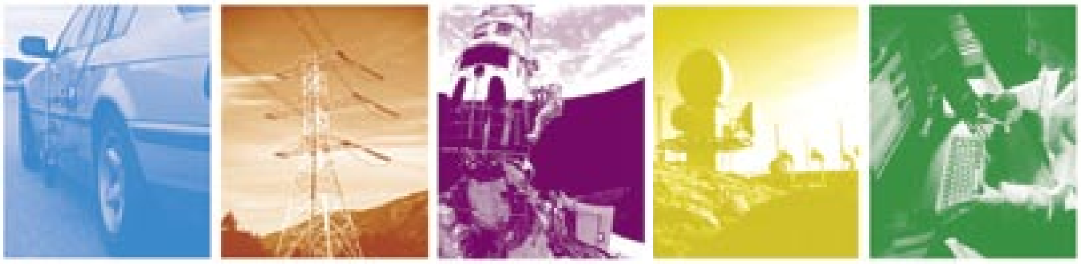

Automotive

Energy & Power Analysis

Field Service

Environmental

Research & Development

DEWESoft Power

Software User Shortform and

Technical Reference Manual

ISO9001

... the precision signal conditioning company

worldwide

DEWETRON

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Warranty agreement

For warrenty information please refer to the *DEWESoft Software Users Manual*, which is shipped together with the software.

1. What is DEWESoft Power

DEWESoft POWER is a module inside DEWESoft which provides all functions which are needed for a total power analysis.

This are:

- Scope
- Vectorscope
- Recorder
- Power Calculation
- FFT
- Frequency measurement
- Wave form recording
- Triggering on all parameters
- Selection of different wiring schematics

In addition all other DEWESoft functions can be used what makes the system the most powerful power measurement system at all:

- Video (Pictures in parallel to data acquisition)
- GPS (exact synchronisation; absolute or from location to location)
- Full frequency signal FFT
- Mathematic library
- Various displays

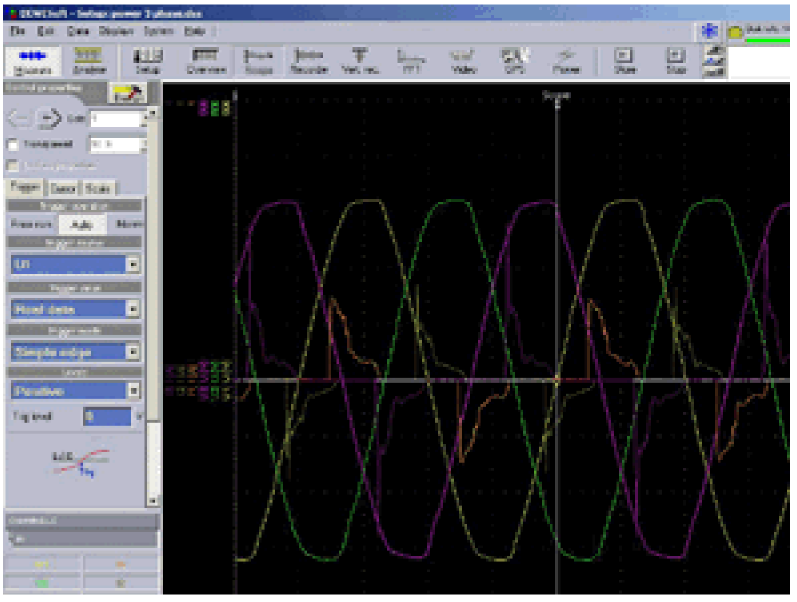
DEWESoft POWER is a part in DEWESoft version 6.2 and higher. The usage requires licensing of the system. The minor DEWESOft version required is DEWESoft light 6.2.

DEWESOFT POWER EXAMPLE SCREEN

1.1 Scope

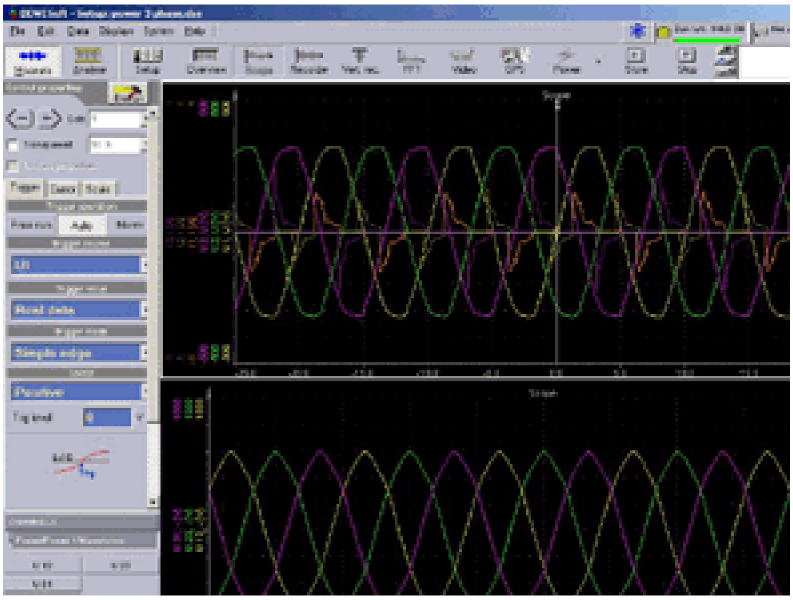
The Scope shows the waveform of voltage and current or other signals connected to your instrument. In total it is possible to show up to 8 curves in one diagram. For detailed handling please see the DEWESoft Manual.

- Selectable graphs
- U1, U2, U3, U12, U23, U31: Line to line and line to earth voltages are supported
- Up to 8 graphs in one diagram
- Zoom in and out are supported online
- Waveforms can be stored



SCOPE SCREEN

A speciality of the DEWESoft POWER is, that it can not only handle the line to earth voltages but also the line to line voltages. Depending on the selected type of wiring scematic the conversion is done inside.
The following picture shows two scope modules on one page. One contains line to earth voltages and current, the other one the related line to line voltages.

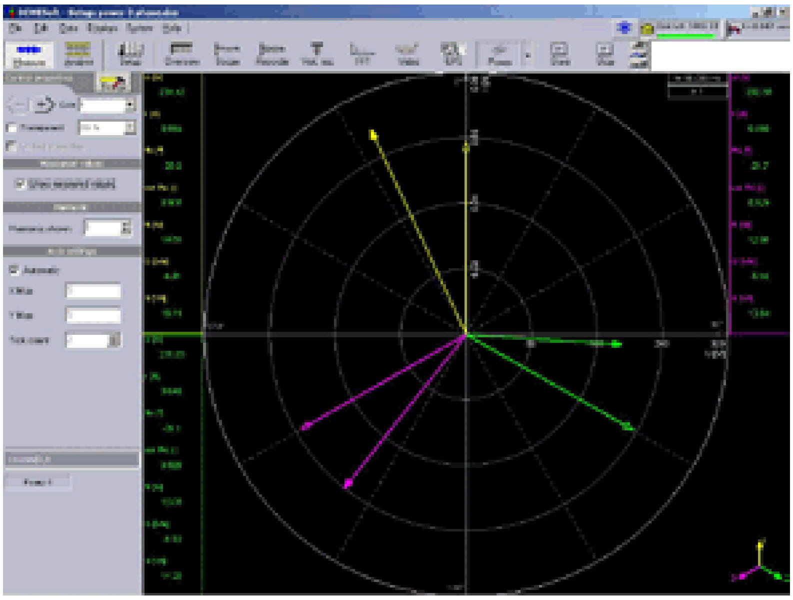


DUAL SCOPE SCREEN

1.2 Vectorscope

The Vectorscope shows the phasors of voltage and current. In addition also the RMS values of voltage and current, the phase angles and the power values are shown (if the check box „show measured values“ is enabled). It is also possible to show the phasors for three phase systems.

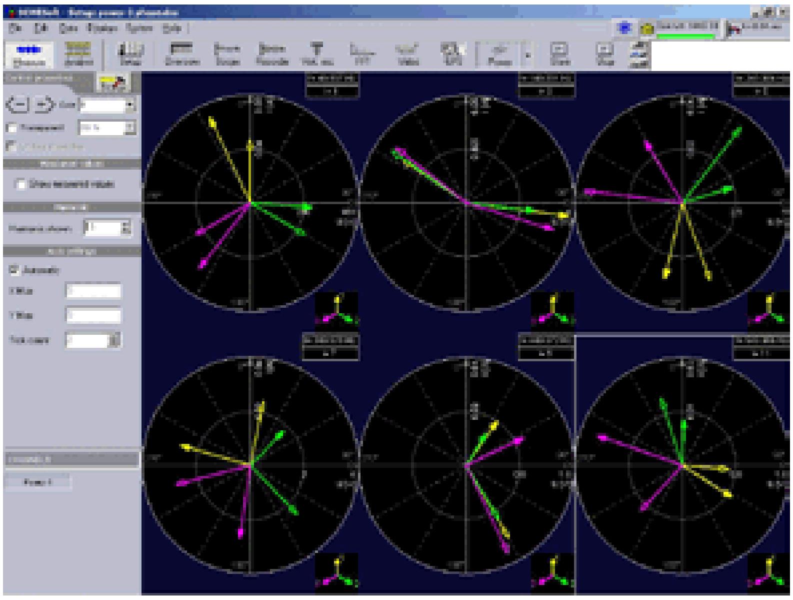
- Vector scope for 3 phase systems
- Each individual harmonic can be shown
- More vector scopes can be displayed on one screen
- Different power systems can be shown on one screen
- With the “transparent” function direct comparisons of phasors are possible



VECTOR SCOPE SCREEN

In a Vectorscope the phasors represent the alternating values. If you „look“ on a voltage or current you will see that it is changing all the time (AC = Alternating Current). In real it is rotating around a central point. If you now rotate the picture with the same speed as the voltage changes (50 Hz for example) it will stand still - and this is how a vectorscope works.

