominal current of the element.

Table 2.6: Current related variables for elements

Name	Unit	Description
$I1$	kA	Positive-Sequence Current, Magnitude
$phii1$	deg	Positive-Sequence Current, Angle
I	kA	Current, Magnitude
$phii$	deg	Current, Angle
$i1$	$p.u.$	Positive-Sequence Current, Magnitude
$i1r$	$p.u.$	Positive-Sequence Current, Real Part
$i1i$	$p.u.$	Positive-Sequence Current, Imaginary Part
i	$p.u.$	Current, Magnitude
ir	$p.u.$	Current, Real Part
ii	$p.u.$	Current, Imaginary Part
$i1P$	$p.u.$	Positive-Sequence Active Current
$i1Q$	$p.u.$	Positive-Sequence Reactive Current
$I1P$	kA	Positive-Sequence Active Current
$I1Q$	kA	Positive-Sequence Reactive Current
$phiui$	deg	Angle between Voltage and Current
$phiu1i1$	deg	Angle between Voltage and Current in positive sequence system
$inet$	$p.u.$	Current, Magnitude, referred to network

The result variables from Table 2.6 are calculated as follows:

- $I1$ is obtained as the amplitude of the complex current $\underline{I}$:

$$I1 = \sqrt{\underline{I}.r^2 + \underline{I}.i^2}$$

- $phii1$ is obtained from the complex voltage $\underline{i}_{net}$ as:

$$phii1 = \arctan\left(\frac{\underline{I}.i}{\underline{I}.r}\right) \cdot \frac{180}{\pi}$$

- I is equivalent to the positive sequence current magnitude:

$$I = I1$$

- $phii$ is obtained as:

$$phii = phii1$$

- $i1$ is obtained as:

$$i1 = \frac{I}{I_{nom\_el}}$$

  where I_{nom_el} is the nominal current of the element.

- $i1r$ is obtained as:

$$i1r = \frac{\underline{I}.r}{I_{nom\_el}}$$

- $i1i$ is obtained as:

$$i1i = \frac{\underline{I}.i}{I_{nom\_el}}$$

- i is obtained as:

$$i = i1$$

- ir is obtained as:

$$ir = i1r$$

- ii is obtained as:

$$ii = i1i$$

- $i1P$ is obtained as:

$$i1P = i1 \cdot cosphi$$

  where $cosphi$ is the power factor of the element.

- $i1Q$ is obtained as:

$$i1Q = i1 \cdot \sin(\phi)$$

  where ϕ is the angle between the active and reactive power and can be also obtained as: $\phi = \arccos(cosphi)$.

- $I1P$ is obtained as:

$$I1P = I1 \cdot cosphi$$

  where $cosphi$ is the power factor of the element.

- $I1Q$ is obtained as:

$$I1Q = I1 \cdot \sin(\phi)$$

  where ϕ is the angle between the active and reactive power and can be also obtained as: $\phi = \arccos(cosphi)$.

- $phiui$ is obtained as:

$$phiui = phiu - phii$$

- $phiu1i1$ is obtained as:

$$phiu1i1 = phiu1 - phii1$$

- $inet$ is obtained as:

$$inet = \frac{I}{I_{nom\_1MVA}}$$

  where $I_{nom\_1MVA} = \dfrac{1}{\sqrt{3} \cdot uknom}$ is the nominal current for $1MVA$ and $uknom$ is the nominal voltage of the connected terminal.

2.2.3 Power related variables for elements

The apparent power is calculated as $\underline{S} = 3 \cdot \underline{U}_1 \cdot \underline{I}^*$ where $\underline{U}_1$ is the positive sequence voltage.

Table 2.7: Power related variables for elements

Name	Unit	Description
S	MVA	Apparent Power
P	MW	Active Power
Q	$Mvar$	Reactive Power
$cosphi$		Power Factor
$tanphi$		tan(phi)
$Psum$	MW	Total Active Power
$Qsum$	$Mvar$	Total Reactive Power
$Ssum$	MVA	Total Apparent Power
$cosphisum$		Total Power Factor
$tanphisum$		Total tan(phi)
Spu	$MVA/p.u.$	Apparent Power per p.u. Voltage

The result variables from Table 2.7 are calculated as follows:

- S is obtained as the magnitude of the apparent power:

$$S = \sqrt{\underline{S}.r^2 + \underline{S}.i^2}$$

- P is obtained as:

$$P = \underline{S}.r$$

- Q is obtained as:

$$Q = \underline{S}.i$$

- $cosphi$ is obtained as:

$$cosphi = \cos\left(\arctan\left(\frac{Q}{P}\right)\right) = \frac{P}{S}$$

- $tanphi$ is obtained as:

$$tanphi = \frac{Q}{P}$$

- $Psum$ is equal to the magnitude of the active power:

$$Psum = P$$

- $Qsum$ is equal to the magnitude of the reactive power:

$$Qsum = Q$$

- $Ssum$ is equal to the magnitude of the apparent power:

$$Ssum = S$$

- $cosphisum$ is obtained as:

$$cosphisum = cosphi$$

- $tanphisum$ is obtained as:

$$tanphisum = tanphi$$

- Spu is obtained as:

$$Spu = \sqrt{3} \cdot uknom \cdot I$$

2.2.4 Miscellaneous variables for elements

Table 2.8: Miscellaneous variables for elements

Name	Unit	Description
$Tfct$	s	Fault Clearing Time
$Brkload$	$\%$	Breaker Loading
$Imax$	kA	Maximum Current
$Smax$	MVA	Maximum Power

The result variables from Table 2.8 are calculated as follows:

- $Tfct$ gives the fault clearing time of a fuse or a relay located in the local cubicle. If the fuse/relay model is not triggered with the Load Flow current, a default value of $9999{,}999s$ is used.
- $Brkload$ is obtained as:

$$Brkload = \frac{I}{BrkInom} \cdot 100$$

  where $BrkInom$ is the rated current of a switch (input parameter $Inom$ in *TypSwitch*).
- $Imax$ is the maximum current from low-voltage load flow analysis (coincidence of low-voltage loads is considered).
- $Smax$ is obtained as:

$$Smax = \sqrt{3} \cdot uknom \cdot Imax$$

3 Unbalanced Load Flow calculation

The balanced load flow calculations uses multi-phase network representation which is valid for unbalanced networks. The resulting quantities are phase quantities.

For DC terminals and elements, the variables displaying imaginary values are zero.

3.1 Result variables for terminals

As described in Section 1.2.2, the result variables from the *Bus Results* set from the port elements are equivalent to the result variables from the *Currents, Voltages and Currents* set for the terminals.

The result variables available for terminals after an unbalanced Load Flow calculation are presented in the following sub chapters.

3.1.1 Phase voltage related variables for terminals

The voltage related variables for the terminals are all based on the phase to ground complex voltages $\underline{u}_A$, $\underline{u}_B$ and $\underline{u}_C$ resulting from the unbalanced load flow. The relationship between the absolute and per unit value voltage is $\underline{U}_A = \underline{u}_A \cdot U_{base}$ where the base voltage is $U_{base} = uknom/\sqrt{3}$ where $uknom$ is the nominal line to line voltage of the terminal.

