POWERFACTORY

PowerFactory 2021

Technical Reference

Voltage Measurement

StaVmea

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POWER SYSTEM SOLUTIONS

MADE IN GERMANY

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1 General Description

The *Voltage Measurement Device* (*StaVmea*) can be used to measure the voltage at terminals and cubicles. The measured voltage can then for example be fed as a signal into a controller for a RMS or EMT simulation.

The *Voltage Measurement Device* has either to be connected to a measurement point by selecting a terminal or cubicle for the *Measurement Point* ($pbusbar$ parameter) or it can be directly stored at the measurement location - which has to be a cubicle (*StaCubic*). If the cubicle has a circuit-breaker, the measurement device is connected to the circuit-breaker from the side of the edge element.

With the option *Measurement*, the *StaVmea* element can be used for:

- measuring voltage at a *Single terminal*, or
- measuring voltage difference *Between two terminals*. The voltage difference (dur, dui, ...) is calculated as the voltage at the first measurement point minus the voltage at the second measurement point.

AC, DC and BI-phase system types can be measured by the *StaVmea* element. Also, *Number of phases* option is available in the *StaVmea*:

- if *Number of phases* =3, the measured quantities are line-ground quantities. With this option, not only three-phase, but also two-phase and single-phase terminals can be measured (the non-relevant outputs are then set to 0).
- if *Number of phases* = 1, the measured quantities can be selected as line-ground or line-neutral quantities (*a, b, c, a-n, b-n, c-n or n*) by selecting the appropriate *Measured Phase*).

The outputs of the measurement device can be selected to be phase or transformed quantities:

- *Phase quantities*, depending on the selection of the *p.u. values* three different options are available:
  - *Equivalent to kV values*, where the $p.u.$ output value corresponds to the phase value in kV,
  - *Based on nominal voltage of connected terminal* where the $p.u.$ output is based on the $uknom$ parameter of the connected terminal, and
  - *Based on user-defined voltage* where the $p.u.$ output has is calculated using the $Unom$ input parameter as base value. If the nominal voltage of the connected/measured terminal is used as $Unom$, this option is equivalent to the second option.
- *Transformed quantities*, depending on the selection of the *p.u. values* there are three different options:
  - *Based on 1kV*, where the $p.u.$ output is based on $1kV$,
  - *Based on nominal voltage of connected terminal*, where the $p.u.$ output is based on the $uknom$ parameter of the connected terminal, and
  - *Based on user-defined voltage* where the $p.u.$ output is calculated using the $Unom$ input parameter.

The voltage magnitudes (u, $u2$, $u0$, ...) are calculated by using the real and imaginary part of the corresponding voltage as follows:

$$u = \sqrt{ur^2 + ui^2} \tag{1}$$

and the voltage difference magnitude is calculated using the real and imaginary voltage difference between the two measurement points:

$$du = \sqrt{(ur_{meas1} - ur_{meas2})^2 + (ui_{meas1} - ui_{meas2})^2} \tag{2}$$

The frequency output is available only for three phase measurement devices (option *No. of Phases = 3*). The frequency is calculated always if the option *Frequency Output* is set to *Calculate always*. If the option *Calculate only if signal is connected* is used, the output frequency fe is calculated only if the output signal is connected to another model e.g. via a composite model. Else, the frequency output signal is constant ($fe = 1p.u.$).

In *PowerFactory* it is possible to use a different simulation algorithm, the so-called A-stable integration algorithm, for parts of the network. If an element and its controller models are using this A-stable integration algorithm, the connected measurement device should also use this algorithm, thus the flag '*iAstabint*' on the RMS-simulation page should be selected.

The output signals and transformation equations of the *StaVmea* element are documented in the following sections.

2 Load Flow

2.1 Phase quantities outputs

The phase quantities output signals available for the Load Flow calculation are identical to the output signals presented in the RMS simulation. Please refer to Subsection 3.1.1 for more information.