If you do this for different frequencies you will get vectors of all different harmonics. The next picture shows the vectors of the Harmonics 1, 3, 5, 7, 9 and 11.

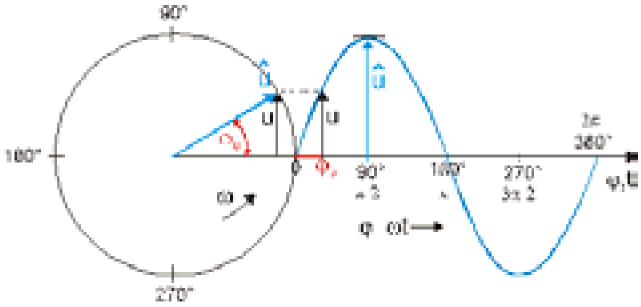


DIFFERENT HARMONICS IN VECTORSCOPE

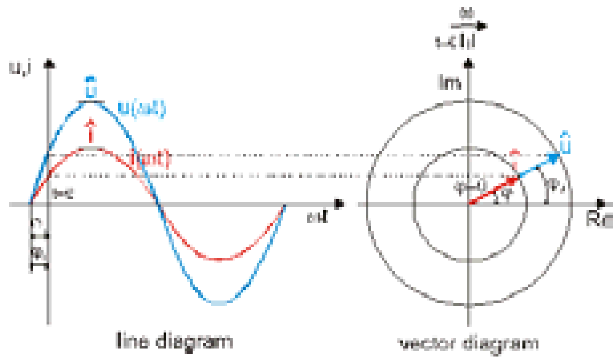
Harmonic 1 and 7 show a nice rotating field in the right direction („positive sequence system“). If you look on 3 and 9 you will see that all 3 phases point into the same direction: This is no more rotating field - it is an alternating field - the so called „zero system“. Harmonic 5 and 11 are rotating in the left direction - this is the so called „negative sequence system“.

1.2.1 Theoretical background from a Vectorscope

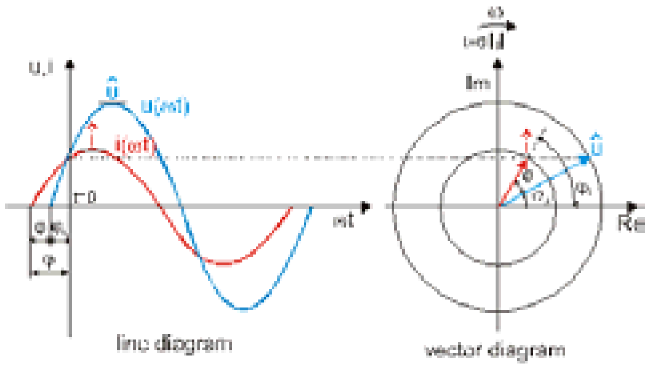
The temporary varying AC voltage of a simple sine function can also be understood as a vector that rotates in the mathematically positive (left -) direction with constant angular speed w (w=2pf). Its projection along the vertical axis represents the instantaneous value u at time t, its length the peak value, û. When these projections are displayed on the time axis with the associated phase angles j=wt, a line diagram is produced in the form of a sinusoidal curve (see Picture below), whose abscissa can be measured in degrees or radians.



CONSTRUCTION OF THE LINE DIAGRAM



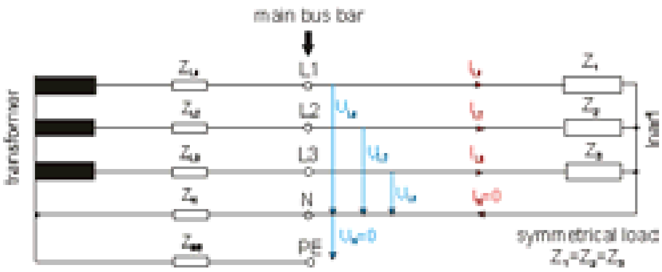
LINE DIAGRAM, VECTOR DIAGRAM FOR INDUCTIVE LOAD



LINE DIAGRAM, VECTOR DIAGRAM FOR CAPACITIVE LOAD

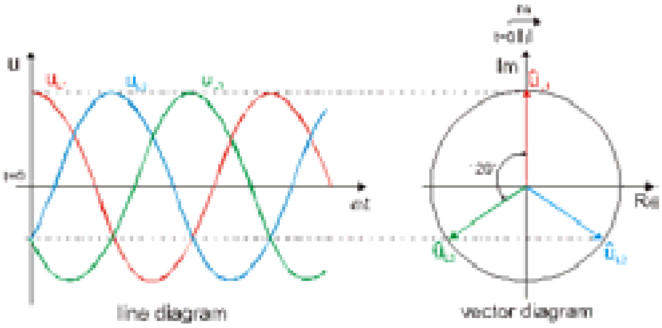
1.2.2. Vectorscope with 3-Phases

Example of a symmetrical 4-wire-system with symmetrical load



SYMMETRICAL LOADED 4-WIRE-SYSTEM

With a symmetrical 4-wire-system (as shown above), the voltages UL1, UL2, UL3 are in each case 120° out of phase with each other (see figure below).



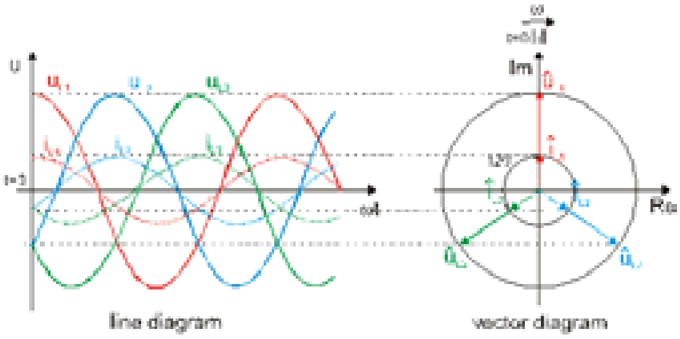
VOLTAGES IN A SYMMETRICAL 4-WIRE-SYSTEM

A symmetrical load (Z1=Z2=Z3) has symmetrical currents IL1, IL2, IL3. Depending on the type of load, the currents run in front of the voltages (capacitive), behind (inductive) or have the same phase (ohmic). The currents themselves are again 120° out of phase with each other. During symmetrical loading, the currents IL1, IL2, IL3 through complex addition at the junction, nullify themselves and therefore no current flows via the neutral conductor, N (IN=0).

$$\overline{I_{L1}} + \overline{I_{L2}} + \overline{I_{L3}} = 0$$

COMPLEX ADDITION

An illustration of voltage and current transfer ratios as line and vector diagrams, as seen at the measurement point in the main distributor frame, is shown in the next figure.

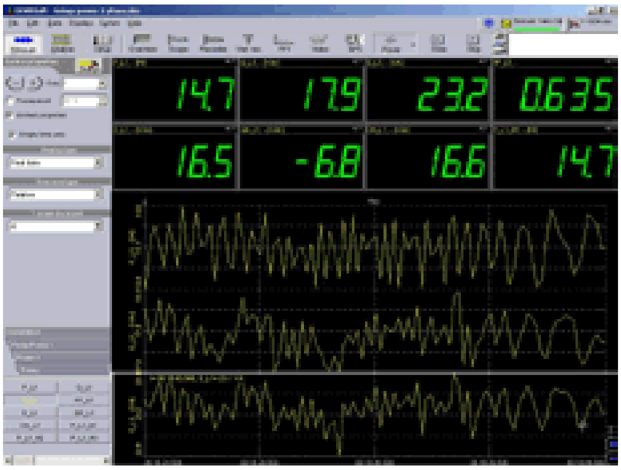


LINE DIAGRAM, VECTOR DIAGRAM FOR A SYMMETRICAL VOLTAGE SYSTEM WITH SYMMETRICAL OHMIC LOAD

1.3 Recorder

The Recorder allows to draw graphs of each individual value which is calculated from the power module or other functions.
The powerful selector (bottom left) provides this values to be selected for the curve.

- Recording of all parameters in individual intervals
- Individual screens can be defined
- Zoom in and out
- Storing fast (full sampling rate)
  or reduced (e.g. 600 sec.)



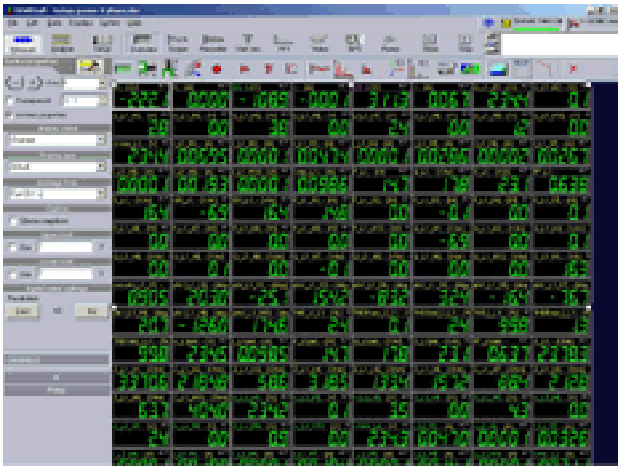
RECORDER SCREEN

Other useful functions could be:
Vertical recorder: for example as a voltage recorder
X-Y recorder: for example to generate Orbitals.