Table 3.1: Phase voltage related variables for terminals

Name	**Unit**	**Description**
$ur{:}A$	$p.u.$	Line-Ground Voltage, Real Part
$ur{:}B$	$p.u.$	Line-Ground Voltage, Real Part
$ur{:}C$	$p.u.$	Line-Ground Voltage, Real Part
$ui{:}A$	$p.u.$	Line-Ground Voltage, Real Part
$ui{:}B$	$p.u.$	Line-Ground Voltage, Real Part
$ui{:}C$	$p.u.$	Line-Ground Voltage, Real Part
$u{:}A$	$p.u.$	Line-Ground Voltage, Magnitude
$u{:}B$	$p.u.$	Line-Ground Voltage, Magnitude
$u{:}C$	$p.u.$	Line-Ground Voltage, Magnitude
$upc{:}A$	$\%$	Line-Ground Voltage, Magnitude
$upc{:}B$	$\%$	Line-Ground Voltage, Magnitude
$upc{:}C$	$\%$	Line-Ground Voltage, Magnitude
$U{:}A$	kV	Line-Ground Voltage, Magnitude
$U{:}B$	kV	Line-Ground Voltage, Magnitude
$U{:}C$	kV	Line-Ground Voltage, Magnitude
$phiu{:}A$	deg	Line-Ground Voltage, Angle
$phiu{:}B$	deg	Line-Ground Voltage, Angle
$phiu{:}C$	deg	Line-Ground Voltage, Angle

The result variables from Table 3.1 are calculated as follows:

- $ur{:}A$, $ur{:}B$, $ur{:}C$ are the real part quantities of the resulting complex line to ground voltages:

$$ur{:}A = \underline{u}_A.r$$
$$ur{:}B = \underline{u}_B.r$$
$$ur{:}C = \underline{u}_C.r$$

- $ui{:}A$, $ui{:}B$, $ui{:}C$ are the imaginary part quantities of the resulting complex line to ground voltages:

$$ui{:}A = \underline{u}_A.i$$
$$ui{:}B = \underline{u}_B.i$$
$$ui{:}C = \underline{u}_C.i$$

- $u{:}A$, $u{:}B$, $u{:}C$ are the magnitudes of the resulting line-ground voltages:

$$u{:}A = \sqrt{ur{:}A^2 + ui{:}A^2}$$
$$u{:}B = \sqrt{ur{:}B^2 + ui{:}B^2}$$
$$u{:}C = \sqrt{ur{:}C^2 + ui{:}C^2}$$

- $upc{:}A$, $upc{:}B$, $upc{:}C$ are obtained as:

$$upc{:}A = u{:}A \cdot 100$$
$$upc{:}B = u{:}B \cdot 100$$
$$upc{:}C = u{:}C \cdot 100$$

- $U{:}A$, $U{:}B$, $U{:}C$ are obtained as:
  for AC terminals ($120°$):

$$U{:}A = u{:}A \cdot uknom/\sqrt{3}$$
$$U{:}B = u{:}B \cdot uknom/\sqrt{3}$$
$$U{:}C = u{:}C \cdot uknom/\sqrt{3}$$

  for AC/BI terminals ($180°$):

$$U{:}A = u{:}A \cdot uknom/2$$
$$U{:}B = u{:}B \cdot uknom/2$$
$$U{:}C = u{:}C \cdot uknom/2$$

  where $uknom$ is the nominal voltage of the terminal.

- $phiu{:}A$, $phiu{:}B$, $phiu{:}C$ are obtained as:

$$phiu{:}A = \arctan\left(\frac{ui{:}A}{ur{:}A}\right) \cdot \frac{180}{\pi}$$
$$phiu{:}B = \arctan\left(\frac{ui{:}B}{ur{:}B}\right) \cdot \frac{180}{\pi}$$
$$phiu{:}C = \arctan\left(\frac{ui{:}C}{ur{:}C}\right) \cdot \frac{180}{\pi}$$

3.1.2 Line to line voltage related variables for terminals

The line to line voltages are calculated as the difference between the two phases:

for AC terminals ($120°$):

$$\underline{u}_{lA} = (\underline{u}_A - \underline{u}_B) / \sqrt{3}$$
$$\underline{u}_{lB} = (\underline{u}_B - \underline{u}_C) / \sqrt{3}$$
$$\underline{u}_{lC} = (\underline{u}_C - \underline{u}_A) / \sqrt{3}$$

for AC/BI terminals ($180°$):

$$\underline{u}_{lA} = (\underline{u}_A - \underline{u}_B) / 2$$
$$\underline{u}_{lB} = (\underline{u}_B - \underline{u}_C) / 2$$
$$\underline{u}_{lC} = (\underline{u}_C - \underline{u}_A) / 2$$

For a system containing two phases only the corresponding voltage phase difference is available ($\underline{u}_{lA}$ or $\underline{u}_{lB}$ or $\underline{u}_{lC}$).

For single phase systems, the line to line voltages are not available (cannot be calculated).

Table 3.2: Line to line voltage related variables for terminals

Name	Unit	Description
$ul{:}A$	$p.u.$	Line to Line Voltage, Magnitude
$ul{:}B$	$p.u.$	Line to Line Voltage, Magnitude
$ul{:}C$	$p.u.$	Line to Line Voltage, Magnitude
$ulpc{:}A$	$\%$	Line to Line Voltage, Magnitude
$ulpc{:}B$	$\%$	Line to Line Voltage, Magnitude
$ulpc{:}C$	$\%$	Line to Line Voltage, Magnitude
$Ul{:}A$	kV	Line to Line Voltage, Magnitude
$Ul{:}B$	kV	Line to Line Voltage, Magnitude
$Ul{:}C$	kV	Line to Line Voltage, Magnitude
$phiul{:}A$	deg	Line to Line Voltage, Angle
$phiul{:}B$	deg	Line to Line Voltage, Angle
$phiul{:}C$	deg	Line to Line Voltage, Angle

The result variables from Table 3.2 are calculated as follows:

- $ul{:}A$, $ul{:}B$, $ul{:}C$ are the magnitudes of the line to line voltages:

$$ul{:}A = \sqrt{\underline{u}_{lA}.r^2 + \underline{u}_{lA}.i^2}$$
$$ul{:}B = \sqrt{\underline{u}_{lB}.r^2 + \underline{u}_{lB}.i^2}$$
$$ul{:}C = \sqrt{\underline{u}_{lC}.r^2 + \underline{u}_{lC}.i^2}$$

- $ulpc{:}A$, $ulpc{:}B$, $ulpc{:}C$ are obtained as:

$$ulpc{:}A = ul{:}A \cdot 100$$
$$ulpc{:}B = ul{:}B \cdot 100$$
$$ulpc{:}C = ul{:}C \cdot 100$$

- $Ul{:}A, Ul{:}B, Ul{:}C$ are obtained as:

$$Ul{:}A = ul{:}A \cdot uknom$$
$$Ul{:}B = ul{:}B \cdot uknom$$
$$Ul{:}C = ul{:}C \cdot uknom$$

  where $uknom$ is the nominal voltage of the terminal.

