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POWERFACTORY

PowerFactory 2021

Technical Reference

Common Result Variables for Terminals and Elements

Harmonics Analysis

PF2021

POWER SYSTEM SOLUTIONS

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1 General Description

The Harmonic Load Flow calculation in *PowerFactory* provides users with a multitude of result (or 'monitor') variables to choose from. The calculation of these variables in PF is described in this document, for three phase systems, considering harmonic sources defined as 'IEC' (see [2]) and 'non-IEC'.

2 Calculation Considering Only Non-IEC Harmonic Sources

2.1 Balanced Calculation

2.1.0.1 Branch Monitor Variables

Table 2.1 provides the basic nomenclature used throughout this section.

Table 2.1: Nomenclature

Name	Unit	Description
f_k	Hz	Frequency of harmonic order k
f_{out}	Hz	Output frequency specified by user in Harmonic Load Flow Command (parameter name: *ifshow*)
$\underline{i}(f_k)$	p.u.	Complex harmonic current at frequency of harmonic order k (all p.u. values are based on I_{nom})
$\underline{u}(f_k)$	p.u.	Complex harmonic voltage at frequency of harmonic order k (all p.u. values are based on U_{nom})
$\underline{I}(f_k)$	A	Complex harmonic current, at frequency of harmonic order k
$\underline{U}(f_k)$	kV	Complex harmonic voltage, at frequency of harmonic order k
I_{nom}, i_{nom}	A, p.u.	Nominal current of element
U_{nom}, u_{nom}	kV, p.u.	Rated voltage of element
i_{max}	p.u.	Maximum current of element
$tif(f_k)$	-	Telephone influence factor (according to IEEE) at frequency of harmonic order k

Monitor Variables for Output Frequency The following monitor variables are calculated for user-selected *Output Frequency*, f_{out}:

Intermediate variables:

$\underline{S} = \sqrt{3} \cdot \underline{U} \cdot \underline{I}^*$	Complex power (kVA)

Monitor variables:

$i = \lvert \underline{i} \rvert$	Current magnitude (p.u.)
$I = i \cdot I_{nom}$	Current magnitude (A)
$I1 = I$	Positive sequence current magnitude (A)
$I1 = 0$	Positive sequence current magnitude (A), for harmonic orders 5, 11, 17, 23,...
$I2 = I$	Negative sequence current magnitude (A), for harmonic orders 5, 11, 17, 23,...
$I2 = 0$	Negative sequence current magnitude (A)
$phiui = \phi_{\underline{S}}$	Angle between voltage and current (deg)
$phii = \phi_{\underline{i}}$	Current angle, absolute (deg)
$P = Re(\underline{S})$	Active power (kW)
$Q = Im(\underline{S})$	Reactive power (kvar)
$S = \lvert \underline{S} \rvert$	Apparent power (kVA)
$cosphi = \frac{P}{S}$	Power factor

Calculation variables: The following calculation variables are available for lines, transformers and series compensation:

$Losses = Re(\underline{S})$	Losses (kW)
$loading = i_{max}/i_{nom} \cdot 100$	Loading (%)

The following calculation variable is available for machines (static generator, asynchronous machine and synchronous machine):

$loading = S/S_n \cdot 100$	Loading (%), where S_n is the total apparent nominal power in MVA.

Monitor Variables Considering All Frequencies: The following variables are calculated considering all frequencies, f_k:

Intermediate variables:

$i(f_k) = \lvert\underline{i}(f_k)\rvert$	Current magnitude (p.u.)
$\underline{S}(f_k) = \sqrt{3} \cdot \underline{U}(f_k) \cdot \underline{I}(f_k)^*$	Complex power (kVA)
$P(f_k) = Re(\underline{S}(f_k))$	Active power (kW)

Monitor variables:

$HD = \frac{i(f_{out})}{i(f_1)} \cdot 100$	Harmonic distortion, current (%); based on fundamental frequency values
$HD = \frac{i(f_{out})}{i_{nom}} \cdot 100$	Harmonic distortion, current (%); based on nominal current
$HF = \frac{i(f_{out})}{irms} \cdot 100$	Harmonic factor, current (%)
$Irms = \sqrt{\sum_{k=1}^{n} i(f_k)^2} \cdot I_{nom}$	Current, RMS (kA)
$irms = \frac{Irms}{I_{nom}}$	Current, RMS (p.u.)
$THD = \frac{1}{i(f_1)} \cdot \sqrt{irms^2 - i(f_1)^2} \cdot 100$	Total harmonic distortion, current (%); based on fundamental frequency values
$THD = \frac{1}{i_{nom}} \cdot \sqrt{irms^2 - i(f_1)^2} \cdot 100$	Total harmonic distortion, current (%); based on nominal current
$THF = \frac{1}{irms} \cdot \sqrt{irms^2 - i(f_1)^2} \cdot 100$	Total harmonic factor, current (%)
$TP = \sum_{k=1}^{n} P(f_k)$	Total active power (MW)
$TS = \sqrt{Irms^2 \cdot Urms^2 \cdot 3}$	Total apparent power (MVA), where $Urms = \sqrt{\sum_{k=1}^{n} \lvert\underline{u}(f_k)\rvert^2} \cdot U_{nom}$
$TQ = \sqrt{TS^2 - TP^2}$	Total reactive power (Mvar)
$Tcosphi = \frac{TP}{TS}$	Total power factor
$IT = \sqrt{\sum_{k=1}^{n} tif(f_k)^2 \cdot i(f_k)^2} \cdot I_{nom}$	IT-product (kA)
$TAD = \frac{1}{i(f_1)} \cdot \sum_{k=1}^{n} [i(f_k) - i(f_1)] \cdot 100$	Total arithmetic distortion (%)

Calculation variables: The following calculation variables are available for lines, transformers, series compensation:

$LossesTot = \sum_{h\geq 1}^{H} Losses$	Total losses, including the fundamental (kW), where h is the harmonic order
$LossesHrm = \sum_{h>1}^{H} Losses$	Harmonic losses (kW)
$loadingTot = irms_{max}/i_{nom} \cdot 100$	Total loading (%)

2.1.0.2 Bus Monitor Variables

Table 2.2 provides the basic nomenclature used throughout this section.

Table 2.2: Nomenclature

Name	Unit	Description
f_k	Hz	Frequency of harmonic order k
f_{out}	Hz	Output frequency specified by user in Harmonic Load Flow Command (parameter name: *ifshow*)
$\underline{u}(f_k)$		Complex harmonic voltage at frequency of harmonic order k
$u(f_k)$	p.u.	Voltage magnitude at frequency of harmonic order k
U_{nom}	kV	Nominal voltage of the busbar
$\phi_{initial}$	deg	Initial voltage angle
$\underline{Z}$	Ohm	Short-circuit impedance
$\underline{Z}_{nc}$	Ohm	Short-circuit impedance without capacitive effects (only available for harmonic frequency sweep calculation)

Monitor Variables for Output Frequency The following monitor variables are calculated for user-selected output frequency, f_{out}:

$R = Re\left(\underline{Z}\right)$	Network resistance (Ω)
$X = Im\left(\underline{Z}\right)$	Network reactance (Ω)
$Z = \lvert\underline{Z}\rvert$	Network impedance magnitude (Ω)
$phiz = \phi_{\underline{Z}}$	Network impedance angle (deg)
$u = \lvert\underline{u}\rvert$	Voltage magnitude (p.u.)
$upc = u \cdot 100$	Voltage magnitude (%)

$u1 = u$	Voltage magnitude (p.u.)
$u1 = 0$	Voltage magnitude (p.u.), for orders 5, 11, 17, 23,. . . ,
$u1pc = u1 \cdot 100$	Voltage magnitude (%)
$U = u \cdot U_{nom}/\sqrt{3}$	Line-ground voltage magnitude (kV)
$Ul = u \cdot U_{nom}$	Line-line voltage magnitude (kV)
$phiu = \phi_{\underline{u}}$	Voltage angle (deg)
$phiurel = \phi_{\underline{u}} - \phi_{initial}$	Voltage, relative angle (deg)
$du = upc - 100$	Voltage deviation (%)
$u2 = u$	Negative sequence voltage (p.u.), for orders 5, 11, 17, 23, . . . ,
$u2 = 0$	Negative sequence voltage (p.u.)

and the following quantities for the short-circuit impedance without capacitive effects (Z_{nc}). The quantities are only available for the harmonic frequency sweep calculation when one of the following calculation variables is selected for recording, otherwise the value is set to zero.

$Rnc = Re\left(\underline{Z}_{nc}\right)$	Network resistance (without C) (Ω)
$Xnc = Im\left(\underline{Z}_{nc}\right)$	Network reactance (without C) (Ω)
$Znc = \lvert\underline{Z}_{nc}\rvert$	Network impedance magnitude (without C) (Ω)
$phiznc = \phi_{\underline{Z}_{nc}}$	Network impedance angle (without C) (deg)

Monitor Variables Considering All Frequencies: The following variables are calculated considering all frequencies, f_k:

Intermediate variables:

$u(f_k) = \lvert\underline{u}(f_k)\rvert$	Voltage magnitude (p.u.)

Monitor variables:

$urms = \sqrt{\sum_{k=1}^{n} u(f_k)^2}$	RMS value of voltage (p.u.)
$HD = \frac{u(f_{out})}{u(f_1)} \cdot 100$	Harmonic distortion (%); based on fundamental frequency values
$HD = \frac{u(f_{out})}{u_{nom}} \cdot 100$	Harmonic distortion (%); Based on nominal voltage, where $u_{nom} = 1$p.u.
$HF = \frac{u(f_{out})}{urms} \cdot 100$	Harmonic factor (%)

$THD = \frac{1}{u(f_1)}\sqrt{urms^2 - u(f_1)^2} \cdot 100$	Total harmonic distortion (%); based on fundamental frequency values
$THD = \frac{1}{u_{nom}}\sqrt{urms^2 - u(f_1)^2} \cdot 100$	Total harmonic distortion (%); based on nominal voltage, where $u_{nom} = 1$ p.u.
$THF = \frac{1}{urms}\sqrt{urms^2 - u(f_1)^2} \cdot 100$	Total harmonic factor (%)
$Ulrms = urms \cdot U_{nom}$	RMS value of line-line voltage (kV)
$Urms = urms \cdot U_{nom}/\sqrt{3}$	RMS value of line-ground voltage (kV)
$TAD = \frac{1}{u(f_1)} \cdot [\sum_{k=1}^{n} u(f_k) - u(f_1)] \cdot 100$	Total arithmetic distortion (%)
$uasum = \sum_{k=1}^{n} \lvert \underline{u}(f_k) \rvert$	Arithmetic voltage sum (p.u.)
$TIF = \frac{1}{urms}\sqrt{\sum_{k=1}^{n} tif(f_k)^2 \cdot u(f_k)^2}$	Telephone interference factor
$urmsint = \sqrt{\sum_{k=2}^{n} u(f_k)^2}$	RMS value of integer harmonics (p.u.)
$uasumint = \sum_{k=2}^{n} u(f_k)$	Arithmetic sum of integer harmonics (p.u.)
$THDint = THD$	Total harmonic distortion (%), integer harmonic orders
$THDnint = 0$	Total harmonic distortion (%), non-integer harmonic orders
$TADint = TAD$	Arithmetic distortion (%), integer harmonic orders
$TADnint = 0$	Arithmetic distortion (%), non-integer harmonic orders

2.2 Unbalanced Calculation

2.2.0.3 Branch Monitor Variables

Table 2.3 provides the basic nomenclature used throughout this section.

Table 2.3: Nomenclature

Name	Unit	Description
f_k	Hz	Frequency at harmonic order k
f_{out}	Hz	Output frequency specified by user in Harmonic Load Flow Command (parameter name: *ifshow*)
$\underline{i}_a(f_k)$	p.u.	Complex harmonic current for phase A, at frequency of harmonic order k (all p.u. values are based on I_{nom}). Similar nomenclature follows for other phases.
$\underline{u}_a(f_k)$	p.u.	Complex harmonic voltage (p.u.) for phase B, at frequency of harmonic order k (all p.u. values are based on U_{nom}). Similar nomenclature follows for other phases.
$\underline{I}_a(f_k)$	A	Complex harmonic current for phase A, at frequency of harmonic order k. Similar nomenclature follows for other phases.
$\underline{U}_a(f_k)$	kV	Complex harmonic voltage for phase A, at frequency of harmonic order k. Similar nomenclature follows for other phases.
$\underline{i}_0(f_k)$	p.u.	Complex zero sequence current, at frequency of harmonic order k.
$\underline{u}_0(f_k)$	p.u.	Complex zero sequence voltage, at frequency of harmonic order k.
$i{:}A(f_k)$	p.u.	Current magnitude at frequency of harmonic order k. Similar nomenclature follows for other phases.
$i0(f_k)$	p.u.	Zero sequence current magnitude at frequency of harmonic order k. Similar nomenclature follows for positive and negative sequence currents.
I_{nom}, i_{nom}	A; p.u.	Nominal current of element
U_{nom}, u_{nom}	kV; p.u.	Rated voltage of element
$tif(f_k)$		Telephone influence factor (according to IEEE) at frequency of harmonic order k.

Monitor Variables for Output Frequency The following monitor variables are calculated for user-selected output frequency, f_{out}:

Intermediate variables:

$\underline{S}_a = \underline{U}_a \cdot \underline{I}_a^*$	Complex power (kVA)
$\underline{S}_b = \underline{U}_b \cdot \underline{I}_b^*$	
$\underline{S}_c = \underline{U}_c \cdot \underline{I}_c^*$	
$\underline{S}_n = \underline{U}_n \cdot \underline{I}_n^*$	

Monitor variables:

$i{:}A = \lvert\underline{i}_a\rvert$	Phase currents (p.u.) based on rated current of element
$i{:}B = \lvert\underline{i}_b\rvert$	
$i{:}C = \lvert\underline{i}_c\rvert$	
$i{:}N = \lvert\underline{i}_n\rvert$	
$I{:}A = i{:}A \cdot I_{nom}$	Phase currents (A)
$I{:}B = i{:}B \cdot I_{nom}$	
$I{:}C = i{:}C \cdot I_{nom}$	
$I{:}N = i{:}N \cdot I_{nom}$	
$phiui{:}A = \phi_{\underline{S}_a}$	Angle between voltage and current (deg)
$phiui{:}B = \phi_{\underline{S}_b}$	
$phiui{:}C = \phi_{\underline{S}_c}$	
$phiui{:}N = \phi_{\underline{S}_n}$	
$phii{:}A = \phi_{\underline{i}_a}$	Current angle, absolute (deg)
$phii{:}B = \phi_{\underline{i}_b}$	
$phii{:}C = \phi_{\underline{i}_c}$	
$phii{:}N = \phi_{\underline{i}_n}$	

$P{:}A = Re\left(\underline{S}_a\right)$	Active power (kW)
$P{:}B = Re\left(\underline{S}_b\right)$	
$P{:}C = Re\left(\underline{S}_c\right)$	
$P{:}N = Re\left(\underline{S}_n\right)$	
$Q{:}A = Im\left(\underline{S}_a\right)$	Reactive power (kvar)
$Q{:}B = Im\left(\underline{S}_b\right)$	
$Q{:}C = Im\left(\underline{S}_c\right)$	
$Q{:}N = Im\left(\underline{S}_n\right)$	
$S{:}A = \lvert\underline{S}_a\rvert$	Apparent power (kVA)
$S{:}B = \lvert\underline{S}_b\rvert$	
$S{:}C = \lvert\underline{S}_c\rvert$	
$S{:}N = \lvert\underline{S}_n\rvert$	
$cosphi{:}A = \frac{P:A}{S:A}$	Power factor
$cosphi{:}B = \frac{P:B}{S:B}$	
$cosphi{:}C = \frac{P:C}{S:C}$	
$cosphi{:}N = \frac{P:N}{S:N}$	
$i0 = \frac{1}{3}\left(i{:}A + i{:}B + i{:}C\right)$	Zero sequence current (p.u.)
$I0 = i0 \cdot I_{nom}$	Zero sequence current (A)
$phiu0i0 = \phi_{\underline{u}_0} - \phi_{\underline{i}_0}$	Angle between voltage and current in zero sequence system (deg)
$i1 = \frac{1}{3}\left(i{:}A + a \cdot i{:}B + a^2 \cdot i{:}C\right)$	Positive sequence current (p.u.), where $a = \angle 120°$
$I1 = i1 \cdot I_{nom}$	Positive sequence current (A)
$phiu1i1 = \phi_{\underline{u}_1} - \phi_{\underline{i}_1}$	Angle between voltage and current in positive sequence system (deg)

$i2 = \frac{1}{3}\left(i{:}A + a^2 \cdot i{:}B + a \cdot i{:}C\right)$	Negative sequence current (p.u.)
$I2 = i2 \cdot I_{nom}$	Negative sequence current (A)
$phiu2i2 = \phi_{\underline{u}_2} - \phi_{\underline{i}_2}$	Angle between voltage and current in negative sequence system (deg)
$Psum = Re\left[\sum_{x=[a,b,c,n]} \underline{S}_x\right]$	Active power (kW)
$Qsum = Im\left[\sum_{x=[a,b,c,n]} \underline{S}_x\right]$	Reactive power (kvar)
$Ssum = \left\lvert\sum_{x=[a,b,c,n]} \underline{S}_x\right\rvert$	Apparent power (kVA)
$cosphisum = \frac{Psum}{Ssum}$	Power factor
$ubfac = \frac{i2}{i1}$	Unbalance factor

Calculation variables: The following calculation variables are available for lines:

$LossesPh{:}A = Re(\underline{S}_a)$	Losses (kW)
$LossesPh{:}B = Re(\underline{S}_b)$	
$LossesPh{:}C = Re(\underline{S}_c)$	
$LossesPh{:}N = Re(\underline{S}_n)$	
$Losses = \sum_{x=[A,B,C,N]} LossesPh{:}x$	Losses (kW)
$loadingPh{:}A = i{:}A_{max}/i_{nom} \cdot 100$	Loading (%)
$loadingPh{:}B = i{:}B_{max}/i_{nom} \cdot 100$	
$loadingPh{:}C = i{:}C_{max}/i_{nom} \cdot 100$	
$loadingPh{:}N = i{:}N_{max}/i_{nom} \cdot 100$	
$loading = i_{max}/i_{nom} \cdot 100$	Loading (%)

The following calculation variables are available for transformers and series compensation:

$Losses = Re(\underline{S})$	Losses (kW)
$loading = i_{max}/i_{nom} \cdot 100$	Loading (%)

The following calculation variable is available for machines (static generator, asynchronous machine and synchronous machine):

$loading = S/S_n \cdot 100$	Loading (%), where S_n is the total apparent nominal power in MVA.

