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Current

Now let’s return to our water analogy of electricity to explain what a current is.

The electric current is a physical quantity caused by voltage and means a flow of electrons between different electric potential. So if we think back to the water system this means the electric current is analog to the water flow rate. An electric current is the flow of the electric charge.

This is a simple DC (direct current) where the electrons (current) travel in one direction, but we also know AC (alternating current) with the constantly changing direction of electrons (in the public grid 50 to 60 times every second), which is hard to explain with the water analogy, because the water usually flows in one direction. Since the reader gets the simple idea of electric current he will be able to imagine AC electric systems without any problems.

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.

![Direct Current vs Alternating Current Diagram]

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*Diagram showing the difference between Direct Current and Alternating Current.*
Current measurement

Now let's take a look how current measurements are done. The simplest way to do it is using an ampere-meter. Therefore the circuit has to be opened and the ampere-meter has to be connected in series into the circuit. To affect the flowing current as least as possible, A-meters must have a very low impedance.

Since there are many current transducers available for DAQ devices, we can measure the current in different ways. We divide the current measurement in two major groups. One is 'direct' when our conductor must be disconnected and a sensor is connected in series with the circuit. The second type of sensors allows a measurement of current flowing through a conductor without opening the circuit, which means we can measure the current with a galvanic isolation of the sensor from the conductor.
Current measurement with conductor interruption

First let’s talk more about the “direct” way of current measurements, which works without any additional logic circuits. The most common measurement method of this kind is done with the shunt resistor, which must be connected in series into the measured circuit.

What is a shunt resistor?

A shunt resistor is a resistor with a very low resistance that is accurately predetermined by the manufacturer. We connect a shunt in series with the circuit that the current is flowing through and then simple measure the voltage drop on that resistor. 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, we can measure AC (alternating) or DC (direct) current but we should be careful with a few things. First one is that we don’t exceed the declared current of the shunt because that can burn the resistor. But the shunt will also heat up and overheat if a maximum declared current flows through it for a longer period of time. The resistance changes with the temperature and if the shunt gets overheated it can be changed permanently. Due to this problem with overheating, shunts are usually used for measuring currents which are up to 60% of the declared shunt current value.

One further problem is the common mode voltage which was already mentioned before. We can encounter this problem early on with the current measurement. Let’s look at an example: We want to measure the current flowing through our room lamp. With the use of a shunt resistor voltage the difference at our amplifier will be very small, but our measured “voltage points” are still high above the ground, they can go as high as the grid voltage. If we connect the grid voltage directly to a 10V range amplifier, we will surely destroy the module and probably ‘measure’ nice sparks. To get rid of this problem, the use of isolated measurement device is recommended.

For easier measurement with Dewesoft instruments, we can choose between two different MSI adapters with a shunt resistor. These adapters include shunt resistors for current measurement. For example inside MSI 20mA, there is a 50 Ohm 0.01% 0.25W shunt. There is some information about this shunt adapters in the table below.

<table>
<thead>
<tr>
<th>Dewesoft adapter</th>
<th>Range</th>
<th>Shunt resistor value</th>
<th>Resistor tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSI 5A</td>
<td>5A</td>
<td>10.0mΩ</td>
<td>+/- 0.01%</td>
</tr>
<tr>
<td>MSI 20mA</td>
<td>4mA-20mA</td>
<td>50.000Ω</td>
<td>+/- 0.01%</td>
</tr>
</tbody>
</table>

Measurements with these two adapters are simple, we don’t need to do any calculations because the adapters already have built-in TEDS for automatic recognition of the sensor in software, which saves us time for setting the sensor configuration. But after all we must still split the conductor for that kind of measurement and connect it to the adapter.
Current measurement without conductor interruption

Because interrupting the conductor with the current we wish to measure is sometimes not possible, we can also measure the flowing current 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 and bring galvanic isolation.

