POWER SOLUTIONS

DEWESoft®

USER MANUAL
Power Solutions V20-4

SIRIUS

PWR/USB

HS

1 HV

2 HV

3 HV

4 HV

1000V MAX

1000V MAX

1000V MAX

1. Table Of Contents

2. Introduction

Welcome to the second version of the Dewesoft Power Manual, a powerful reference document filled with valuable insights into the world of measurement technology! This manual offers the user a comprehensive variety of explanations and useful examples for many measurement applications. You will be amazed how easy measuring can be with basic knowledge and the unbeatable combination of easy-to-use hardware and software by Dewesoft!

2.1. About this document

The purpose of this document is to provide the user with all the necessary knowledge about voltage and current measurements as well as analyzing this data in terms of Power and Power Quality. Besides the theoretical knowledge a strong emphasis is put on practical aspects of measuring and the instruments used to do so. Therefore, you will find helpful hints and examples on how to use this newly acquired knowledge in combination with the Dewesoft instruments throughout this document.

Caution
We at Dewesoft are always looking to improve the experience of our valued customers. Therefore, we would like to invite you the user to give us feedback on your experience with this reference document. This will help us to continuously improve the quality of this reference document.

2.2. Further information about Dewesoft

The most recent version of this reference manual can be downloaded from our homepage.
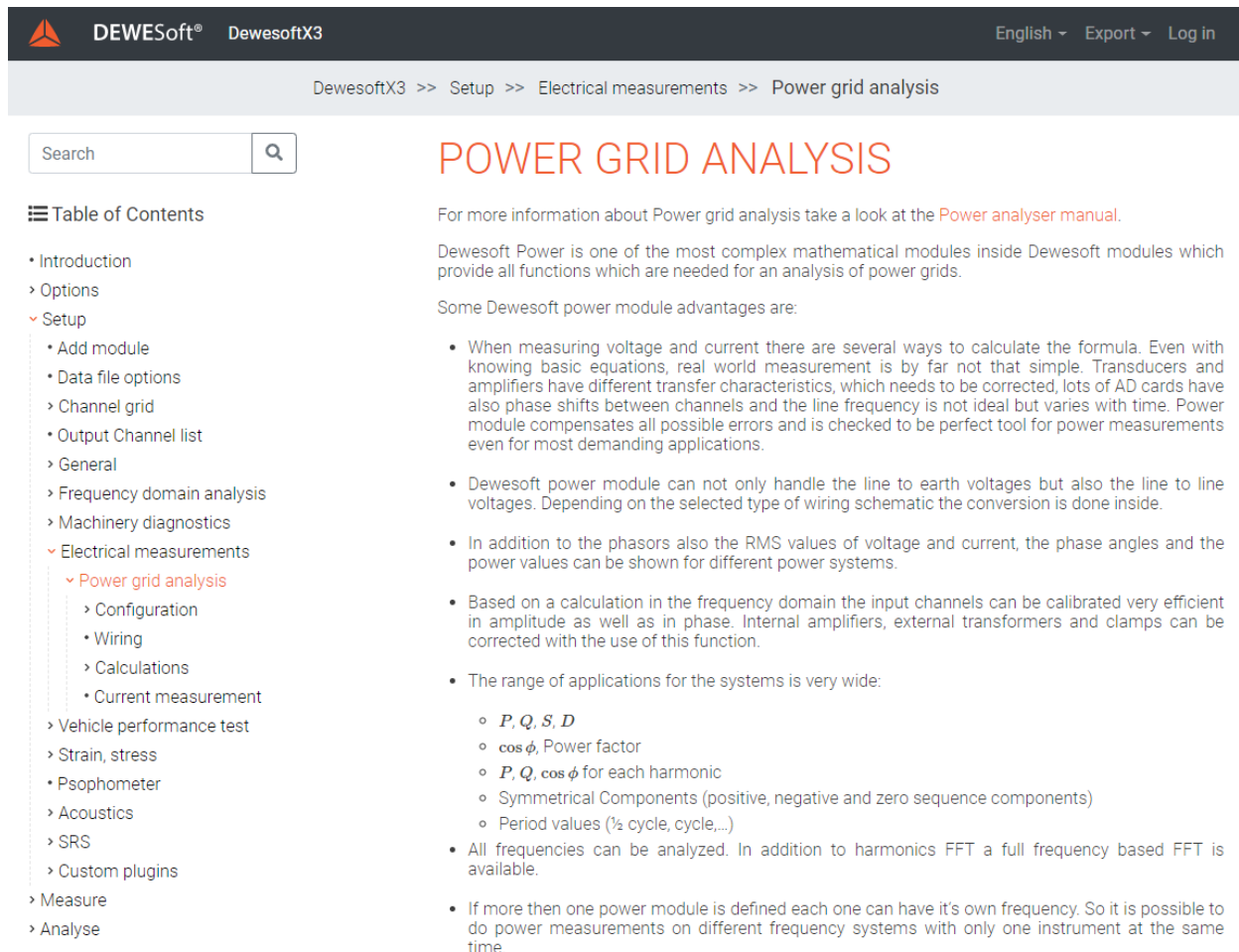
If you would like to learn more about the solutions that are offered by Dewesoft for other applications, please refer to the download section of our website for more information.

The content of this reference manual can also be found in the Dewesoft PRO Training on our homepage. This is a new learning platform for measurement professionals and those who would like to become one. There you will also find further introductory courses in our other application areas like Automotive, DSA or Aerospace & Defence among others. It's free of charge and accessible to anyone who wants to learn. Your effort in each course is also rewarded. Curious? Go and have a look!

2.3. Help F1 in DewesoftX®

Since the release of DewesoftX® the F1 toggle button has been introduced as a dedicated help button. This button will direct you to the Dewesoft Manuals site automatically to the right chapter to receive prompt help. For Example, if you are unsure of how to perform a setting correctly, you can use this tool for a step by step guide.

3. Voltage

Voltage, sometimes also called electromotive force, is what makes electric charges move. It is an electrical potential difference between two poles, the positive and the negative.

3.1. What is voltage
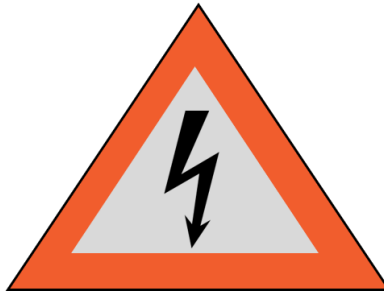
Image 1: High voltage sign

Electricity is very hard to imagine because we cannot physically see if voltage is present or if a current is flowing, so we'll use a water analogy to try and explain how electrical circuits function. Water systems are simple to understand because we can physically see the water and the behavior that it possesses. Now let's take a look at how a water system behaves. It is a well-known physical fact that if water is to flow out of a pipe the water needs to be pressurized, this is mostly achieved by a pump. In electricity, the flow is the current, water pressure is the voltage and the pump is the battery. This means that the voltage instigates the flow of the current like the water pressure is the cause of volume flow rate of water.
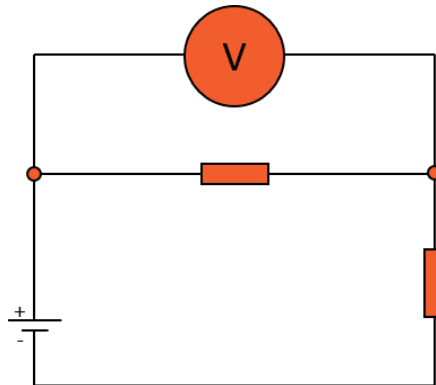
Image 2: Schematic illustration for connecting a voltmeter

Measuring voltage is the most basic measurement with Data Acquisition (DAQ) devices because most of the Analog-to-Digital converters (ADC) use voltage as the input value. That's why measuring voltage with DAQ seems simple, right? The answer is yes if we are measuring voltages in the range that is directly supported by the ADC. But when measuring very small voltages in the range of microVolts (μV) or very high voltages up to several kilo-Volts (kV), an amplifier is needed to prepare the signal for the AD conversion. For both challenges Dewesoft has the right solution.

On one hand the Low Voltage amplifier (LV and HS-LV) in combination with the 24-bit ADC technology allow for measurements of very low voltages even at high measurement ranges (e.g. μV resolution at a range of ± 10V).

On the other hand, the High Voltage amplifier (HV and HS-HV) allows the direct measurement of voltages up to 1600V DC (1200V DC at HS-module). For measuring voltages higher than 1600 VDC, voltage probes/dividers or voltage transducers can be connected to the instrument.

3.1.1. Isolation Voltages

When measuring voltage, it's important to choose the right amplifier range. Using the incorrect amplifier range can destroy the amplifier if the measured voltage exceeds the isolation voltage of the integrated amplifiers in the measurement instruments. For example, measuring the public grid voltage (230 V_{rms} / 325 V_{peak}) with a STG module can destroy the entire module as the isolation voltage is rated at 200 V_{peak} for the measurement range below 10 V and 300 V peak for the measurement range above 10 V. In order to measure voltages higher than ±100 V the use of the HV-amplifiers is mandatory.

3.1.2. Measurement range

The appropriate selection of the measurement range is essential for high accuracy and reliable measurement results. There are a number of measurement ranges available with every amplifier which can be configured in the DewesoftX® channel setup. If the measurement range is too low, the signal will exceed the input range and errors and channel overloads will appear instead of correct values. On the other hand, if the measurement range is too high, the inaccuracy will be too high to make correct measurements.

The most precise measurement is achieved when the measurement value range coincides with the DAQ amplifier input range. In this case the highest resolution of the measurement is received with the same number of bits used by the AD converter.

Let's take a look at an easy example measuring voltage. If only one tenth of the AD converter input range is used, the resolution of the outcome will only be one tenth of the actual performance of the AD converter. A 16-bit converter can read 65536 different discrete values, but the measurement will only consist of 6500 different values which is a very low resolution. Measuring a signal from 0 – 7 V will be pointless with a 1200 V range (resolution 18 mV) instead a module with 10 V range should be used (resolution 0,15 mV) this will yield a much higher measurement resolution. That's why there are diverse modules with different input and measurement ranges available.

3.2. Differences between Peak, Average and RMS voltage

There is a variety of different voltage types, therefore the type of voltage needs to be identified. Voltage types include peak, peak-to-peak, average, RMS, AC and DC. The differences can be better explained using the image below.
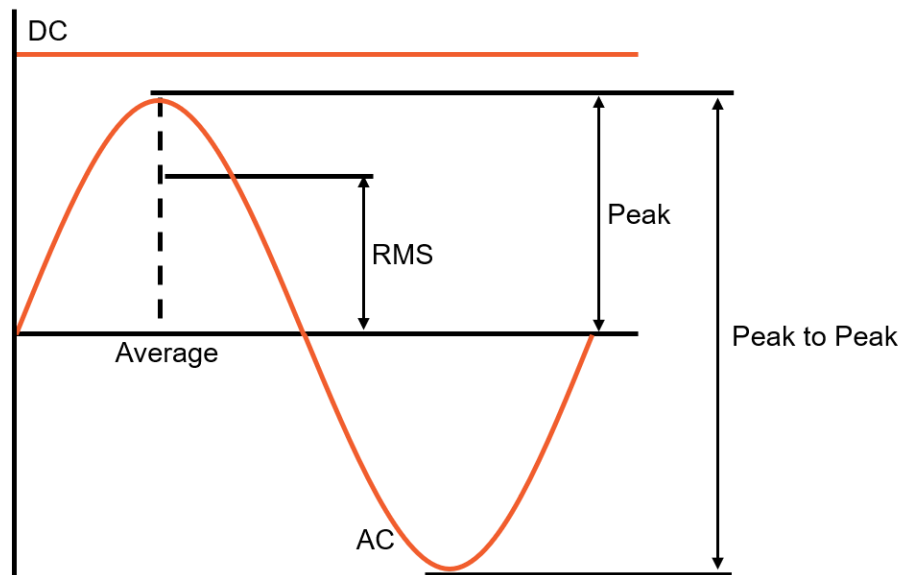
Image 3: Voltage types: peak, peak-to-peak, average, RMS, AC and DC

The average voltage is, as the name already states, the average value for a certain time period. For pure sinusoidal signals (AC), the average will be zero.

The RMS voltage is the root-mean-square voltage and it is the square root of the arithmetic mean of the squared function values that define the continuous wave forms. It is the most commonly used value to define the AC voltage at a certain point and produces the same energy as the DC voltage at an ohmic load.

$$U_{rms} = \sqrt{\frac{\sum_{n=0}^{N-1} u^2(n)}{N}}$$

The peak voltage describes the highest voltage at any given period. In the datasheet specifications the peak voltage or the DC voltage of an input is given which means the same. To calculate the RMS value for sine waves, the peak value has to be divided by the square root of 2.

The peak-to-peak ratio shows the amplitude of positive and negative peaks in a period.

The Crest factor is the peak amplitude divided by the RMS value of the waveform.

$$C = \frac{|x_{peak}|}{x_{rms}}$$

The rectified mean is the average of the rectified signal. In terms of an AC signal it's the average of the absolute value of voltage or current.

$$U_{RECT} = \frac{1}{T} \int_{t=0}^{T} |u|(t)\, dt$$
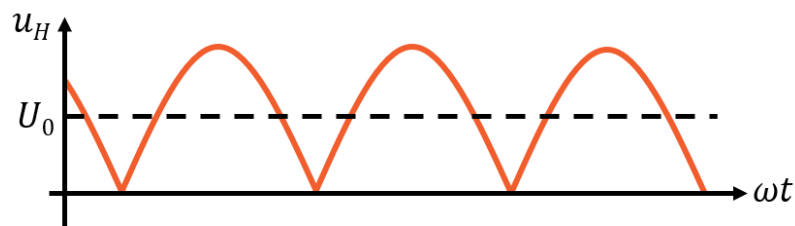
Image 4: Voltage rectified mean

The rectified mean is used e.g. for transformer testing as the rectified mean is proportional to the magnetic flux.

3.3. Why use isolated amplifiers

Basically, there are three different "types" of DAQ amplifiers: Single ended, differential and isolated amplifiers. These will be shortly explained below.

3.3.1. Single ended amplifier

Single ended amplifiers have only one input pin because the second input pin is connected directly to the ground. Because of this kind of connection this amplifier is only suitable for measuring floating voltage sources where one output point can be connected to ground. This type of amplifier is easy to use but has two major disadvantages:

- Unwanted ground loops
- The amplifier is not isolated
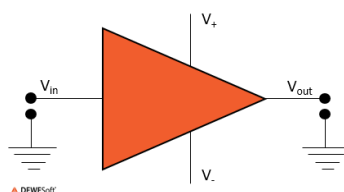
Image 5: Schematic illustration of a single ended amplifier

A ground loop is an unwanted current from the sensor ground to the instrument ground because of a small difference in the ground potentials. These potential differences are in the micro volt (µV) region, but it can cause a large amount of noise in a measured signal.

An example of the problems that noise in a measurement can cause: a sensor with an output range of 10 V is connected to a single-ended amplifier, it is assumed that a dynamic range of 140 dB is needed. After a simple calculation, it is determined that the allowed potential difference between the sensor and the instrument ground is 1 μV. The solution for the potential difference – isolation of the sensor or the instrument.

3.3.2. Differential amplifier

The differential amplifier has two inputs separated from ground. This type of amplifier is the most common and amplifies the voltage difference between both inputs. With this technology it is possible to avoid ground loops but be careful of the common-mode input voltage.
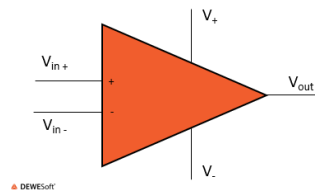
Image 6: Schematic illustration of a differential amplifier

What is common-mode input voltage? One way to describe input common mode voltage (VICM) is that it is seen as the average voltage of the inverting and non-inverting input pins.

$$V_{ICM} = \frac{V_{in+} + V_{in-}}{2}$$

Another way to imagine a VICM: It is the voltage level common to both inputs V_{in}(+) and V_{in}(-). That means that the differential inputs of DAQ which measure the differences between inputs, the differentially measured value is the small, but common mode input voltage and can still be in hundreds of volts (current measurement with shunts).

Another term which describes differential amplifier inputs is input common-mode voltage range (VICMR). This is the parameter most often used in datasheets and is also the one that should receive the most attention. VICMR defines a range of common-mode input voltages in which the amplifier will work properly and describes how close the inputs can get to either supply rail. This means the potential of the input pins must be between supply voltages (V+ and V-).

3.3.3. Isolated amplifier

Using isolated amplifiers eliminates the disadvantage of single-ended amplifiers and differential amplifiers. They are independent of ground loops, common mode voltage, short circuits etc. These modules are isolated from the housing and the main board of the measurement device. Therefore, the amplifier will only "see" the difference of the absolute voltage. The high isolation voltage (compared to measurement range) allows safe and reliable operation also at voltage peaks, faults etc. and so enables the usage for an array of different applications.

After a short description of amplifiers, it can be said that the main advantage of differential amplifiers is the lower price. They are perfect for measurements with isolated sensors like strain gauges or current clamps. Differential amplifiers also provide the high-quality measurement for non-isolated sensors, but engineers also need to know sensor behavior like common mode range or isolation to provide correct

measurements. On the other hand, isolated signal conditions are more expensive, but a worry-free solution up to isolation voltage.

3.4. Voltage measurement up to 50 V

Let's take a look at how a low voltage measurement of up to 50V can be done. Voltages of up to 50V can be connected directly to a couple of different Dewesoft amplifiers. The amplifiers differ from each other in measurement range, isolation, bandwidth, noise, and extended functionalities.

Every measurement channel supports a number of input voltage ranges. The most precise measurement will be achieved when the input voltage range of the measurement channel is set in such a way that it coincides with the voltage of the measured signal.

The table below shows which Dewesoft amplifiers can be used for the measurement of voltages of up to 50V. The table also contains information about the maximal sampling rate and the bandwidth as well as the available measurement ranges for each amplifier.

DEWESoft amp	Range	Noise floor (Range)	Bandwidth (vs. Sampling Rate)			Unisolated version	Isolated version	Isolation (ch-ch; ch-gnd)
			1 kS/s→ 50 kS/s	50 kS/s→ 100 kS/s	100 kS/s→ 200 kS/s			
DEWE-43	±10 mV, ±100 mV, ±1 V, ±10 V	-75 dB	0.5 fs	0.5 fs	0.39 fs			-
SIRIUS-STG	±100 mV, ±1 V, ±10 V, ±50 V	-100 dB, -107 dB, -107 dB, -108 dB	0.494 fs	0.49 fs	0.38 fs			300 V
SIRIUS-ACC	±500 mV, 10 V	-100 dB, -107 dB	0.494 fs	0.49 fs	0.38 fs			300 V
SIRIUS-LV	±100 mV, ±1 V, ±1 0V, ±100 V, ±200 V	-97 dB, -109 dB, -109 dB, -109 dB	0.494 fs	0.49 fs	0.38 fs			300 V - 1000 V
HIGH SPEED								
SIRIUS HS-LV	±100mV, ±1V, ±10V, ±100V	-59 dB, -78 dB, -86 dB, -85 dB	Sample Rate: 1MS/s					300 V - 1000 V
SIRIUS-HS-ACC	±200mV, ±1V, ±5V, ±10V	-83 dB, -86 dB, -89 dB, -89 dB	Sample Rate: 1MS/s					300V

The common low-voltage amplifiers allow a sampling rate of up to 200 kS/s per channel with a maximal bandwidth of 75 kHz. The high-speed series (HS) is used for applications that require a high sampling

rate and high bandwidths like voltage or current measurement in inverters. The sampling rate of the HS series is 1 MS/s. After choosing the right amplifier, the signal only needs to be connected to the amplifier.

3.5. Voltage measurement up to 1 kV

Measuring voltages higher than 100 V require the use of the SIRIUS® HV or HS-HV module. The SIRIUS® HV module allows measuring voltages of up to 1200 VDC while the HS-HV module allows measuring voltages of up to 1600 VDC.

The table below shows the two different amplifiers for measuring high voltages with information about the measurement range, sampling rate, bandwidth and isolation.

DEWESoft amp	Range	Bandwidth (vs. Sampling Rate)			Isolation
		1kS/s...50kS/s	50kS/s...100kS/s	100kS/s...200kS/s	
SIRIUS HV	±50 V, ±1200 V	0.494 fs	0.49 fs	0.38 fs	1400 V rms
HIGH SPEED					
SIRIUS HS-HV	±20 V, ±50 V, ±100 V, ±200 V, ±400 V, ±800 V, ±1600 V	Sample Rate: 1MS/s			1800 V rms

Just as with low-voltage amplifiers the HS-series is designed for measuring very fast signals like Pulse-width modulation (PWM) regulated voltages of an inverter. Inverters operate at a switching frequency of up to 200 kHz which requires high bandwidth of the whole measurement chain and a high sampling rate. To allow analysis of every kind of application the maximal sampling rate of the HS-HV module is 1 MS/s.

> **!** **Warning**
> Please ensure that the measured voltage doesn't exceed the isolation voltage of the amplifier otherwise it can quickly become dangerous. Depending on the level of the voltage, the measurement instrument can be destroyed and it could cause serious injury or even death.

3.6. HV vs HS HV

To simplify the choice of which one of the modules will fit better to which application, both modules will be used to measure the voltage of a PWM regulated 3-phase servo motor. The results will then be compared. Both of the module sample rates are set to the maximum, which is 200 kS/s for the HV module and 1 MS/s for the HS-HV module. Coarsely measured data will have some similarities, whereas the real difference will become apparent when the data of the PWM modulated sine wave voltages is further analyzed.

The first difference seen here is for the "chopped" sine. With an HV module (200 kS/s) we get an overshoot when the signal "jumps". In the image below the measured motor voltage with the HV module with 200 kS/s rate is depicted. The overshoot is clearly seen as little tick at start and stop of the voltage level shift.

When the signal is zoomed into for a better view of the resolution of the single samples, it becomes apparent that the reason for this overshoot is that the sample rate is too low. This happens because of the short rise time of the voltage therefore, there is only one or even no samples on the slope, which causes an error of measurement on the edges of our signal.
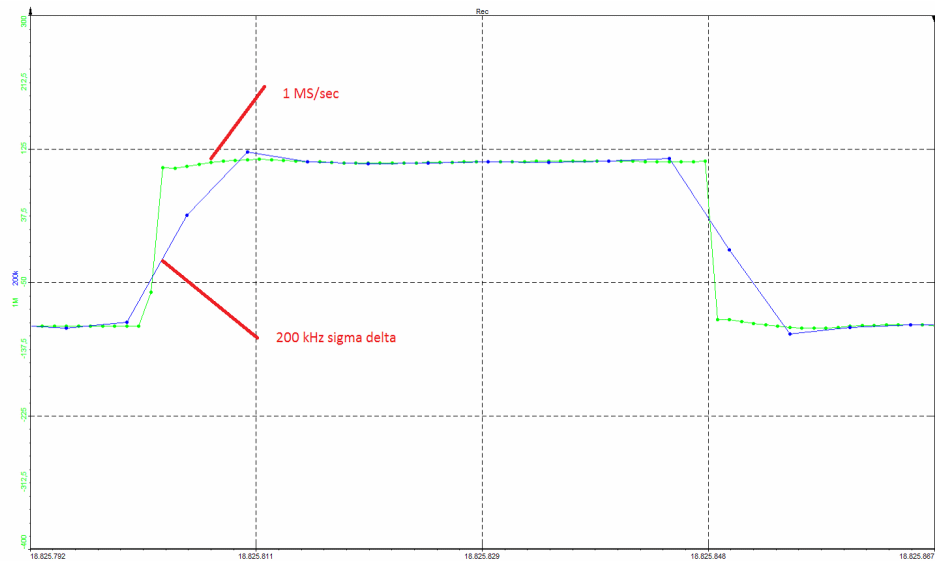
Image 7: Overshoot of samples which is caused by setting the sample rate too low

The HS-HV module has a higher bandwidth and therefore delivers 5 times more samples for the same measured time period, this means that there is no overshoot on the same measured signal. The cleaner transition is the result of more than one sample on the slope, this delivers a better resolution at the edges of the signal jump.

The problem with the overshoot begins at switching frequencies at around 2 kHz. At higher switching frequencies, it is expected that there will be even more differences between the dual core and the HS modules. To illustrate this a second measurement was done again using the voltage output of the frequency converter, but the frequency was increased to 16 kHz.
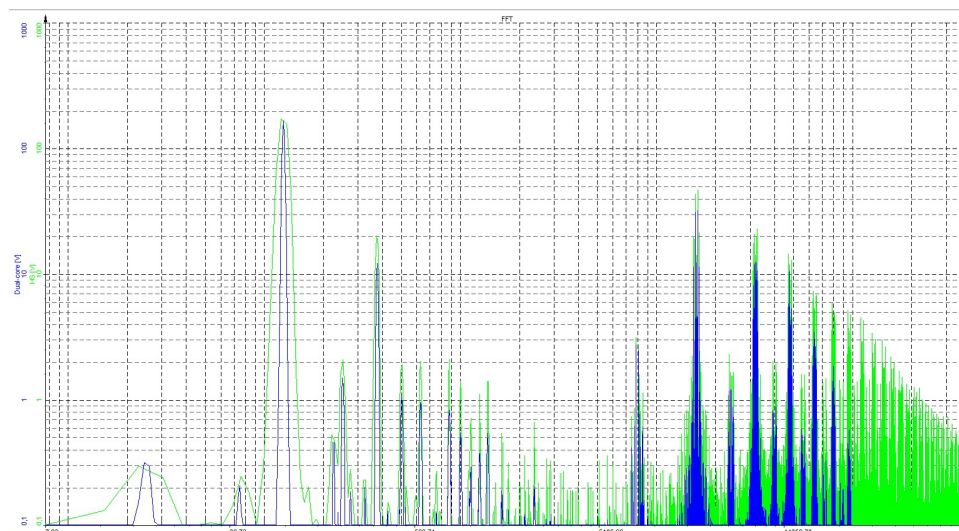
Image 8: High speed amplifier vs. dual core amplifier bandwidth range

The first obvious difference is seen in the bandwidth of the measured signal. With the dual core channel (blue) the frequency starts to damp at 66 kHz and there are absolutely no frequencies above 100 kHz in the measured signal. With the HS module (green) the dampening of the frequencies starts much later than that of the dual core. As seen in the image below the HS module can measure a much wider bandwidth than its dual core counterpart.

When observing both measured signals on the scope we see that the HS module is a few microseconds faster than the Dual core module.
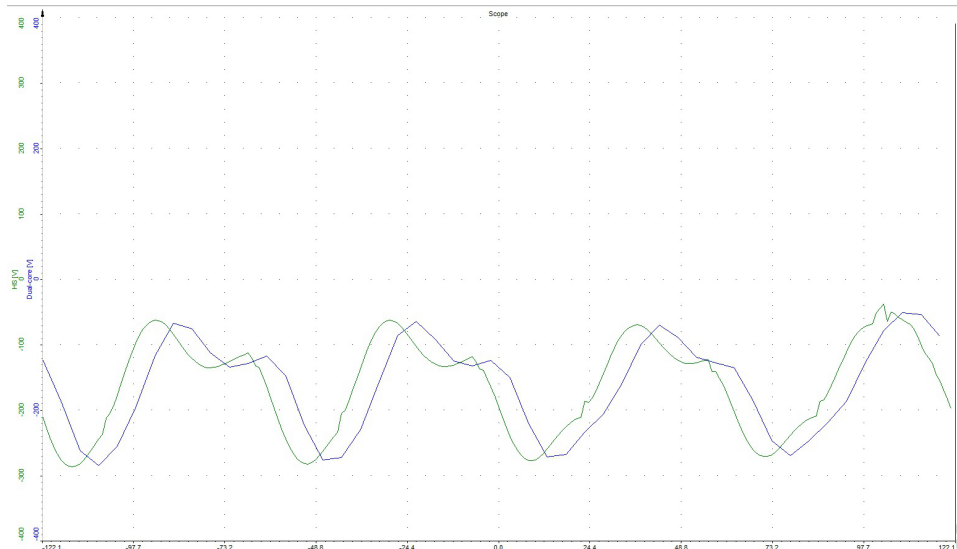
Image 9: High speed amplifier vs. dual core amplifier measurement speed

Another difference that must be considered when measuring high-frequency voltages are the transients in the signal. The HS module is much better at transient measuring and yields a much better oscillation coverage after every peak.
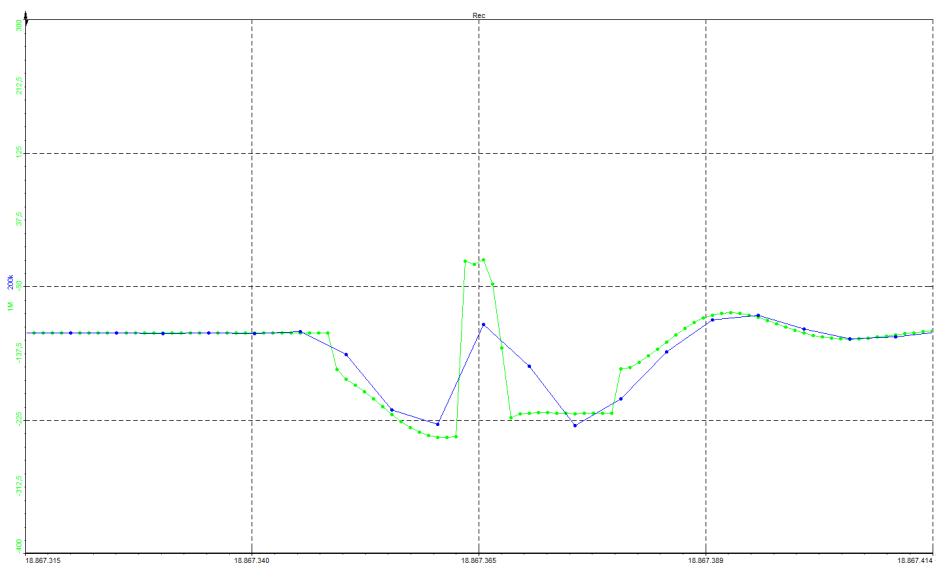
Image 10: High speed amplifier vs. dual core amplifier transient recording

3.7. Voltage measurement higher than 1 kV

While voltage measurements up to 1kV are relatively simple, things tend to get more complicated when measuring voltages over 1600 VDC because voltage probes/dividers or voltage transducers are necessary which adjust and reduce the voltage to a level that is suitable for the amplifier.

Image 11: High voltage warning

> **Warning**
> Please be especially careful when using voltage probes or voltage transducers. There are several things which must be considered when using voltage probes or voltage transducers in order to ensure safe operation. False operation may lead to injury or even death.

3.7.1. Voltage Probe (Voltage dividers)

There are two different types of voltage probes: The pure resistor voltage probe (for AC and DC measurement) and the resistor-capacitive voltage probe (for AC measurement only). The input impedance of the voltage probe should be as high as possible; therefore, the input resistance should be as high as possible and the input capacitance as low as possible.

There are active, passive and differential voltage probes available. Passive voltage probes are simple, cheap and robust but have a high input capacitance and problems measuring low voltages.
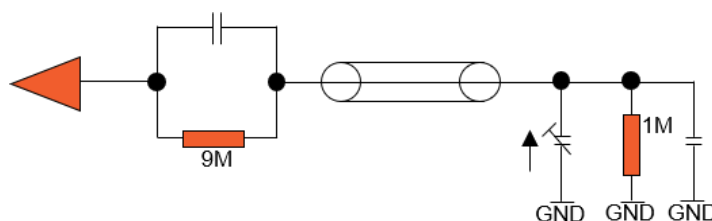
Image 12: Schematic illustration of a passive voltage probe

Active voltage probes have a high input resistance and low input capacitance but need an external power supply. They are a lot more sensitive and more expensive than passive ones.
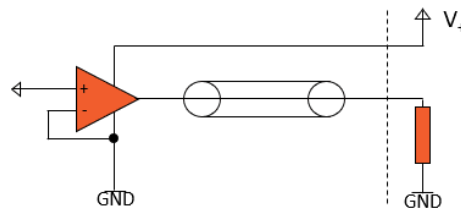
Image 13: Schematic illustration of a active voltage probe

Differential Voltage Probes: Passive and active voltage probes are single-ended amplifiers with reference to earth. If a differential signal needs to be measured a differential voltage probe must be used.
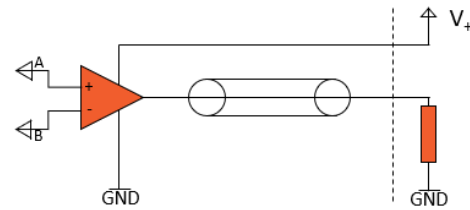
Image 14: Schematic illustration of a differential voltage probe

Warning

Voltage probes have no galvanic isolation. If the GND connection is interrupted the full voltage potential is carried over to the measurement instrument and can damage the device and cause serious injury or even death.

The function of the voltage probe can be easily explained using a simple resistor voltage probe with the serial connection of two resistors with high resistance.
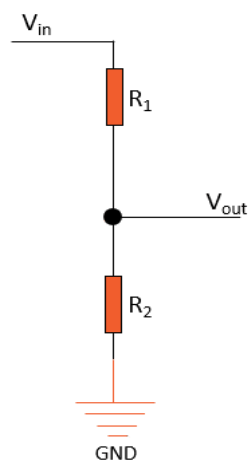
Image 15: Simple resistor voltage probe with the serial connection of two resistors

When using a voltage divider with the same resistance value ($R_1 = R_2$), the voltage drop on one resistor will be half of the connected voltage. So, when measuring high voltages in the range of up to 2000 V, this simple transducer reduces the voltage to 1000 V. This is low enough to measure it using a Sirius high voltage module with an input range up to 1200 V.

Resistors with too low impedance, compared to a circuit in which voltage is measured will cause a substantial current spike. This current affects the measured circuit and reduces the accuracy of the measurement. The input impedance of the measurement instrument must be 100 to 1000 times higher than the value of R_1, otherwise the ratio will change, and the impedance of the measurement instrument must also be taken in account. Another factor that must be considered is the short circuit resistance which is the sum of R_1 and R_2 – if this value is too low it will cause a short circuit.

When using a voltage probe, the ratio between the input and the output voltage must be calculated and adapted to the "in-channel" setup in the software. This ratio is important because the measured voltage of the measurement device must be multiplied by this ratio to yield the real voltage (V_{in} in the image).
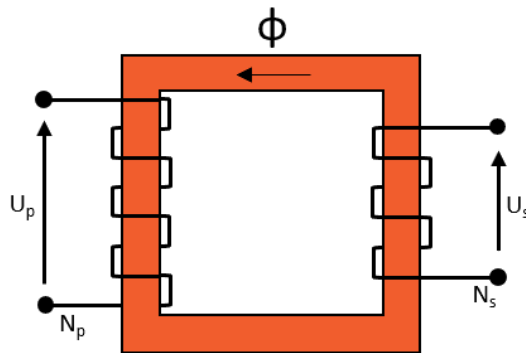
Image 16: Schematic illustration of the working principle of a voltage transducer

$$V_{out} = \frac{V_{in}}{K_r} \qquad\qquad R_s = R_1 + R_2 = 2R$$

$$R_1 = R_2 = R \qquad\qquad K_r = \frac{R_s}{R_1} = \frac{2R}{R} = 2$$

Caution
Never operate voltage transducers with a short-circuit on the secondary side. This creates high currents which will destroy the transducer.

Hint
Voltage dividers and transducers always have a frequency dependent behavior concerning amplitude and phase. Using the Dewesoft sensor editor allows for the correction of this behavior and increases the accuracy of measurement. See details in the "Current Pro Training" in the chapter "Sensor Editor".

3.7.2. Voltage measurement with Dewesoft

Following the theory, a practical example of how the Dewesoft measurement instruments work will follow. The voltage of the public grid will be measured. The value input voltage of the public grid must

be considered to identify what type of amplifier input is needed for the measurement. The public grid in Europe is declared with a value of 230 V$_{RMS}$ but to ensure safe operation of the measurement instruments the peak values of the grid must be considered for the input range. The peak value of the grid in Europe equals the RMS value multiplied by the square root of 2 as seen in the equation below.

$$230 \ V_{RMS} \cdot \sqrt{2} \approx 325 \ V_{peak}$$

With a peak value of 325 V we can directly use a SIRIUS® HV-HS module which supports voltage up to 1.6 kV. This means that we can make a simple measurement without any additional voltage dividers or amplifiers and a simple connection as illustrated below. Channel 4 will be used, which has a SIRIUS® HV-HS amplifier integrated into it. The other channels can be left inactive ("unused" in the software) as they are not relevant to this measurement. The next step is to configure the measurement channel setup in the software as illustrated below.
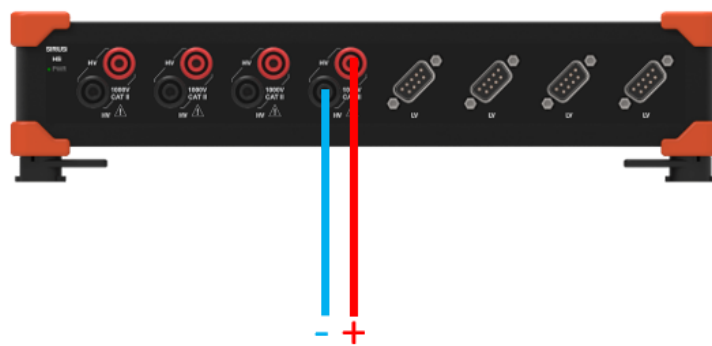
Image 17: Single phase voltage connection to a Sirius 4xHV 4xLV

There are two sides for the set-up window, the left side is the amplifier side and the right side is the sensor side.
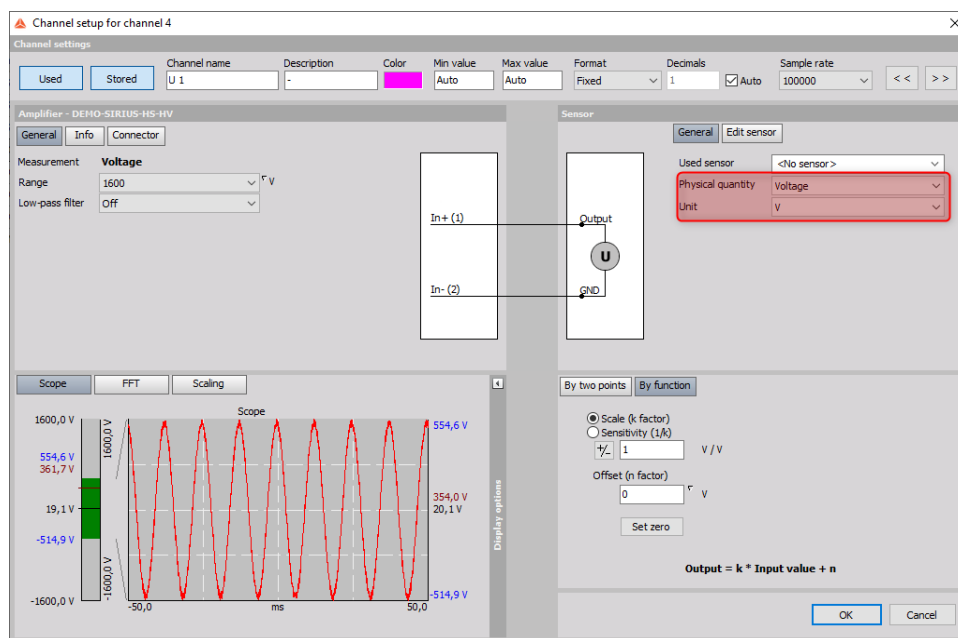
Image 18: Channel set up screen in DewesoftX®

On the Amplifier side, we can toggle between the 50 V and 1600 V range. In this example the 1600 V range will be used. A Low-pass filter can also be used to cut off the higher frequencies, but caution should be taken when doing that. If a frequency lower than half of the sample rate is taken it will cut the signal in the measurement range, this might be useful in some applications but mostly this configuration is set by mistake.

The setup on the Sensor side is about selecting which sensor is used for measurement. In this case the voltage is directly measured without a sensor, so only the physical quantity must be set as Voltage and the unit as Volt (V). In this part of the setup, the scaling factor can also be set if sensors or dividers are used for the measurement. In this case it will have the value 1 as the voltage is measured directly and no scaling is done.

For this example, the settings are done so the measurement can be started. By clicking on the "Measure" button. The best way to observe a sinusoidal waveform is with the scope. When the scope is first opened there will be a running wave that is impossible to analyze, this is due to the fact that the software is running in free mode, and the measurement needs to be "held" somehow. It is recommended to add a trigger on norm trigger and defining the source and the trigger level. For the purposes of this example it can be left as it is, as the trigger source is the U_1 channel and the level equals 0.
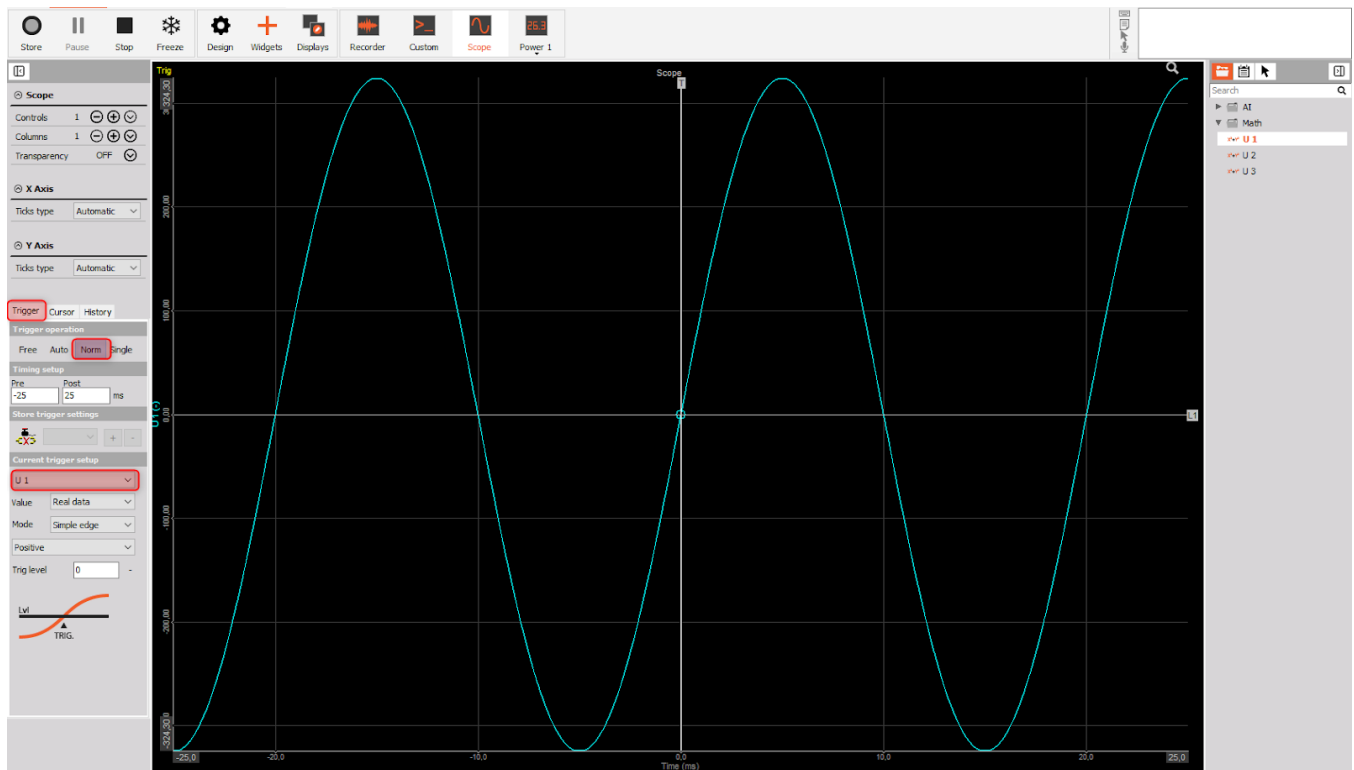
Image 19: Measurement screen of voltage with a simple trigger

3.7.3. Dual core mode

In the previous section a lot was said about proper amplifier measurement range selection. Now it's time to take a look at the impressive options offered by the dual core mode in the SIRIUS® amplifiers.

When using the SIRIUS® dual-core mode it is possible to get a better resolution (less noise) at low amplitudes. That is solved with two 24-bit AD converters with different ranges on each channel.

The first AD converter has a full input channel range and the range of the second AD converter is only 5% of the full channel range. This technology measures the signal with low and a high gain simultaneously which means that the signal can be measured with a relatively high amplitude but at the same time it has a perfect resolution at low amplitudes of the same signal.

Let's take a look at the difference between dual core mode and normal mode when measuring low signals with a high range:
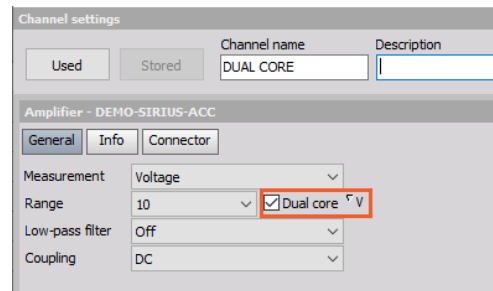
Image 20: Enabling the dual core mode in DewesoftX®

In this example a 0.3 V DC signal from the calibrator on two ACC amplifiers will be measured. On both amplifiers, a 10 V range will be chosen (which is complete nonsense) but it's the easiest way to see the difference between dual core mode on or off. This can be toggled in the channel setup where range can also be set.