Monitor Variables Considering All Frequencies: The following monitor variables are calculated considering all frequencies f_k:

Intermediate variables:

$i{:}A(f_k) = \lvert \underline{i}_a(f_k) \rvert$	Current magnitude (p.u.)
$i{:}B(f_k) = \lvert \underline{i}_b(f_k) \rvert$	
$i{:}C(f_k) = \lvert \underline{i}_c(f_k) \rvert$	
$i{:}N(f_k) = \lvert \underline{i}_n(f_k) \rvert$	
$\underline{S}_a(f_k) = \underline{U}_a(f_k) \cdot \underline{I}_a(f_k)^*$	Complex power (kVA)
$\underline{S}_b(f_k) = \underline{U}_b(f_k) \cdot \underline{I}_b(f_k)^*$	
$\underline{S}_c(f_k) = \underline{U}_c(f_k) \cdot \underline{I}_c(f_k)^*$	
$\underline{S}_n(f_k) = \underline{U}_n(f_k) \cdot \underline{I}_n(f_k)^*$	
$P{:}A(f_k) = Re(\underline{S}_a(f_k))$	Active power (kW)
$P{:}B(f_k) = Re(\underline{S}_b(f_k))$	
$P{:}C(f_k) = Re(\underline{S}_c(f_k))$	
$P{:}N(f_k) = Re(\underline{S}_n(f_k))$	
$\underline{i0}(f_k) = \frac{1}{3}\left(\underline{i}_a(f_k) + \underline{i}_b(f_k) + \underline{i}_c(f_k)\right)$	Zero sequence current (p.u.)
$\underline{i1}(f_k) = \frac{1}{3}\left(i{:}A(f_k) + a \cdot i{:}B(f_k) + a^2 \cdot i{:}C(f_k)\right)$	Positive sequence current (p.u.), where $a = \angle 120°$
$\underline{i2}(f_k) = \frac{1}{3}\left(\underline{i}_a(f_k) + a^2 \cdot \underline{i}_b(f_k) + a \cdot \underline{i}_c(f_k)\right)$	Negative sequence current (p.u.)
$i0(f_k) = \lvert \underline{i0}(f_k) \rvert$	Zero sequence current magnitude (p.u.)
$i1(f_k) = \lvert \underline{i1}(f_k) \rvert$	Positive sequence current magnitude (p.u.)
$i2(f_k) = \lvert \underline{i2}(f_k) \rvert$	Negative sequence current magnitude (p.u.)

Monitor variables:

$irms{:}A = \sqrt{\sum_{k\geq 1} i{:}A(f_k)^2}$ Phase currents (p.u.) based on rated current of element

$irms{:}B = \sqrt{\sum_{k\geq 1} i{:}B(f_k)^2}$

$irms{:}C = \sqrt{\sum_{k\geq 1} i{:}C(f_k)^2}$

$irms{:}N = \sqrt{\sum_{k\geq 1} i{:}N(f_k)^2}$

$Irms{:}A = irms{:}A \cdot I_{nom}$ Phase currents (A)

$Irms{:}B = irms{:}B \cdot I_{nom}$

$Irms{:}C = irms{:}C \cdot I_{nom}$

$Irms{:}N = irms{:}N \cdot I_{nom}$

$HD{:}A = \frac{i{:}A(f_{out})}{i{:}A(f_1)} \cdot 100$ Harmonic distortion (%); based on fundamental frequency values

$HD{:}B = \frac{i{:}B(f_{out})}{i{:}B(f_1)} \cdot 100$

$HD{:}C = \frac{i{:}C(f_{out})}{i{:}C(f_1)} \cdot 100$

$HD{:}N = \frac{i{:}N(f_{out})}{i{:}N(f_1)} \cdot 100$

$HD{:}A = \frac{i{:}A(f_{out})}{i_{nom}(f_1)} \cdot 100$ Harmonic distortion (%); based on nominal current

$HD{:}B = \frac{i{:}B(f_{out})}{i_{nom}(f_1)} \cdot 100$

$HD{:}C = \frac{i{:}C(f_{out})}{i_{nom}(f_1)} \cdot 100$

$HD{:}N = \frac{i{:}N(f_{out})}{i_{nom}(f_1)} \cdot 100$

$HF{:}A = \frac{i{:}A(f_{out})}{irms{:}A(f_1)} \cdot 100$ Harmonic factor (%)

$HF{:}B = \frac{i{:}B(f_{out})}{irms{:}B(f_1)} \cdot 100$

$HF{:}C = \frac{i{:}C(f_{out})}{irms{:}C(f_1)} \cdot 100$

$HF{:}N = \frac{i{:}N(f_{out})}{irms{:}N(f_1)} \cdot 100$

$THD{:}A = \frac{1}{i{:}A(f_1)} \cdot \sqrt{irms{:}A^2 - i{:}A(f_1)^2} \cdot 100$ Total harmonic distortion, current (%); based on fundamental frequency values

$THD{:}B = \frac{1}{i{:}B(f_1)} \cdot \sqrt{irms{:}B^2 - i{:}B(f_1)^2} \cdot 100$

$THD{:}C = \frac{1}{i{:}C(f_1)} \cdot \sqrt{irms{:}C^2 - i{:}C(f_1)^2} \cdot 100$

$THD{:}N = \frac{1}{i{:}N(f_1)} \cdot \sqrt{irms{:}N^2 - i{:}N(f_1)^2} \cdot 100$

$THD{:}A = \frac{1}{i_{nom}} \cdot \sqrt{irms{:}A^2 - i{:}A(f_1)^2} \cdot 100$ Total harmonic distortion, current (%); based on nominal current

$THD{:}B = \frac{1}{i_{nom}} \cdot \sqrt{irms{:}B^2 - i{:}B(f_1)^2} \cdot 100$

$THD{:}C = \frac{1}{i_{nom}} \cdot \sqrt{irms{:}C^2 - i{:}C(f_1)^2} \cdot 100$

$THD{:}N = \frac{1}{i_{nom}} \cdot \sqrt{irms{:}N^2 - i{:}N(f_1)^2} \cdot 100$

$THF{:}A = \frac{1}{irms{:}A} \cdot \sqrt{irms{:}A^2 - i{:}A(f_1)^2} \cdot 100$ Total harmonic factor, current (%)

$THF{:}B = \frac{1}{irms{:}B} \cdot \sqrt{irms{:}B^2 - i{:}B(f_1)^2} \cdot 100$

$THF{:}C = \frac{1}{irms{:}C} \cdot \sqrt{irms{:}C^2 - i{:}C(f_1)^2} \cdot 100$

$THF{:}N = \frac{1}{irms{:}N} \cdot \sqrt{irms{:}N^2 - i{:}N(f_1)^2} \cdot 100$

$TP{:}A = \sum_{k\geq 1} P{:}A(f_k)$ Total active power (MW)

$TP{:}B = \sum_{k\geq 1} P{:}B(f_k)$

$TP{:}C = \sum_{k\geq 1} P{:}C(f_k)$

$TP{:}N = \sum_{k\geq 1} P{:}N(f_k)$

$TS{:}A = \sqrt{Irms{:}A^2 \cdot Urms{:}A^2}$ Total apparent power (MVA), where $Urms{:}A = \sqrt{\sum_{k\geq 1} \left|\underline{u}_a(f_k)\right|^2} \cdot U_{nom}$

$TS{:}B = \sqrt{Irms{:}B^2 \cdot Urms{:}B^2}$

$TS{:}C = \sqrt{Irms{:}C^2 \cdot Urms{:}C^2}$

$TS{:}N = \sqrt{Irms{:}N^2 \cdot Urms{:}N^2}$

$TQ{:}A = \sqrt{TS{:}A^2 - TP{:}A^2}$ Total reactive power (Mvar)

$TQ{:}B = \sqrt{TS{:}B^2 - TP{:}B^2}$

$TQ{:}C = \sqrt{TS{:}C^2 - TP{:}C^2}$

$TQ{:}N = \sqrt{TS{:}N^2 - TP{:}N^2}$

$Tcosphi{:}A = \frac{TP{:}A}{TS{:}A}$ Total power factor

$Tcosphi{:}B = \frac{TP{:}B}{TS{:}B}$

$Tcosphi{:}C = \frac{TP{:}C}{TS{:}C}$

$Tcosphi{:}N = \frac{TP{:}N}{TS{:}N}$

$TAD{:}A = \frac{1}{i{:}A(f_1)} \cdot \left[\sum_{k\geq 1} i{:}A(f_k) - i{:}A(f_1)\right] \cdot 100$ Arithmetic distortion (%)

$TAD{:}B = \frac{1}{i{:}B(f_1)} \cdot \left[\sum_{k\geq 1} i{:}B(f_k) - i{:}B(f_1)\right] \cdot 100$

$TAD{:}C = \frac{1}{i{:}C(f_1)} \cdot \left[\sum_{k\geq 1} i{:}C(f_k) - i{:}C(f_1)\right] \cdot 100$

$TAD{:}N = \frac{1}{i{:}N(f_1)} \cdot \left[\sum_{k\geq 1} i{:}N(f_k) - i{:}N(f_1)\right] \cdot 100$

$IT{:}A = \sqrt{\sum_{k\geq 1} tif(f_k)^2 \cdot i{:}A(f_k)^2} \cdot I_{nom}$ IT-product (kA)

$IT{:}B = \sqrt{\sum_{k\geq 1} tif(f_k)^2 \cdot i{:}B(f_k)^2} \cdot I_{nom}$

$IT{:}C = \sqrt{\sum_{k\geq 1} tif(f_k)^2 \cdot i{:}C(f_k)^2} \cdot I_{nom}$

$IT{:}N = \sqrt{\sum_{k\geq 1} tif(f_k)^2 \cdot i{:}N(f_k)^2} \cdot I_{nom}$

$I0rms = \sqrt{\sum_{k\geq 1} i0(f_k)^2} \cdot I_{nom}$ Zero sequence current, RMS value (kA)

$i0rms = \frac{I0rms}{I_{nom}}$ Zero sequence current, RMS value (p.u.)

$THD0 = \frac{1}{i0(f_1)} \sqrt{i0rms^2 - i0(f_1)^2} \cdot 100$	Total harmonic distortion (%) (current, zero sequence); based on fundamental frequency values
$THD0 = \frac{1}{i_{nom}} \sqrt{i0rms^2 - i0(f_1)^2} \cdot 100$	Total harmonic distortion (%) (current, zero sequence); based on nominal current
$THF0 = \frac{1}{i0rms} \sqrt{i0rms^2 - i0(f_1)^2} \cdot 100$	Total harmonic factor (%) (current, zero sequence)
$I1rms = \sqrt{\sum_{k \geq 1} i1(f_k)^2} \cdot I_{nom}$	Positive sequence current, RMS value (kA)
$i1rms = \frac{I1rms}{I_{nom}}$	Positive sequence current, RMS value (p.u.)
$THD1 = \frac{1}{i1(f_1)} \sqrt{i1rms^2 - i1(f_1)^2} \cdot 100$	Total harmonic distortion (%) (current, positive sequence); based on fundamental frequency values
$THD1 = \frac{1}{i_{nom}} \sqrt{i1rms^2 - i1(f_1)^2} \cdot 100$	Total harmonic distortion (%) (current, positive sequence); based on nominal current
$THF1 = \frac{1}{i1rms} \sqrt{i1rms^2 - i1(f_1)^2} \cdot 100$	Total harmonic factor (%) (current, positive sequence)
$I2rms = \sqrt{\sum_{k \geq 1} i2(f_k)^2} \cdot I_{nom}$	Negative sequence current, RMS value (kA)
$i2rms = \frac{I2rms}{I_{nom}}$	Negative sequence current, RMS value (p.u.)
$THD2 = \frac{1}{i2(f_1)} \sqrt{i2rms^2 - i2(f_1)^2} \cdot 100$	Total harmonic distortion (%) (current, negative sequence); based on fundamental frequency values
$THD2 = \frac{1}{i_{nom}} \sqrt{i2rms^2 - i2(f_1)^2} \cdot 100$	Total harmonic distortion (%) (current, negative sequence); based on nominal current
$THF2 = \frac{1}{i2rms} \sqrt{i2rms^2 - i2(f_1)^2} \cdot 100$	Total harmonic factor (%) (current, negative sequence)
$HD0 = \frac{i0(f_{out})}{\sqrt{i0(f_1)^2 + i1(f_1)^2 + i2(f_1)^2}} \cdot 100$	Harmonic distortion, zero sequence (%); based on fundamental frequency values
$HD1 = \frac{i1(f_{out})}{\sqrt{i0(f_1)^2 + i1(f_1)^2 + i2(f_1)^2}} \cdot 100$	Harmonic distortion, positive sequence (%)
$HD2 = \frac{i2(f_{out})}{\sqrt{i0(f_1)^2 + i1(f_1)^2 + i2(f_1)^2}} \cdot 100$	Harmonic distortion, negative sequence (%)

$HD0 = \frac{i0(f_{out})}{i_{nom}} \cdot 100$	Harmonic distortion, zero sequence (%); based on nominal current
$HD1 = \frac{i1(f_{out})}{i_{nom}} \cdot 100$	Harmonic distortion, positive sequence (%)
$HD2 = \frac{i2(f_{out})}{i_{nom}} \cdot 100$	Harmonic distortion, negative sequence (%)
$HF0 = \frac{i0(f_{out})}{i0rms} \cdot 100$	Harmonic factor, zero sequence (%)
$HF1 = \frac{i1(f_{out})}{i1rms} \cdot 100$	Harmonic factor, positive sequence (%)
$HF2 = \frac{i2(f_{out})}{i2rms} \cdot 100$	Harmonic factor, negative sequence (%)
$TPsum = \sum_{x=[A,B,C,N]} TP{:}x$	Total active power (MW)
$TQsum = \sum_{x=[A,B,C,N]} TQ{:}x$	Total reactive power (Mvar)
$TSsum = \sqrt{TPsum^2 + TQsum^2}$	Total apparent power (MVA)
$Tcosphisum = \frac{TPsum}{TSsum}$	Total power factor
$THDbal = \sqrt{THD1^2 + THD2^2}$	Total harmonic distortion (%), excluding zero sequence
$THDtot = \sqrt{THD1^2 + THD2^2 + THD0^2}$	Total harmonic distortion (%), including zero sequence
$TADmx = \max\limits_{x=[A,B,C,N]}(TAD{:}x)$	Arithmetic distortion (%)
$TADint = \max\limits_{x=[A,B,C,N]}(TADint{:}x)$	Arithmetic distortion (%), where $TADint{:}x = \frac{1}{i{:}x(f_1)} \cdot \left[\sum\limits_{\substack{k \geq 1 \\ integer}} i{:}x(f_k) - i{:}x(f_1) \right] \cdot 100$
$TADnint = \max\limits_{x=[A,B,C,N]}(TADnint{:}x)$	Arithmetic distortion (%), where $TADnint{:}x = \frac{1}{i{:}x(f_1)} \cdot \left[\sum\limits_{\substack{k \geq 1 \\ non-integer}} i{:}x(f_k) - i{:}x(f_1) \right] \cdot 100$
$TAD\_3 = \max\limits_{x=[A,B,C,N]}(TADint{:}x)$	Arithmetic distortion (%), harmonic orders: multiples of three
$TAD\_2 = \max\limits_{x=[A,B,C,N]}(TADint{:}x)$	Arithmetic distortion (%), harmonic orders: multiples of two

$THDint = \max\limits_{x=[A,B,C,N]}(THDint{:}x)$	Total harmonic distortion (%), where $THDint{:}x = \frac{1}{i{:}x(f_1)} \cdot \sqrt{irms{:}x^2 - i{:}x(f_1)^2} \cdot 100$ (Fundamental frequency values) or $THDint{:}x = \frac{1}{inom} \cdot \sqrt{irms{:}x^2 - i{:}x(f_1)^2} \cdot 100$ (Nominal current) and $irms{:}x = \sqrt{\sum\limits_{\substack{k\geq 1\\ integer}} i{:}x(f_k)^2}$
$THDnint = \max\limits_{x=[A,B,C,N]}(THDnint{:}x)$	Total harmonic distortion (%), where $THDnint{:}x = \frac{1}{i{:}x(f_1)} \cdot \sqrt{irms{:}x^2 - i{:}x(f_1)^2} \cdot 100$ (Fundamental frequency values) or $THDnint{:}x = \frac{1}{inom} \cdot \sqrt{irms{:}x^2 - i{:}x(f_1)^2} \cdot 100$ (Nominal current) and $irms{:}x = \sqrt{\sum\limits_{\substack{k>1\\ non-integer}} i{:}x(f_k)^2}$
$THD\_3 = \max\limits_{x=[A,B,C,N]}(THDint{:}x)$	Total harmonic distortion (%), harmonic orders: multiples of three
$THD\_2 = \max\limits_{x=[A,B,C,N]}(THDint{:}x)$	Total harmonic distortion (%), harmonic orders: multiples of two
$ITmx = \max(IT{:}x)$	IT-Product (kA)

Calculation variables: The following calculation variables are available for lines, transformers and series compensation:

$LossesTot = \sum_{h\geq 1}^{H} \sum_{x=[A,B,C,N]} Losses{:}x$	Total losses, including the fundamental (kW), where h is the harmonic order
$LossesHrm = \sum_{h>1}^{H} \sum_{x=[A,B,C,N]} Losses{:}x$	Harmonic losses (kW)
$loadingTot = irms_{max}/i_{nom} \cdot 100$	Total loading (%)

2.2.0.4 Bus Monitor Variables

Table2.4 provides the basic nomenclature used throughout this section.