Let's take a look at the sensors and how they measure the current via the magnetic field. All of these sensors are obviously isolated from the conductor which means an easy, faster and safer measurement. Safer for persons and the measuring equipment because galvanic isolation eliminates the problems with a dangerously high common mode voltage, which is present when measuring high voltage currents with shunt resistors.

We must bear in mind that these kind of sensors have a phase shift of the output voltage compared to the measured current. The extent of the phase shift depends on the type of the current sensor and on the measured frequency. With high accuracy current sensors the phase shift is nearly zero; with very cheap 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 next subchapters the following current sensors will be described in more detail:

- Rogowski coil
- Iron-core clamp
- Hall compensated AC/DC clamp
- Zero flux transducers
- Current transducers in public grids

Overview

The following table shows the main differences between the different types of current transducers and the applications for which they are used.
<table>
<thead>
<tr>
<th>Type</th>
<th>AC</th>
<th>DC</th>
<th>Range</th>
<th>Accuracy</th>
<th>Bandwidth</th>
<th>Pros</th>
<th>Cons</th>
<th>Power Analyser</th>
<th>E-Mobility</th>
<th>Grid Monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron-Core Clamp</td>
<td>Yes</td>
<td>No</td>
<td>5 kA</td>
<td>0,5 - 4%</td>
<td>10 kHz</td>
<td>Cheap</td>
<td>- Heavy</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Cheap Rogowsky Coil</td>
<td>Yes</td>
<td>No</td>
<td>10 kA</td>
<td>1%</td>
<td>20 kHz</td>
<td>- rugged, flexible</td>
<td>- Positioning Error</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Good Rogowsky Coil</td>
<td>Yes</td>
<td>No</td>
<td>50 kA</td>
<td>0,30%</td>
<td>up to 20 MHz</td>
<td>- rugged, flexible</td>
<td>- No DC</td>
<td>partly</td>
<td>partly</td>
<td>Yes</td>
</tr>
<tr>
<td>Hall compensated AC/DC Clamp</td>
<td>Yes</td>
<td>Yes</td>
<td>300 A</td>
<td>0,50%</td>
<td>100 kHz</td>
<td>- AC &amp; DC</td>
<td>- low measurement range</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Zero-Flux Transducers</td>
<td>Yes</td>
<td>Yes</td>
<td>1000 A</td>
<td>highest accuracy</td>
<td>up to 300 kHz</td>
<td>- AC &amp; DC</td>
<td>- not to open</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

NOTE: Please always use in the analogue setup "DC coupling" and as input type bipolar for all types of current measurement. If you select AC coupling a highpass filter will be activated which can lead to deviation in phase measurement (e.g. at 50Hz). The option AC coupling is just used for special applications.

ADVICE: If you want to measure smaller currents using a current transducer with a too large measuring range, simply lead the conductor through the clamp or zero flux transducer several times. So if you lead through the conductor 5 times, you will measure 100A instead of 20A, for example. Please do not forget to consider this scaling in the setup of the respecting analog input channel!
Current measurement with Rogowski coils

Rogowski coil

A Rogowski coil is a simple measurement device which allows us to measure AC current without splitting the conductor. It consists of a helical coil of wire with the lead from one end returning through the centre 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 be done. This allows us a measurement without cutting, disconnecting or stripping the wire. The alternating current in the conductor will cause a voltage induction in the coil.

Measurement with the Rogowski coil has several advantages. Rogowski coils are available for measuring very small currents (some 100mA) 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, have 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 derivate of the current, we must use an integrator circuit 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 can 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 behaviour can be compensated using the sensor editor.
When we specifically need to measure an AC current we can simply use the Dewesoft current sensors which work with the use of the Rogowski coil. These sensors have, same as the MSI shunt adapters, built-in TEDS chip with all the configuration data stored.