2.2 Transformed quantities outputs

The transformed quantities output signals available for the Load Flow calculation are identical to the output signals presented in the RMS simulation, except that the frequency-related quantities are not available. Please refer to Subsection 3.1.2 for more information.

3 RMS simulation

The output signals available for balanced and unbalanced RMS simulation are described in the following subsections.

3.1 Balanced

From the balanced RMS simulation, the real and imaginary part of the positive-sequence voltage are available. Based on these voltages, also additional voltage quantities can be calculated.

3.1.1 Phase quantities outputs

The available outputs for a measurement at a single terminal are presented in Table 3.1.

Table 3.1: Phase quantities outputs for Balanced RMS simulation, single terminal

Name	Unit	Type	Description
$u1r$	$p.u.$	Output	Positive sequence voltage, real part
$u1i$	$p.u.$	Output	Positive sequence voltage, imaginary part
$fref$	$p.u.$	Output	Reference frequency (from the reference machine)
fe	$p.u.$	Output	Measured frequency

For information on the calculation of fe, please refer to subsection 3.1.2.

The available outputs for a measurement between two terminals are presented in Table 3.2.

Table 3.2: Phase quantities outputs for Balanced RMS simulation, between two terminals

Name	Unit	Type	Description
$du1r$	$p.u.$	Output	Voltage difference, positive sequence, real part
$du1i$	$p.u.$	Output	Voltage difference, positive sequence, imaginary part

3.1.2 Transformed quantities outputs

The available outputs for a measurement at a single terminal are presented in Table 3.3.

Table 3.3: Transformed quantities outputs for Balanced RMS simulation, single terminal

Name	Unit	Type	Description
ur	$p.u.$	Output	Positive sequence voltage, real part
ui	$p.u.$	Output	Positive sequence voltage, imaginary part
u	$p.u.$	Output	Positive sequence voltage, magnitude
$fref$	$p.u.$	Output	Reference frequency (from the reference machine)
fe	$p.u.$	Output	Measured frequency

- The frequency fe is calculated by adding the frequency deviation to the frequency of the reference machine. The calculation of the frequency deviation is based on the following equation:

$$\Delta f = \frac{d\,\phi}{dt} \tag{3}$$

Equation 3 is implemented using the following differential equations (two state variables are defined internally $\cos\phi$ and $\sin\phi$) for calculating the frequency output fe:

$$\frac{d\,\cos\phi}{dt} = \left(\frac{ur}{\sqrt{ur^2+ui^2}} - \cos\phi\right)\Big/T_{fe} \tag{4}$$

$$\frac{d\,\sin\phi}{dt} = \left(\frac{ui}{\sqrt{ur^2+ui^2}} - \sin\phi\right)\Big/T_{fe} \tag{5}$$

where $T_fe = 3/Fnom$ and $Fnom$ is the Nominal Frequency of the network in Hz.

The frequency change (in $p.u.$) is equal to:

$$dfe = \begin{cases} \left(\frac{d\,\sin\phi}{dt}\cdot\frac{1}{\cos\phi}\right)\Big/(2\cdot\pi\cdot Fnom) & if\,|\cos\phi| > |\sin\phi| \\ -\left(\frac{d\,\cos\phi}{dt}\cdot\frac{1}{\sin\phi}\right)\Big/(2\cdot\pi\cdot Fnom) & if\,|\cos\phi|\ \le\ |\sin\phi| \end{cases} \tag{6}$$

The frequency is then calculated using $fref$ (reference machine frequency in $p.u.$) as:

$$fe = fref + dfe \tag{7}$$

- For DC systems, only one signal is available ur ($ui = 0,\ fe = 0$):

The available outputs for a measurement between two terminals are presented in Table 3.4.

Table 3.4: Transformed quantities outputs for Balanced RMS simulation, between two terminals

Name	Unit	Type	Description
dur	$p.u.$	Output	Voltage difference, positive sequence, real part
dui	$p.u.$	Output	Voltage difference, positive sequence, imaginary part
du	$p.u.$	Output	Voltage difference, positive sequence, magnitude

3.2 Unbalanced

From the unbalanced RMS simulation, the real and imaginary parts of the line-ground voltages ($\underline{u}_a$, $\underline{u}_b$ and $\underline{u}_c$) are available to the measurement device. Using these available voltages, also additional quantities like the positive-, negative-, and zero-sequence voltages can be calculated.