Table 2.4: Nomenclature

Name	Unit	Description
f_k	Hz	Frequency of harmonic order k
f_{out}	Hz	Output frequency specified by user in Harmonic Load Flow Command (parameter name: *ifshow*)
$\underline{u}_a(f_k)$	p.u.	Complex harmonic voltage, phase A. Similar nomenclature is used for the other phases.
$\underline{ul}_a(f_k)$	p.u.	Complex line-line voltage, phase A, where $\underline{ul}_a(f_k) = \underline{u}_a(f_k) - \underline{u}_b(f_k)$.
$ul{:}A(f_k)$	p.u.	Line-line voltage magnitude, phase A, where $ul{:}A(f_k) = \lvert\underline{u}_a(f_k) - \underline{u}_b(f_k)\rvert$. Similar follows for the other phases.
$\underline{uln}_a(f_k)$	p.u.	Complex line-neutral voltage, phase A, where $\underline{uln}_a(f_k) = \underline{u}_a(f_k) - \underline{u}_n(f_k)$. Similar follows for the other phases.
$uln{:}A(f_k)$	p.u.	Line-line voltage magnitude, phase A, where $uln{:}A(f_k) = \lvert\underline{u}_a(f_k) - \underline{u}_n(f_k)\rvert$. Similar follows for the other phases.
$u{:}A(f_k)$	p.u.	Voltage magnitude at frequency of harmonic order k
U_{nom}	kV	Nominal voltage of the busbar (kV)
$\phi_{initial_a}$	deg	Initial voltage angle, phase A. Similar nomenclature is used for other phases.
$\underline{Zl}_a$	Ohm	Line impedance, phase A. Similar follows for the other phases.
$\underline{Zln}_a$	Ohm	Line-neutral impedance, phase A. Similar follows for the other phases.
$\underline{Z}_a$	Ohm	Short-circuit impedance, phase A. Similar nomenclature is used for other phases.
$\underline{Z}_{nc,a}$	Ohm	Short-circuit impedance without capacitive effects, phase A. Similar nomenclature is used for other phases (only available for harmonic frequency sweep calculation).

Monitor Variables for Output Frequency The following monitor variables are calculated for user-selected output frequency, f_{out}:

Intermediate variables:

$\underline{u0} = \frac{1}{3}\left(\underline{u}_a + \underline{u}_b + \underline{u}_c\right)$	Zero sequence voltage (p.u.)
$\underline{u1} = \frac{1}{3}\left(\underline{u}_a + a \cdot \underline{u}_b + a^2 \cdot \underline{u}_c\right)$	Positive sequence voltage (p.u.)
$\underline{u2} = \frac{1}{3}\left(\underline{u}_a + a^2 \cdot \underline{u}_b + a \cdot \underline{u}_c\right)$	Negative sequence voltage (p.u.)

Monitor variables:

$u{:}A = \lvert\underline{u}_a\rvert$	Line-ground voltage, magnitude (p.u.)
$u{:}B = \lvert\underline{u}_b\rvert$	
$u{:}C = \lvert\underline{u}_c\rvert$	
$upc{:}A = u{:}A \cdot 100$	Line-ground voltage, magnitude (%)
$upc{:}B = u{:}B \cdot 100$	
$upc{:}C = u{:}C \cdot 100$	
$U{:}A = u{:}A \cdot U_{nom}/\sqrt{3}$	Line-ground voltage magnitude (kV)
$U{:}B = u{:}B \cdot U_{nom}/\sqrt{3}$	
$U{:}C = u{:}C \cdot U_{nom}/\sqrt{3}$	
$phiu{:}A = \phi_{\underline{u}_a}$	Voltage angle (deg)
$phiu{:}B = \phi_{\underline{u}_b}$	
$phiu{:}C = \phi_{\underline{u}_c}$	
$phiurel{:}A = \phi_{\underline{u}_a} - \phi_{initial_a}$	Voltage, relative angle (deg)
$phiurel{:}B = \phi_{\underline{u}_b} - \phi_{initial_b}$	
$phiurel{:}C = \phi_{\underline{u}_c} - \phi_{initial_c}$	
$ul{:}A = \lvert\underline{ul}_a\rvert$	Line-line voltage magnitude (p.u.)
$ul{:}B = \lvert\underline{ul}_b\rvert$	
$ul{:}C = \lvert\underline{ul}_c\rvert$	
$ulpc{:}A = ul{:}A \cdot 100$	Line-line voltage magnitude (%)
$ulpc{:}B = ul{:}B \cdot 100$	
$ulpc{:}C = ul{:}C \cdot 100$	

$Ul{:}A = ul{:}A \cdot U_{nom}$	Line-line voltage magnitude (kV)
$Ul{:}B = ul{:}B \cdot U_{nom}$	
$Ul{:}C = ul{:}C \cdot U_{nom}$	
$phiul{:}A = \phi_{\underline{ul}_a}$	Line-line voltage angle (deg)
$phiul{:}B = \phi_{\underline{ul}_b}$	
$phiul{:}C = \phi_{\underline{ul}_c}$	
$uln{:}A = \lvert\underline{uln}_a\rvert$	Line-neutral voltage magnitude (p.u.)
$uln{:}B = \lvert\underline{uln}_b\rvert$	
$uln{:}C = \lvert\underline{uln}_c\rvert$	
$Uln{:}A = uln{:}A \cdot U_{nom}/\sqrt{3}$	Line-neutral voltage magnitude (kV)
$Uln{:}B = uln{:}B \cdot U_{nom}/\sqrt{3}$	
$Uln{:}C = uln{:}C \cdot U_{nom}/\sqrt{3}$	
$phiuln{:}A = \phi_{\underline{uln}_a}$	Line-neutral voltage angle (deg)
$phiuln{:}B = \phi_{\underline{uln}_b}$	
$phiuln{:}C = \phi_{\underline{uln}_c}$	
$R{:}A = Re(\underline{Z}_a)$	Line-ground resistance (Ω)
$R{:}B = Re(\underline{Z}_b)$	
$R{:}C = Re(\underline{Z}_c)$	
$X{:}A = Im(\underline{Z}_a)$	Line-ground network reactance (Ω)
$X{:}B = Im(\underline{Z}_b)$	
$X{:}C = Im(\underline{Z}_c)$	
$Z{:}A = \lvert\underline{Z}_a\rvert$	Line-ground network impedance (Ω)
$Z{:}B = \lvert\underline{Z}_b\rvert$	
$Z{:}C = \lvert\underline{Z}_c\rvert$	

$phiz{:}A = \phi_{\underline{Z}_a}$	Line-ground angle of network impedance (deg)
$phiz{:}B = \phi_{\underline{Z}_b}$	
$phiz{:}C = \phi_{\underline{Z}_c}$	
$Rl{:}A = Re(\underline{Z}l_a)$	Line-line resistance (Ω)
$Rl{:}B = Re(\underline{Z}l_b)$	
$Rl{:}C = Re(\underline{Z}l_c)$	
$Xl{:}A = Im(\underline{Zl}_a)$	Line-line network reactance (Ω)
$Xl{:}B = Im(\underline{Zl}_b)$	
$Xl{:}C = Im(\underline{Zl}_c)$	
$Zl{:}A = \lvert\underline{Zl}_a\rvert$	Line-line network impedance (Ω)
$Zl{:}B = \lvert\underline{Zl}_b\rvert$	
$Zl{:}C = \lvert\underline{Zl}_c\rvert$	
$phizl{:}A = \phi_{\underline{Z}l_a}$	Line-line angle of network impedance (deg)
$phizl{:}B = \phi_{\underline{Z}l_b}$	
$phizl{:}C = \phi_{\underline{Z}l_c}$	
$Rln{:}A = Re(\underline{Zln}_a)$	Line-neutral resistance (Ω)
$Rln{:}B = Re(\underline{Zln}_b)$	
$Rln{:}C = Re(\underline{Zln}_c)$	
$Xln{:}A = Im(\underline{Zln}_a)$	Line-neutral network reactance (Ω)
$Xln{:}B = Im(\underline{Zln}_b)$	
$Xln{:}C = Im(\underline{Zln}_c)$	
$Zln{:}A = \lvert\underline{Zln}_a\rvert$	Line-neutral network impedance (Ω)
$Zln{:}B = \lvert\underline{Zln}_b\rvert$	
$Zln{:}C = \lvert\underline{Zln}_c\rvert$	

$phizln{:}A = \phi_{\underline{Zln}_a}$	Line-neutral angle of network impedance (deg)
$phizln{:}B = \phi_{\underline{Zln}_b}$	
$phizln{:}C = \phi_{\underline{Zln}_c}$	
$u0 = \lvert\underline{u0}\rvert$	Line-ground zero sequence voltage magnitude (p.u.)
$U0 = u0 \cdot U_{nom}/\sqrt{3}$	Zero sequence voltage magnitude (kV)
$U0x3 = 3 \cdot U0$	(kV)
$phiu0 = \phi_{\underline{u0}}$	Zero sequence voltage angle (deg)
$u1 = \lvert\underline{u1}\rvert$	Line-ground positive sequence voltage magnitude (p.u.)
$u1pc = u1 \cdot 100$	Line-ground positive sequence voltage magnitude (%)
$u1r = Re(\underline{u1})$	Positive sequence voltage magnitude, real part (p.u.)
$u1i = Im(\underline{u1})$	Positive sequence voltage magnitude, imaginary part (p.u.)
$U1 = u1 \cdot U_{nom}/\sqrt{3}$	Line-ground positive sequence voltage magnitude (kV)
$phiu1 = \phi_{\underline{u1}}$	Line-ground positive sequence voltage angle (deg)
$u2 = \lvert\underline{u2}\rvert$	Line-ground negative sequence voltage magnitude (p.u.)
$U2 = u2 \cdot U_{nom}/\sqrt{3}$	Line-ground negative sequence voltage magnitude (kV)
$phiu2 = \phi_{\underline{u2}}$	Line-ground negative sequence voltage magnitude (deg)
$U1l = u1 \cdot U_{nom}$	Line-line positive sequence voltage magnitude (kV)
$U2l = u2 \cdot U_{nom}$	Line-line negative sequence voltage magnitude (kV)
$un = \lvert\underline{u}_n\rvert$	Neutral-ground voltage magnitude (p.u.)
$Un = un \cdot U_{nom}/\sqrt{3}$	Neutral-ground voltage magnitude (kV)
$R0 = Re(\underline{Z0})$	Zero sequence resistance (Ω)
$X0 = Im(\underline{Z0})$	Zero sequence network reactance (Ω)
$Z0 = \lvert\underline{Z0}\rvert$	Zero sequence network impedance (Ω)
$phiz0 = \phi_{\underline{Z0}}$	Zero sequence network impedance angle (deg)

$R1 = Re(\underline{Z1})$	Positive sequence resistance (Ω)
$X1 = Im(\underline{Z1})$	Positive sequence network reactance (Ω)
$Z1 = \lvert\underline{Z1}\rvert$	Positive sequence network impedance (Ω)
$phiz1 = \phi_{\underline{Z1}}$	Positive sequence network impedance angle (deg)
$R2 = Re(\underline{Z2})$	Negative sequence resistance (Ω)
$X2 = Im(\underline{Z2})$	Negative sequence network reactance (Ω)
$Z2 = \lvert\underline{Z2}\rvert$	Negative sequence network impedance (Ω)
$phiz2 = \phi_{\underline{Z2}}$	Negative sequence network impedance angle (deg)
$Rn = Re(\underline{Z}_n)$	Resistance, neutral (Ω)
$Xn = Im(\underline{Z}_n)$	Network reactance, neutral (Ω)
$Zn = \lvert\underline{Z}_n\rvert$	Network impedance, neutral (Ω)
$phizn = \phi_{\underline{Z}_n}$	Angle of network impedance, neutral (Ω)
$ubfac = \frac{u2}{u1}$	Unbalance factor

and the following quantities for the short-circuit impedance without capacitive effects ($Z_{nc,a/b/c}$). The quantities are only available for the harmonic frequency sweep calculation when one of the following calculation variables is selected for recording, otherwise the value is set to zero.

$Rnc{:}A = Re(\underline{Z}_{nc,a})$ $Rnc{:}B = Re(\underline{Z}_{nc,b})$ $Rnc{:}C = Re(\underline{Z}_{nc,c})$	Line-ground resistance (without C) (Ω)
$Xnc{:}A = Im(\underline{Z}_{nc,a})$ $Xnc{:}B = Im(\underline{Z}_{nc,b})$ $Xnc{:}C = Im(\underline{Z}_{nc,c})$	Line-ground network reactance (without C) (Ω)
$Znc{:}A = \lvert\underline{Z}_{nc,a}\rvert$ $Znc{:}B = \lvert\underline{Z}_{nc,b}\rvert$ $Znc{:}C = \lvert\underline{Z}_{nc,c}\rvert$	Line-ground network (without C) impedance (Ω)

$phiznc{:}A = \phi_{\underline{Z}_{nc,a}}$	Line-ground angle of network impedance (without C) (deg)
$phiznc{:}B = \phi_{\underline{Z}_{nc,b}}$	
$phiznc{:}C = \phi_{\underline{Z}_{nc,c}}$	
$R0nc = Re(\underline{Z0}_{nc})$	Zero sequence resistance (without C) (Ω)
$X0nc = Im(\underline{Z0}_{nc})$	Zero sequence network reactance (without C) (Ω)
$Z0nc = \lvert\underline{Z0}_{nc}\rvert$	Zero sequence network impedance (without C) (Ω)
$phiz0nc = \phi_{\underline{Z0}_{nc}}$	Zero sequence network impedance angle (without C) (deg)
$R1nc = Re(\underline{Z1}_{nc})$	Positive sequence resistance (without C) (Ω)
$X1nc = Im(\underline{Z1}_{nc})$	Positive sequence network reactance (without C) (Ω)
$Z1nc = \lvert\underline{Z1}_{nc}\rvert$	Positive sequence network impedance (without C) (Ω)
$phiz1nc = \phi_{\underline{Z1}_{nc}}$	Positive sequence network impedance angle (without C) (deg)
$R2nc = Re(\underline{Z2}_{nc})$	Negative sequence resistance (without C) (Ω)
$X2nc = Im(\underline{Z2}_{nc})$	Negative sequence network reactance (without C) (Ω)
$Z2nc = \lvert\underline{Z2}_{nc}\rvert$	Negative sequence network impedance (without C) (Ω)
$phiz2nc = \phi_{\underline{Z2}_{nc}}$	Negative sequence network impedance angle (without C) (deg)

Monitor Variables Considering All Frequencies: The following monitor variables are calculated considering all frequencies, f_k:

Intermediate variables:

$\underline{u0}(f_k) = \frac{1}{3}\left[\underline{u}_a(f_k) + \underline{u}_b(f_k) + \underline{u}_c(f_k)\right]$	Zero sequence voltage (p.u.)
$\underline{u1}(f_k) = \frac{1}{3}\left[\underline{u}_a(f_k) + a \cdot \underline{u}_b(f_k) + a^2 \cdot \underline{u}_c(f_k)\right]$	Positive sequence voltage (p.u.)
$\underline{u2}(f_k) = \frac{1}{3}\left[\underline{u}_a(f_k) + a^2 \cdot \underline{u}_b(f_k) + a \cdot \underline{u}_c(f_k)\right]$	Negative sequence voltage (p.u.)
$u0(f_k) = \lvert\underline{u0}(f_k)\rvert$	Zero sequence voltage magnitude (p.u.)
$u1(f_k) = \lvert\underline{u1}(f_k)\rvert$	Positive sequence voltage magnitude (p.u.)
$u2(f_k) = \lvert\underline{u2}(f_k)\rvert$	Negative sequence voltage magnitude (p.u.)

$u{:}A(f_k) = \lvert\underline{u}_a(f_k)\rvert$	Line-ground voltage, magnitude (p.u.)
$u{:}B(f_k) = \lvert\underline{u}_b(f_k)\rvert$	
$u{:}C(f_k) = \lvert\underline{u}_c(f_k)\rvert$	

$ul{:}A(f_k) = \lvert\underline{ul}_a(f_k)\rvert$	Line-line voltage magnitude (p.u.)
$ul{:}C(f_k) = \lvert\underline{ul}_c(f_k)\rvert$	
$ul{:}B(f_k) = \lvert\underline{ul}_b(f_k)\rvert$	

Monitor variables:

$urms{:}A = \sqrt{\sum_{k\geq 1} u{:}A(f_k)^2}$ RMS value of line-neutral voltage (p.u.)

$urms{:}B = \sqrt{\sum_{k\geq 1} u{:}B(f_k)^2}$

$urms{:}C = \sqrt{\sum_{k\geq 1} u{:}C(f_k)^2}$

$Urms{:}A = urms{:}A \cdot U_{nom}/\sqrt{3}$ RMS value of line-neutral voltage (kV)

$Urms{:}B = urms{:}B \cdot U_{nom}/\sqrt{3}$

$Urms{:}C = urms{:}C \cdot U_{nom}/\sqrt{3}$

$u0rms = \sqrt{\sum_{k\geq 1} u0(f_k)^2}$ RMS value of zero sequence voltage (p.u.)