<table>
<thead>
<tr>
<th>DEWESoft sensor</th>
<th>Range</th>
<th>Bandwidth</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS-FLEX-300-17</td>
<td>300 Arms</td>
<td>5 Hz to 20 kHz</td>
<td>1%</td>
</tr>
<tr>
<td>DS-FLEX-3000-35</td>
<td>3000 Arms</td>
<td>5 Hz to 20 kHz</td>
<td>1%</td>
</tr>
</tbody>
</table>
Current measurement with iron-core current clamps

Current clamps

Current clamps allow us to measure the current with galvanic isolation. Clamps have two jaws that can be opened and allow us to clamp the sensor around the conductor. The measurement with clamps is based on the Hall’s effect or current transformer technology, which means that the magnetic field of the flowing current is used to cause a voltage output of 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 (ratio), a certain current will be induced on the secondary side. Like any transformer, this only works for measuring AC current.

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 (maximal 20 kHz).
Current measurement with Hall-compensated AC/DC current clamps

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. This is why we should use the Hall Effect based current clamps to also measure DC currents.

The advantages of a 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.

We can choose the Dewesoft current clamps which are using the Hall effect for measuring current.
The voltage output of this kind of clamps is also directly proportional to the current. But current clamps also produce a phase shift which is up to ~10°, but if we use really good clamps this phase shift can be less than 1°. We must also know that the phase shift of every current sensor changes with frequency, which can be very important when power measurements are made.

<table>
<thead>
<tr>
<th>DEWESoft sensor</th>
<th>Range</th>
<th>Bandwidth</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS-CLAMP-150-DC</td>
<td>300 Apk</td>
<td>DC to 100 kHz</td>
<td>1% ± 2 mA</td>
</tr>
<tr>
<td>DS-CLAMP-1800-DC</td>
<td>1800 Apk</td>
<td>DC to 20 kHz</td>
<td>2.5% ± 0.5A</td>
</tr>
</tbody>
</table>
Current measurement with zero-flux transducers

Zero-flux transducers

Current transducers allow us to measure the current with galvanic isolation. They reduce the high voltage currents to a much lower value. The conductor with the measured current must be guided through a loop of the sensor because they are using the principle of the transformer, which means they have a current output signal and this low current signal should be measured with the DAQ.

Zero-flux current transducers are not simple transformers, they also have a sophisticated construction and 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 available zero flux compensation. 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 this transducers, the parasite flux is perfectly compensated. Therefore current transducers are used for measuring currents with high precision, but they are inappropriate for simple and fast measurement like clamps or Rogowski coil. Zero-flux transducers allow us to measure currents with the highest accuracy for AC and DC with a high bandwidth (up to 1 MHz). They are very linear and have a low phase and offset error.
This chapter explains how to connect the MCTS zero-flux transducers to a Sirius system. The connection of the zero-flux transducers is shown by means of MCTS-400 transducers.

What do we need for setting up?

**Step 1:**
At first connect the zero-flux transducer IT 400-S with the D9m-D9f-5M-MCTS cable to the SIRIUSi-PWR-MCTS slice at 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).

**Step 2**

Then take the DSI-MCTS-400-03M cable and use Output 1 of the SIRIUS-i-PWR-MCTS and connect it to the first LV input of the **Sirius** PWR amplifier.

![Image](image.png)

**Note:** The DSI-MCTS-XXX cable only can be used for the certain zero-flux transducer. The cables have a build-in shunt which fits only for the certain transducer. See in the following table which shunt cables belongs to the according zero-flux transducer.

<table>
<thead>
<tr>
<th>Shunt Cable</th>
<th>Zero-Flux Transducer</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSI-MCTS-60-03M</td>
<td>IT 60-S</td>
</tr>
<tr>
<td>DSI-MCTS-200-03M</td>
<td>IT 200-S</td>
</tr>
<tr>
<td>DSI-MCTS-400-03M</td>
<td>IT 400-S</td>
</tr>
<tr>
<td>DSI-MCTS-700-03M</td>
<td>IT 700-S</td>
</tr>
<tr>
<td>DSI-MCTS-1000-03M</td>
<td>IT 1000-S</td>
</tr>
</tbody>
</table>

Repeat Step 1 and 2 for all zero-flux transducers you want connect to the system.

