POWERFACTORY

PowerFactory 2021

Technical Reference

Power Measurement

StaPqmea

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POWER SYSTEM SOLUTIONS

MADE IN GERMANY

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1 General Description

The *Power Measurement Device* (*StaPqmea*) can be used to measure the power flow at a cubicle of any element, which is connected to a terminal/busbar. The measured active and reactive power can then be fed for example into a DSL model of a controller.

The power direction (sign) can be defined for the measurement device individually according to the parameter *Orientation* (*i_orient*):

- Load oriented
- Generator oriented
- Orientation of connected element

If the third option is selected, the direction of the power flow depends on the element where the power is being measured. For loads, motors or passive elements (lines, transformers, etc.) the power flow is defined in load orientation. This means the power which flows out of the terminal into the element is positive. For sources, e.g. generators, external network, current and voltage sources, etc. the power flow is in generator orientation and thus out of the element in the direction of the connected bus is defined as positive.

The power output is normalised using the normalisation factor $1/Srated$ where $Srated$ is set depending on the selected *Power Rating* (i_mode parameter) as shown in Table 1.1.

Table 1.1: Options available for the Power Rating

Current Rating	***Irated***
Rated on $1MVA$	$1MVA$
Rating of Connected Element	MVA rating of Connected Element
User Defined Power Rating	$Snom$ entered by the user in MVA

The measurement device is mostly used in combination with controller models. 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 equations and parameters of the *StaPqmea* element are documented in the following sections.

2 RMS-Simulation

2.1 Balanced

- For AC systems, the input signals to the *StaPqmea*, ur_A and ui_A, ir_A and ii_A (in p.u.), are set to the real and imaginary part of the positive-sequence voltage:

$$\underline{U}_1 = Un/\sqrt{3} \cdot (ur\_A + j \cdot ui\_A) \qquad in\ kV \tag{1}$$

  and positive-sequence current:

$$\underline{I}_1 = 1/(\sqrt{3} \cdot Un) \cdot (ir\_A + j \cdot ii\_A) \qquad in\ kA \tag{2}$$

  available from the simulation. Then, the power output signals are calculated as follows:

$$p = \mathrm{Re}\left\{3 \cdot \underline{U}_1 \cdot \underline{I}_1^*\right\}/Srated \tag{3}$$
$$q = \mathrm{Im}\left\{3 \cdot \underline{U}_1 \cdot \underline{I}_1^*\right\}/Srated \tag{4}$$

  where * is the complex conjugate operator.

- For DC systems, only the real parts of the voltage and current are available:

$$p = ur\_A \cdot ir\_A/Srated \tag{5}$$
$$q = 0 \tag{6}$$

2.1.1 Signals

The signals used in the balanced RMS model are presented in Table 2.1.

Table 2.1: Signals (Balanced RMS-Simulation)

Name	Symbol	Unit	Type	Description
ur_A		$p.u.$	IN	Input Voltage, Real Part
ui_A		$p.u.$	IN	Input Voltage, Imaginary Part
ir_A		$p.u.$	IN	Input Current, Real Part
ii_A		$p.u.$	IN	Input Current, Imaginary Part
p		$p.u.$	OUT	Output Active Power
q		$p.u.$	OUT	Output Reactive Power

2.1.2 Calculation parameters

The calculation parameters used in the balanced RMS model are presented in Table 2.2.

Table 2.2: Calculation parameters (RMS-Simulation)

Name	Symbol	Unit	Description
$Srated$		MVA	Rated Power

2.2 Unbalanced

The unbalanced measurement depends on the *No. of Phases* option (parameter $nphase$).

The three-phase unbalanced RMS simulation delivers the complex voltages and currents for phase A, B and C to the measurement device ($\underline{u}_a$, $\underline{u}_b$, $\underline{u}_c$, $\underline{i}_a$, $\underline{i}_b$ and $\underline{i}_c$) .

The output power signals for three-phase unbalanced RMS simulation are calculated depending on the phase technology of the element.

In the case of a three-phase system, the output signals are the active and reactive power which are calculated using the positive sequence of the voltage and current. Similar calculation is done for the BI and two phase system.

- 3-phase system (using symmetrical components transformation):
  The positive sequence voltage and current are calculated:

$$\underline{U}_1 = \frac{1}{3} \cdot \left(\underline{U}_a + \left(-\frac{1}{2} + j\frac{\sqrt{3}}{2} \right) \cdot \underline{U}_b + \left(-\frac{1}{2} - j\frac{\sqrt{3}}{2} \right) \cdot \underline{U}_c \right) \tag{7}$$

$$\underline{I}_1 = \frac{1}{3} \cdot \left(\underline{I}_a + \left(-\frac{1}{2} + j\frac{\sqrt{3}}{2} \right) \cdot \underline{I}_b + \left(-\frac{1}{2} - j\frac{\sqrt{3}}{2} \right) \cdot \underline{I}_c \right) \tag{8}$$

$$\tag{9}$$

  The output powers are calculated as:

$$p = \mathrm{Re}\left\{3 \cdot \underline{U}_1 \cdot \underline{I}_1^*\right\}/Srated \tag{10}$$

$$q = \mathrm{Im}\left\{3 \cdot \underline{U}_1 \cdot \underline{I}_1^*\right\}/Srated \tag{11}$$

  where $\underline{I}_1^*$ is the complex conjugate of the current $\underline{I}_1$ in kA and $\underline{U}_1$ in kV.