1.4 Power calculation inside DEWESoft Power

The power module is a very accurate system to calculate power with all its components like active-, reactive- and deviation power.
Based on a calculation in the frequency domain the input channels can be calibrated very efficient in amplitude as well as in phase. Internal amplifiers, external transformers and clamps can be corrected with the use of this function.
Based on this principle the range of applications for the systems is very wide.

- P, Q, S, D
- Cos Phi, Power factor
- P, Q, cos Phi for each harmonic
- Symmetrical Components (positive, negative and zero sequence components)
- Period values (1/2 cycle, cycle, ...)

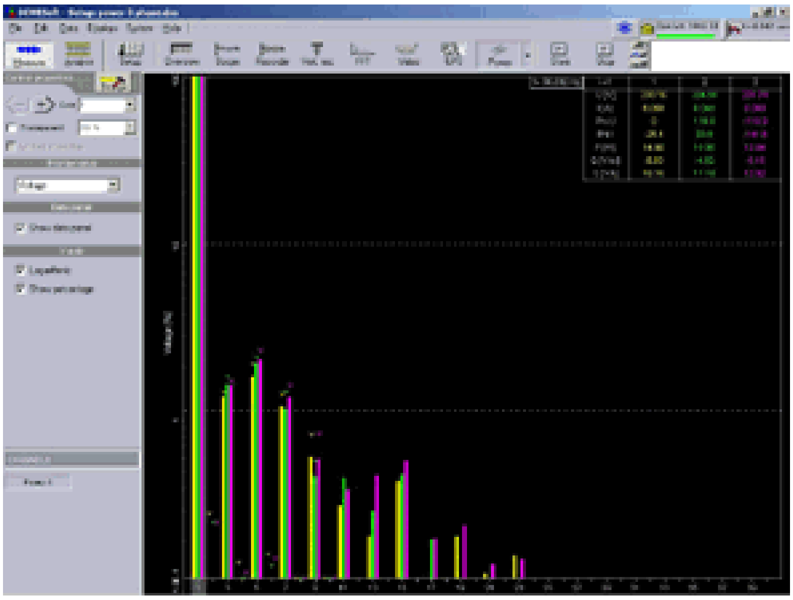


POWER VALUES

1.5 FFT

The FFT module shows the harmonics of either voltage, current active or reactive power. The x-axis does not contain the frequency as we know from a standard FFT, but the order of the harmonic. The order of the harmonic multiplied with the fundamental frequency gives the frequency of the harmonic.

- I
- P
- Q
- Individual setup of the number of harmonics (e.g. sampling rate 20 kHz = 200 harmonics)
- Calculation corrected to the actual real frequency
- THD
- THD even
- THD odd
- Trigger on each parameter

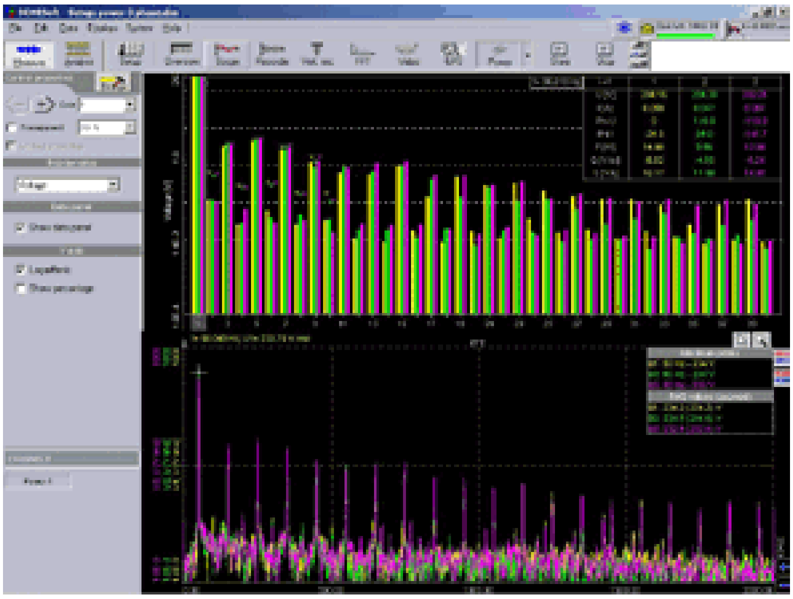


FFT SCREEN

1.5.1 Harmonics versus frequency

The difference between frequency and harmonic order based FFT is shown in the next picture. The input source is the same voltage. The full FFT (bottom) allows a total frequency analysis. The harmonics analysis for power evaluations (top) is reduced to multiples of the fundamental oscillation.

- In addition to Harmonics FFT a full frequency based FFT is available.
- All frequencies can be analyzed with this function
- Trigger on FFT patterns

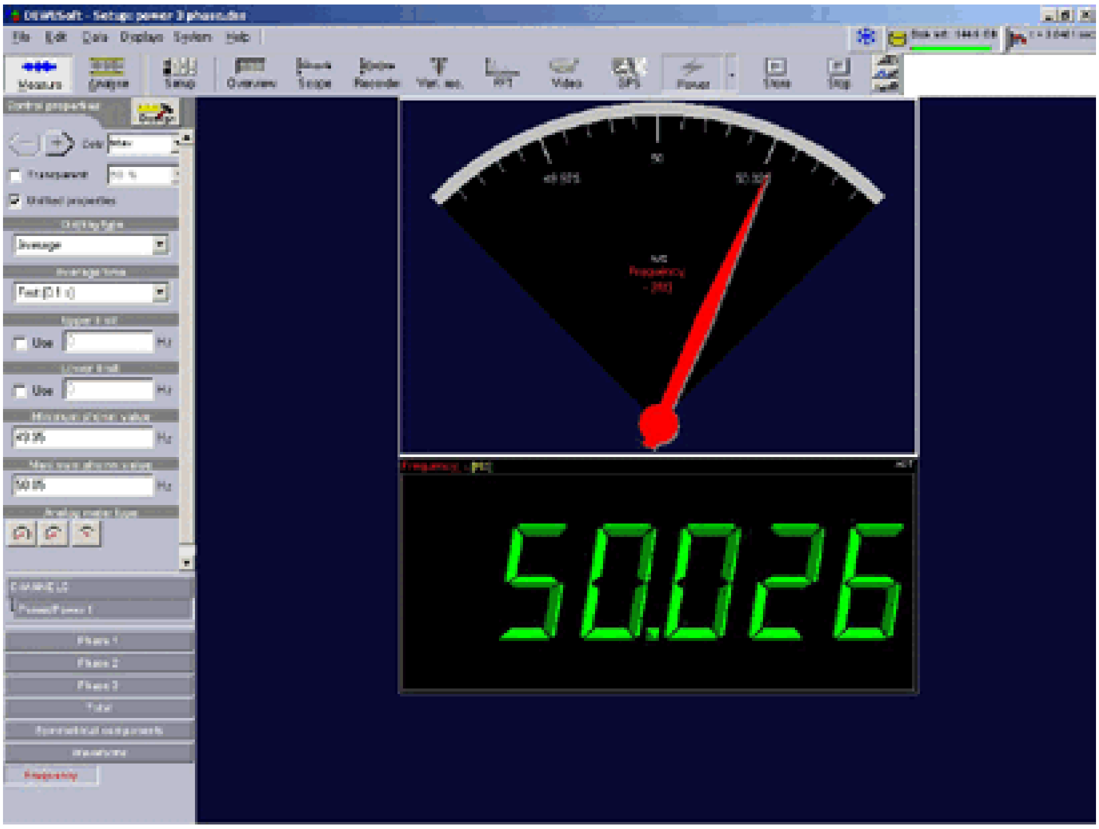


POWER FFT AND FREQUENCY FFT

1.6 Frequency measurement

The frequency measurement is done based on a software PLL. The input source are the voltage channels of a power module. The largest phase voltage is taken for this calculation. The accuracy is mHz. If more then one power module is defined each one can have it's own frequency. So it is possible to do power measurements on different frequency systems with only one instrument at the same time.

The following picture shows a numeric display and a meter which show the value of frequency in a DEWESOft POWER screen.

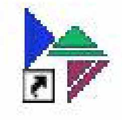


FREQUENCY METER

2. 10 Steps to run DEWESoft Power

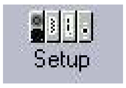
2.1 Start DEWESoft with DEWESoft POWER

Click on the DEWESoft icon on your desktop. Make sure POWER is enabled and licensed

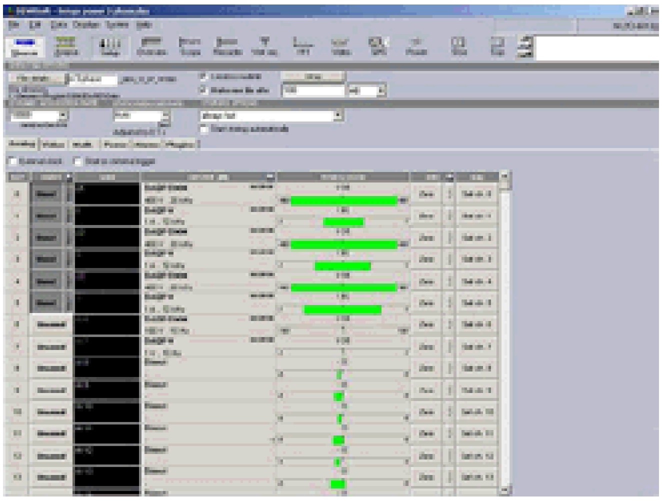


DEWESOFT ICON BUTTON

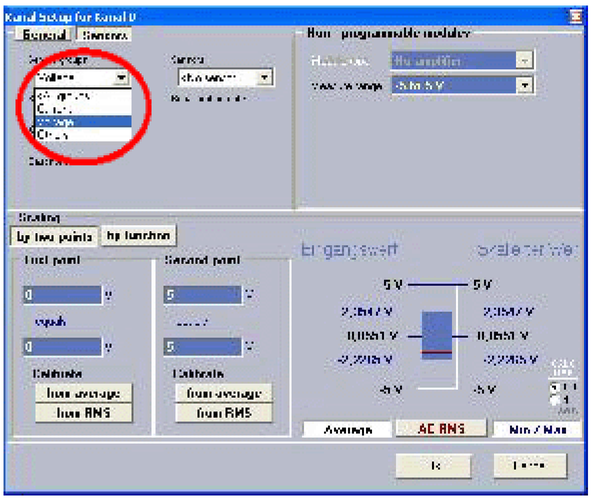
2.2 Setup of hardware channels



Enable all required voltage and current inputs in the analog channel setup.