- $phiul{:}A, phiul{:}B, phiul{:}C$ are obtained as:

$$phiul{:}A = \arctan\left(\frac{\underline{u}_{lA}.i}{\underline{u}_{lA}.r}\right) \cdot \frac{180}{\pi}$$
$$phiul{:}B = \arctan\left(\frac{\underline{u}_{lB}.i}{\underline{u}_{lB}.r}\right) \cdot \frac{180}{\pi}$$
$$phiul{:}C = \arctan\left(\frac{\underline{u}_{lC}.i}{\underline{u}_{lC}.r}\right) \cdot \frac{180}{\pi}$$

3.1.3 Line to neutral voltage related variables for terminals

The line to neutral voltages are calculated as the difference between the phase and neutral complex voltages:

$$\underline{u}_{lnA} = \underline{u}_A - \underline{u}_n$$
$$\underline{u}_{lnB} = \underline{u}_B - \underline{u}_n$$
$$\underline{u}_{lnC} = \underline{u}_C - \underline{u}_n$$

Table 3.3: Line to neutral voltage related variables for terminals

Name	Unit	Description
$uln{:}A$	$p.u.$	Line-Neutral Voltage, Magnitude
$uln{:}B$	$p.u.$	Line-Neutral Voltage, Magnitude
$uln{:}C$	$p.u.$	Line-Neutral Voltage, Magnitude
$Uln{:}A$	kV	Line-Neutral Voltage, Magnitude
$Uln{:}B$	kV	Line-Neutral Voltage, Magnitude
$Uln{:}C$	kV	Line-Neutral Voltage, Magnitude
$phiuln{:}A$	deg	Line-Neutral Voltage, Angle
$phiuln{:}B$	deg	Line-Neutral Voltage, Angle
$phiuln{:}C$	deg	Line-Neutral Voltage, Angle
$upht{:}A$	$p.u.$	Phase Technology dependent Voltage, Magnitude
$upht{:}B$	$p.u.$	Phase Technology dependent Voltage, Magnitude
$upht{:}C$	$p.u.$	Phase Technology dependent Voltage, Magnitude
$Upht{:}A$	kV	Phase Technology dependent Voltage, Magnitude
$Upht{:}B$	kV	Phase Technology dependent Voltage, Magnitude
$Upht{:}C$	kV	Phase Technology dependent Voltage, Magnitude

If no neutral connection exists the values of the variables from Table 3.3 are set to zero. If neutral connection exists, the result variables are calculated as follows:

- $uln{:}A, uln{:}B, uln{:}C$ are the magnitudes of the line to neutral voltages:

$$uln{:}A = \sqrt{\underline{u}_{lnA}.r^2 + \underline{u}_{lnA}.i^2}$$
$$uln{:}B = \sqrt{\underline{u}_{lnB}.r^2 + \underline{u}_{lnB}.i^2}$$
$$uln{:}C = \sqrt{\underline{u}_{lnC}.r^2 + \underline{u}_{lnC}.i^2}$$

- $Uln{:}A$, $Uln{:}B$, $Uln{:}C$ are obtained as:
  for AC terminals with neutral ($120°$):

$$Uln{:}A = uln{:}A \cdot uknom \big/ \sqrt{3}$$
$$Uln{:}B = uln{:}B \cdot uknom \big/ \sqrt{3}$$
$$Uln{:}C = uln{:}C \cdot uknom \big/ \sqrt{3}$$

  for AC/BI terminals with neutral ($180°$):

$$Uln{:}A = uln{:}A \cdot uknom \big/ 2$$
$$Uln{:}B = uln{:}B \cdot uknom \big/ 2$$
$$Uln{:}C = uln{:}C \cdot uknom \big/ 2$$

  where $uknom$ is the nominal voltage of the terminal.

- $phiuln{:}A$, $phiuln{:}B$, $phiuln{:}C$ are obtained as:

$$phiuln{:}A = \arctan\left(\frac{\underline{u}_{lnA}.i}{\underline{u}_{lnA}.r}\right) \cdot \frac{180}{\pi}$$
$$phiuln{:}B = \arctan\left(\frac{\underline{u}_{lnB}.i}{\underline{u}_{lnB}.r}\right) \cdot \frac{180}{\pi}$$
$$phiuln{:}C = \arctan\left(\frac{\underline{u}_{lnC}.i}{\underline{u}_{lnC}.r}\right) \cdot \frac{180}{\pi}$$

- $upht{:}A$, $upht{:}B$, $upht{:}C$ are obtained depending if there is neutral connection or not. If there is neutral connection the variables are obtained as:

$$upht{:}A = uln{:}A$$
$$upht{:}B = uln{:}B$$
$$upht{:}C = uln{:}C$$

  If there is no neutral connection as:

$$upht{:}A = ul{:}A$$
$$upht{:}B = ul{:}B$$
$$upht{:}C = ul{:}C$$

- $Upht{:}A$, $Upht{:}B$, $Upht{:}C$ are obtained depending if there is neutral connection or not. If there is neutral connection the variables are obtained as:

$$Upht{:}A = Uln{:}A$$
$$Upht{:}B = Uln{:}B$$
$$Upht{:}C = Uln{:}C$$

  If there is no neutral connection as:

$$Upht{:}A = Ul{:}A$$
$$Upht{:}B = Ul{:}B$$
$$Upht{:}C = Ul{:}C$$

3.1.4 0,1,2 sequence and neutral voltage related variables for terminals

In addition to the phase, line to line and line to neutral voltage quantities, also quantities in the positive, negative and zero sequence are available. $\underline{u}_1$, $\underline{u}_2$ and $\underline{u}_0$ are obtained when the phase values are transformed to symmetrical components.

For 3-phase terminals:

$$\underline{u}0 = \frac{1}{3}\left(\underline{u}_A + \underline{u}_B + \underline{u}_C\right)$$
$$\underline{u}1 = \frac{1}{3}\left(\underline{u}_A + a \cdot \underline{u}_B + a^2 \cdot \underline{u}_C\right)$$
$$\underline{u}2 = \frac{1}{3}\left(\underline{u}_A + a^2 \cdot \underline{u}_B + a \cdot \underline{u}_C\right)$$

where $a = \angle 120°$

For BI-phase terminals ($180°$):

$$\underline{u}0 = \frac{1}{2}\left(\underline{u}_A + \underline{u}_B\right)$$
$$\underline{u}1 = \frac{1}{2}\left(\underline{u}_A - \underline{u}_B\right)$$
$$\underline{u}2 = 0$$

For 2-phase terminals ($120°$):

$$\underline{u}0 = \frac{1}{\sqrt{3}}\left(\underline{u}_A + \underline{u}_B\right)$$
$$\underline{u}1 = \frac{1}{\sqrt{3}}\left(\underline{u}_A - \underline{u}_B\right)$$
$$\underline{u}2 = 0$$

For 1-phase terminals:

$$\underline{u}0 = 0$$
$$\underline{u}1 = \underline{u}_A$$
$$\underline{u}2 = 0$$

Table 3.4: 0,1,2 sequence voltage related variables for terminals

Name	Unit	Description
un	$p.u.$	Neutral-Ground Voltage, Magnitude
Un	kV	Neutral-Ground Voltage, Magnitude
$phiun$	deg	Neutral-Ground Voltage, Angle
um	$p.u.$	Average-Voltage, Magnitude
Um	kV	Average-Voltage, Magnitude
$u0$	$p.u.$	Zero-Sequence Voltage, Magnitude
$U0$	kV	Zero-Sequence Voltage, Magnitude
$U0\times3$	kV	3*U0
$phiu0$	deg	Zero-Sequence Voltage, Angle
$u1$	$p.u.$	Positive-Sequence Voltage, Magnitude
$u1pc$	$\%$	Positive-Sequence Voltage, Magnitude
$u1r$	$p.u.$	Positive-Sequence Voltage, Real Part
$u1i$	$p.u.$	Positive-Sequence Voltage, Imaginary Part
$U1$	kV	Line-Ground Positive-Sequence Voltage, Magnitude
$phiu1$	deg	Positive-Sequence Voltage, Angle
$phiurel$	deg	Voltage, Relative Angle
$u2$	$p.u.$	Negative-Sequence Voltage, Magnitude
$U2$	kV	Line-Ground Negative-Sequence Voltage, Magnitude
$phiu2$	deg	Negative-Sequence Voltage, Angle
$U1l$	kV	Line to Line Positive-Sequence Voltage, Magnitude
$U2l$	kV	Line to Line Negative-Sequence Voltage, Magnitude
$uphtmin$	$p.u.$	Minimum of Phase Technology dependent Voltage, Magnitude
$uphtmax$	$p.u.$	Maximum of Phase Technology dependent Voltage, Magnitude
$ubfac$	$\%$	Unbalance factor

The variables from Table 3.4 are calculated as follows:

- un is obtained from the neutral complex voltage as:

$$un = \sqrt{\underline{u}_n.r^2 + \underline{u}_n.i^2}$$

- Un is obtained as:
  for AC terminals $(120°)$:

$$Un = un \cdot uknom/\sqrt{3}$$

  for AC/BI terminals $(180°)$:

$$Un = un \cdot uknom/2$$

  where $uknom$ is the nominal voltage of the terminal.