- BI-phase system ($180°$)

$$\underline{U}_1 = \frac{1}{2} \cdot (\underline{U}_a - \underline{U}_b) \tag{12}$$

$$\underline{I}_1 = \frac{1}{2} \cdot (\underline{I}_a - \underline{I}_b) \tag{13}$$

$$p = \mathrm{Re}\left\{2 \cdot \underline{U}_1 \cdot \underline{I}_1^*\right\}/Srated \tag{14}$$

$$q = \mathrm{Im}\left\{2 \cdot \underline{U}_1 \cdot \underline{I}_1^*\right\}/Srated \tag{15}$$

- 2-phase system ($120°$)

$$\underline{U}_1 = \frac{1}{\sqrt{3}} \cdot (\underline{U}_a - \underline{U}_b) \tag{16}$$

$$\underline{I}_1 = \frac{1}{\sqrt{3}} \cdot (\underline{I}_a - \underline{I}_b) \tag{17}$$

$$p = \mathrm{Re}\left\{3/2 \cdot \underline{U}_1 \cdot \underline{I}_1^*\right\}/Srated \tag{18}$$

$$q = \mathrm{Im}\left\{3/2 \cdot \underline{U}_1 \cdot \underline{I}_1^*\right\}/Srated \tag{19}$$

- Single-phase (system): In case of a single phase system at the measurement point the option *No. of Phases* can be set to 3 and the powers are calculated as follows:

$$\underline{U}_1 = \underline{U}_a \tag{20}$$

$$\underline{I}_1 = \underline{I}_a \tag{21}$$

$$p = \mathrm{Re}\left\{\underline{U}_1 \cdot \underline{I}_1^*\right\}/Srated \tag{22}$$

$$q = \mathrm{Im}\left\{\underline{U}_1 \cdot \underline{I}_1^*\right\}/Srated \tag{23}$$

In case of a multi phase system where only the power of one phase should be measured the option *No. of Phases* has to be set to 1 and the power is then calculated as follows. Depending on the selected *Measurement Point*, the power can be measured at phase *a, b, c, a-n, b-n or c-n* by selecting the appropriate *Measured Phase*.

The unbalanced RMS simulation delivers the complex phase to ground voltages and currents for phase A, B, C and N (if available) to the measurement device ($\underline{u}_a$, $\underline{u}_b$, $\underline{u}_c$, $\underline{u}_n$, $\underline{i}_a$, $\underline{i}_b$, $\underline{i}_c$ and $\underline{i}_n$). According to the selected *Measured Phase*, the corresponding values are set to the input signals uin_r, uin_i, iin_r and iin_i.

The output signals are calculated as follows:

$$p = \mathrm{Re}\left\{(uin\_r + j\, uin\_i) \cdot (iin\_r + j\, iin\_i)^*\right\} / Srated \tag{24}$$

$$q = \mathrm{Im}\left\{(uin\_r + j\, uin\_i) \cdot (iin\_r + j\, iin\_i)^*\right\} / Srated \tag{25}$$

- DC system:

$$p = u \cdot i / Srated \tag{26}$$

$$q = 0 \tag{27}$$

2.2.1 Signals

The signals used in the three-phase unbalanced RMS model are presented in Table 2.3.

Table 2.3: Signals (Three-phase unbalanced RMS-Simulation)

Name	Symbol	Unit	Type	Description
ur_A		$p.u.$	IN	Input Voltage, Real Part, Phase A
ui_A		$p.u.$	IN	Input Voltage, Imaginary Part, Phase A
ur_B		$p.u.$	IN	Input Voltage, Real Part, Phase B
ui_B		$p.u.$	IN	Input Voltage, Imaginary Part, Phase B
ur_C		$p.u.$	IN	Input Voltage, Real Part, Phase C
ui_C		$p.u.$	IN	Input Voltage, Imaginary Part, Phase C
ir_A		$p.u.$	IN	Input Current, Real Part, Phase A
ii_A		$p.u.$	IN	Input Current, Imaginary Part, Phase A
ir_B		$p.u.$	IN	Input Current, Real Part, Phase B
ii_B		$p.u.$	IN	Input Current, Imaginary Part, Phase B
ir_C		$p.u.$	IN	Input Current, Real Part, Phase C
ii_C		$p.u.$	IN	Input Current, Imaginary Part, Phase C
p		$p.u.$	OUT	Output Active Power
q		$p.u.$	OUT	Output Reactive Power

2.2.2 Calculation parameters

The calculation parameters used in the balanced RMS model are presented in Table 2.4.

Table 2.4: Calculation parameters (Three-phase unbalanced RMS-Simulation)

Name	Symbol	Unit	Description
$Srated$		MVA	Rated Power

3 EMT-Simulation

Same as in the RMS simulation, two types of measurement modes available depending on the *No. of Phases* parameter ($nphase$).