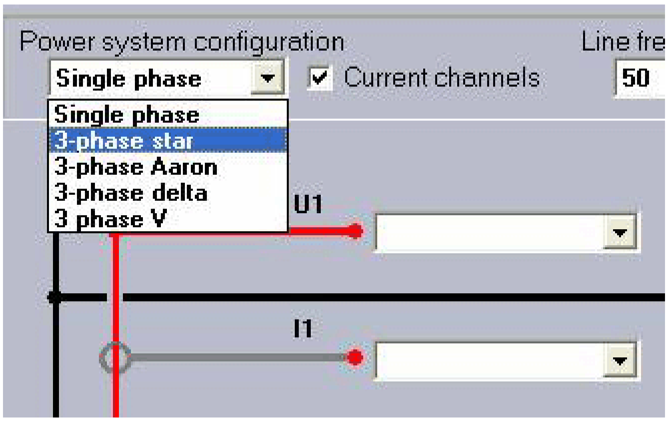
Set all parameters in the channel setup



If required set up a sensor like current clamps or voltage transformers

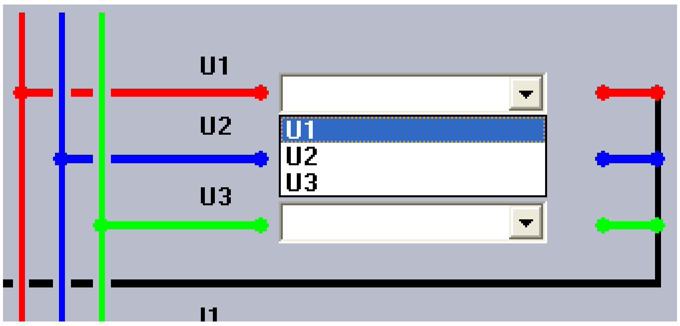
2.3. Add a power module

2.4 Define your wiring schematic

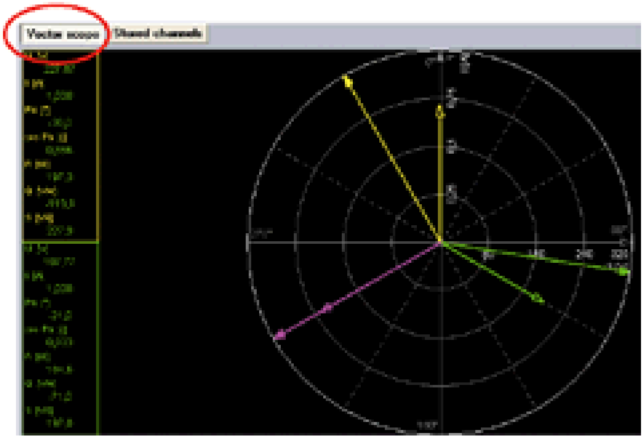


2.5 Define input channels

Select the corresponding channel from the preselected analog inputs (see point 2.2)

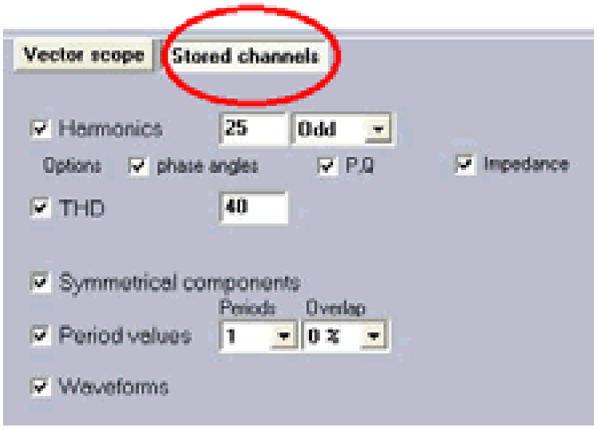


2.6. Check your values: use the vector scope on the setup screen



2.7. Define calculated values to be stored

Enable the check box for the required values



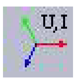
2.8. Define your screen

As usual in DEWESoft you can define your own screens. Switch to the POWER view (of course power elements can be added also on other views)

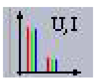
Add elements on your own needs

Special POWER Elements:

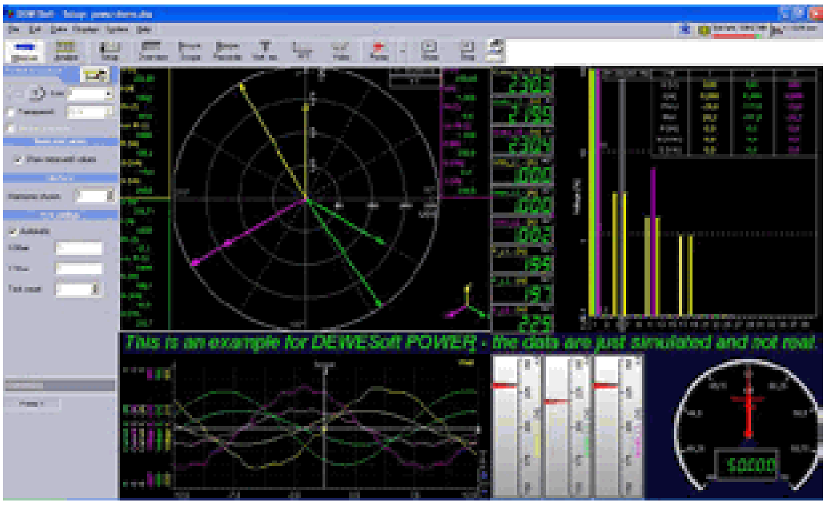
Vectorscope



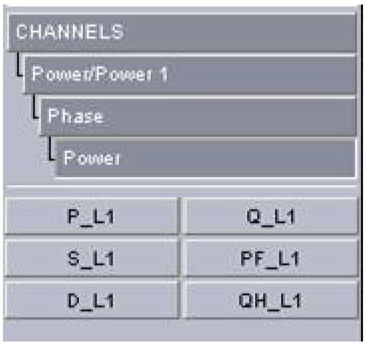
Power FFT



Example of a setup with a vector scope, power FFT, scope, needle meters and digital meters.

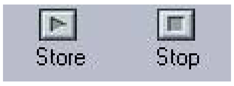


To show values in the recorder or any meters select the appropriate value from the channels selector (left bottom)

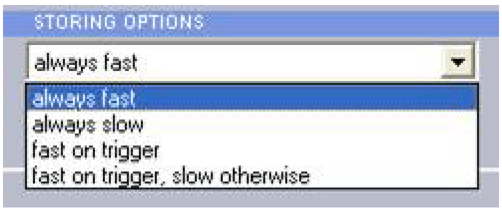


2.9. Start storing of values

Use the store and stop buttons to start and stop storing of data.



Other storing options on the setup page:

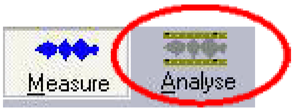


Always fast: non reduced sampling rate (full waveform recording)

Always slow: reduced sampling rate for data logging (for example 60 sec average values)

Fast on trigger: for transient recorder function (waveform recording)
Fast on trigger, slow otherwise: mix of data logging and waveform recording

2.10. Analyze your measurement



To analyze your data stop the measurement and go to the analyze mode.

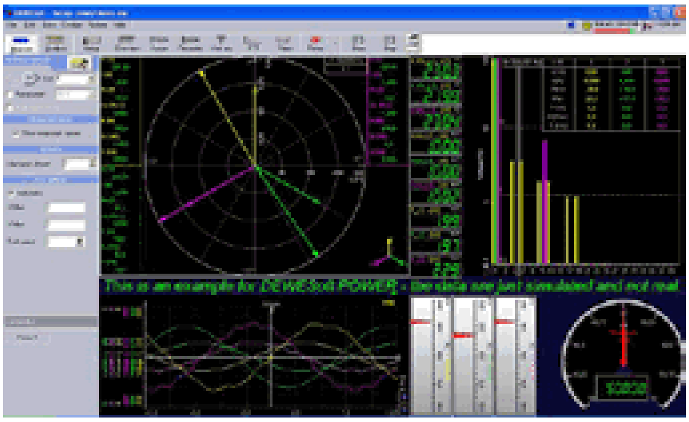
3. Examples

This examples shall give the user some ideas how he could use the strong DEWESoft POWER flexibility for his applications.

Install them by choosing the Item „Install POWER Examples“ in your DEWESoft Setup Program (see program disk) or download them from our FTP Server.