3.2.1 Phase quantities outputs

The available outputs for a measurement at a single terminal are presented in Table 3.5.

Table 3.5: Phase quantities outputs for Unbalanced RMS simulation, single terminal

Name	Unit	Type	Description
ur_A	$p.u.$	Output	Voltage, phase a, real part
ui_A	$p.u.$	Output	Voltage, phase a, imaginary part
ur_B	$p.u.$	Output	Voltage, phase b, real part
ui_B	$p.u.$	Output	Voltage, phase b, imaginary part
ur_C	$p.u.$	Output	Voltage, phase c, real part
ui_C	$p.u.$	Output	Voltage, phase c, imaginary part
$fref$	$p.u.$	Output	Reference frequency (from the reference machine)
fe	$p.u.$	Output	Measured frequency

For information on the calculation of fe, please refer to subsection 3.2.2.

The available outputs for a measurement between two terminals are presented in Table 3.6.

Table 3.6: Phase quantities outputs for Unbalanced RMS simulation, between two terminals

Name	Unit	Type	Description
dur_A	$p.u.$	Output	Voltage difference, phase a, real part
dui_A	$p.u.$	Output	Voltage difference, phase a, imaginary part
dur_B	$p.u.$	Output	Voltage difference, phase b, real part
dui_B	$p.u.$	Output	Voltage difference, phase b, imaginary part
dur_C	$p.u.$	Output	Voltage difference, phase c, real part
dui_C	$p.u.$	Output	Voltage difference, phase c, imaginary part

3.2.1.1 Single-phase measurement (*Number of phases*$= 1$)

The available outputs for a single-phase measurement at a single terminal are presented in Table 3.7.

Table 3.7: Phase quantities outputs for Unbalanced RMS simulation, single-phase measurement at a single terminal

Name	Unit	Type	Description
ur	$p.u.$	Output	Phase voltage, real part
ui	$p.u.$	Output	Phase voltage, imaginary part

The available outputs for a single-phase measurement (*Number of phases*$= 1$) between two terminals are presented in Table 3.8.

Table 3.8: Phase quantities outputs for Unbalanced RMS simulation, single-phase measurement between two terminals

Name	Unit	Type	Description
dur	$p.u.$	Output	Voltage difference, real part
dui	$p.u.$	Output	Voltage difference, imaginary part

3.2.2 Transformed quantities outputs

In the case of the three-phase system, the Transformed quantities outputs are the real and imaginary parts and magnitude of the positive-, negative- and zero-sequence voltage that are calculated using the symmetrical components transformation. Similar transformation is being used for the two-phase system (modal components transformation).

The available outputs for a measurement at a single terminal are presented in Table 3.9.

Table 3.9: Transformed quantities outputs for Unbalanced RMS simulation, single terminal

Name	Unit	Type	Description
ur	$p.u.$	Output	Positive sequence voltage, real part
ui	$p.u.$	Output	Positive sequence voltage, imaginary part
u	$p.u.$	Output	Positive sequence voltage, magnitude
$u2r$	$p.u.$	Output	Negative sequence voltage, real part
$u2i$	$p.u.$	Output	Negative sequence voltage, imaginary part
$u2$	$p.u.$	Output	Negative sequence voltage, magnitude
$u0r$	$p.u.$	Output	Zero sequence voltage, real part
$u0i$	$p.u.$	Output	Zero sequence voltage, imaginary part
$u0$	$p.u.$	Output	Zero sequence voltage, magnitude
$fref$	$p.u.$	Output	Reference frequency (from the reference machine)
fe	$p.u.$	Output	Measured frequency

The output voltages for unbalanced RMS simulation are calculated depending on the phase technology of the terminal as follows:

- 3-phase system (using symmetrical components transformation)

$$ur + j\,ui = \frac{1}{3} \cdot \left(\underline{u}_a + \left(-\frac{1}{2} + j\,\frac{\sqrt{3}}{2} \right) \cdot \underline{u}_b + \left(-\frac{1}{2} - j\,\frac{\sqrt{3}}{2} \right) \cdot \underline{u}_c \right) \tag{8}$$

$$u2r + j\,u2i = \frac{1}{3} \cdot \left(\underline{u}_a + \left(-\frac{1}{2} + j\,\frac{\sqrt{3}}{2} \right) \cdot \underline{u}_b + \left(-\frac{1}{2} - j\,\frac{\sqrt{3}}{2} \right) \cdot \underline{u}_c \right) \tag{9}$$

$$u0r + j\,u0i = \frac{1}{3} \cdot \left(\underline{u}_a + \underline{u}_b + \underline{u}_c \right) \tag{10}$$

- BI-phase system ($180°$):

$$ur + j\,ui = \frac{1}{2} \cdot \left(\underline{u}_a - \underline{u}_b \right) \tag{11}$$

$$u2r + j\,u2i = 0 \tag{12}$$

$$u0r + j\,u0i = \frac{1}{2} \cdot \left(\underline{u}_a + \underline{u}_b \right) \tag{13}$$

- 2-phase system ($120°$):

$$ur + j\,ui = \frac{1}{\sqrt{3}} \cdot \left(\underline{u}_a - \underline{u}_b \right) \tag{14}$$

$$u2r + j\,u2i = 0 \tag{15}$$

$$u0r + j\,u0i = \frac{1}{\sqrt{3}} \cdot \left(\underline{u}_a + \underline{u}_b \right) \tag{16}$$

- Single-phase (*Number of phases*$= 3$):

  The voltage is set (transformation is not used) to the complex voltage $\underline{u}$ available from the RMS simulation as follows:

$$ur + j\,ui = \underline{u} \tag{17}$$

- For DC systems, only one signal is available ur ($ui = 0$, $fe = 0$).
- The reference frequency $fref$ is the frequency of the reference machine.
- The frequency fe is calculated using the positive-sequence voltage and the same equations are valid as for the balanced RMS simulation (Equation 3 to Equation 7).

The available outputs for a measurement between two terminals are presented in Table 3.10.

Table 3.10: Transformed quantities outputs for Unbalanced RMS simulation, between two terminals

Name	Unit	Type	Description
dur	$p.u.$	Output	Voltage difference, positive sequence, real part
dui	$p.u.$	Output	Voltage difference, positive sequence, imaginary part
du	$p.u.$	Output	Voltage difference, positive sequence, magnitude
$du2r$	$p.u.$	Output	Voltage difference, negative sequence, real part
$du2i$	$p.u.$	Output	Voltage difference, negative sequence, imaginary part
$du2$	$p.u.$	Output	Voltage difference, negative sequence, magnitude
$du0r$	$p.u.$	Output	Voltage difference, zero sequence, real part
$du0i$	$p.u.$	Output	Voltage difference, zero sequence, imaginary part
$du0$	$p.u.$	Output	Voltage difference, zero sequence, magnitude

3.2.2.1 Single-phase measurement (***Number of phases***$=1$)

The available outputs for a single-phase measurement (*Number of phases*$=1$) at a single terminal are presented in Table 3.11.

Table 3.11: Transformed quantities outputs for Unbalanced RMS simulation, single-phase measurement at a single terminal

Name	Unit	Type	Description
ur	$p.u.$	Output	Voltage, real part
ui	$p.u.$	Output	Voltage, imaginary part
u	$p.u.$	Output	Voltage, magnitude

- Single-phase measurement (*Number of phases*$=1$):

  The voltage is set (transformation is not used) to the complex voltage $\underline{u}$ available from the RMS simulation for the selected measured phase (*a, b, c, a-n, b-n, c-n or n*) as follows:

$$ur + j\,ui = \underline{u} \tag{18}$$

The available outputs for a single-phase measurement (*Number of phases*$=1$) between two terminals are presented in Table 3.12.