$U0rms = u0rms \cdot U_{nom}/\sqrt{3}$ RMS value of zero sequence voltage (kV)

$u1rms = \sqrt{\sum_{k\geq 1} u1(f_k)^2}$ RMS value of positive sequence voltage (p.u.)

$U1rms = u1rms \cdot U_{nom}/\sqrt{3}$ RMS value of positive sequence voltage (kV)

$U1lrms = u1rms \cdot U_{nom}$ RMS value of positive sequence line-line voltage (kV)

$u2rms = \sqrt{\sum_{k\geq 1} u2(f_k)^2}$ RMS value of negative sequence voltage (p.u.)

$U2rms = u2rms \cdot U_{nom}/\sqrt{3}$ RMS value of negative sequence voltage (kV)

$U2lrms = u2rms \cdot U_{nom}$ RMS value of negative sequence line-line voltage (kV)

$HD{:}A = \frac{u{:}A(f_{out})}{u{:}A(f_1)} \cdot 100$ Harmonic distortion (%); based on fundamental frequency values

$HD{:}B = \frac{u{:}B(f_{out})}{u{:}B(f_1)} \cdot 100$

$HD{:}C = \frac{u{:}C(f_{out})}{u{:}C(f_1)} \cdot 100$

$HD{:}A = \frac{u{:}A(f_{out})}{u_{nom}{:}A} \cdot 100$ Harmonic distortion (%); based on nominal voltage, where $u_{nom} = 1$ p.u.

$HD{:}B = \frac{u{:}B(f_{out})}{u_{nom}{:}B} \cdot 100$

$HD{:}C = \frac{u{:}C(f_{out})}{u_{nom}{:}C} \cdot 100$

$HF{:}A = \frac{u{:}A(f_{out})}{urms{:}A} \cdot 100$ Harmonic factor (%)

$HF{:}B = \frac{u{:}B(f_{out})}{urms{:}B} \cdot 100$

$HF{:}C = \frac{u{:}C(f_{out})}{urms{:}C} \cdot 100$

$HD0 = \frac{u0(f_{out})}{\sqrt{u0(f_1)^2+u1(f_1)^2+u2(f_1)^2}} \cdot 100$ Harmonic distortion, zero sequence (%); based on fundamental frequency values

$HD1 = \frac{u1(f_{out})}{\sqrt{u0(f_1)^2+u1(f_1)^2+u2(f_1)^2}} \cdot 100$ Harmonic distortion, positive sequence (%)

$HD2 = \frac{u2(f_{out})}{\sqrt{u0(f_1)^2+u1(f_1)^2+u2(f_1)^2}} \cdot 100$ Harmonic distortion, negative sequence (%)

$HF0 = \frac{u0(f_{out})}{u0rms} \cdot 100$ Harmonic factor, zero sequence (%)

$HF1 = \frac{u1(f_{out})}{u1rms} \cdot 100$ Harmonic factor, positive sequence (%)

$HF2 = \frac{u2(f_{out})}{u2rms} \cdot 100$ Harmonic factor, negative sequence (%)

$HD0 = \frac{u0(f_{out})}{u_{nom}} \cdot 100$ Harmonic distortion, zero sequence (%); based on nominal voltage, where $u_{nom} = 1$ p.u.

$HD1 = \frac{u1(f_{out})}{u_{nom}} \cdot 100$ Harmonic distortion, positive sequence (%)

$HD2 = \frac{u2(f_{out})}{u_{nom}} \cdot 100$ Harmonic distortion, negative sequence (%)

$THD{:}A = \frac{1}{u{:}A(f_1)} \sqrt{urms{:}A^2 - u{:}A(f_1)^2} \cdot 100$ Total harmonic distortion (%); based on fundamental frequency values

$THD{:}B = \frac{1}{u{:}B(f_1)} \sqrt{urms{:}B^2 - u{:}B(f_1)^2} \cdot 100$

$THD{:}C = \frac{1}{u{:}C(f_1)} \sqrt{urms{:}C^2 - u{:}C(f_1)^2} \cdot 100$

$THD{:}A = \frac{1}{u_{nom}{:}A} \sqrt{urms{:}A^2 - u{:}A(f_1)^2} \cdot 100$ Total harmonic distortion (%); based on nominal voltage, where $u_{nom} = 1$ p.u.

$THD{:}B = \frac{1}{u_{nom}{:}B} \sqrt{urms{:}B^2 - u{:}B(f_1)^2} \cdot 100$

$THD{:}C = \frac{1}{u_{nom}{:}C} \sqrt{urms{:}C^2 - u{:}C(f_1)^2} \cdot 100$

$THF{:}A = \frac{1}{urms{:}A}\sqrt{urms{:}A^2 - u{:}A(f_1)^2} \cdot 100$	Total harmonic factor (%)
$THF{:}B = \frac{1}{urms{:}B}\sqrt{urms{:}B^2 - u{:}B(f_1)^2} \cdot 100$	
$THF{:}C = \frac{1}{urms{:}C}\sqrt{urms{:}C^2 - u{:}C(f_1)^2} \cdot 100$	
$ulrms{:}A = \sqrt{\sum_{k\geq 1} ul{:}A(f_k)^2}$	RMS value of line-line voltage (p.u.)
$ulrms{:}B = \sqrt{\sum_{k\geq 1} ul{:}B(f_k)^2}$	
$ulrms{:}C = \sqrt{\sum_{k\geq 1} ul{:}C(f_k)^2}$	
$Ulrms{:}A = ulrms{:}A \cdot U_{nom}$	RMS value of line-line voltage (kV)
$Ulrms{:}B = ulrms{:}B \cdot U_{nom}$	
$Ulrms{:}C = ulrms{:}C \cdot U_{nom}$	
$TAD{:}A = \frac{1}{u{:}A(f_1)} \cdot \left[\sum_{k\geq 1} u{:}A(f_k) - u{:}A(f_1)\right] \cdot 100$	Arithmetic distortion (%)
$TAD{:}B = \frac{1}{u{:}B(f_1)} \cdot \left[\sum_{k\geq 1} u{:}B(f_k) - u{:}B(f_1)\right] \cdot 100$	
$TAD{:}C = \frac{1}{u{:}C(f_1)} \cdot \left[\sum_{k\geq 1} u{:}C(f_k) - u{:}C(f_1)\right] \cdot 100$	
$uasum{:}A = \sum_{k\geq 1} u{:}A(f_k)$	Arithmetic voltage sum (p.u.)
$uasum{:}B = \sum_{k\geq 1} u{:}B(f_k)$	
$uasum{:}C = \sum_{k\geq 1} u{:}C(f_k)$	
$TIF{:}A = \frac{1}{urms{:}A}\sqrt{\sum_{k\geq 1} tif(f_k)^2 \cdot u{:}A(f_k)^2}$	Telephone interference factor
$TIF{:}B = \frac{1}{urms{:}B}\sqrt{\sum_{k\geq 1} tif(f_k)^2 \cdot u{:}B(f_k)^2}$	
$TIF{:}C = \frac{1}{urms{:}C}\sqrt{\sum_{k\geq 1} tif(f_k)^2 \cdot u{:}C(f_k)^2}$	
$urmsint = \max\limits_{x=[A,B,C]}(urmsint : x)$	RMS value of integer harmonics (p.u.), where $urmsint : x = \sqrt{\sum\limits_{\substack{k\geq 1\\ integer}} u : x(f_k)^2}$
$urmsnint = \max\limits_{x=[A,B,C]}(urmsnint : x)$	RMS value of non-integer harmonics (p.u.), where $urmsnint : x = \sqrt{\sum\limits_{\substack{k>1\\ non-integer}} u : x(f_k)^2}$

$THD0 = \frac{1}{u1(f_1)^2+u0(f_1)^2+u2(f_1)^2}\sqrt{u0rms^2 - u0(f_1)^2}$	Total harmonic distortion (%) (voltage, zero sequence)
$THD1 = \frac{1}{u1(f_1)^2+u0(f_1)^2+u2(f_1)^2}\sqrt{u1rms^2 - u1(f_1)^2}$	Total harmonic distortion (%) (voltage, positive sequence)
$THD2 = \frac{1}{u1(f_1)^2+u0(f_1)^2+u2(f_1)^2}\sqrt{u2rms^2 - u2(f_1)^2}$	Total harmonic distortion (%) (voltage, negative sequence)
$THDbal = \sqrt{THD1^2 + THD2^2}$	Total harmonic distortion (%), excluding zero sequence
$THDtot = \sqrt{THD1^2 + THD2^2 + THD0^2}$	Total harmonic distortion (%), including zero sequence
$TADmx = \max\limits_{x=[A,B,C]}(TAD{:}x)$	Arithmetic distortion (%)

$TADint = \max\limits_{x=[A,B,C]}(TADint{:}x)$

Arithmetic distortion (%), where

$$TADint{:}x = \frac{1}{u{:}x(f_1)} \cdot \left[\sum_{\substack{k \geq 1 \\ integer}} u{:}x(f_k) - u{:}x(f_1) \right] \cdot 100$$

$TADnint = \max\limits_{x=[A,B,C]}(TADnint{:}x)$

Arithmetic distortion (%), where

$$TADnint{:}x = \frac{1}{u{:}x(f_1)} \cdot \left[\sum_{\substack{k > 1 \\ non-integer}} u{:}x(f_k) - u{:}x(f_1) \right] \cdot 100$$

$TAD\_3 = \max\limits_{x=[A,B,C]}(TADint{:}x)$

Arithmetic distortion (%), harmonic orders: multiples of three

$TAD\_2 = \max\limits_{x=[A,B,C]}(TADint{:}x)$

Arithmetic distortion (%), harmonic orders: multiples of two

$THDint = \max\limits_{x=[A,B,C]}(THDint{:}x)$

Total harmonic distortion (%), where

$$THDint{:}x = \frac{1}{u{:}x(f_1)} \cdot \sqrt{urms{:}x^2 - u{:}x(f_1)^2} \cdot 100$$

(Fundamental frequency values) or

$$THDint{:}x = \frac{1}{u_{nom}{:}x} \cdot \sqrt{urms{:}x^2 - u{:}x(f_1)^2} \cdot 100$$

(Nominal voltage) and

$$urms{:}x = \sqrt{\sum_{\substack{k \geq 1 \\ integer}} u{:}x(f_k)^2}$$

$THDnint = \max\limits_{x=[A,B,C]}(THDnint{:}x)$

Total harmonic distortion (%), where

$$THDnint{:}x = \frac{1}{u{:}x(f_1)} \cdot \sqrt{urms{:}x^2 - u{:}x(f_1)^2} \cdot 100$$

(Fundamental frequency values) or

$$THDnint{:}x = \frac{1}{urms{:}x} \cdot \sqrt{urms{:}x^2 - u{:}x(f_1)^2} \cdot 100$$

(Nominal voltage) and

$$urms{:}x = \sqrt{\sum_{\substack{k > 1 \\ non-integer}} u{:}x(f_k)^2}$$

$THD\_3 = \max\limits_{x=[A,B,C]}(THDint{:}x)$

Total harmonic distortion (%), harmonic orders: multiples of three

$THD\_2 = \max\limits_{x=[A,B,C]}(TADint{:}x)$

Total harmonic distortion (%), harmonic orders: multiples of two

$TIFmx = \max\limits_{x=[A,B,C]}(TIF{:}x)$	Total interference factor, for harmonic orders
$uasummx = \max\limits_{x=[A,B,C]}(uasum{:}x)$	Arithmetic voltage sum (p.u.)
$uasumint = \max\limits_{x=[A,B,C]}(uasumint{:}x)$	Arithmetic sum of integer harmonics (p.u.), where $uasumint{:}x = \sum\limits_{\substack{k \geq 2 \\ integer}} u{:}x(f_k)$
$uasumnint = \max\limits_{x=[A,B,C]}(uasumnint{:}x)$	Arithmetic sum of integer harmonics (p.u.), where $uasumnint{:}x = \sum\limits_{\substack{k > 2 \\ non-integer}} u{:}x(f_k)$

3 Calculation Considering IEC Harmonic Sources

3.1 Balanced Calculation

3.1.0.5 Branch Monitor Variables

Table 3.1 provides the basic nomenclature used throughout this section.

Table 3.1: Nomenclature

Name	Unit	Description
f_k		Frequency of harmonic order k
f_{out}		Output frequency specified by user in Harmonic Load Flow Command (parameter name: *ifshow*)
$\underline{i}(f_k)$		Complex harmonic current at frequency of harmonic order k (all p.u. values are based on I_{nom})
$\underline{u}(f_k)$		Complex harmonic voltage at frequency of harmonic order k (all p.u. values are based on U_{nom})
$\underline{I}(f_k)$		Complex harmonic current (A), at frequency of harmonic order k
$\underline{U}(f_k)$		Complex harmonic voltage (kV), at frequency of harmonic order k
I_{nom}, i_{nom}		Nominal current of element (A), (p.u.)
U_{nom}, u_{nom}		Rated voltage of element (kV), (p.u.)
$tif(f_k)$		Telephone influence factor at frequency of harmonic order k

PowerFactory calculates monitor variables for the Harmonic Analysis command (balanced calculation) in the following manner provided that at least one harmonic source in the network is defined as 'IEC' (TypHmccur parameter name: *i_usym*).

Per IEC source (subscript $m \geq 1$) and per frequency (f_k), the quantities shown in Table 3.2 are available for the calculation of branch monitor variables:

Table 3.2: Nomenclature

Complex voltage	**Complex current**
$\underline{u}_m(f_k)$	$\underline{i}_m(f_k)$

For non-IEC sources (subscript $m = 0$), the quantities shown in Table 3.3 are available as a lumped representation of all non-IEC sources, for the calculation of branch monitor variables:

Table 3.3: Nomenclature

Complex voltage	**Complex current**
$\underline{u}_0(f_k)$	$\underline{i}_0(f_k)$

Monitor Variables for Output Frequency The following monitor variables are calculated for user-selected output frequency, f_{out}:

Intermediate variables:

$u = \sqrt[\alpha]{\sum_{m=0}^{N} \lvert\underline{u}_m\rvert^{\alpha}}$	Voltage magnitude (kV) according to IEC-61000-3-6

Monitor variables:

$i = \sqrt[\alpha]{\sum_{m=0}^{N} \lvert\underline{i}_m\rvert^{\alpha}}$	Current magnitude (p.u.), according to IEC-61000-3-6
$I = i \cdot I_{nom}$	Current magnitude (A)
$I1 = I$	Positive sequence current magnitude (A)
$I1 = 0$	Positive sequence current magnitude (A), for harmonic orders 5, 11, 17, 23,. . . ,
$I2 = I$	Negative sequence current magnitude (A), for harmonic orders 5, 11, 17, 23,. . . ,
$I2 = 0$	Negative sequence current magnitude (A)
$phiui$	(N/A) Angle between voltage and current (deg)
$phii$	(N/A) Current angle, absolute (deg)

$P = ku \cdot ki \cdot \sum_{m=0}^{N} Re(\underline{u}_m \cdot \underline{i}_m^*)$	Active power (kW), where $ku = \frac{\left(\sqrt[\alpha]{\sum_{m=0}^{N} \lvert\underline{u}_m\rvert^{\alpha}}\right)^2}{u_{tot}^2}$ $u_{tot}(f_k) = \sum_{m=0}^{N} \lvert\underline{u}_m\rvert$ $ki = \frac{\left(\sqrt[\alpha]{\sum_{m=0}^{N} \lvert\underline{i}_m\rvert^{\alpha}}\right)^2}{i_{tot}^2}$ $i_{tot}(f_k) = \sum_{m=0}^{N} \lvert\underline{i}_m\rvert$
$S = u \cdot i$	Apparent power (kVA)
$Q = \sqrt{S^2 - P^2}$	Reactive power (kvar)
$cosphi = \frac{P}{S}$	Power factor

Calculation variables: The following calculation variables are available for lines, transformers, series compensation:

$Losses = Re(\underline{S})$	Losses (kW)
$loading = i_{max}/i_{nom} \cdot 100$	Loading (%)

The following calculation variable is available for machines (static generator, asynchronous machine and synchronous machine):

$loading = S/S_n \cdot 100$	Loading (%), where S_n is the total apparent nominal power in MVA.