3.1 Example 01: simulation of voltage and current

Open the setup file „Powerdemo.dss“ in your DEWESoft setup directory. After opening the POWER page you will see a typical setup which could be useful for a complete power analysis



It shows a 3 phase system where the 3 phases are totally different (not typical for real measurements).
Phase 1 (Yellow) is a typical voltage where a lot of harmonics are added - could be typical for a 6 pulse converter for example.
Phase 2 (green) is a pure sine wave where the amplitude is changing all the time (voltage) and the phase angle (current)
Phase 3 (violet) has added frequencies which are not multiples of the fundamental.
The source for this data are just simulations by using the strong DEWESoft MATH library. Open SETUP / MATH for changing the signals.

3.2 Example 02: drilling machine

Open the data file „Power 01 drilling.dsd“ in your DEWESoft data directory. The following window will appear when you click on the Power page:

With the „PLAY“ button you can easily replay the example.

What can be seen ?

The yellow recorder chart shows the current.

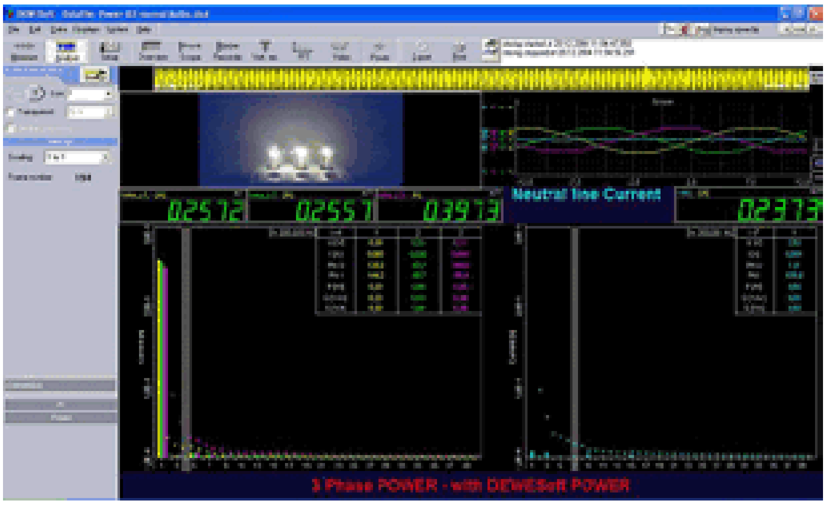
On the left side you can see that there is only a positive part what means that the power controller of the drilling machine uses only the upper half wave of the voltage. This can be seen also on the scope (right, top) of the example. The harmonics (right, bottom) are all available. Not only the 3rd, 5th, 7th but also the 2nd, 4th, 6th (DC components !).

At the end of the example the drilling machine needs more power and the controller switches on also the second half of the voltage. The current is now positive and negative. The scope shows the usage of the full wave and the Harmonics are now only 3rd, 5th, 7th and so on.

An other interesting part is the Vectorscope which shows very nice the „bad“ phase angle at the beginning of the example and the much better one at the end.

3.3 Example 03: phase loads

Open the data file „Power 02 normal bulbs.dsd“ in your DEWESoft data directory. The following window will appear when you click on the Power page:



With the „PLAY“ button you can easily replay the example.

What can be seen ?
During this example the lamps will be switched on one after the next. In the scope can be seen that the blue current which is the neutral current always compensates the line currents. When only one lamp is switched on the blue is exactly the negative of current one. For two lamps it is the difference of this two and for three lamps it is exactly zero. We have a fully balanced system.

Now we repeat this example with the file „Power 03 energy saving bulbs.dsd“ in your DEWESoft data directory.

What can be seen now ?

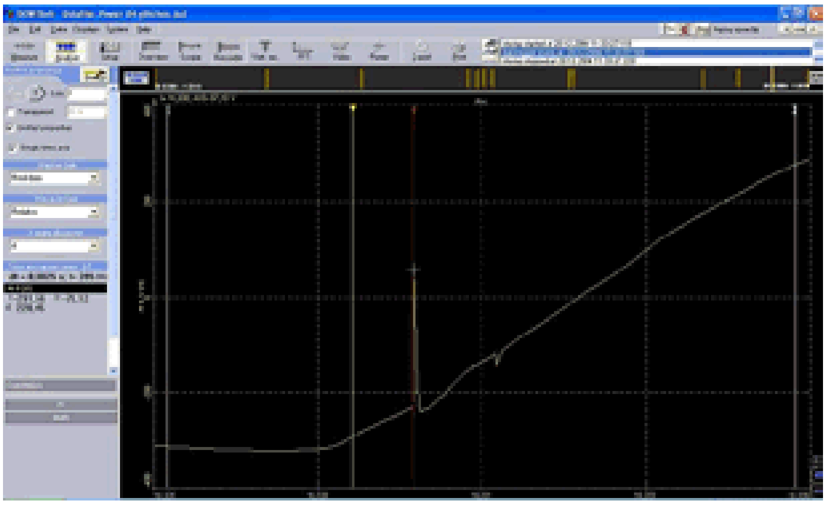
The currents are now no longer pure sine waves like from the normal bulbs. We have electronical switched devices. Not only energy saving bulbs are representative for this „bad“ current - nearly all devices which we use today (computers, TV sets, drilling machines like in example 02, etc...) have currents like this and that‘s why the harmonics are coming more and more into our minds.

The example shows very nice what happens in the phase lines but also in the neutral line. At the end, when all lamps are switched on, the neutral is loaded higher then the phase lines and the harmonic 3 is the largest one - not the fundamental ! That‘s why sometimes the neutral line is heated up and can begin to burn. Have you ever watched the current in your neutral ?

3.4 Example 04: glitch detection

Open the data file „Power 04 glitches“ in your DEWESoft data directory.

The example shows how very fast glitches can be detected with the use of DEWESoft. Fast glitches come from over voltages or from discharges of capactitors. Those capacitors are for example in supply parts of computers and can be very high and very short. They can destroy other instruments and that‘s why it is necessary to suppress them. But before you can install surge protectors you need to know how high and long the glitches are. To „catch“ them you need a high sampling rate and a input module which has enough bandwidth - and a DEWETRON instrument with DEWESoft POWER of course.

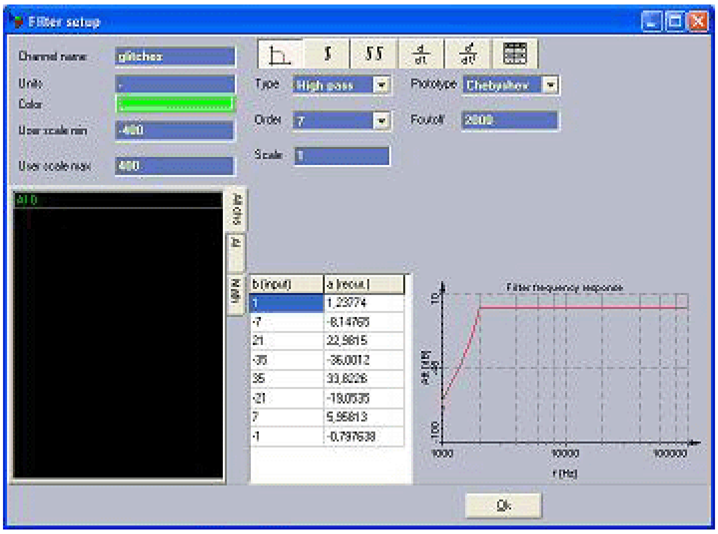


How is the setup done? (see also setup file „glitchdetection.dss“)

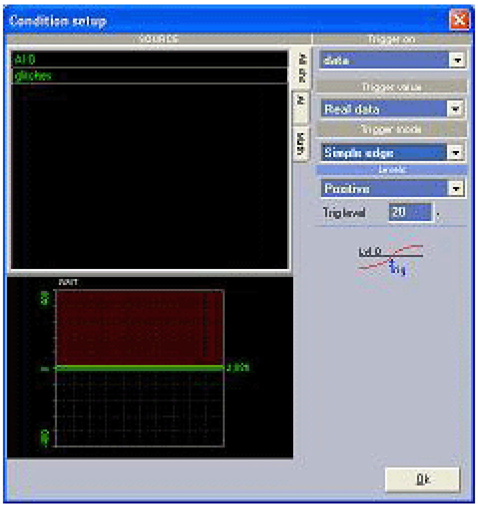
Basically we use a voltage input and a high pass filter. The fundamental is chuted of now and only high frequencies are seen. This chuted signal is the input for the trigger condition and then the original signal will be stored in case of a glitch.

1. Define an input channel (take care of enough amplitude reserve (example 1 kV) and enough sam-

pling rate (200 kHz, 1 MHz, depending on the A/D board)
2. Define a MATH channel as a filter.
3. Select the hardware channel from step 1 as input in the math channel



4. Define the filter: chebyshev, highpass, cut off frequency=2000 Hz (example)
5. Define the storing mode „fast storing on trigger“



6. Define the trigger: input channel is the math channel „glitches“, amplitude 20 V (example)
7. Start the instrument for storing

4. Technical Reference

Formulas and calculations in the DEWESoft POWER module

4.1 General

The software DEWESoft Power is a software for applications in the field of measuring electrical energy and disturbances in power grids.

Some Typical applications are:

- Measurements in single phase and three phase systems.
- Energy measurement and load profiles in the supply grid.
- Measurements of the power usage and energy demand of equipment.
- Frequency measurement (16 2/3 Hz, 50 Hz, 60 Hz, 400 Hz, 800 Hz).
- FFT of Power Networks.
- Transient Fault Recorder in Power Grids.
- Multichannel Energy Logger.