- $phiun$ is obtained as:

$$phiun = \arctan\left(\frac{\underline{u}_n.i}{\underline{u}_n.r}\right) \cdot \frac{180}{\pi}$$

- um is calculated by dividing the sum of phase voltage magnitudes of all phases by the number of phases.

- Um is obtained as:
  for AC terminals:

$$Um = um \cdot uknom/\sqrt{3}$$

for AC/BI terminals:

$$Um = um \cdot uknom/2$$

where $uknom$ is the nominal voltage of the terminal.

- $u0$ is obtained from the zero sequence complex voltage as:

$$u0 = \sqrt{\underline{u}_0.r^2 + \underline{u}_0.i^2}$$

- $U0$ is obtained as:
  for AC terminals ($120°$):

$$U0 = u0 \cdot uknom/\sqrt{3}$$

for AC/BI terminals ($180°$):

$$U0 = u0 \cdot uknom/2$$

where $uknom$ is the nominal voltage of the terminal.

- $U0{\times}3$ is calculated as $3 \cdot U0$ for three phase, as $2 \cdot U0$ for two phase and as $U0$ for single phase systems.

- $phiu0$ is obtained as:

$$phiu0 = \arctan\left(\frac{\underline{u}_0.i}{\underline{u}_0.r}\right) \cdot \frac{180}{\pi}$$

- $u1$ is obtained from the positive sequence complex voltage as:

$$u1 = \sqrt{\underline{u}_1.r^2 + \underline{u}_1.i^2}$$

- $u1pc$ is obtained as:

$$u1pc = u1 \cdot 100$$

- $u1r$ is obtained from the positive sequence complex voltage as:

$$u1r = \underline{u}_1.r$$

- $u1i$ is obtained from the positive sequence complex voltage as:

$$u1i = \underline{u}_1.i$$

- $U1$ is obtained as:
  for AC terminals ($120°$):

$$U1 = u1 \cdot uknom/\sqrt{3}$$

for AC/BI terminals ($180°$):

$$U1 = u1 \cdot uknom/2$$

where $uknom$ is the nominal voltage of the terminal.

- $phiu1$ is obtained as:

$$phiu1 = \arctan\left(\frac{\underline{u}_1.i}{\underline{u}_1.r}\right) \cdot \frac{180}{\pi}$$

- $phiurel$ is obtained by using the *Initial Angle of Bus Voltage* $phiini$ basic data parameter as:

$$phiurel = phiu_1 - phiini \cdot \frac{180}{\pi}$$

- $u2$ is obtained from the negative sequence complex voltage as:

$$u2 = \sqrt{\underline{u}_2.r^2 + \underline{u}_2.i^2}$$

- $U2$ is obtained as (only for 3-phase terminals):

$$U2 = u2 \cdot uknom/\sqrt{3}$$

  where $uknom$ is the nominal voltage of the terminal.

- $phiu2$ is obtained as:

$$phiu2 = \arctan\left(\frac{\underline{u}_2.i}{\underline{u}_2.r}\right) \cdot \frac{180}{\pi}$$

- $U1l$ is obtained as:
  for 2-phase and 3-phase terminals:

$$U1l = u1 \cdot uknom$$

  for 1-phase terminals:

$$U1l = U1$$

- $uphtmin$ is the minimum of $upht{:}A$, $upht{:}B$, $upht{:}C$.
- $uphtmax$ is the maximum of $upht{:}A$, $upht{:}B$, $upht{:}C$.
- $ubfac$ is calculated as:

$$ubfac = \frac{u2}{u1} \cdot 100$$

  If number of phases is less then three, it is set to zero.

3.1.5 Aggregated power variables for terminals

Table 3.5: Aggregated power variables for terminals

Name	Unit	Description
$Pgen$	MW	Generation, Active Power
$Qgen$	$Mvar$	Generation, Reactive Power
$Pmot$	MW	Motor Load, Active Power
$Qmot$	$Mvar$	Motor Load, Reactive Power
$Pload$	MW	General Load, Active Power
$Qload$	$Mvar$	General Load, Reactive Power
$Pcomp$	MW	Compensation (Losses)
$Qcomp$	$Mvar$	Compensation
$Pnet$	MW	External Networks, Active Power
$Qnet$	$Mvar$	External Networks, Reactive Power
$Pflow$	MW	Power Flow, Active Power
$Qflow$	$Mvar$	Power Flow, Reactive Power
$Pout$	MW	Outgoing Flow, Active Power
$Qout$	$Mvar$	Outgoing Power, Reactive Power
$Sout$	MVA	Outgoing Power, Apparent Power
$cosphiout$		Outgoing Power, Power Factor
$Pbalance$	MW	Active Power Balance (=0)
$Qbalance$	$Mvar$	Reactive Power Balance (=0)

The result variables from Table 3.5 are equivalent as the variables presented from the balanced load flow calculation in Table 2.2. Please refer to Table 2.2 for more information.

3.1.6 Low-voltage analysis related variables for terminals

Table 3.6: Low-voltage analysis related variables for terminals

Name	Unit	Description
$umin$	$p.u.$	Minimum Voltage
$Umin$	kV	Minimum Voltage (Line to Neutral)
$dumax$	$\%$	Maximum Voltage Drop along Feeder

The result variables from Table 3.6 are calculated from a low-voltage load flow analysis where coincidence of low-voltage loads is considered.

3.1.7 Feeder losses variables for terminals

Table 3.7: Load flow, unbalanced, feeder losses variables (terminals)

Name	Unit	Description
$LossPdown$	MW	Losses, downstream
$LossQdown$	$Mvar$	Losses, downstream (Reactive Power)
$LossPdownload$	MW	Load losses, downstream
$LossQdownload$	$Mvar$	Load losses, downstream
$LossPdownnoload$	MW	No load losses, downstream
$LossQdownnoload$	$Mvar$	No load losses, downstream

Please refer to Table 2.4 for more information on the variables from Table 3.7.

3.2 Result variables for elements

The result variables available for for single- and multiple-port elements after an unbalanced Load Flow calculation are presented in the following sub chapters.

3.2.1 Voltage related variables for elements

The voltage related variables for the terminals are all based on the phase to ground complex voltages $\underline{u}_A$, $\underline{u}_B$, $\underline{u}_C$ and $\underline{u}_N$ resulting from the unbalanced load flow.

For the element based variables, the relationship between the absolute and per unit value voltage is $\underline{U}_A = \underline{u}_A \cdot U_{base}$ where the base voltage is $U_{base} = U_{nom\_el}/\sqrt{3}$ where U_{nom_el} is the nominal line to line voltage of the element. Due to the change in base, the per unit values are multiplied with the factor $uknom/U_{nom\_el}$.