On the first channel, we will turn Dual core mode off, on the second Dual core mode will be turned on. This will render an image as seen below, where the difference in the noise levels can be seen. The graphs that are seen below are set to have the same scaling.
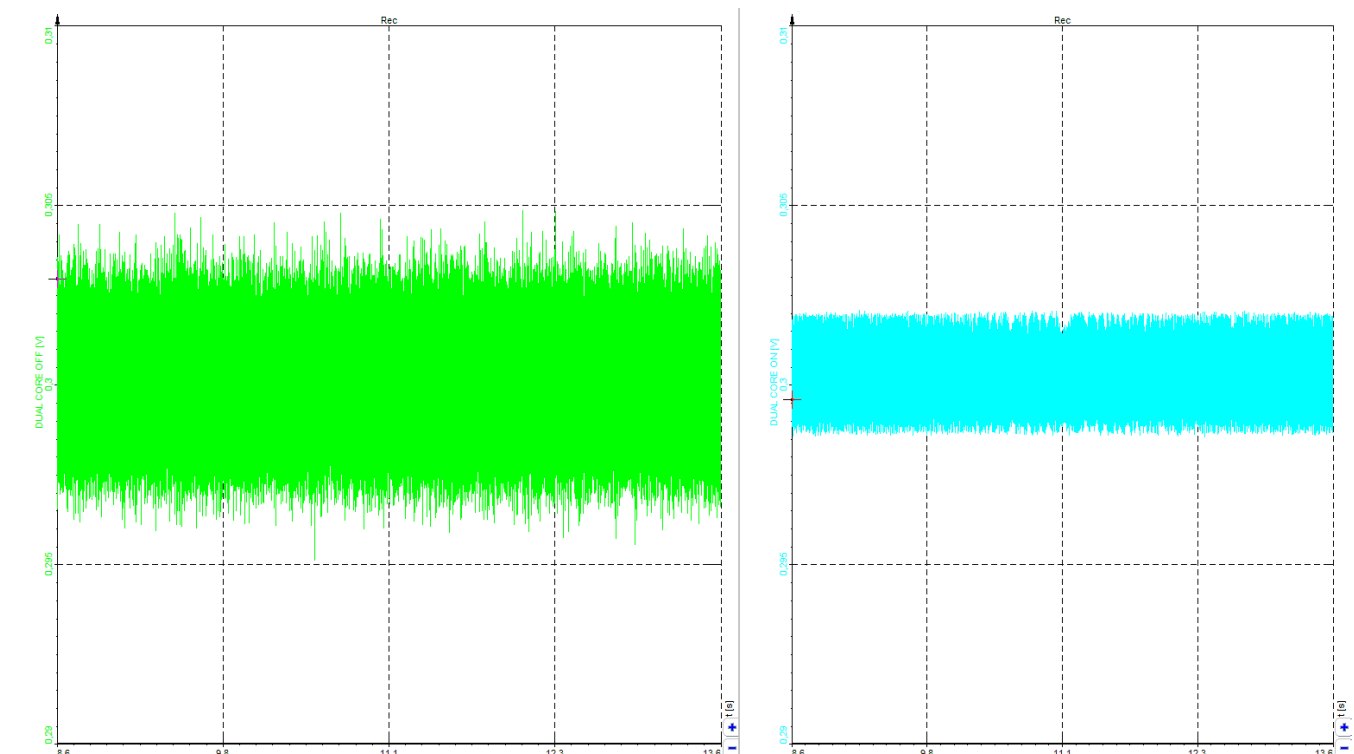
Image 21: Difference in noise levels with dual core turned off and on

By the noise level, it's not hard to see where dual core mode is doing its job (right), and where it's turned off (left). With dual core mode turned on we get the same noise level in the 10 V measurement range as it would be if we were using 0.5 V range. This gives us a better look at lower signals.

3.7.4. Practical Voltage measurement

Now it's time to do some practical voltage measurements and have some fun while doing it.

Also, it is important to emphasize how much Dewesoft does autonomously to speed up the measuring experience.

As an example, a simple voltage measurement will be done on a discharging capacitor. Connected to the circuit are two capacitors with rectifying diodes as illustrated in the image below, these are then connected to the grid voltage between the L (live) and N (neutral) conductor cables. This type of connection allows the capacitors to charge with the peak voltage in both polarity directions. This yields around 700 V on both capacitors together. The instrument used in this example is the SIRIUS® LV-HV, the HV channel is chosen for the higher voltages. For discharging the capacitors an input capacitance of 10 MΩ will be used on the module as the discharging resistor which will be connected to points IN$_+$ and IN$_-$.
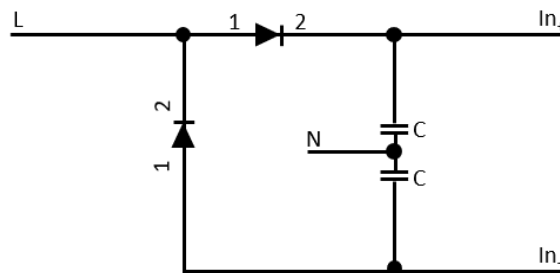
Image 22: Schematic illustration of a simple voltage measurement on a discharging capacitor

The measurement yields the following result as shown in the image, where the capacitor is instantaneously charged and then discharges exponentially.
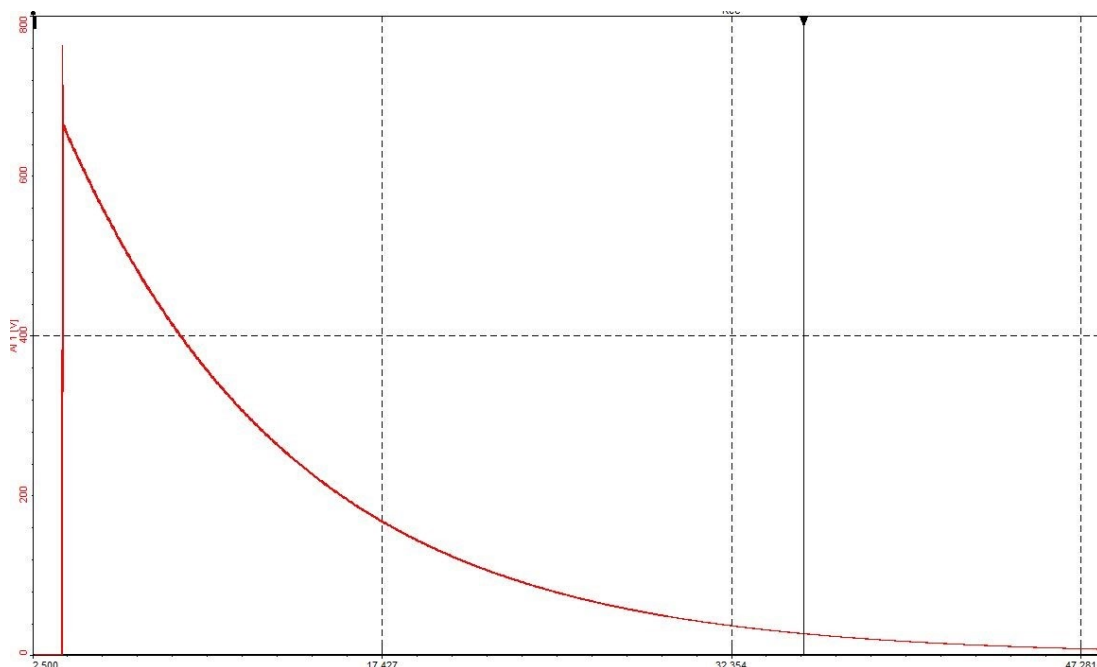
Image 23: Capacitor charge and discharge measurement

In this example the advantage of the dual core amplifier can be seen. For the voltage that is used the 1200 V measurement range must be taken to perform the measurement correctly, but the voltage on the capacitors fall very fast when they discharge, this will cause a noticeable noise level.

When the voltage drops under 50 V, meaning into the low voltage spectrum, is when the dual core amplifier starts to shine, as it then switches over and starts measuring in the lower ranges, which greatly reduces the noise. This switch can be seen in the image below, it has been zoomed in to exactly where the switch takes place and the voltage drops under 50 V, and the second core then measures the lower voltage range.
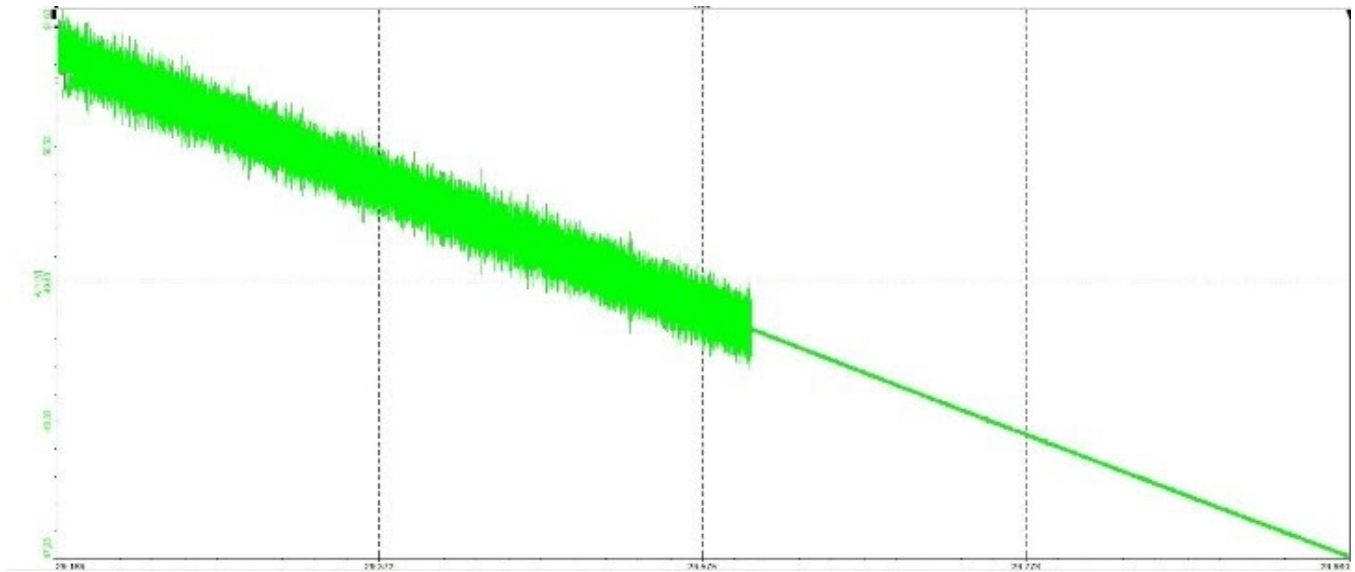
Image 24: Dual core measurement of low voltage with a reduced noise level

4. Current

An electric current is defined as the flow rate of electric charge past a point. Current exists when there is an electric charge flowing.

4.1. What is current

Now let's return to the water analogy of electricity to explain what current is.

Electric current is a physical quantity caused by voltage and means a flow of electrons between different electric potentials (usually from the positive to the negative poles in the case of direct current, this differs with alternating current). This means in the water analogy the current is the actual water flow rate flowing from upstream in the downstream direction. Concretely this means that the current is the flow of an electrical charge between two poles.

As mentioned above there are two types of current, these are direct current (DC) and alternating current (AC). The simpler of the two is DC where the electrons only flow in one direction and the flow is constant, on the other hand there is AC where the electrons change direction and amplitude with the frequency (depending on the grid frequency, in Europe that is 50 Hz meaning that the electrons change direction and amplitude 50 times a second). AC is difficult to explain with the water analogy as water in most cases does not change direction and only flows in one direction.
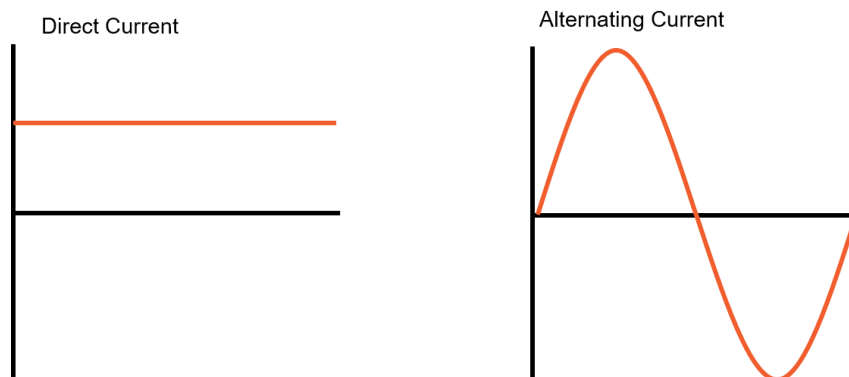
Image 25: Direct and alternating current

The cause of the direct current is "direct" or constant voltage, for example, a battery. But for generating an alternating current we need a source of alternating voltage, which is, for example, an AC generator in the power plants. The normal waveform of an alternating current is a sine wave, where the positive half cycle corresponds to the positive flow of the current and the negative half cycle corresponds to the reversed flow of the current.

4.2. Current measurement

Now let's take a look at how current measurements are done. The simplest way to do this is using an ammeter. In order to do the measurement, the circuit must be opened, and the ammeter connected in series with the circuit. To affect the flow of current as little as possible, ammeters must have a very low impedance.
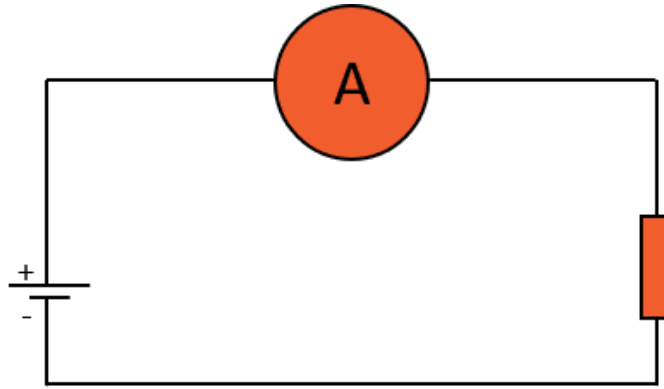
Image 26: Schematic illustration of connecting an amperemeter

Since there are many current transducers available for DAQ instruments, current can be measured in a variety of ways. Current measurement is usually divided in two major groups. One is "direct" ; this is when the conductor must be disconnected and a sensor is connected in series with the circuit. The second type is "indirect", this allows a measurement of current flowing through a conductor without opening the circuit, which means we can measure the current with galvanic isolation of the sensor from the conductor.

4.2.1. Current measurement with conductor interruption

The "direct" measurement method of currents works without any additional logic circuits. The most common method used in this kind of measurement is using a shunt resistor, which is then connected in series with the measured electrical circuit.

A shunt resistor is a resistor with a very low resistance that is accurately predetermined by the manufacturer. A shunt resistor works on the principle that it is connected in series with the electrical circuit and as the current flows through it and the voltage drop on the resistor is measured. The voltage is directly proportional to the flowing current according to Ohm's Law, because we know the exact resistance of the shunt. Choosing a shunt with high accuracy is essential because it will actually define the precision of the measurement itself.

$$I = \frac{V}{R}$$

With this method, AC or DC can be measured, but there are a few things that should be considered. Firstly, the declared current of the shunt should not be exceeded as this may burn the resistor. Secondly the shunt will heat up and eventually over heat if the maximum declared current flows through it for extended periods of time. The shunts resistance changes with increasing temperature, and if the shunt

overheats the resistance can change permanently. Due to this a shunt is usually only used up to about 60 % of its declared current level.

Further there is the common mode voltage, which we discussed earlier. This might cause some complications in the early stages of the current measurement. An example of this would be: When measuring the current that is flowing through a normal incandescent light bulb using a shunt resistor, the difference in voltage at the amplifier will be very small. Although the measured "voltage points" are still higher than the ground, they can go as high as the grid voltage. If the grid voltage is connected to a 10 V range amplifier the measurement instrument will be destroyed and the only thing left to "measure" will be the sparks coming out of it. To ensure that this doesn't not happen it is recommended to use an isolated measurement instrument.

To simplify measurements with Dewesoft instruments we can choose between two different DSI adapters with an integrated shunt resistor. For example, inside the DSI 20mA adaptor, there is a 50 Ohm 0.01% 0.25W shunt. Below is some information about these shunt adapters in the table.

Dewesoft adapter	Range	Shunt resistor value	Resistor tolerance
DSI-5-A	5 A	10 Ω	± 0.01 %
DSI-20-mA	4 mA – 20 mA	50 Ω	± 0.01 %

Measurements with these two adapters are simple, as there are no additional calculations to be made. The adapters have built in TEDS that recognize the sensors automatically in the DewesoftX® software. This saves valuable time in sensor configuration, but the conductor must still be split and connected to the sensor in order to do the measurement.

4.2.2. Current measurements without conductor interruption

Interrupting the conductor in order to attach the adapter for the current we wish to measure is sometimes not possible. Flowing current can also be measured with current sensors. This is possible because the flowing current causes a magnetic field around the conductors and current sensors measure the intensity of the magnetic field around the conductor in many different ways, current sensors are also galvanically isolated.

A quick overview of the sensors and how they measure current via the magnetic field. These kinds of sensors are isolated from the conductors which mean easier, faster and safer measurements. This type of measurement is safer for both the user and the measurement instrument because the galvanic isolation eliminates the possibility of a high common mode voltage, which is present when measuring high voltage currents with shunt resistors.

We must bear in mind that these kinds of sensors have a phase shift to the output voltage compared to the measured current. The extent of the phase shift depends on the type of current sensor and on the measured frequency. With high accuracy current sensors, the phase shift is nearly zero; with cheaper sensors the phase shift can be more than 10° at the fundamental frequency and even more at higher frequencies. Phase shift itself can be problematic but if we have this in mind when setting up the measurement configuration this shouldn't cause any problems at all. Furthermore, Dewesoft offers an

additional sensor calibration in the software (Sensor Editor) which improves the accuracy and phase shift even more.

In the following sub-chapters, the different current sensors will be described in more detail:

- **Rogowski coils**
- **Iron-core clamps**
- **Hall compensated AC/DC clamps**
- **Zero flux transducers**
- **Current transducers in public grids**

4.2.3. Overview

The following table shows the main differences between the different types of current transducers and their applications:

Properties								Applications		
Type	AC	DC	Range	Accuracy	Bandwidth	Pros	Cons	Power Analyzer	E-Mobility	Grid monitoring
Iron-Core Clamp	✔	✘	5 KA	0,5 – 4 %	10 kHz	- Cheap	- Heavy - Inflexible - No DC measurement -Low Bandwidth	No	No	Yes
Cheap Rogowski Coil	✔	✘	10kA	1 %	20 kHz	- Rugged, flexible -Linear - No magnetic influence - Over-load withstand capability	- No DC measurement - High Position Errors	No	No	Yes
Good Rogowski coil	✔	✘	50 kA	0,3 %	Up to 20 MHz	- Rugged, flexible -Linear - No magnetic influence - Over-load withstand capability	- No DC measurement - High Position Errors	Partly	Partly	Yes
Hall compensated AC/DC Clamp	✔	✔	300 A	1,5 %	100 kHz	- AC/DC measurement - High Accuracy - High Bandwidth - Clamp can open	- Low Measurement Range	Yes	Yes	Yes
Fluxgate AC/DC Clamp	✔	✔	700 A	0,3 %	500 kHz	- AC/DC measurement - High Accuracy - High Bandwidth - Clamp can open	-Needs external power supply	Yes	Yes	Yes
Zero –Flux Transducer	✔	✔	2000 A	0,002 %	Up to 300 kHz	- AC/DC measurement - High Accuracy - High Bandwidth - Low Phase Error - Low Offset	- Cannot be opened	Yes	Yes	Yes

Important

Please always use the analogue setup DC coupling and as an input type bipolar for all types of current measurements. When AC-coupling is selected a high pass filter will be activated which can lead to deviation in the phase measurement (e.g. at 50 Hz). The AC coupling option is only used in special applications.

Hint

Should the situation call for smaller currents to be measured with a current transducer with an over proportional range, simply lead the conductor through the transducer several times. For example, if you lead a 20 A conductor through the transducer 5 times the measurement will yield 100 A. **Please do not forget to consider the scaling in the setup of the corresponding analog input channel!**

4.3. Rogowski coils

A Rogowski coil is a simple measurement device which allows an AC current measurement without splitting the conductor. It consists of a helical coil of wire with the lead from one end returning through the center of the coil to the other end so that both terminals are at the same end of the coil. This coil must be wrapped around the conductor where the current measurement will take place. This allows for a measurement to be done without cutting, disconnecting or stripping the wire. The alternating current in the conductor will cause a voltage induction in the coil.

Image 28: Rogowski coil connected to a Surius DAQ

Measurement with the Rogowski coil has several advantages. Rogowski coils are available for measuring very small currents (some 100 mA) up to very high currents (> 100 kA). The coil itself is flexible, thin, light and robust. Since there are no magnetic materials, the Rogowski coils cannot saturate and, therefore, has a high overload withstand capability. They are very linear and immune to DC currents which allow for measuring small AC currents with the presence of a large DC component. The bandwidth of the Rogowski coils depends on the type and price and can go up to several MHz.

There are also some disadvantages. Because the principle of measurement with the Rogowski coil is the measurement of the induced voltage caused by the current flowing inside of the coil, which is proportional to the derivation of the current, an integrator circuit must be used on the output side to make the output voltage proportional to the current flowing through the conductor. Therefore, an external power supply is necessary. It's not possible to measure DC currents (exception: special types of Rogowski coils are able to measure DC currents). The biggest disadvantage of the Rogowski coil is the phase shift. The phase shift also depends heavily on the positioning of the coil (vertical and horizontal). This positioning error of the coil cannot be compensated using the Dewesoft sensor editor. But the phase and amplitude error due to frequency behavior can be compensated using the sensor editor.
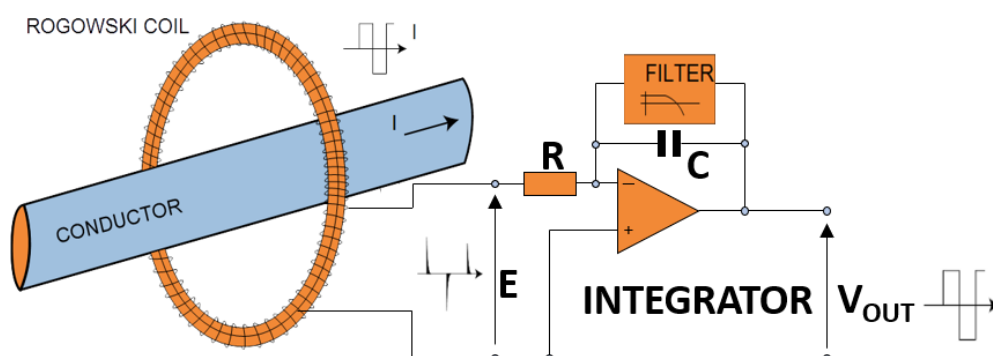
Image 29: Schematic illustration of the working principle of a Rowgowski coil

To measure an AC current simply use a Dewesoft current sensor which works with the use of a Rogowski coil. These sensors are integrated similarly to the DSI shunt adapters, with built-in TEDS chips with all the configuration data stored.

Rogowski Coils			
Dewesoft Sensor	**Range**	**Bandwidth**	**Accuracy**
DS-Flex-3000-17	3 A, 30 A, 300 A, 3000 A	3 A: 10 Hz to 10 kHz Others: 10Hz to 20 kHz	≤ 1,5 %
DS-Flex-3000-35	3 A, 30 A, 300 A, 3000 A	3 A: 10 Hz to 10 kHz Others: 10Hz to 20 kHz	≤ 1,5 %
DS-Flex-3000-35-HS	3000 A	5 Hz to 1 MHz	≤ 1,5 %
DS-Flex-3000-80	3 A, 30 A, 300 A, 3000 A	3 A: 10 Hz to 10 kHz Others: 10Hz to 20 kHz	≤ 1,5 %
DS-Flex-30000-120	3 A, 30 A, 300 A, 3000 A, 30000 A	3 A: 10 Hz to 5 kHz Others: 10 Hz to 20 kHz	≤ 1,5 %

4.4. Iron core clamps

Current clamps allow the measurement of current flows with galvanic isolation. The clamps have jaws which can be opened, and the clamp can simply be clamped around the conductor. The measurement with this clamp is based on Hall's effect or current transformer technology, which means that the magnetic field of the flowing current is used to cause a voltage output on the current clamps.

The iron-core clamp works on the principle of a transformer. Depending on the number of windings on the primary side compared to the secondary side (turns ratio), a certain current will be induced on the secondary side. Like any transformer, this only works for measuring AC current.

Image 30: Iron core clamp connected to a Surius DAQ

The advantages are that the current clamps are cheap, they don't need an external power supply and they are available for small to very high current measurement ranges. The disadvantages are that they are heavy, inflexible and it is not possible to measure DC currents. Furthermore, the bandwidth is limited (max. 20 kHz).
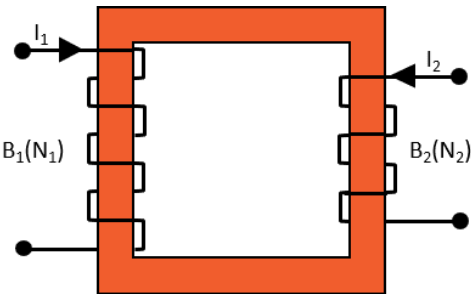
Image 31: Schematic illustration of the working principle of an iron core clamp

Iron-Core Clamps			
Dewesoft Sensor	**Range**	**Bandwidth**	**Accuracy**
DS-Clamp-5AC	10 mA to 12 A	5 kHz	0,5 % for 12 A 0,5 % for 5 A 1 % for 500 mA 2 % for 5 mA
DS-Clamp-15AC	15 A	10 kHz	1 % for currents of 1 to 15 A 2,5 % for currents < 1A
DS-Clamp-200AC	200 A	10 kHz	1% for currents of 100 to 240 A 2,5% for currents of 10 to 100 A 3,5% for currents of 0,5 to 10 A
DS-Clamp-1000AC	1000 A	10 kHz	0,3% for currents of 100A - 1200 A 0,5% for currents of 10A - 100 A 2 % for currents < 1 A

4.5. Hall compensated AC/DC current clamps

The Hall Effect is conveniently used to measure both the AC and DC current with a wide amplitude and frequency range (up to 100 kHz) with high sensitivity. For this reason, it is recommended to use hall effect-based clamps to measure DC currents.

Image 32: Hall compensated clamp connected to a Surius DAQ

The advantages of hall-compensated AC/DC current clamps are the high accuracy (0,5 %), a high bandwidth (100 kHz), the measurement of AC and DC currents and the circuit doesn't need to be opened.
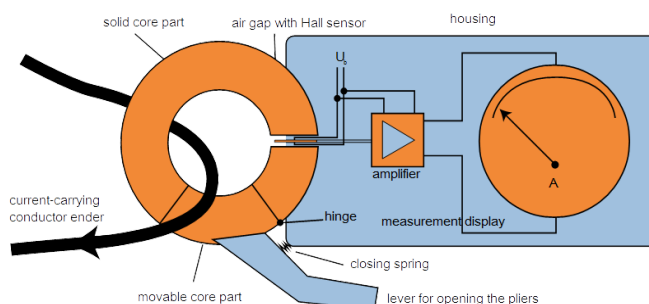
Image 33: Schematic illustration of the working principle of a Hall compensated clamp

Dewesoft offers a variety of clamps that function using the Hall effect for measuring current, these are listed in the table below.

Hall-compensated AC/DC current clamps			
Dewesoft Sensor	**Range**	**Bandwidth**	**Accuracy**
DS-CLAMP-150DC	200 A DC or 150 A AC rms	DC to 100 kHz	1 % + 2 mA
DS-CLAMP-150DCS	290 A DC or 150 A AC rms	DC to 100 kHz	1 % + 2 mA
DS-CLAMP-1800DC	1800 A DC or AC rms	DC to 20 kHz	0 - 1000 A: ±2.5 % of reading ±0.5 A 1000 - 1500 A: ±3.5 % of reading 1500 - 1800 A: ±5 % of reading

The voltage output of these kinds of clamps are also directly proportional to the current. Current clamps also produce a phase shift which can be up to ~10°, but really good clamps can reduce the phase shift to under 1°. The phase shift of current sensors changes with frequency, this is important to remember when doing any power related measurements.

4.6. Fluxgate current clamp

Fluxgate current sensors make use of a high permeability magnetic core in order to ascertain the magnetic field that is produced as a current flows through a conductor. Fluxgate technology depends on a negative feedback circuit, including a magnetic circuit, as can be seen in the schematic image. This is done by reverting a current back through the feedback coil so that the magnetic flux can be canceled out. The magnetic flux is caused in the coil by the current that is measured in the DUT. This decreases the effect of the material's magnetic nonlinearity, as it is compensated and can be kept low.

Image 34: Fluxgate clamp connected to a Surius DAQ

Fluxgate technology can detect current using the DC current detection method. This brings the inherent advantage with it that there is no need to use semiconductors. This enables the current clamps to have a long-term stability as well as a wide temperature stability range and a very low off-set voltage.
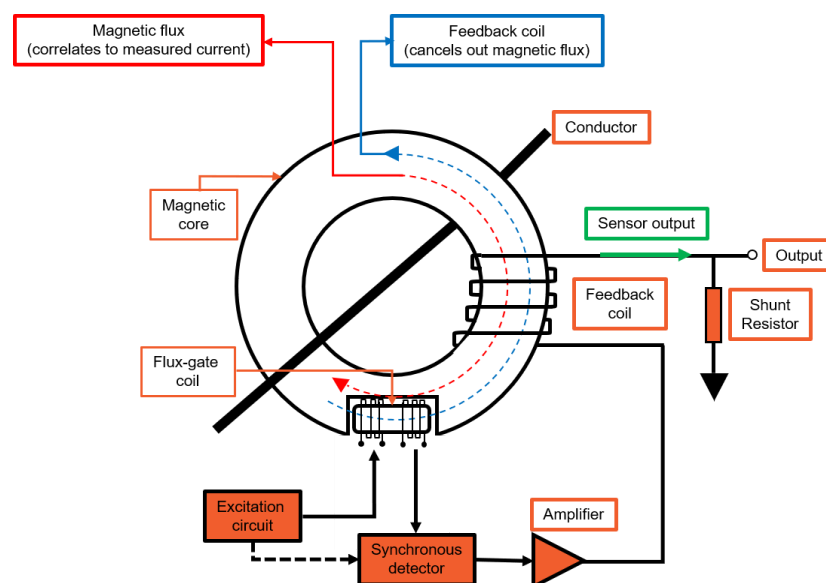
Image 35: Schematic illustration of the working principle of a Fluxgate clamp

Most clamp-type transducers have a lower accuracy than their unibody counterparts, this is mainly due to the split in the magnetic core that is needed to open the clamp. Fluxgate current clamps are the industry leading clamps when it comes to linearity, bandwidth and temperature drift, second only to the high quality unibody zero-flux transducers.

Fluxgate current clamps			
Dewesoft Sensor	**Range**	**Bandwidth**	**Accuracy**
DS-CLAMP-200DC	200 A DC or AC rms	DC to 500 kHz	± 0.3 % of reading ± 40 mA
DS-CLAMP-500DC	500 A DC or AC rms	DC to 100 kHz	± 0.3 % of reading ± 100 mA
DS-CLAMP-500DCS	500 A DC or AC rms	DC to 200 kHz	± 0.3 % of reading ± 100 mA
DS-CLAMP-500DS	1000 A DC or AC rms	DC to 20 kHz	± 0.3 % of reading ± 200 mA

Hint
The connection schematic applies to all the fluxgate current transducers listed in the table above. Please ensure that a SIRIUSi-PWR MCTS is always used to supply power to the current transducers.

4.7. Zero-flux current transducers

Current transducers measure current flows with galvanic isolation. They reduce the high currents to a much lower value. The conductor with the measured current must be guided through the loop of the sensor because current transducers function on the principle of a transformer, which means they have a current output signal and this low current signal can then be measured with the DAQ.
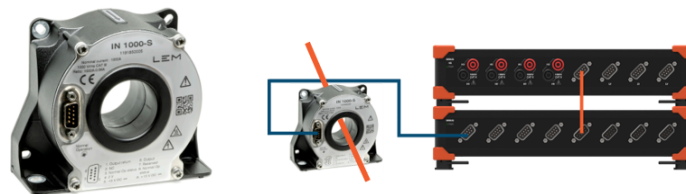
Image 36: Zero-flux transducer connected to a Surius DAQ

Zero-flux current transducers are not simple transformers, they have sophisticated constructions and integrated electronics. They have two windings which are operated in saturation to measure the DC current, one winding for the AC current and an additional winding for compensation. This kind of current measurement is very precise because of the zero-flux compensation.
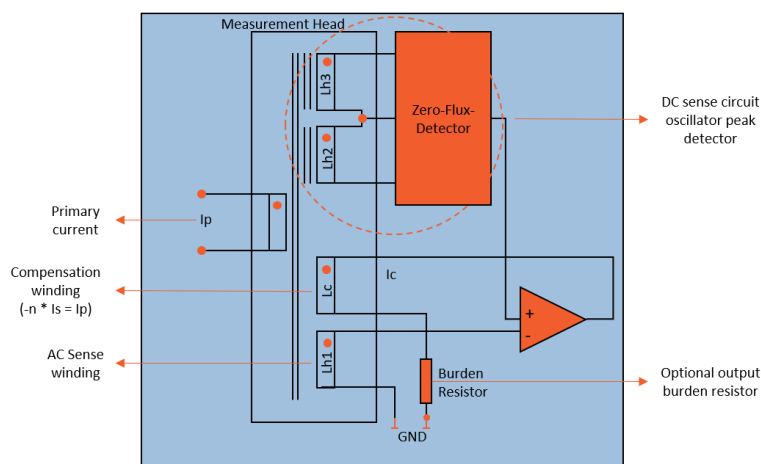
Image 37: Schematic illustration of the working principle of a Zero-flux transducer

This is a very important point because the magnetic core of the transformer stays magnetized with the residual magnetic flux, which destroys the accuracy of the measurement. In these transducers, the parasitic flux is perfectly compensated. Therefore, zero-flux current transducers are used for measuring currents with high precision, but they are not suitable for simple and fast measurement like iron-core clamps or Rogowski coils.

Image 38: Product line of Zero-flux transducers

Zero-flux transducers are used to measure currents with the highest accuracy for both AC and DC and have high bandwidth capabilities (up to 1 MHz). They are very linear and have low phase and offset errors.

Zero-Flux current Transducers				
Dewesoft Sensor	**Range**	**bandwidth**	**Accuracy (% of MR)**	**Angular accuracy**
IT-60-S	60 A	DC to 800 kHz	0,027	<0.025° +0.06°/kHz
IT-200-S	200 A	DC to 500 kHz	0,009	<0.025° +0.05°/kHz
IT-400-S	400 A	DC to 500 kHz	0,0044	<0.025° +0.09°/kHz
IN-500-S	500 A	DC to 520 kHz	0,0018	<0.01°/kHz
IT-700-S	700 A	DC to 250 kHz	0,0055	<0.025° +0.18°/kHz
IN-1000-S	1000 A	DC to 440 kHz	0,0018	<0.01° +0.05°/kHz
IN-2000-S	2000 A	DC to 140 kHz	0,0015	<0.01° +0.075°/kHz

4.7.1. Connecting a zero-flux transducer to a PWR-MCTS2 and a SIRIUS DAQ

For demonstration purposes a IT-400-S transducer will be connected to both a Sirius 4xHV 4xLV as well as a PWR-MCTS2.

Caution
It is important to note that a zero-flux transducer needs to be connected correctly to the measurement equipment, this is due to the fact that if it is connected incorrectly the instruments may be damaged.

The connection will require the following components:

SIRIUSi HS 4xHV 4xLV	Shunt Cable DSI-MCTS-XXX-03M	Zeroflux transducer IT XXX-S or IN XXX-S
SIRIUSi-PWR-MCTS2	Connection Cable D9m-D9f-5M-MCTS	
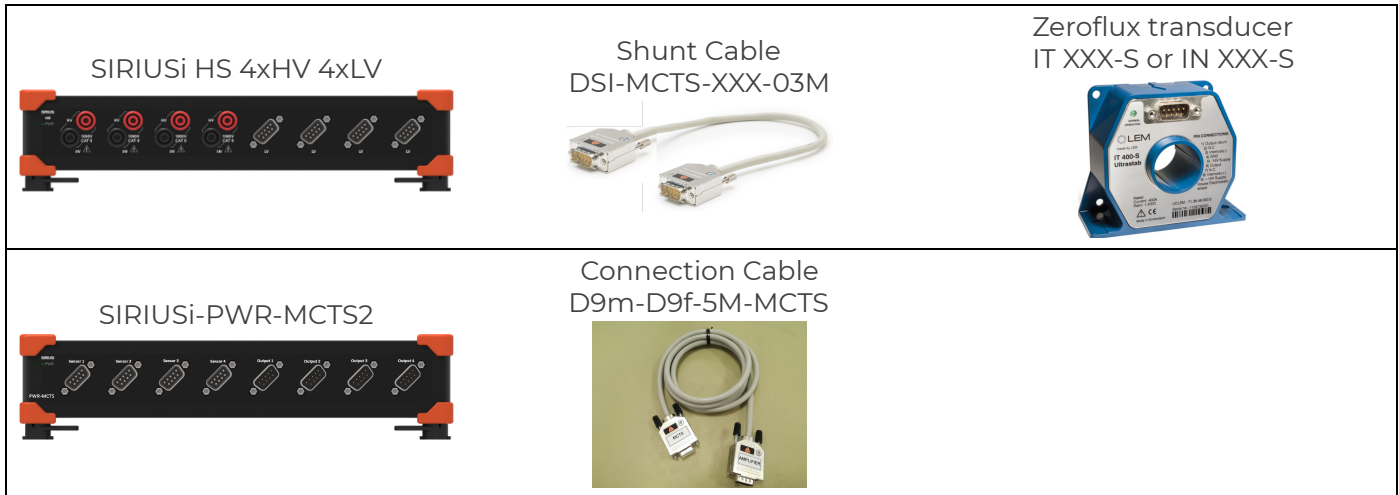
Step 1:

Firstly, connect the zero-flux transducer IT 400-S with the D9m-D9f-5M-MCTS cable to the SIRIUSi-PWR-MCTS slice at the Sensor 1 input. The D9m-D9f-5M-MCTS cable is a simple extension cable and can be used for all zero-flux transducers (60A up to 1000A).

Image 39: Zero-flux transducer connected to a SIRIUS-PWR-MCTS2

Step 2:

Connect the DSI-MCTS-400-03M cable to Output 1 of the SIRIUSi-PWR-MCTS2 and connect it to the first LV input of the SIRIUS® PWR amplifier.

Image 40: Zero-flux transducer connected to a SIRIUS-PWR-MCTS2 and a SIRIUS® DAQ

Hint

The DSI-MCTS-XXX cable can only be used for certain zero-flux transducers. The cables have a built-in shunt which only correspond to certain transducers. Please refer to the following table for information on which shunt cables belong to which zero-flux transducers.

DSI-MCTS-XXX	
Shunt cable	**Zero-Flux Transducer**
DSI-MCTS-60-03M	IT-60-S
DSI-MCTS-200-03M	IT-200-S
DSI-MCTS-400-03M	IT-400-S
DSI-MCTS-500N-03M	IN-500-S
DSI-MCTS-700-03M	IT-700-S
DSI-MCTS-1000N-03M	IN-1000-S
DSI-MCTS-2000N-03M	IN-2000-S

Repeat Step 1 and Step 2 for all zero-flux transducers that need to be connected to the system. For measuring a three-phase system with a star connection the connection will look like the image below:
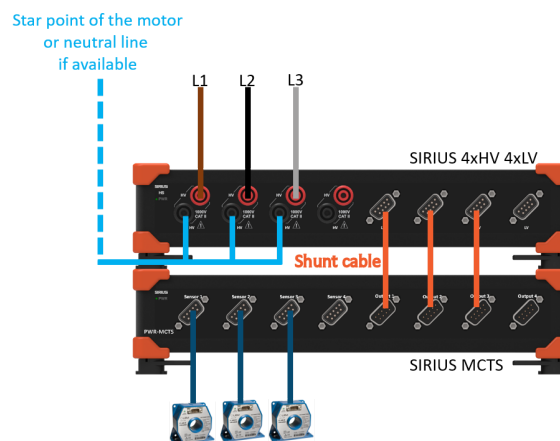
Image 41: Three phase star point connection with zero-flux transducers

Instructions on how to connect voltage and current transducers for all the different wiring configurations such as DC, 1-phase, 2-phase, 3 -phase delta -star -Aron -V, etc. can be found in a later chapter of power reference manual.

Caution

Never operate the zero-flux-transducers (IT 60-S, IT 200-S, IT 400-S, IN 500-S, IT 700-S, IN 1000-S, IN 2000-S) without a proper power supply (SIRIUSi-PWR-MCTS, SIRIUSir-PWR-MCTS). The zero-flux transducer may be destroyed!!!

4.7.2. Software configuration

In most of the Dewesoft current transducers there is an integrated TEDS chip, where data such as scaling, calibration etc. of the transducer is stored. When the shunt cable is connected to the Low-Voltage input of the SIRIUS® amplifier all these configurations are done automatically. Therefore, the DSI adapters and TEDS sensors must be activated. Please check "Devices" → "Settings" and ensure that this option is enabled, see screen-shot below.
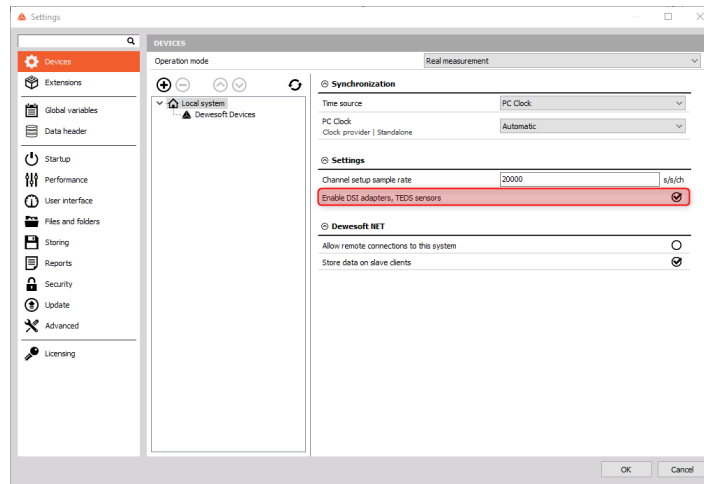
Image 42: Enabling DSI and TEDS in DewesoftX®

After connecting the sensor (e.g. MCTS 400) the software will recognize the TEDS and will automatically fill in the column Ampl.name with the current transducer description (e.g. DSI-MCTS-400), the type of measurement as well as the physical quantity and the measurement unit will be changed to "Current".

Image 43: Automatic sensor recognition in DewesoftX®

Finally, a suitable measurement range should be set, and a low-pass filter should this be necessary, as shown in the image.
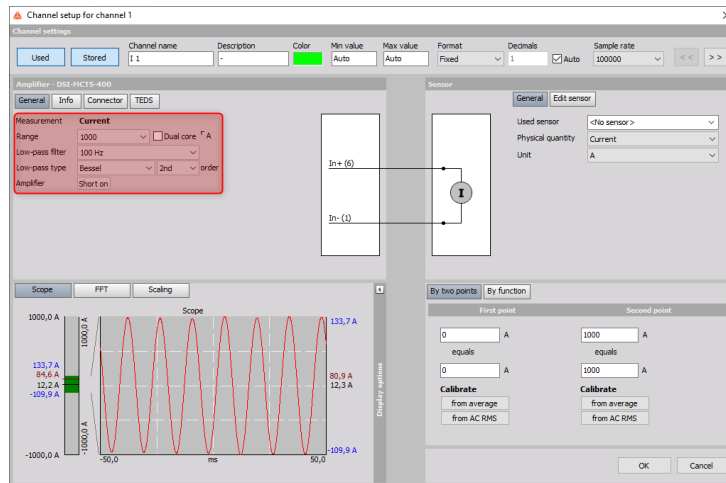
Image 44: Set up screen for transducers in DewesoftX®

4.7.3. Current transducers in the public grid

Current transducers are used to monitor the current flow in the public grid and protect the equipment from overloading. A current transducer is easily explained as a transformer which is operated in short-circuit on the secondary side (or with a small load). On the output (secondary) side of the current transducer, there is a low current signal which is directly proportional to the current on the primary side. In public grid operation, the secondary current is standardized with a level of 1 A or 5 A.
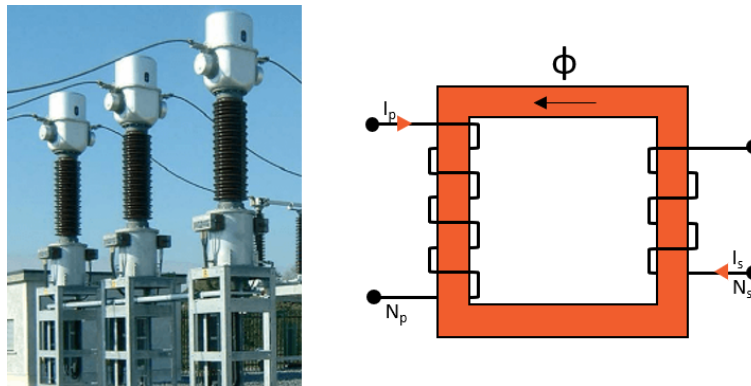
Image 45: Public grid monitoring

There are different measurement classes of current transducers which describe the accuracy and the phase shift of the transducers. The classes range from 0,1 to 5. Class 0,1 means that the accuracy of the measured amplitude is 0,1 % and the phase shift is ± 5 minutes. In class 5 the accuracy is 5 % and the phase shift ± 120 minutes.

The description of the current transducers also defines the overload factor, the rated power (load) and the application of the transducer (protection, measurement). The load (input resistance of the measurement device) is important because it influences the overload capability of a current transducer. If the load is higher than the rated load, the transducer will go into saturation prematurely and, therefore, will lose the overload capability.

> **Warning**
> Never operate current transducers in open-loop mode on the secondary side. This creates high voltages which can destroy the transducers and can be hazardous for people.

> **Hint**
> Please always consider the bandwidth of the current transducers when measuring Power Quality parameters such as harmonics

4.7.4. Software sensor correction

As an example, a classic 40 W light bulb will be measured. Noticeable is that the load on the grid is linear to the voltage. The measured power is exactly 40 W as it should be, but in the vector-scope as seen in the image below things are not quite as they should be. A light bulb is a purely ohmic load on the grid and therefore the voltage and current should be perfectly aligned (no phase shift). What could be the reason for this?

In previous chapters the differences between current transducers and shunt resistors were explained, it was mentioned that these may cause a phase shift when carrying out measurements (the extent of the phase shift relies greatly on the quality of the sensor that is used). This is exactly what can be seen in the image below, the current transducer used for the measurement is causing a phase shift in the vector scope and this is negatively influencing the measurement that is being done.
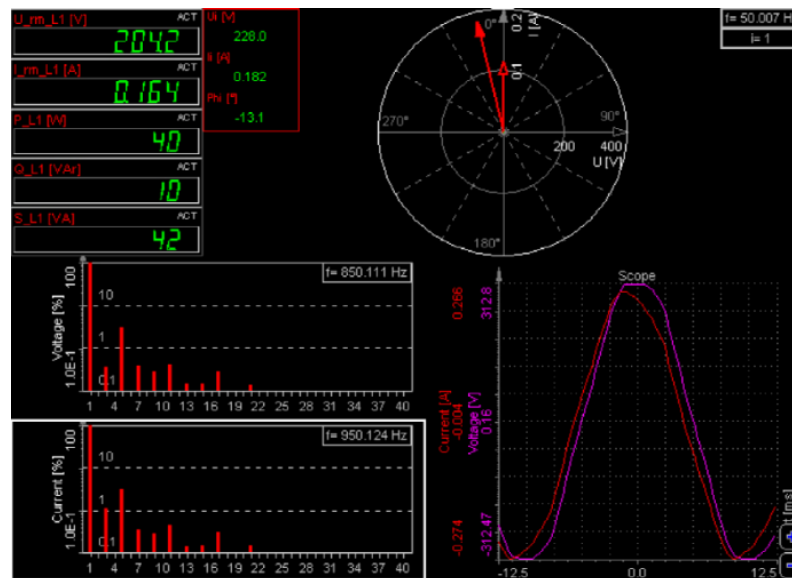
Image 46: Phase shift caused by a current transducer

Luckily in the DewesoftX® software there is the option to rectify this phase shift and it will be compensated to reduce the chance of measurement errors. Here is how to do it:

As mentioned earlier all current transducers have frequency dependent behavior regarding the amplitude and the phase. In the DewesoftX® software the compensation is done in the sensor editor, this will make the measurement with the sensor much more accurate. This is achieved by using the

specifications that the manufacturer of the sensor supplies with the sensor. This is unique on the market of DAQ systems, as the math is done automatically in the DewesoftX® software!