For measuring a three-phase system in star connection the connection will look like this:
You will find how to connect voltage and current transducers to the system for different wiring configurations (DC, 1-phase, 2-phase, 3-phase delta-star-aron-V, etc.) in the Dewesoft PRO training course “POWER ANALYSIS” http://www.dewesoft.com/pro/course/power-analysis-...

Software Configuration

In the DSI-MCTS-XXX cable there is a TEDS chip integrated, where data about scaling, calibration etc. of the zero-flux transducer is stored. If you connect this shunt cable to the Low-Voltage input of the Sirius amplifier all these configurations are done automatically. Therefore the MSI adapters and TEDS sensors have to be activated. Please check at “Settings” – “Settings” if this option is enabled, see screenshot below.

After connecting the sensor (e.g. MCTS 400) you will see in the column Ampl.name the current transducer (e.g. DSI-MCTS-400) and the type of measurement will be changed to “Current”.
Finally you just have to set a suitable measurement range and set a low-pass filter if necessary.
Current measurement with current transducers in public grids

Current transducers in public grids

Current transducers are used to monitor the current flow in the public grid and protect the equipment from overload. A current transducer is easily explained as a transformer which is operated in short-circuit on the secondary site (or with only a small load). On the output (secondary) side of the current transducer, we get 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 1A or 5A.

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. At 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.

Please also consider the bandwidth of current transducers when measuring Power Quality parameters like Harmonics.

Attention: 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.
Now let's take a look at the classic 40 W light bulb. The first thing to notice is that the load on the grid is linear to the voltage. The measured power is exactly 40 W, but the vector scope looks strange. In fact, since the light bulb is a purely ohmic load, the voltage and current should be perfectly aligned, but as we can see, they are not. What is the reason for this? Do you remember the previous chapters where we have seen the difference between the current clamps and the shunt resistor? Since we are using the current clamps, we have amplitude and phase errors. As a result, the current clamp is the main source of the calculation error in this case.

In **Dewesoft X** we have a chance to compensate these errors. Let's take a look at it!

As it was explained before every current sensor has a frequency dependent behavior regarding the amplitude and phase. In **Dewesoft X**, it is possible to correct this behavior in the Sensor editor and make the sensor even more accurate as the manufacturer of the sensor specifies it. This is unique in the market.

Let's choose the settings "Sensor editor" menu item to get a list of all possible sensors. Now let's add one sensor and enter the Sensor type and Serial number. Enter the Physical (input) unit, which is A (amperes) in our case and the Electrical (Output) unit, which is V (volts).
Next let’s enter the SCALING factor. Since the sensor is linear with the amplitude, we only need to enter the scaling factor, which is 1 in our case (1A=1V). Do not worry about the polarity of the sensor, it can be reversed in the channel setup.

Now we come to the most important part - the definition of the transfer curve. In the table under the TRANSFER CURVE column, we select Yes to signify that a transfer curve will be defined. Now we need to enter the points of the curve. We need to enter the a[dB] - amplitude deviation in dB and the phi[deg] - phase angle in degrees. The next question is: Where do we to get this transfer curve? There are a lot of transfer curves for the most common sensors that have already been measured, so it’s worth checking if it already exists. A second option is to copy it from the calibration sheet of the sensor if the calibration sheet includes a transfer curve. The third option is to measure it with the FRF option, but this requires some equipment. When we get this transfer curve, we just need to enter it in the table. We see that at 50 Hz, the angle is around 10 deg, which explains the phase shift we saw in the measurement.