Table 3.8: Voltage related variables for elements

Name	**Unit**	**Description**
$ur{:}A$	$p.u.$	Phase Voltage, Real Part
$ur{:}B$	$p.u.$	Phase Voltage, Real Part
$ur{:}C$	$p.u.$	Phase Voltage, Real Part
$ur{:}N$	$p.u.$	Phase Voltage, Real Part
$ui{:}A$	$p.u.$	Phase Voltage, Imaginary Part
$ui{:}B$	$p.u.$	Phase Voltage, Imaginary Part
$ui{:}C$	$p.u.$	Phase Voltage, Imaginary Part
$ui{:}N$	$p.u.$	Phase Voltage, Imaginary Part
$u{:}A$	$p.u.$	Phase Voltage, Magnitude
$u{:}B$	$p.u.$	Phase Voltage, Magnitude
$u{:}C$	$p.u.$	Phase Voltage, Magnitude
$u{:}N$	$p.u.$	Phase Voltage, Magnitude

The result variables from Table 3.8 are calculated as follows:

- $ur{:}A$, $ur{:}B$, $ur{:}C$, $ur{:}N$ are obtained from the complex phase voltages as:

$$ur{:}A = \underline{u}_A.r \cdot \frac{uknom}{U_{nom\_el}}$$
$$ur{:}B = \underline{u}_B.r \cdot \frac{uknom}{U_{nom\_el}}$$
$$ur{:}C = \underline{u}_C.r \cdot \frac{uknom}{U_{nom\_el}}$$
$$ur{:}N = \underline{u}_N.r \cdot \frac{uknom}{U_{nom\_el}}$$

  where $uknom$ is the nominal voltage of the connected terminal and U_{nom_el} is the nominal voltage of the element.

- $ui{:}A$, $ui{:}B$, $ui{:}C$, $ui{:}N$ are obtained from the complex phase voltages as:

$$ui{:}A = \underline{u}_A.i \cdot \frac{uknom}{U_{nom\_el}}$$
$$ui{:}B = \underline{u}_B.i \cdot \frac{uknom}{U_{nom\_el}}$$
$$ui{:}C = \underline{u}_C.i \cdot \frac{uknom}{U_{nom\_el}}$$
$$ui{:}N = \underline{u}_N.i \cdot \frac{uknom}{U_{nom\_el}}$$

  where $uknom$ is the nominal voltage of the connected terminal and U_{nom_el} is the nominal voltage of the element.

- $u{:}A$, $u{:}B$, $u{:}C$, $u{:}N$ are obtained from the complex phase voltages as:

$$u{:}A = \sqrt{\underline{u}_A.r^2 + \underline{u}_A.i^2} \cdot \frac{uknom}{U_{nom\_el}}$$
$$u{:}B = \sqrt{\underline{u}_B.r^2 + \underline{u}_B.i^2} \cdot \frac{uknom}{U_{nom\_el}}$$
$$u{:}C = \sqrt{\underline{u}_C.r^2 + \underline{u}_C.i^2} \cdot \frac{uknom}{U_{nom\_el}}$$
$$u{:}N = \sqrt{\underline{u}_N.r^2 + \underline{u}_N.i^2} \cdot \frac{uknom}{U_{nom\_el}}$$

3.2.2 Current related variables for elements

The current related variables for the elements are all based on the complex phase current resulting from the unbalanced load flow. The relationship between the absolute and per unit value current is $\underline{I}_A = \underline{i}_A \cdot I_{nom\_el}$ where $I_{nom\_el} = \dfrac{MVA_{el}}{\sqrt{3} \cdot U_{nom\_el}}$ is the nominal current of the element.

Table 3.9: Current related variables for elements

Name	Unit	Description
$I{:}A$	kA	Phase Current, Magnitude
$I{:}B$	kA	Phase Current, Magnitude
$I{:}C$	kA	Phase Current, Magnitude
$I{:}N$	kA	Phase Current, Magnitude
$phii{:}A$	deg	Phase Current, Angle
$phii{:}B$	deg	Phase Current, Angle
$phii{:}C$	deg	Phase Current, Angle
$phii{:}N$	deg	Phase Current, Angle
$ir{:}A$	$p.u.$	Phase Current, Real Part
$ir{:}B$	$p.u.$	Phase Current, Real Part
$ir{:}C$	$p.u.$	Phase Current, Real Part
$ir{:}N$	$p.u.$	Phase Current, Real Part
$ii{:}A$	$p.u.$	Phase Current, Imaginary Part
$ii{:}B$	$p.u.$	Phase Current, Imaginary Part
$ii{:}C$	$p.u.$	Phase Current, Imaginary Part
$ii{:}N$	$p.u.$	Phase Current, Imaginary Part
$i{:}A$	$p.u.$	Phase Current, Magnitude
$i{:}B$	$p.u.$	Phase Current, Magnitude
$i{:}C$	$p.u.$	Phase Current, Magnitude
$i{:}N$	$p.u.$	Phase Current, Magnitude
$phiui{:}A$	deg	Angle between Voltage and Current
$phiui{:}B$	deg	Angle between Voltage and Current
$phiui{:}C$	deg	Angle between Voltage and Current
$phiui{:}N$	deg	Angle between Voltage and Current
$inet{:}A$	$p.u.$	Phase Current, Magnitude, referred to network
$inet{:}B$	$p.u.$	Phase Current, Magnitude, referred to network
$inet{:}C$	$p.u.$	Phase Current, Magnitude, referred to network
$inet{:}N$	$p.u.$	Phase Current, Magnitude, referred to network

The result variables from Table 3.9 are calculated as follows:

- $I{:}A$, $I{:}B$, $I{:}C$, $I{:}N$ are obtained as amplitudes of the complex currents:

$$I{:}A = \sqrt{\underline{I}_A.r^2 + \underline{I}_A.i^2}$$
$$I{:}B = \sqrt{\underline{I}_B.r^2 + \underline{I}_B.i^2}$$
$$I{:}C = \sqrt{\underline{I}_C.r^2 + \underline{I}_C.i^2}$$
$$I{:}N = \sqrt{\underline{I}_N.r^2 + \underline{I}_N.i^2}$$

- $phii{:}A$, $phii{:}B$, $phii{:}C$, $phii{:}N$ are obtained as:

$$phii{:}A = \arctan\left(\frac{\underline{I}_A.i}{\underline{I}_A.r}\right)\cdot\frac{180}{\pi}$$
$$phii{:}B = \arctan\left(\frac{\underline{I}_B.i}{\underline{I}_B.r}\right)\cdot\frac{180}{\pi}$$
$$phii{:}C = \arctan\left(\frac{\underline{I}_C.i}{\underline{I}_C.r}\right)\cdot\frac{180}{\pi}$$
$$phii{:}N = \arctan\left(\frac{\underline{I}_N.i}{\underline{I}_N.r}\right)\cdot\frac{180}{\pi}$$

- $ir{:}A$, $ir{:}B$, $ir{:}C$, $ir{:}N$ are obtained as:

$$ir{:}A = \frac{\underline{I}_A.r}{I_{nom\_el}}$$
$$ir{:}B = \frac{\underline{I}_B.r}{I_{nom\_el}}$$
$$ir{:}C = \frac{\underline{I}_C.r}{I_{nom\_el}}$$
$$ir{:}N = \frac{\underline{I}_N.r}{I_{nom\_el}}$$

- $ii{:}A$, $ii{:}B$, $ii{:}C$, $ii{:}N$ are obtained as:

$$ii{:}A = \frac{\underline{I}_A.i}{I_{nom\_el}}$$
$$ii{:}B = \frac{\underline{I}_B.i}{I_{nom\_el}}$$
$$ii{:}C = \frac{\underline{I}_C.i}{I_{nom\_el}}$$
$$ii{:}N = \frac{\underline{I}_N.i}{I_{nom\_el}}$$

- $i{:}A$, $i{:}B$, $i{:}C$, $i{:}N$ are obtained as:

$$i{:}A = \frac{I{:}A}{I_{nom\_el}}$$
$$i{:}B = \frac{I{:}B}{I_{nom\_el}}$$
$$i{:}C = \frac{I{:}C}{I_{nom\_el}}$$
$$i{:}N = \frac{I{:}N}{I_{nom\_el}}$$