By navigating to the Setting section and choosing the "Sensor Editor" menu, there will be a list of known sensors that can be chosen from, and there is the option for the user to add sensors that are not on the list. For this example, a sensor is added, enter the sensor type and the serial number. Enter the Physical (input) unit, which is A (amperes) in this case and the Electrical (Output) unit, which is V (volts).
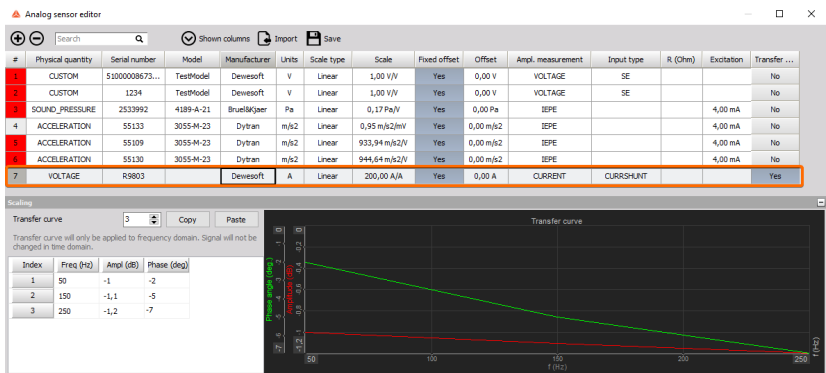
Image 47: Analog sensor editor

The next step would be to add a SCALING factor (this is mostly supplied by the manufacturer). In this example the sensor is linear with the amplitude, only the scaling factor needs to be added, in this case it is 1 as (1A = 1V). The polarity in this step is not that important as it can also be changed (reversed) in the channel setup at a later stage.
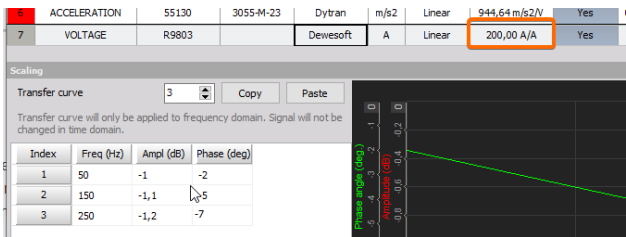
Image 48: Scaling factor

This is the most important part – defining the TRANSFER CURVE. In the table under the transfer curve column select **YES** to signify that a transfer curve will be defined. Now the points of the curve need to be added, the a[dB] – amplitude deviation in dB – and the phi [deg] – phase angles in degrees. Where does one obtain such transfer curves? There are many transfer curves available for the most common sensors that have already been measured, so it's worth checking if it already exists. Secondly the transfer curve can be copied from the calibration sheet if it is included.

A third option would be to measure it with the FRF (Frequency Response Function) option, but this requires some equipment. When the transfer curve is obtained, it needs to be entered into the table. As can be seen in the image below at 50 Hz the angle is around 10°, this explains the phase shift that was seen in the vectorscope.
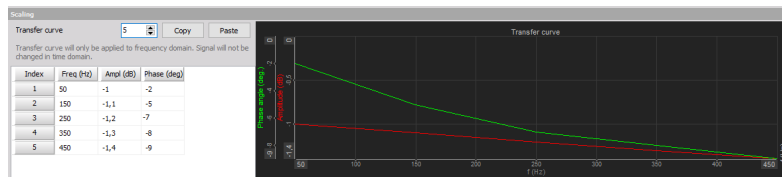
Image 49: Defining the transfer curve in the analog sensor editor

When the sensor set-up has been done, save it with the save file button and exit the sensor editor with Exit. Then go back to the analog set-up and select the sensor for the current channel. Open the Sensors tab and select the serial number of the sensor previously entered in the Sensor field of the editor. Nothing much happens but note that the normal scaling or sensitivity cannot be entered any more. To reverse the polarity of the sensor, choose the Scaling by function and select Sensitivity. By clicking the ± button, the polarity can be reversed.
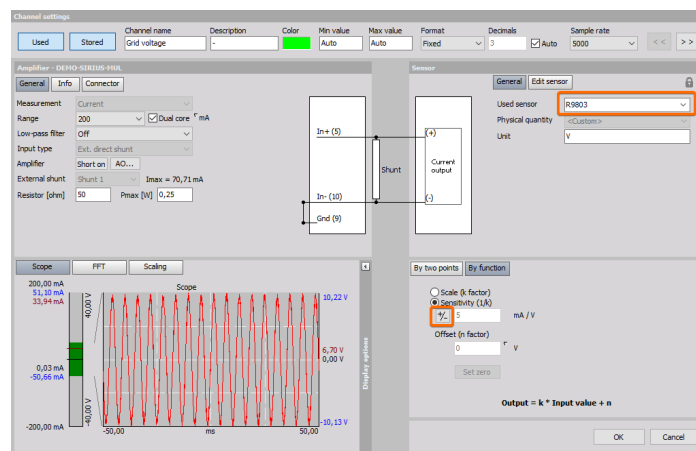
Image 50: Channel setup in DewesoftX®

The sensor has now been set-up and the Software should auto compensate the phase shift automatically. This sensor set-up does not have to be done again as it has been saved to the sensor list (database), if needed just select it from the sensor list and the set-up will be ready to use. The following image shows how the sensor correction affected the measurement. The results are now correct, the phase angle has been virtually eliminated and the power is calculated correctly.
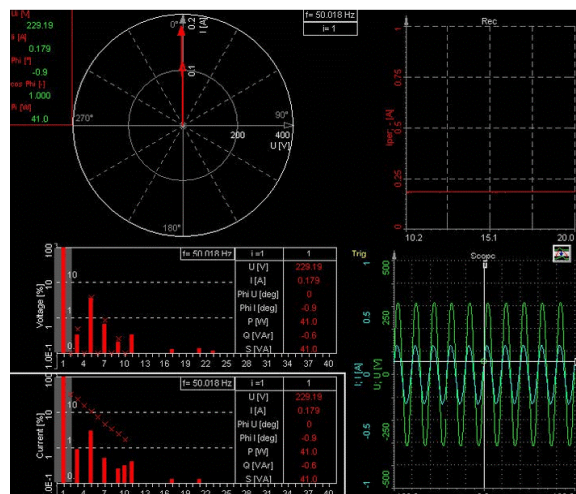
Image 51: Eliminated phase shift that was caused by the current transducer

4.7.5. Current measurement with Dewesoft

Now some current measurements will be done using Dewesoft equipment. The measurement will be done on two light bulbs, to determine the current consummation of a classic 40 W incandescent and an 11 W energy saving light bulb. In this measurement two approaches will be used, the first being a direct voltage measurement using a shunt resistor and the second using current clamps.

Before the measurement can commence some calculations need to be done. These calculations will determine which SIRIUS® amplifier and the range of the amplifier that needs to be used as well as the type of current clamps. When both light bulbs are switched on simultaneously the declared power will be 51 W and the RMS value of the grid is 230 V, these are the variables that we need to do the calculation. Below is the calculation.

$$P_1 = 40 \ W \qquad\qquad P_2 = 11W \qquad\qquad P = P_1 + P_2 = 51W$$

$$I = \frac{P}{V} = \frac{51W}{230V} \approx 0.22 \ A$$

After the rough calculations have been made the current RMS will be approximately 0.22 A. But we need to consider that the max value of the sine wave signal is √2 times the RMS value, but since the energy saving light bulb doesn't use the current in sine waveform we should have some reserve in our measurement ranges due to the higher crest factor of the energy saving bulb. This taken into consideration a 10 A range is chosen on the current clamps and the shunt a DSI SHUNT 5 A adapter. The shunt has a resistance of 0.01 Ω, meaning that 1 A of current will cause a voltage drop of 10 mV in the shunt. This information is necessary for the measurement channel set-up that the voltage drop of the shunt will be measured on. The Dewesoft DSI adapters are already equipped with the channel set-up information (integrated TEDS), so the software can conImage the channel set-up automatically. This is just one less thing to keep in mind when Dewesoft DSI adapters are used for measurements.

The measurement can now be started. For this measurement two different SIRIUS® amplifiers, a LV module and an ACC module will be used. Below on the image is shown what the measurement set-up looks like when all the components have been connected. The current clamps are directly connected to the LV module and the DSI SHUNT 5A is directly connected to the ACC module.
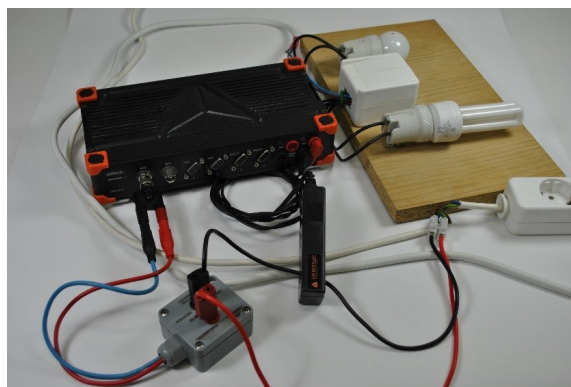
Image 52: Equipment for the demo measurement

As the image illustrates the wires must be split for the shunt installation. Please be careful when doing this as it can be dangerous due to the grid voltage. Next the channel configuration of channel 1 (shunt channel) is done. It is recommended to rename the channel to keep a clear overview of which components are connected to which channels (to do this simply click where it says channel name and type the chosen name in), in this example the name shunt current was chosen for the channel name.

Secondly the physical quantity will be set to current, the unit which is A (Ampere) is set automatically by the DewesoftX® software. Once these settings have been changed it is recommended that the sensor be "calibrated". In this example a 2-point calibration will be chosen as it is already known that 1 V will equal 10 A. These two values are simply typed into the supplied space on the bottom right of the screen. If the parameters were set correctly and the classic 40 W light bulb is switched on, the sine wave from the current will be displayed in the lower left corner of the set-up screen on the scope. Please refer to the image on the next page.
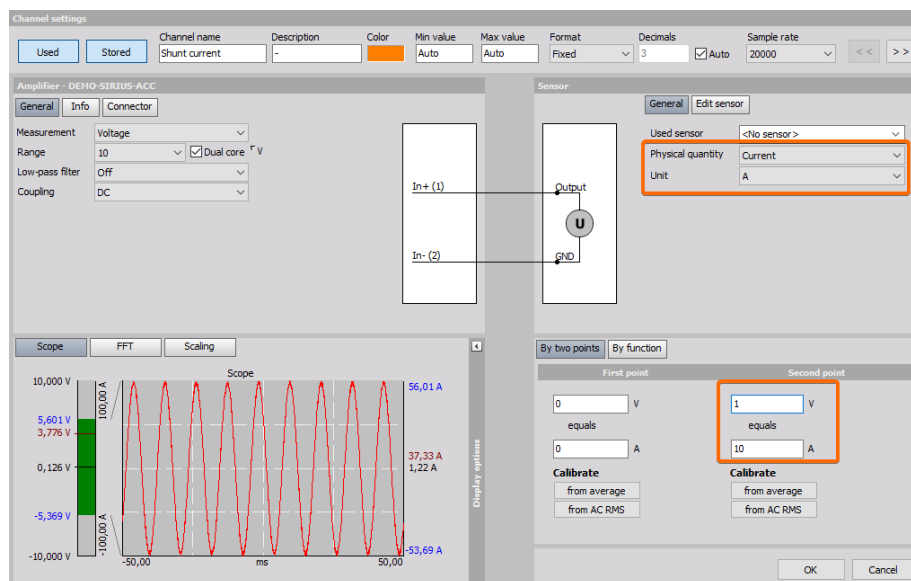
Image 53: Channel setup for shunt current

For channel 8 where the current clamps are connected, the settings will differ a little from the shunt (Channel 1) set-up that was done before, this is mainly due to the fact that the current clamps are connected to the HV part of the SIRIUS® instrument. The current clamps are set to a range of 10 A which means that they yield 1mV/1mA output (the scaling factor is 1). This means that an output of more than 10 V is not possible, therefore that amplifier will be set to have a range of 50 V this is to ensure that the resolution is sufficient for the measurement. The physical quantity must be set to current again and the unit will again automatically switch to ampere (A).

The image below illustrates what the combined waveform of the energy saving light bulb and the classic light bulb would look like when they are switched on simultaneously. The waveform changes due to the non-sinusoidal waveform and the high crest factor of the energy saver light bulb.
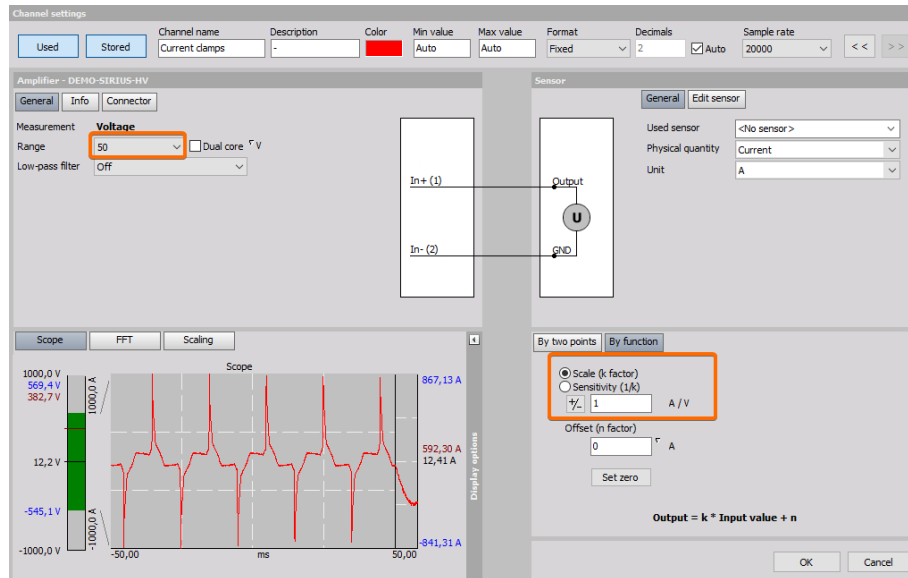
Image 54: Channel setup for the current clamp

When switched to the measure mode screen, the phase shift of the current clamps compared to the shunt resistor can be seen, as illustrated in the image below. The phase shift does not seem too big at first glance (it is at around 10°), but with applications such a power measurement the phase shift is a critical component in order to yield the correct results for measurements.

This means that the 10° phase shift that is present in the measurement at the moment can have a significant influence on the measurement results especially when doing a detailed power analysis (especially for reactive and apparent power). Again, this phase shift of the current can be compensated using the sensor editor, as was explained earlier.
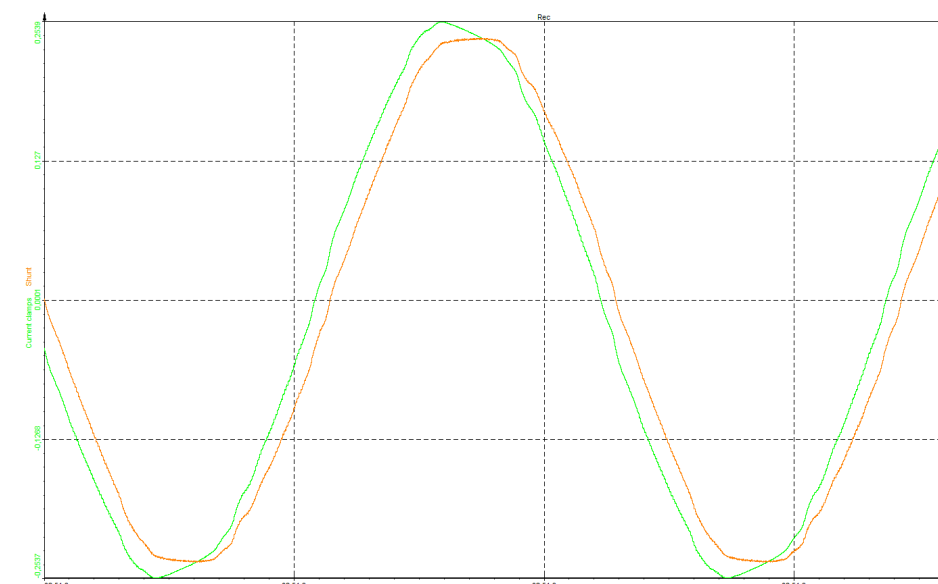
Image 55: Phase shift between the current clamp and the shunt resistor

5. Power Analysis

Power is the rate of doing work. The power of an electrical system is the multiplication of the voltage with the current, integrated over and then divided through the periodic time. The periodic time (equals the frequency) must be known in order to calculate the power of an electrical system.

5.1. What is Power

In physics power is the rate of doing work. It is equivalent to an amount of energy consumed per unit of time. The unit for power is Joule per second [J/s], also known as Watt [W]. The integral of power over time defines the energy (performed work).

5.1.1. Power calculation

The power of an electrical system is calculated by multiplying the voltage with the current.

$$P(t) = I(t) \cdot V(t)$$

But is it really that simple? What about measuring a 7-phase system or measuring frequency inverters? Power calculation can be very easy for example when measuring DC systems, but it can also be challenging when measuring inverters with multiple phases.

In this reference manual the correct way to measure the electrical power of different systems will be explained as well as for different applications such as grid, motor and inverters among others. First of all, the theoretical part will be covered, including a theoretical background on power calculations. Secondly, the calculation of easy power parameters and explanations of how to conImage the power module and how to visualize the power parameters in the measurement screen of the Dewesoft software. Lastly, there is a practical part showing step-by-step how to measure DC power, single phase, 2-phase, 3-phase in star, delta, Aron and V-connection AC power, as well as what is to consider when measuring inverters and an example of how to calculate the power of a 6-phase motor.
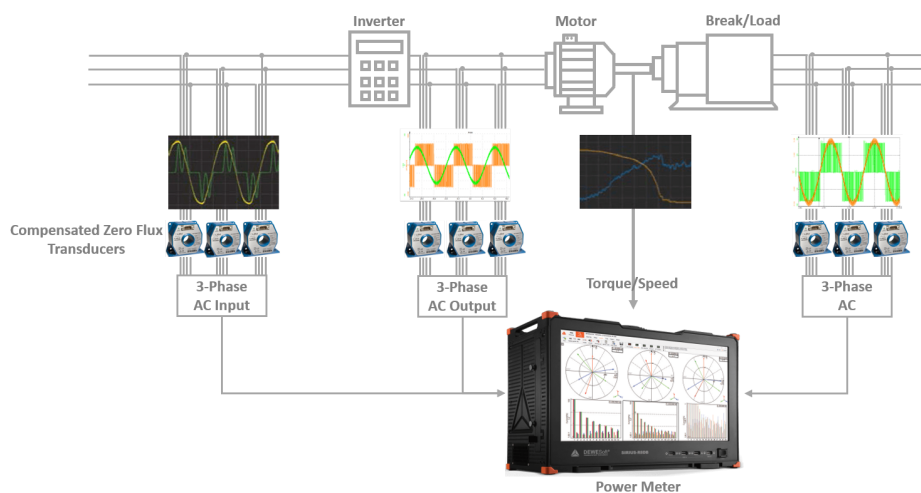
Image 56: Schematic illustration of a complex 3-phase measurement

5.1.2. Power calculation background

Electrical power is the rate at which electric energy is transferred by an electric circuit. The SI unit of power is watt [W]. The following formula describes the calculation of the electric power for AC or DC systems in general.

$$P = \frac{1}{T} \int_{t=0}^{T} u(t) \cdot i(t) \, dt$$
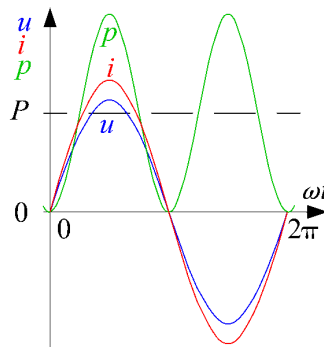
Image 57: Power calculation graph

P is power in Watt [W]   u is voltage in Volt [V]

i is current in Ampere [A]   T is the periodic time in seconds [s]

So, the power is not just voltage multiplied with current as was initially stated, it's the integration over the periodic time of this term, divided through the periodic time. This means that it is a requirement to know the period of time (frequency) to calculate the power of an electrical system.

Measuring DC power is not as complicated, as the voltage and current are constant and there is no frequency as seen in the image below. The time interval for the integration just defines the average interval of the power calculation.
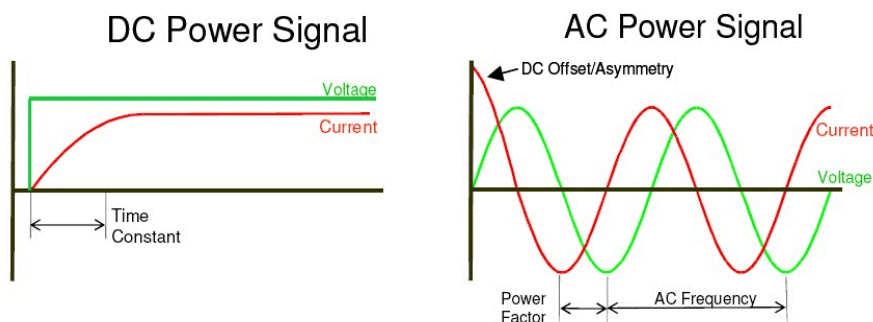
Image 58: Direct current and alternating current waveforms

To measure AC systems the periodic time needs to be known.This cannot be done by taking the normal grid frequency (e.g. 50 Hz) as a constant. This is due to the fact that the grid frequency is ever changing depending on the balance of the energy supply and the electric load at that exact moment. With variable drives, where the frequency continuously changes with a large bandwidth (ranging from 1 Hz up to 2000 Hz) makes it even more difficult to calculate the power. Therefore, the period time must be determined. This is especially difficult when measuring inverters where the voltage is not a sinusoidal waveform anymore but packets of pulses.

5.1.3. Frequency determination

This is where the Dewesoft power analysis tool distinguishes itself from the conventional power analyzers. Conventional power analyzers use a zero-point detection to determine the periodic time. This means that they evaluate when the voltage or current crosses that x-axis and use that value to calculate the periodic time. This works well most of the time, but especially when measuring strongly distorted signals this method can lead to measurement errors.

Dewesoft was not happy with "works well most of the time". Therefore, a special FFT (Fast Fourier Transform) algorithm (Software PPL) to determine the periodic time (frequency) was developed. The algorithm determines the periodic time of the signal via a special FFT algorithm using a sampling window of multiple periods (typically 10 periods, definable in the power module). The calculated frequency is highly accurate (mHz) and works for every application (motor, inverter, grid, ...).

5.1.4. How a low cost Watt-meter calculates the power of an AC system

A low-cost watt-meter calculates the power of an AC system out of the peak values from the voltage and the current, according to this formula:

$$U_{RMS} = \frac{u_{peak}}{\sqrt{2}}$$

In order to calculate the power, they simply multiply the RMS values of the voltage and current. This way of measuring the power works well when the waveform for both current and voltage is an ideal sinusoid (as it is produced in the generators at power-plants). Nowadays the waveform of both voltage and current are never ideal due to non-linear loads and also non-linear generation units. This way of calculating the power is outdated, especially when measuring inverters, the calculation will mostly be completely wrong.

5.1.5. How a conventional power analyzer calculates the power of an AC system

Conventional power analyzers calculate the RMS values of the voltage and current out of each sample point. The RMS values are calculated out of the square root of all squared sample points of the curve divided by the number of samples.

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

5.1.6. How Dewesoft calculates the power of an AC system

As mentioned earlier conventional power analyzers calculate the power in the time domain. Dewesoft on the other hand calculates power in the frequency domain. With the predetermined period time, an FFT analysis for voltage and current is done for a definable number of periods (typically 10, with electrical applications) and a definable sampling rate. The FFT yields an amplitude for the voltage, current and the cos phi for each harmonic. One major benefit of this FFT transformation is that the behavior of amplifiers, current or voltage transducers in amplitude and phase for the whole frequency range (using the Sensor XML) can now be corrected. This way of power analysis has the highest possible accuracy. Another benefit is that harmonic analysis and other power quality analysis can be done completely synchronized to the fundamental frequency.

With the FFT corrected values, the RMS voltages and currents are calculated out of the RMS values of each harmonic.

$$U_{rms_{total}} = \sqrt{U_0^2 + U_1^2 + U_2^2 + ... U_n^2}$$

$$I_{rms_{total}} = \sqrt{I_0^2 + I + I_2^2 + ... I_n^2}$$

The power values for each harmonic and the total values are calculated wit the following formulae:

	N^{th} - Harmonic	Total
Apparent power	$S_h = U_h \cdot I_h$	$S = U_{rms_{tottaö}} \cdot I_{rms_{total}}$
Active power	$P_h = U_h \cdot I_h \cdot cos(\varphi_h)$	$P = \sum_{h=1}^{H} P_h$
Reactive power	$Q_h = U_h \cdot I_h \cdot sin(\varphi_h) = \sqrt{S_h^2 - P_h^2}$	$Q = \sqrt{S^2 - P^2}$

Some of the benefits of the Dewesoft power calculation method compared to conventional methods are as follows:

- Raw data storing simultaneous to power analysis
- Additional sensor calibration for amplifier and sensors for amplitude and phase for the full frequency spectrum
- Easy power quality analysis (harmonics, inter harmonics, higher frequencies)
- Resampling
- Period values for power, voltage, current and symmetrical components

5.2. Types of power

AC power can be classified into three different types of power, these are called active power, reactive power and apparent power.

5.2.1. Active power

Active power is measured in Watt (W) and refers to the energy transfer from an electric generator to a load. The active power is the power which can be used by electric loads (useful power).

$$P = U \cdot I \cdot cos(\varphi)$$

5.2.2. Reactive power

The reactive power is measured in Volt-Ampere-reactive (VAr). The reactive power doesn't consist of energy but is necessary for most types of magnetic equipment (motors, transformers) to work. Reactive power is provided by generators, synchronous condensers or electrostatic equipment such as capacitors and directly influences the electric system voltage and also the capacity of the power transmission line.

$$Q = U \cdot I \cdot sin(\varphi) \; = \; \sqrt{S^2 - P^2}$$

5.2.3. Apparent power

Apparent power is measured in Volt-Amperes (VA) and is the voltage on an AC system multiplied by the total current that flows in it. It is the vector sum of the active and the reactive power.

$$S = U \cdot I$$

5.2.4. Power factor

The ratio between active power and apparent power in a circuit is called the power factor. For two systems transmitting the same amount of active power, the system with the lower power factor will have higher circulating currents due to energy that returns to the source from the energy storage in the load. These higher currents produce higher losses and reduce the overall transmission efficiency. A lower power factor circuit will have a higher apparent power and higher losses for the same amount of active power. The equation is multiplied by 100 to yield the power factor in percent.

$$PF = \frac{P}{S} \cdot 100$$

5.2.5. Cos Phi

Cos phi is the angle difference between a phase voltage relative to the current. The difference between cos phi and the power factor is that the cos phi is calculated for each individual harmonic starting at the fundamental frequency compared to the power factor which includes the whole spectrum (all harmonics).

5.3. Power Triangle

The power triangle illustrates the relation between active, reactive and apparent power.
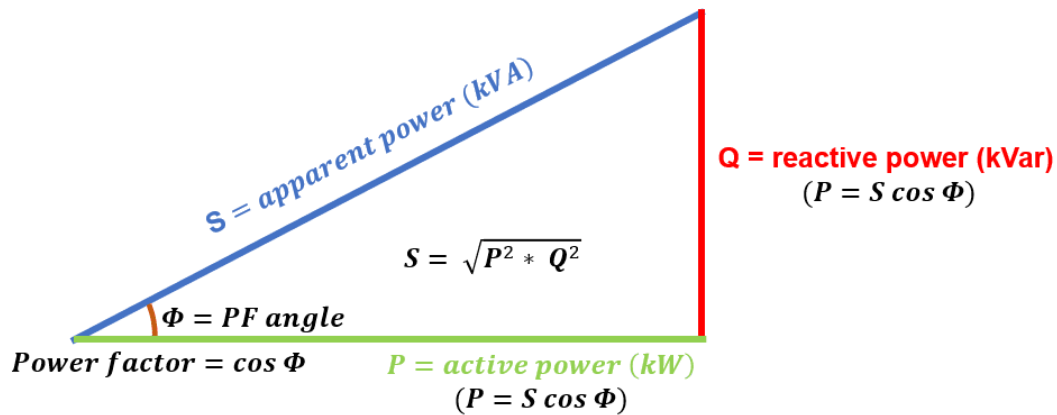
Image 59: Power triangle

In the diagram, P is the active power, Q is the reactive power (in this case positive), S is the complex power and the length of S is the apparent power. Reactive power does not do any work, so it is represented as the imaginary axis of the vector diagram. Active power does do work, so it is the real axis.

5.3.1. Power triangle - analogy to beer

It is easier to understand the power triangle using a beer analogy. The reactive power is like the foam (head) on top of the beer. The active power is the actual liquid gold in the glass. The foam in the glass does take up space and thereby reduces the volume that the actual beer has in the glass. The foam is a natural part of the process of pouring beer, but one does try to keep it as low as possible to increase the volume in the glass for the Beer. By comparison the reactive power will always be in the transmission lines and reduce the capacity in which real power can be transported, but it is kept as low as possible. Only the real power can be used.
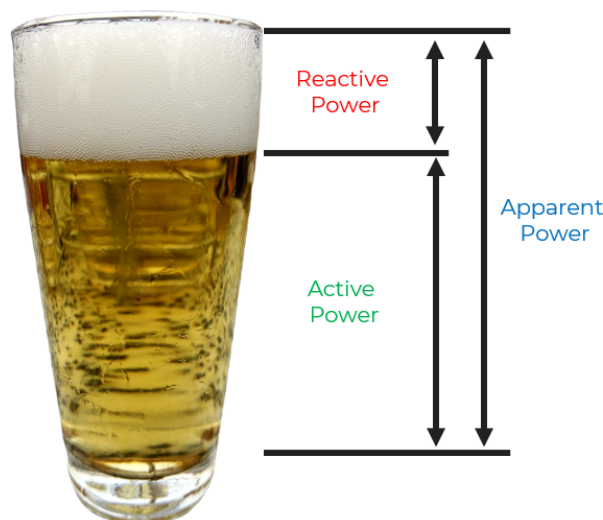
Image 60: Power triangle analogy to beer

5.3.2. Calculation of power values (P, Q, S) for each harmonic

To easier understand how the power of each harmonic component is calculated, refer to the image below illustrating the calculation of several harmonic active power values. The same calculation is done for both apparent and reactive power, just using different equations.
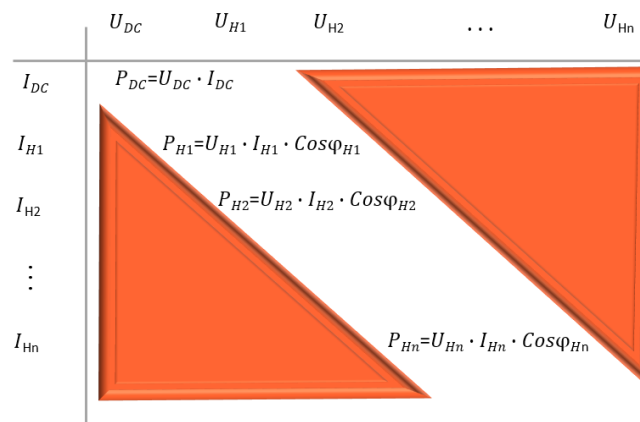
Image 61: Calculation of harmonic active power values

5.4. The NEW power triangle

Nowadays the typical power triangle that was illustrated above doesn't comply with the times anymore because other parameters such as distortion or harmonic reactive power have to be considered in the new power triangle as illustrated below. This new triangle shape is mainly due to more and more non-linear loads (inverter, electronic ballast unit, etc...) and also new power generation units (the wind, PV, etc...). The new power triangle, therefore, has an additional dimension added to it:
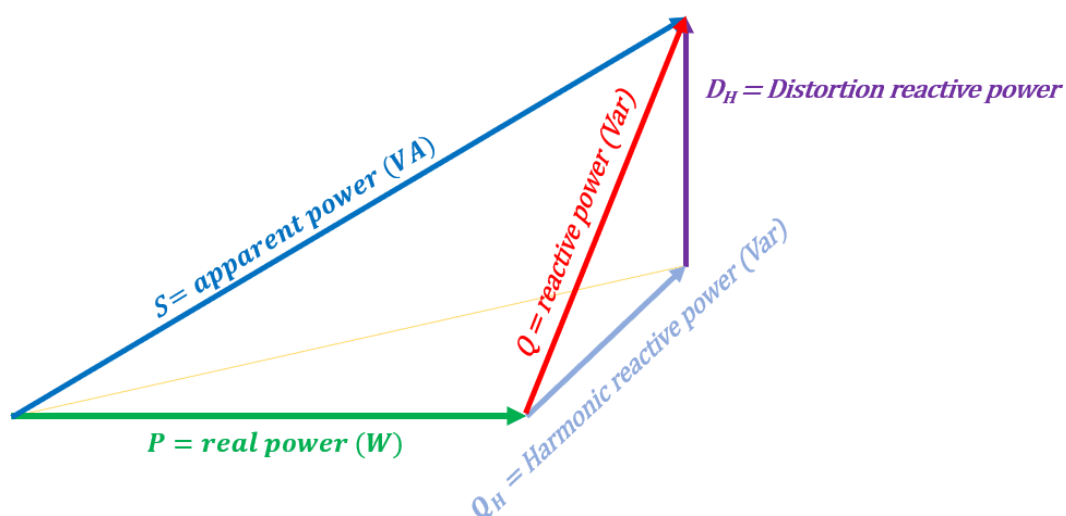
Image 62: New power triangle

5.4.1. Harmonic reactive power - QH

The sum of the harmonic reactive power. This reactive power occurs through the phase shift between voltages and currents of the same frequency.

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

5.4.2. Distortion reactive power - DH

The combination of voltages and currents of different frequencies which produce the distortion power.

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

Name in DewesoftX® (e.g. for L1): DH_L1, distortion power of all harmonic components' reactive powers where u and i have different harmonic orders.

5.4.3. Distortion - D

Distortion power considers everything except the first harmonic.

$$D = \sqrt{Q^2 - Q_{h=1}^2}$$

Name in DewesoftX® (e.g. for L1): D_L1, distortion power of all harmonic components' reactive powers (u and i have the same order but not equal 1 or have a different order)

These are the power quality (PQ) parameters. All other PQ parameters which are calculated in DewesoftX® (Harmonics, THD, Rapid voltage changes, Symmetrical components ...) can be found in the chapter, Power Quality.

5.4.4. Calculation of power values (P, Q, S) for each harmonic for the new power triangle
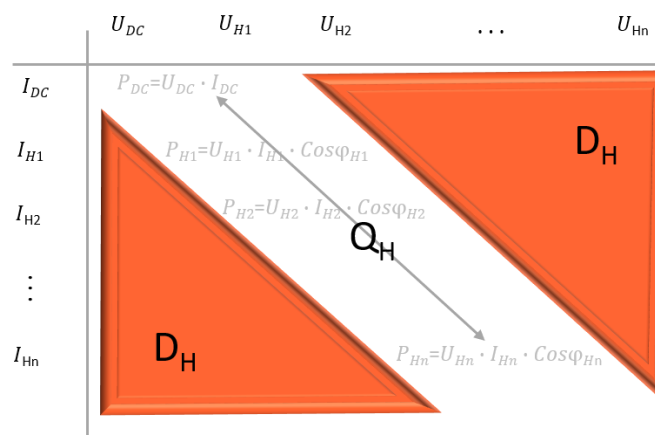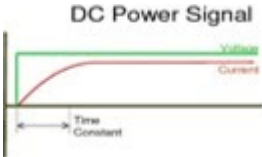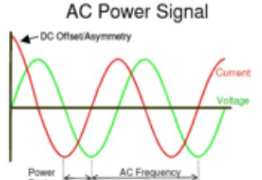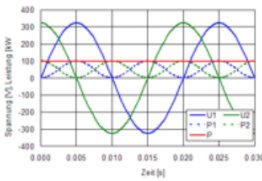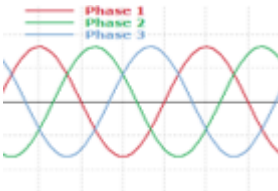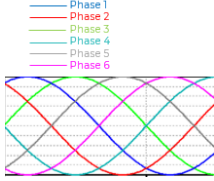
Image 63:. Calculation of harmonic power values for the new power triangle

5.4.5. Power calculations for different wiring schematics

DC		$P = U \cdot I$
1-Phase		$P = \frac{1}{T} \int\limits_{t=0}^{T} u(t) \cdot i(t)\, dt$
2-Phase		$P_1 = \frac{1}{T} \int\limits_{t=0}^{T} u_1(t) \cdot i_1(t)\, dt$ $P_2 = \frac{1}{T} \int\limits_{t=0}^{T} u_2(t) \cdot i_2(t)\, dt$ $P = P_1 + P_2$
3-Phase		$P_1 = \frac{1}{T} \int\limits_{t=0}^{T} u_1(t) \cdot i_1(t)\, dt$ $P_2 = \frac{1}{T} \int\limits_{t=0}^{T} u_2(t) \cdot i_2(t)\, dt$ $P_3 = \frac{1}{T} \int\limits_{t=0}^{T} u_3(t) \cdot i_3(t)\, dt$ $P_{3\sim} = P_1 + P_2 + P_3$ $S_{3\sim} = S_1 + S_2 + S_3$
6 to 12 Phase		$P_1 = \frac{1}{T} \int\limits_{t=0}^{T} u_1(t) \cdot i_1(t)\, dt$ $....$ $P_n = \frac{1}{T} \int\limits_{t=0}^{T} u_n(t) \cdot i_n(t)\, dt$ $P = P_1 + P_2 + ...P_n$

5.5. Power module

The power module is one of the most complex mathematical modules in DewesoftX®. It allows measurements of different frequency power grids in different configurations and even variable frequency sources. This section will demonstrate how to use it.

After the configuration of the voltage (please refer to the voltage pro training) and current (please refer to the current pro training) inputs it is now possible to add a new power module by clicking on the "+" button in the channel set-up. Then click on the "power analysis" button by doing this the power icon will be available.
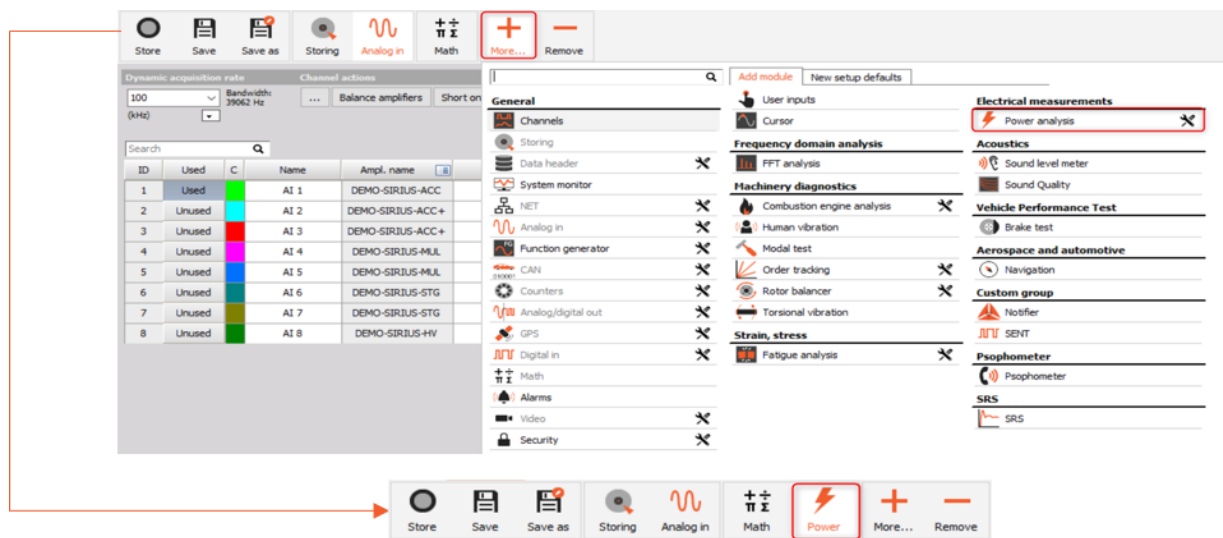
Image 64: Activating the power module in DewesoftX®

The following image gives an overview of the power module set up screen.
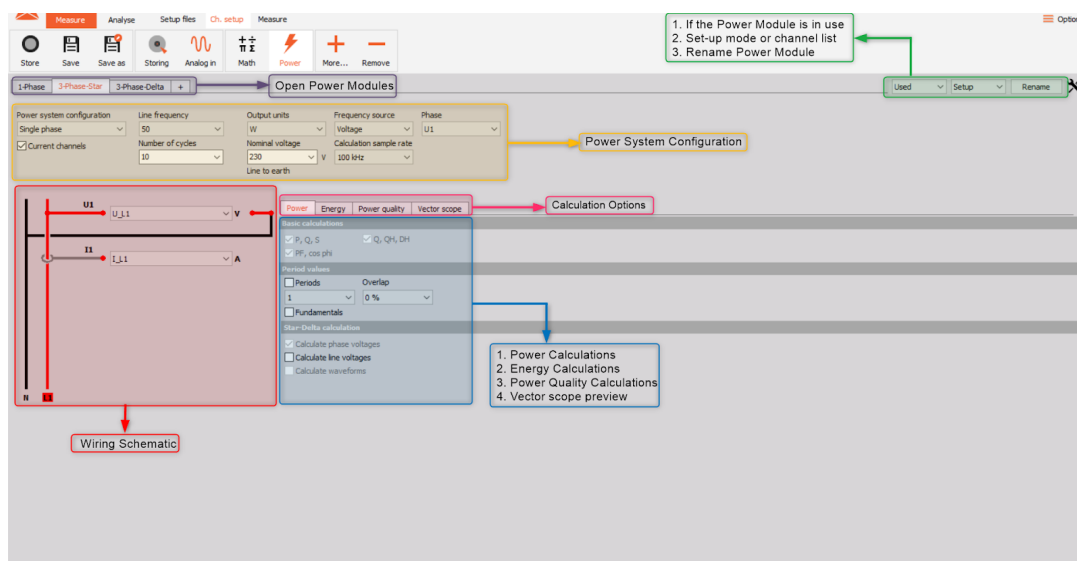
Image 65: Overview of the power module setup screen

5.5.1. Power module configuration and wiring

In the power module, there are several wiring schematic configurations available. The most common ones are 1-phase and 3-phase star and 3-phase delta connections. 2-phase is used with special motors and also in some applications of the grid. The Aron and V configuration are basically star or delta configuration but measuring only 2 currents instead of 3 (see 3-phase measurement). Special configurations like 6-, 7-, 9- or 12 phase motor measurement can be done with multiple single-phase systems and adding up the power values in the Math library.

The wiring schematics are covered in a later chapter, while this chapter focuses on the configuration of the power module
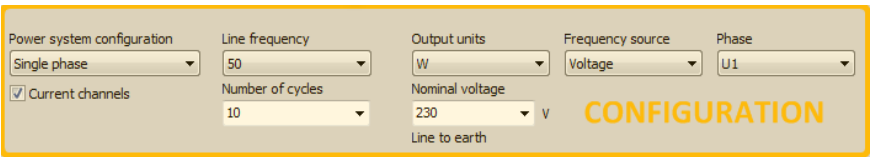
Image 66: Wiring schematics in DewesoftX®

5.5.2. Line Frequency

Firstly, the line frequency must be set. In the public grids the frequencies are 50 Hz for Europe and 60 Hz in the USA (please make sure that the correct frequency is set for the region where the measurement will take place). There are also other line frequencies available (16,7 Hz, 25 Hz, 400 Hz, 800 Hz) for special applications. For inverter measurements "variable frequency" must be selected. The "variable frequency" setting searches automatically for the fundamental frequency in the signal via an FFT algorithm (highest peak).

Frequency	Application	
16,7 Hz	Railway	
25 Hz	Railway	
50 Hz	Public Grid	
60 Hz	Public Grid	
400 Hz	Aerospace	
800 Hz	Aerospace	
Variable frequency from 1 Hz to 2 kHz	Inverter and all other applications	

This algorithm calculates the frequency with very high accuracy (mHz) but is also very CPU intensive (CPU power). For optimal performance, it's recommended to set a range (start and end frequency) where the fundamental frequency could be via the "Exact frequency settings". For example, when measuring an inverter driven motor and it is known the fundamental frequency is no higher than 200

Hz it is recommended to add an end frequency a little higher than the known frequency for example at 250 Hz.
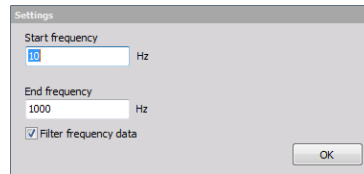
Image 67: Start and end frequency ranges

5.5.3. Output units

When measuring high power, it could be useful to change the output unit to a higher unit. Available are Watt, Kilowatt and Megawatt.
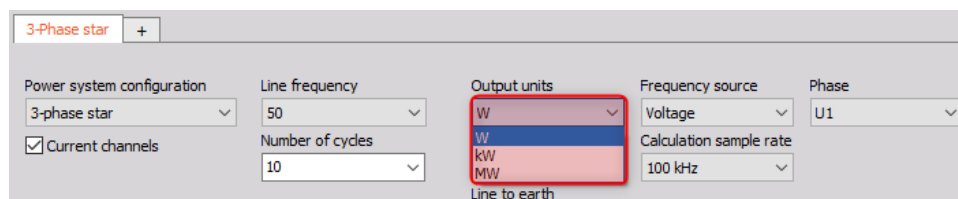
Image 68: Output units in the power module

5.5.4. Frequency source

A special functionality in the power module is the selection of the frequency source. As a source, the voltage, the current, external signal or an arbitrary channel can be selected.
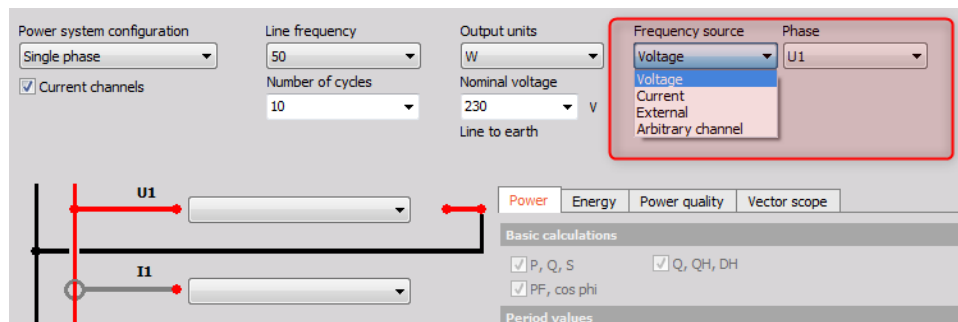
Image 69: Frequency source in the power module

Arbitrary channel uses filters for better and more stable frequency determination. For all different types of frequency sources, it is possible to select the channel which should be used for the frequency calculation.