Values which can be measured are:

- U,I
- f
- P, Q, S, PF
- P1, Q1, S1, cos Phi1
- Q, Q1, D, QH, DH
- Symmetrical Components U, I
- FFT: U, I, cos Phi, P, Q for each Harmonic
- THD, THD even, THD odd

4.1.1 Sine waves and other periodic signals

Electrical Energy is generated mainly in rotating generators – three phase synchronous motors. Due to the nature of this engine the voltage is a pure sine wave with a frequency calculated by the rotation speed and the number of poles of the rotor/stator system.

Voltage waveform = sine wave

The RMS value of this sinusoidal voltage is the value which a pure direct voltage would have to produce the same “heat” – what means the area under the curve must be the same. Mathematical it is the so called RMS value and for a pure sine wave it is the peak value divided by SQRT(2).

$$RMS = \sqrt{\frac{1}{n}\sum_{i=}^{n}}$$

FORMULA 4.1-1. RMS OF A PURE SINE WAVE

Because of non linear characteristics of for example transformers and non linear load currents the voltage which is seen at the customer side is not longer the sine wave which came out of the generator – but it is still periodic.

To calculate the RMS value now it is necessary to have a look on the real wave form.

The above mentioned formula is only valid for sine waves.

A RMS value can also be calculated as the integration of all squared sample points of the curve and divided by the number of samples and taking the root of the result.

$$RMS = \frac{1}{n}\sqrt{\sum_{i=1}^{n} u_i^{\,2}}$$

FORMULA 4.1-2. RMS FOR NON SINE WAVES

The base for this formula is a signal which has no time delay or other shift inside the curve.

For calculations where you have to compensate also non linear characteristics of transformers you must first transfer the signal into the frequency domain, correct it by amplitude and phase, and then you can calculate the RMS values.

Those transformers are typically current clamps, voltage and current measurement transformers but also all measurement amplifiers. Also a sampling shift of non synchronous sampling in digital recorders can be suppressed by the use of this method.

4.1.2 RMS calculation and the problem of non linear signal transformers

To calculate the RMS value with the use of the frequency domain you first have to transfer the input signal from time domain into frequency domain.

$$\text{(u(t))}\, U_{FFT} = FFT(u(t))$$

FORMULA 4.1-3: FFT PRINCIPLE

This is done by the use of the Fast Fourier Transformation [see 2, 11]. The typical window duration in electrical applications are 10 periods [see 3].
Now you can multiply each frequency by itself with the correction factor for the amplitude and for the phase shift.

$$U_{FFTcorrected} = U_{FFT} * FFT_{correctionfactors}$$

FORMULA 4.1-4: FFT CORRECTION

Typically you have to calibrate the instrument itself and also external transformers. This can be made with a two step calibration for inner and outer correction.

$$U_{FFTcorrected} = U_{FFT} * FFT_{innercorrection} * FFT_{outercorrection}$$

FORMULA 4.1-5: FFT FULL CORRECTION

To get now the total RMS value the RMS for each frequency has to be calculated and then the sum of all this values.

$$U_{RMStotal} = \sqrt{U_0^{\,2} + U_1^{\,2} + U_2^{\,2} + \ldots}$$

FORMULA 4.1-6: U RMS TOTAL

0,1,2,..harmonic index (including all interharmonics)
The RMS value now is totally corrected in amplitude and phase.

For current correction the way is the same and for power calculations the way is similar. The additional need is that current and voltage have to be exactly in phase and this is done by use of the inner calibration values. The calculation of the individual power values is described in chapter 4.4.1.

4.1.3 General terms

Values in capital letters: RMS or AVG values

Examples:

RMS: U,I

AVG: P, S, Q

Values in small letters are: waveforms or sample point values

Examples:

u(t), i(t), p(t)

RMS (root mean square value) is calculated as :

$$RMS = \sqrt{\frac{1}{n}\sum_{i=1}^{n} u_i^{\,2}}$$

FORMULA 4.1-7: RMS

AVG (average values) are calculated as:

$$AVG = \frac{1}{n}\sum_{i=1}^{n} u_i$$

FORMULA 4.1-8: AVG

4.2 Voltage and current

Because on one hand side very accurate values (corrected 10 period FFT values) are needed (later called “frequency domain values”) and on the other hand side also fast values (half period and multiples of it, later called “time domain values”) both values for further evaluations are provided.

4.2.1 Frequency domain values

High accuracy

Phase and amplitude corrected

Typical: 10 period window length

$$u_{nh} \ldots fromFFT$$

$$U_{nh} = \frac{u_{nh}}{\sqrt{2}}$$

$$U_n = \sqrt{\sum_{h=1}^{H} U_{nh}^2}$$

FORMULA 4.2-1: U PHASE

U…RMS value of the voltage
unit: V (volt)
name in software: U rms_L1, U rms_L2, U rms_L3
directory in software: channels – power – module Nr – Phase x – Voltages

u…voltage amplitude for line to neutral voltages (Phase voltage) from FFT calculation
h…harmonic order
H…number of Harmonics
n…phase number 1,2 or 3

$$i_{nh}...fromFFT$$

$$I_{nh} = \frac{i_{nh}}{\sqrt{2}}$$

$$I_n = \sqrt{\sum_{h=1}^{H} I_{nh}^2}$$

FORMULA 4.2-2: I

I…RMS value of the current
unit: A (ampere)
name in software: I rms_L1, I rms_L2, I rms_L3
directory in software: channels – power – module Nr – Phase x – Currents

i…current amplitude from FFT calculation
h…harmonic order
H…number of Harmonics
n…phase number 1,2 or 3

4.2.1.1 Calibration

4.2.1.1.1 Inner calibration

For amplitude and phase corrections inside the instrument.

4.2.1.1.2 Outer calibration

For additional external clamps and transformers.

4.2.2 Time domain values

Typically the one period value is needed as a trigger argument for a fault recorder. This can be either voltage, current but also for example power, reactive power or the power factor. To provide this the so called period value is implemented. This values are not corrected in amplitude and phase.

$$U_{perRMS} = \frac{1}{n}\sqrt{\sum_{1}^{n} u_i^2}$$

FORMULA 4.2-3: U PER

unit: V (volt)
name in software: U_L1per, U_L2per, U_L3per
directory in software: channels – power – module Nr – Phase x – Period values

U per RMS...Period value of the voltage
n…number of samples = duration * sampling speed
i…voltage of sample

$$I_{perRMS} = \frac{1}{n}\sqrt{\sum_{1}^{n} i_i^2}$$

FORMULA 4.2-4: I PER

unit: A (ampere)
name in software: I_L1per, I_L2per, I_L3per
directory in software: channels – power – module Nr – Phase x – Period values

I per RMS...Period value of the current
n…number of samples = duration * sampling speed
i…current of sample

Duration: length of the RMS calculation. ½ period, 1 period, 2, 4,….or absolute time: ½ sec

Overlapping: sometimes a sliding window is needed for this calculation. In [3] a ½ period RMS value is required which is in real a period value which is shifted all ½ periods. Overlapping in this case is 50%, length is 1 period.

Also Power values can be calculated like this – see chapter 4.2

4.2.3 3 Phase systems

In multi phase systems not only the line to earth voltages are of interest but also the line to line voltages. For example a line to earth voltage is required to detect earth faults. Line to line voltages are converted in a delta star transformer into the voltage which the customer will get at the end – so in medium and high voltage applications line to line voltages are of interest as well.

Line to line voltages can be measured as well directly or calculated by the use of the following formula:

$$u_{ik} = u_k - u_i$$
$$U_{ik} = RMS(u_{ik})$$

FORMULA 4.2-5: U LINE

U_{ik} …line to line voltage (line voltage)
unit: V (volt)
name in software: U 12, U 23, U 31
directory in software: channels – power – module Nr – Waveforms
for scope mode: channels – power / Module Nr/Waveforms

i…Phase number 1
k…Phase number 2
possible values for ik: 12, 23, 31

4.2.3.1 Wiring conversions

Depending on the selected wiring schematic the other voltages can be calculated as following:

4.2.3.1.1 star to delta

$$u_{ik} = u_k - u_i$$
$$U_{ik} = RMS(u_{ik})$$

FORMULA 4.2-6: STAR TO DELTA CONVERSION

4.2.3.1.2 delta to star

$$u_1 = \frac{2}{3}(-u_{12} - \frac{1}{2}u_{23}), U_1 = RMS(u_1)$$
$$u_2 = \frac{2}{3}(-u_{23} - \frac{1}{2}u_{31}), U_2 = RMS(u_2)$$
$$u_3 = \frac{2}{3}(-u_{31} - \frac{1}{2}u_{12}), U_3 = RMS(u_3)$$

FORMULA 4.2-7: DELTA TO STAR CONVERSION

4.2.3.2 3 Phase systems with missing currents (Aaron and V connection)

In some wiring schematics one current is not measured but calculated out of the other two. This schematic can be used ONLY when there is NO neutral line!

$$i_3 = -i_2 - i_1$$

FORMULA 4.2-8: MISSING CURRENT

i_3 …missing current
i_1, i_2 …measured currents

4.3 Frequency

The frequency calculation is done based on a Software PLL and the sampling window of multiple periods (typical 10 periods).

$$f \ldots fromFFT$$

FORMULA 4.3-1: FREQUENCY

typical value: 16 2/3, 50, 60, 400, 800, variable
unit: Hz (hertz)
name in software: frequency
directory in software: channels – power – module Nr
f…frequency of the fundamental oscillation (highest peak in FFT spectrum)

4.4 Power

4.4.1 Frequency domain (high accuracy and calibrated values)

- High accuracy
- Phase and amplitude corrected
- Typical 10 period window length

4.4.1.1 Single phase

As a result from the fast fourier transformation (FFT) we have the values of u, i and cos Phi for each harmonic. With the help of this values all power values can be calculated as following. Because of the already done calibration the results have the highest possible accuracy.