Save the sensors with the Save file button and close the sensor editor with Exit. Now let’s go back to the analog setup and choose 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 we can’t enter the normal scaling or sensitivity any more. To reverse the polarity of the sensor you have to choose the Scaling by function and select Sensitivity. With clicking the ± button, you can reverse the polarity.
That's it. For the next setup we don't have to define a sensor anymore, instead we can just select it from the sensors list.

Now let's see what the effect of sensor correction on our measurement is. The results are much better. The phase angle is virtually eliminated and the power is calculated correctly.
Current measurement with Dewesoft X

Now we will make some current measurements with the Dewesoft X software and a measurement device.

We will measure the current which is consumed by a classic 40W light bulb and 11W energy saving light bulb. For this measurement, we will use two approaches, the first will be the direct voltage measurement on a shunt resistor and the other will be a measurement with current clamps.

Before the measurement we must do some calculations that will help us to choose the SIRIUS amplifier and range of the amplifier and current clamps. If we turn on both light bulbs the declared power will be 51W and the RMS value of the grid voltage is 230V, so let’s take those numbers into our calculations.

\[
P_1 = 40W \quad P_2 = 11W
\]

\[
P = P_1 + P_2 = 51W
\]

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

After the rough calculations, we get the results that our RMS value of the current is approximately 0.22A. We know that the max value of the sine wave signal is \(\sqrt{2}\) times RMS, 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 means that we will choose the 10A range on the current clamps and use the MSI SHUNT 5A adapter. The shunt resistance is 0.01\(\Omega\) which means 1A current will cause 10mV drop on shunt. This information is needed when we are setting the measurement channel on which we measure a voltage drop on the shunt. Since Dewesoft MSI adapters are already equipped with this information, the software is able to configure the setup in the correct way. This is one thing less for taking care of when we are using Dewesoft MSI adapters.

Now we can start with our measurement. We will use two different SIRIUS amplifiers, LV and ACC. Let’s see how the connection for our measurement looks like. Current clamps are directly connected to the ACC module and the MSI SHUNT 5A adapter is connected directly to the LV module like on the photo below.
As you can see in the photo we must split the wire for the shunt installation. This can be dangerous because of the grid voltage and we should be careful when doing this at home. Now let's see how the configuration of channel 1 with the shunt is done. First we rename the channel to Shunt current so we will later know the output of which sensor’s output we are looking at when the measurement is in progress. Physical quantity should be set to Current and Unit is set to Amperes (A) by default. Once these settings are done we should “calibrate” our sensor. We will choose calibration by two points in this case because we already know that 1V equals 10A. We just simply type this two values in the prepared place. If we set all the parameters correctly and the classic light bulb is turned on, we can already see the sine form of our current in Scope mode on the left bottom side of the setup window.
For channel 8, where we have connected the Current clamps, the settings will be a little different because we are using HV module for this measurement. Since the current clamps are set on 10A range they provide 1mv/1mA on the output (scaling factor is 1). That means we can't get more than 10V on output and range of our amplifier should be set to 50V to achieve greater resolution of the measurement. We should also set the Physical quantity to "Current" and measured unit to Amperes.

In the next snapshot, you can see the combined waveform of the energy saving bulb and the light bulb. The waveform changed mostly due to the non-sine waveform and the high crest factor of the energy saving light bulb.
Now when we switch to Measure mode, we can see the phase shift of the current clamps compared to the shunt resistor. At first sight, there is no big phase shift (around 10°) on the picture below, but with applications like the power measurement phase shift is very important for correct results. The phase shift is around 10° in the picture below, and can influence the measurement results for detailed power analysis significant (especially reactive and apparent power). The phase-shift of this current can be compensated using the sensor editor.
Calculate the AC RMS value

To see the RMS value of the current signal, add a **Basic statistic** math function.

Select the input channel (current signal) and the RMS as the output channel. We can display one value per measurement or we can display new values for each defined block of data.
Another option is also to display the RMS value of the signal directly in the recorder. Select the RMS as the Display type (in the left corner of the screen).