If there are more than one power module, it is possible to synchronize the modules with arbitrary channels. (E.g. by selecting one phase out of another power module)

As seen in the following image of an inverter measurement, the voltage (green) isn't a sinusoidal waveform any more. It has become a packet of pulses. In this case, if voltage is selected as the frequency source there is a chance that the determination might be faulty. On the other hand, the current

waveform (orange) has a nice stable sinusoidal form and should rather be selected as the frequency source as this will yield much better results. The oscilloscope function in the DewesoftX® software is extremely helpful in analyzing the signals for frequency source determination.
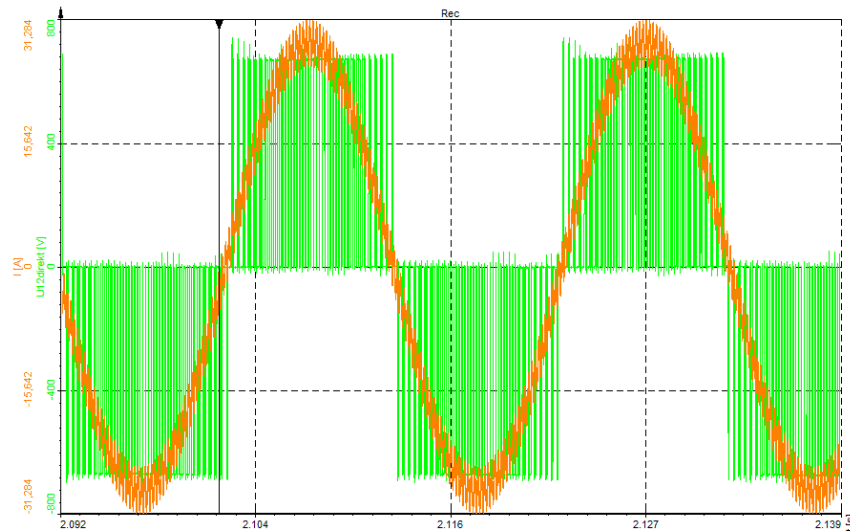
Image 70: Voltage PWM signal and a sinusoidal current signal

> **Hint**
> Please use voltage as the Frequency source for frequency calculation even if it is a PWM signal as in the picture above!

5.5.5. Number of cycles

In this option, the number of cycles for the power calculation can be set as shown in the image below on the left-hand side. As standard, this value is 10 periods for 50 Hz measurements and 12 periods for 60 Hz applications (required in the 61000-4-30 standard). In the dropdown list only 10 and 12 cycles are selectable, but any arbitrary number up to 999 can be entered into the field, the lowest number of periods is 5. For all other applications, if there is a need for faster values the "period values" functionality can be used, please ensure that this function is enabled by clicking in the checkbox, it is activated when there is a tick in the box as seen in the image on the right-hand side.
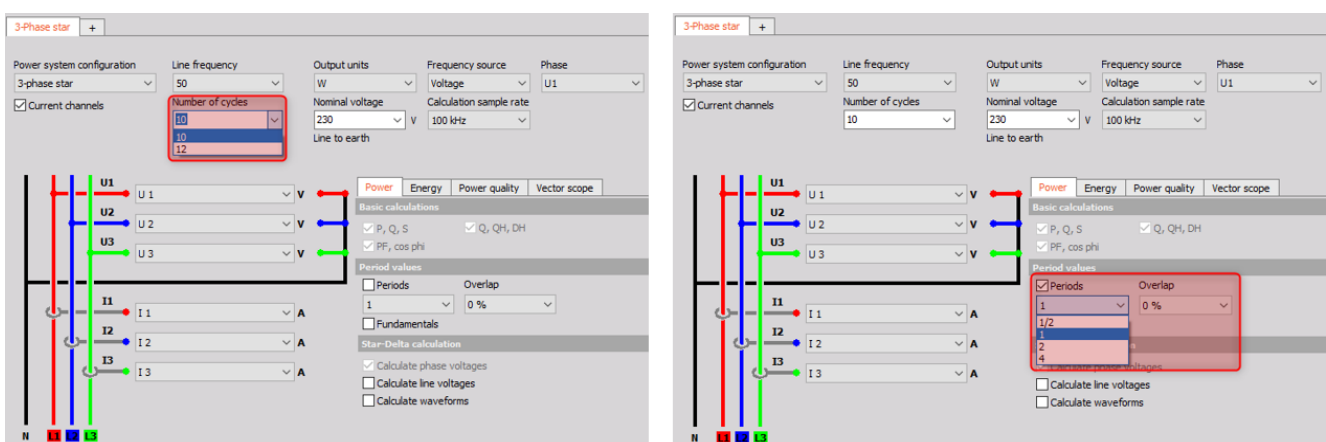
Image 71: Number of cycles and period values in the power module

5.5.6. Nominal voltage

The entry of the nominal voltage is important if you want to calculate the Flicker values. For other measurements the voltage should be set to at least an approximate voltage of the measurement. If this value is set very high (e.g. measuring inverter with 20 V output and the nominal voltage is selected to 400V) the frequency determination might fail.

Example:

- 230 V - line to earth voltage for star configuration
- 400 V - line to line voltage for delta configuration
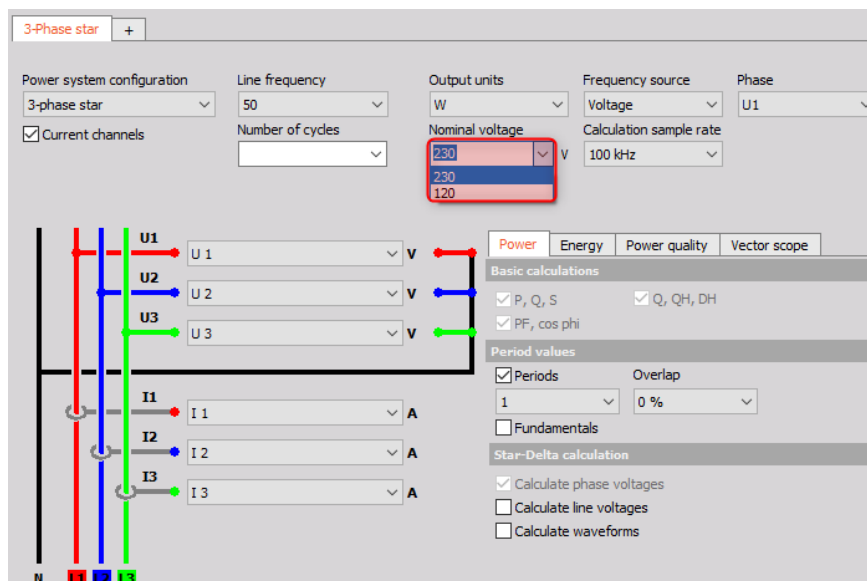
Image 72: Nominal voltage selection in the power module

In the drop-down list 120 V and 230 V is available, but it is possible to enter any arbitrary voltage that is required for the measurement in the nominal voltage field.

5.5.7. Calculation sample rate

The calculation sampling rate in the power module is like a sample rate divider for the power calculations. At high sampling rates (>100 kHz) this is often necessary due to performance problems (CPU power reaching its limit). Nevertheless, the calculation rate that is required shall be selected for the measurement. If all the data is stored at the full sampling rate (always fast) it is also possible to calculate in the power module at the full calculation rate in the post-processing function.

Typical calculation rates:

- grid measurement - 10 to 20 kHz
- wind, renewable, etc. - 50 kHz
- inverter measurement - 100 kHz or more
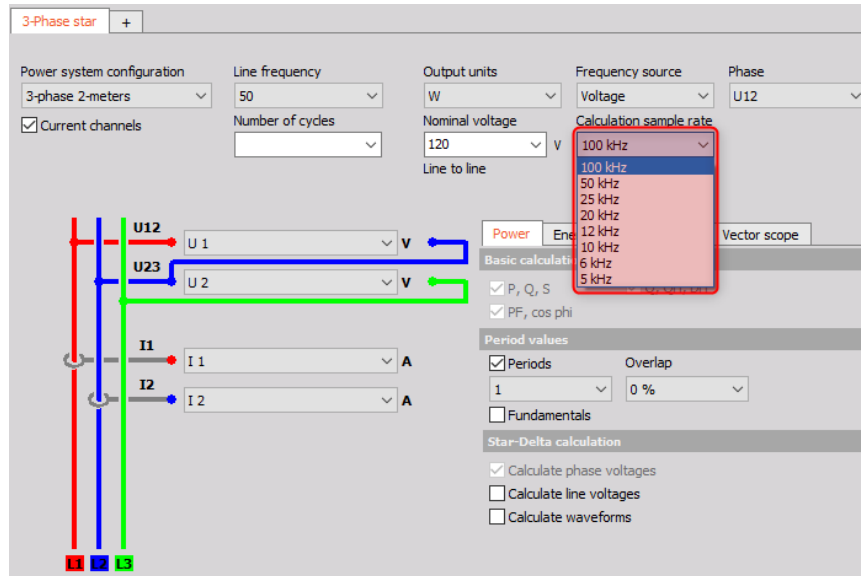
Image 73: Calculation sample rate in the power module

After all the configurations have been done, the channel list will show which parameters will be calculated by the DewesoftX® software.

Period values for each phase	
Channel name in DEWESoft	**Description**
U_L1per	phase-to-earth voltage
U_L12per	phase-to-phase voltage
U_L1_H1per	fundamental phase-to-earth voltage
I_L1per	phase current
I_L1_H1per	fundamental phase current
P_L1per	active power of phase
P_L1_H1per	active power of the fundamental of the phase
Q_L1per	reactive power of phase
Q_L1_H1per	reactive power of the fundamental of the phase
S_L1per	apparent power of phase
S_L1_H1per	apparent power of the fundamental of the phase
PF_L1per	power factor of the phase
phi_L1_H1per	period value of phi

Power values total	
Channel name in DEWESoft	**Description**
Uper	average voltage of all phases
U_H1per	average voltage of all phases for the fundamental
Iper	cumulate current of all phases
I_H1per	cumulate current of all phases for the fundamental
Pper	active power
P_H1per	active power of the fundamental
Qper	reactive power
Q_H1per	reactive power of the fundamental
Sper	apparent power
S_H1per	apparent power of the fundamental
PFper	Power Factor
phi_H1_per	average phi of the fundamental

The power module calculates many parameters. Most of the time not all these parameters are needed for the current application. In this case it is possible to deselect some of the unneeded parameters. This will reduce the data file sizes (The size of the reduction relies strongly on the number of deselected parameters but also on the parameter calculation intensity as these also differ).

Image 74: Channel list in DewesoftX®

5.5.8. Multiple power modules

In the DewesoftX® software multiple power modules can be created. This means that power can be measured at multiple points completely synchronous. In the math library the power modules can be further refined, for example the efficiency can be calculated automatically (see efficiency calculation). This is also very helpful when measuring multi-phase motors (6-12 phases). Just click on the + next to the already active power modules to add another one.
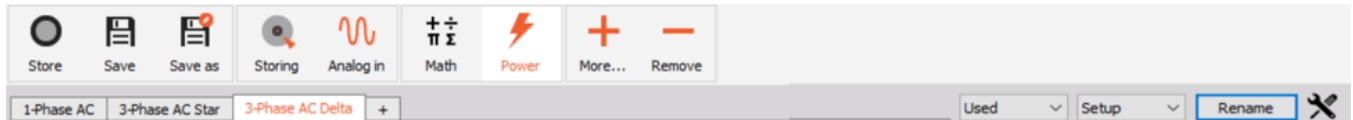
Image 75: Multiple power modules

5.5.9. Vectorscope

The vectorscope in the power module gives a fast overview of all voltage and current channels that are connected to the power module and if they are connected correctly to the measurement device.

The bottom right of the vectorscope depicts what the voltages and currents should look like. If a voltage or current has been connected incorrectly the hardware connections don't have to be changed, this can be corrected in the DewesoftX® software using the wiring schematics. In addition to the correct positioning of the phases, it is also possible to verify that the current transducers have been connected correctly. Should this not be the case, it can also simply be changed within the software, in the analog set-up using the scaling option just click on the "±" to change the polarity.
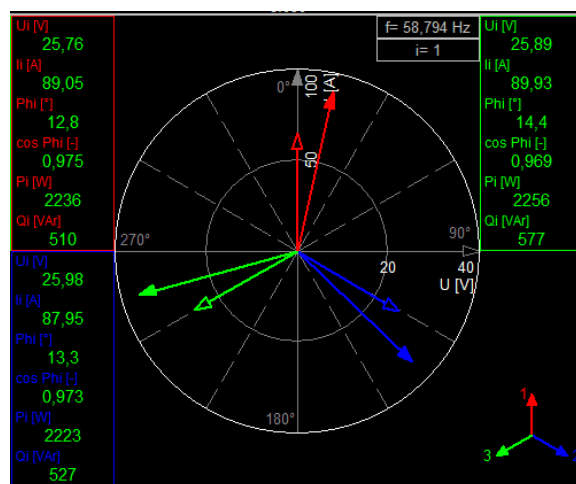
Image 76: 3-phase vectorscope

5.5.10. Harmonics, THD, Flicker emissions, RVC and background harmonics

These features will be discussed in the power quality section in the next chapter

5.5.11. Period values

Period values are needed to perform a detailed analysis of electrical equipment (e.g. analyzing behavior at faults or switching processes) and for fault recording (as a trigger argument). The period values are calculated for voltages, currents, active-, reactive-, apparent-power, power factor as well as other parameters.

The period values can be calculated with a definable overlap (up to 99%) and for a definable number of periods (up to 4). Using an overlap of 99% at a 50 Hz measurement you can calculate the power values for every 0,2 ms. That's a unique feature of DewesoftX®.

Overlap: 25%, 50%, 75%, 90%, 95%, 99%

Periods: 1/2, 1, 2, 4

Image 77: Period values in the power module

The period values are not corrected in amplitude and phase as is the case for the other power calculations in the power module.

Considering the period values for the symmetrical components (for more details please see the Power Quality Pro training) there are more than 50 parameters available.

Period Values for each phase:	
Channel name in Dewesoft	**Description**
U_L1per	phase-to-earth voltage
U_L12per	phase-to-phase voltage
U_L1_H1per	fundamental phase-to-earth voltage
I_L1per	phase current
I_L1_H1per	fundamental phase current
P_L1per	active power phase
Q_L1_H1per	active power of the fundamental of the phase
Q_L1per	reactive power of phase
Q_L1_H1per	reactive power of the fundamental of the phase
S_L1per	apparent power of phase
S_L1_H1per	apparent power of the fundamental of the phase
PF_L1per	power factor of the phase
phi_L1_H1per	period value of phi

Period Values Total:	
Channel name in Dewesoft	**Description**
Uper	average voltage of all phases
U_H1per	average voltage of all phases for the fundamental
Iper	cumulate current of all phases
I_H1per	cumulate current of all phases for the fundamental
Pper	active power
P_H1per	active power of the fundamental
Qper	reactive power
Q_H1per	reactive power of the fundamental
Sper	apparent power
S_H1per	apparent power of the fundamental
PFper	power factor

5.5.12. Visualization in the power module

After configuring the power module, the measurement screen(s) can be configured in measurement mode. As discussed earlier different visualization modes can be added by switching to design mode. The visualizations that are available are located at the top of the window. On the right side of the window is the channel list and on the left side is the properties of the different visualizations.
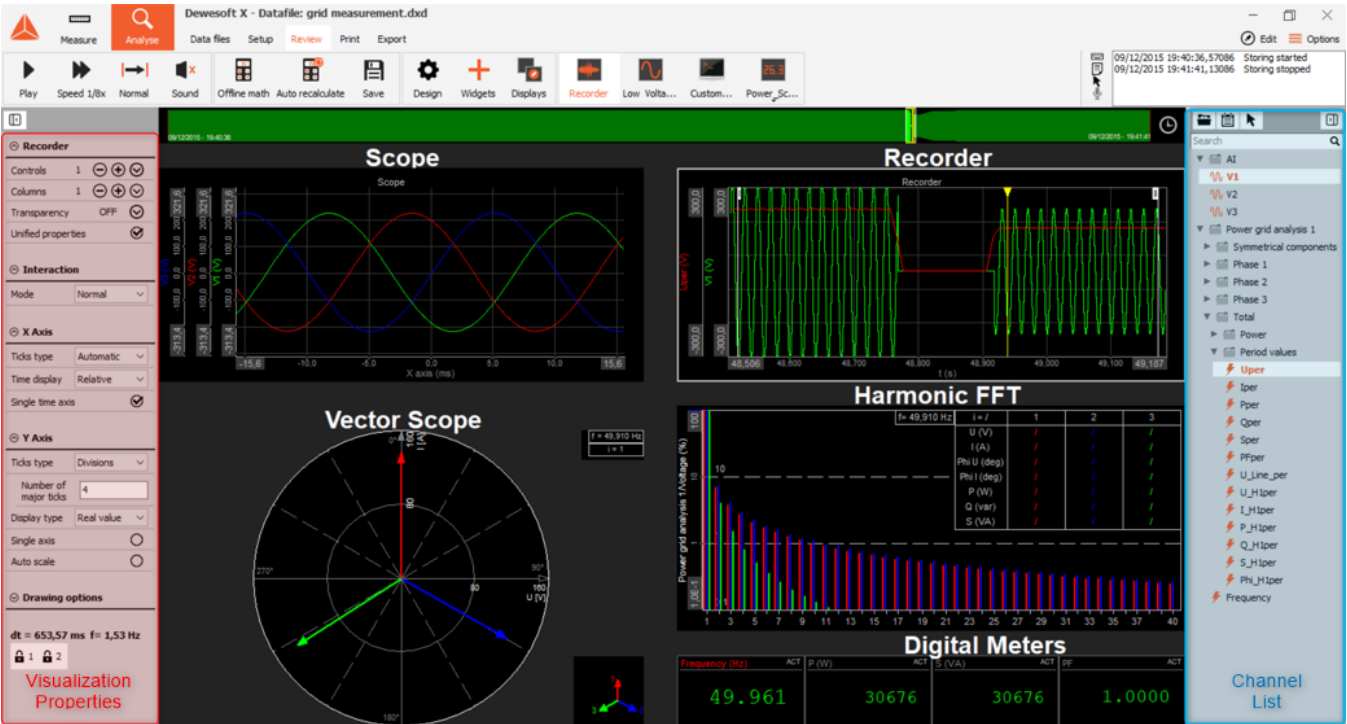
Image 78: Visualization overview of the measurement screen in the power module

The most relevant visualizations for power analysis are:

- Digital meters (depicts the different instantaneous values calculated out of the power module)
- Recorder (depicts the chart of power values)
- Scope (depicts waveforms of voltages and currents)
- Vector-scope (depicts the relation between the voltages and currents)
- Harmonic FFT (depicts the harmonics of voltage, current, power and reactive power synchronized to the fundamental frequency of the signal)
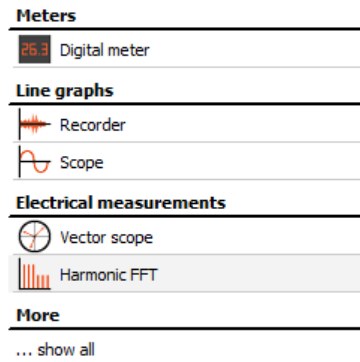
Image 79: Most relevant visualizations for power analysis

5.5.13. Channel list

In the channel list you now find all the parameters which are automatically calculated out of the power module. They are categorized to easily find the desired values:
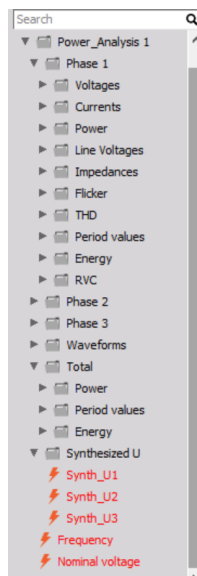
Image 80: Channel list in the power module

In the next section the vectorscope and the harmonic FFT will be described in more detail as these two visualizations were specifically implemented for power module calculations.

5.5.14. Vectorscope

"Vectorscope" means that not only the absolute values of current and voltage are important but also the phase relation between current and voltage. This is essential as only current that is in phase with the voltage can be used to produce useful work.

Therefore, in the vector scope both the absolute values and the angle known as the angle φ (phi) is measured. From the angle φ the value of cos φ can also be calculated (which in principle is just the cosine of the angle φ, this is important because it is the direct ratio of work that is done compared to the consumed current). In the vectorscope the voltage vector (hollow point arrow) and the current vector (full point arrow) for each harmonic can be shown.
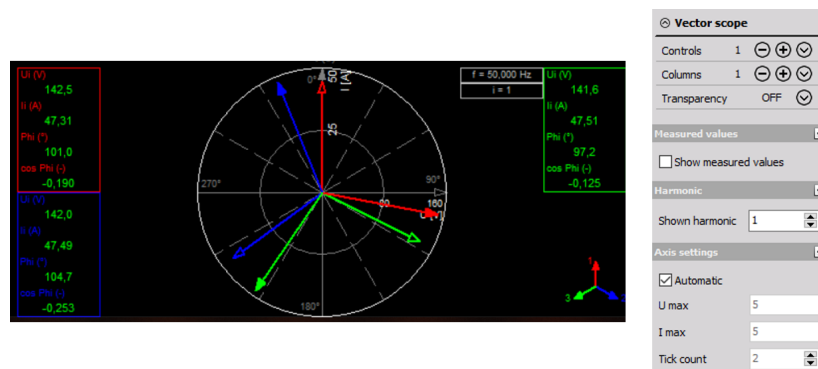
Image 81: Vectorscope settings

DewesoftX® has a special feature where the vectorscope's orientation can be changed. This means that the scope can be shown in a clockwise and in an anti-clockwise manner, and it is also possible in some special applications to change the vectorscope orientation to the right. This can be changed in "Settings'' → "Extension" → " Power grid analysis". The default setting is to show the vectorscope for the first harmonic. Via the input field "shown harmonic" in the visualization properties each individual harmonic can be selected.
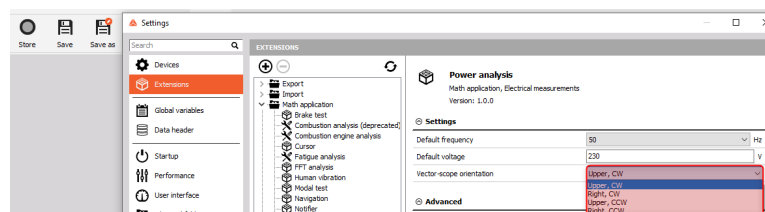
Image 82: Changing the orientation of the vectorscope in DewesoftX®

Furthermore, the scaling for voltage and current can be defined either manually or automatically. The option "Show measured values" adds digital values of basic power parameters for each phase on the right and left side of the vector scope. The option "Tick count" defines the number of circles to be shown.

- upper, CW - zero is top, the positive phase angle is right
- right, CW - zero is right, the positive phase angle is right
- upper, CCW - zero is top, the positive phase angle is left
- right, CCW - zero is right, the positive phase angle is left

5.5.15. Harmonic FFT

In the power module the harmonics can be calculated for apparent-, active- and reactive-power for each individual harmonic. But is it necessary to calculate the harmonics?

In theory, voltage and current have a perfect 50 (or 60) Hz sine wave. This is the case if there are just linear loads (Ohmic) connected to the grid (e.g. incandescent light bulbs). But as there are more and more non-linear loads connected (ballast unit, inverter, etc.), some generation units are not linear anymore either e.g. Wind, PV, etc., therefore the waveform of voltage is not an ideal sinusoidal wave anymore. The images below show the voltage and current of an incandescent light bulb (left) and a LED (right). It can clearly be seen that the incandescent light bulb waveform for current (blue) is sinusoidal but the current of the LED (red) is a pulse waveform with a high crest factor.
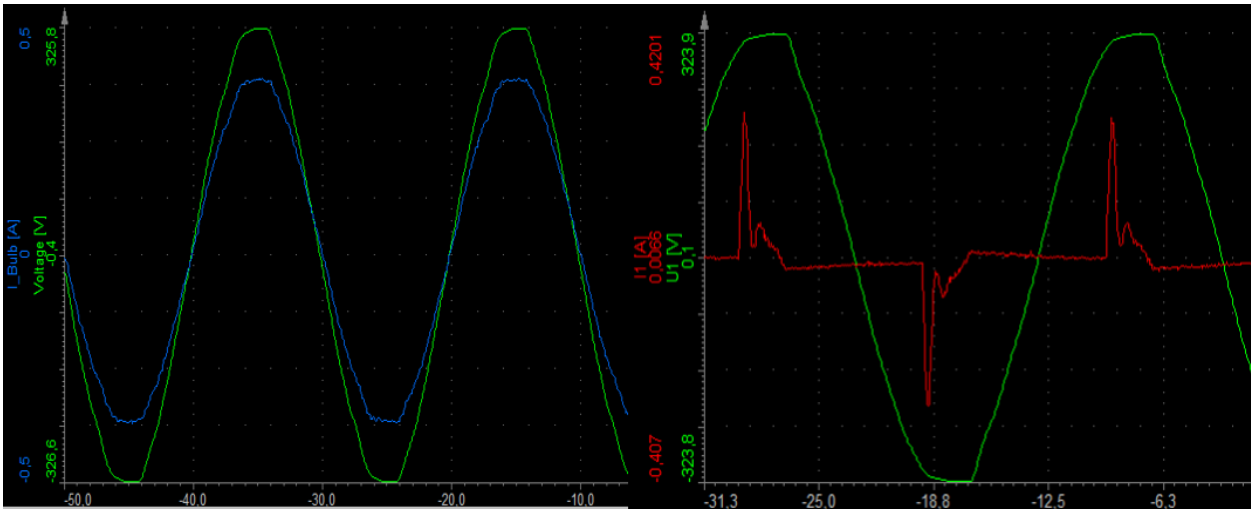
Image 83: Scope view of a pure ohmic load and a non-linear load

The following Harmonic FFTs depicts the big difference of the two different loads (current harmonics):
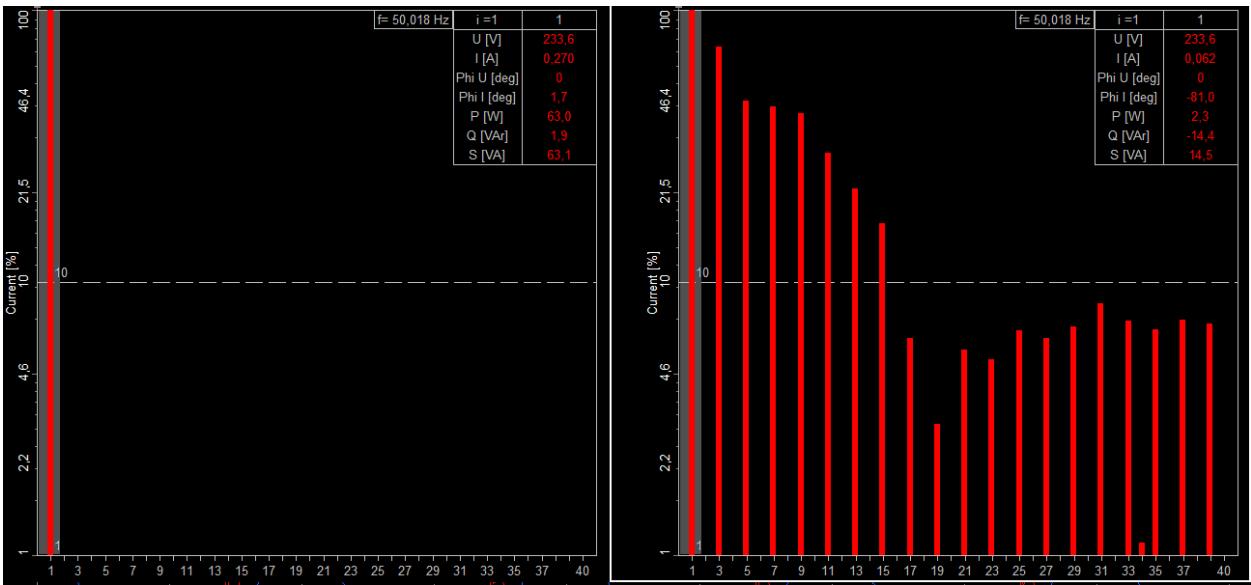
Image 84: Harmonic FFT view of a pure ohmic load and a non-linear load

What is the effect of harmonics? Using an AC electromotor, the first harmonic (line frequency) drives the motor. The rest of the harmonics are either producing vibrations or noise. In truth there are bad and then there are worse harmonics. The 2nd, 5th, 8th... harmonics are really bad since they are braking the motor. The 3rd, 6th, 9th... harmonics are either driving or braking, while 4th, 7th, 10th... harmonics are driving the motor, but they are still producing high noise and vibrations.

In the Harmonic FFT the following can be visualized, harmonic - voltage, current, active and reactive power as well as the line voltage each fully synchronized to the fundamental frequency.

Image 85: Harmonic FFT options in DewesoftX®

In the visualization properties, there are additional options available:

- **Show Data Panel** – The power values of each harmonic can be displayed in the top right corner of the FFT when "Show Data Panel" is selected. The individual harmonic values can be shown by clicking on the order number.
- **Y-Axis** – Here the harmonics can be displayed on a linear or logarithmic scale, as well as if they are shown in an absolute or percentile relative to the fundamental frequency.
- **Draw full FFT** - The option "Draw full FFT" shows all frequencies, not only multiples of the fundamental frequency. As seen in the Line Voltage FFT in the Image.

More details about harmonics and full FFT will be given in the Power Quality section, in a later chapter.

6. Measurement setups

The following section will go into more detail on the possible measurement setups that are available in DewesoftX®. We will show how to connect both voltage and current in various setups, along with explanations on setting up the measurements in the software. There are also a few screens that show what the possible measurements could look like when the setups are done and measurements are made.

6.1. DC power measurement

First we will start with a DC setup.

6.1.1. Hardware configuration

For a simple DC measurement please connect the voltage and the current to the SIRIUS® as it is shown in the following image.

Image 86: DC measurement hardware configuration

6.1.2. Analog setup

In the next step the analog setup must be done in DewesoftX® for both the voltage and the current (Please refer to the pro trainings on current on voltage as references). The image below shows what a typical DC set-up would look like.

ID	Used	C	Name	Ampl. name	Range	LP filter	Measurement	Min	Values	Max	Physical quantity	Units	Zero	Setup
1	Used		U_DC	DEMO-SIRIUS-HS-HV	1600 V	Off	Voltage	-1600,00	-1290,1 / 1332,5	1600,00	Voltage	V	Zero	Setup
2	Used		I_DC	DEMO-SIRIUS-HS-LV	100 V	Off	Voltage	-100,00	-50,52 / 52,77	100,00	Current	A	Zero	Setup

Image 87: DC measurement analog setup

6.1.3. Power module setup

In the power module, the wiring must be set to DC measurement, this is illustrated in the image below in the red square. Then configuration for the selected application must be done.

On the wiring schematic page, it is possible to select two different calculation modes, this is illustrated in the blue square in the image. Firstly, it is possible to select or type the required calculation rate, or the measurement can be synchronized to another channel. This synchronized channel can be from another power module e.g. a 3-phase power module. Additionally, an energy calculation can be added, as seen in the yellow square in the image.
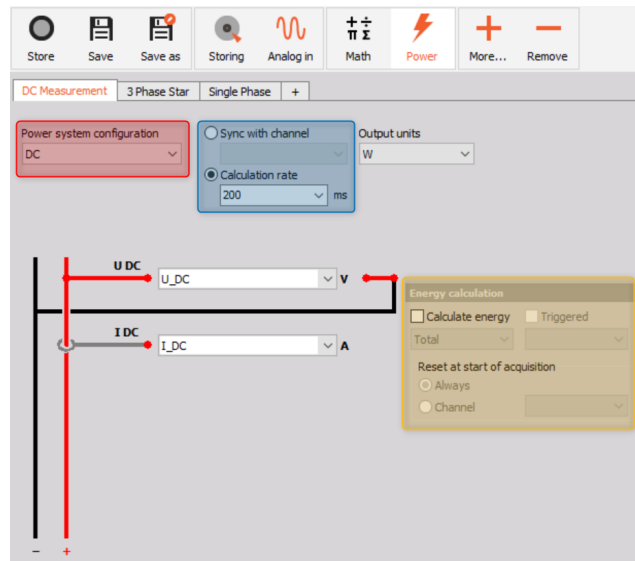
Image 88: DC measurement power module setup

6.1.4. DC Math power calculation (only required in Dewesoft X2)

In Dewesoft X2, a simple math formula needs to be created, by multiplying the DC voltage with the DC current the DC power is calculated.
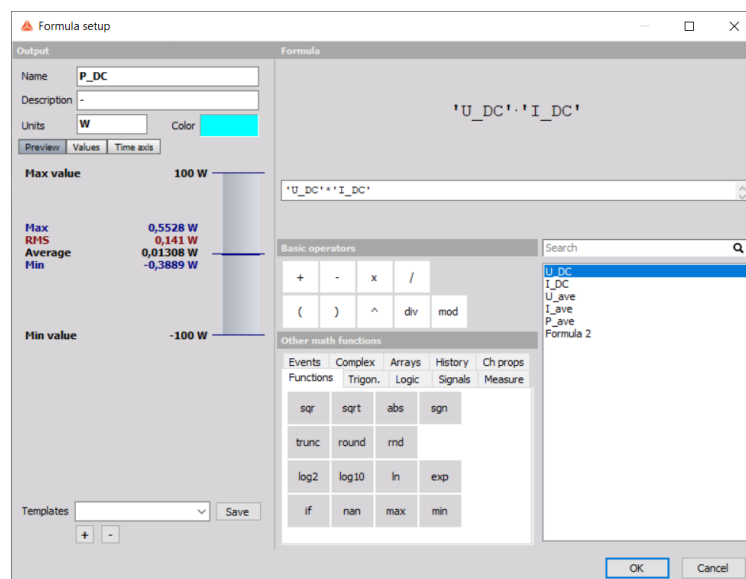
Image 89: DC math power calculation (only required in Dewesoft X2)

> **Important**
>
> Never calculate the DC power using a 1-phase power module. This won't work and will yield incorrect results.

6.1.5. Measurement screen

Switching to the measurement screen the voltage, current and power can be visualized. In the image below, the battery power of an electric vehicle is shown. The voltage (magenta) is relatively constant while the current (green) is only present when power (acceleration - blue) is actuated.
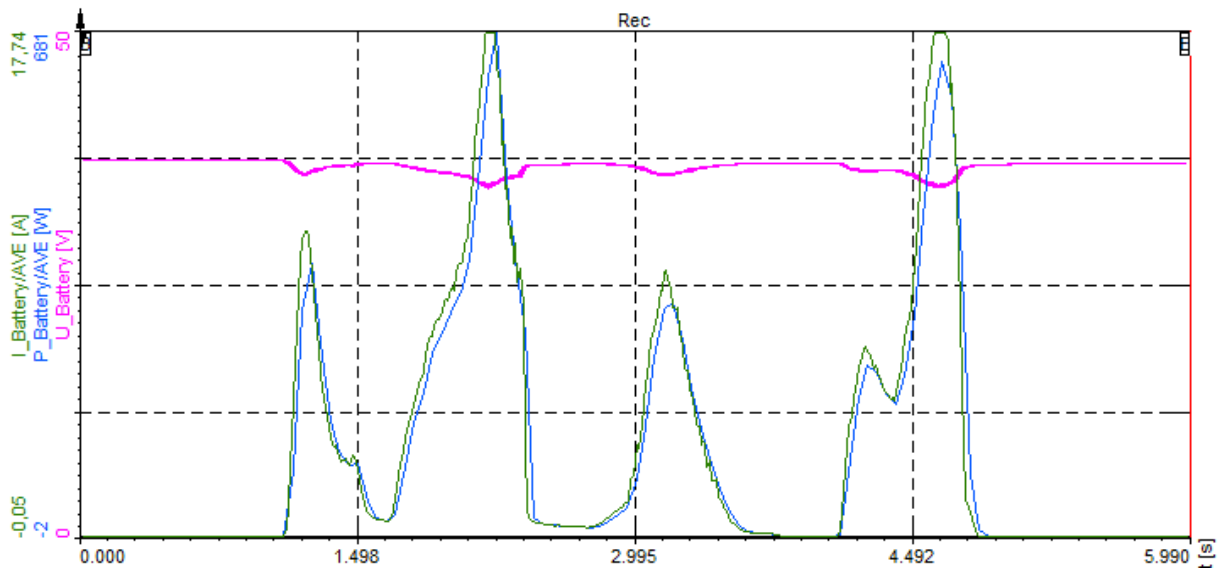
Image 90: DC measurement recorder screen

6.2. 1-Phase measurement

6.2.1. Hardware configuration

For a single-phase AC measurement please connect the voltage and the current to the SIRIUS® as it is shown in the following picture.

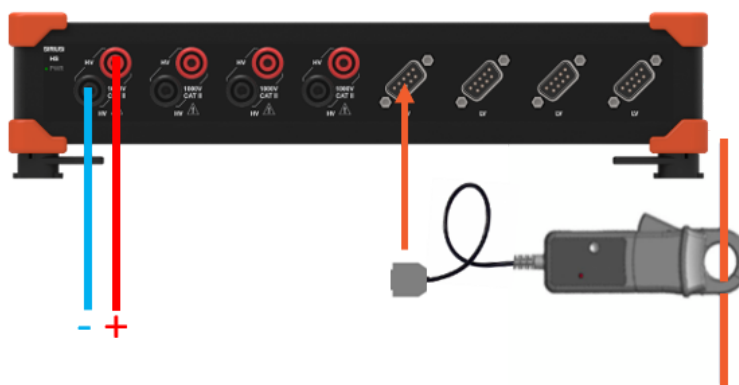*Image 91: Single phase measurement hardware configuration*

6.2.2. Analog setup

In the next step the analog setup must be done in DewesoftX® for both the voltage and the current (Please refer to the pro training on current on voltage as references). The image below shows what a typical 1-Phase set-up would look like.

ID	Used	C	Name	Ampl. name	Range	LP filter	Measurement	Min	Values	Max	Physical quantity	Units	Zero	Setup
1	Used		U_L1	DEMO-SIRIUS-HS-HV	1600 V	Off	Voltage	-1600,00	-1065,0 / 1109,6	1600,00	Voltage	V	Zero	Setup
2	Used		I_L1	DEMO-SIRIUS-HS-LV	100 V	Off	Voltage	-100,00	-88,35 / 91,03	100,00	Current	A	Zero	Setup

Image 92: Single phase measurement analog setup

Hint
Use the XML correction factor for the current transducer to ensure that the highest accuracy is yielded in the power calculation. (Please refer to the pro trainings for more information on how to do this)

6.2.3. Power module setup

In the power module, the wiring must be set to single phase and the configurations for the specific application must be done.

For example, measuring a load connected to the public grid the line frequency will be set to 50 Hz (60 Hz in North America, parts of South America, Japan, etc.), the output unit should be Watt, the frequency source is voltage, number of cycles are 10 (12 in case of 60 Hz) and the nominal voltage (line to earth) is 230 Volts in Europe (this varies from country to county). In the drop down list 120 V and 230 V can be selected, but in the input mask it is possible to enter the value that corresponds to the measurement.

Image 93: Single phase power module setup screen

6.2.4. Measurement screen

After switching to measurement mode, the screen design for the measurement can be set up to the requirements of the user. The image depicts a measurement screen with most common graphs and values that are measured in a 1-phase measurement.
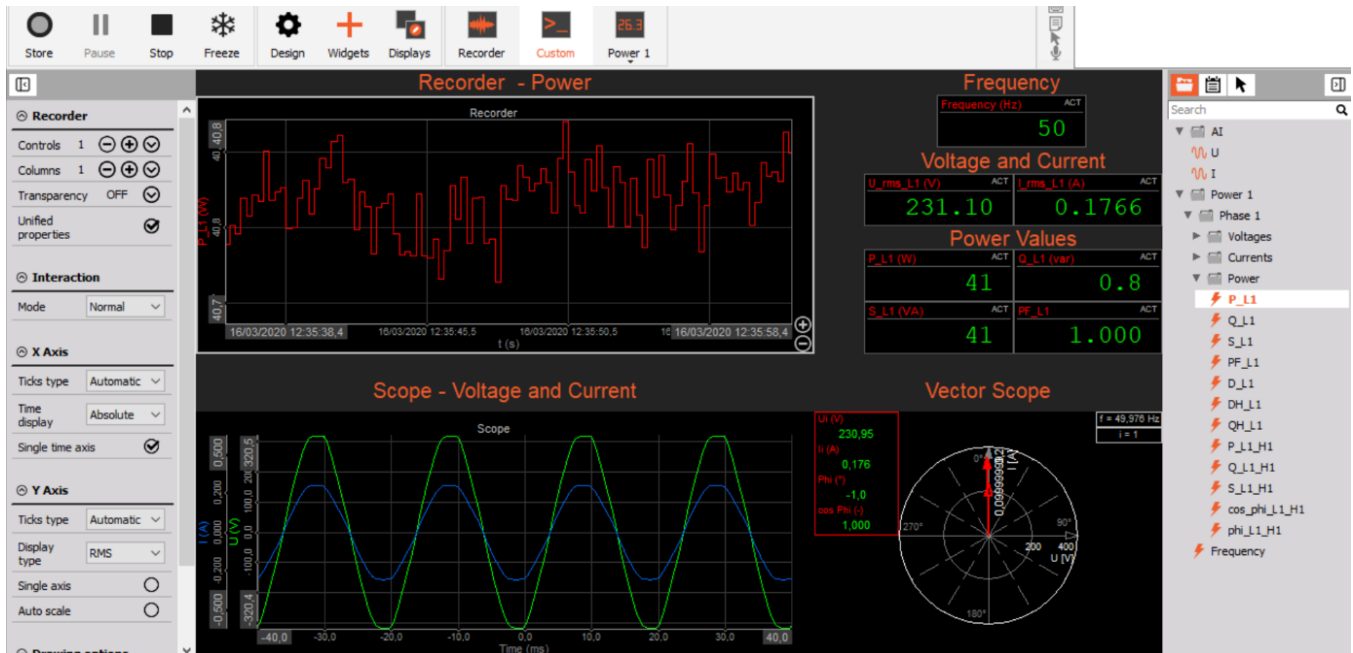
Image 94: Single phase measurement screen

6.3. 2-Phase measurement

2-phase measurements are seldom, but some motors (e.g. step motors) for example are operated with two phases (one phase has a phase shift of 90° to the other).

6.3.1. Hardware setup

For a 2-phase AC measurement please connect the voltage and the current to the SIRIUS® as it is shown in the following image.

Image 95: 2-Phase measurement hardware setup

6.3.2. Analog Setup

The next step would be setting the analog setup for the voltage and current input (please refer to the pro training on voltage and current for more information).

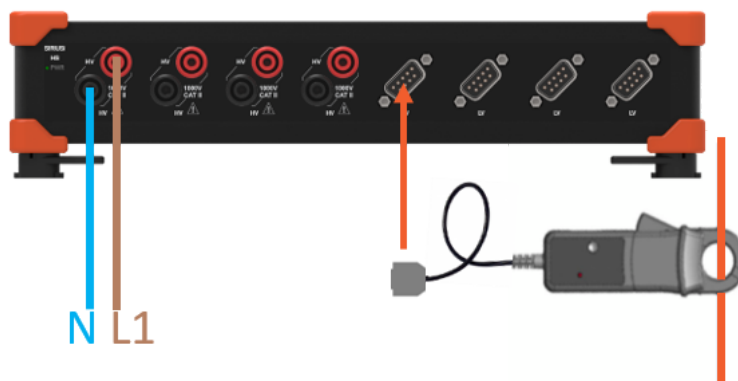| ID	Used	C	Name	Ampl. name	Range	LP filter	Measurement	Min	Values	Max	Physical quantity	Units	Zero	Setup
1	Used		U_M 1	SIRIUS-HS-HV	400 V	Off	Voltage	-400,01	-321,4 / 321,4	399,99	Voltage	V	Zero	Setup
2	Used		U_M 2	SIRIUS-HS-HV	400 V	Off	Voltage	-400,02	-321,4 / 321,4	399,98	Voltage	V	Zero	Setup
3	Unused		AI 3	SIRIUS-HS-HV	1600 V	Off	Voltage	-1600,04	0,0	1599,96		V	Zero	Setup
4	Unused		AI 4	SIRIUS-HS-HV	1600 V	Off	Voltage	-1599,98	0,0	1600,02		V	Zero	Setup
5	Used		I_M 1	SIRIUS-HS-LV	0,5 V	10 kHz	Voltage	-5,00	-0,250 / 0,250	5,00	Current	A	Zero	Setup
6	Used		I_M 2	SIRIUS-HS-LV	0,5 V	10 kHz	Voltage	-5,00	-0,255 / 0,252	5,00	Current	A	Zero	Setup
7	Unused		AI 7	SIRIUS-HS-LV	100 V	Off	Voltage	-100,00	0,00	100,00		V	Zero	Setup
8	Unused		AI 8	SIRIUS-HS-LV	100 V	Off	Voltage	-100,00	0,00	100,00		V	Zero	Setup

Image 96: 2-Phase measurement analog setup

Hint
Use the XML correction factor for the current transducer to ensure that the highest accuracy is yielded in the power calculation. (Please refer to the pro trainings for more information on how to do this)

6.3.3. Power module setup

In the power module, the wiring must be set to 2-phase and the configurations for the specific application must be done.