- $phiui{:}A$, $phiui{:}B$, $phiui{:}C$, $phiui{:}N$ are obtained as:

$$phiui{:}A = \arctan\left(\frac{\underline{u}_A.i}{\underline{u}_A.r}\right)\cdot\frac{180}{\pi} - phii{:}A$$
$$phiui{:}B = \arctan\left(\frac{\underline{u}_B.i}{\underline{u}_B.r}\right)\cdot\frac{180}{\pi} - phii{:}B$$
$$phiui{:}C = \arctan\left(\frac{\underline{u}_C.i}{\underline{u}_C.r}\right)\cdot\frac{180}{\pi} - phii{:}C$$
$$phiui{:}N = \arctan\left(\frac{\underline{u}_N.i}{\underline{u}_N.r}\right)\cdot\frac{180}{\pi} - phii{:}N$$

- $inet{:}A$, $inet{:}B$, $inet{:}C$, $inet{:}N$ are obtained from the amplitude of the phase currents as:

$$inet{:}A = \frac{I{:}A}{I_{nom\_1MVA}}$$
$$inet{:}B = \frac{I{:}B}{I_{nom\_1MVA}}$$
$$inet{:}C = \frac{I{:}C}{I_{nom\_1MVA}}$$
$$inet{:}N = \frac{I{:}N}{I_{nom\_1MVA}}$$

where $I_{nom\_1MVA} = \dfrac{1}{\sqrt{3} \cdot uknom}$ is the nominal current for $1MVA$ and $uknom$ is the nominal voltage of the connected terminal.

3.2.3 Miscellaneous variables per phase for elements

Table 3.10: Miscellaneous variables per phase for elements

Name	Unit	Description
$TfctPh{:}A$	s	Fault Clearing Time
$TfctPh{:}B$	s	Fault Clearing Time
$TfctPh{:}C$	s	Fault Clearing Time
$TfctPh{:}N$	s	Fault Clearing Time
$BrkloadPh{:}A$	$\%$	Breaker Loading
$BrkloadPh{:}B$	$\%$	Breaker Loading
$BrkloadPh{:}C$	$\%$	Breaker Loading
$BrkloadPh{:}N$	$\%$	Breaker Loading

The result variables from Table 3.10 are calculated as follows:

- $TfctPh{:}A$, $TfctPh{:}B$, $TfctPh{:}C$, $TfctPh{:}N$ give the fault clearing time of a fuse or a relay located in the local cubicle. If the fuse/relay model is not triggered with the Load Flow current, a default value of $9999{,}999s$ is used.
- $BrkloadPh{:}A$, $BrkloadPh{:}B$, $BrkloadPh{:}C$, $BrkloadPh{:}N$ are calculated as:

$$BrkloadPh{:}A = \frac{I{:}A}{BrkInom} \cdot 100$$
$$BrkloadPh{:}B = \frac{I{:}B}{BrkInom} \cdot 100$$
$$BrkloadPh{:}C = \frac{I{:}C}{BrkInom} \cdot 100$$
$$BrkloadPh{:}N = \frac{I{:}N}{BrkInom} \cdot 100$$

where $BrkInom$ is the rated current of a switch (input parameter $Inom$ in *TypSwitch*) located in the cubicle.

3.2.4 0,1,2 sequence voltage related variables for elements

In addition to the phase, line to line and line to neutral voltage quantities, also quantities in the positive, negative and zero sequence are available.

For 3-phase elements:

$$\underline{u}0 = \frac{1}{3}\left(\underline{u}_A + \underline{u}_B + \underline{u}_C\right)$$
$$\underline{u}1 = \frac{1}{3}\left(\underline{u}_A + a \cdot \underline{u}_B + a^2 \cdot \underline{u}_C\right)$$
$$\underline{u}2 = \frac{1}{3}\left(\underline{u}_A + a^2 \cdot \underline{u}_B + a \cdot \underline{u}_C\right)$$

where $a = \angle 120°$

For BI-phase elements ($180°$):

$$\underline{u}0 = \frac{1}{2}\left(\underline{u}_A + \underline{u}_B\right)$$
$$\underline{u}1 = \frac{1}{2}\left(\underline{u}_A - \underline{u}_B\right)$$
$$\underline{u}2 = 0$$

For 2-phase elements ($120°$):

$$\underline{u}0 = \frac{1}{\sqrt{3}}\left(\underline{u}_A + \underline{u}_B\right)$$
$$\underline{u}1 = \frac{1}{\sqrt{3}}\left(\underline{u}_A - \underline{u}_B\right)$$
$$\underline{u}2 = 0$$

For 1-phase elements:

$$\underline{u}0 = 0$$
$$\underline{u}1 = \underline{u}_A$$
$$\underline{u}2 = 0$$

Table 3.11: 0,1,2 sequence voltage related variables for elements

Name	**Unit**	**Description**
$u0$	$p.u$	Zero-Sequence-Voltage, Magnitude
$phiu0$	deg	Zero-Sequence-Voltage, Angle
$u1r$	$p.u$	Positive-Sequence-Voltage, Real Part
$u1i$	$p.u$	Positive-Sequence-Voltage, Imaginary Part
$u1$	$p.u$	Positive-Sequence-Voltage, Magnitude
$U1$	kV	Line-Ground Positive-Sequence-Voltage, Magnitude
$U1l$	kV	Line-Line Positive-Sequence-Voltage, Magnitude
$phiu1$	deg	Positive-Sequence-Voltage, Angle
$u2$	$p.u$	Negative-Sequence-Voltage, Magnitude
$phiu2$	deg	Negative-Sequence-Voltage, Angle

The variables from Table 3.11 are calculated as follows:

- $u0$ is obtained from the zero sequence complex voltage as:

$$u0 = \sqrt{\underline{u}_0.r^2 + \underline{u}_0.i^2} \cdot \frac{uknom}{U_{nom\_el}}$$

  where $uknom$ is the nominal voltage of the connected terminal and U_{nom_el} is the nominal voltage of the element.

- $phiu0$ is obtained as:

$$phiu0 = \arctan\left(\frac{\underline{u}_0.i}{\underline{u}_0.r}\right) \cdot \frac{180}{\pi}$$

- $u1r$ is obtained from the positive sequence complex voltage as:

$$u1r = \underline{u}_1.r \cdot \frac{uknom}{U_{nom\_el}}$$

- $u1i$ is obtained from the positive sequence complex voltage as:

$$u1i = \underline{u}_1.i \cdot \frac{uknom}{U_{nom\_el}}$$

- $u1$ is obtained from the positive sequence complex voltage as:

$$u1 = \sqrt{\underline{u}_1.r^2 + \underline{u}_1.i^2} \cdot \frac{uknom}{U_{nom\_el}}$$

- $U1$ is obtained as:
  for AC elements:

$$U1 = u1 \cdot U_{nom\_el} \big/ \sqrt{3}$$

  for AC/BI elements:

$$U1 = u1 \cdot U_{nom\_el} \big/ 2$$

- $U1l$ is obtained as:
  for 2-phase and 3-phase terminals:

$$U1l = u1 \cdot U_{nom\_el}$$

  for 1-phase terminals:

$$U1l = U1$$

- $phiu1$ is obtained as:

$$phiu1 = \arctan\left(\frac{\underline{u}_1.i}{\underline{u}_1.r}\right) \cdot \frac{180}{\pi}$$

- $u2$ is obtained from the negative sequence complex voltage as:

$$u2 = \sqrt{\underline{u}_2.r^2 + \underline{u}_2.i^2} \cdot \frac{uknom}{U_{nom\_el}}$$

- $phiu2$ is obtained as:

$$phiu2 = \arctan\left(\frac{\underline{u}_2.i}{\underline{u}_2.r}\right) \cdot \frac{180}{\pi}$$

3.2.5 0,1,2 sequence current related variables for elements

In addition to the phase quantities, also quantities in the positive, negative and zero sequence are available. $\underline{I}_1$, $\underline{I}_2$ and $\underline{I}_0$ are obtained when the phase values are transformed to symmetrical components.

