Jomitek I3 Power Sensor

- User manual-

-   May 10, 2021   -

Contents

1 Introduction to the Jomitek I3 Power Sensor system

1.1 Overview

The Jomitek I3 Power Sensor system is designed for retrofitting, to measure voltage, current and derived quantities (i.e. reactive power, THD, earth faults) for multiple conductors in low- or medium voltage installations. It is designed to provide an operational overview of a power grid, both during normal operation, as well as for fault events and faulty operation. This functionality is a key component in establishing a smart grid operation.

A unique and patented feature of the Jomitek I3 Power Sensor system is the ability to measure currents of individual conductors in a 3 phase screened cable, without the need to split the cable into individual conductors. By utilizing a number of magnetic field sensors within the Jomitek I3 Power Sensor casing, the position of the conductors within a 3 phase cable is calculated on the fly, and the current running in each conductor is then determined sample-by-sample. This eliminates the need for calibration both during the installation, and as a maintenance activity. In addition, it makes installation of current measurements extremely simple and flexible compared to installation of current transformers, especially for retrofitting scenarios.

A basic system consists of one or more capacitive voltage interfaces, towards a low- or medium voltage capacitor, integrated magnetic current sensors, a power supply using either PoE or DC via an Ethernet cable (RJ45 connector), and data transmission either via the Ethernet cable.

In summary a Jomitek I3 Power Sensor is a very compact self-contained voltage and current sensor and data processing platform, including high level post-processing of measurements, remotely configurable, easy to install, easy to use, and virtually maintenance free.

For the latest documentation and software, please visit the Jomitek I3 Power Sensor support web site at http://jomitek.dk/support/i3.
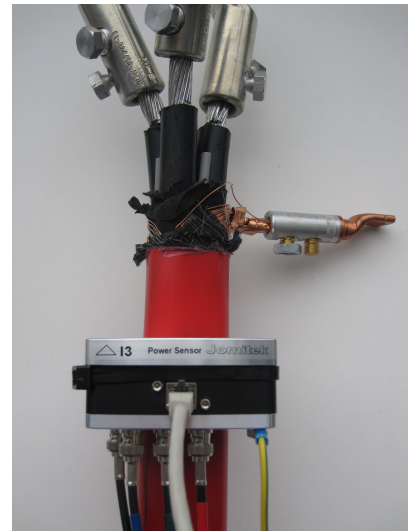
Figure 1: Illustrative image of the Jomitek I3 Power Sensor mounted on a screened three phase cable.

1.2 First time quick start guide

1. Attach the Jomitek I3 Power Sensor to a PoE switch on your network (DHCP assumed).

2. Determine the IP address of the sensor by looking into the allocation table in your network switch/router/firewall or by use of the Jomitek Device Locator software which can be found at http://jomitek.dk/downloads.

3. Open your browser and type in the IP address of the Jomitek I3 Power Sensor .

4. Explore the graphical web interface.

1.3 Interface options and requirements in brief

The sensor uses a single RJ45 Ethernet connector for both communication and the power supply. The sensor may be powered by either a Power over Ethernet (PoE) class 2 device or through 24V or 48V DC power supplied via the Ethernet cable.

When the sensor is connected, it can be accessed through a graphical web interface, IEC 60870-5-104 protocol, modbus, FTP, WebDav, a Telnet or Lua command line interface.

Upon request the sensor can be delivered with digital input and/or output interface, serial communication and RTU capabilities.

2 System installation

Installation of the Jomitek I3 Power Sensor system is simple and requires no calibration for current measurements, and optional calibration for voltage measurements, depending on accuracy needs. Simply attach the Jomitek I3 Power Sensor to the cable to be measured. Connect the capacitive voltage measurement interface connectors, a grounding wire to the ground bolt, and finally attach the Ethernet cable. The installation procedure is described in detail in the following sections.

2.1 Low voltage sensor interfacing

Jomitek supplies CEE connector based capacitive voltage measurement interfaces for voltage sources below 0.5 kV nominal peak, which are thus well suited for 110-240 VAC measurements. The measurement interface uses built-in capacitors in the CEE casing and can therefore be directly connected between a voltage source with a CEE plug and the BNC connectors on the Jomitek I3 Power Sensor . If your voltage source is not equipped a CEE plug, you may use a CEE adapter to convert to any other interface relevant. For interfacing options towards medium voltage inputs, and further detail on the voltage measurement setup, please see section 4.

Figure 2: Front and bottom view of the Jomitek I3 Power Sensor showing the PoE connector, grounding bolt and voltage measurement BNC connectors.

Figure 3: Voltage measurement BNC connectors. The default channel usage starting from the lower left going up to the right is: neutral, L3, L2, L1.

Figure 4: Capacitive voltage measurement interface attached to the Jomitek I3 Power Sensor . The CEE adapter is shown to the left.

Figure 5: CEE connector for use with the capacitive voltage measurement interface. Note the integrated ground connector.

When using the CEE adapter for a custom interfacing, please refer to the voltage phase identification color codes listed in table 1 for correct wiring of your own connector.

Electrical potential	Capacitive voltage measurement interface (wire color)	CEE adapter (wire color)
Ground	Green/yellow	Green/yellow
Neutral	Blue	Blue
L1	Red	Brown
L2	Green	Black
L3	Black (no label)	Grey

Table 1: Electrical phase color coding for voltage measurement.

2.2   Jomitek I3 Power Sensor mounting

Place the sensor on the cable and secure it with the provided cable ties as shown in Fig. 12. The sensor must be mounted such that the voltage BNC connectors are facing down.

Note, that for a steel armored cable that can be magnetized, the installation must be made at a point where such armor is removed. The steel cannot measure on multiple conductors through metals that can be magnetized. Measuring through lead shielding or similar non-magnetizable metals is not a problem. A simple test is to use a permanent magnet, or magnetic screw driver to see if a particular shielding layer is magnetizable.