Monitor Variables Considering All Frequencies: The following variables are calculated considering all frequencies, f_k:

Intermediate variables:

$i(f_k) = \sqrt[\alpha]{\sum_{m=0}^{N} \lvert\underline{i}_m(f_k)\rvert^{\alpha}}$	Current magnitude (p.u.), according to IEC-61000-3-6
$u(f_k) = \sqrt[\alpha]{\sum_{m=0}^{N} \lvert\underline{u}_m(f_k)\rvert^{\alpha}}$	Voltage magnitude (p.u.), according to IEC-61000-3-6
$P(f_k) = ku(f_k) \cdot ki(f_k) \cdot \sum_{m=0}^{N} Re(\underline{u}_m(f_k) \cdot \underline{i}_m(f_k)^*)$	Active power (kW), where $ku(f_k) = \frac{\left(\sqrt[\alpha]{\sum_{m=0}^{N} \lvert\underline{u}_m(f_k)\rvert^{\alpha}}\right)^2}{u_{tot}(f_k)^2}$ $u_{tot}(f_k) = \sum_{m=0}^{N} \lvert\underline{u}_m(f_k)\rvert$ $ki(f_k) = \frac{\left(\sqrt[\alpha]{\sum_{m=0}^{N} \lvert\underline{i}_m(f_k)\rvert^{\alpha}}\right)^2}{i_{tot}(f_k)^2}$ $i_{tot}(f_k) = \sum_{m=0}^{N} \lvert\underline{i}_m(f_k)\rvert$

Monitor variables:

$HD = \frac{i(f_{out})}{i(f_1)} \cdot 100$	Harmonic distortion, current (%); based on fundamental frequency values
$HD = \frac{i(f_{out})}{i_{nom}} \cdot 100$	Harmonic distortion, current (%); based on nominal current
$HF = \frac{i(f_{out})}{irms} \cdot 100$	Harmonic factor, current (%)
$Irms = \sqrt{\sum_{k \geq 1} i(f_k)^2} \cdot I_{nom}$	Current, RMS (kA)
$irms = \frac{Irms}{I_{nom}}$	Current, RMS (p.u.)
$THD = \frac{1}{i(f_1)} \cdot \sqrt{irms^2 - i(f_1)^2} \cdot 100$	Total harmonic distortion, current (%); based on fundamental frequency values
$THF = \frac{1}{irms} \cdot \sqrt{irms^2 - i(f_1)^2} \cdot 100$	Total harmonic factor, current (%)
$THD = \frac{1}{i_{nom}} \cdot \sqrt{irms^2 - i(f_1)^2} \cdot 100$	Total harmonic distortion, current (%); based on nominal current
$TP = \sum_{k \geq 1} P(f_k)$	Total active power (MW)
$TS = \sqrt{Irms^2 \cdot Urms^2 \cdot 3}$	Total apparent power (MVA), where $Urms = \sqrt{\sum_{k \geq 1} u(f_k)^2} \cdot U_{nom}$
$TQ = \sqrt{TS^2 - TP^2}$	Total reactive power (Mvar)
$Tcosphi = \frac{TP}{TS}$	Total power factor
$IT = \sqrt{\sum_{k \geq 1} tif(f_k)^2 \cdot i(f_k)^2} \cdot I_{nom}$	IT-product (kA)
$TAD = \frac{1}{i(f_1)} \cdot \left[\sum_{k \geq 1} i(f_k) - i(f_1)\right] \cdot 100$	Arithmetic distortion (%)

Calculation variables: The following calculation variables are available for lines, transformers and series compensation:

$LossesTot = \sum_{h \geq 1}^{H} Losses$	Total losses, including the fundamental (kW), where h is the harmonic order
$LossesHrm = \sum_{h > 1}^{H} Losses$	Harmonic losses (kW)
$loadingTot = irms_{max}/i_{nom} \cdot 100$	Total loading (%)

3.1.0.6 Bus Monitor Variables

Table 3.4 provides the basic nomenclature used throughout this section.

Table 3.4: Nomenclature

Name	Unit	Description
f_k	Hz	Frequency of harmonic order k
f_{out}	Hz	Output frequency specified by user in Harmonic Load Flow command (parameter name: *ifshow*)
$\underline{u}(f_k)$	p.u.	Complex harmonic voltage at frequency of harmonic order k
$u(f_k)$	p.u.	Voltage magnitude at frequency of harmonic order k
U_{nom}	kV	Nominal voltage of the busbar
$\phi_{initial}$	deg	Initial voltage angle
$\underline{Z}$	Ohm	Short-circuit impedance

PowerFactory calculates monitor variables for the Harmonic Analysis command (balanced calculation) in the following manner provided that at least one harmonic source in the network is defined as 'IEC' (TypHmccur parameter name: *i_usym*).

Per IEC source (subscript $m \geq 1$) and per frequency (f_k), the relevant quantities shown in Table 3.5 are available for the calculation of bus monitor variables:

Table 3.5: IEC sources: given quantities

Complex voltage
$\underline{u}_m(f_k)$

For non-IEC sources (subscript $m = 0$), the quantities shown in Table 3.6 are available as a lumped representation of all non-IEC sources, for the calculation of bus monitor variables:

Table 3.6: Non-IEC sources: given quantities

Complex voltage
$\underline{u}_0(f_k)$

Monitor Variables for Output Frequency The following monitor variables are calculated for user-selected output frequency, f_{out}:

Monitor variables:

$R = Re\,(\underline{Z})$	Resistance (Ω)
$X = Im\,(\underline{Z})$	Network reactance (Ω)
$Z = \lvert\underline{Z}\rvert$	Network impedance magnitude (Ω)

$phiz = \phi_{\underline{Z}}$	Network impedance angle (deg)
$u = \sqrt[\alpha]{\sum_{m=0}^{N} \lvert\underline{u}_m\rvert^{\alpha}}$	Voltage magnitude (p.u.), according to IEC-61000-3-6
$upc = u \cdot 100$	Voltage magnitude (%)
$u1 = u$	Voltage magnitude (p.u.)
$u1 = 0$	Voltage magnitude (p.u.), for harmonic orders 5, 11, 17, 23,. . . ,
$u1pc = u1 \cdot 100$	Voltage magnitude (%)
$U = u \cdot U_{nom}/\sqrt{3}$	Line-ground voltage magnitude (kV)
$Ul = u \cdot U_{nom}$	Line-line voltage magnitude (kV)
$phiu$	(N/A) Voltage angle (deg)
$phiurel$	(N/A) Voltage, relative angle (deg)
$du = upc - 100$	Voltage deviation (%)
$u2 = u$	Negative sequence voltage (p.u.), for orders 5, 11, 17, 23,. . . ,
$u2 = 0$	Negative sequence voltage (p.u.)

Monitor Variables Considering All Frequencies: The following variables are calculated considering all frequencies, f_k:

Intermediate variables:

$u(f_k) = \sqrt[\alpha]{\sum_{m=0}^{N} \lvert\underline{u}_m(f_k)\rvert^{\alpha}}$	Voltage magnitude (p.u.), according to IEC-61000-3-6

Monitor variables:

$urms = \sqrt{\sum_{k\geq 1} u(f_k)^2}$	RMS value of voltage (p.u.)
$HD = \frac{u(f_{out})}{u(f_1)} \cdot 100$	Harmonic distortion (%); based on fundamental frequency values
$HD = \frac{u(f_{out})}{u_{nom}} \cdot 100$	Harmonic distortion (%); based on nominal voltage, where $u_{nom} = 1$p.u.
$HF = \frac{u(f_{out})}{urms} \cdot 100$	Harmonic factor (%)

$THD = \frac{1}{u(f_1)} \sqrt{urms^2 - u(f_1)^2} \cdot 100$	Total harmonic distortion (%); based on fundamental frequency values
$THD = \frac{1}{u_{nom}} \sqrt{urms^2 - u(f_1)^2} \cdot 100$	Total harmonic distortion (%); based on nominal voltage, where $u_{nom} = 1$p.u.
$THF = \frac{1}{urms} \sqrt{urms^2 - u(f_1)^2} \cdot 100$	Total harmonic factor (%)
$THF = \frac{1}{urms} \sqrt{urms^2 - u(f_1)^2} \cdot 100$	Total harmonic factor (%)
$Ulrms = urms \cdot U_{nom}$	RMS value of line-line voltage (kV)
$Urms = urms \cdot U_{nom}/\sqrt{3}$	RMS value of line-ground voltage (kV)
$TAD = \frac{1}{u(f_1)} \cdot \left[\sum_{k \geq 1} u(f_k) - u(f_1)\right] \cdot 100$	Arithmetic distortion (%)
$THF = \frac{1}{urms} \sqrt{urms^2 - u(f_1)^2} \cdot 100$	Total harmonic factor (%)
$uasum = \sum_{k=1}^{n} u(f_k)$	Arithmetic voltage sum (p.u.)
$TIF = \frac{1}{urms} \sqrt{\sum_{k=1}^{n} tif(f_k)^2 \cdot u(f_k)^2}$	Telephone interference factor
$urmsint = \sqrt{\sum_{\substack{k \geq 2 \\ integer}} u(f_k)^2}$	RMS value of integer harmonics (p.u.)
$uasumint = \sum_{\substack{k \geq 2 \\ integer}} u(f_k)$	Arithmetic sum of integer harmonics (p.u.)
$THDint = \frac{1}{u(f_1)} \sqrt{urms^2 - u(f_1)^2} \cdot 100$	Total harmonic distortion (%), integer orders, (Fundamental frequency values)
$THDint = \frac{1}{u_{nom}} \sqrt{urms^2 - u(f_1)^2} \cdot 100$	Total harmonic distortion (%), integer orders (nominal voltage), where $u_{nom} = 1$p.u. and $urms = \sqrt{\sum_{\substack{k \geq 1 \\ integer}} u(f_k)^2}$
$THDnint = \frac{1}{u(f_1)} \sqrt{urms^2 - u(f_1)^2} \cdot 100$	Total harmonic distortion (%), non-integer orders, (Fundamental frequency values)
$THDnint = \frac{1}{u_{nom}} \sqrt{urms^2 - u(f_1)^2} \cdot 100$	Total harmonic distortion (%), non-integer orders (nominal voltage), where $u_{nom} = 1$p.u. and $urms = \sqrt{\sum_{\substack{k > 1 \\ non-integer}} u(f_k)^2}$

$TADint = \frac{1}{u(f_1)} \cdot \left[\sum_{\substack{k \geq 1 \\ integer}} u(f_k) - u(f_1) \right] \cdot 100$	Arithmetic distortion (%), integer orders
$TADnint = \frac{1}{u(f_1)} \cdot \left[\sum_{\substack{k \geq 1 \\ non-integer}} u(f_k) - u(f_1) \right] \cdot 100$	Arithmetic distortion (%), non-integer orders

3.2 Unbalanced Calculation

3.2.0.7 Branch Monitor Variables

Table 3.7 provides the basic nomenclature used throughout this section.

Table 3.7: Nomenclature

Name	Unit	Description
f_k		Frequency at harmonic order k
f_{out}		Output frequency specified by user in Harmonic Load Flow Command (parameter name: *ifshow*)
$\underline{i}_a(f_k)$	p.u.	Complex harmonic current for phase A, at frequency of harmonic order k (all p.u. values are based on I_{nom}). Similar nomenclature follows for other phases.
$\underline{u}_a(f_k)$	p.u.	Complex harmonic voltage for phase B, at frequency of harmonic order k (all p.u. values are based on U_{nom}). Similar nomenclature follows for other phases.
$\underline{I}_a(f_k)$	A	Complex harmonic current for phase A, at frequency of harmonic order k. Similar nomenclature follows for other phases.
$\underline{U}_a(f_k)$	kV	Complex harmonic voltage for phase A, at frequency of harmonic order k. Similar nomenclature follows for other phases.
$\underline{i}_0(f_k)$	p.u.	Complex zero sequence current, at frequency of harmonic order k.
$\underline{u}_0(f_k)$	p.u.	Complex zero sequence voltage, at frequency of harmonic order k.
$i{:}A(f_k)$	p.u.	Current magnitude at frequency of harmonic order k. Similar nomenclature follows for other phases.
$i0(f_k)$	p.u.	Zero sequence current magnitude at frequency of harmonic order k. Similar nomenclature follows for positive and negative sequence currents.
I_{nom}, i_{nom}	A, p.u.	Nominal current of element
U_{nom}, u_{nom}	kV, p.u.	Rated voltage of element
$tif(f_k)$	-	Telephone influence factor (according to IEEE) at frequency of harmonic order k.

PowerFactory calculates monitor variables for the Harmonic Analysis command (unbalanced calculation) in the following manner provided that at least one harmonic source in the network is defined as ‘IEC’ (TypHmccur parameter name: *i_usym*).

Per IEC source (subscript $m \geq 1$) and per frequency (f_k), the quantities shown in Table 3.8 are available for the calculation of branch monitor variables:

Table 3.8: IEC sources: given quantities

Complex phase voltages	Complex phase currents
$\underline{u}_{a,m}(f_k)$	$\underline{i}_{a,m}(f_k)$
$\underline{u}_{b,m}(f_k)$	$\underline{i}_{b,m}(f_k)$
$\underline{u}_{c,m}(f_k)$	$\underline{i}_{c,m}(f_k)$
$\underline{u}_{n,m}(f_k)$	$\underline{i}_{n,m}(f_k)$

For non-IEC sources (subscript $m = 0$), the quantities shown in Table 3.9 are available as a lumped representation of all non-IEC sources, for the calculation of branch monitor variables:

Table 3.9: Non-IEC sources: given quantities

Complex phase voltage	Complex phase current
$\underline{u}_{a,0}(f_k)$	$\underline{i}_{a,0}(f_k)$
$\underline{u}_{b,0}(f_k)$	$\underline{i}_{b,0}(f_k)$
$\underline{u}_{c,0}(f_k)$	$\underline{i}_{c,0}(f_k)$
$\underline{u}_{n,0}(f_k)$	$\underline{i}_{n,0}(f_k)$

Monitor Variables for Output Frequency The following monitor variables are calculated for user-selected output frequency, f_{out}:

Intermediate variables:

$u{:}A = \sqrt[\alpha]{\sum_{m=0}^{N} \left|\underline{u}_{a,m}\right|^{\alpha}}$ Phase voltage magnitudes (p.u.) according to IEC-61000-3-6

$u{:}B = \sqrt[\alpha]{\sum_{m=0}^{N} \left|\underline{u}_{b,m}\right|^{\alpha}}$

$u{:}C = \sqrt[\alpha]{\sum_{m=0}^{N} \left|\underline{u}_{c,m}\right|^{\alpha}}$

$u{:}N = \sqrt[\alpha]{\sum_{m=0}^{N} \left|\underline{u}_{n,m}\right|^{\alpha}}$

Monitor variables:

$i{:}A = \sqrt[\alpha]{\sum_{m=0}^{N} \left|\underline{i}_{a,m}\right|^{\alpha}}$ Phase current magnitudes (p.u.) according to IEC-61000-3-6

$i{:}B = \sqrt[\alpha]{\sum_{m=0}^{N} \left|\underline{i}_{b,m}\right|^{\alpha}}$

$i{:}C = \sqrt[\alpha]{\sum_{m=0}^{N} \left|\underline{i}_{c,m}\right|^{\alpha}}$

$i{:}N = \sqrt[\alpha]{\sum_{m=0}^{N} \left|\underline{i}_{n,m}\right|^{\alpha}}$

$I{:}A = \lvert i{:}A \rvert \cdot I_{nom}$	Phase currents (A)
$I{:}B = \lvert i{:}B \rvert \cdot I_{nom}$	
$I{:}C = \lvert i{:}C \rvert \cdot I_{nom}$	
$I{:}N = \lvert i{:}N \rvert \cdot I_{nom}$	
$phiui{:}A$	(N/A) Angle between voltage and current (deg)
$phiui{:}B$	(N/A)
$phiui{:}C$	(N/A)
$phiui{:}N$	(N/A)
$phii{:}A$	(N/A) Current angle, absolute (deg)
$phii{:}B$	(N/A)
$phii{:}C$	(N/A)
$phii{:}N$	(N/A)
$P{:}A = \sum_{m=0}^{N} Re(\underline{u}_{a,m} \cdot \underline{i}_{a,m}^{*})$	Active power (kW)
$P{:}B = \sum_{m=0}^{N} Re(\underline{u}_{b,m} \cdot \underline{i}_{b,m}^{*})$	
$P{:}C = \sum_{m=0}^{N} Re(\underline{u}_{c,m} \cdot \underline{i}_{c,m}^{*})$	
$P{:}N = \sum_{m=0}^{N} Re(\underline{u}_{n,m} \cdot \underline{i}_{n,m}^{*})$	
$S{:}A = u{:}A \cdot i{:}A$	Apparent power (kVA)
$S{:}B = u{:}B \cdot i{:}B$	
$S{:}C = u{:}C \cdot i{:}C$	
$S{:}N = u{:}N \cdot i{:}N$	
$Q{:}A = \sqrt{S{:}A^2 - P{:}A^2}$	Reactive power (kvar)
$Q{:}B = \sqrt{S{:}B^2 - P{:}B^2}$	
$Q{:}C = \sqrt{S{:}C^2 - P{:}C^2}$	
$Q{:}N = \sqrt{S{:}N^2 - P{:}N^2}$	

$cosphi{:}A$	(N/A) Power factor
$cosphi{:}B$	(N/A)
$cosphi{:}C$	(N/A)
$cosphi{:}N$	(N/A)
$i0 = \sqrt[\alpha]{\sum_{m=0}^{N} \left\lvert \underline{i}_{0,m} \right\rvert^{\alpha}}$	Zero sequence current (p.u.), where $\underline{i}_{0,m} = \frac{1}{3}(\underline{i}_{a,m} + \underline{i}_{b,m} + \underline{i}_{c,m})$
$I0 = i0 \cdot I_{nom}$	Zero sequence current (A)
$phiu0i0$	(N/A) Angle between voltage and current in zero sequence system (deg)
$i1 = \sqrt[\alpha]{\sum_{m=0}^{N} \left\lvert \underline{i}_{1,m} \right\rvert^{\alpha}}$	Positive sequence current (p.u.), where $\underline{i}_{1,m} = \frac{1}{3}(\underline{i}_{a,m} + a \cdot \underline{i}_{b,m} + a^2 \cdot \underline{i}_{c,m})$ and $a = \angle 120°$
$I1 = i1 \cdot I_{nom}$	Positive sequence current (A)
$phiu1i1$	(N/A) Angle between voltage and current in positive sequence system (deg)
$i2 = \sqrt[\alpha]{\sum_{m=0}^{N} \left\lvert \underline{i}_{2,m} \right\rvert^{\alpha}}$	Negative sequence current (p.u.) where $\underline{i}_{2,m} = \frac{1}{3}(\underline{i}_{a,m} + a^2 \cdot \underline{i}_{b,m} + a \cdot \underline{i}_{c,m})$ and $a = \angle 120°$
$I2 = i2 \cdot I_{nom}$	Negative sequence current (A)
$phiu2i2$	(N/A) Angle between voltage and current in negative sequence system (deg)
$Psum = P{:}A + P{:}B + P{:}C + P{:}N$	Active power (kW)
$Qsum = Q{:}A + Q{:}B + Q{:}C + Q{:}N$	Reactive power (kvar)
$Ssum = \left\lvert \sum_{x=[A,B,C,N]} \sqrt{P{:}x^2 + Q{:}x^2} \right\rvert$	Apparent power (kVA)
$cosphisum = \frac{Psum}{Ssum}$	Power factor
$ubfac = \frac{i2}{i1}$	Unbalance factor

Calculation variables: The following calculation variables are available for lines:

$LossesPh{:}A = Re(\underline{S}_a)$	Losses (kW)
$LossesPh{:}B = Re(\underline{S}_b)$	
$LossesPh{:}C = Re(\underline{S}_c)$	
$LossesPh{:}N = Re(\underline{S}_n)$	
$Losses = \sum_{x=[A,B,C,N]} LossesPh{:}x$	Losses (kW)
$loadingPh{:}A = i{:}A_{max}/i_{nom} \cdot 100$	Loading (%)
$loadingPh{:}B = i{:}B_{max}/i_{nom} \cdot 100$	
$loadingPh{:}C = i{:}C_{max}/i_{nom} \cdot 100$	
$loadingPh{:}N = i{:}N_{max}/i_{nom} \cdot 100$	
$loading = i_{max}/i_{nom} \cdot 100$	Loading (%)

The following calculation variables are available for transformers and series compensation:

$Losses = Re(\underline{S})$	Losses (kW)
$loading = i_{max}/i_{nom} \cdot 100$	Loading (%)

The following calculation variable is available for machines (static generator, asynchronous machine and synchronous machine):

$loading = S/S_n \cdot 100$	Loading (%), where S_n is the total apparent nominal power in MVA.