The three-phase unbalanced EMT simulation provides the phase voltages and currents for phase A, B and C to the measurement device (u_a, u_b, u_c, i_a, i_b and i_c).

The output power signals for EMT simulation are calculated as follows:

- 3-phase system:
  The phase voltages and currents are first transformed using the $\alpha\beta$ transformation.

$$U_\alpha = \frac{1}{3} \cdot (2 \cdot U_a - U_b - U_c) \tag{28}$$

$$U_\beta = \frac{1}{3} \cdot (\sqrt{3} \cdot U_b - \sqrt{3} \cdot U_c) \tag{29}$$

$$I_\alpha = \frac{1}{3} \cdot (2 \cdot I_a - I_b - I_c) \tag{30}$$

$$I_\beta = \frac{1}{3} \cdot (\sqrt{3} \cdot I_b - \sqrt{3} \cdot I_c) \tag{31}$$

$$\tag{32}$$

  The output signals are then calculated as follows:

$$p = \mathrm{Re}\left\{3 \cdot (U_\alpha + j\, U_\beta) \cdot (I_\alpha - j\, I_\beta)\right\} / Srated \tag{33}$$

$$q = \mathrm{Im}\left\{3 \cdot (U_\alpha + j\, U_\beta) \cdot (I_\alpha - j\, I_\beta)\right\} / Srated \tag{34}$$

- BI-phase system ($180°$):

$$U_1 = \frac{1}{2} \cdot (U_a - U_b) \tag{35}$$

$$I_1 = \frac{1}{2} \cdot (I_a - I_b) \tag{36}$$

$$p = \left(2 \cdot \sqrt{2}\, U_1 \cdot \sqrt{2}\, I_1\right) / Srated \tag{37}$$

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

- 2-phase system ($120°$):

$$U_1 = \frac{1}{\sqrt{3}} \cdot (U_a - U_b) \tag{39}$$

$$I_1 = \frac{1}{\sqrt{3}} \cdot (I_a - I_b) \tag{40}$$

$$p = \left(3/2 \cdot \sqrt{2}\, U_1 \cdot \sqrt{2}\, I_1\right) / Srated \tag{41}$$

$$q = 0 \tag{42}$$

- Single-phase (system): In case of a single phase system at the measurement point the option *No. of Phases* can be set to 3 and the powers are calculated as follows:

$$ur = u_a \tag{43}$$

$$ui = 0 \tag{44}$$

$$ir = i_a \tag{45}$$

$$ii = 0 \tag{46}$$

$$p = \mathrm{Re}\left\{(ur + j\, ui) \cdot (ir + j\, ii)^*\right\} / Srated \tag{47}$$

$$q = \mathrm{Im}\left\{(ur + j\, ui) \cdot (ir + j\, ii)^*\right\} / Srated \tag{48}$$

For the unbalanced EMT simulation, depending on the selected *Measurement Point*, the power can be measured at phase *a, b, c, a-n, b-n and c-n*.

The three-phase unbalanced EMT simulation provides the phase voltages and currents for phase A, B and C to the measurement device (u_a, u_b, u_c, u_n, i_a, i_b, i_c and i_n). According to the selected *Measured Phase*, the corresponding values are set to the input signals uin_r and iin_r. As output signals the active and reactive power are available.

The measurement is analogue to the measurement described in Section 2.2. The only difference is that in the EMT case, the input signals uin_i and iin_i are zero:

$$ur = uin\_r \tag{49}$$
$$ui = 0 \tag{50}$$
$$ir = iin\_r \tag{51}$$
$$ii = 0 \tag{52}$$
$$p = \mathrm{Re}\left\{(ur + j\,ui) \cdot (ir + j\,ii)^*\right\}/Srated \tag{53}$$
$$q = 0 \tag{54}$$

- DC system:

$$ur = u \tag{55}$$
$$ui = 0 \tag{56}$$
$$ir = i \tag{57}$$
$$ii = 0 \tag{58}$$
$$p = ur \cdot ir/Srated \tag{59}$$
$$q = 0 \tag{60}$$

3.1 Signals

The input and output signals used by the three-phase EMT model are presented in Table 3.1.

Table 3.1: Signals (Three-phase EMT-Simulation)

Name	Symbol	Unit	Type	Description
u_A	u_a	$p.u.$	IN	Input Voltage, Phase A
u_B	u_b	$p.u.$	IN	Input Voltage, Phase B
u_C	u_c	$p.u.$	IN	Input Voltage, Phase C
i_A	i_a	$p.u.$	IN	Input Current, Phase A
i_B	i_b	$p.u.$	IN	Input Current, Phase B
i_C	i_c	$p.u.$	IN	Input Current, Phase C
p		$p.u.$	OUT	Output Active Power
q		$p.u.$	OUT	Output Reactive Power

3.2 Calculation parameters

The calculation parameters used by the three-phase EMT model are presented in Table 3.2.

Table 3.2: Calculation parameters (Three-phase EMT-Simulation)

Name	Symbol	Unit	Description
$Srated$		MVA	Rated Power

List of Tables