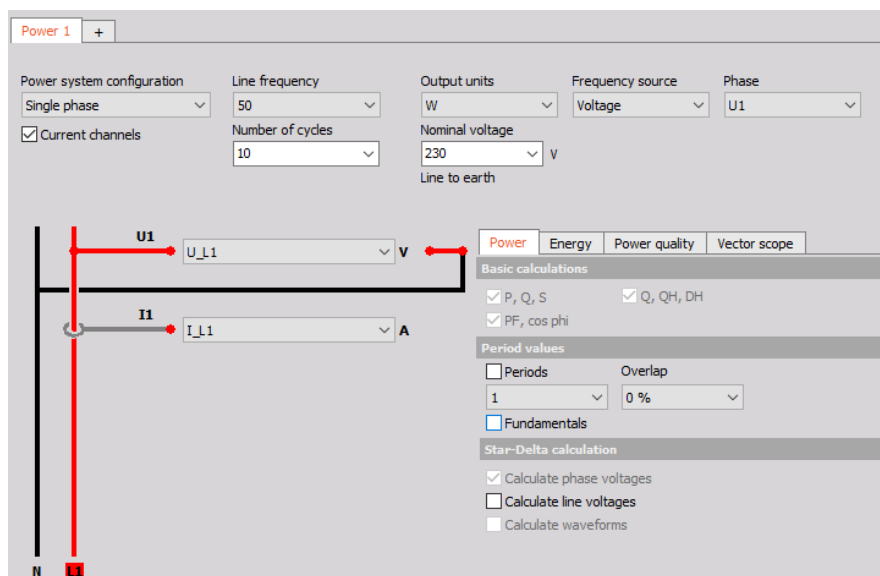*Image 97: 2-Phase measurement power module setup screen*

6.3.4. Measurement screen

After switching to measurement mode, the screen design for the measurement can be set up to the requirements of the user. In this case, the scope and vector scope of a 2-phase step motor is shown as well as the single-phase voltage and current of the grid.
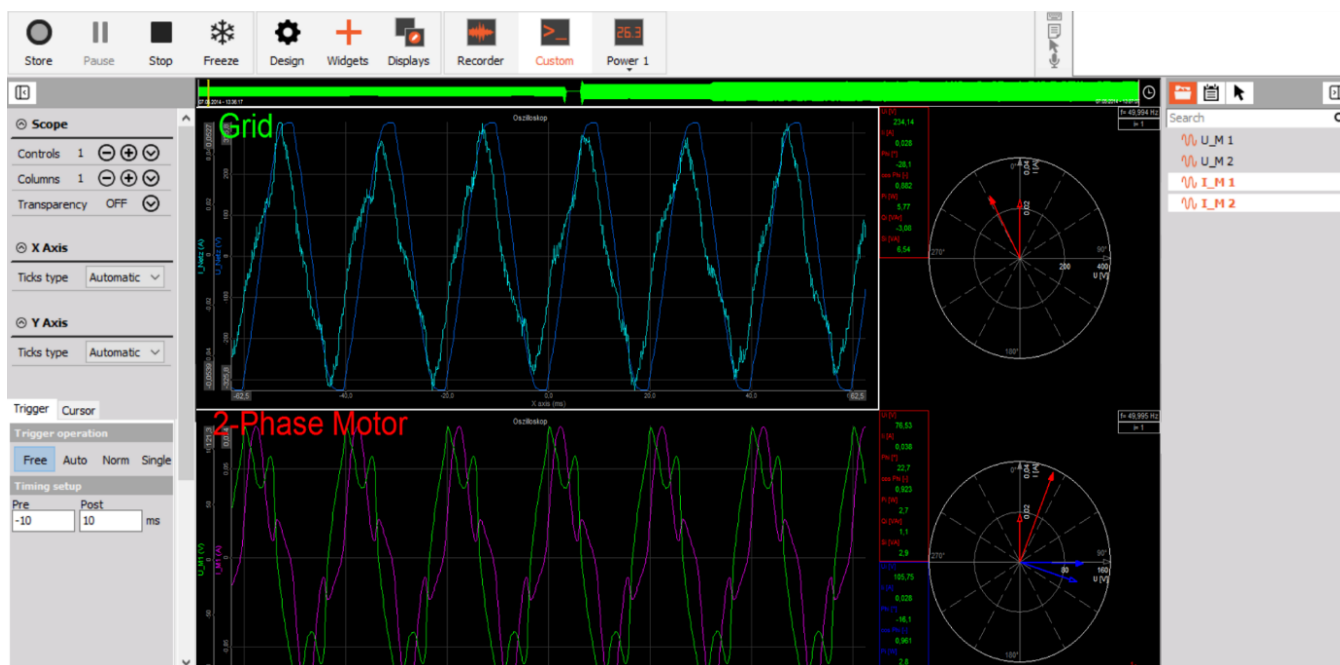
Image 98: 2-Phase measurement screen

6.4. 3-Phase star measurement

The star connection is mainly used for measuring 3-phase systems, especially if a neutral line from the grid or the star point of a motor is available. The three phase voltages are connected to the SIRIUS® HV modules on the high voltage side. The low voltage side of the three inputs is on the potential of the neutral line or motor start point. If both are not available an artificial star-point can be created by short-circuiting the low sides of the amplifiers.

6.4.1. Hardware configuration

The following image shows the connection for a 3-phase star measurement including three zero flux transducers for current measurement. In this measurement zero flux transducers are used therefore, a SIRIUS® MCTS slice needs to be connected as well. This is because the zero flux transducers need more power than the SIRIUS® 4xHv 4xLV can deliver. The SIRIUS® MCTS is designed to deliver power up to 20W per channel.
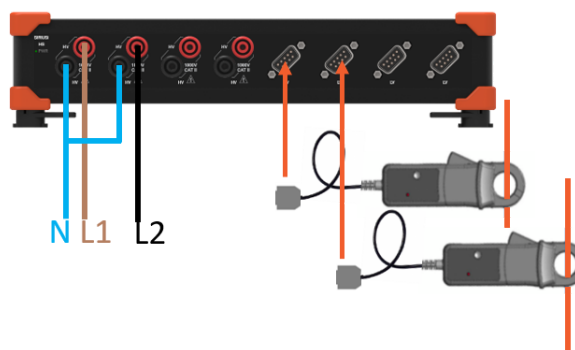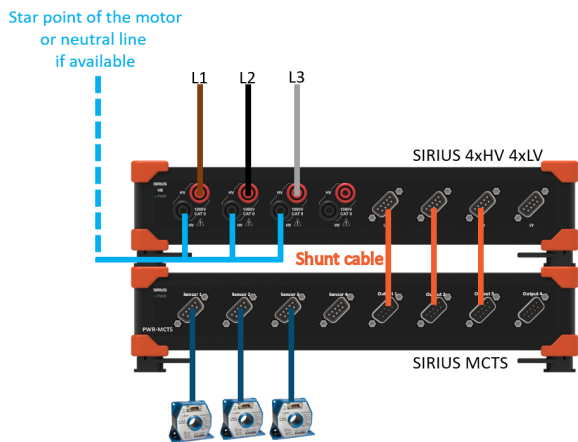

Image 99: 3-Phase star measurement hardware setup

6.4.2. Analog setup

The next step would be setting the analog setup for the voltage and current input (please refer to the pro training on voltage and current for more information).

Image 100: 3-Phase star measurement analog setup

Hint
Use the XML correction factor for the current transducer to ensure that the highest accuracy is yielded in the power calculation. (Please refer to the pro trainings for more information on how to do this)

6.4.3. Power module setup

In the power module, the wiring must be set to 3-phase star and the configuration for the specific application must be done.
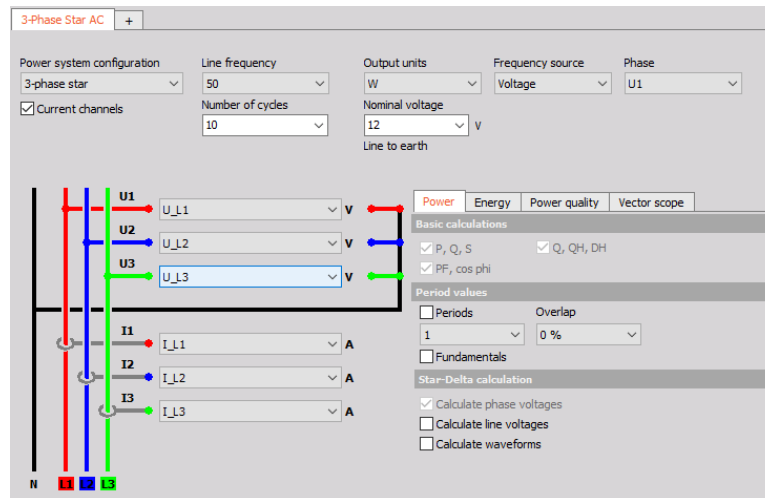
Image 101: 3-Phase star power module setup

6.4.4. Measurement screen

After switching to measurement mode, the screen design for the measurement can be set up to the requirements of the user. In this example the load of a household is shown.

On the top left of the screen there are digital meters that display the voltage and current values in RMS, in the middle is the current power that is being consumed from the grid and on the top right-hand side current power values of the three phases are shown. The left scope in the middle of the screen shows the waveform of the voltage, and the right one the waveform of the current (which is quite distorted). At the bottom of the screen the load profile is shown in a recorder.
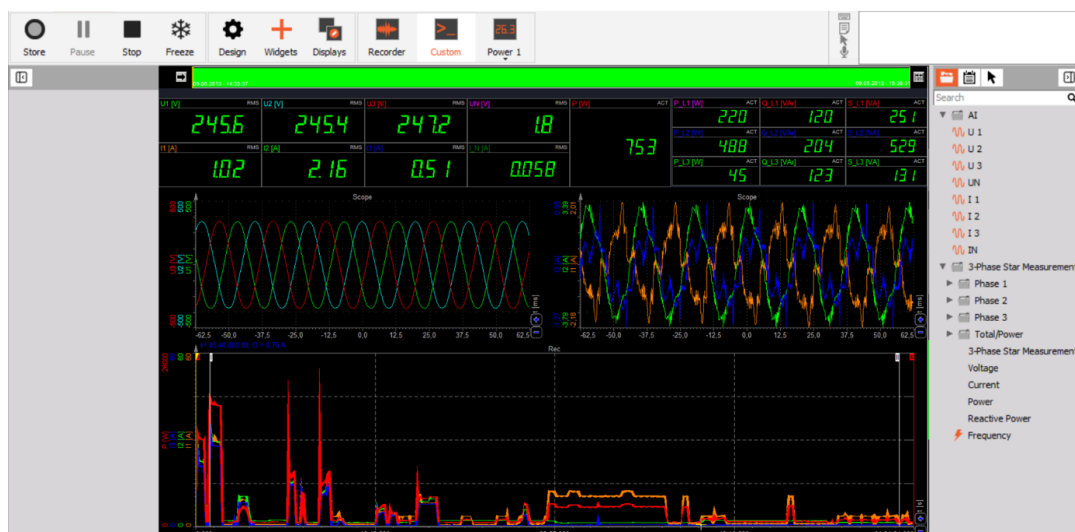
Image 102: 3-Phase star measurement screen

6.5. 3-Phase delta measurement

The delta connection is used in the absence of a neutral line or star point on a motor. The three phase voltages are connected to the SIRIUS® HV modules on the high voltage side to the live terminals (Red). The neutral terminals of the HV amplifier must be connected to the next live terminal (neutral terminal L1 to live terminal L2, neutral terminal L2 to live terminal L3 and then the neutral terminal L3 to the live terminal L1).

6.5.1. Hardware configuration

The following image shows the connection for a 3-phase Delta measurement including three zero flux transducers for current measurement. In this measurement zero flux transducers are used therefore, a SIRIUS® MCTS slice needs to be connected as well. This is because the zero flux transducers need more power than the SIRIUS® 4xHV 4xLV can deliver. The SIRIUS® MCTS is designed to deliver power up to 20W per channel.
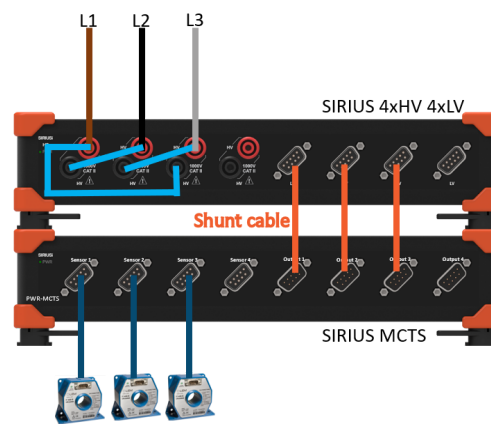
Image 103: 3-Phase delta measurement hardware setup

6.5.2. Analog setup

The next step would be setting the analog setup for the voltage and current input (please refer to the pro training on voltage and current for more information).

Image 104: 3-Phase delta measurement analog setup

💡 **Hint**
Use the XML correction factor for the current transducer to ensure that the highest accuracy is yielded in the power calculation. (Please refer to the pro trainings for more information on how to do this)

6.5.3. Power module setup

In the power module, the wiring must be set to 3 phase-delta and the configuration for the specific application must be done.
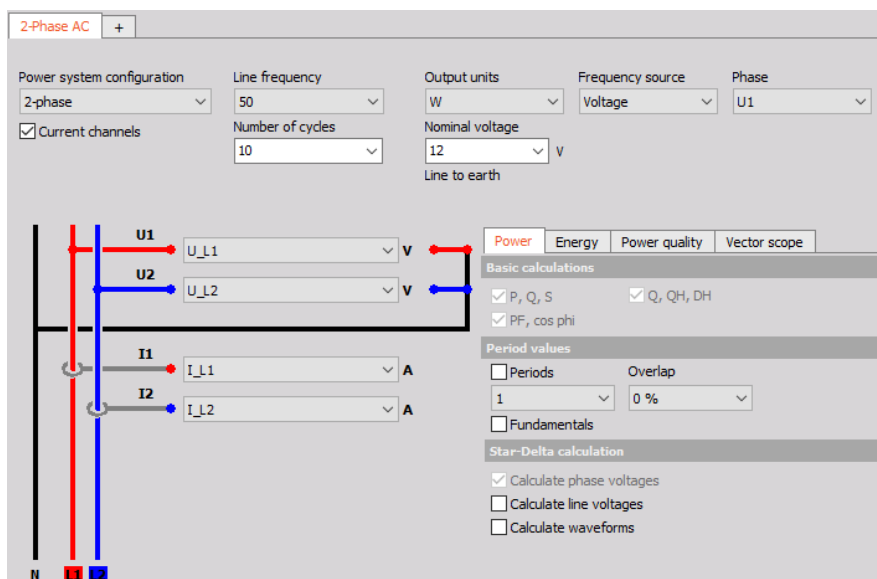

Image 105: 3-Phase delta power module setup

6.5.4. Measurement screen

After switching to measurement mode, the screen design for the measurement can be set-up to the requirements of the user. In this example the measurement of a PV inverter in delta configuration is shown. The vectorscope on the top right shows that the power is being fed into the grid, therefore the current vectors have a phase shift of 180° to the voltage vectors compared to where they would be if the system was consuming power. Further illustrated are the waveforms of both voltage and current on the scopes as perfect sinusoidal waveforms.
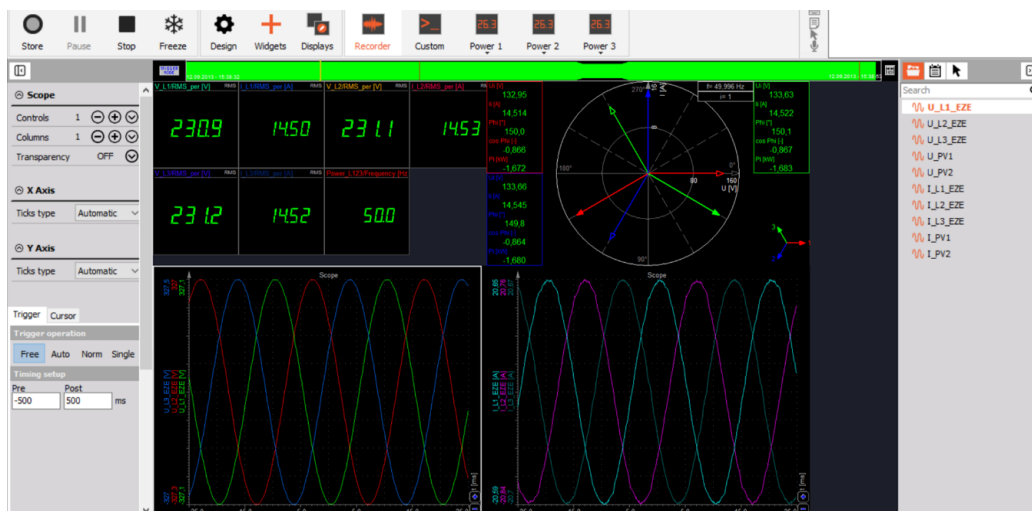
Image 106: 3-Phase delta measurement screen

As a comparison in the next image a 1-phase PV inverter is depicted, with unfavorable wave-forms for both voltage and current. The voltage has a rectangular waveform, electrical devices like this one puts large amounts of stress on the grid. This is mainly due to harmonics that are present in the signals, they cause distortion in voltage and current waveforms causing them to take on different waveforms compared to the ideal Please refer to the Power Quality pro training for more information.
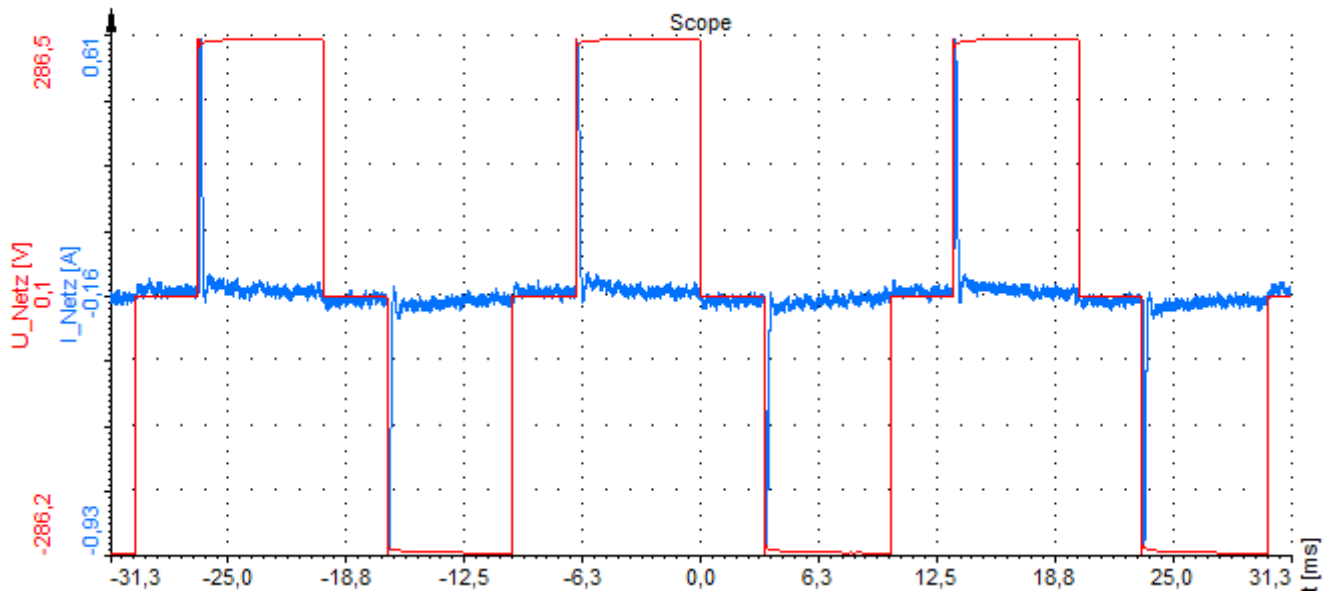
Image 107: 1-Phase PV inverter measurement screen

6.6. Star - Delta calculation

A special feature in the Dewesoft power module is the star-delta calculation.
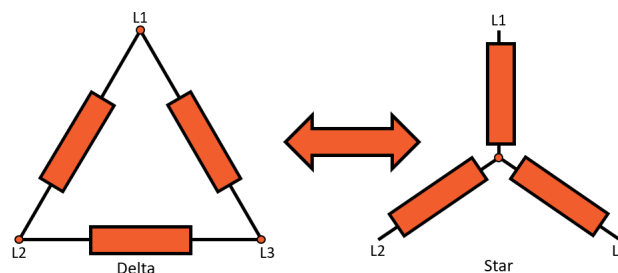
Image 108: Star-Delta calculation

This feature allows for the calculation of all values of a delta connection out of a star connection (waveform, RMS values) and vice versa. This means that no matter the hardware connection to the system, both connection types can be measured. For example, to see the analog voltage signal of a delta connection when a star connection is being used, just select the option "Calculate waveforms" highlighted in BLUE in the image. The next option highlighted in RED "Calculate line voltages" allows RMS voltages and harmonics to be displayed.
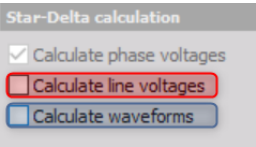
Image 109: Calculate line voltages and calculate waveforms

The following table shows the calculations that are used in [DewesoftX®](#) to do the star-delta and the delta-star conversions.

Star - Delta calculation	Delta - Star Calculation
$u_{12} = u_1 - u_2$	$u_1(t) = \frac{1}{3}(u_{12}(t) - u_{31}(t))$
$u_{23} = u_2 - u_3$	$u_2(t) = \frac{1}{3}(u_{23}(t) - u_{12}(t))$
$u_{31} = u_3 - u_1$	$u_3(t) = \frac{1}{3}(u_{31}(t) - u_{23}(t))$

6.7. Aron, V-connection and 3-phase 2-meters

With some applications, only two currents and / or voltages are measured instead of three in a three-phase arrangement. The main reason for this type of measurement is to save costs.

This is done for measurements where it is completely sure that the load is absolutely synchronous, the third current can then be calculated from the two currents that were measured. This is often done with grid measurements (expensive current transducers, symmetrical load).

Hint
These measurement options can ONLY be used when there is NO neutral line.

Important
Never use these measurement options for an inverter measurement as the measurements will be wrong.

6.7.1. Aron connection

6.7.1.1. Hardware configuration

The most common way of measuring active power with symmetrical and asymmetrical loads without an N connection is the two-power meter circuit or Aron circuit. It has the advantage over the three-power meter circuit that it saves one measuring device and that cos phi and reactive power determination is also possible with a symmetrical load. The Aron connection is a star connection where only two currents are measured.
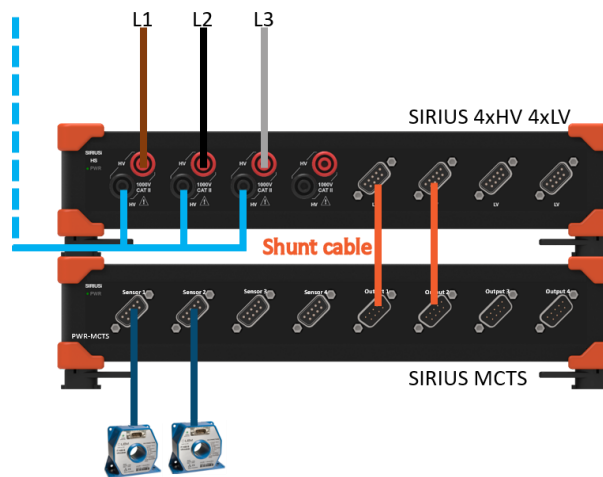
Image 110: Aron connection hardware setup

6.7.1.2. Power module setup

In the power module, the wiring must be set to 3-phase Aron and the configurations for the specific application must be done.
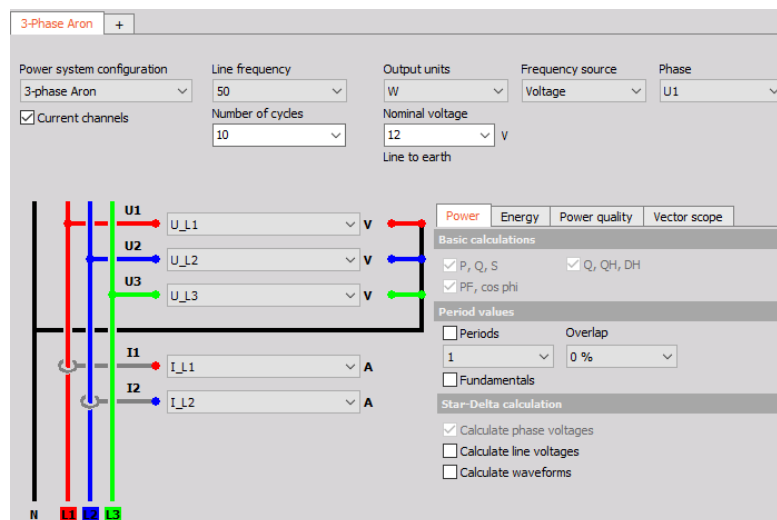
Image 111: Aron connection power module setup

6.7.2. V-connection

6.7.2.1. Hardware configuration

The V-connection is a delta connection where only two currents are measured, but fundamentally works with the same principle as the Aron connection.
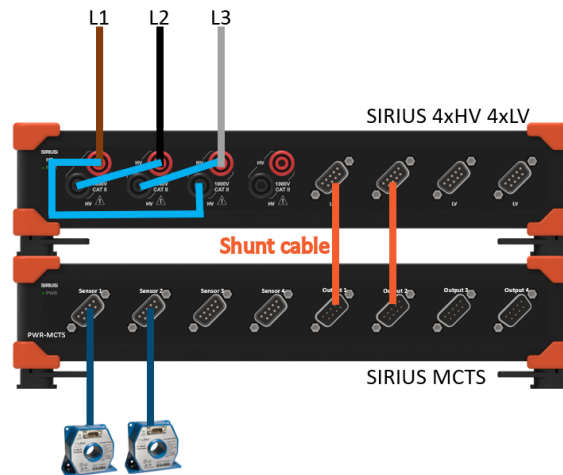
Image 112: V-connection hardware setup

6.7.2.2. Power Module setup

In the power module, the wiring must be set to 3-phase V and the configurations for the specific application must be done.
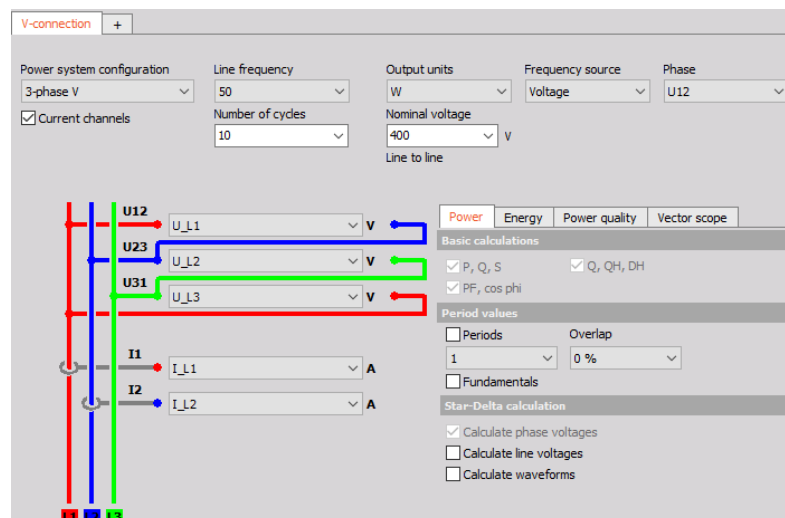
Image 113: V-connection power module setup

6.7.3. 3-Phase 2-meters connection

6.7.3.1. Hardware configuration

The 3-phase 2-meters Connection is a delta connection where just two voltages and two currents are measured.
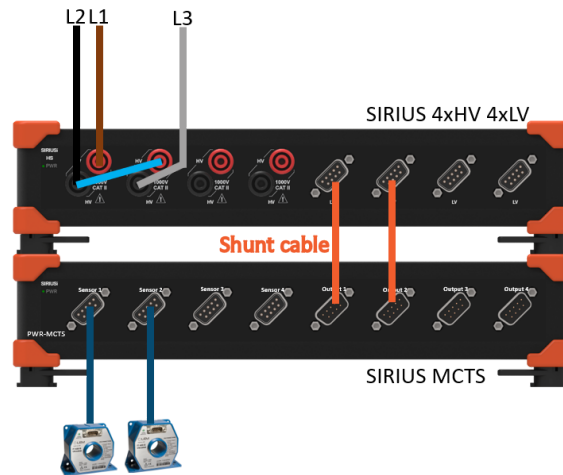
Image 114: 3-Phase 2-meters hardware setup

6.7.3.2. Power module setup

In the power module, the wiring must be set to 3-phase 2-meters and the configurations for the specific application must be done.
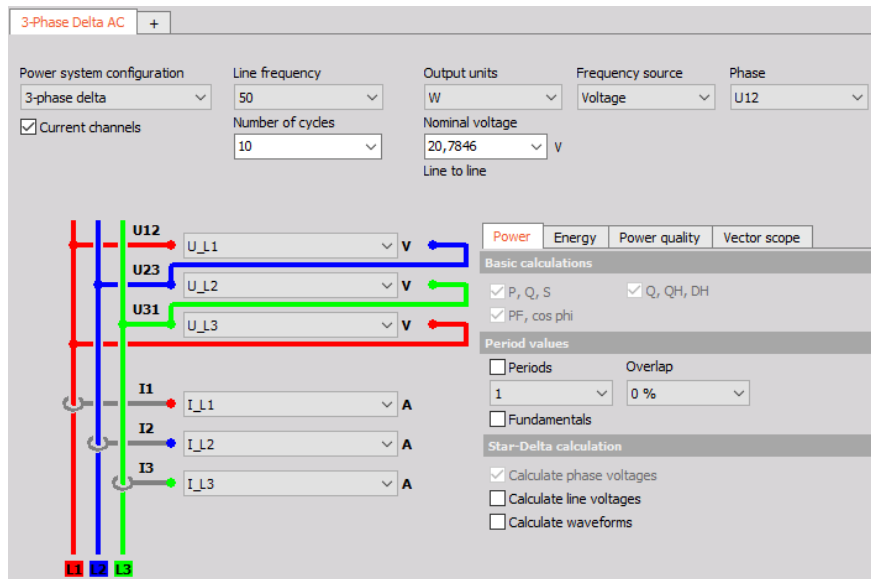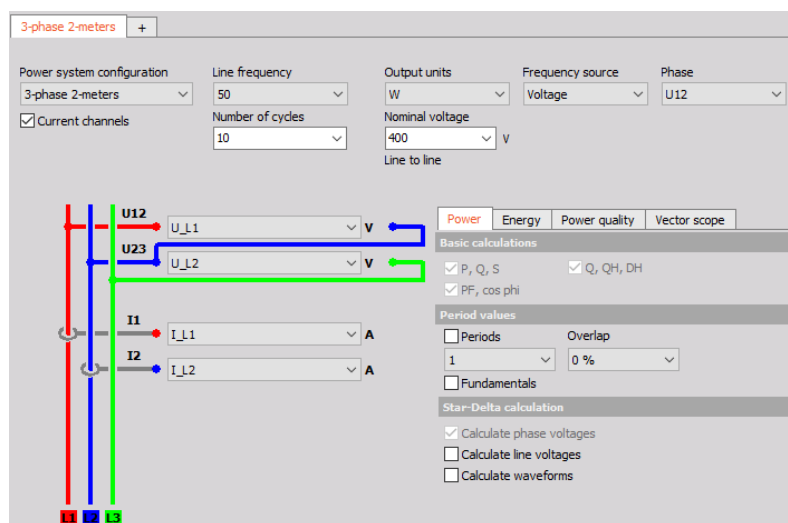

Image 115: 3-Phase 2-meters power module setup

6.8. Inverter measurement

When measuring inverters or after the inverters care must be taken as there are a few things that have to be considered to ensure that the correct results are yielded with the highest possible accuracy.

6.8.1. High-speed amplifiers

Always use high-speed (HS-HV and HS-LV) amplifiers for measuring inverters. As the voltage is modulated (amplitude or phase) with switching frequencies up to several hundred kilohertz, therefore, it is absolutely necessary to use high-speed amplifiers to get correct results.

Image 116: SIRIUSi 4xHV 4xLV DAQ

6.8.2. Current sensors

There are a lot of higher frequency components and some DC components contained in measurements of inverters or after inverters. Therefore, please ensure to always use current sensors with high bandwidth capabilities as well as having the capability to measure both DC and AC currents. The recommended current transducers to use would be Dewesoft zero-flux transducers, flux-gate current clamps or hall-compensated AC current clamps (Please take note that Fluxgate and Zero-flux current sensors require a PWR-MCTS to power them).

Image 117: Current sensors for inverter measurements

6.8.3. Frequency source

It is important to set the current as frequency source for this measurement, because the voltage out of an inverter hasn't got a sinusoidal waveform any more. The inverter has modulated the signal by pulse width or amplitude, so it's a packet of pulses. In the following image an inverter modulated voltage (green) is depicted. The current (orange) has a sinusoidal waveform and should therefore, be used as the frequency source.
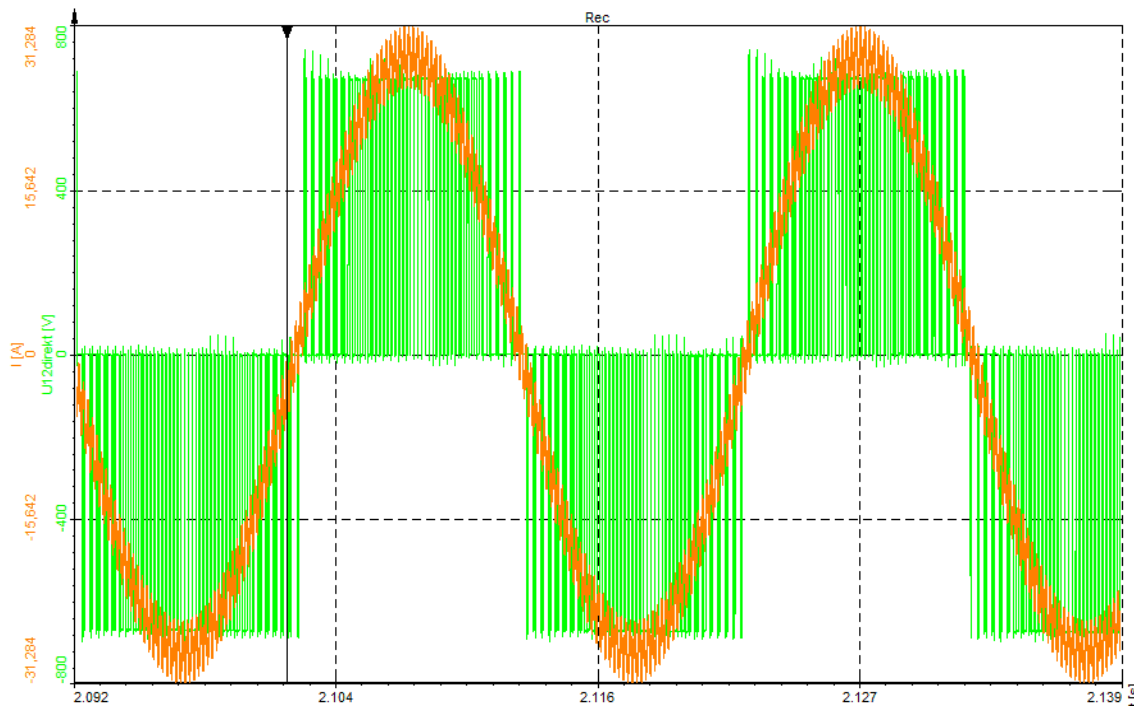
Image 118: Frequency source for inverter measurements

6.8.4. Measurement configuration

The choice of either using a star or a delta connection for measuring after inverters is open and can be freely selected by the user. Please note that an Aron or a V-connection should never be used for this type of measurement. For basic power analysis, a delta connection is a commendable choice, especially if there is no star-point available. But please use caution as the measurement is made between voltages this connection is not always suitable for a detailed inverter analysis (analysis of switching pulses).

When measuring with a star point connection a star point adapter should always be used. The artificial star point via the modules doesn't conform due to differences in impedances. The active power analysis will not be affected by this, but the analog signals that are displayed will be false. The apparent power and the power factor that this type of measurement will yield will also be false. Using a star connection with a star point adapter will yield very accurate power values as well as the true analog signal which can then be used for a detailed power analysis.

The best way of measuring an inverter is using the star connection with a star point adapter. If this is not possible then opt for the delta configuration.

6.8.5. Motor cable shielded or unshielded

A frequently asked question when measuring an inverter: Is there a difference when measuring with or without a shielded motor cable?

The answer is, yes, there could be a difference. Due to the high switching frequencies of the inverter there could be leakage currents via the shield of the cable. This leakage current can affect the results in the following ways:

- **Phase shift** - it's possible that a phase shift occurs. Comparative measurements, where a motor cable was measured parallel with and without shielded motor cables, has shown that the phase shift can be more than 15°.
- **Bandwidth damped** - with shielded motor cables it is very likely that the signal is damped, especially at higher frequency parts.
- **Higher DC current** - with the measurement of the shielded motor cables there is a possibility of a higher DC current occurring.

Therefore, this capacitive leakage can have low-pass characteristics (phase shift, no higher frequencies) and can affect the measurement results.

6.8.6. Special measurements

All the most common configuration setups are available in the Dewesoft power module. But especially in E-Mobility there are applications and configurations for 6-, 7-, 9- or even 12 –phase motors needed. There can be various reasons for this such as lowering the voltage level or reducing the stress on the components.

With conventional power analyzers there is no way to do a comprehensive analysis of such motors. But with the modular hardware systems of Dewesoft in combination with its powerful software these types of applications do not present any type of challenge.

For example, a 6-phase motor can be measured by using 6 single-phase power modules and calculating the total power in the power module.
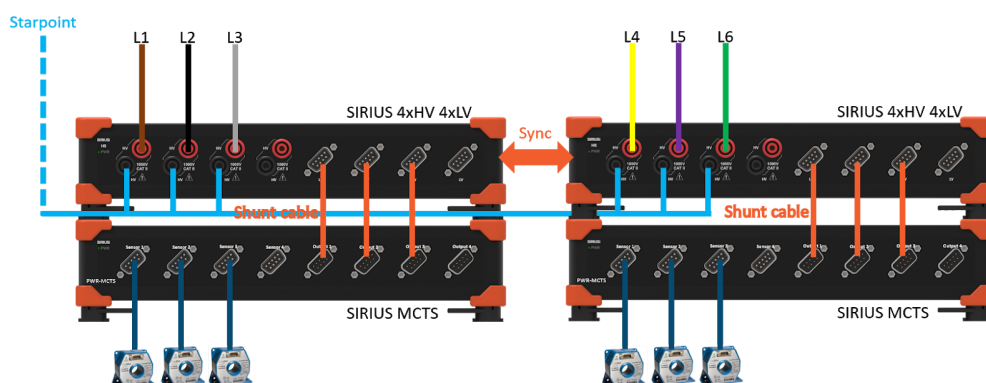
Image 119: 6-Phase motor measurement setup

This application should demonstrate how powerful the <u>Dewesoft Power analyzer</u> is. Should there be a special application or any uncertainty on how to measure or set up such a special application please feel free to contact either:

Rupert Schwarz - rupert.schwarz@dewesoft.com , +43 676 700 4847

Daren Bezuidenhout - daren.bezuidenhout@dewesoft.com, +43 676 791 0220

6.9. Energy

The <u>DewesoftX®</u> software can automatically calculate the measured system's energy using the power module. It's possible to calculate the total energy consumption or it can be split up into positive (energy consumption) and negative energy (energy delivery). This is helpful when measuring electric vehicles with recuperation (energy recovery) or when measuring the load profile of households/industry which have a power generation unit e.g. photovoltaic.

The energy calculation is a simple integration of all power values. To get the positive energy, the positive power values are integrated, for the negative energy the negative power values are integrated. A selection can be made between positive, negative or both.

Description	Calculation
Total energy	$E = \int_{t=0}^{T} p(t)\,dt$
Positive energy	$E_{mot} = \int_{t=0}^{T} p_{mot}(t)\,dt$ if $p_{mot}(t) > 0$
Negative energy	$E_{recup} = \int_{t=0}^{T} p_{mot}(t)\,dt$ if $p_{mot}(t) < 0$

P is power in Watt [W] and E in energy in Watt hours [Wh].

In the following images the settings for the Energy calculation in the power module are shown.
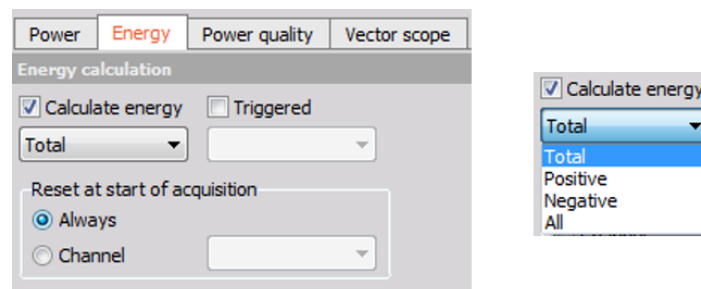
Image 120: Energy calculations in the power module

In addition to the basic power calculations it is also possible to start/reset the energy calculation at trigger events. Otherwise, the energy will be calculated as soon as you switch into measure mode. It is also possible to reset values at start of acquisition or with a channel.

6.9.1. Efficiency calculation

The efficiency of electrical devices can easily be calculated using the Dewesoft Math library, using the Formula editor. It can be calculated for power or for energy values, during the measurement as well.

$$\eta = \frac{P_{motor}}{P_{grid}} \cdot 100$$

Where η is the efficiency in [%]
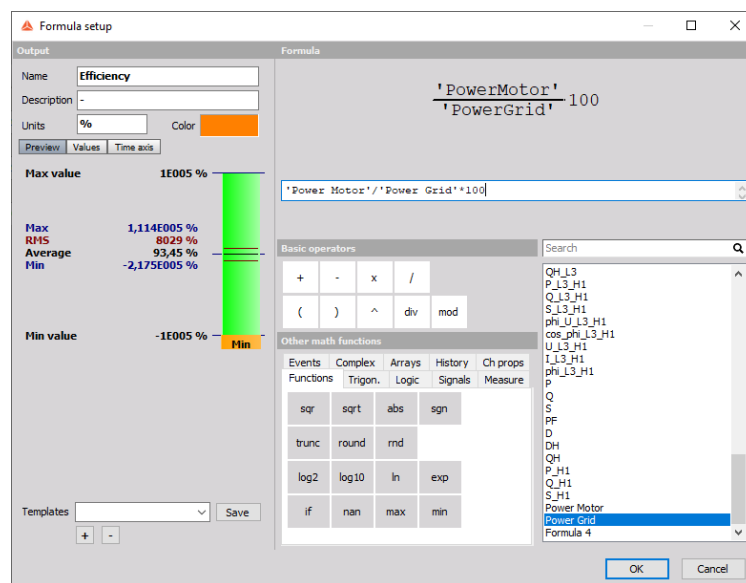
Image 121: Efficiency calculation in the power module

There are applications where the energy is measured at multiple points for instance in electric vehicles that use recuperation of energy. The following Sankey diagram is a representation of the energy flow that would likely be measured with a recuperation electric vehicle.
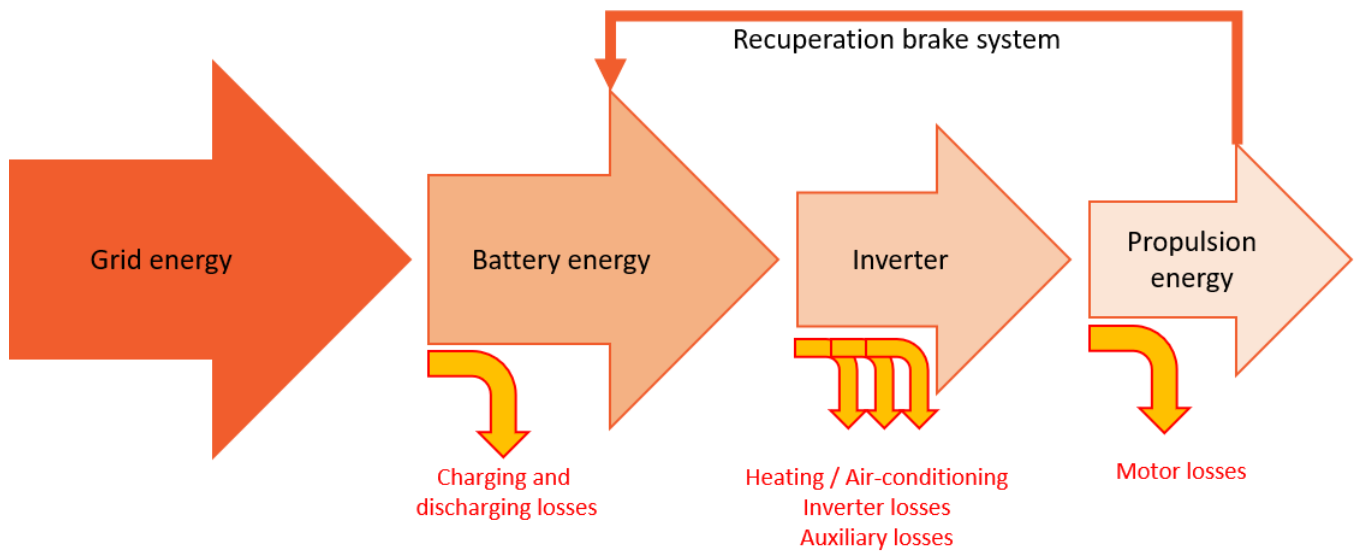
Image 122: Sankey diagram of an electric vehicle

6.9.2. Performance optimization

💡 **Hint**
This section will end off with a few tips that can be used if the computing power of the device being used seems to be inefficient.

Should the situation arise where the computer that is being used for the measurements has inefficient computing power to calculate all the parameters that are available, there are a few tips that could help with that.

- **Acquisition rate** - the acquisition rate should be set to suit the respective application. Often lowering the acquisition rate doesn't affect the measurement results. With inverter measurements, the sampling rate should be 10 - 20 times that of the switching frequency.
- **Calculation rate in the power module** - lowering the calculation rate often doesn't influence the power calculation. The benefit of this compared to lowering the acquisition rate is that the analog signal is still available. If the data is stored with the "always fast" option, the power module can be calculated after the measurement using the full sampling rate.
- **Post Processing** - the power module is already present (Offline mode) or recording raw data, power modules are subsequently added and calculated (Analyze mode).
- **Downsizing** - deselection of options and channels (analog, math, power) that are not needed for the measurement. In the power module a lot of options are very performance intensive, especially the following ones: Harmonic Smoothing Filter, Flicker and Period Values, and in Math especially Filters, Statistics, FFT, Formulas with cosine and sine calculations need a lot of CPU power.

7. Power Quality

The different Power Quality parameters describe the deviation of the voltage from its ideal sinusoidal waveform at a certain frequency. These deviations can lead to disturbances, outages or damages of electrical equipment connected to the grid. It is essential to permanently track these parameters: starting during the development phase (of the electrical equipment) up until the live operation and beyond: e.g. continuous monitoring of a couple of points in the electrical grid in order to prevent and correct quality disturbances.