Monitor Variables Considering All Frequencies: The following monitor variables are calculated considering all frequencies f_k:

Intermediate variables:

$i{:}A(f_k) = \sqrt[\alpha]{\sum_{m=0}^{N} \left\lvert \underline{i}_{a,m}(f_k) \right\rvert^{\alpha}}$	Phase current magnitudes (p.u.) according to IEC-61000-3-6
$i{:}B(f_k) = \sqrt{[\alpha] \sum_{m=0}^{N} \left\lvert \underline{i}_{b,m}(f_k) \right\rvert^{\alpha}}$	
$i{:}C(f_k) = \sqrt{[\alpha] \sum_{m=0}^{N} \left\lvert \underline{i}_{c,m}(f_k) \right\rvert^{\alpha}}$	
$i{:}N(f_k) = \sqrt{[\alpha] \sum_{m=0}^{N} \left\lvert \underline{i}_{n,m}(f_k) \right\rvert^{\alpha}}$	

$u{:}A(f_k) = \sqrt{[\alpha] \sum_{m=0}^{N} \left|\underline{u}_{a,m}(f_k)\right|^{\alpha}}$ Phase voltage magnitudes (p.u.) according to IEC-61000-3-6

$u{:}B(f_k) = \sqrt{[\alpha] \sum_{m=0}^{N} \left|\underline{u}_{b,m}(f_k)\right|^{\alpha}}$

$u{:}C(f_k) = \sqrt{[\alpha] \sum_{m=0}^{N} \left|\underline{u}_{c,m}(f_k)\right|^{\alpha}}$

$u{:}N(f_k) = \sqrt{[\alpha] \sum_{m=0}^{N} \left|\underline{u}_{n,m}(f_k)\right|^{\alpha}}$

$i0(f_k) = \sqrt{[\alpha] \sum_{m=0}^{N} \left|\underline{i}_{0,m}(f_k)\right|^{\alpha}}$ Zero sequence current (p.u.) where $\underline{i}_{0,m}(f_k) = \frac{1}{3}(\underline{i}_{a,m}(f_k) + \underline{i}_{b,m}(f_k) + \underline{i}_{c,m}(f_k))$ and $a = \angle 120°$

$i1(f_k) = \sqrt{[\alpha] \sum_{m=0}^{N} \left|\underline{i}_{1,m}(f_k)\right|^{\alpha}}$ Positive sequence current (p.u.) where $\underline{i}_{1,m}(f_k) = \frac{1}{3}(\underline{i}_{a,m}(f_k) + a \cdot \underline{i}_{b,m}(f_k) + a^2 \cdot \underline{i}_{c,m}(f_k))$ and $a = \angle 120°$

$i2(f_k) = \sqrt{[\alpha] \sum_{m=0}^{N} \left|\underline{i}_{2,m}(f_k)\right|^{\alpha}}$ Negative sequence current (p.u.) where $\underline{i}_{2,m}(f_k) = \frac{1}{3}(\underline{i}_{a,m}(f_k) + a^2 \cdot \underline{i}_{b,m}(f_k) + a \cdot \underline{i}_{c,m}(f_k))$ and $a = \angle 120°$

$P{:}A(f_k) = \sum_{m=0}^{N} Re(\underline{u}_{a,m}(f_k) \cdot \underline{i}_{a,m}(f_k)^*)$ Active power (kW)

$P{:}B(f_k) = \sum_{m=0}^{N} Re(\underline{u}_{b,m}(f_k) \cdot \underline{i}_{b,m}(f_k)^*)$

$P{:}C(f_k) = \sum_{m=0}^{N} Re(\underline{u}_{c,m}(f_k) \cdot \underline{i}_{c,m}(f_k)^*)$

$P{:}N(f_k) = \sum_{m=0}^{N} Re(\underline{u}_{n,m}(f_k) \cdot \underline{i}_{n,m}(f_k)^*)$

Monitor variables:

$irms{:}A = \sqrt{\sum_{k\geq 1} i{:}A(f_k)^2}$ Phase currents (p.u.) based on rated current of element

$irms{:}B = \sqrt{\sum_{k\geq 1} i{:}B(f_k)^2}$

$irms{:}C = \sqrt{\sum_{k\geq 1} i{:}C(f_k)^2}$

$irms{:}N = \sqrt{\sum_{k\geq 1} i{:}N(f_k)^2}$

$Irms{:}A = irms{:}A \cdot I_{nom}$ Phase currents (A)

$Irms{:}B = irms{:}B \cdot I_{nom}$

$Irms{:}C = irms{:}C \cdot I_{nom}$

$Irms{:}N = irms{:}N \cdot I_{nom}$

$HD{:}A = \frac{i{:}A(f_{out})}{i{:}A(f_1)} \cdot 100$ Harmonic distortion (%); based on fundamental frequency values

$HD{:}B = \frac{i{:}B(f_{out})}{i{:}B(f_1)} \cdot 100$

$HD{:}C = \frac{i{:}C(f_{out})}{i{:}C(f_1)} \cdot 100$

$HD{:}N = \frac{i{:}N(f_{out})}{i{:}N(f_1)} \cdot 100$

$HD{:}A = \frac{i{:}A(f_{out})}{i_{nom}(f_1)} \cdot 100$ Harmonic distortion (%); based on nominal current

$HD{:}B = \frac{i{:}B(f_{out})}{i_{nom}(f_1)} \cdot 100$

$HD{:}C = \frac{i{:}C(f_{out})}{i_{nom}(f_1)} \cdot 100$

$HD{:}N = \frac{i{:}N(f_{out})}{i_{nom}(f_1)} \cdot 100$

$HF{:}A = \frac{i{:}A(f_{out})}{irms{:}A(f_1)} \cdot 100$ Harmonic factor (%)

$HF{:}B = \frac{i{:}B(f_{out})}{irms{:}B(f_1)} \cdot 100$

$HF{:}C = \frac{i{:}C(f_{out})}{irms{:}C(f_1)} \cdot 100$

$HF{:}N = \frac{i{:}N(f_{out})}{irms{:}N(f_1)} \cdot 100$

$THD{:}A = \frac{1}{i{:}A(f_1)} \cdot \sqrt{irms{:}A^2 - i{:}A(f_1)^2} \cdot 100$ Total harmonic distortion, current (%); based on fundamental frequency values

$THD{:}B = \frac{1}{i{:}B(f_1)} \cdot \sqrt{irms{:}B^2 - i{:}B(f_1)^2} \cdot 100$

$THD{:}C = \frac{1}{i{:}C(f_1)} \cdot \sqrt{irms{:}C^2 - i{:}C(f_1)^2} \cdot 100$

$THD{:}N = \frac{1}{i{:}N(f_1)} \cdot \sqrt{irms{:}N^2 - i{:}N(f_1)^2} \cdot 100$

$THD{:}A = \frac{1}{i_{nom}} \cdot \sqrt{irms{:}A^2 - i{:}A(f_1)^2} \cdot 100$	Total harmonic distortion, current (%); based on nominal current
$THD{:}B = \frac{1}{i_{nom}} \cdot \sqrt{irms{:}B^2 - i{:}B(f_1)^2} \cdot 100$	
$THD{:}C = \frac{1}{i_{nom}} \cdot \sqrt{irms{:}C^2 - i{:}C(f_1)^2} \cdot 100$	
$THD{:}N = \frac{1}{i_{nom}} \cdot \sqrt{irms{:}N^2 - i{:}N(f_1)^2} \cdot 100$	
$THF{:}A = \frac{1}{irms{:}A} \cdot \sqrt{irms{:}A^2 - i{:}A(f_1)^2} \cdot 100$	Total harmonic factor, current (%)
$THF{:}B = \frac{1}{irms{:}B} \cdot \sqrt{irms{:}B^2 - i{:}B(f_1)^2} \cdot 100$	
$THF{:}C = \frac{1}{irms{:}C} \cdot \sqrt{irms{:}C^2 - i{:}C(f_1)^2} \cdot 100$	
$THF{:}N = \frac{1}{irms{:}N} \cdot \sqrt{irms{:}N^2 - i{:}N(f_1)^2} \cdot 100$	
$TP{:}A = \sum_{k\geq 1} P{:}A(f_k)$	Total active power (MW)
$TP{:}B = \sum_{k\geq 1} P{:}B(f_k)$	
$TP{:}C = \sum_{k\geq 1} P{:}C(f_k)$	
$TP{:}N = \sum_{k\geq 1} P{:}N(f_k)$	
$TS{:}A = \sqrt{Irms{:}A^2 \cdot Urms{:}A^2}$	Total apparent power (MVA), where $Urms{:}A = \sqrt{\sum_{k\geq 1} u{:}A(f_k)^2} \cdot U_{nom}$
$TS{:}B = \sqrt{Irms{:}B^2 \cdot Urms{:}B^2}$	
$TS{:}C = \sqrt{Irms{:}C^2 \cdot Urms{:}C^2}$	
$TS{:}N = \sqrt{Irms{:}N^2 \cdot Urms{:}N^2}$	
$TQ{:}A = \sqrt{TS{:}A^2 - TP{:}A^2}$	Total reactive power (Mvar)
$TQ{:}B = \sqrt{TS{:}B^2 - TP{:}B^2}$	
$TQ{:}C = \sqrt{TS{:}C^2 - TP{:}C^2}$	
$TQ{:}N = \sqrt{TS{:}N^2 - TP{:}N^2}$	

$Tcosphi{:}A = \frac{TP{:}A}{TS{:}A}$	Total power factor
$Tcosphi{:}B = \frac{TP{:}B}{TS{:}B}$	
$Tcosphi{:}C = \frac{TP{:}C}{TS{:}C}$	
$Tcosphi{:}N = \frac{TP{:}N}{TS{:}N}$	
$TAD{:}A = \frac{1}{i{:}A(f_1)} \cdot \left[\sum_{k\geq 1} i{:}A(f_k) - i{:}A(f_1)\right] \cdot 100$	Arithmetic distortion (%)
$TAD{:}B = \frac{1}{i{:}B(f_1)} \cdot \left[\sum_{k\geq 1} i{:}B(f_k) - i{:}B(f_1)\right] \cdot 100$	
$TAD{:}C = \frac{1}{i{:}C(f_1)} \cdot \left[\sum_{k\geq 1} i{:}C(f_k) - i{:}C(f_1)\right] \cdot 100$	
$TAD{:}N = \frac{1}{i{:}N(f_1)} \cdot \left[\sum_{k\geq 1} i{:}N(f_k) - i{:}N(f_1)\right] \cdot 100$	
$IT{:}A = \sqrt{\sum_{k\geq 1} tif(f_k)^2 \cdot i{:}A(f_k)^2} \cdot I_{nom}$	IT-product (kA)
$IT{:}B = \sqrt{\sum_{k\geq 1} tif(f_k)^2 \cdot i{:}B(f_k)^2} \cdot I_{nom}$	
$IT{:}C = \sqrt{\sum_{k\geq 1} tif(f_k)^2 \cdot i{:}C(f_k)^2} \cdot I_{nom}$	
$IT{:}N = \sqrt{\sum_{k\geq 1} tif(f_k)^2 \cdot i{:}N(f_k)^2} \cdot I_{nom}$	
$I0rms = \sqrt{\sum_{k\geq 1} i0(f_k)^2} \cdot I_{nom}$	Zero sequence current, RMS value (kA)
$i0rms = \frac{I0rms}{I_{nom}}$	Zero sequence current, RMS value (p.u.)
$THD0 = \frac{1}{i0(f_1)} \sqrt{i0rms^2 - i0(f_1)^2} \cdot 100$	Total harmonic distortion (%) (current, zero sequence); based on fundamental frequency values
$THF0 = \frac{1}{i0rms} \sqrt{i0rms^2 - i0(f_1)^2} \cdot 100$	Total harmonic factor (%) (current, zero sequence)
$THD0 = \frac{1}{i_{nom}} \sqrt{i0rms^2 - i0(f_1)^2} \cdot 100$	Total harmonic distortion (%) (current, zero sequence); based on nominal current
$I1rms = \sqrt{\sum_{k\geq 1} i1(f_k)^2} \cdot I_{nom}$	Positive sequence current, RMS value (kA)
$i1rms = \frac{I1rms}{I_{nom}}$	Positive sequence current, RMS value (p.u.)
$THD1 = \frac{1}{i1(f_1)} \sqrt{i1rms^2 - i1(f_1)^2} \cdot 100$	Total harmonic distortion (%) (current, positive sequence); based on fundamental frequency values
$THD1 = \frac{1}{i_{nom}} \sqrt{i1rms^2 - i1(f_1)^2} \cdot 100$	Total harmonic distortion (%) (current, positive sequence); based on nominal current

$THF1 = \frac{1}{i1rms}\sqrt{i1rms^2 - i1(f_1)^2} \cdot 100$	Total harmonic factor (%) (current, positive sequence)
$I2rms = \sqrt{\sum_{k\geq 1} i2(f_k)^2} \cdot I_{nom}$	Negative sequence current, RMS value (kA)
$i2rms = \frac{I2rms}{I_{nom}}$	Negative sequence current, RMS value (p.u.)
$THD2 = \frac{1}{i2(f_1)}\sqrt{i2rms^2 - i2(f_1)^2} \cdot 100$	Total harmonic distortion (%) (current, negative sequence); based on fundamental frequency values
$THD2 = \frac{1}{i_{nom}}\sqrt{i2rms^2 - i2(f_1)^2} \cdot 100$	Total harmonic distortion (%) (current, negative sequence)l; based on nominal current
$THF2 = \frac{1}{i2rms}\sqrt{i2rms^2 - i2(f_1)^2} \cdot 100$	Total harmonic factor (%) (current, negative sequence)
$HD0 = \frac{i0(f_{out})}{\sqrt{i0(f_1)^2+i1(f_1)^2+i2(f_1)^2}} \cdot 100$	Harmonic distortion, zero sequence (%); based on fundamental frequency values
$HD1 = \frac{i1(f_{out})}{\sqrt{i0(f_1)^2+i1(f_1)^2+i2(f_1)^2}} \cdot 100$	Harmonic distortion, positive sequence (%)
$HD2 = \frac{i2(f_{out})}{\sqrt{i0(f_1)^2+i1(f_1)^2+i2(f_1)^2}} \cdot 100$	Harmonic distortion, negative sequence (%)
$HD0 = \frac{i0(f_{out})}{i_{nom}} \cdot 100$	Harmonic distortion, zero sequence (%); based on nominal current
$HD1 = \frac{i1(f_{out})}{i_{nom}} \cdot 100$	Harmonic distortion, positive sequence (%)
$HD2 = \frac{i2(f_{out})}{i_{nom}} \cdot 100$	Harmonic distortion, negative sequence (%)
$HF0 = \frac{i0(f_{out})}{i0rms} \cdot 100$	Harmonic factor, zero sequence (%)
$HF1 = \frac{i1(f_{out})}{i1rms} \cdot 100$	Harmonic factor, positive sequence (%)
$HF2 = \frac{i2(f_{out})}{i2rms} \cdot 100$	Harmonic factor, negative sequence (%)
$TPsum = \sum_{x=[A,B,C,N]} TP{:}x$	Total active power (MW)
$TQsum = \sum_{x=[A,B,C,N]} TQ{:}x$	Total reactive power (Mvar)
$TSsum = \sqrt{TPsum^2 + TQsum^2}$	Total apparent power (MVA)
$Tcosphisum = \frac{TPsum}{TSsum}$	Total power factor

$THDbal = \sqrt{THD1^2 + THD2^2}$ Total harmonic distortion (%), excluding zero sequence

$THDtot = \sqrt{THD1^2 + THD2^2 + THD0^2}$ Total harmonic distortion (%), including zero sequence

$TADmx = \max_{x=[A,B,C,N]} (TAD{:}x)$ Arithmetic distortion (%)