For 3-phase elements:

$$\begin{aligned}\underline{i}0 &= \tfrac{1}{3}\left(\underline{i}_A + \underline{i}_B + \underline{i}_C\right)\\ \underline{i}1 &= \tfrac{1}{3}\left(\underline{i}_A + a \cdot \underline{i}_B + a^2 \cdot \underline{i}_C\right)\\ \underline{i}2 &= \tfrac{1}{3}\left(\underline{i}_A + a^2 \cdot \underline{i}_B + a \cdot \underline{i}_C\right)\end{aligned}$$

where $a = \angle 120°$

For BI-phase elements $(180°)$:

$$\begin{aligned}\underline{i}0 &= \tfrac{1}{2}\left(\underline{i}_A + \underline{i}_B\right)\\ \underline{i}1 &= \tfrac{1}{2}\left(\underline{i}_A - \underline{i}_B\right)\\ \underline{i}2 &= 0\end{aligned}$$

For 2-phase elements $(120°)$:

$$\begin{aligned}\underline{i}0 &= \tfrac{1}{\sqrt{3}}\left(\underline{i}_A + \underline{i}_B\right)\\ \underline{i}1 &= \tfrac{1}{\sqrt{3}}\left(\underline{i}_A - \underline{i}_B\right)\\ \underline{i}2 &= 0\end{aligned}$$

For 1-phase elements:

$$\begin{aligned}\underline{i}0 &= 0\\ \underline{i}1 &= \underline{i}_A\\ \underline{i}2 &= 0\end{aligned}$$

Table 3.12: 0,1,2 sequence current related variables for elements

Name	Unit	Description
$I0$	kA	Zero-Sequence Current, Magnitude
$I0{\times}3$	kA	3*I0
$phii0$	deg	Zero-Sequence Current, Angle
$i0$	$p.u$	Zero-Sequence Current, Magnitude
$i0r$	$p.u$	Zero-Sequence Current, Real Part
$i0i$	$p.u$	Zero-Sequence Current, Imaginary Part
$I1$	kA	Positive-Sequence Current, Magnitude
$phii1$	deg	Positive-Sequence Current, Angle
$i1$	$p.u$	Positive-Sequence Current, Magnitude
$i1r$	$p.u$	Positive-Sequence Current, Real Part
$i1i$	$p.u$	Positive-Sequence Current, Imaginary Part
$I2$	kA	Negative-Sequence Current, Magnitude
$phii2$	deg	Negative-Sequence Current, Angle
$i2$	$p.u$	Negative-Sequence Current, Magnitude
$i2r$	$p.u$	Negative-Sequence Current, Real Part
$i2i$	$p.u$	Negative-Sequence Current, Imaginary Part
$i1P$	$p.u.$	Positive-Sequence Active Current
$i1Q$	$p.u.$	Positive-Sequence Reactive Current
$I1P$	kA	Positive-Sequence Active Current
$I1Q$	kA	Positive-Sequence Reactive Current
$i2P$	$p.u.$	Negative-Sequence Active Current
$i2Q$	$p.u.$	Negative-Sequence Reactive Current
$I2P$	kA	Negative-Sequence Active Current
$I2Q$	kA	Negative-Sequence Reactive Current
$phiu0i0$	deg	Angle between Voltage and Current in zero sequence system
$phiu1i1$	deg	Angle between Voltage and Current in positive sequence system
$phiu2i2$	deg	Angle between Voltage and Current in negative sequence system
$ubfacI$	$\%$	Current Unbalance Factor

The result variables from Table 3.12 are calculated as follows:

- $I0$ is obtained as the magnitude of the zero sequence current:

$$I0 = \sqrt{\underline{I}_0.r^2 + \underline{I}_0.i^2}$$

- $I0{\times}3$ is obtained as $3 \cdot I0$ for three phase, as $2 \cdot I0$ for two phase and as $I0$ for single phase systems.

- $phii0$ is obtained as:

$$phii0 = \arctan\left(\frac{\underline{I}_0.i}{\underline{I}_0.r}\right) \cdot \frac{180}{\pi}$$

- $i0$ is obtained as:

$$i0 = \frac{I0}{I_{nom\_el}}$$

  where I_{nom_el} is the nominal current of the element.

- $i0r$ is obtained as:

$$i0r = \frac{\underline{I}_0.r}{I_{nom\_el}}$$

- $i0i$ is obtained as:

$$i0i = \frac{\underline{I}_0.i}{I_{nom\_el}}$$

- $I1$ is obtained as the magnitude of the positive sequence current:

$$I1 = \sqrt{\underline{I}_1.r^2 + \underline{I}_1.i^2}$$

- $phii1$ is obtained as:

$$phii1 = \arctan\left(\frac{\underline{I}_1.i}{\underline{I}_1.r}\right) \cdot \frac{180}{\pi}$$

- $i1$ is obtained as:

$$i1 = \frac{I1}{I_{nom\_el}}$$

  where I_{nom_el} is the nominal current of the element.

- $i1r$ is obtained as:

$$i1r = \frac{\underline{I}_1.r}{I_{nom\_el}}$$

- $i1i$ is obtained as:

$$i1i = \frac{\underline{I}_1.i}{I_{nom\_el}}$$

- $I2$ is obtained as the magnitude of the negative sequence current:

$$I2 = \sqrt{\underline{I}_2.r^2 + \underline{I}_2.i^2}$$

- $phii2$ is obtained as:

$$phii2 = \arctan\left(\frac{\underline{I}_2.i}{\underline{I}_2.r}\right) \cdot \frac{180}{\pi}$$

- $i2$ is obtained as:

$$i2 = \frac{I2}{I_{nom\_el}}$$

  where I_{nom_el} is the nominal current of the element.

- $i2r$ is obtained as:

$$i2r = \frac{\underline{I}_2.r}{I_{nom\_el}}$$

- $i2i$ is obtained as:

$$i2i = \frac{\underline{I}_2.i}{I_{nom\_el}}$$

- $i1P$ is obtained as:

$$i1P = i1 \cdot \cos(\phi_1)$$

  where ϕ_1 is the angle between the active and reactive power in the positive sequence.

- $i1Q$ is obtained as:

$$i1Q = i1 \cdot \sin(\phi_1)$$

- $I1P$ is obtained as:

$$I1P = I1 \cdot \cos(\phi_1)$$

- $I1Q$ is obtained as:

$$I1Q = I1 \cdot \sin(\phi_1)$$

- $i2P$ is obtained as:

$$i2P = i2 \cdot \cos(\phi_2)$$

  where ϕ_2 is the angle between the active and reactive power in the negative sequence.

- $i2Q$ is obtained as:

$$i2Q = i2 \cdot \sin(\phi_2)$$

- $I2P$ is obtained as:

$$I2P = I2 \cdot \cos(\phi_2)$$

- $I2Q$ is obtained as:

$$I2Q = I2 \cdot \sin(\phi)$$

- $phiu0i0$ is obtained as:

$$phiu0i0 = phiu0 - phii0$$

- $phiu1i1$ is obtained as:

$$phiu1i1 = phiu1 - phii1$$

- $phiu2i2$ is obtained as:

$$phiu2i2 = phiu2 - phii2$$

- $ubfacI$ is obtained as:

$$ubfacI = \frac{i2}{i1} \cdot 100$$

  If number of phases (without neutral) is less then three, it is set to zero.