4.4.1.1.1 For each individual Harmonic h:

$$S_h = U_h * I_h$$

FORMULA 4.4-1: S h

S…power of harmonic h
unit: VA (volt ampere)

h…harmonic number
U…phase voltage
I…phase current

$$P_h = U_h * I_h * \cos Phi_h$$

FORMULA 4.4-2: P h

P…active power of harmonic h
unit: W (watt)
name in software: P_L1_H2, P_L1_H3, P_L1_H4, …
directory in software: channels – power – module Nr – phase x – power

Phi…Phase angle of harmonic h

$$Q_h = U_h * I_h * \sin Phi_h = \sqrt{S_h^2 - P_h^2}$$

FORMULA 4.4-3: Q h

Q…reactive power of harmonic h
unit: VAr (volt ampere radiant)

4.4.1.1.2 For the fundamental oscillation h=1:

$$S1_1 = U1 * I1$$

FORMULA 4.4-4: S1

S1…power of the fundamental
unit: VA (volt ampere)
name in software: S_L1_H1, S_L2_H2, S_L3_H3
directory in software: channels – power – module Nr – phase x – power

$$P1 = U1 * I1 * \cos Phi1$$

FORMULA 4.4-5: P1

P1…active power of the fundamental
unit: W (watt)
name in software: P_L1_H1, P_L2_H1, P_L3_H1
directory in software: channels – power – module Nr – phase x – power

$$Q1 = U1 * I1 * \sin Phi1 = \sqrt{S1^2 - P1^2}$$

FORMULA 4.4-6: Q1

S1…reactive power of the fundamental
unit: VAr (volt ampere radiant)
name in software: Q_L1_H1, Q_L2_H1, Q_L3_H1

directory in software: channels – power – module Nr – phase x – power
Q1 has a positive or negative sign

4.4.1.1.3 For the full waveform:

$$S = \sum_{h=1}^{H} S_h$$

FORMULA 4.4-7: S

S…power of the full signal
unit: VA (volt ampere)
name in software: S_L1, S_L2, S_L3
directory in software: channels – power – module Nr – phase x – power
H…number of all Harmonics
h…individual harmonic

$$P = \sum_{h=1}^{H} P_h$$

FORMULA 4.4-8: P

P…active power of the full signal
unit: W (watt)
name in software: P_L1, P_L2, P_L3
directory in software: channels – power – module Nr – phase x – power

$$Q = \sqrt{S^2 - P^2}$$

FORMULA 4.4-9: Q

Q…reactive power of the full signal
unit: VAr (volt ampere radiant)
name in software: Q_L1, Q_L2, Q_L3
directory in software: channels – power – module Nr – phase x – power
Q has no sign!

$$PF = \frac{P}{S}$$

FORMULA 4.4-10: PF

PF…power factor of the full signal
unit: 1
name in software: PF_L1, PF_L2, PF_L3
directory in software: channels – power – module Nr – phase x – power

$$D = \sqrt{Q^2 - Q1^2}$$

FORMULA 4.4-11: D

D… distortion power of all harmonics components reactive powers (u and I have the same order but not equal 1 or have different order)
unit: VAr (volt ampere radiant)
name in software: D_L1, D_L2, D_L3
directory in software: channels – power – module Nr – phase x – power

D has no sign!

$$QH = \sum_{h=1}^{H} Q_h$$

FORMULA 4.4-12: QH

QH…reactive power of all harmonics where u and i have the same harmonics order
unit: VAr (volt ampere radiant)
name in software: QH_L1, QH_L2, QH_L3
directory in software: channels – power – module Nr – phase x – power
QH has a positive or negative sign

$$DH = \sqrt{Q^2 - QH^2}$$

FORMULA 4.4-13: DH

DH…distortion power of all harmonics components reactive powers where u and i have different harmonic orders
unit: VAr (volt ampere radiant)
name in software: DH_L1, DH_L2, DH_L3
directory in software: channels – power – module Nr – phase x – power
DH has no sign!

4.4.1.2 3 Phase systems

$$P_{3\sim} = P_1 + P_2 + P_3$$

FORMULA 4.4-14: P3~

P 3~…total active power of a three phase system
unit: W (watt)
name in software: P
directory in software: channels – power – module Nr – total – power

$$S_{3\sim} = S_1 + S_2 + S_3$$

FORMULA 4.4-15: S3~

S 3~…total power of a three phase system
unit: VA (volt ampere)
name in software: S
directory in software: channels – power – module Nr – total – power

$$Q_{3\sim} = \sqrt{S_{3\sim}^2 - P_{3\sim}^2}$$

FORMULA 4.4-16: Q3~

Q 3~…total reactive power of a three phase system

unit: VAr (volt ampere radiant)
name in software: Q
directory in software: channels – power – module Nr – total – power
Q has no sign!

$$PF_{3\sim} = \frac{P_{3\sim}}{S_{3\sim}}$$

FORMULA 4.4-17: PF3~

PF 3~…total power factor of a three phase system
unit: 1
name in software: PF
directory in software: channels – power – module Nr – total – power

$$S1_{3\sim} = S1_1 + S1_2 + S1_3$$

FORMULA 4.4-18: S1 3~

S 3~…total power of the fundamentals of a three phase system
unit: VA (volt ampere)
name in software: S_H1
directory in software: channels – power – module Nr – total – power

$$P1_{3\sim} = P1_1 + P1_2 + P1_3$$

FORMULA 4.4-19: P1 3~

P 3~…total active power of the fundamentals of a three phase system
unit: W (watt)
name in software: P_H1
directory in software: channels – power – module Nr – total – power

$$\cos Phi_{3\sim} = \frac{P1_{3\sim}}{S1_{3\sim}}$$

FORMULA 4.4-20: COS PHI 3~

cos Phi 3~…total power factor of the fundamentals of a three phase system
unit: 1
name in software: cos Phi_H1
directory in software: channels – power – module Nr – total – power

$$D_{3\sim} = \sqrt{Q_{3\sim}^2 - Q1_{3\sim}^2}$$

FORMULA 4.4-21: Q1 3~

Q 3~…total reactive power of the fundamentals of a three phase system
unit: VAr (volt ampere radiant)
name in software: Q_H1
directory in software: channels – power – module Nr – total – power
Q1 has a positive or negative sign

$$D_{3\sim} = \sqrt{Q_{3\sim}^2 - Q1_{3\sim}^2}$$

FORMULA 4.4-22: D 3~

D 3~…total distortion power of a three phase system
unit: VAr (volt ampere radiant)
name in software: D
directory in software: channels – power – module Nr – total – power

$$QH_{3\sim} = QH_1 + QH_2 + QH_3$$

FORMULA 4.4-23: QH 3~

DH 3~…total reactive power of all harmonics components of a three phase system
unit: VAr (volt ampere radiant)
name in software: QH
directory in software: channels – power – module Nr – total – power
QH has a positive or negative sign

$$DH_{3\sim} = \sqrt{Q_{3\sim}^2 - QH_{3\sim}^2}$$

FORMULA 4-24: DH 3~

D 3~…total distortion power of all harmonics components of a three phase system where u and i have different harmonic orders
unit: VAr (volt ampere radiant)
name in software: DH
directory in software: channels – power – module Nr – total – power
DH has no sign!

4.4.2 Time domain (period values for disturbance calculations)

4.4.2.1 Single phase

$$S_{per} = U_{perRMS} * I_{perRMS}$$

FORMULA 4.4-25: S PER

S per…power
unit: VA (volt ampere)
name in software: S_L1per, S_L2per, S_L3per
directory in software: channels – power – module Nr – phase x – period values

$$p_{per}(t) = u(t) * i(t)$$
$$P_{per} = AVG(p_{per}(t))$$

FORMULA 4.4-26: P PER

P per…active power
unit: W (watt)
name in software: P_L1per, P_L2per, P_L3per
directory in software: channels – power – module Nr – phase x – period values

$$Q_{per} = \sqrt{S_{per}{}^2 - P_{per}{}^2}$$

FORMULA 4.4-27: Q PER

Q per…reactive power
unit: VAr (volt ampere radiant)
name in software: Q_L1per, Q_L2per, Q_L3per

directory in software: channels – power – module Nr – phase x – period values

$$PF_{per} = P_{per} / S_{per}$$

FORMULA 4.4-28: PF PER

PF per…power factor
unit: 1
name in software: PF_L1per, PF_L2per, PF_L3per
directory in software: channels – power – module Nr – phase x – period

4.4.2.2 3 phase systems

$$U_{3\sim per} = \frac{1}{3}(U_{1perRMS} + U_{2perRMS} + U_{3perRMS})$$

FORMULA 4.4-29: U 3~ PER

U 3~ per…average of the voltages in a 3 phase system
unit: V (volt)
name in software: U_per
directory in software: channels – power – module Nr – total – period values

$$I_{3\sim per} = I_{1perRMS} + I_{2perRMS} + I_{3perRMS}$$

FORMULA 4.4-30: I 3~ PER

I 3~ per…sum of the currents of a three phase system
unit: A (ampere)
name in software: I_per
directory in software: channels – power – module Nr – total – period values

$$P_{3\sim per} = P_{1perRMS} + P_{2perRMS} + P_{3perRMS}$$

FORMULA 4.4-31: P 3~ PER

P 3~ per…total active power of a three phase system
unit: W (watt)
name in software: P_per
directory in software: channels – power – module Nr – total – period values

$$S_{3\sim per} = S_{1perRMS} + S_{2perRMS} + S_{3perRMS}$$

FORMULA 4.4-32: S 3~ PER

S 3~ per…total power of a three phase system
unit: VA (volt ampere)
name in software: S_per
directory in software: channels – power – module Nr – total – period values

$$Q_{3\sim per} = \sqrt{S_{3\sim per}^2 - P_{3\sim per}^2}$$

FORMULA 4.4-33: Q 3~ PER

Q 3~ per…total reactive power of a three phase system
unit: VAr (volt ampere radiant)
name in software: Q_per
directory in software: channels – power – module Nr – total – period values
Q 3~ per has no sign !