$TADint = \max_{x=[A,B,C,N]} (TADint{:}x)$ Arithmetic distortion (%), where

$TADint{:}x =$

$\frac{1}{i{:}x(f_1)} \cdot \left[\sum_{\substack{k \geq 1 \\ integer}} i{:}x(f_k) - i{:}x(f_1) \right] \cdot 100$

$TADnint = \max_{x=[A,B,C,N]} (TADnint{:}x)$ Arithmetic distortion (%), where

$TADnint{:}x =$

$\frac{1}{i{:}x(f_1)} \cdot \left[\sum_{\substack{k > 1 \\ non-integer}} i{:}x(f_k) - i{:}x(f_1) \right] \cdot 100$

$TAD\_3 = \max_{x=[A,B,C,N]} (TADint{:}x)$ Arithmetic distortion (%), harmonic orders: multiples of three

$TAD\_2 = \max_{x=[A,B,C,N]} (TADint{:}x)$ Arithmetic distortion (%), harmonic orders: multiples of two

$THDint = \max_{x=[A,B,C,N]} (THDint{:}x)$ Total harmonic distortion (%), where

$THDint{:}x = \frac{1}{i{:}x(f_1)} \cdot \sqrt{irms{:}x^2 - i{:}x(f_1)^2} \cdot 100$

(Fundamental frequency values) or

$THDint{:}x = \frac{1}{inom} \cdot \sqrt{irms{:}x^2 - i{:}x(f_1)^2} \cdot 100$

(Nominal current) and

$irms{:}x = \sqrt{\sum_{\substack{k \geq 1 \\ integer}} i{:}x(f_k)^2}$

$THDnint = \max_{x=[A,B,C,N]} (THDnint{:}x)$ Total harmonic distortion (%), where

$THDnint{:}x = \frac{1}{i{:}x(f_1)} \cdot \sqrt{irms{:}x^2 - i{:}x(f_1)^2} \cdot 100$

(Fundamental frequency values) or

$THDnint{:}x = \frac{1}{inom} \cdot \sqrt{irms{:}x^2 - i{:}x(f_1)^2} \cdot 100$

(Nominal current) and

$irms{:}x = \sqrt{\sum_{\substack{k > 1 \\ non-integer}} i{:}x(f_k)^2}$

$THD\_3 = \max\limits_{x=[A,B,C,N]}(THDint{:}x)$	Total harmonic distortion (%), harmonic orders: multiples of three
$THD\_2 = \max\limits_{x=[A,B,C,N]}(TADint{:}x)$	Total harmonic distortion (%), harmonic orders: multiples of two
$ITmx = \max(IT{:}x)$	IT-Product (kA)

Calculation variables: The following calculation variables are available for lines, transformers, series compensation:

$LossesTot = \sum_{h\geq 1}^{H} \sum_{x=[A,B,C,N]} Losses{:}x$	Total losses, including the fundamental (kW), where h is the harmonic order
$LossesHrm = \sum_{h>1}^{H} \sum_{x=[A,B,C,N]} Losses{:}x$	Harmonic losses (kW)
$loadingTot = irms_{max}/i_{nom} \cdot 100$	Total loading (%)

3.2.0.8 Bus Monitor Variables

Table 3.10 provides the nomenclature used in this section.

Table 3.10: Nomenclature

Name	Unit	Description
f_k	Hz	Frequency of harmonic order k
f_{out}	Hz	Output frequency specified by user in Harmonic Load Flow Command (parameter name: *ifshow*)
$\underline{u}_a(f_k)$	p.u.	Complex harmonic voltage, phase A. Similar nomenclature is used for the other phases.
$\underline{ul}_a(f_k)$	p.u.	Complex line-line voltage, phase A, where $\underline{ul}_a(f_k) = \underline{u}_a(f_k) - \underline{u}_b(f_k)$
$ul{:}A(f_k)$	p.u.	Line-line voltage magnitude, phase A, where $ul{:}A(f_k) = \lvert\underline{u}_a(f_k) - \underline{u}_b(f_k)\rvert$. Similar follows for the other phases.
$\underline{uln}_a(f_k)$	p.u.	Complex line-neutral voltage, phase A, where $\underline{uln}_a(f_k) = \underline{u}_a(f_k) - \underline{u}_n(f_k)$. Similar follows for the other phases.
$uln{:}A(f_k)$	p.u.	Line-line voltage magnitude, phase A, where $uln{:}A(f_k) = \lvert\underline{u}_a(f_k) - \underline{u}_n(f_k)\rvert$. Similar follows for the other phases.
$u{:}A(f_k)$	p.u.	Voltage magnitude at frequency of harmonic order k
U_{nom}	kV	Nominal voltage of the busbar
$\underline{Zl}_a$	Ohm	Line impedance, phase A. Similar follows for the other phases.
$\underline{Zln}_a$	Ohm	Line-neutral impedance, phase A. Similar follows for the other phases.
$\underline{Z}_a$	Ohm	Short-circuit impedance, phase A. Similar nomenclature is used for other phases.

PowerFactory calculates monitor variables for the Harmonic Analysis command (unbalanced calculation) in the following manner provided that at least one harmonic source in the network is defined as 'IEC' (TypHmccur parameter name: *i_usym*).

Per IEC source (subscript $m \geq 1$) and per frequency (f_k), the relevant quantities shown in Table 3.11 are available for the calculation of bus monitor variables:

Table 3.11: IEC sources: given quantities

Complex phase voltage
$\underline{u}_{a,m}(f_k)$
$\underline{u}_{b,m}(f_k)$
$\underline{u}_{c,m}(f_k)$

For non-IEC sources (subscript $m = 0$), the quantities shown in Table 3.12 are available as a lumped representation of all non-IEC sources, for the calculation of bus monitor variables:

Table 3.12: Non-IEC sources: given quantities

Complex phase voltage
$\underline{u}_{a,0}(f_k)$
$\underline{u}_{b,0}(f_k)$
$\underline{u}_{c,0}(f_k)$

Monitor Variables for Output Frequency The following monitor variables are calculated for user-selected output frequency, f_{out}:

Intermediate variables:

$u{:}A = \sqrt{[\alpha]\sum_{m=0}^{N}\left\|\underline{u}_{a,m}\right\|^{\alpha}}$	Line-ground voltage, magnitude (p.u.), according to IEC-61000-3-6
$u{:}B = \sqrt{[\alpha]\sum_{m=0}^{N}\left\|\underline{u}_{b,m}\right\|^{\alpha}}$	
$u{:}C = \sqrt{[\alpha]\sum_{m=0}^{N}\left\|\underline{u}_{c,m}\right\|^{\alpha}}$	
$u{:}A = \sqrt{[\alpha]\sum_{m=0}^{N}\left\|\underline{u}_{a,m}\right\|^{\alpha}}$	Line-ground voltage, magnitude (p.u.), according to IEC-61000-3-6
$u{:}B = \sqrt{[\alpha]\sum_{m=0}^{N}\left\|\underline{u}_{b,m}\right\|^{\alpha}}$	
$u{:}C = \sqrt{[\alpha]\sum_{m=0}^{N}\left\|\underline{u}_{c,m}\right\|^{\alpha}}$	
$upc{:}A = u{:}A \cdot 100$	Line-ground voltage, magnitude (%)
$upc{:}B = u{:}B \cdot 100$	
$upc{:}C = u{:}C \cdot 100$	
$U{:}A = u{:}A \cdot U_{nom}/\sqrt{3}$	Line-ground voltage magnitude (kV)
$U{:}B = u{:}B \cdot U_{nom}/\sqrt{3}$	
$U{:}C = u{:}C \cdot U_{nom}/\sqrt{3}$	

Monitor variables:

$phiu{:}A$	(N/A) Voltage angle (deg)
$phiu{:}B$	(N/A)
$phiu{:}C$	(N/A)
$phiurel{:}A$	(N/A) Voltage, relative angle (deg)
$phiurel{:}B$	(N/A)
$phiurel{:}C$	(N/A)
$ul{:}A = \sqrt{[\alpha] \sum_{m=0}^{N} \left\lvert \underline{ul}_{a,m} \right\rvert^{\alpha}}$	Line-line voltage magnitude (p.u.)
$ul{:}B = \sqrt{[\alpha] \sum_{m=0}^{N} \left\lvert \underline{ul}_{b,m} \right\rvert^{\alpha}}$	
$ul{:}C = \sqrt{[\alpha] \sum_{m=0}^{N} \left\lvert \underline{ul}_{c,m} \right\rvert^{\alpha}}$	
$ulpc{:}A = u{:}A \cdot 100$	Line-line voltage magnitude (%)
$ulpc{:}B = u{:}B \cdot 100$	
$ulpc{:}C = u{:}C \cdot 100$	
$Ul{:}A = u{:}A \cdot U_{nom}$	Line-line voltage magnitude (kV)
$Ul{:}B = u{:}B \cdot U_{nom}$	
$Ul{:}C = u{:}C \cdot U_{nom}$	
$phiul{:}A$	(N/A) Line-line voltage angle (deg)
$phiul{:}B$	(N/A)
$phiul{:}C$	(N/A)
$uln{:}A = \sqrt{[\alpha] \sum_{m=0}^{N} \left\lvert \underline{uln}_{a,m} \right\rvert^{\alpha}}$	Line-neutral voltage magnitude (p.u.)
$uln{:}B = \sqrt{[\alpha] \sum_{m=0}^{N} \left\lvert \underline{uln}_{b,m} \right\rvert^{\alpha}}$	
$uln{:}C = \sqrt{[\alpha] \sum_{m=0}^{N} \left\lvert \underline{uln}_{c,m} \right\rvert^{\alpha}}$	

$Uln{:}A = uln{:}A \cdot Unom/\sqrt{3}$	Line-neutral voltage magnitude (kV)
$Uln{:}B = uln{:}B \cdot Unom/\sqrt{3}$	
$Uln{:}C = uln{:}C \cdot Unom/\sqrt{3}$	
$phiuln{:}A$	(N/A) Line-neutral voltage angle (deg)
$phiuln{:}B$	(N/A)
$phiuln{:}C$	(N/A)
$Upht{:}A = uln{:}A \cdot Unom$	Phase technology dependent voltage magnitude (kV)
$Upht{:}B = uln{:}B \cdot Unom$	
$Upht{:}C = uln{:}C \cdot Unom$	
$R{:}A = Re(\underline{Z}_a)$	Line-ground resistance (Ω)
$R{:}B = Re(\underline{Z}_b)$	
$R{:}C = Re(\underline{Z}_c)$	
$X{:}A = Im(\underline{Z}_a)$	Line-ground network reactance (Ω)
$X{:}B = Im(\underline{Z}_b)$	
$X{:}C = Im(\underline{Z}_c)$	
$Z{:}A = \lvert\underline{Z}_a\rvert$	Line-ground network impedance (Ω)
$Z{:}B = \lvert\underline{Z}_b\rvert$	
$Z{:}C = \lvert\underline{Z}_c\rvert$	
$phiz{:}A = \phi_{\underline{Z}_a}$	Line-ground angle of network impedance (deg)
$phiz{:}B = \phi_{\underline{Z}_b}$	
$phiz{:}C = \phi_{\underline{Z}_c}$	
$Rl{:}A = Re(\underline{Z}l_a)$	Line-line resistance (Ω)
$Rl{:}B = Re(\underline{Z}l_b)$	
$Rl{:}C = Re(\underline{Z}l_c)$	

$Xl{:}A = Im(\underline{Zl}_a)$	Line-line network reactance (Ω)
$Xl{:}B = Im(\underline{Zl}_b)$	
$Xl{:}C = Im(\underline{Zl}_c)$	
$Zl{:}A = \lvert\underline{Zl}_a\rvert$	Line-line network impedance (Ω)
$Zl{:}B = \lvert\underline{Zl}_b\rvert$	
$Zl{:}C = \lvert\underline{Zl}_c\rvert$	
$phizl{:}A = \phi_{\underline{Zl}_a}$	Line-line angle of network impedance (deg)
$phizl{:}B = \phi_{\underline{Zl}_b}$	
$phizl{:}C = \phi_{\underline{Zl}_c}$	
$Rln{:}A = Re(\underline{Zln}_a)$	Line-neutral resistance (Ω)
$Rln{:}B = Re(\underline{Zln}_b)$	
$Rln{:}C = Re(\underline{Zln}_c)$	
$Xln{:}A = Im(\underline{Zln}_a)$	Line-neutral network reactance (Ω)
$Xln{:}B = Im(\underline{Zln}_b)$	
$Xln{:}C = Im(\underline{Zln}_c)$	
$Zln{:}A = \lvert\underline{Zln}_a\rvert$	Line-neutral network impedance (Ω)
$Zln{:}B = \lvert\underline{Zln}_b\rvert$	
$Zln{:}C = \lvert\underline{Zln}_c\rvert$	
$phizln{:}A = \phi_{\underline{Zln}_a}$	Line-neutral angle of network impedance (deg)
$phizln{:}B = \phi_{\underline{Zln}_b}$	
$phizln{:}C = \phi_{\underline{Zln}_c}$	

$u0 = \sqrt{[\alpha] \sum_{m=0}^{N} \lvert \underline{u0}_m \rvert^{\alpha}}$	Line-ground zero sequence voltage magnitude (p.u.), where $\underline{u0}_m = \frac{1}{3}\left(\underline{u}_{a,m} + \underline{u}_{b,m} + \underline{u}_{c,m}\right)$
$U0 = u0 \cdot U_{nom}/\sqrt{3}$	Zero sequence voltage magnitude (kV)
$U0x3 = 3 \cdot U0$	(kV)
$phiu0$	(N/A) Zero sequence voltage angle (deg)
$u1 = \sqrt{[\alpha] \sum_{m=0}^{N} \lvert \underline{u1}_m \rvert^{\alpha}}$	Line-ground positive sequence voltage magnitude (p.u.), according to IEC-61000-3-6 where $\underline{u1}_m = \frac{1}{3}(\underline{u}_{a,m} + a \cdot \underline{u}_{b,m} + a^2 \cdot \underline{u}_{c,m})$ and $a = \angle 120°$
$U1 = u1 \cdot U_{nom}/\sqrt{3}$	Line-ground positive sequence voltage magnitude (kV)
$phiu1$	(N/A) Line-ground positive sequence voltage angle (deg)
$u2 = \sqrt{[\alpha] \sum_{m=0}^{N} \lvert \underline{u2}_m \rvert^{\alpha}}$	Line-ground negative sequence voltage magnitude (p.u.), according to IEC-61000-3-6 where $\underline{u2}_m = \frac{1}{3}(\underline{u}_{a,m} + a^2 \cdot \underline{u}_{b,m} + a \cdot \underline{u}_{c,m})$ and $a = \angle 120°$
$U2 = u2 \cdot U_{nom}/\sqrt{3}$	Line-ground negative sequence voltage magnitude (kV)
$phiu2$	(N/A) Line-ground negative sequence voltage angle (deg)
$u1pc = u1 \cdot 100$	Line-ground positive sequence voltage magnitude (%)
$U1l = u1 \cdot U_{nom}$	Line-line positive sequence voltage magnitude (kV)
$U2l = u2 \cdot U_{nom}$	Line-line negative sequence voltage magnitude (kV)
$un = \sqrt{[\alpha] \sum_{m=0}^{N} \lvert \underline{un}_m \rvert^{\alpha}}$	Neutral-ground voltage magnitude (p.u.)
$Un = un \cdot U_{nom}/\sqrt{3}$	Neutral-ground voltage magnitude (kV)
$R0 = Re(\underline{Z0})$	Zero sequence resistance (Ω)
$X0 = Im(\underline{Z0})$	Zero sequence network reactance (Ω)
$Z0 = \lvert \underline{Z0} \rvert$	Zero sequence network impedance (Ω)
$phiz0 = \phi_{\underline{Z0}}$	Zero sequence network impedance angle (deg)
$R1 = Re(\underline{Z1})$	Positive sequence resistance (Ω)
$X1 = Im(\underline{Z1})$	Positive sequence network reactance (Ω)
$Z1 = \lvert \underline{Z1} \rvert$	Positive sequence network impedance (Ω)
$phiz1 = \phi_{\underline{Z1}}$	Positive sequence network impedance angle (deg)

$R2 = Re(\underline{Z2})$	Negative sequence resistance (Ω)
$X2 = Im(\underline{Z2})$	Negative sequence network reactance (Ω)
$Z2 = \lvert\underline{Z2}\rvert$	Negative sequence network impedance (Ω)
$phiz2 = \phi_{\underline{Z2}}$	Negative sequence network impedance angle (deg)
$Rn = Re(\underline{Z}_n)$	Resistance, neutral (Ω)
$Xn = Im(\underline{Z}_n)$	Network reactance, neutral (Ω)
$Zn = \lvert\underline{Z}_n\rvert$	Network impedance, neutral (Ω)
$phizn = \phi_{\underline{Z}_n}$	Angle of network impedance, neutral (Ω)
$ubfac = \frac{u2}{u1}$	Unbalance factor

Monitor Variables Considering All Frequencies: The following monitor variables are calculated considering all frequencies, f_k:

Intermediate variables:

$u{:}A(f_k) = \sqrt[\alpha]{\sum_{m=0}^{N} \left\lvert\underline{u}_{a,m}(f_k)\right\rvert^{\alpha}}$	Line-ground voltage, magnitude (p.u.), according to IEC-61000-3-6
$u{:}B(f_k) = \sqrt[\alpha]{\sum_{m=0}^{N} \left\lvert\underline{u}_{b,m}(f_k)\right\rvert^{\alpha}}$	
$u{:}C(f_k) = \sqrt[\alpha]{\sum_{m=0}^{N} \left\lvert\underline{u}_{c,m}(f_k)\right\rvert^{\alpha}}$	
$u0(f_k) = \sqrt[\alpha]{\sum_{m=0}^{N} \lvert\underline{u0}_m(f_k)\rvert^{\alpha}}$	Zero sequence voltage magnitude (p.u.) where $\underline{u0}(f_k) = \frac{1}{3}\left(\underline{u}_{a,m}(f_k) + \underline{u}_{b,m}(f_k) + \underline{u}_{c,m}(f_k)\right)$
$u1(f_k) = \sqrt[\alpha]{\sum_{m=0}^{N} \lvert\underline{u1}_m(f_k)\rvert^{\alpha}}$	Positive sequence voltage (p.u.) where $\underline{u1}_m(f_k) = \frac{1}{3}(\underline{u}_{a,m}(f_k) + a \cdot \underline{u}_{b,m}(f_k) + a^2 \cdot \underline{u}_{c,m}(f_k))$ and $a = \angle 120°$
$u2(f_k) = \sqrt[\alpha]{\sum_{m=0}^{N} \lvert\underline{u2}_m(f_k)\rvert^{\alpha}}$	Negative sequence voltage (p.u.) where $\underline{u2}_m(f_k) = \frac{1}{3}(\underline{u}_{a,m}(f_k) + a^2 \cdot \underline{u}_{b,m}(f_k) + a \cdot \underline{u}_{c,m}(f_k))$ and $a = \angle 120°$
$ul{:}A(f_k) = \sqrt[\alpha]{\sum_{m=0}^{N} \left\lvert\underline{ul}_{a,m}(f_k)\right\rvert^{\alpha}}$	Line-line voltage magnitude (p.u.)
$ul{:}B(f_k) = \sqrt[\alpha]{\sum_{m=0}^{N} \left\lvert\underline{ul}_{b,m}(f_k)\right\rvert^{\alpha}}$	
$ul{:}C(f_k) = \sqrt[\alpha]{\sum_{m=0}^{N} \left\lvert\underline{ul}_{c,m}(f_k)\right\rvert^{\alpha}}$	

Monitor variables:

$urms{:}A = \sqrt{\sum_{k\geq 1} u{:}A(f_k)^2}$ RMS value of line-neutral voltage (p.u.)