Table 3.12: Transformed quantities outputs outputs for Unbalanced RMS simulation, single-phase measurement between two terminals

Name	Unit	Type	Description
dur	$p.u.$	Output	Voltage difference, real part
dui	$p.u.$	Output	Voltage difference, imaginary part
du	$p.u.$	Output	Voltage difference, magnitude

4 EMT Simulation

From the EMT Simulation, the line-ground voltages (u_a, u_b and u_c) are available to the measurement device. Using these voltages, additional quantities like the alpha, beta and gamma components of the voltage can be calculated.

The output signals available for the EMT Simulation are described in the following subsections.

4.1 Phase quantities outputs

The available outputs for a measurement at a single terminal are presented in Table 4.1.

Table 4.1: Phase quantities outputs for EMT Simulation, single terminal

Name	Unit	Type	Description
u_A	$p.u.$	Output	Voltage, phase a
u_B	$p.u.$	Output	Voltage, phase b
u_C	$p.u.$	Output	Voltage, phase c
fe	$p.u.$	Output	Measured frequency
$phiref$	rad	Output	Reference angle (rotating system)

For information on the calculation of fe and $phiref$, please refer to subsection 4.2.

The available outputs for a measurement between two terminals are presented in Table 4.2.

Table 4.2: Phase quantities outputs for EMT Simulation, between two terminals

Name	Unit	Type	Description
du_A	$p.u.$	Output	Voltage difference, phase a
du_B	$p.u.$	Output	Voltage difference, phase b
du_C	$p.u.$	Output	Voltage difference, phase c

4.1.1 Single-phase measurement (***Number of phases***$= 1$)

The available outputs for a single-phase measurement at a single terminal are presented in Table 4.3.

Table 4.3: Phase quantities outputs for EMT Simulation, single-phase measurement (*Number of phases*$= 1$) at a single terminal

Name	Unit	Type	Description
u	$p.u.$	Output	Phase voltage

The available outputs for a single-phase measurement between two terminals are presented in Table 4.4.

Table 4.4: Phase quantities outputs for EMT Simulation, single-phase measurement between two terminals

Name	Unit	Type	Description
du	$p.u.$	Output	Voltage difference

4.2 Transformed quantities outputs

In the case of the EMT Simulation, the Transformed quantities outputs signals are the alpha, beta and gamma voltage components that are calculated using the Clarke transformation.

The available outputs for a measurement at a single terminal are presented in Table 4.6.

Table 4.5: Transformed quantities outputs for EMT Simulation, single terminal

Name	Unit	Type	Description
ur	$p.u.$	Output	Voltage, alpha-component
ui	$p.u.$	Output	Voltage, beta-component
u	$p.u.$	Output	Voltage, magnitude (using the alpha and beta component)
$u0$	$p.u.$	Output	Voltage, gamma-component
fe	$p.u.$	Output	Measured frequency
$phiref$	rad	Output	Reference angle (rotating system)

The output voltages for the EMT simulation are calculated depending on the phase technology of the terminal as follows:

- 3-phase system:

  The phase voltages are transformed using the $\alpha\beta\gamma$ transformation:

$$ur = u_\alpha = \frac{1}{3} \cdot (2 \cdot u_a - u_b - u_c) \tag{19}$$

$$ui = u_\beta = \frac{1}{3} \cdot (\sqrt{3} \cdot u_b - \sqrt{3} \cdot u_c) \tag{20}$$

$$u0 = u_\gamma = \frac{1}{3} \cdot (u_a + u_b + u_c) \tag{21}$$

- BI-phase system $(180°)$:

$$ur = \frac{1}{2} \cdot (u_a - u_b) \tag{22}$$

$$ui = 0 \tag{23}$$

$$u0 = \frac{1}{2} \cdot (u_a + u_b) \tag{24}$$

- 2-phase system $(120°)$:

$$ur = \frac{1}{\sqrt{3}} \cdot (u_a - u_b) \tag{25}$$

$$ui = 0 \tag{26}$$

$$u0 = \frac{1}{\sqrt{3}} \cdot (u_a + u_b) \tag{27}$$

- Single-phase (*Number of phases*$= 3$):