$$PF_{3\sim per} = \frac{P_{3\sim per}}{S_{3\sim per}}$$

FORMULA 4.4-34: PF 3~ PER

PF 3~ per…total power factor of a three phase system
unit: 1
name in software: PF_per
directory in software: channels – power – module Nr – total – period values

4.5 Symmetrical components (3 Phase systems only)

4.5.1 Voltage

$$a = e^{\frac{j2\pi}{3}}$$

FORMULA 4.5-1: COMPLEX FACTOR

a…complex factor

$$\underline{U} = Ue^{j\varphi_U}$$

FORMULA 4.5-2: COMPLEX RMS VALUE OF VOLTAGE

U…complex RMS value of voltage
unit: V (volt)

$$\underline{U}^0 = \frac{1}{3}(\underline{U}_1 + \underline{U}_2 + \underline{U}_3)$$

FORMULA 4.5-3: ZERO COMPONENT OF VOLTAGE

U 0…zero component of the voltage
unit: V (volt)
name in software: U0
directory in software: channels – power – module Nr – symmetrical components

$$\underline{U}^1 = \frac{1}{3}(\underline{U}_1 + a\underline{U}_2 + a^2\underline{U}_3)$$

FORMULA 4.5-4: POSITIVE COMPONENT OF VOLTAGE

U 1…positive component of the voltage
unit: V (volt)

name in software: U1
directory in software: channels – power – module Nr – symmetrical components

$$\underline{U}^2 = \frac{1}{3}(\underline{U}_1 + a^2\underline{U}_2 + a\underline{U}_3)$$

FORMULA 4.5-5: NEGATIVE COMPONENT OF VOLTAGE

U 2…negative component of the voltage
unit: V (volt)
name in software: U2
directory in software: channels – power – module Nr – symmetrical components

$$u_2 = \frac{\underline{U}^2}{\underline{U}^1} * 100\%$$

FORMULA 4.5-6: NEGATIVE SEQUENCE COMPONENT OF VOLTAGE (FORMER: ALPHA)

u2…negative sequence component of the voltage
unit: %
name in software: u2
directory in software: channels – power – module Nr – symmetrical components

$$u_0 = \frac{\underline{U}^0}{\underline{U}^1} * 100\%$$

FORMULA 4.5-7: ZERO SEQUENCE COMPONENT OF VOLTAGE

u0…zero sequence component of the voltage
unit: %
name in software: u0
directory in software: channels – power – module Nr – symmetrical components

$$u_{2\_1} = \frac{\underline{U1}^2}{\underline{U1}^1} * 100\%$$

FORMULA 4.5-8: NEGATIVE SEQUENCE COMPONENT OF FUNDAMENTAL VOLTAGE

u2_1…negative sequence component of the fundamental oscillation of the voltage
unit: %
name in software: u2_1
directory in software: channels – power – module Nr – symmetrical components

$$u_{0\_1} = \frac{\underline{U1}^0}{\underline{U1}^1} * 100\%$$

FORMULA 4.5-9: ZERO SEQUENCE COMPONENT OF FUNDAMENTAL VOLTAGE

u0_1…zero sequence component of the fundamental oscillation of the voltage

unit: %
name in software: u0_1
directory in software: channels – power – module Nr – symmetrical components

4.5.2 Current

$$\underline{I} = Ie^{j\varphi_i}$$

FORMULA 4.5-10: COMPLEX RMS VALUE OF CURRENT

I…complex RMS value of current
unit: A (ampere)

$$\underline{I}^0 = \frac{1}{3}(\underline{I}_1 + \underline{I}_2 + \underline{I}_3)$$

FORMULA 4.5-11: ZERO COMPONENT OF CURRENT

I 0…zero component of the current
unit: A (ampere)
name in software: I0
directory in software: channels – power – module Nr – symmetrical components

$$\underline{I}^1 = \frac{1}{3}(\underline{I}_1 + a\underline{I}_2 + a^2\underline{I}_3)$$

FORMULA 4.5-12: POSITIVE COMPONENT OF CURRENT

I 1…positive component of the current
unit: A (ampere)
name in software: I1
directory in software: channels – power – module Nr – symmetrical components

$$\underline{I}^2 = \frac{1}{3}(\underline{I}_1 + a^2\underline{I}_2 + a\underline{I}_3)$$

FORMULA 4.5-13: NEGATIVE COMPONENT OF CURRENT

I 2…negative component of the current
unit: A (ampere)
name in software: I2
directory in software: channels – power – module Nr – symmetrical components

$$i_2 = \frac{\underline{I}^2}{\underline{I}^1} * 100\%$$

FORMULA 4.5-14: NEGATIVE SEQUENCE COMPONENT OF CURRENT

i2…negative sequence component of the current
unit: %
name in software: i2
directory in software: channels – power – module Nr – symmetrical components

$$i_0 = \frac{\underline{I}^0}{\underline{I}^1} * 100\%$$

FORMULA 4.5-15: ZERO SEQUENCE COMPONENT OF CURRENT

i0…zero sequence component of the current
unit: %
name in software: i0
directory in software: channels – power – module Nr – symmetrical components

$$i_{2\_1} = \frac{\underline{I1}^2}{\underline{I1}^1} * 100\%$$

FORMULA 4.5-16: NEGATIVE SEQUENCE COMPONENT OF FUNDAMENTAL CURRENT

i2_1…negative sequence component of the fundamental oscillation of the current
unit: %
name in software: i2_1
directory in software: channels – power – module Nr – symmetrical components

$$i_{0\_1} = \frac{\underline{I1}^0}{\underline{I1}^1} * 100\%$$

FORMULA 4.5-17: ZERO SEQUENCE COMPONENT OF FUNDAMENTAL CURRENT

i0_1…zero sequence component of the fundamental oscillation of the current
unit: %
name in software: i0_1
directory in software: channels – power – module Nr – symmetrical components

4.6 Additional FFT values

4.6.1 Voltage

$$THDU = \frac{\sqrt{\sum_{2}^{n} U_h^2}}{U1}$$

FORMULA 4.6-1: THD U

THD U…total harmonic distortion of the voltage
unit: %
name in software: THD_U_L1, THD_U_L2, THD_U_L3
directory in software: channels – power – module Nr – phase x – THD

n…number of harmonics (typical: 40)
U1…fundamental of the voltage

h…harmonic order

$$THDU_{even} = \frac{\sqrt{\sum_{2}^{n} U_h^2}}{U1}$$

FORMULA 4.6-2: THD U EVEN

THD U even…total harmonic distortion of the voltage for even harmonics
unit: %
name in software: THDEven_U_L1, THDEven_U_L2, THDEven_U_L3
directory in software: channels – power – module Nr – phase x – THD

h…harmonic order only even: 2, 4, 6,…

$$THDU_{odd} = \frac{\sqrt{\sum_{2}^{n} U_h^2}}{U1}$$

FORMULA 4.6-3: THD U ODD

THD U…total harmonic distortion of the voltage for odd harmonics
unit: %
name in software: THDOdd_U_L1, THDOdd_U_L2, THDOdd_U_L3
directory in software: channels – power – module Nr – phase x – THD

h…harmonic order only odd: 3, 5, 7,…

4.6.2 Current

$$THDI = \frac{\sqrt{\sum_{2}^{n} I_h^2}}{I1}$$

FORMULA 4.6-4: THD I

THD I…total harmonic distortion of the current
unit: %
name in software: THD_I_L1, THD_I_L2, THD_I_L3
directory in software: channels – power – module Nr – phase x – THD

n…number of harmonics (typical: 40)
I1…fundamental of the current
h…harmonic order

$$THDI_{even} = \frac{\sqrt{\sum_{2}^{n} I_h^2}}{I1}$$

FORMULA 4.6-5: THD I EVEN

THD I even…total harmonic distortion of the current for even harmonics
unit: %
name in software: THDEven_I_L1, THDEven_I_L2, THDEven_I_L3
directory in software: channels – power – module Nr – phase x – THD

h…harmonic order only even: 2, 4, 6,…

$$THDI_{odd} = \frac{\sqrt{\sum_{2}^{n} I_h^2}}{I1}$$

FORMULA 4.6-6: THD I ODD

THD I…total harmonic distortion of the current for odd harmonics
unit: %
name in software: THDOdd_I_L1, THDOdd_I_L2, THDOdd_I_L3
directory in software: channels – power – module Nr – phase x – THD

h…harmonic order only odd: 3, 5, 7,…

4.7 Impedances

$$Z = \frac{U}{I}$$

FORMULA 4.7-1: Z

Z…Impedance for total waveform
unit: Ohm
name in software: Z_L1
directory in software: channels – power – module Nr – phase x – Impedances

$$Z_h = \frac{U_h}{I_h}$$

FORMULA 4.7-2: ZH

Zh…Impedance of Harmonic h
unit: Ohm
name in software: Z_L1_H1, Z_L1_H2,...
directory in software: channels – power – module Nr – phase x – Impedances

4.8 Literature

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