$urms{:}B = \sqrt{\sum_{k\geq 1} u{:}B(f_k)^2}$

$urms{:}C = \sqrt{\sum_{k\geq 1} u{:}C(f_k)^2}$

$Urms{:}A = urms{:}A \cdot U_{nom}/\sqrt{3}$ RMS value of line-neutral voltage (kV)

$Urms{:}B = urms{:}B \cdot U_{nom}/\sqrt{3}$

$Urms{:}C = urms{:}C \cdot U_{nom}/\sqrt{3}$

$u0rms = \sqrt{\sum_{k\geq 1} u0(f_k)^2}$ RMS value of zero sequence voltage (p.u.)

$U0rms = u0rms \cdot U_{nom}/\sqrt{3}$ RMS value of zero sequence voltage (kV)

$u1rms = \sqrt{\sum_{k\geq 1} u1(f_k)^2}$ RMS value of positive sequence voltage (p.u.)

$U1rms = u1rms \cdot U_{nom}/\sqrt{3}$ RMS value of positive sequence voltage (kV)

$U1lrms = u1rms \cdot U_{nom}$ RMS value of positive sequence line-line voltage (kV)

$u2rms = \sqrt{\sum_{k\geq 1} u2(f_k)^2}$ RMS value of negative sequence voltage (p.u.)

$U2rms = u2rms \cdot U_{nom}/\sqrt{3}$ RMS value of negative sequence voltage (kV)

$U2lrms = u2rms \cdot U_{nom}$ RMS value of negative sequence line-line voltage (kV)

$HD{:}A = \frac{u{:}A(f_{out})}{u{:}A(f_1)} \cdot 100$ Harmonic distortion (%); based on fundamental frequency values

$HD{:}B = \frac{u{:}B(f_{out})}{u{:}B(f_1)} \cdot 100$

$HD{:}C = \frac{u{:}C(f_{out})}{u{:}C(f_1)} \cdot 100$

$HD{:}A = \frac{u{:}A(f_{out})}{u_{nom}{:}A} \cdot 100$	Harmonic distortion (%); based on nominal voltage, where $u_{nom} = 1$p.u.
$HD{:}B = \frac{u{:}B(f_{out})}{u_{nom}{:}B} \cdot 100$	
$HD{:}C = \frac{u{:}C(f_{out})}{u_{nom}{:}C} \cdot 100$	
$HF{:}A = \frac{u{:}A(f_{out})}{urms{:}A} \cdot 100$	Harmonic factor (%)
$HF{:}B = \frac{u{:}B(f_{out})}{urms{:}B} \cdot 100$	
$HF{:}C = \frac{u{:}C(f_{out})}{urms{:}C} \cdot 100$	
$HD0 = \frac{u0(f_{out})}{\sqrt{u0(f_1)^2+u1(f_1)^2+u2(f_1)^2}} \cdot 100$	Harmonic distortion, zero sequence (%); based on fundamental frequency values
$HD1 = \frac{u1(f_{out})}{\sqrt{u0(f_1)^2+u1(f_1)^2+u2(f_1)^2}} \cdot 100$	Harmonic distortion, positive sequence (%)
$HD2 = \frac{u2(f_{out})}{\sqrt{u0(f_1)^2+u1(f_1)^2+u2(f_1)^2}} \cdot 100$	Harmonic distortion, negative sequence (%)
$HD0 = \frac{u0(f_{out})}{u_{nom}} \cdot 100$	Harmonic distortion, zero sequence (%); based on nominal voltage
$HD1 = \frac{u1(f_{out})}{u_{nom}} \cdot 100$	Harmonic distortion, positive sequence (%)
$HD2 = \frac{u2(f_{out})}{u_{nom}} \cdot 100$	Harmonic distortion, negative sequence (%)
$HF0 = \frac{u0(f_{out})}{u0rms} \cdot 100$	Harmonic factor, zero sequence (%)
$HF1 = \frac{u1(f_{out})}{u1rms} \cdot 100$	Harmonic factor, positive sequence (%)
$HF2 = \frac{u2(f_{out})}{u2rms} \cdot 100$	Harmonic factor, negative sequence (%)

$THD{:}A = \frac{1}{u{:}A(f_1)} \sqrt{urms{:}A^2 - u{:}A(f_1)^2} \cdot 100$ Total harmonic distortion (%); based on fundamental frequency values

$THD{:}B = \frac{1}{u{:}B(f_1)} \sqrt{urms{:}B^2 - u{:}B(f_1)^2} \cdot 100$

$THD{:}C = \frac{1}{u{:}C(f_1)} \sqrt{urms{:}C^2 - u{:}C(f_1)^2} \cdot 100$

$THD{:}A = \frac{1}{u_{nom}{:}A} \sqrt{urms{:}A^2 - u{:}A(f_1)^2} \cdot 100$ Total harmonic distortion (%); based on nominal voltage, where $u_{nom} = 1$p.u.

$THD{:}B = \frac{1}{u_{nom}{:}B} \sqrt{urms{:}B^2 - u{:}B(f_1)^2} \cdot 100$

$THD{:}C = \frac{1}{u_{nom}{:}C} \sqrt{urms{:}C^2 - u{:}C(f_1)^2} \cdot 100$

$THF{:}A = \frac{1}{urms{:}A} \sqrt{urms{:}A^2 - u{:}A(f_1)^2} \cdot 100$ Total harmonic factor (%)

$THF{:}B = \frac{1}{urms{:}B} \sqrt{urms{:}B^2 - u{:}B(f_1)^2} \cdot 100$

$THF{:}C = \frac{1}{urms{:}C} \sqrt{urms{:}C^2 - u{:}C(f_1)^2} \cdot 100$

$ulrms{:}A = \sqrt{\sum_{k \geq 1} ul{:}A(f_k)^2}$ RMS value of line-line voltage (p.u.)

$ulrms{:}B = \sqrt{\sum_{k \geq 1} ul{:}B(f_k)^2}$

$ulrms{:}C = \sqrt{\sum_{k \geq 1} ul{:}C(f_k)^2}$

$Ulrms{:}A = ulrms{:}A \cdot U_{nom}$ RMS value of line-line voltage (kV)

$Ulrms{:}B = ulrms{:}B \cdot U_{nom}$

$Ulrms{:}C = ulrms{:}C \cdot U_{nom}$

$TAD{:}A = \frac{1}{u{:}A(f_1)} \cdot \left[\sum_{k \geq 1} u{:}A(f_k) - u{:}A(f_1)\right] \cdot 100$ Total arithmetic distortion (%)

$TAD{:}B = \frac{1}{u{:}B(f_1)} \cdot \left[\sum_{k \geq 1} u{:}B(f_k) - u{:}B(f_1)\right] \cdot 100$

$TAD{:}C = \frac{1}{u{:}C(f_1)} \cdot \left[\sum_{k \geq 1} u{:}C(f_k) - u{:}C(f_1)\right] \cdot 100$

$uasum{:}A = \sum_{k \geq 1} u{:}A(f_k)$ Arithmetic voltage sum (p.u.)

$uasum{:}B = \sum_{k \geq 1} u{:}B(f_k)$

$uasum{:}C = \sum_{k \geq 1} u{:}C(f_k)$

$TIF{:}A = \frac{1}{urms{:}A}\sqrt{\sum_{k\geq 1} tif(f_k)^2 \cdot u{:}A(f_k)^2}$	Telephone interference factor
$TIF{:}B = \frac{1}{urms{:}B}\sqrt{\sum_{k\geq 1} tif(f_k)^2 \cdot u{:}B(f_k)^2}$	
$TIF{:}C = \frac{1}{urms{:}C}\sqrt{\sum_{k\geq 1} tif(f_k)^2 \cdot u{:}C(f_k)^2}$	
$urmsint = \max\limits_{x=[A,B,C]}(urmsint{:}x)$	RMS value of integer harmonics (p.u.), where $urmsint{:}x = \sqrt{\sum\limits_{\substack{k\geq 1\\ integer}} u{:}x(f_k)^2}$
$urmsnint = \max\limits_{x=[A,B,C]}(urmsnint{:}x)$	RMS value of non-integer harmonics (p.u.), where $urmsnint{:}x = \sqrt{\sum\limits_{\substack{k>1\\ non-integer}} u{:}x(f_k)^2}$
$THD0 = \frac{1}{u1(f_1)^2+u0(f_1)^2+u2(f_1)^2}\sqrt{u0rms^2 - u0(f_1)^2}$	Total harmonic distortion (%) (voltage, zero sequence)
$THD1 = \frac{1}{u1(f_1)^2+u0(f_1)^2+u2(f_1)^2}\sqrt{u1rms^2 - u1(f_1)^2}$	Total harmonic distortion (%) (voltage, positive sequence)
$THD2 = \frac{1}{u1(f_1)^2+u0(f_1)^2+u2(f_1)^2}\sqrt{u2rms^2 - u2(f_1)^2}$	Total harmonic distortion (%) (voltage, negative sequence)
$THDbal = \sqrt{THD1^2 + THD2^2}$	Total harmonic distortion (%), excluding zero sequence
$THDtot = \sqrt{THD1^2 + THD2^2 + THD0^2}$	Total harmonic distortion (%), including zero sequence
$TADmx = \max\limits_{x=[A,B,C]}(TAD{:}x)$	Arithmetic distortion (%)
$TADint = \max\limits_{x=[A,B,C]}(TADint{:}x)$	Arithmetic distortion (%), where $TADint{:}x = \frac{1}{u{:}x(f_1)} \cdot \left[\sum\limits_{\substack{k\geq 1\\ integer}} u{:}x(f_k) - u{:}x(f_1)\right] \cdot 100$
$TADnint = \max\limits_{x=[A,B,C]}(TADnint{:}x)$	Arithmetic distortion (%), where $TADnint{:}x = \frac{1}{u{:}x(f_1)} \cdot \left[\sum\limits_{\substack{k>1\\ non-integer}} u{:}x(f_k) - u{:}x(f_1)\right] \cdot 100$
$TAD\_3 = \max\limits_{x=[A,B,C]}(TADint{:}x)$	Arithmetic distortion (%), harmonic orders: multiples of three
$TAD\_2 = \max\limits_{x=[A,B,C]}(TADint{:}x)$	Arithmetic distortion (%), harmonic orders: multiples of two

$THDint = \max\limits_{x=[A,B,C]}(THDint{:}x)$

Total harmonic distortion (%), where

$THDint{:}x = \frac{1}{u{:}x(f_1)} \cdot \sqrt{urms{:}x^2 - u{:}x(f_1)^2} \cdot 100$

(Fundamental frequency values) or

$THDint{:}x = \frac{1}{u_{nom}{:}x} \cdot \sqrt{urms{:}x^2 - u{:}x(f_1)^2} \cdot 100$

(Nominal voltage) and

$urms{:}x = \sqrt{\sum\limits_{\substack{k \geq 1 \\ integer}} u{:}x(f_k)^2}$

$THDnint = \max\limits_{x=[A,B,C]}(THDnint{:}x)$

Total harmonic distortion (%), where

$THDnint{:}x = \frac{1}{u{:}x(f_1)} \cdot \sqrt{urms{:}x^2 - u{:}x(f_1)^2} \cdot 100$

(Fundamental frequency values) or

$THDnint{:}x = \frac{1}{u_{nom}{:}x} \cdot \sqrt{urms{:}x^2 - u{:}x(f_1)^2} \cdot 100$

(Nominal voltage) and

$urms{:}x = \sqrt{\sum\limits_{\substack{k > 1 \\ non-integer}} u{:}x(f_k)^2}$

$THD\_3 = \max\limits_{x=[A,B,C]}(THDint{:}x)$

Total harmonic distortion (%), harmonic orders: multiples of three

$THD\_2 = \max\limits_{x=[A,B,C]}(TADint{:}x)$

Total harmonic distortion (%), harmonic orders: multiples of two

$TIFmx = \max\limits_{x=[A,B,C]}(TIF{:}x)$

Total interference factor, for harmonic orders

$uasummx = \max\limits_{x=[A,B,C]}(uasum{:}x)$

Arithmetic voltage sum (p.u.)

$uasumint = \max\limits_{x=[A,B,C]}(uasumint{:}x)$

Arithmetic sum of integer harmonics (p.u.), where

$uasumint{:}x = \sum\limits_{\substack{k \geq 2 \\ integer}} u{:}x(f_k)$

$uasumnint = \max\limits_{x=[A,B,C]}(uasumnint{:}x)$

Arithmetic sum of integer harmonics (p.u.), where

$uasumnint{:}x = \sum\limits_{\substack{k > 2 \\ non-integer}} u{:}x(f_k)$

4 Calculation Considering IEC Flicker Sources

PowerFactory calculates monitor variables for the Flicker Assessment calculation within the Harmonic Load Flow command if at least one flicker source is identified in the network. Such sources may include asynchronous machines (*ElmAsm*), doubly-fed asynchronous machines (*ElmAsmsc*) and static generators (*ElmGenstat*).

The calculation of flicker sources in the network is always based on the fundamental frequency. Quantities are computed for busbars only. Table 4.1 provides the nomenclature used in this section; detailed derivation of these quantities can be found in [1].

Table 4.1: Nomenclature

Name	**Unit**	**Description**
ψ_k	deg	Network impedance angle, as seen by WTG k
v_a	m/s	Annual average wind speed (m/s)
$c(\psi_k,v_a)$		Flicker coefficient for continuous operation of the WTG
S_n	VA	Rated apparent power of WTG
S_k	VA	Short-circuit apparent power of grid
N_{wt}	-	Number of WTGs connected to PCC
i	-	The ith WTG
N_{10}	-	Maximum number of switching operations within a 10-minute period
N_{120}	-	Maximum number of switching operations within a 120-minute period
k_f	-	Flicker step factor
k_u	-	Voltage change factor

4.1 Balanced and Unbalanced Calculations

4.1.0.9 Bus Monitor Variables

$P_{st\Sigma\_c} = \frac{1}{S_k} \cdot \sqrt{\sum_{i=1}^{N_{wt}} \left(c_i\left(\psi_k, v_a\right) \cdot S_{n,i}\right)^2}$	Short-term flicker disturbance factor (continuous operation of the WTG)
$P_{lt\Sigma\_c} = \frac{1}{S_k} \cdot \sqrt{\sum_{i=1}^{N_{wt}} \left(c_i\left(\psi_k, v_a\right) \cdot S_{n,i}\right)^2}$	Long-term flicker disturbance factor (continuous operation of the WTG)
$P_{st\Sigma\_s} = \frac{18}{S_k} \cdot \left[\sum_{i=1}^{N_{wt}} N_{10,i} \cdot (k_{f,i}(\psi_k) \cdot S_{n,i})^{3.2}\right]^{0.31}$	Short-term flicker disturbance factor (switching operation of the WTG)
$P_{lt\Sigma\_s} = \frac{8}{S_k} \cdot \left[\sum_{i=1}^{N_{wt}} N_{120,i} \cdot (k_{f,i}(\psi_k) \cdot S_{n,i})^{3.2}\right]^{0.31}$	Short-term flicker disturbance factor (switching operation of the WTG)
$d = 100 \cdot k_u(\psi_k) \cdot \frac{S_n}{S_k}$	Relative voltage change due to the switching operation of a single WTG (%) (Note: only maximum for entire network reported)

5 References

[1] IEC 61400 Part 21: Measurement and Assessment of Power Quality Characteristics of Grid Connected Wind Turbines, 2001.

[2] Standards Australia. AS/NZS61000.3.6:2001 Electromagnetic compatibility (EMC) - Limits - Assessment of emission limits for distorting loads in MV and HV power systems (IEC 61000-3-6:1996).