POWERFACTORY

PowerFactory 2021

Technical Reference

Common Result Variables for Terminals and Elements

RMS Simulation

PF2021

POWER SYSTEM SOLUTIONS

MADE IN GERMANY

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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 which are not specific to a certain element, that can be selected to be displayed in the result boxes, in the flexible data page of the elements or can be plotted in the virtual instruments.

Variables starting with capital letters are expressed in absolute values and variables starting with a lower case letters are expressed in per unit values. However for the RMS simulation there are few exceptions for the frequency related variables.

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 RMS Simulation

The balanced RMS simulation 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 RMS simulation 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 RMS simulation. 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 Short circuit variables for terminals

If a short circuit event is defined at the terminal, the short circuit current $\underline{I_{shc}}$ can be monitored by these variables.

Table 2.2: Short circuit variables for terminals

Name	**Unit**	**Description**
$Ishc$	kA	Short-Circuit Current, magnitude
$ishc$	$p.u.$	Short-Circuit Current, magnitude
$ishcr$	$p.u.$	Short-Circuit Current, real
$ishci$	$p.u.$	Short-Circuit Current, imag

The result variables from Table 2.2 are calculated as follows:

- $Ishc$ is the magnitude of the short circuit current at the terminal flowing through the short circuit impedance:

$$Ishc = \sqrt{\underline{I_{shc}}.r^2 + \underline{I_{shc}}.i^2}$$

- $ishc$ is obtained as:

$$ishc = \frac{Ishc}{I_{nom\_1MVA}}$$

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.

- $ishcr$ is obtained as:

$$ishcr = \frac{\underline{I_{shc}}.r}{I_{nom\_1MVA}}$$

- $ishci$ is obtained as:

$$ishci = \frac{\underline{I_{shc}}.i}{I_{nom\_1MVA}}$$

2.1.3 Frequency related variables for terminals

Table 2.3: Frequency related variables for terminals

Name	**Unit**	**Description**
$frnom$	Hz	Nominal Frequency
fe	$p.u.$	Electrical Frequency
$dfedt$	$1/s$	Derivative of Electrical Frequency
$fehz$	Hz	Electrical Frequency
$dfehz$	Hz	Deviation of the Electrical Frequency
$frdev$	Hz	Average frequency

The result variables from Table 2.3 are calculated as follows:

- $frnom$ is the nominal frequency defined in the Grid (*ElmNet*).
- fe is calculated by measuring the phase variation between the past and present positive sequence voltage phasors with respect to the integration step size.
- $dfedt$ is calculated using the past and present frequency values and the integration step size.
- $fehz$ is calculated as:

$$fehz = fe \cdot frnom$$

- $dfehz$ is calculated as:

$$dfehz = fehz - frnom$$

- $frdev$ is the average frequency value calculated using all terminals.

2.2 Result variables for elements

The result variables available for single- and multiple-port elements after a balanced RMS simulation 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 RMS simulation.

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 2.4: 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 2.4 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 RMS simulation. 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 2.5: 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 2.5 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 2.6: 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 2.6 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 2.7: Miscellaneous variables for elements

Name	Unit	Description
$Tfct$	s	Fault Clearing Time
$Brkload$	%	Breaker Loading

The result variables from Table 2.7 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 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*).

3 Unbalanced RMS simulation

The balanced RMS simulations 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 RMS simulation 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 RMS simulation. 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:

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

  For AC/BI terminals:

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

  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 3-phase and 2-phase (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 BI-phase 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:

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

  For AC/BI terminals with neutral:

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

  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 Short circuit variables for terminals

If a short circuit event is defined at the terminal, the short circuit currents $\underline{I_{shc}}_A$, $\underline{I_{shc}}_B$ and $\underline{I_{shc}}_C$ can be monitored by these variables.

Table 3.4: Short circuit variables for terminals

Name	Unit	Description
$Ishc{:}A$	kA	Short-Circuit Current, magnitude
$Ishc{:}B$	kA	Short-Circuit Current, magnitude
$Ishc{:}C$	kA	Short-Circuit Current, magnitude
$ishc{:}A$	$p.u.$	Short-Circuit Current, magnitude
$ishc{:}B$	$p.u.$	Short-Circuit Current, magnitude
$ishc{:}C$	$p.u.$	Short-Circuit Current, magnitude
$ishcr{:}A$	$p.u.$	Short-Circuit Current, real
$ishcr{:}B$	$p.u.$	Short-Circuit Current, real
$ishcr{:}C$	$p.u.$	Short-Circuit Current, real
$ishci{:}A$	$p.u.$	Short-Circuit Current, imag
$ishci{:}B$	$p.u.$	Short-Circuit Current, imag
$ishci{:}C$	$p.u.$	Short-Circuit Current, imag

The result variables from Table 3.4 are calculated as follows:

- $Ishc{:}A$, $Ishc{:}B$, $Ishc{:}C$ are the magnitudes of the short circuit currents at the terminal flowing through the short circuit impedance:

$$Ishc{:}A = \sqrt{\underline{I_{shc}}_A.r^2 + \underline{I_{shc}}_A.i^2}$$
$$Ishc{:}B = \sqrt{\underline{I_{shc}}_B.r^2 + \underline{I_{shc}}_B.i^2}$$
$$Ishc{:}C = \sqrt{\underline{I_{shc}}_C.r^2 + \underline{I_{shc}}_C.i^2}$$

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

$$ishc{:}A = \frac{Ishc{:}A}{I_{nom\_1MVA}}$$
$$ishc{:}B = \frac{Ishc{:}B}{I_{nom\_1MVA}}$$
$$ishc{:}C = \frac{Ishc{:}C}{I_{nom\_1MVA}}$$

  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.

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

$$ishcr{:}A = \frac{\underline{I_{shc}}_A.r}{I_{nom\_1MVA}}$$
$$ishcr{:}B = \frac{\underline{I_{shc}}_B.r}{I_{nom\_1MVA}}$$
$$ishcr{:}C = \frac{\underline{I_{shc}}_C.r}{I_{nom\_1MVA}}$$

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

$$ishci{:}A = \frac{\underline{I_{shc}}_A.i}{I_{nom\_1MVA}}$$
$$ishci{:}B = \frac{\underline{I_{shc}}_B.i}{I_{nom\_1MVA}}$$
$$ishci{:}C = \frac{\underline{I_{shc}}_C.r}{I_{nom\_1MVA}}$$

3.1.5 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 3.5: 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

The variables from Table 3.5 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:

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

  for AC/BI terminals:

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

  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 3-phase, 1-phase and 2-phase terminals:

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

  for AC/BI terminals:

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

  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:

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

  for AC/BI terminals:

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

  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:

$$U1l = U1$$

- $U2l$ is obtained as (only for 3-phase terminals):

$$U2l = u2 \cdot uknom$$

3.1.6 Neutral short circuit current related variables for terminals

If a short circuit event is defined at the terminal, the short circuit current flowing through the neutral can be monitored by these variables.

Table 3.6: Neutral short circuit current related variables for terminals

Name	Unit	Description
$Inshc$	kA	Neutral Short-Circuit Current, Magnitude
$inshc$	$p.u.$	Neutral Short-Circuit Current, Magnitude

The variables from Table 3.6 are calculated as follows:

- $Inshc$ is the magnitudes of the short circuit currents at the terminal flowing through the short circuit impedance:

$$Inshc = \sqrt{\underline{I_{shc}}_n.r^2 + \underline{I_{shc}}_n.i^2}$$

- $inshc$ is obtained as:

$$inshc = \frac{Inshc}{I_{nom\_1MVA}}$$

  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.

3.1.7 Frequency related variables for terminals

The frequency calculation is based on the positive sequence voltage which is transformed from the phase values through the symmetrical components.

Table 3.7: Frequency related variables for terminals

Name	Unit	Description
$frnom$	Hz	Nominal Frequency
fe	$p.u.$	Electrical Frequency
$dfedt$	$1/s$	Derivative of Electrical Frequency
$fehz$	Hz	Electrical Frequency
$dfehz$	Hz	Deviation of the Electrical Frequency
$frdev$	Hz	Average frequency

The result variables from Table 3.7 are calculated same as the result variables from Table 2.3.

3.2 Result variables for elements

The result variables available for for single- and multiple-port elements after an unbalanced RMS simulation 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 RMS simulation.

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 RMS simulation. The relationship between the absolute and per unit value current is $\underline{I}_A = \underline{i}_A \cdot I_{nom\_el}$ where $I_{nom\_el} = \frac{MVA_{el}}{\sqrt{3} \cdot U_{nom\_el}}$ 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:

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

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

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

- $ir{:}A$, $ir{:}B$, $ir{:}C$, $ir{:}N$ 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 $I_{nom\_1MVA} = \frac{1}{\sqrt{3} \cdot uknom}$ 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 current, a default value of $9999{,}999s$ is used.
- $BrkloadPh{:}A$, $BrkloadPh{:}B$, $BrkloadPh{:}C$, $BrkloadPh{:}N$ are calculated as:

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

  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:

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

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:

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

  for AC/BI elements:

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

- $U1l$ 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 ($180°$):

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

For 2-phase elements ($120°$):

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

For 1-phase elements:

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

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

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:

$$phiu2i2 = phiu2 - phii2$$

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:

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

and the sequence powers:

For 3-phase elements:

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

For AC/BI elements ($180°$):

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

For 2-phase elements ($120°$):

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

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

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.

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

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

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: $BrkloadPh{:}A$, $BrkloadPh{:}B$, $BrkloadPh{:}C$, $BrkloadPh{:}N$.