The Dewesoft Power Quality Analyzer can measure all these parameters according to the IEC 61000-4-30 Class A Standard. In comparison to conventional Power Quality Analyzers it's possible to do more detailed analyses (e.g. raw data storing, behavior at faults, calculation of additional parameters etc.).
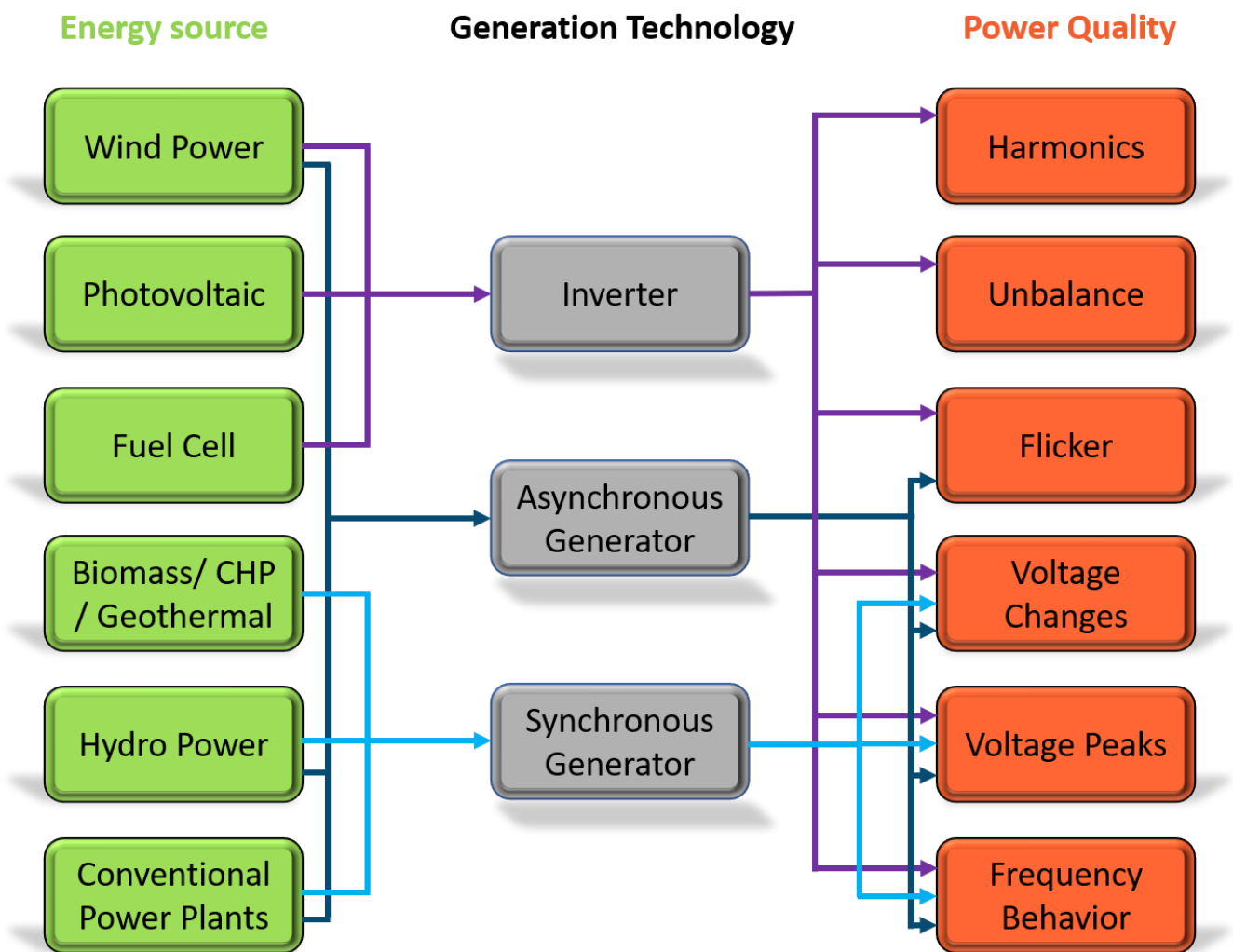
Image 123: Power quality application overview

The purpose of this chapter is to cover all Power Quality parameters which Dewesoft is able to calculate. After a short introduction and explanation of each parameter, a description on how the specific calculations are carried out and which variable names they are defined as in the DewesoftX® software.

7.1. Harmonics

Harmonics are integer multiples of the fundamental frequency (e.g. 50 Hz for the grid in Europe) and cause a distortion in voltage and current from the original sinusoidal waveform. Harmonic voltages and currents caused by non-sinusoidal loads can affect the operation and lifetime of electrical equipment and devices. Harmonic frequencies in motors and generators can increase heating (iron & copper losses), can affect torque (pulsating or reduced torque), can create mechanical oscillations and higher audible noise, it also causes ageing of the shaft, insulation and mechanical parts and reduce the efficiency of the motor.
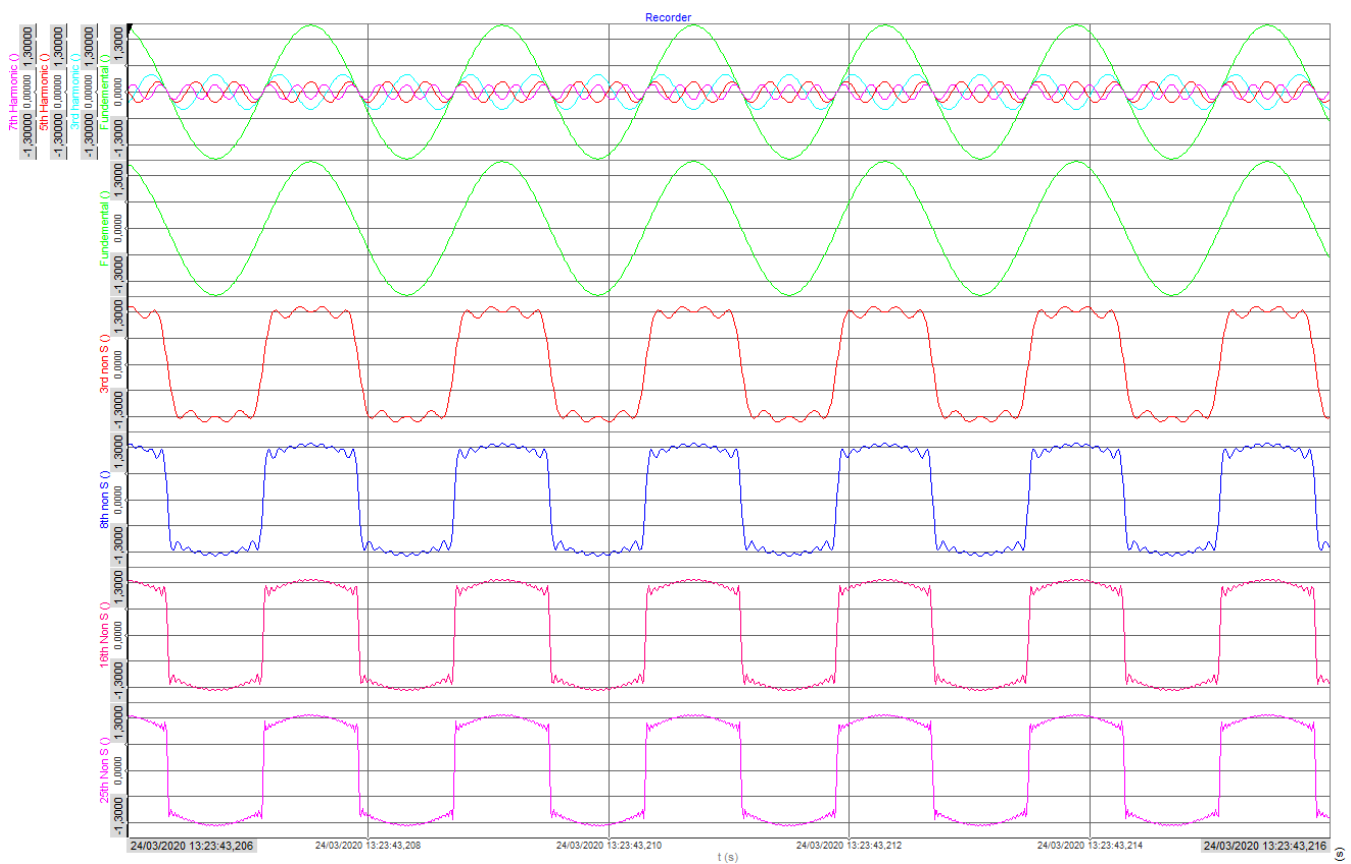
Image 124: Harmonic summation of sinusoidal waveforms

The image depicts such a case. In the first recorder the fundamental frequency with the 3rd, 5th and 7th harmonic orders overlapping are depicted. So, what is the problem, they are all sinusoidal waveforms with different amplitudes, right? Well no, look at the second recorder this is the fundamental frequency, perfect sinusoidal waveform would be perfect as all electrical equipment prefers receiving signals in this form as it is the ideal waveform to work with.

The problem with the harmonic orders is that they sum together with the fundamental frequency, causing non-sinusoidal waves to form. The recorders following the fundamental frequency depict what happens to the sinusoidal waveform as more and more harmonic orders are added. It is clearly visible that the higher the order goes the less sinusoidal the wave becomes. Already at the 25th harmonic order it is visible how the waveform is changing onto a square wave. The higher the harmonic orders that are added to the wave form the squarer it will get. If there were infinitely many harmonics added to the waveform it would become a perfect square wave.

7.1.1. Overview

Current harmonics in transformers increase copper and stray flux losses. Voltage harmonics increase iron losses. The losses are directly proportional to the frequency and, therefore, higher frequency harmonic components are more important than lower frequency components. Harmonics can also cause vibrations and higher noise. The effects on other electrical equipment and devices are very similar and are mainly: reduced efficiency and lifetime, increased heating, malfunction or even unpredictable behavior.
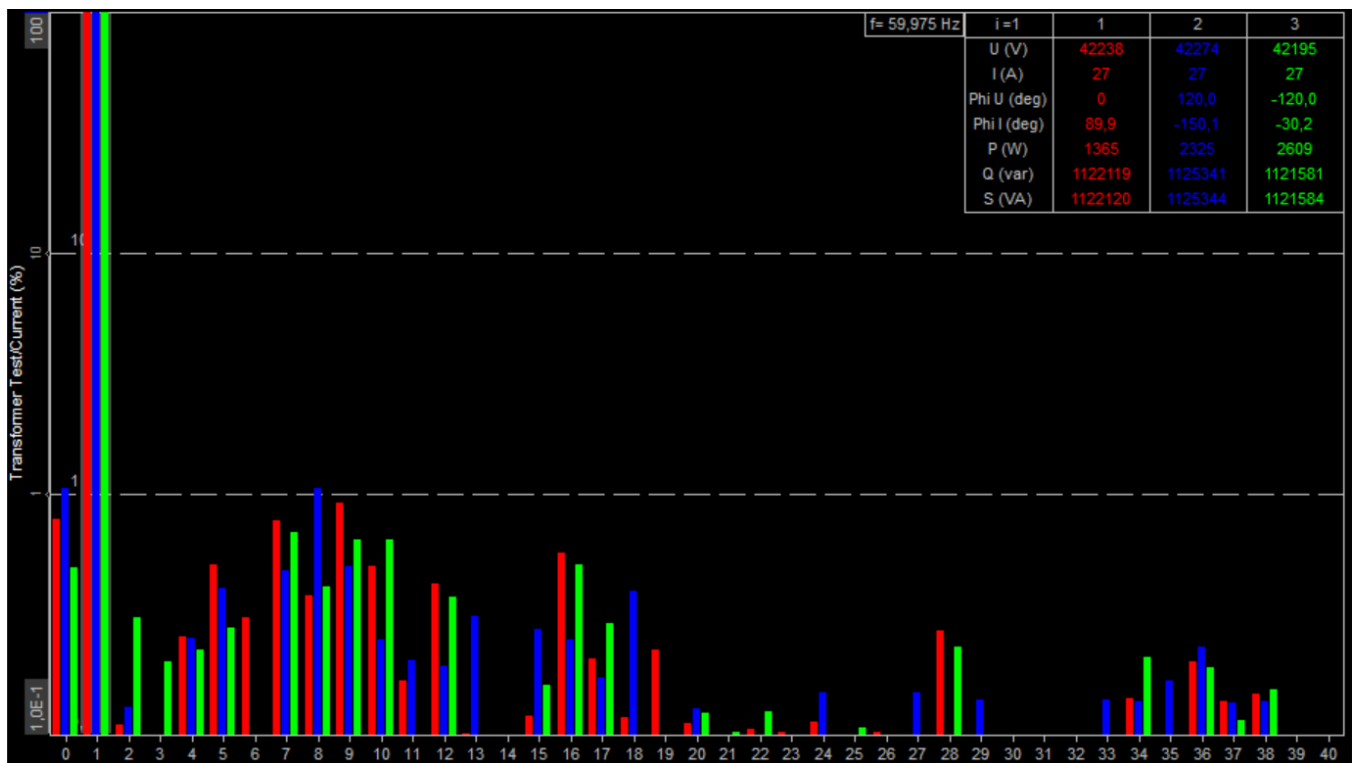
Image 125: Current harmonic measurement screen

Dewesoft measures harmonics for voltage and current as well as active and reactive power up to the 3000th order. All calculations are implemented according to IEC 61000-4-7 and can be selected in the power module according to the following image. In order to calculate higher harmonics, the sampling rate has to be adjusted accordingly, for instance at a sampling rate of 500 kS/sec or higher DewesoftX® can calculate up to the 3000th order.
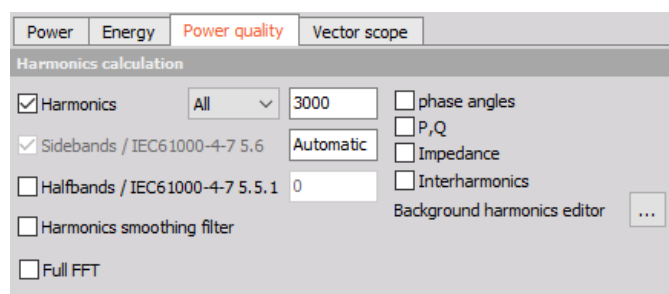
Image 126: Harmonic measurement options in the power module

7.1.2. Harmonics

Up to 500 harmonics can be calculated, in addition there is the option to choose all harmonics or just even or odd ones. If there are current channels used in the power module it is also possible to calculate phase angles, P, Q and the impedance.
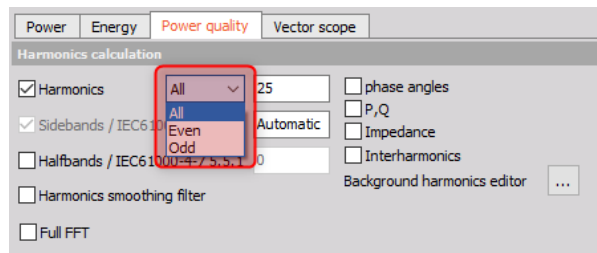
Image 127: Harmonic measurement calculation options in the power module

7.1.3. Number of sidebands

The basic idea of sidebands is that a certain frequency range is considered as one harmonic.

Example: 1 full sideband (equals +/-5Hz) at a frequency of 50 Hz means that a frequency range from 45-55 Hz is considered to be the first harmonic (it's the same for all other harmonics). If you select 2 sidebands the first harmonic will cover the frequency range 40 to 60 Hz.
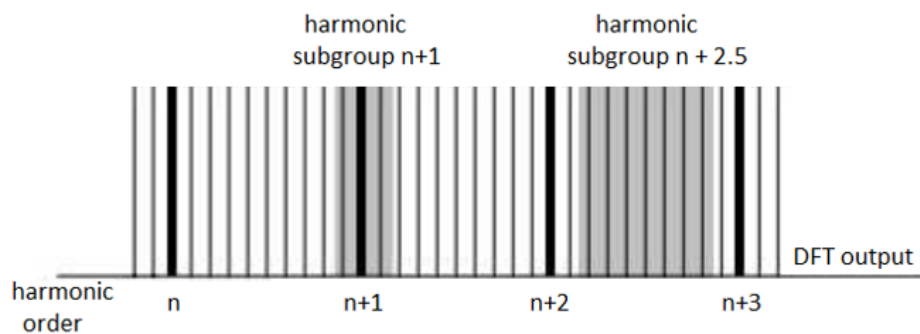
Image 128: Harmonic sidebands

7.1.4. Number of halfbands

The IEC 61000-4-7 (page 22) requires for the grouping of the harmonic sidebands where only the square root of the quadratic half should be added. This is required for the lowest and highest line and is defined as halfbands in Dewesoft.

Example I: 1 sideband and 1 halfband at a frequency of 50 Hz means that a frequency ranges from 45 – 55 Hz and the square root of the quadratic half of the 40 Hz to 60 Hz lines are considered to be the first harmonic.

Example II: 2 sidebands and 1 halfband at a frequency of 50 Hz mean that the lines from 40 Hz to 60 Hz have the full amplitude, while the lines at 35 Hz and 65 Hz are only considered with the square root of the quadratic half.
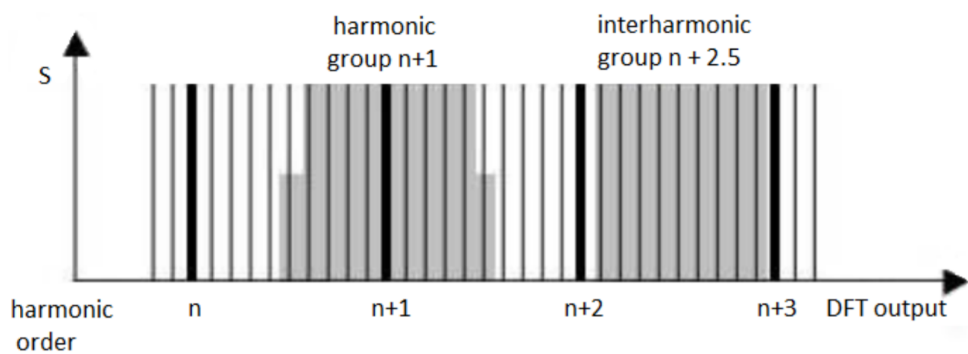
Image 129: Harmonic halfbands

7.1.5. Interharmonics

Interharmonics cover all lines not covered by the harmonics (please refer to page 26 of IEC 61000-4-7).

Example: 1 sideband and 1 halfband at a frequency of 50 Hz, the first interharmonic is the area between 0 Hz and 45Hz.
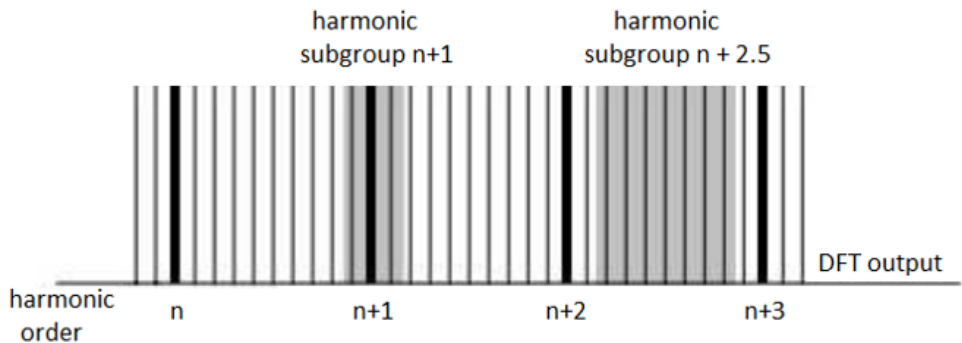
Image 130: Interharmonics

7.1.6. Group FFT lines

The higher frequency parts can be grouped in 200 Hz and in 2kHz bands up to 150 kHz.

Depending on which grouping the measurement might require. Dewesoft offers the possibility to select one or both of these harmonic groupings.

Image 131: Group FFT lines in the power module
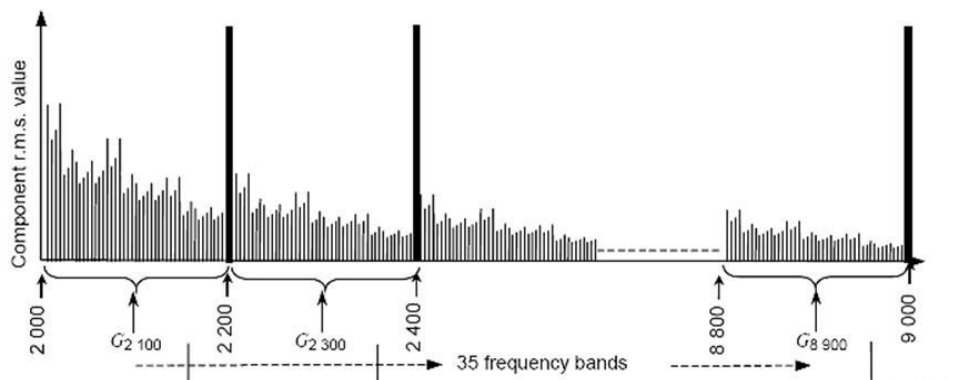
Image 132: Harmonic grouping according to the IEC 61000-4-7 standard

Important

Please be aware that according to page 29 of the IEC 61000-4-7 these groups start at - 95 Hz to + 100 Hz around the middle of the frequency.

7.1.8. Full FFT

This option calculates a Full FFT which can then be exported to the database and displayed via a 2D-graph.
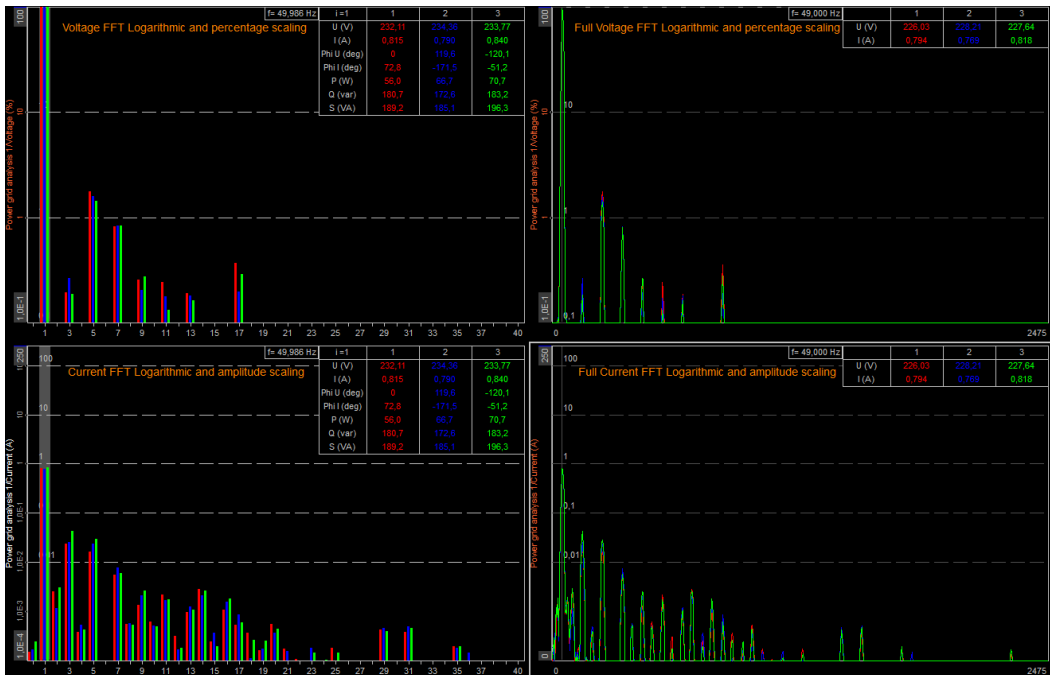
Image 133: Full FFT display options in the power module

7.1.9. Harmonic smoothing filter

This option enables the low-pass filter which is required according to the IEC 61000-4-7 standard, page 23.

7.1.10. Background harmonics

With this option it is possible to subtract an existing and known harmonic pattern (magnitude and phase) from measured values. This is a typical application for the commissioning of a powerful power converter in order to ascertain the noise of the converter.

This function is available for both voltage and/or current, and it can be selected from the background harmonics editor in DewesoftX®.

The only values that need to be entered for this calculation are the magnitude and the phase angle of the harmonic pattern as illustrated in the image of the input mask below.
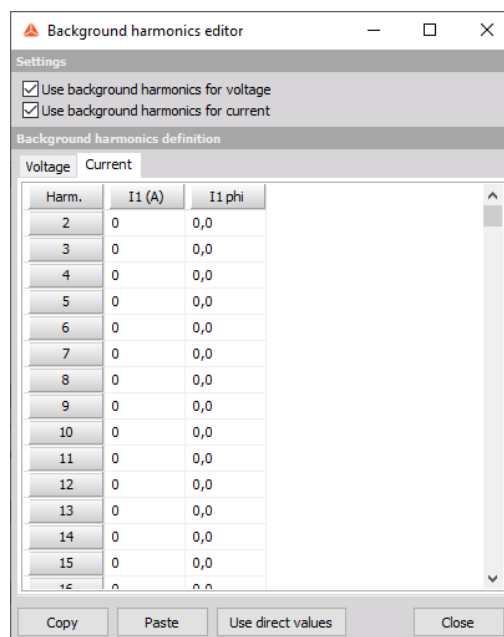
Image 134: Background harmonics editor

Example: The following images depict a certain harmonic pattern that was measured using Dewesoft DAQ devices. A harmonic filter was then applied to the same measurement in DewesoftX®, and it yielded an adjusted harmonic by subtracting the background harmonics.
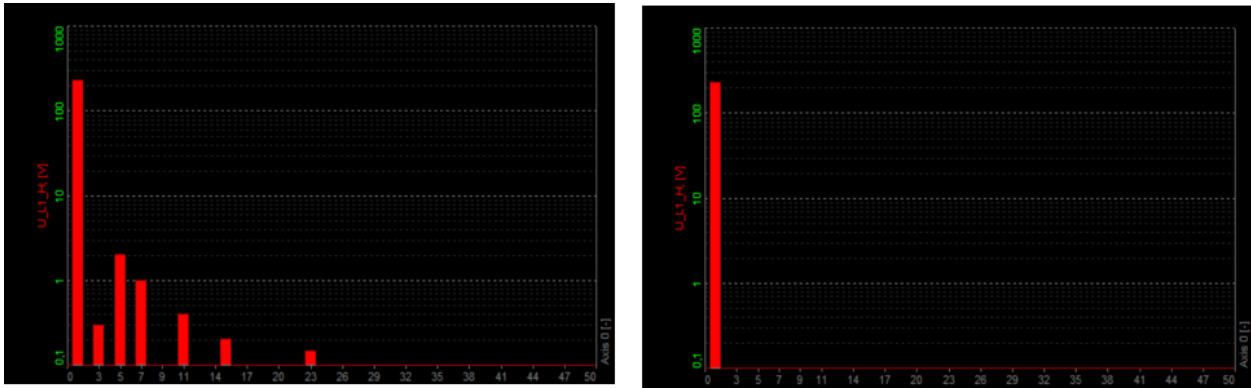
Image 135: Measurement screen without and with a harmonic filter applied

7.2. Measurement with Dewesoft

DewesoftX® offers an array of display options for the following measurements: voltage, current, active and reactive power, phase angle, impedance, interharmonics and higher frequencies, these can be displayed as Numeric Displays, on Recorders or as 2D-Graphs as the following image depicts. The user is absolutely free to configure the display as required.
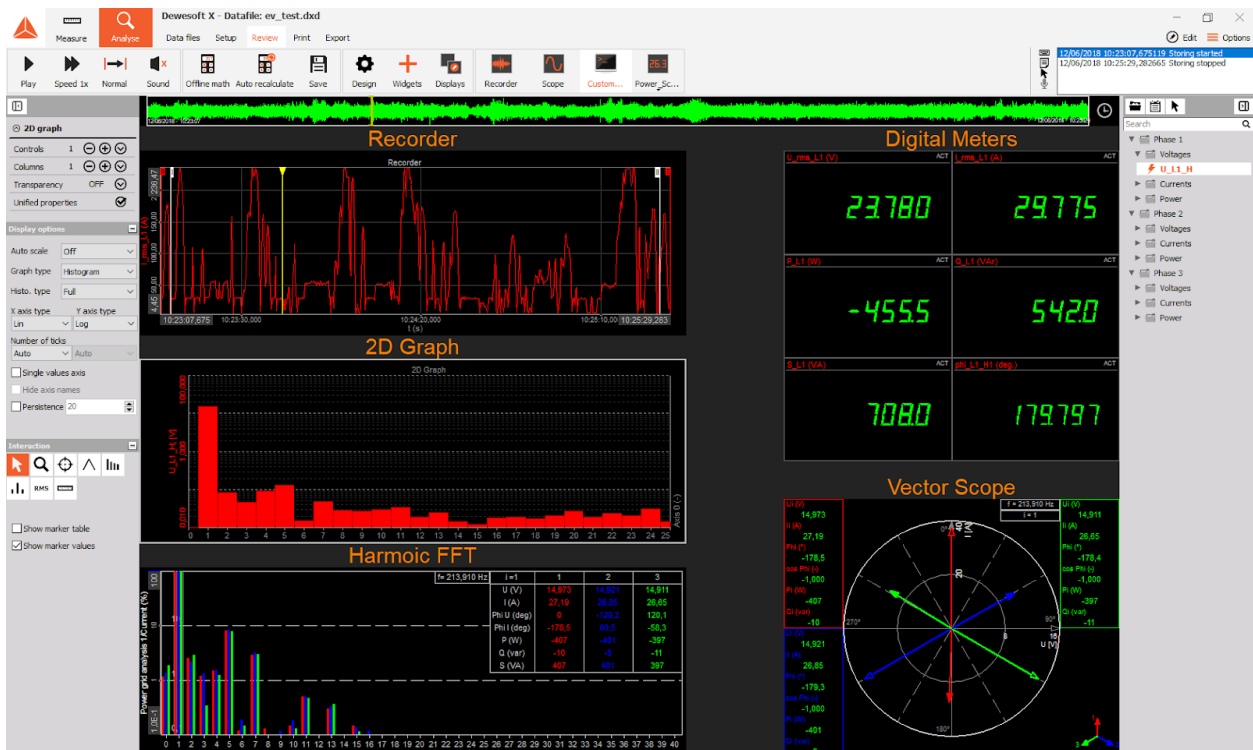
Image 136: Display options for the measurement screen in the power module

There are two possibilities for displaying harmonics in Dewesoft. The available choices are the **Harmonic FFT** and the **2D graph**. The following image depicts the icons that are used for the two choices, left is the harmonic FFT and right is the 2D graph.
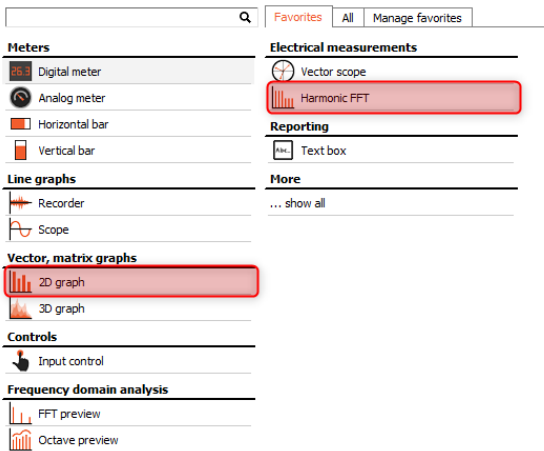
Image 137: Display options for harmonics in the power module

In the Harmonic FFT the harmonics of the voltage, current, power and reactive power can be displayed. The following image depicts the voltage harmonics of a three-phase system.
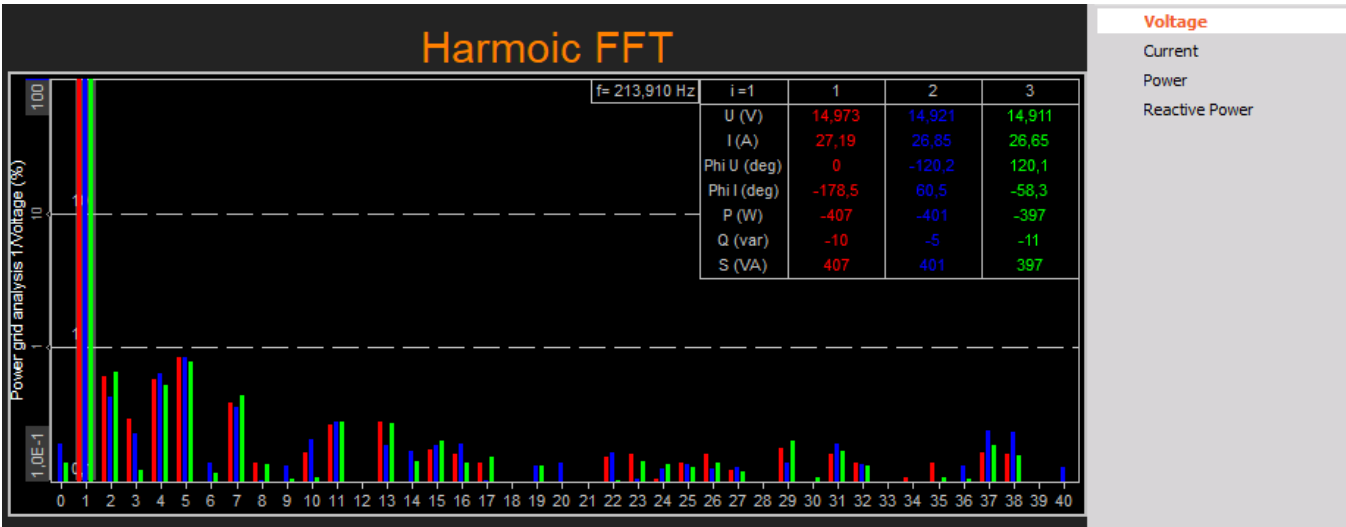
Image 138: Harmonic FFT measurement screen

With the 2D graph it is possible to display voltages and currents of different phases in one graph. In addition to this there is a wide array of display options that the user can configure as needed for the specific application. The following image displays the harmonics for the phase voltage of L1. On the right-hand side are the display options that are available for 2D graphs. Here the graph type can be chosen, whether line or histogram as well as the graph scale which can be either linear or logarithmic. The scaling of the graph axes can also be set independently.
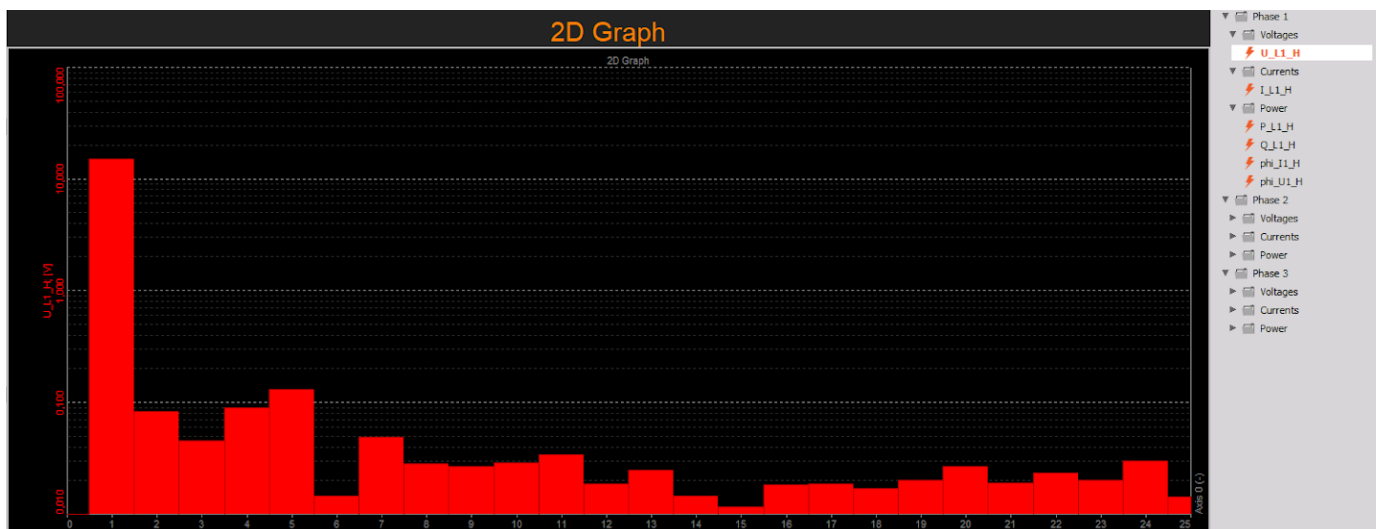
Image 139: Harmonic 2D graph measurement screen

There is also the option available to depict the **Persistence** of the harmonics in the 2D Graph. This means that when the harmonics change during a measurement, the changes are displayed blurred, as illustrated in the following image.
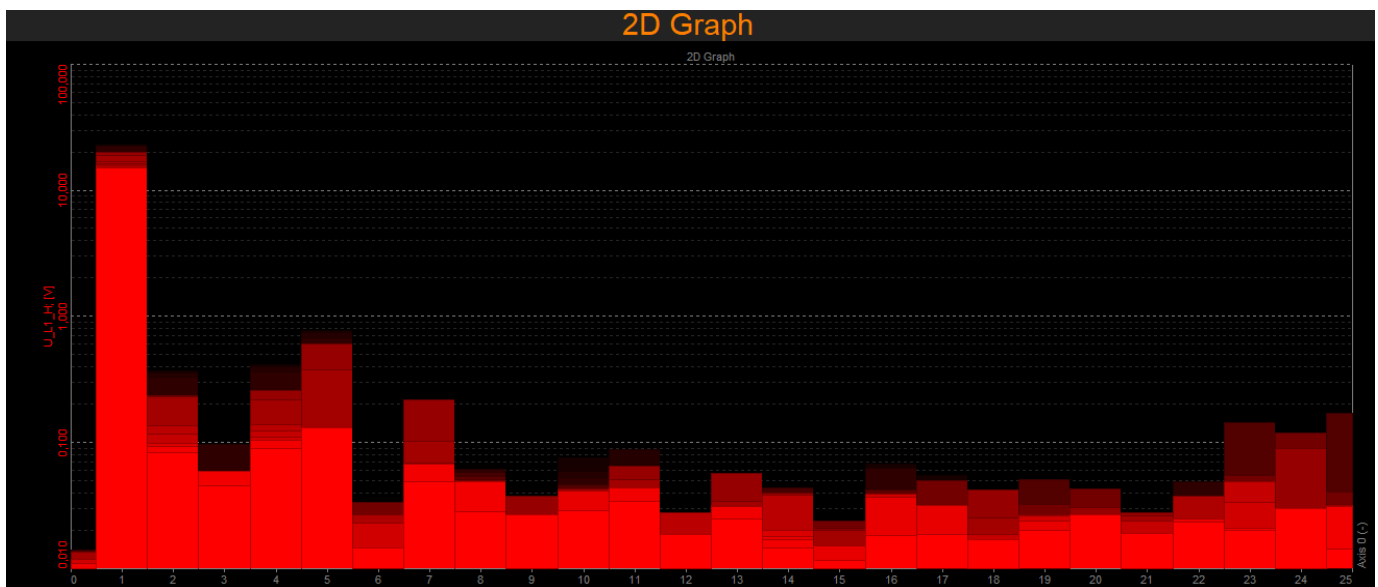
Image 140: Harmonic 2D graph measurement screen with persistence

7.2.1. Higher frequencies

Example: Higher Frequencies from 2 up to 20 kHz shown in a 2D-Graph as Histogram (application: HVDC converter station).
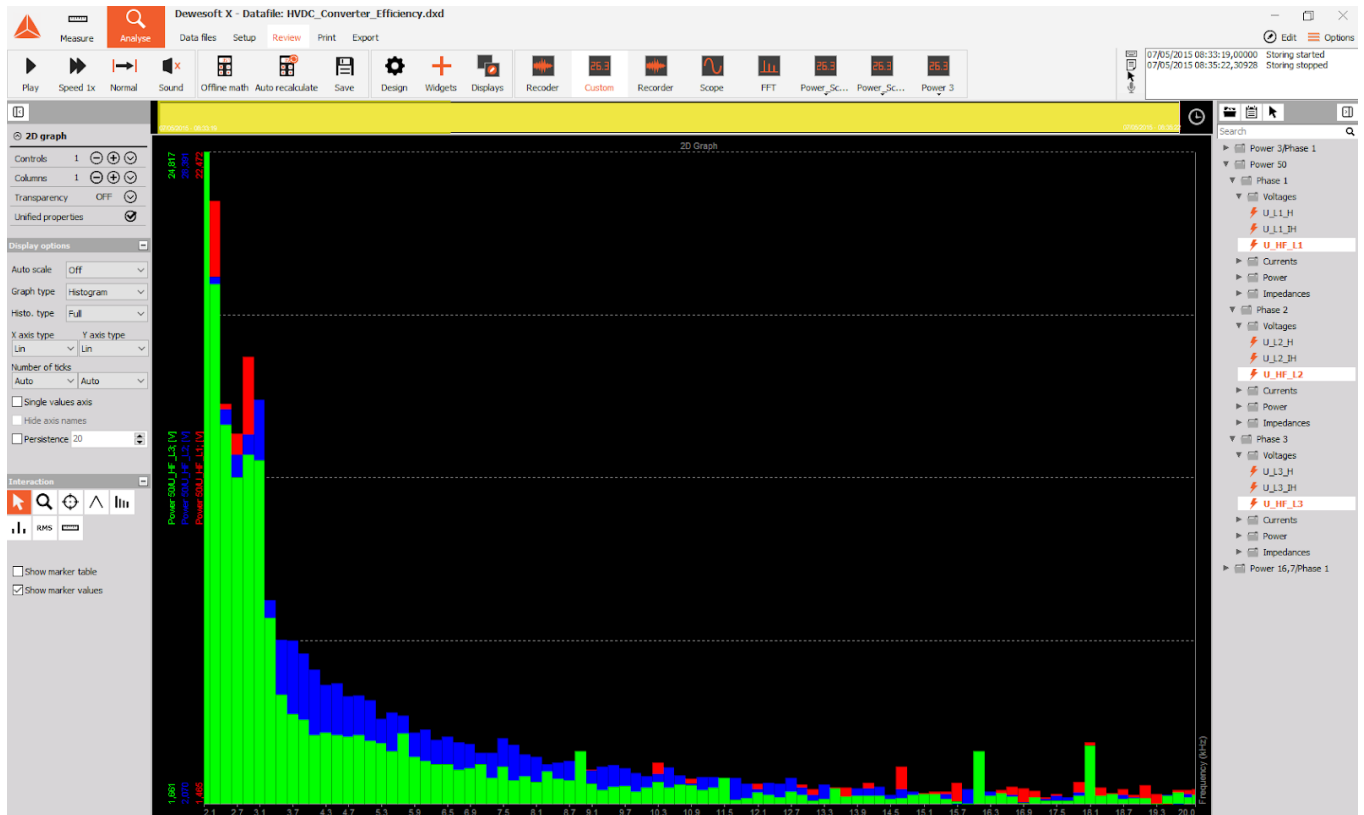
Image 141: Higher frequencies measurement screen in a 2D histogram

7.2.2. Interharmonics

Example: Interharmonics shown in 2D-Graph as Histogram. Peak at 900 Hz which is the switching frequency of a HVDC converter operated in the public grid.
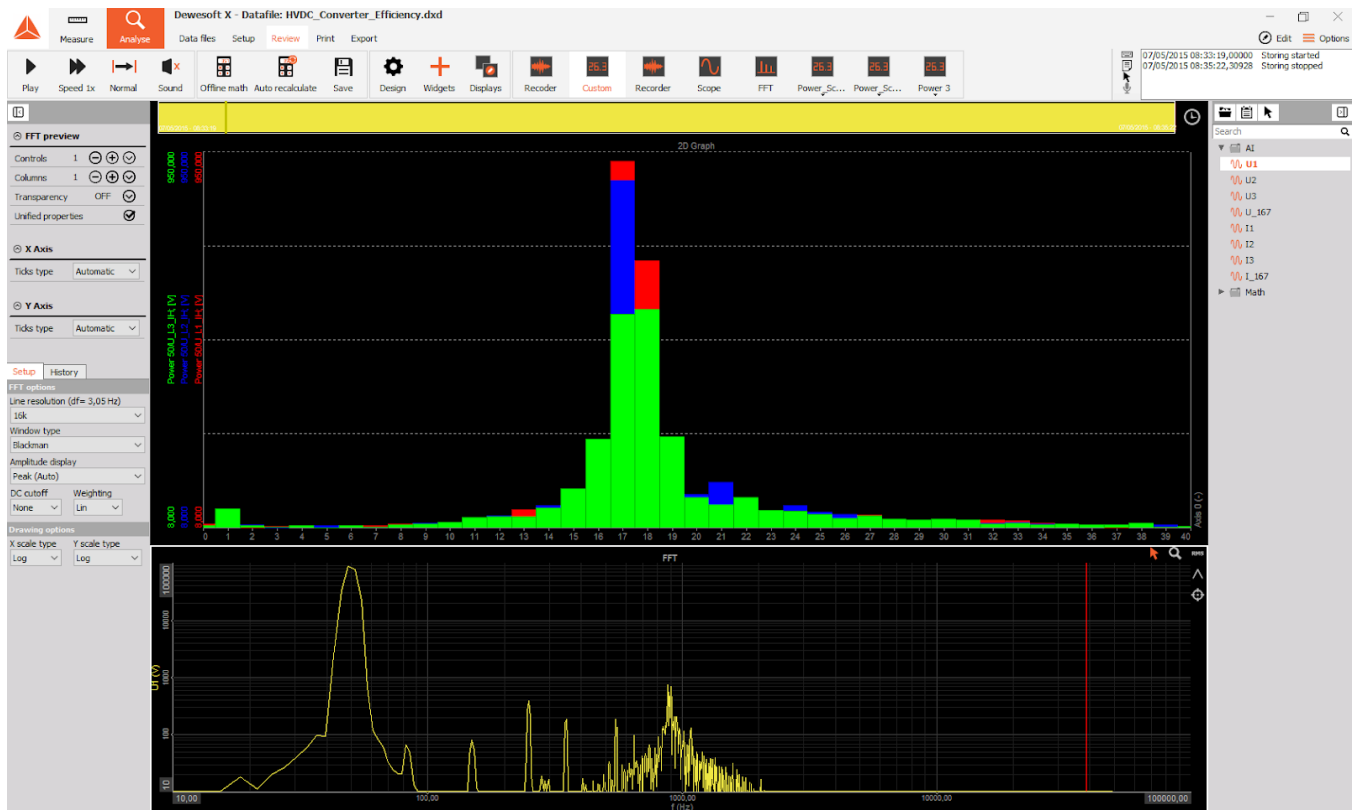
Image 142: Interharmonic measurement screen in a 2D graph and a FFT graph

7.2.3. Dewesoft calculations for each harmonic/whole waveform

Channel name in DEWESoft	Calculation	Description
S_L1_H1	$S_h = U_h \cdot I_h$	Apparent, active and reactive power for a certain harmonic frequency (e.g. for L1 and h=1)
P_L1_H1	$P_h = U_h \cdot I_h \cdot cos(\varphi_h)$	
Q_L1_H1	$Q_h = U_h \cdot I_h \cdot sin(\varphi_h) = \sqrt{S_h^2 - P_h^2}$	
S_L1	$S = U_{1_{rms}} \cdot I_{1_{rms}}$	Three power parameters for the whole waveform (e.g. for L1)
P_L1	$P = \sum_{h=1}^{H} P_h$	
Q_L1	$Q = \sqrt{S^2 - P^2}$	
Z_L1	$Z_{L1} = \frac{U}{I}$	Impedance for the whole waveform (e.g. for L1)
Z_L1_H1	$Z_{L1} = \frac{U_H}{I_H}$	Impedance for a certain harmonic (e.g. for L1 and H1)
PF_L1	$PF = \frac{P}{S}$	Power factor (e.g. for L1)
D_L1	$D = \sqrt{Q^2 - Q_{h=1}^2}$	D_L1, distortion power of all harmonic components reactive powers (u and i have the same order but not equal 1 or have different order) (e.g. for L1)
QH_L1	$Q = \sum_{h=1}^{H} Q_h$	Reactive power of all harmonics where u and i have the same harmonics order (e.g. for L1)
DH_L1	$DH = \sqrt{Q^2 - QH^2}$	Distortion power of all harmonic components reactive powers where u and i have different harmonic orders (e.g. for L1)

Important
There are two definitions for reactive power included, because there is up to date no official definition that has been standardized. The formula of Q1_L1 loses sign, while QH_L1 does not. If there is a need to calculate the reactive power form only the harmonics (no fundamental included) the following simple math formula can be used: 'QH_L1' – 'Q_L1_H1'

7.2.4. Dewesoft calculations for a 3-phase system

Channel name in DEWESoft	Calculation	Description
S	$S_{3\sim} = S_{L1} + S_{L2} + S_{L3}$	Apparent, active and reactive power of a 3 phase system
P	$P_{3\sim} = P_{L1} + P_{L2} + P_{L3}$	
Q	$Q_{3\sim} = \sqrt{S_{3\sim}^2 - P_{3\sim}^2}$	
PF	$PF_{3\sim} = \frac{P_{3\sim}}{S_{3\sim}}$	Power factor

7.3. Total Harmonic Distortion (THD)

The term THD stands for the ratio of the effective value of the sum of all harmonic components up to a specified order to the effective value of the fundamental component. In general, it is defined as the sum of all harmonics relative to the fundamental frequency. The Total Harmonic Distortion (THD) for voltage and current can be calculated up to the 3000th order.