3.2.6 0,1,2 sequence power related variables for elements

The total complex apparent power is the sum of apparent powers of all phases:

$$\underline{S}_{sum} = \underline{S}_A + \underline{S}_B + \underline{S}_C + \underline{S}_N$$

where:

$$\underline{S}_A = \underline{U}_A \cdot \underline{I}_A^*$$
$$\underline{S}_B = \underline{U}_B \cdot \underline{I}_B^*$$
$$\underline{S}_C = \underline{U}_C \cdot \underline{I}_C^*$$
$$\underline{S}_N = \underline{U}_N \cdot \underline{I}_N^*$$

and the sequence powers:

For 3-phase elements:

$$\underline{S}_1 = 3 \cdot \underline{U1} \cdot \underline{I1}^*$$
$$\underline{S}_2 = 3 \cdot \underline{U2} \cdot \underline{I2}^*$$
$$\underline{S}_0 = 3 \cdot \underline{U0} \cdot \underline{I0}^*$$

For AC/BI elements ($180°$):

$$\underline{S}_1 = 2 \cdot \underline{U1} \cdot \underline{I1}^*$$
$$\underline{S}_2 = 0$$
$$\underline{S}_0 = 2 \cdot \underline{U0} \cdot \underline{I0}^*$$

For 2-phase elements ($120°$):

$$\underline{S}_1 = 3/2 \cdot \underline{U1} \cdot \underline{I1}^*$$
$$\underline{S}_2 = 0$$
$$\underline{S}_0 = 3/2 \cdot \underline{U0} \cdot \underline{I0}^*$$

where

$$\underline{S}_{sum} = \underline{S}_1 + \underline{S}_2 + \underline{S}_0$$

Table 3.13: 0,1,2 sequence power related variables for elements

Name	**Unit**	**Description**
$Psum$	MW	Total Active Power
$Qsum$	$Mvar$	Total Reactive Power
$Ssum$	MVA	Total Apparent Power
$cosphisum$		Total Power Factor
$tanphisum$		Total tan(phi)
$P1$	MW	Positive Sequence Active Power
$Q1$	$Mvar$	Positive Sequence Reactive Power
$P2$	MW	Negative Sequence Active Power
$Q2$	$Mvar$	Negative Sequence Reactive Power
$ubfacS$	$\%$	Power Unbalance Factor

The result variables from Table 3.13 are calculated as follows:

- $Psum$ is obtained as:

$$Psum = \underline{S}_{sum}.r$$

- $Qsum$ is obtained as:

$$Qsum = \underline{S}_{sum}.i$$

- $Ssum$ is obtained as:

$$Ssum = \sqrt{\underline{S}_{sum}.r^2 + \underline{S}_{sum}.i^2}$$

- $cosphisum$ is obtained as:

$$cosphisum = \cos(\phi_s)$$

  where the angle is defined as:

$$\phi_s = \arctan\left(\frac{\underline{S}_{sum}.i}{\underline{S}_{sum}.r}\right)$$

- $tanphisum$ is obtained as:

$$tanphisum = \tan(\phi_s)$$

- $P1$ is the positive sequence active power of the element.

$$P1 = \underline{S1}.r$$

- $Q1$ is the positive sequence reactive power of the element.

$$Q1 = \underline{S1}.i$$

- $P2$ is the negative sequence active power of the element.

$$P2 = \underline{S2}.r$$

- $Q2$ is the negative sequence reactive power of the element.

$$Q2 = \underline{S2}.i$$

- $ubfacS$ is calculated as a ratio between Δ_{max_abs} and the average of absolute apparent powers. Δ_{max_abs} is the biggest absolute difference between the apparent power of a phase and the average apparent power. In this calculation the neutral connection is not taken into account.

3.2.7 Miscellaneous variables (min/max values) for elements

Table 3.14: Miscellaneous variables (min/max values) for elements

Name	Unit	Description
$Tfct$	s	Fault Clearing Time
$Brkload$	$\%$	Breaker Loading
$Imax$	kA	Maximum Current
$Smax$	MVA	Maximum Power

The result variables from Table 3.14 are calculated as follows:

- $Tfct$ is the minimum from the fault clearing times: $TfctPh{:}A$, $TfctPh{:}B$, $TfctPh{:}C$, $TfctPh{:}N$.
- $Brkload$ is the maximum breaker loading from: $BrkloadPh{:}A$, $BrkloadPh{:}B$, $BrkloadPh{:}C$, $BrkloadPh{:}N$.
- $Imax$ is the biggest value of the maximum currents per phase from low-voltage load flow analysis (coincidence of low-voltage loads is considered).
- $Smax$ is obtained as:

$$Smax = \sqrt{3} \cdot uknom \cdot Imax$$

4 Linear DC Load Flow calculation

For the linear DC calculation all the terminal magnitudes are set to $1 p.u.$ and the losses are neglected. The calculation delivers only active power and voltage angles as results.

4.1 Result variables for terminals

As described in Section 1.2.2, the result variables from the *Bus Results* set from the port elements are equivalent to the result variables from the *Currents, Voltages and Currents* set for the terminals.

The result variables available for terminals after a linear DC Load Flow calculation are presented in the following sub chapters.

4.1.1 Voltage related variables for terminals

Table 4.1: Voltage related variables for terminals

Name	**Unit**	**Description**
u	$p.u.$	Voltage, Magnitude
$u1$	$p.u.$	Positive-Sequence Voltage, Magnitude
upc	$\%$	Voltage, Magnitude
U	kV	Line-Ground Voltage, Magnitude
Ul	kV	Line-Line Voltage, Magnitude
$phiu$	deg	Voltage, Angle
$phiurel$	deg	Voltage, Relative Angle

The result variables from Table 4.1 are calculated as follows:

- u has a constant value of $1 p.u.$.
- $u1$ has a constant value of $1 p.u.$.
- upc has a constant value of 100%.
- U is obtained as:

$$U = 1 \cdot uknom/\sqrt{3}$$

  where $uknom$ is the nominal voltage of the terminal.
- Ul is obtained as:

$$Ul = 1 \cdot uknom$$

- $phiu$ is a result from the calculation.
- $phiurel$ is obtained using the *Initial Angle of Bus Voltage* $phiini$ basic data parameter as:

$$phiurel = phiu - phiini \cdot \frac{180}{\pi}$$

4.1.2 Power related variables for terminals

Table 4.2: Power related variables for terminals

Name	Unit	Description
$Pgen$	MW	Generation, Active Power
$Pmot$	MW	Motor Load, Active Power
$Pload$	MW	General Load, Active Power
$Pcomp$	MW	Compensation (Losses)
$Pnet$	MW	External Networks, Active Power
$Pflow$	MW	Power Flow, Active Power

The result variables from Table 4.2 are calculated as follows:

- $Pgen$ is the active power sum of all synchronous, asynchronous and static generators connected to the terminal. If generation is defined in the MV Load (*ElmLodmv*), the generated active power is added to this sum.
- $Pmot$ is the active power sum of all synchronous and asynchronous motors connected to the terminal.
- $Pload$ is the active power sum of all loads connected to the terminal.
- $Pcomp$ is the active power sum of all shunts and filters connected to the terminal.
- $Pnet$ is the active power sum of all external network elements connected to the terminal.
- $Pflow$ is the sum of all active power flowing out of the terminal.

4.2 Result variables for elements

The result variables available for for single- and multiple-port elements after a linear DC Load Flow calculation are presented in the following sub chapters.

4.2.1 Power related variables for elements

Table 4.3: Power related variables for elements

Name	Unit	Description
P	MW	Active Power
Q	$Mvar$	Reactive Power

The result variables from Table 4.3 are calculated as follows:

- P is a calculation result.
- Q is always $0Mvar$.