  The voltage is set (transformation is not used) to the voltage u available from the EMT Simulation as follows:

$$ur = u \tag{28}$$

$$ui = 0 \tag{29}$$

$$u0 = 0 \tag{30}$$

- For DC systems, only one signal is available ur ($ui = 0$, $u0 = 0$, $fe = 0$).
- The angle $phiref$ in $[rad]$ is used when calculating the frequency (artificially created rotating system). Its time derivative is calculated using the nominal frequency of the network $Fnom$ in Hz as follows:

$$\frac{d\ phiref}{dt} = 2 \cdot \pi \cdot Fnom \tag{31}$$

- The calculation of the frequency fe is similar to the calculation in the RMS simulation, with the difference that instead the positive-sequence, the dq voltage values are used. The dq quantities of the voltage are obtained as:

$$ud + j\ uq = (ur + j\ ui) \cdot (\cos(phiref) - j\ (\sin(phiref))) \tag{32}$$

The following differential equations are being used:

$$\frac{d\ \cos\phi}{dt} = \left(\frac{ud}{\sqrt{ud^2 + uq^2}} - \cos\phi\right) \Big/ T_{fe} \tag{33}$$

$$\frac{d\ \sin\phi}{dt} = \left(\frac{uq}{\sqrt{ud^2 + uq^2}} - \sin\phi\right) \Big/ T_{fe} \tag{34}$$

where T_fe is fixed to $3/Fnom$.

The frequency change (in $p.u.$) is equal to:

$$dfe = \sqrt{\frac{\left(\frac{d\ \cos\phi}{dt}\right)^2 + \left(\frac{d\ \sin\phi}{dt}\right)^2}{(\cos\phi)^2 + (\sin\phi)^2}} \Big/ (2 \cdot \pi \cdot Fnom) \tag{35}$$

The frequency is then calculated as:

$$fe = \begin{cases} 1 + dfe & if\ dfe \geq 0 \\ 1 - dfe & if\ dfe < 0 \end{cases} \tag{36}$$

The available outputs for a measurement between two terminals are presented in Table 4.6.

Table 4.6: Transformed quantities outputs for EMT Simulation, between two terminals

Name	Unit	Type	Description
dur	$p.u.$	Output	Voltage difference, alpha-componentt
dui	$p.u.$	Output	Voltage difference, beta-component
du	$p.u.$	Output	Voltage difference, magnitude (using the alpha and beta component)
$du0$	$p.u.$	Output	Voltage difference, gamma-component

4.2.0.1 Single-phase measurement (*Number of phases*$= 1$)

The available outputs for a single-phase measurement (*Number of phases*$= 1$) at a single terminal are presented in Table 4.7.

Table 4.7: Transformed quantities outputs for EMT Simulation, single-phase measurement at a single terminal

Name	**Unit**	**Type**	**Description**
ur	$p.u.$	Output	Voltage
ui	$p.u.$	Output	Voltage (set to 0)
u	$p.u.$	Output	Voltage, magnitude

- Single-phase measurement (*Number of phases*$= 1$):

  The voltage is set (transformation is not used) to the voltage u_{phase} available from the EMT Simulation for the selected measured phase (*a, b, c, a-n, b-n, c-n or n*) as follows:

$$ur = u_{phase} \tag{37}$$

$$ui = 0 \tag{38}$$

The available outputs for a single-phase measurement (*Number of phases*$= 1$) between two terminals are presented in Table 4.8.

Table 4.8: Transformed quantities outputs for EMT Simulation, single-phase measurement between two terminals

Name	**Unit**	**Type**	**Description**
du	$p.u.$	Output	Voltage difference, magnitude

List of Tables