Channel name in DEWESoft	Calculation	Description
THD_U_L1, …	$THD_U = \frac{\sqrt{\sum_{h=2}^{n}(U_h)^2}}{U_1}$	THD of the voltage
THDOdd_U_L1, …	$THD_{U\,odd} = \frac{\sqrt{(\sum_{h=1}^{n}\cdot(U_{2h+1})^2)}}{U_1}$	THD of the voltage for odd and even harmonics
THDEven_U_L1, …	$THD_{U\,even} = \frac{\sqrt{(\sum_{h=1}^{n}\cdot(I_{2h})^2)}}{U_1}$	
THD_I_L1, …	$THD_I = \frac{\sqrt{\sum_{h=2}^{n}(U_h)^2}}{I_1}$	THD of the current
THDOdd_I_L1, …	$THD_{I\,odd} = \frac{\sqrt{(\sum_{h=1}^{n}\cdot(I_{2h+1})^2)}}{I_1}$	THD of the current for odd and even harmonics
THDEven_I_L1, …	$THD_{I\,even} = \frac{\sqrt{(\sum_{h=1}^{n}\cdot(I_{2h})^2)}}{I_1}$	

Channel name in DEWESoft	Calculation	Description
TIHD_U_L1, …	$TIHD_U = \dfrac{\sqrt{\sum\limits_{k=1}^{n}(U_k)^2}}{U_1}$	Total Interharmonic distortion of the voltage/current.
TIHD_I_L1, …	$TIHD_I = \dfrac{\sqrt{\sum\limits_{k=1}^{n}(I_k)^2}}{I_1}$	Equivalent to the THD, but defined for interharmonics
K_U_L1	$K_U = \dfrac{\sqrt{\sum\limits_{h=2}^{n}(U_h)^2}}{U}$	K-factor for voltage and current. Refers to the full-spectrum, the THD only to the fundamental voltage
K_I_L1	$K_I = \dfrac{\sqrt{\sum\limits_{h=2}^{n}(I_h)^2}}{I}$	

The most important origins of harmonics are loads which are controlled by converters (diodes, thyristors, transistors). The following images depict a typical comparison of different light bulbs and the current waveforms that they produce (Blue). The green waveforms represent the Voltages. The Voltage, Current, THDI (Total harmonic distortion for current), power and power factor values that correspond to the individual light bulbs are also depicted.
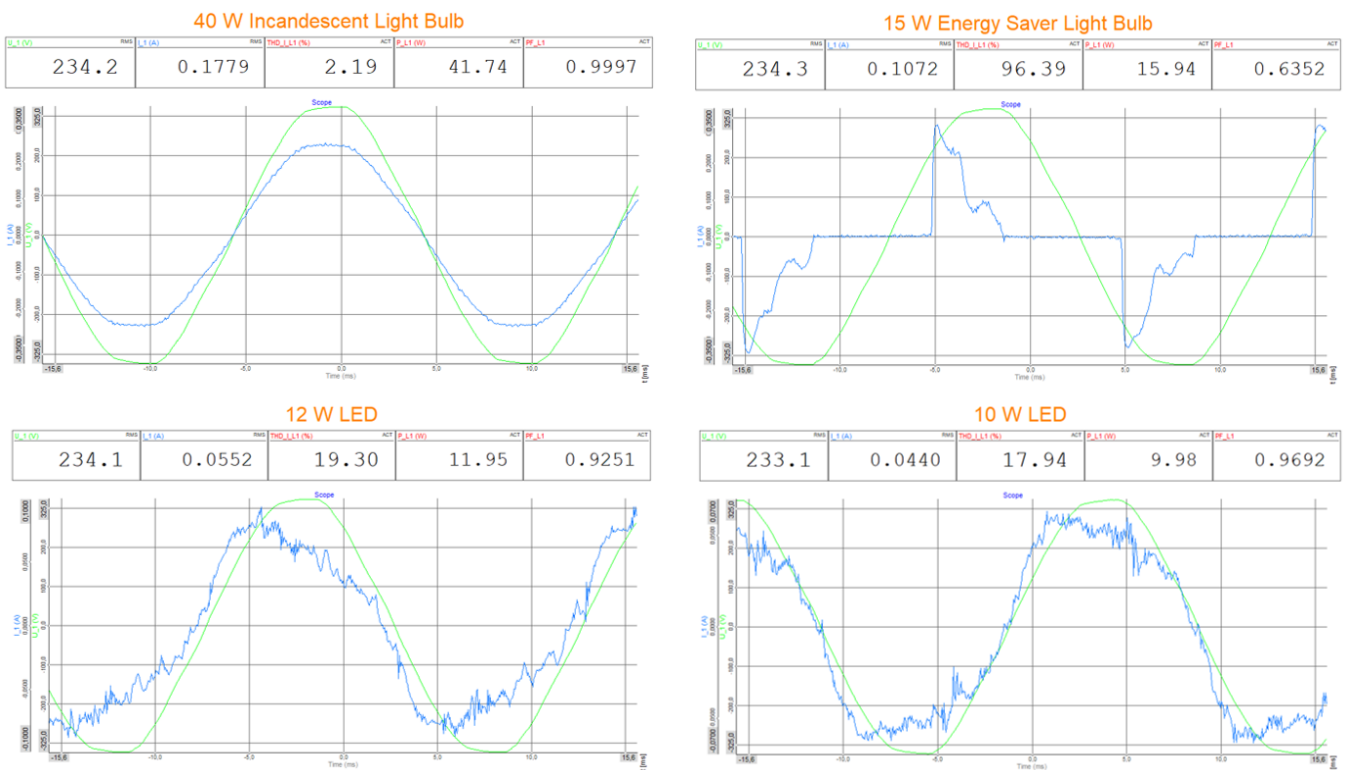
Image 143: Total harmonic distortion waveform for different light bulbs

Circuit	Curve shape	THD	Application
Single phase bridge rectifier with decoupling capacitor (2 pulse)		130 – 160 %	Switching power supply
6 pulse rectifiers with decoupling capacitor (voltage intermediate circuit, voltage inverter)		70 – 120 %	UPS facilities, frequency inverters for three-phase motors
6 pulse rectifiers with decoupling capacitor and ripple filter choke		40 – 70 %	(pumps, fans, paper machines, conveyors)
6 pulse rectifiers with ripple filter choke (current intermediate circuit, current inverter)		30 %	DC drives (ski lifts, extruders, bandsaws) Inverters for wind power plants
12 pulse rectifiers with ripple filter choke (current intermediate circuit, current inverter)		15 %	DC drives with high power (rolling mills, ropeways) DC electric arc furnaces, HVDC facilities
Active inverter (DC-voltage intermediate circuit, voltage inverter)		< 10 %	State of the art, RPM regulated 4-quadrant drives

7.3.1. THC and TDD calculation

In addition to the THD calculation it is now possible to add THC and TDD calculations as well.

Total Harmonic Current (THC) is the accumulated currents of the orders 2 to 40 that contribute to the distortion of the current waveform. This value is particularly useful in determining the required characteristics for installation of modern active harmonic filters:

$$THC = \sqrt{\sum_{n=2}^{n=40} I_h^2}$$

Current Total Demand Distortion (TDD). It is defined as the ratio of the root-sum-square values of the harmonic current to the maximum demand load current times 100 to get the result in percentage. The maximum demand load current can be defined in the software with an input field.

$$I_{TDD} = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + I_5^2 + \ldots}}{I_L} \cdot 100$$

In the power module in DewesoftX® under power quality the THC and TDD options can be selected, as shown in the image below.
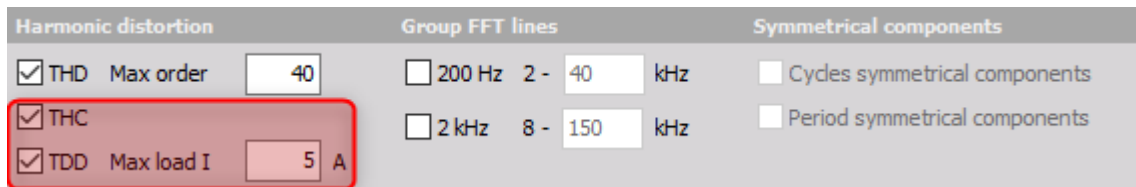
Image 144: Total harmonic current and Current total demand distortion

7.4. Symmetrical components

Normally an electric power system operates in a balanced three-phase sinusoidal steady-state mode. Disturbances, for example a fault or short circuit, lead to an unbalanced condition. As the following image depicts on the left-hand side is a balanced system with a symmetrical phase shift and equal vector distances. On the right-hand side is an unbalanced system with an unsymmetrical phase shift and uneven vector lengths.
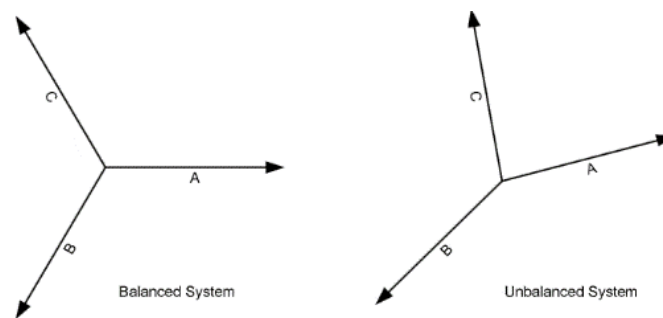
Image 145: Balanced system and an unbalanced system

By using the method of the symmetrical components, it is possible to transform any unbalanced 3-phase system into 3 separated sets of balanced three-phase components, the positive, negative and zero sequence.
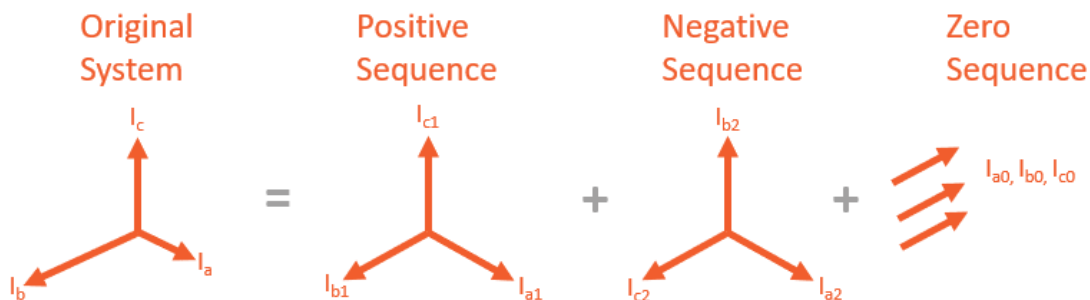
Image 146: Unbalanced system to balanced system transformation

The advantage of the symmetrical balanced system lies in that the calculations are simplified. Should a fault arise or there is a short circuit in the system, an unbalanced system can be transformed into a

balanced system with symmetrical components, where the system calculations can be done with the normal formulas that would be used in a balanced system. The calculated values are then transformed back to the unsymmetrical system (real-scenario) phase voltages and currents. In general, a 3-phase system can be depicted and mathematically described such as follows:
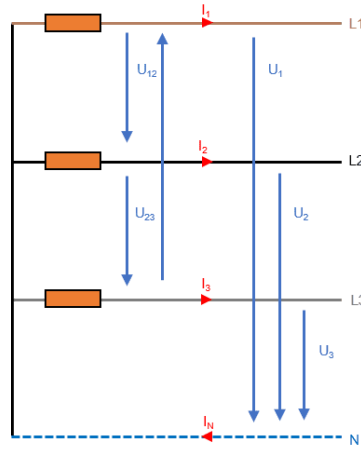
Image 147: Symmetrical system

$$U_{L1} = U_{L1_{RMS}} e^{j\varphi U_{L1}} \quad I_{L1} = I_{L1_{RMS}} e^{j\varphi I_{L1}}$$

$$U_{L2} = U_{L2_{RMS}} e^{j\varphi U_{L2}} \quad I_{L2} = I_{L2_{RMS}} e^{j\varphi I_{L2}}$$

$$U_{L3} = U_{L3_{RMS}} e^{j\varphi U_{L3}} \quad I_{L3} = I_{L3_{RMS}} e^{j\varphi I_{L3}}$$

A balanced 3-phase system looks like the image below with the same RMS-value for all line voltages and currents, and a 120° phase shift between each of them.
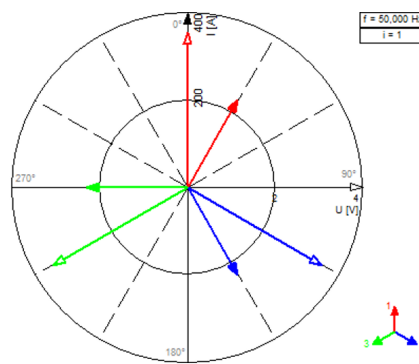
Image 148: Symmetrical balanced system vectorscope

$$U_{L1} = U_{Rms} e^{j0°} \quad I_{L1} = I_{L1_{RMS}} e^{j\varphi}$$

$$U_{L2} = U_{L2_{RMS}} e^{j-120°} \quad I_{L2} = I_{L2_{RMS}} e^{j(\varphi-70°)}$$

$$U_{L3} = U_{L3_{RMS}} e^{j\varphi-240°} \quad I_{L3} = I_{L3_{RMS}} e^{j(\varphi-190°)}$$

In order to explain the basic idea of the symmetrical components, the first step would be to define the operator „ " as a unit vector with a phase angle of 120° or 2pi/3.

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

Voltages	Complex view I	Complex view II	Angle view
U_{L1}	$\Re(U_{L1}) + \Im(U_{L1})$	$U_{L1} \cdot e^{j0°}$	U
U_{L2}	$\Re(U_{L2}) + \Im(U_{L2})$	$U_{L2} \cdot e^{j0°}$	$a^2 \cdot U$
U_{L3}	$\Re(U_{L3}) + \Im(U_{L3})$	$U_{L3} \cdot e^{j0°}$	$a \cdot U$

7.4.1. Calculation of the Zero-sequence system

In a symmetrical system the following equation is valid:

$$U_{L1} + U_{L2} + U_{L3} = 0$$

In a real system the sum won't be zero. There will be a voltage difference:

$$U_{L1} + U_{L2} + U_{L3} = \Delta u$$

This voltage difference divided through 3 represents the so called zero-sequence system:

$$U_0 = \tfrac{1}{3} \cdot \Delta u \ = u_{10} = u_{20} = u_{30}$$

The zero-sequence systems for the three phases (u_{10}, u_{20}, u_{30}) all have the same amplitude and phase. Therefore, only the value for the zero-sequence system „U_0" will be shown.

The calculation of the zero-sequence current is analog to that of the voltage equation.

> **Hint**
> When the currents of the zero-sequence system are multiplied by three (=I_0 · 3) it will yield the current that is flowing in the neutral line U_N.

7.4.2. Calculation of the positive-sequence system

The positive sequence system has the same rotating direction as the original system (clockwise). This means it will have the same rotating direction as an electrical machine connected to the grid.

$$\underline{v}_{1m} = \tfrac{1}{3}\,(\underline{v}_1 + \underline{a}\underline{v}_1 + \underline{a}^2\underline{v}_1)$$

$$\underline{v}_{2m} = \underline{a}^2\underline{v}_{1m} = \tfrac{1}{3}\,(\underline{v}_1 + \underline{a}\underline{v}_2 + \underline{a}^2\underline{v}_1)\cdot\underline{a}^2$$

$$\underline{v}_{3m} = \underline{a}\underline{v}_{1m} = \tfrac{1}{3}\,(\underline{v}_1 + \underline{a}\underline{v}_2 + \underline{a}^2\underline{v}_3)\cdot\underline{a}$$

As the values of the positive-sequence system for all three phases have the same amplitude (now that they are symmetrical) and have a phase shift of exactly 120°, it's adequate to show only one value. The value for the positive-sequence system in DewesoftX® is called „U_1".

7.4.3. Calculation of the negative-sequence system

The negative sequence system has the opposite rotating direction compared to the original system (anticlockwise). This means it will rotate in the opposite direction of an electrical machine connected to the grid.

$$\underline{v}_{1g} = \tfrac{1}{3}\,(\underline{v}_1 + \underline{a}^2\underline{v}_2 + \underline{a}\underline{v}_3)$$

$$\underline{v}_{2g} = \underline{a}\underline{v}_{1g} = \tfrac{1}{3}\,(\underline{a}\underline{v}_1 + \underline{v}_2 + \underline{a}^2\underline{v}_3)$$

$$\underline{v}_{3g} = \underline{a}^2\underline{v}_{1g} = \tfrac{1}{3}\,(\underline{a}^2\underline{v}_1 + \underline{a}\underline{v}_2 + \underline{v}_3)$$

As the values of the negative-sequence system for all three phases have the same amplitude (now they are symmetrical) and have a phase shift of exactly 120°, it's adequate to show one value. The value for the negative-sequence system in DewesoftX® is called „U_2".

7.4.4. Matrix of zero-, positive-, and negative-sequence system

According to the following equations the phase voltages and currents are transformed into the symmetrical components. This results in three balanced 3-phase systems, the positive (U_1, I_1), negative (U_2, I_2) and zero sequence (U_0, I_0).

Channel name in Dewesoft	Calculation
U_0, U_1, U_2	$$\begin{bmatrix} \underline{U}^0 \\ \underline{U}^1 \\ \underline{U}^2 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \cdot \begin{bmatrix} \underline{U}_{L1} \\ \underline{U}_{L2} \\ \underline{U}_{L3} \end{bmatrix}$$
I_0, I_1, I_2	$$\begin{bmatrix} \underline{I}^0 \\ \underline{I}^1 \\ \underline{I}^2 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \cdot \begin{bmatrix} \underline{I}_{L1} \\ \underline{I}_{L2} \\ \underline{I}_{L3} \end{bmatrix}$$

👆 **Important**
The basic values of symmetrical components (U_0, U_1, U_2, I_0, I_1, I_2) are calculated for each harmonic and added up geometrically.

As illustrated in the following images, an unbalanced system can be rectified using the positive, negative and zero symmetrical components. The image below depicts an unsymmetrical system as a screen shot taken from DewesoftX®.
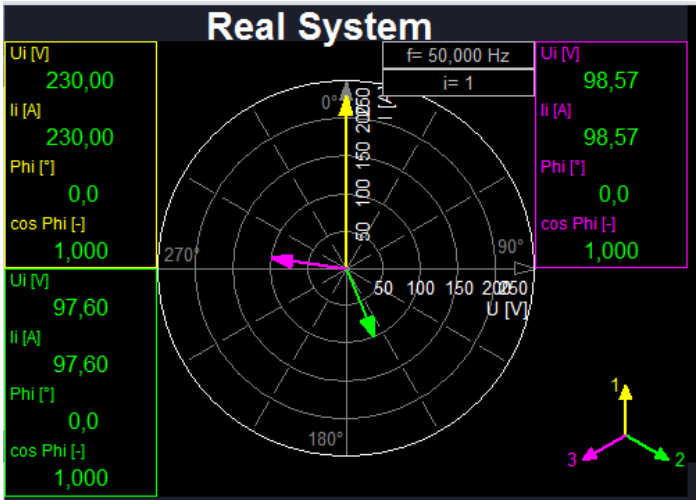
Image 149: Unbalanced system vectorscope in DewesoftX®

This screen was provided by Kurt STRANNER (KNG Netz GmbH)

The following image depicts a screen-shot showing the three systems (positive, negative and zero) of the symmetrical components in DewesoftX®:
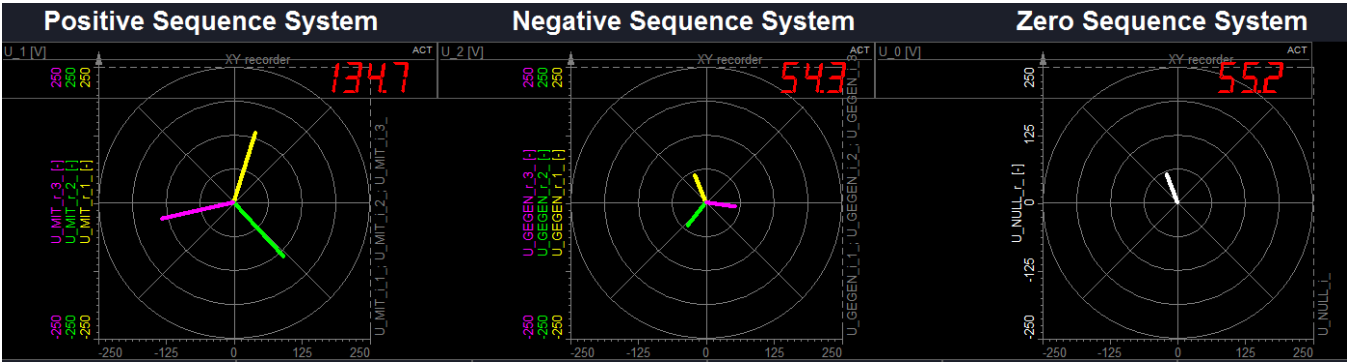
Image 150: Unbalanced system to balanced system transformation in DewesoftX®

This screen was provided by Kurt STRANNER (KNG Netz GmbH)

Out of the parameters of the symmetrical components (positive-, negative- and zero- sequence) the original system can be rebuilt easily, e.g.:

$$U_{L1} = U_0 + U_1 + U_2$$

The following variables are calculated in DewesoftX® and show the components of the zero- and negative-sequence system compared to the positive-sequence system (for the total and the fundamental harmonic).

Channel name in Dewesoft	Calculation	Description
u2,i2	$u_2 = \frac{U_1}{U_2} \cdot 100\ [\%]$ $i_2 = \frac{I_1}{I_2} \cdot 100\ [\%]$	Negative sequence component of the voltage / current of all harmonics **Note: This parameter is regulated in the EN 50160**
u0, i0	$u_0 = \frac{U_0}{U_1} \cdot 100\ [\%]$ $i_0 = \frac{I_0}{I_1} \cdot 100\ [\%]$	Zero sequence component of the voltage / current of all harmonics
u2_1, i2_1	$u_{2-1} = \frac{U_{2_{H1}}}{U_{1_{H1}}} \cdot 100\ [\%]$ $i_{2-1} = \frac{I_{2_{H1}}}{I_{1_{H1}}} \cdot 100\ [\%]$	Negative sequence component of the fundamental voltage / current in percent (unbalance factor according to EN50160)
u0_1, i0_1	$u_{0-1} = \frac{U_{0_{H1}}}{U_{1_{H1}}} \cdot 100\ [\%]$ $i_{0-1} = \frac{I_{0_{H1}}}{I_{1_{H1}}} \cdot 100\ [\%]$	Zero sequence component of the fundamental voltage / current in percent

7.4.5. Extended positive sequence parameters (according to IEC 61400)

The following calculations are based on Annex C of IEC 61400-21. Based on the measured phase voltages and currents, the fundamental Fourier coefficients are calculated over one fundamental cycle T.

$$u_{a,cos} = \frac{2}{T} \int_{t-T}^{t} u_a(t) \, cos \, (2\pi f_1 t) \, dt \qquad\qquad u_{a,sin} = \frac{2}{T} \int_{t-T}^{t} u_a(t) \, sin \, (2\pi f_1 t) \, dt$$

It is important to mention that the index a represents the line voltage L_1 (ua). The coefficients for L_2 (ub) and L_3 (uc) as well as the coefficients for the currents (ia, ib, ic) are calculated in exactly the same way. Furthermore, f_1 is the frequency of the fundamental. The RMS value of the fundamental line voltage is:

$$U_{a1} = \sqrt{\frac{u_{a,cos}^2 + u_{a,sin}^2}{2}}$$

Channel name in Dewesoft	Calculation	Description
U_ap_cos_per	$U_{1+,cos} = \frac{1}{6}[2u_{a,cos} - u_{b,cos} - u_{c,cos} - \sqrt{3}(u_{c,sin} - u_{b,sin}]$	Voltage and current vector components of the positive sequence for the fundamental
U_ap_sin_per	$U_{1+,sin} = \frac{1}{6}[2u_{a,sin} - u_{b,sin} - u_{c,sin} - \sqrt{3}(u_{c,cos} - u_{b,cos}]$	
I_ap_cos_per	$i_{1+,cos} = \frac{1}{6}[2i_{a,cos} - i_{b,cos} - i_{c,cos} - \sqrt{3}(i_{c,sin} - i_{b,sin}]$	
I_ap_sin_per	$i_{1+,sin} = \frac{1}{6}[2i_{a,sin} - i_{b,sin} - i_{c,sin} - \sqrt{3}(i_{c,cos} - i_{b,cos}]$	
P_1p_per	$P_{1+} = \frac{3}{2}((u_{1+,cos} \cdot i_{1+,cos}) - (u_{1+,sin} \cdot i_{+,sin}))$	Active and reactive power from the fundamental positive sequence
Q_1p_per	$Q_{1+} = \frac{3}{2}((u_{1+,cos} \cdot i_{1+,sin}) - (u_{1+,sin} \cdot i_{+,cos}))$	
U_1p_per	$U_{1+} = \sqrt{\frac{3}{2}(U_{1+,sin}^2 + U_{1+,cos}^2}$	RMS value of the line voltage of the fundamental positive sequence
U_1p_per	$I_{P1+} = \frac{P_{1+}}{\sqrt{3} \cdot U_{1+}}$	RMS values of the active and reactive current from the fundamental positive sequence
I_q1p_per	$I_{Q1+} = \frac{Q_{1+}}{\sqrt{3} \cdot U_{1+}}$	
cos_phi_1p_per	$cos\varphi_{1+} = \frac{P_{1+}}{\sqrt{P_{1+}^2 + Q_{1+}^2}}$	Power factor of the fundamental positive sequence
S_1p_per	$S_{1+} = \sqrt{P_{1+}^2 + Q_{1+}^2}$	Further calculation
I_1p_per	$i_{1+} = \frac{S_{1+}}{\sqrt{3} \cdot U_{1+}}$	

7.4.6. Extended negative sequence parameters (according to IEC 61400)

Channel name in Dewesoft	Calculation	Description
U_an_cos_per	$U_{1-,cos} = \frac{1}{6}[2u_{a,cos} - u_{b,cos} - u_{c,cos} + \sqrt{3}(u_{c,sin} - u_{b,sin}]$	Voltage and current vector components of the negative sequence for the fundamental
U_an_sin_per	$U_{1-,sin} = \frac{1}{6}[2u_{a,sin} - u_{b,sin} - u_{c,sin} + \sqrt{3}(u_{c,cos} - u_{b,cos}]$	
I_an_cos_per	$i_{1-,cos} = \frac{1}{6}[2i_{a,cos} - i_{b,cos} - i_{c,cos} + \sqrt{3}(i_{c,sin} - i_{b,sin}]$	
I_an_sin_per	$i_{1-,sin} = \frac{1}{6}[2i_{a,sin} - i_{b,sin} - i_{c,sin} + \sqrt{3}(i_{c,cos} - i_{b,cos}]$	
P_1n_per	$P_{1-} = \frac{3}{2}((u_{1-,cos} \cdot i_{1-,cos}) - (u_{1-,sin} \cdot i_{-,sin}))$	Active and reactive power from the fundamental negative sequence
Q_1n_per	$Q_{1-} = \frac{3}{2}((u_{1-,cos} \cdot i_{1-,sin}) - (u_{1-,sin} \cdot i_{-,cos}))$	
U_1n_per	$U_{1-} = \sqrt{\frac{3}{2}(U_{1-,sin}^2 + U_{1-+,cos}^2}$	RMS value of the line voltage of the fundamental negative sequence
S_1n_per	$S_{1-} = \sqrt{P_{1-}^2 + Q_{1-}^2}$	Further calculations
I_1n_per	$i_{1-} = \frac{S_{1-}}{\sqrt{3} \cdot U_{1-}}$	

7.4.7. Extended Zero sequence parameters (according to IEC 61400)

Channel name in Dewesoft	Calculation	Description
U_az_cos_per	$U_{1z,cos} = \frac{1}{3}[u_{a,cos} + u_{b,cos} + u_{c,cos}]$	Voltage and current vector components of the zero sequence for the fundamental
U_az_sin_per	$U_{1z,sin} = \frac{1}{3}[u_{a,sin} + u_{b,sin} + u_{c,sin}]$	
I_az_cos_per	$i_{1z,cos} = \frac{1}{3}[i_{a,cos} + i_{b,cos} + i_{c,cos}]$	
I_az_sin_per	$i_{1z,sin} = \frac{1}{3}[i_{a,sin} + i_{b,sin} + i_{c,sin}]$	
P_1z_per	$P_{1z} = \frac{3}{2}((u_{1z,cos} \cdot i_{1z,cos}) - (u_{1z,sin} \cdot i_{z,sin}))$	Active and reactive power from the fundamental negative sequence
Q_1z_per	$Q_{1z} = \frac{3}{2}((u_{1z,cos} \cdot i_{1z,sin}) - (u_{1z,sin} \cdot i_{z,cos}))$	
U_1z_per	$U_{1-} = \sqrt{\frac{3}{2}(U_{1z,sin}^2 + U_{1z+,cos}^2}$	RMS value of the line voltage of the fundamental negative sequence
S_1z_per	$S_{1z} = \sqrt{P_{1z}^2 + Q_{1z}^2}$	Further calculations
I_1z_per	$i_{1z} = \frac{S_{1z}}{\sqrt{3} \cdot U_{1z}}$	

7.4.8. Flicker

Flicker is a term used to describe fluctuations (repetitive variations) of voltage. Flashing light bulbs are indicators of high flicker exposure. Flicker is especially present in grids with a low short-circuit resistance and is caused by the frequent connection and disconnection (e.g. heat pumps, rolling mills, etc.) of loads which affect the voltage. A high level of flicker is perceived as psychologically irritating and can be harmful to humans.
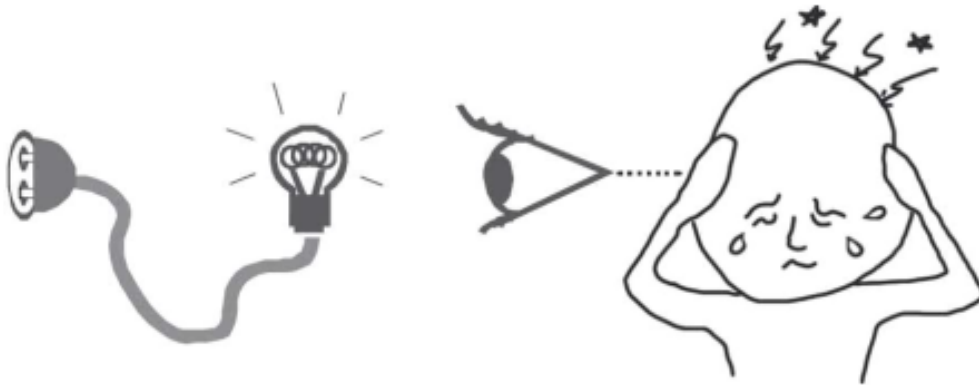
Image 151: Flicker impact on humans

The Dewesoft Power Analyzer can measure all the Flicker parameters according to the IEC 61000-4-15 standard. The Flicker emission calculation is implemented according to the IEC 61400-21 standard and allows for the evaluation of flicker emissions that are fed into the grid by wind power plants and other power generation units.

The flicker-meter architecture is depicted as a block diagram in the next image. It is divided into two parts, simulation of the response to the lamp-eye-brain chain and the on-line statistical analysis of the flicker signal leading to the known parameters. The blocks within the block diagram will be discussed briefly.
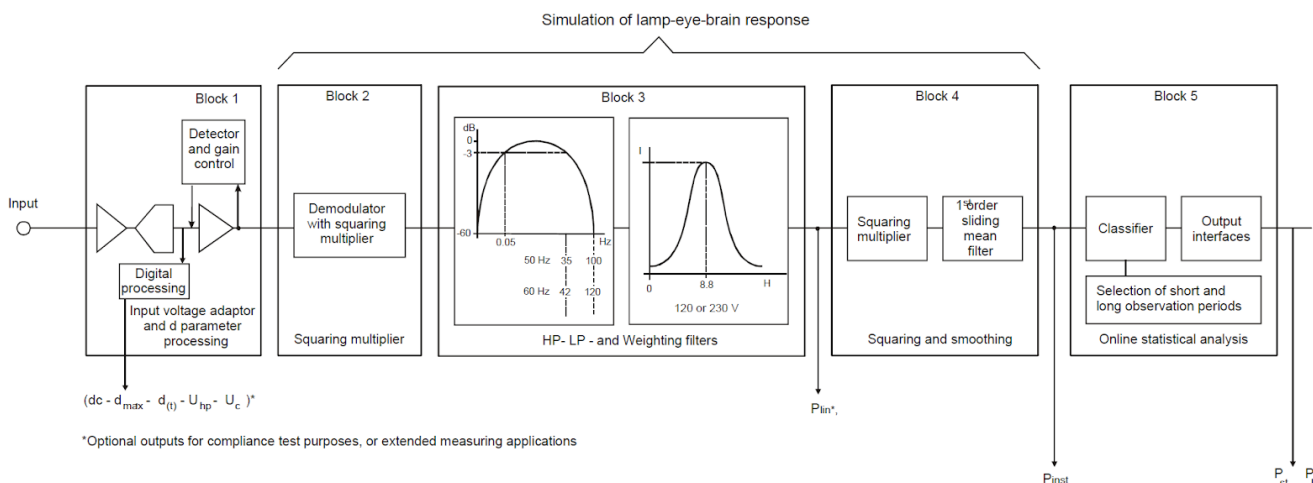
Image 152: Flicker-meter architecture

Block 1

The first block contains a voltage adapting circuit that scales the input mains frequency voltage to an internal reference level. This method permits flicker measurements to be made, independently of the actual input carrier voltage level and may be expressed as a percent ratio.

Block 2

The second block has the function of recovering the voltage fluctuation by squaring the input voltage scaled to the reference level, thus simulating the behavior of a lamp.

Block 3

The third block is composed of a cascade of two filters, which can precede or follow the selective filter circuit. The first low-pass filter eliminates the double mains frequency ripple components of the demodulator output.

The high pass filter can then be used to eliminate any DC voltage component. The second filter is a weighting filter block that simulates the frequency response of the human visual system to sinusoidal voltage fluctuations of a coiled filament gas-filled lamp (60 W/230 V and/or 60 W/120 V).

Block 4

The fourth block consists of a squaring multiplier and a first order low-pass filter. The human flicker perception, with an eye and brain combination, to voltage fluctuations applied to the reference lamp, is simulated by the combined non-linear response of the blocks 2,3 and 4.

Block 5
The last block of the chain performs an on-line analysis of the flicker level, thus allowing direct calculation of significant evaluation parameters.

The following image is an example of a rectangular voltage flicker.
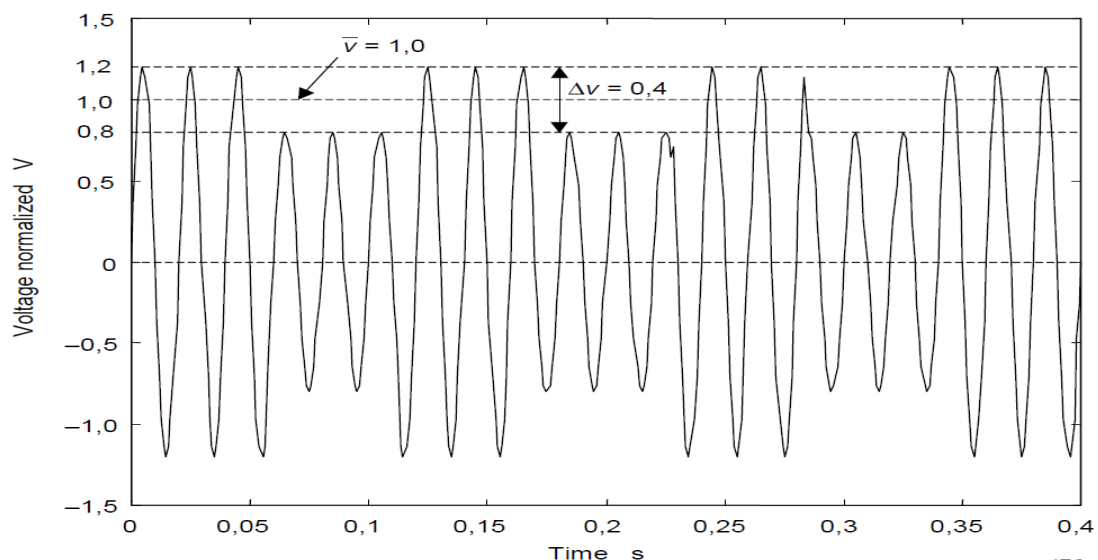
Image 153: Rectangular voltage flicker

7.4.9. Measurement with DewesoftX®

With DewesoftX® the Short-Term Perceptibility (Pst) and Long-Term Perceptibility (Plt) values can be calculated according to the IEC standard, with a calculation time of 10 minutes and 120 minutes respectively. It is of course also possible to adapt the calculation time to the needs of the user, simply set a calculation overlap and filter.
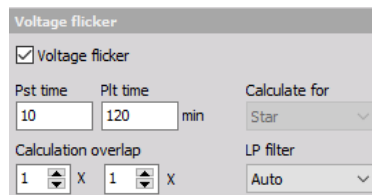
Image 154: Voltage flicker options in the power module
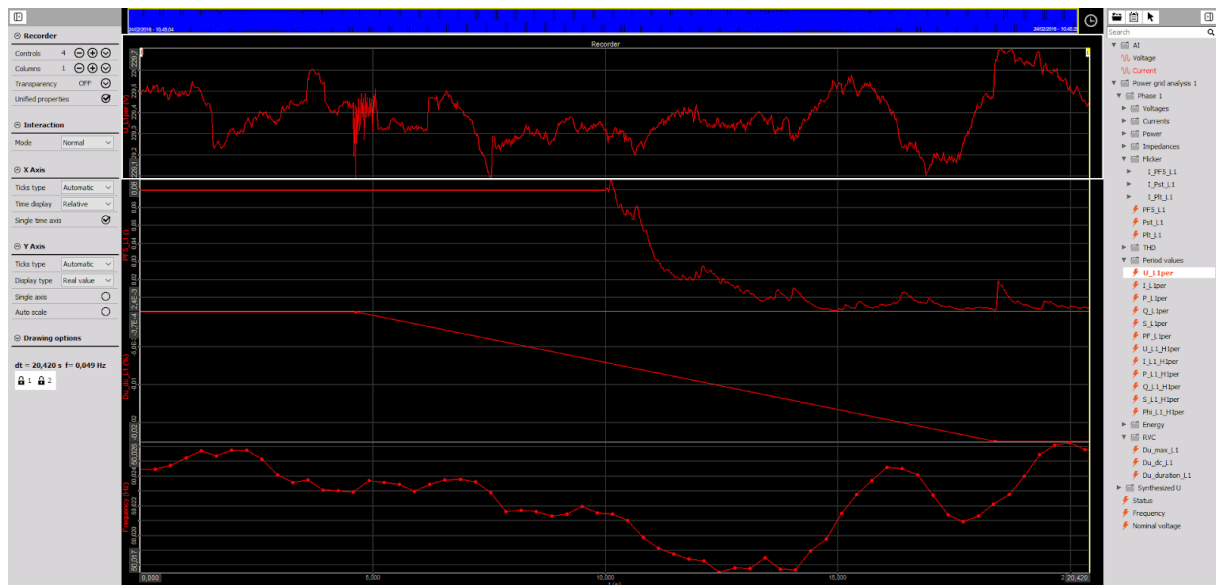
Image 155: Flicker measurement screen

7.4.10. Flicker emission

The flicker emission (also called current flicker) calculates the proportion of the flicker, which is added to the grid by a producer or a consumer. In addition, the internal voltage drop is calculated by the grid impedance of the current flow.
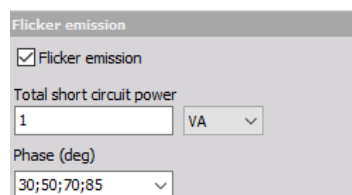
Image 156: Flicker emission options in the power module

The voltage drop is added to an idealized voltage source vectorially ($U=U_{sim}+R{\cdot}I+L{\cdot}di/dt$). Using the flicker algorithm and the new voltage, the current flicker values are calculated.
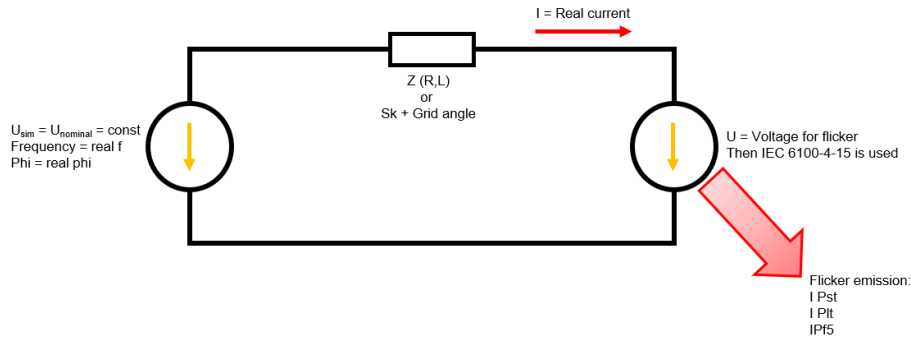
Image 157: Schematic illustration of the current flicker calculation

Enable "Flicker" and "Flicker emission" and add the grid parameters. The short circuit and the impedance of the grid can then also be added. The phase will be the impedance phase of the grid. The number of different phase angles can also be added (e.g. 30;50;70;85).

Important
In the power module the nominal voltage must be set.
This value is also the value for the idealized voltage source.
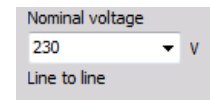
The following table expresses the channel names of the different parameters as they are presented in the DewesoftX® software. All the parameters are calculated using the IEC 61000-4-15 Standard's predefined calculation methods.

Channel name in Dewesoft	Calculation	Description
PF5_L1		Represents the P_{inst} value from **IEC 61000-4-15**.
Pst_L1		Short time flicker value
Plt_L1		Long-time flicker value
I_PF5_L1	According to IEC 61000-4-15	Represents the P_{inst} value from **IEC 61000-4-1**5 for the current
I_Pst_L1		Short time flicker value for the current
I_Plt_L1		Long-time flicker value for the current
I_PF5_L1_30; I_Pst_L1_30; I_Plt_L1_30		Flicker values for a certain phase angle

7.5. Rapid voltage changes

Rapid Voltage Changes are parameters which are added as a supplement to the flicker standard. Rapid Voltage Changes describe all voltage changes that change the voltage for more than 3% at a certain time interval. These voltage changes can afterwards be analyzed with different parameters (depth of voltage change, duration, steady state deviation, etc.).

The Rapid Voltage Changes (RVC) are special calculations in DewesoftX® which allows the calculation of the maximal voltage drop (d_{max}), the stationary deviation after the voltage drop (dc) and the time where the voltage drops below 3,3% of U_n. All values are calculated according to the IEC 61000-4-15. Analysis can be done for example for IEC 61000-3-3 and IEC 61000-3-11. The following image shows the calculated parameters (IEC 61000-4-15 page 35).
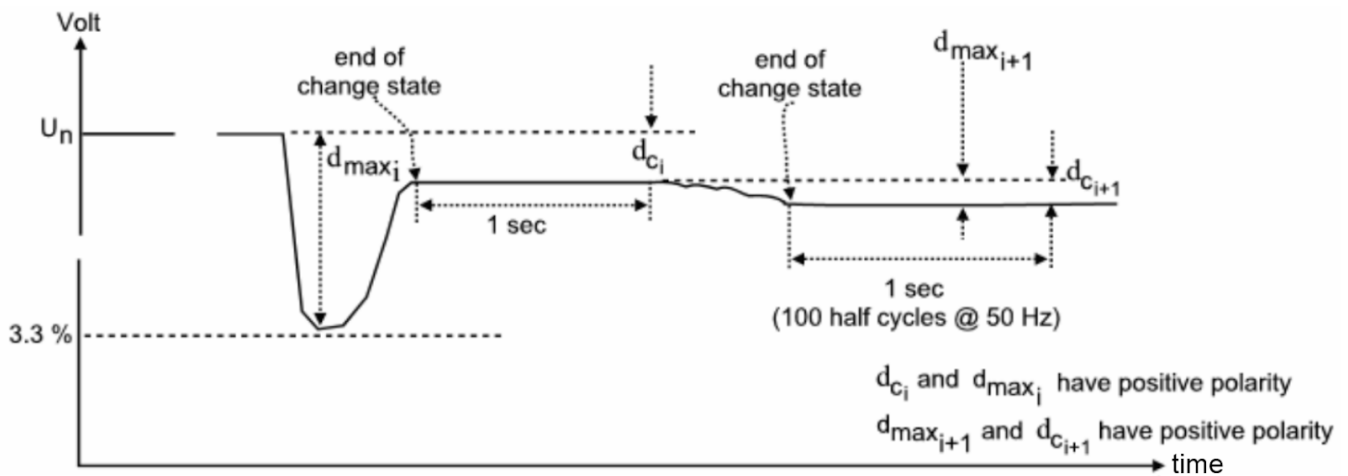
Image 158: Rapid voltage changes according to the IEC 61000-4-15 standard

7.5.1. Measurement with Dewesoft

RVCs measurements with DewesoftX®:

Image 159: Rapid voltage change options in the power module

Steady state duration: This defines the duration of the steady state defined in seconds.
Hysteresis: is the condition for the stationary deviation (d_u–d_c) defined in percentage, see IEC 61000-4-15 page 8.

Example: If a hysteresis of 0,2% and a steady state duration of 1s is defined, the stationary condition is reached if the voltage doesn't deviate more than +- 0,2% for 1 second.

> **Hint**
> The Rapid Voltage Change values ($d_{u(max)}$, $d_{u(duration)}$ and $d_{u(dc)}$) are calculated from the defined settings for period values (Number of periods and overlap). Please ensure that the correct settings are used for analysis according to the related standards (½ period values for RVC determination according to IEC 61000-4-15)

Channel name in Dewesoft	Calculation	Description
Du_max_L1		Maximum absolute voltage changes during an observation period
Du_dc_L1	According to IEC 61000-4-15	Stationary deviation after the voltage drop
Du_duration_L1		time where the voltage drop is below 3,3% of Un

Image 160: Rapid voltage change measurement screen

7.6. Vectorscope

The default orientation of the vector-scope is "upper, clockwise". This means the phase L1 will be located on the y-axis. The orientation can be changed to the user preference in the settings. To do this go to "Options" → "Settings". In "Settings" select "Extensions" → "Power Analysis" the orientation of the vector-scope can be changed in this section. There are four possibilities for vector-scope orientation:

- Upper and clockwise
- Right and clockwise
- Upper and counterclockwise
- Right and counter clockwise
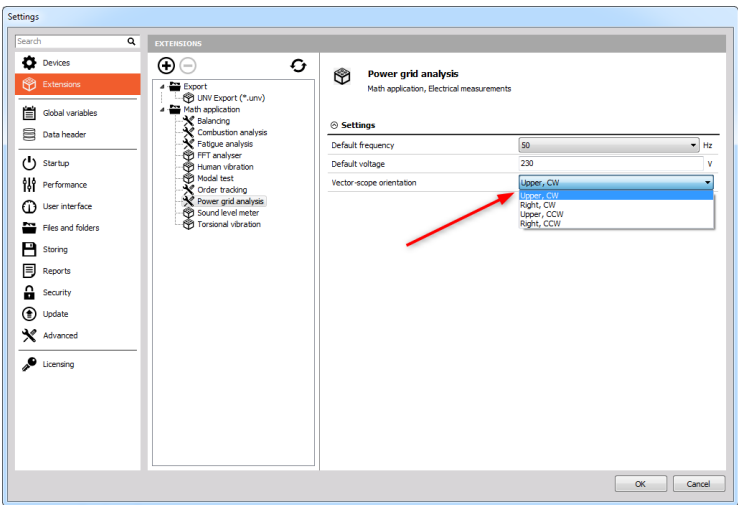
Image 161: Changing the orientation of the vectorscope in DewesoftX®

With the default setting "Upper, clockwise" capacitive and inductive currents are represented as follows
Capacitive currents (Voltage [Blue], current [Red])
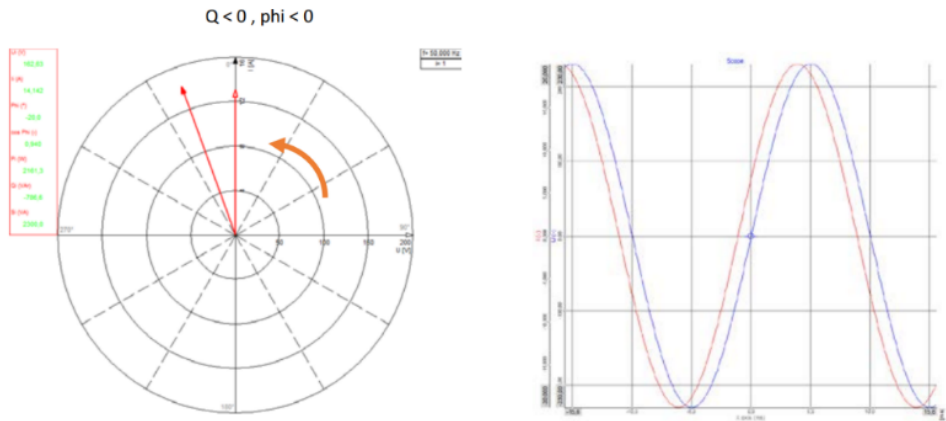
Image 162: Capacitive current vectorscope and oscilloscope measurement screen

Inductive currents (Voltage [Blue], current [Red])
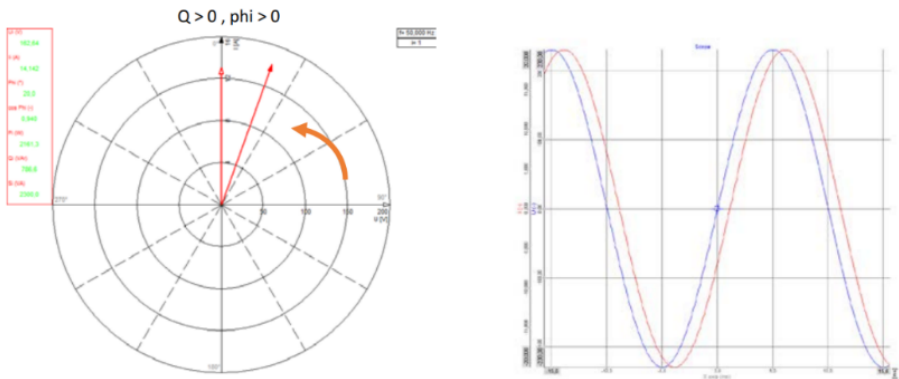
Image 163: Inductive current vectorscope and oscilloscope measurement screen

8. Data storage

Data storage and processing are very important components of data acquisition. For this reason, Dewesoft offers an array of possibilities to store data according to the users' needs and preferences. The storing options can be found in acquisition mode → channel set-up → storing as depicted in the image below. This chapter will elaborate on the storage possibilities that are offered in DewesoftX®.
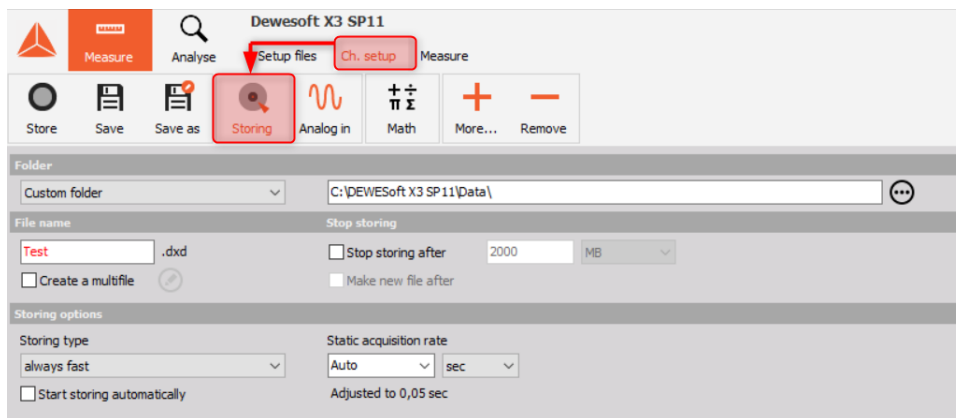
Image 164: Data storage in DewesoftX®

If start **storing automatically** is selected the data storage will start as soon as there is a change to any online display (scope, recorder, etc.). The file name for each measurement can be defined as well as the default folder where the data files will be stored.

8.1. Multi-File storage

Multifile automatically assigns a new file name for each cycle (start) of storage. To create a multifile tick the box in the storing options as seen in the image highlighted in red.
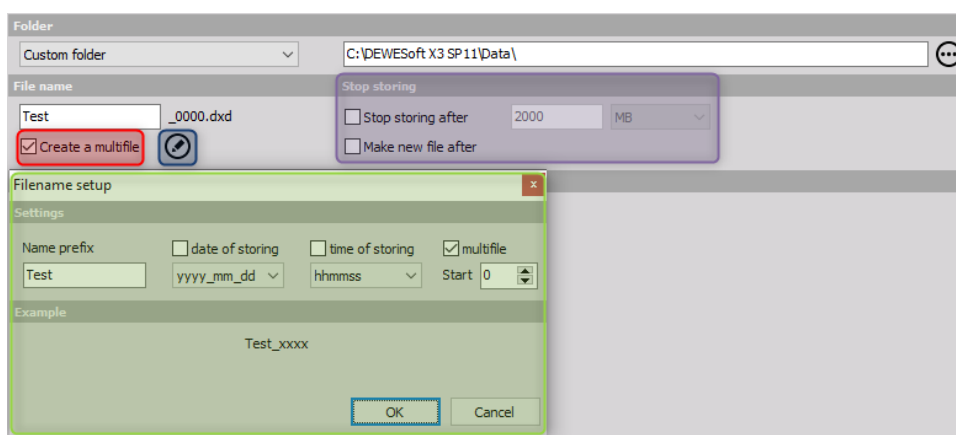
Image 165: Multi-file storage

File names can either be consecutive (such as 0001, 0002, 0003) or catalogued by date and time. To define these parameters please select the pencil icon that is highlighted in blue. This will bring up the settings mask that is highlighted in green. The file can be given a name prefix that is freely definable by the user. In this case it is named Test. If only name prefix and multifile are selected the data files will be

saved using consecutive numbers as the example above shows. If date and time are chosen, the file name will be displayed as seen in the image below.
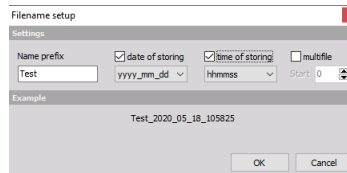
Image 166: Multi-file storage filename setup

Additionally, the creation of a new file can be set after a certain file size has been reached or after a predefined time has been reached. This is done in the settings mask "Make new file after". This is shown in the settings mask highlighted in violet.
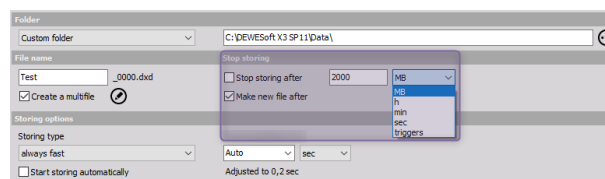
Image 167: Multi-file storage new file creation options

The criteria for switching to a new file can either be the size or the time (in seconds, minutes, hours or after reaching an absolute time) as mentioned above. This can be very useful especially when data acquisition is done over extended periods of time. If the option to switch the file after each hour with absolute time is selected, a new file will be created every hour on the hour (01:00, 02:00, 03:00, etc.), the time stamp will be taken form the absolute PC time (or a more exact time source, if it is available, and defined in the hardware set-up). The file switching will take place in such a manner that there are no data points lost in the process.

8.2. Storing options

The following image depicts the different options that are available for data storage in DewesoftX®. These options will be elaborated on below.
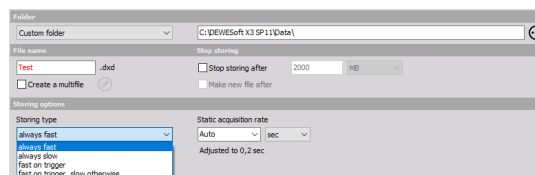
Image 168: Storing options

With the always fast and always slow storing options the possibility exists to choose between different static acquisition rates and units. With the trigger storing options, a new trigger tab will automatically appear on the DewesoftX® set-up screen.

> **Important**
> With Dewesoft it is possible to trigger the signals by setting up any channel(s) to start and stop recording data according to predefined parameters (levels).

8.2.1. Always fast

This is the default data storage option in DewesoftX®. This means that if there is no other storage option selected as shown above, data will be stored in this manner. This is a dynamic acquisition rate and will store the entire measurement in full-speed. This is the best option to use for post processing as all the data points are available making the post processing reliable and very accurate.

8.2.2. Always slow

If it is required that the data be acquired at a lower rate (interval storage), the always slow storing option should be selected. This option is mostly used to reduce the size of the data file that is stored. This option stores that data at intervals that are set with static/reduced rates. Although this option is selected DewesoftX® will still acquire the data at full speed, then calculate the minimum, maximum, and average RMS values for the defined intervals and only store these values.

In the image below the static acquisition rate is set to 0,1 seconds, this in essence means that the file size where the data is stored will be smaller than that of a file where the data was acquired dynamically.
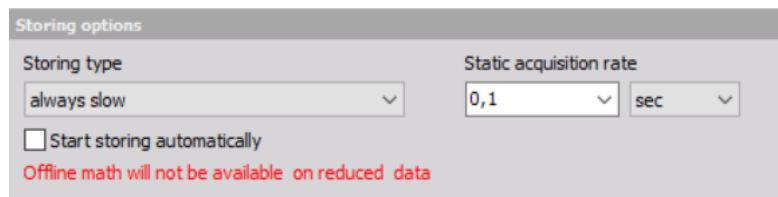
Image 169: Always slow storing option

Hint
Please note that when this storing option is selected, offline math will not be available, meaning that the post processing capabilities will be very limited.

8.2.3. Fast on trigger

If the measurement consists of "events" which need to be captured and stored, the fast on trigger storage option can be used. The trigger event(s) can be defined by the user and Dewesoft will only acquire the data when the triggered event (point of interest) takes place. By choosing the fast on trigger option, a new tab will appear where it is then possible to define the trigger conditions.

There are three conditions that the user can define namely pre-time, post-time and holdoff-time as seen below.

Image 170: Fast on trigger storing option

Pre time: Pre-trigger time defined in milliseconds. This value defines the storage duration before the trigger event occurs, DewesoftX® will keep the data in a buffer until the trigger event occurs and then store the predefined pre-time data to the file as well. As a default, this feature is deselected, and storage starts with the trigger event itself.

Post time: Post-trigger time defined in milliseconds. This value defines the storage duration after the trigger event has taken place. DewesoftX® will continue to store data until stopped manually or the predefined stop condition occurs. As a default, this feature is deselected, and storage stops immediately after the trigger event is over.

Holdoff time: The post time extension is checked automatically as long as the Post time option is not selected. The acquisition duration will be prolonged when further trigger events appear while the first one is still being recorded.

Trigger condition setup: For a trigger to work the trigger conditions need to be defined, to initiate the beginning of storage as well as other parameters. The image below depicts the condition set-up screen.
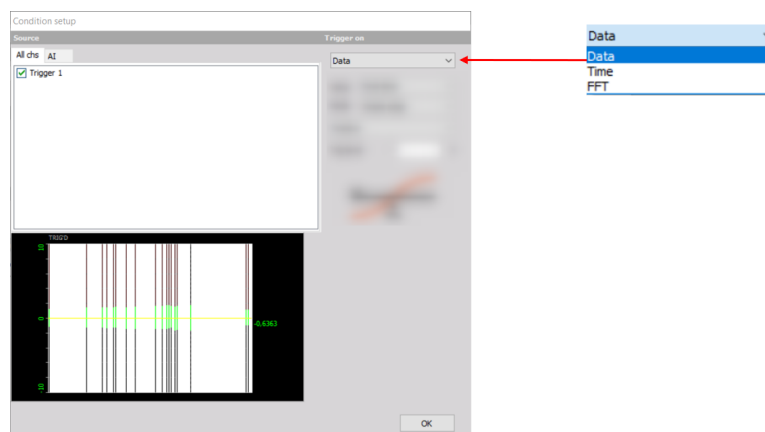
Image 171: Trigger condition setup

In the trigger set-up window, the channels that will be used for the trigger can be selected. Several channels can be selected for triggering, but in this example, there will only be one channel available. The trigger criteria must be defined. The user can trigger on data, time or FFT.

Data triggering: This triggering option can be triggered on various data points namely the real data, average, RMS, Max value or Min value. It also includes various modes such as simple edge, filtered edge, window, pulse-width, window and pulse-width and Delta amplitude all triggered on the value that was set previously. The trigger can also be set to trigger on positive or negative values.

For this simple application, the simple edge triggered on a real value with a trigger level of 0.5 will be selected. This means that when the value crosses the 0,5 V limit, it will produce a trigger and data acquisition will be initialized. The trigger behavior can already be tested from the scope in the lower left side of the set-up window.
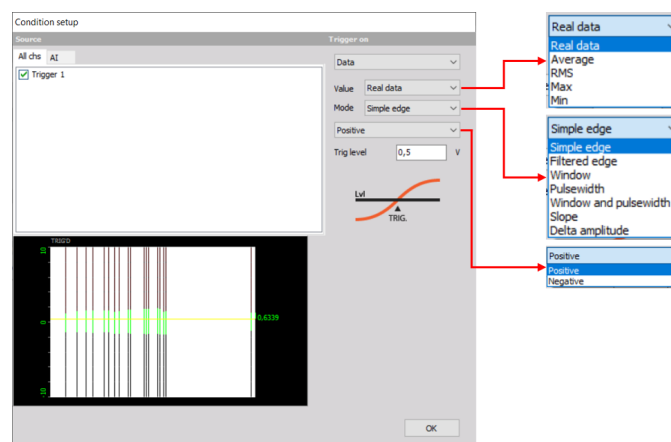
Image 172: Data triggering setup

Time triggering: This triggering option uses time as the triggering reference. The time format can be set to either relative time, the system triggers when the defined time x (unit) has passed since the measurement was started, or absolute time, the system triggers exactly at the defined time hh:mm:ss.xxx (will also trigger daily when time matches).

The next trigger parameter is the time itself, here the time can be set to equal to which means the measurement will begin at exactly the denied time, or every where the measurement will take place every time the predefined time window has been reached.
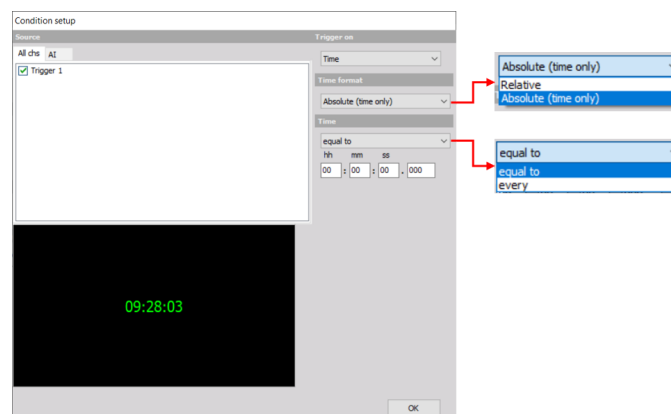
Image 173: Time triggering setup

FFT Triggering: The previous two triggering conditions are set to trigger only on amplitude values in the time domain. The FFT trigger enables the user to trigger amplitude values in the frequency domain. This trigger option comes in very handy when doing dynamic signal analysis where frequency consistency is important. This is because all in the time domain almost all signals are made up of a series of sine waves. The FFT transform deconstructs these sine waves from a time domain representation to a frequency domain representation. This allows us to evaluate the various frequencies that make up a signal.
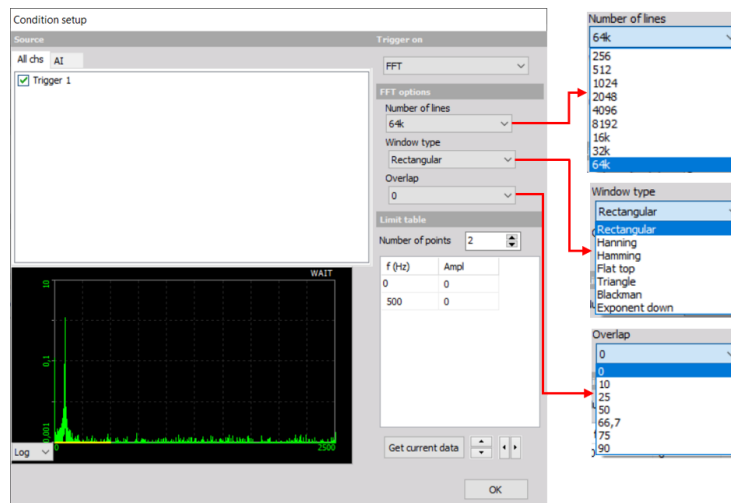
Image 174: FFT triggering setup

The trigger on FFT has quite a few parameters that must be set. Firstly the number of lines, this defines the resolution of the FFT, the higher the number of lines the higher the resolution of the FFT will be. The window type defines the signal output, the default setting is the rectangular window (a.k.a uniform window). There are different windows available for analysis, the most notable is the Hanning window, this is because the hanning window is sufficient to analyse about 95% of all signals, the others that are available are used in special cases. Overlapping, this is in essence a zoom function, it elongates the time scale, by doing this it enables us to better visualize the frequency changes within the overlapped time frame. This option is given in percent of the original signal.

In the bottom left corner of the image a preview of the measurement window can be seen with the FFT, it is possible to view the FFT on a logarithmic scale or it can be viewed in a linear scale. Simply click on where it shows Log and select Lin to change it.

For a more detailed explanation of the Trigger conditions or the FFT analysis please follow the integrated links.

> **Hint**
> The higher the number of lines, the higher the sampling rate for the data acquisition must be. This will also increase the amount of data storage space that is needed for the measurement.

8.2.4. Fast on trigger, slow otherwise

There is a possibility to acquire data at two speeds, but to accomplish this a different strategy needs to be implemented namely fast on trigger, slow otherwise. With this option the data will be stored at the dynamic rate at trigger events, and with a reduced rate when there are no trigger events. The settings for this mode are similar to that of the fast on trigger. However, it shall be noted that if the user acquires and reloads similar data with this strategy, the data is also reduced for the regions without the trigger.
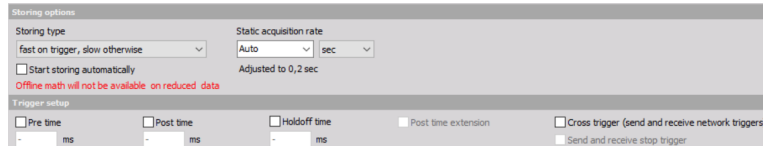
Image 175: Fast on trigger, slow otherwise setup

Noteworthy is that post processing capabilities will be limited with this storage method, but on the other hand the data file size will be greatly reduced. Post processing can be done on the triggered events as they are acquired at full speed.

8.3. Storing data

When all the storing options have been set, the actual storing of data is very simple. As shown in the image below, simply click on the store button when in the measurement screen.
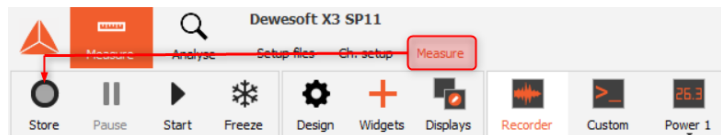
Image 176: Start data acquisition

When the store button is clicked the grey circle will change to orange which indicates that the data is now being stored.
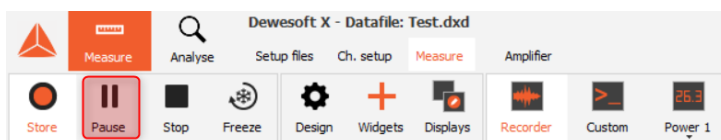
Image 177: Pausing data acquisition

When the pause button is clicked the data acquisition will still continue, only data storage will be interrupted. The store button will then automatically change to a resume button, when it is clicked the data storage will resume.
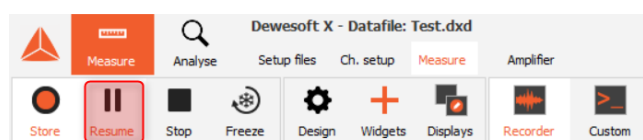
Image 178: Resuming data acquisition

The purpose of this chapter was to give the user a short introduction into the storing options that are available in the DewesoftX® software. For further information please refer to the Dewesoft Pro Training Storing options, which is available on the Dewesoft web page under pro training. Here the topic is covered in much more detail. There are also application examples.

9. Technical Reference - Channel List

	Nth - Harmonic	Total
Apparent power	$S_h = U_h \cdot I_h$	$S = U_{rms_{totta\ddot{o}}} \cdot I_{rms_{total}}$
Active power	$P_h = U_h \cdot I_h \cdot cos(\varphi_h)$	$P = \sum_{h=1}^{H} P_h$
Reactive power	$Q_h = U_h \cdot I_h \cdot sin(\varphi_h) = \sqrt{S_h^2 - P_h^2}$	$Q = \sqrt{S^2 - P^2}$

Channel name in DEWESoft	Calculation	Description
S_L1_H1	$S_h = U_h \cdot I_h$	Apparent, active and reactive power for a certain harmonic frequency (e.g. for L1 and h=1)
P_L1_H1	$P_h = U_h \cdot I_h \cdot cos(\varphi_h)$	
Q_L1_H1	$Q_h = U_h \cdot I_h \cdot sin(\varphi_h) = \sqrt{S_h^2 - P_h^2}$	
S_L1	$S = U_{1_{rms}} \cdot I_{1_{rms}}$	Three power parameters for the whole waveform (e.g. for L1)
P_L1	$P = \sum_{h=1}^{H} P_h$	
Q_L1	$Q = \sqrt{S^2 - P^2}$	
Z_L1	$Z_{L1} = \frac{U}{I}$	Impedance for the whole waveform (e.g. for L1)
Z_L1_H1	$Z_{L1} = \frac{U_H}{I_H}$	Impedance for a certain harmonic (e.g. for L1 and H1)
PF_L1	$PF = \frac{P}{S}$	Power factor (e.g. for L1)
D_L1	$D = \sqrt{Q^2 - Q_{h=1}^2}$	D_L1, distortion power of all harmonic components reactive powers (u and i have the same order but not equal 1 or have different order) (e.g. for L1)
QH_L1	$Q = \sum_{h=1}^{H} Q_h$	Reactive power of all harmonics where u and i have the same harmonics order (e.g. for L1)
DH_L1	$DH = \sqrt{Q^2 - QH^2}$	Distortion power of all harmonic components reactive powers where u and i have different harmonic orders (e.g. for L1)

Channel name in DEWESoft	Calculation	Description
THD_U_L1, ...	$THD_U = \dfrac{\sqrt{\sum\limits_{h=2}^{n}(U_h)^2}}{U_1}$	THD of the voltage
THDOdd_U_L1, ...	$THD_{Uodd} = \dfrac{\sqrt{(\sum\limits_{h=1}^{n}\cdot(U_{2h+1})^2)}}{U_1}$	THD of the voltage for odd and even harmonics
THDEven_U_L1, ...	$THD_{Ueven} = \dfrac{\sqrt{(\sum\limits_{h=1}^{n}\cdot(I_{2h})^2)}}{U_1}$	
THD_I_L1, ...	$THD_I = \dfrac{\sqrt{\sum\limits_{h=2}^{n}(U_h)^2}}{I_1}$	THD of the current
THDOdd_I_L1, ...	$THD_{Iodd} = \dfrac{\sqrt{(\sum\limits_{h=1}^{n}\cdot(I_{2h+1})^2)}}{I_1}$	THD of the current for odd and even harmonics
THDEven_I_L1, ...	$THD_{Ieven} = \dfrac{\sqrt{(\sum\limits_{h=1}^{n}\cdot(I_{2h})^2)}}{I_1}$	

Channel name in DEWESoft	Calculation	Description
TIHD_U_L1, ...	$TIHD_U = \dfrac{\sqrt{\sum\limits_{k=1}^{n}(U_k)^2}}{U_1}$	Total Interharmonic distortion of the voltage/current.
TIHD_I_L1, ...	$TIHD_I = \dfrac{\sqrt{\sum\limits_{k=1}^{n}(I_k)^2}}{I_1}$	Equivalent to the THD, but defined for interharmonics
K_U_L1	$K_U = \dfrac{\sqrt{\sum\limits_{h=2}^{n}(U_h)^2}}{U}$	K-factor for voltage and current. Refers to the full-spectrum, the THD only to the fundamental voltage
K_I_L1	$K_I = \dfrac{\sqrt{\sum\limits_{h=2}^{n}(I_h)^2}}{I}$	

Channel name in Dewesoft	Calculation
U_0, U_1, U_2	$$\begin{bmatrix} \underline{U^0} \\ \underline{U^1} \\ \underline{U^2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \cdot \begin{bmatrix} \underline{U_{L1}} \\ \underline{U_{L2}} \\ \underline{U_{L3}} \end{bmatrix}$$
I_0, I_1, I_2	$$\begin{bmatrix} \underline{I^0} \\ \underline{I^1} \\ \underline{I^2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \cdot \begin{bmatrix} \underline{I_{L1}} \\ \underline{I_{L2}} \\ \underline{I_{L3}} \end{bmatrix}$$

Channel name in Dewesoft	Calculation	Description
u2,i2	$u_2 = \frac{U_1}{U_2} \cdot 100 \ [\%]$ $i_2 = \frac{I_1}{I_2} \cdot 100 \ [\%]$	Negative sequence component of the voltage / current of all harmonics **Note: This parameter is regulated in the EN 50160**
u0, i0	$u_0 = \frac{U_0}{U_1} \cdot 100 \ [\%]$ $i_0 = \frac{I_0}{I_1} \cdot 100 \ [\%]$	Zero sequence component of the voltage / current of all harmonics
u2_1, i2_1	$u_{2-1} = \frac{U_{2_{H1}}}{U_{1_{H1}}} \cdot 100 \ [\%]$ $i_{2-1} = \frac{I_{2_{H1}}}{I_{1_{H1}}} \cdot 100 \ [\%]$	Negative sequence component of the fundamental voltage / current in percent (unbalance factor according to EN50160)
u0_1, i0_1	$u_{0-1} = \frac{U_{0_{H1}}}{U_{1_{H1}}} \cdot 100 \ [\%]$ $i_{0-1} = \frac{I_{0_{H1}}}{I_{1_{H1}}} \cdot 100 \ [\%]$	Zero sequence component of the fundamental voltage / current in percent

Channel name	Calculation	Description

in Dewesoft		
U_ap_cos_per	$U_{1+,cos} = \frac{1}{6}[2u_{a,cos} - u_{b,cos} - u_{c,cos} - \sqrt{3}(u_{c,sin} - u_{b,sin}]$	Voltage and current vector components of the positive sequence for the fundamental
U_ap_sin_per	$U_{1+,sin} = \frac{1}{6}[2u_{a,sin} - u_{b,sin} - u_{c,sin} - \sqrt{3}(u_{c,cos} - u_{b,cos}]$	
I_ap_cos_per	$i_{1+,cos} = \frac{1}{6}[2i_{a,cos} - i_{b,cos} - i_{c,cos} - \sqrt{3}(i_{c,sin} - i_{b,sin}]$	
I_ap_sin_per	$i_{1+,sin} = \frac{1}{6}[2i_{a,sin} - i_{b,sin} - i_{c,sin} - \sqrt{3}(i_{c,cos} - i_{b,cos}]$	
P_1p_per	$P_{1+} = \frac{3}{2}((u_{1+,cos} \cdot i_{1+,cos}) - (u_{1+,sin} \cdot i_{+,sin}))$	Active and reactive power from the fundamental positive sequence
Q_1p_per	$Q_{1+} = \frac{3}{2}((u_{1+,cos} \cdot i_{1+,sin}) - (u_{1+,sin} \cdot i_{+,cos}))$	
U_1p_per	$U_{1+} = \sqrt{\frac{3}{2}(U^2_{1+,sin} + U^2_{1+,cos}}$	RMS value of the line voltage of the fundamental positive sequence
I_p1p_per	$I_{P1+} = \frac{P_{1+}}{\sqrt{3} \cdot U_{1+}}$	RMS values of the active and reactive current from the fundamental positive sequence
I_q1p_per	$I_{Q1+} = \frac{Q_{1+}}{\sqrt{3} \cdot U_{1+}}$	
cos_phi_1p_per	$cos\varphi_{1+} = \frac{P_{1+}}{\sqrt{P^2_{1+}+Q^2_{1+}}}$	Power factor of the fundamental positive sequence
S_1p_per	$S_{1+} = \sqrt{P^2_{1+} + Q^2_{1+}}$	Further calculation
I_1p_per	$i_{1+} = \frac{S_{1+}}{\sqrt{3} \cdot U_{1+}}$	

Channel name in Dewesoft	Calculation	Description
Du_max_L1	According to IEC 61000-4-15	Maximum absolute voltage changes during an observation period
Du_dc_L1		Stationary deviation after the voltage drop
Du_duration_L1		time where the voltage drop is below 3,3% of Un

Channel name in Dewesoft	Calculation	Description
U_an_cos_per	$U_{1-,cos} = \frac{1}{6}[2u_{a,cos} - u_{b,cos} - u_{c,cos} + \sqrt{3}(u_{c,sin} - u_{b,sin}]$	Voltage and current vector components of the negative sequence for the fundamental
U_an_sin_per	$U_{1-,sin} = \frac{1}{6}[2u_{a,sin} - u_{b,sin} - u_{c,sin} + \sqrt{3}(u_{c,cos} - u_{b,cos}]$	
I_an_cos_per	$i_{1-,cos} = \frac{1}{6}[2i_{a,cos} - i_{b,cos} - i_{c,cos} + \sqrt{3}(i_{c,sin} - i_{b,sin}]$	
I_an_sin_per	$i_{1-,sin} = \frac{1}{6}[2i_{a,sin} - i_{b,sin} - i_{c,sin} + \sqrt{3}(i_{c,cos} - i_{b,cos}]$	
P_1n_per	$P_{1-} = \frac{3}{2}((u_{1-,cos} \cdot i_{1-,cos}) - (u_{1-,sin} \cdot i_{-,sin}))$	Active and reactive power from the fundamental negative sequence
Q_1n_per	$Q_{1-} = \frac{3}{2}((u_{1-,cos} \cdot i_{1-,sin}) - (u_{1-,sin} \cdot i_{-,cos}))$	
U_1n_per	$U_{1-} = \sqrt{\frac{3}{2}(U_{1-,sin}^2 + U_{1-+,cos}^2}$	RMS value of the line voltage of the fundamental negative sequence
S_1n_per	$S_{1-} = \sqrt{P_{1-}^2 + Q_{1-}^2}$	Further calculations
I_1n_per	$i_{1-} = \frac{S_{1-}}{\sqrt{3} \cdot U_{1-}}$	

Channel name in Dewesoft	Calculation	Description
U_az_cos_per	$U_{1z,cos} = \frac{1}{3}[u_{a,cos} + u_{b,cos} + u_{c,cos}]$	Voltage and current vector components of the zero sequence for the fundamental
U_az_sin_per	$U_{1z,sin} = \frac{1}{3}[u_{a,sin} + u_{b,sin} + u_{c,sin}]$	
I_az_cos_per	$i_{1z,cos} = \frac{1}{3}[i_{a,cos} + i_{b,cos} + i_{c,cos}]$	
I_az_sin_per	$i_{1z,sin} = \frac{1}{3}[i_{a,sin} + i_{b,sin} + i_{c,sin}]$	
P_1z_per	$P_{1z} = \frac{3}{2}((u_{1z,cos} \cdot i_{1z,cos}) - (u_{1z,sin} \cdot i_{z,sin}))$	Active and reactive power from the fundamental negative sequence
Q_1z_per	$Q_{1z} = \frac{3}{2}((u_{1z,cos} \cdot i_{1z,sin}) - (u_{1z,sin} \cdot i_{z,cos}))$	
U_1z_per	$U_{1-} = \sqrt{\frac{3}{2}(U_{1z,sin}^2 + U_{1z+,cos}^2}$	RMS value of the line voltage of the fundamental negative sequence
S_1z_per	$S_{1z} = \sqrt{P_{1z}^2 + Q_{1z}^2}$	Further calculations
I_1z_per	$i_{1z} = \frac{S_{1z}}{\sqrt{3} \cdot U_{1z}}$	

Channel name in Dewesoft	Calculation	Description
PF5_L1		Represents the P_{inst} value from **IEC 61000-4-15**.
Pst_L1		Short time flicker value
Plt_L1		Long-time flicker value
I_PF5_L1	According to IEC 61000-4-15	Represents the P_{inst} value from **IEC 61000-4-15** for the current
I_Pst_L1		Short time flicker value for the current
I_Plt_L1		Long-time flicker value for the current
I_PF5_L1_30; I_Pst_L1_30; I_Plt_L1_30		Flicker values for a certain phase angle

Period values for each phase	
Channel name in DEWESoft	**Description**
U_L1per	phase-to-earth voltage
U_L12per	phase-to-phase voltage
U_L1_H1per	fundamental phase-to-earth voltage
I_L1per	phase current
I_L1_H1per	fundamental phase current
P_L1per	active power of phase
P_L1_H1per	active power of the fundamental of the phase
Q_L1per	reactive power of phase
Q_L1_H1per	reactive power of the fundamental of the phase
S_L1per	apparent power of phase
S_L1_H1per	apparent power of the fundamental of the phase
PF_L1per	power factor of the phase
phi_L1_H1per	period value of phi

Power values total	
Channel name in DEWESoft	**Description**
Uper	average voltage of all phases
U_H1per	average voltage of all phases for the fundamental
Iper	cumulate current of all phases
I_H1per	cumulate current of all phases for the fundamental
Pper	active power
P_H1per	active power of the fundamental
Qper	reactive power
Q_H1per	reactive power of the fundamental
Sper	apparent power
S_H1per	apparent power of the fundamental
PFper	Power Factor
phi_H1_per	average phi of the fundamental

Description	**Calculation**
Total energy	$$E = \int_{t=0}^{T} p(t)\, dt$$
Positive energy	$$E_{mot} = \int_{t=0}^{T} p_{mot}(t)\, dt$$ $$if\ p_{mot}(t) > 0$$
Negative energy	$$E_{recup} = \int_{t=0}^{T} p_{mot}(t)\, dt$$ $$if\ p_{mot}(t) < 0$$

10. Warranty information

Notice:
The information contained in this document is subject to change without notice.

Note:
Dewesoft d.o.o. shall not be liable for any errors contained in this document. Dewesoft MAKES NO WARRANTIES OF ANY KIND WITH REGARD TO THIS DOCUMENT, WHETHER EXPRESS OR IMPLIED. DEWESOFT SPECIFICALLY DISCLAIMS THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. Dewesoft shall not be liable for any direct, indirect, special, incidental, or consequential damages, whether based on contract, tort, or any other legal theory, in connection with the furnishing of this document or the use of the information in this document.

The copy of the specific warranty terms applicable to your Dewesoft product and replacement parts can be obtained from your local sales and service office. To find a local dealer for your country, please visit https://dewesoft.com/support/distributors.

10.1. Calibration
Every instrument needs to be calibrated at regular intervals. The standard norm across nearly every industry is annual calibration. Before your Dewesoft data acquisition system is delivered, it is calibrated. Detailed calibration reports for your Dewesoft system can be requested. We retain them for at least one year, after system delivery.

10.2. Support
Dewesoft has a team of people ready to assist you if you have any questions or any technical difficulties regarding the system. For any support please contact your local distributor first or Dewesoft directly.

Dewesoft d.o.o.
Gabrsko 11a
1420 Trbovlje Slovenia

Europe Tel.: +386 356 25 300
Web: http://www.dewesoft.com
Email: support@dewesoft.com
The telephone hotline is available Monday to Friday from 07:00 to 16:00 CET (GMT +1:00)

10.3. Service/repair
The team of Dewesoft also performs any kinds of repairs to your system to assure a safe and proper operation in the future. For information regarding service and repairs please contact your local distributor first or Dewesoft directly on https://dewesoft.com/support/rma-service.

10.4. Restricted Rights
Use Slovenian law for duplication or disclosure. Dewesoft d.o.o. Gabrsko 11a, 1420 Trbovlje, Slovenia / Europe.

10.5. Printing History

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10.6. Copyright

10.7. Trademarks

We take pride in our products and we take care that all key products and technologies are registered as trademarks all over the world. The Dewesoft name is a registered trademark. Product families (KRYPTON®, SIRIUS®, DSI, DS-NET) and technologies (DualCoreADC, SuperCounter, GrandView) are registered trademarks as well. When used as the logo or as part of any graphic material, the registered trademark sign is used as a part of the logo. When used in text representing the company, product or technology name, the ® sign is not used. The Dewesoft triangle logo is a registered trademark but the ® sign is not used in the visual representation of the triangle logo.

11. Safety instructions

Your safety is our primary concern! Please be safe!

Safety and information symbols used in this manual

Warning
Calls attention to a procedure, practice, or condition that could cause the serious injury or even death.

Caution
Calls attention to a procedure, practice, or condition that could possibly cause damage to equipment or permanent loss of data.

Hint
Supplies useful information on the usage of hardware as well as software.

Important
Additional information concerning the topic in order to present a deeper understanding.

General Safety Instructions

Warning

The following general safety precautions must be observed during all phases of operation, service, and repair of this product. Failure to comply with these precautions or with specific warnings elsewhere in this manual violates safety standards of design, manufacture, and intended use of the product. Dewesoft GmbH assumes no liability for the customer's failure to comply with these requirements.

All accessories shown in this document are available as an option and will not be shipped as standard parts.

Environmental Considerations
Information about the environmental impact of the product.

Product End-of-Life Handling
Observe the following guidelines when recycling a Dewesoft system:

System and Components Recycling
Production of these components required the extraction and use of natural resources. The substances contained in the system could be harmful to your health and to the environment if the system is improperly handled at its end of life! Please recycle this product in an appropriate way to avoid unnecessary pollution of the environment and to keep natural resources.

This symbol indicates that this system complies with the European Union's requirements according to Directive 2002/96/EC on waste electrical and electronic equipment (WEEE). Please find further information about recycling on the Dewesoft web site www.dewesoft.com

Restriction of Hazardous Substances
This product has been classified as Monitoring and Control equipment and is outside the scope of the 2002/95/EC RoHS Directive. However, we take care of our environment and the product is lead-free.

General safety and hazard warnings for all Dewesoft systems
Safety of the operator and the unit depend on following these rules.
- Use this system under the terms of the specifications only to avoid any possible danger.
- Read your manual before operating the system.
- Observe local laws when using the instrument.
- DO NOT touch internal wiring!
- DO NOT use higher supply voltage than specified!
- Use only original plugs and cables for harnessing.
- You may not connect higher voltages than rated to any connectors.
- The power cable and connector serve as Power-Breaker. The cable must not exceed 3 meters, the disconnect function must be possible without tools.
- Maintenance must be executed by qualified staff only.

- During the use of the system, it might be possible to access other parts of a more comprehensive system. Please read and follow the safety instructions provided in the manuals of all other components regarding warning and security advice for using the system.
- With this product, only use the power cable delivered or defined for the host country.
- DO NOT connect or disconnect sensors, probes or test leads, as these parts are connected to a voltage supply unit.
- Ground the equipment: For Safety Class 1 equipment (equipment having a protective earth terminal), a non-interruptible safety earth ground must be provided from the mains power source to the product input wiring terminals.
- Please note the characteristics and indicators on the system to avoid fire or electric shocks. Before connecting the system, please read the corresponding specifications in the product manual carefully.
- The inputs must not, unless otherwise noted (CATx identification), be connected to the main circuit of category II, III and IV.
- The power cord separates the system from the power supply. Do not block the power cord, since it has to be accessible for the users.
- DO NOT use the system if equipment covers or shields are removed.
- If you assume the system is damaged, get it examined by authorized personnel only.
- Adverse environmental conditions are Moisture or high humidity Dust, flammable gases, fumes or dissolver Thunderstorm or thunderstorm conditions (except assembly PNA) Electrostatic fields, etc.
- The measurement category can be adjusted depending on module configuration.
- Any other use than described above may damage your system and is attended with dangers like short-circuiting, fire or electric shocks.
- The whole system must not be changed, rebuilt or opened.
- DO NOT operate damaged equipment: Whenever it is possible that the safety protection features built into this product have been impaired, either through physical damage, excessive moisture, or any other reason, REMOVE POWER and do not use the product until the safe operation can be verified by service-trained personnel. If necessary, return the product to Dewesoft sales and service office for service and repair to ensure that safety features are maintained.
- If you assume a more riskless use is not provided anymore, the system has to be rendered inoperative and should be protected against inadvertent operation. It is assumed that a more riskless operation is not possible anymore if the system is damaged obviously or causes strange noises. the system does not work anymore. The system has been exposed to long storage in adverse environments. the system has been exposed to heavy shipment strain.
- Warranty void if damages caused by disregarding this manual. For consequential damages, NO liability will be assumed!
- Warranty void if damage to property or persons caused by improper use or disregarding the safety instructions.
- Unauthorized changing or rebuilding the system is prohibited due to safety and permission reasons (CE).
- Be careful with voltages >25 VAC or >35 VDC! These voltages are already high enough in order to get a perilous electric shock by touching the wiring.
- The product heats during operation. Make sure there is adequate ventilation. Ventilation slots must not be covered!
- Only fuses of the specified type and nominal current may be used. The use of patched fuses is prohibited.
- Prevent using metal bare wires! Risk of short circuit and fire hazard!

- DO NOT use the system before, during or shortly after a thunderstorm (risk of lightning and high energy over-voltage). An advanced range of application under certain conditions is allowed with therefore designed products only. For details please refer to the specifications.
- Make sure that your hands, shoes, clothes, the floor, the system or measuring leads, integrated circuits and so on, are dry.
- DO NOT use the system in rooms with flammable gases, fumes or dust or in adverse environmental conditions.
- Avoid operation in the immediate vicinity of high magnetic or electromagnetic fields, transmitting antennas or high-frequency generators, for exact values please refer to enclosed specifications.
- Use measurement leads or measurement accessories aligned with the specification of the system only. Fire hazard in case of overload!
- Do not switch on the system after transporting it from a cold into a warm room and vice versa. The thereby created condensation may damage your system. Acclimatise the system unpowered to room temperature.
- Do not disassemble the system! There is a high risk of getting a perilous electric shock. Capacitors still might be charged, even if the system has been removed from the power supply.
- The electrical installations and equipment in industrial facilities must be observed by the security regulations and insurance institutions.
- The use of the measuring system in schools and other training facilities must be observed by skilled personnel.
- The measuring systems are not designed for use in humans and animals.
- Please contact a professional if you have doubts about the method of operation, safety or the connection of the system.
- Please be careful with the product. Shocks, hits and dropping it from already- lower level may damage your system.
- Please also consider the detailed technical reference manual as well as the security advice of the connected systems.
- This product has left the factory in safety-related flawless and in proper condition. In order to maintain this condition and guarantee safety use, the user has to consider the security advice and warnings in this manual.

EN 61326-3-1:2008

IEC 61326-1 applies to this part of IEC 61326 but is limited to systems and equipment for industrial applications intended to perform safety functions as defined in IEC 61508 with SIL 1-3.

The electromagnetic environments encompassed by this product family standard are industrial, both indoor and outdoor, as described for industrial locations in IEC 61000-6-2 or defined in 3.7 of IEC 61326-1.

Equipment and systems intended for use in other electromagnetic environments, for example, in the process industry or in environments with potentially explosive atmospheres, are excluded from the scope of this product family standard, IEC 61326-3-1.

Devices and systems according to IEC 61508 or IEC 61511 which are considered as "operationally well-tried", are excluded from the scope of IEC 61326-3-1.

Fire-alarm and safety-alarm systems, intended for the protection of buildings, are excluded from the scope of IEC 61326-3-1.

12. Document version history

Revision Number: 4
Last modified: 19 August 2020

Version	Date [yyyy.mm]	Notes
V20-3	2020-06	☑ Complete revision and update of entire power manual
V20-3	2020-06	☑ Moved the Table of images and tables to the bottom of the document
V20-4	2020-08	☑ Removed section 3.8