Figure 6: Place the sensor on the cable to be measured.

Figure 7: Make sure that the sensor is mounted such that the voltage BNC connectors are facing down.

Figure 8: Wrap the cable tie around the cable to be measured.

Figure 9: Wrap the cable tie around the cable and thread it through the cutout on the opposite side of the sensor.

Figure 10: Complete the cable tie connection.

Figure 11: Use the provided tool to tighten the cable tie.

Figure 12: Illustrative step-by-step instruction on how to mount the steel.

2.3   Installation considerations

The Jomitek I3 Power Sensor current measurements work by measuring the magnetic field generated by the currents running in the cable. For optimum sensor performance, it is important to minimize magnetic disturbances close to the sensor. In general, this means that iron and other ferromagnetic materials should be avoided within 5-10 cm of the sensor box.

If building a laboratory setup for testing and evaluation, please contact Jomitek for free technical support.

The sensor is designed to be particularly weather resistant when mounted with the bottom part facing down.

If connection of BNC interfacing is limited by the physical space at the installation point, please note the option of using right angle connectors, rather than straight connectors. Please contact Jomitek, if this need should arise.

3   The Jomitek I3 Power Sensor as a networked device

3.1   Communication hardware

Communication with the Jomitek I3 Power Sensor is via a standard Ethernet RJ45 cable. The Ethernet interface supports 10/100Mbps. A screened Ethernet cable must be used. The cable screen is connected to the Jomitek I3 Power Sensor casing. The casing must be earthed/grounded.

In at typical installation an industrial PoE Switch is used. High quality UV resistant Ethernet cables with robust connectors are recommended to ensure a long lasting installation.

During installation the technician must ensure that the LED's integrated in the Ethernet connector in the sensor starts blinking, when the PoE source is turned on and the cable is connected. When confirmed, the Ethernet communication can be checked i.e. using the 'Jomitek Device Locator'[1]. Note that the computer running the locator software must be connected to the same network, in the same subnet, as the Jomitek I3 Power Sensor , in order to be discoverable.

3.2   Network architecture

It is possible to realize the network architecture of a collection of sensors in numerous ways, supported by the adaptability and wide usage of Ethernet. A sensor deployment for a single utility may have a volume ranging from hundreds to tens of thousands of sensor units, and many different communication backhaul media used, e.g. a closed radio network operated by the utility, use of the network of commercial cellular networks, via microwave links, fixed connections via fiber or copper, or even satellite based backhaul. With the diversity in sensor volume and backhaul used, it is good practice to establish a routing, and possibly NAT, architecture which supports placing all the sensors within the same subnet, seen from the SCADA point of view.

Having the sensor base placed within the same subnet ensures that a single server may easily reach the entire sensor base, and through this server performance and configuration management data may be distributed as needed within the network operations center and beyond.

Please contact Jomitek for verification or suggestions regarding your communication network architecture towards the Jomitek I3 Power Sensor .

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[1]http://jomitek.dk/downloads/tools

3.3 Power supply

The Jomitek I3 Power Sensor uses Power over Ethernet (PoE) as the power source. PoE is specified in the standard IEEE 802.3. Power is transferred in the 8-conductor Ethernet wire. The standard specifies 2 options for selection of wire-pairs, signal pair or separate pair, named Alternative A or B. The Jomitek I3 Power Sensor supports both options. PoE devices informs the Power Supply of the required power class at power up. The Jomitek I3 Power Sensor is characterized as a Class 2 device, drawing power in the range 3.84 W-6.49 W.

If the installation does not offer a PoE power supply, an external 24/48 VDC supply may be used. This supply has to enter through the Ethernet cable. A special splitter cable can be ordered at Jomitek, which makes use of the mode B pins 4/5 (DC+) and pins 7/8 (DC-).

The power supply circuit is electrically isolated from the sensor electronics by a 1.5 kV isolating transformer.

Pins at switch	T568A color	T568B color	10/100 mode B, DC on spares		10/100 mode A, mixed DC & data		1000 (1 gigabit) mode B, DC & bi-data		1000 (1 gigabit) mode A, DC & bi-data	
Pin 1	White/green stripe	White/orange stripe	Rx +		Rx +	DC +	TxRx A +		TxRx A +	DC +
Pin 2	Green solid	Orange solid	Rx −		Rx −	DC +	TxRx A −		TxRx A −	DC +
Pin 3	White/orange stripe	White/green stripe	Tx +		Tx +	DC −	TxRx B +		TxRx B +	DC −
Pin 4	Blue solid	Blue solid		DC +	Unused		TxRx C +	DC +	TxRx C +	
Pin 5	White/blue stripe	White/blue stripe		DC +	Unused		TxRx C −	DC +	TxRx C −	
Pin 6	Orange solid	Green solid	Tx −		Tx −	DC −	TxRx B −		TxRx B −	DC −
Pin 7	White/brown stripe	White/brown stripe		DC −	Unused		TxRx D +	DC −	TxRx D +	
Pin 8	Brown solid	Brown solid		DC −	Unused		TxRx D −	DC −	TxRx D −	

802.3af Standards A and B from the power sourcing equipment perspective

Figure 13: Image source: https://en.wikipedia.org/wiki/Power_over_Ethernet

4 Measuring voltages

4.1 Connecting a voltage source

The Jomitek I3 Power Sensor measures voltage capacitively trough a large range of external capacitors suited for many different purposes. The external capacitors are connected through the BNC connectors in the bottom of the Jomitek I3 Power Sensor see Fig. 3. A range of the possible external capacitors and their accuracy are listed in table 2, for any questions or special requirements, please contact Jomitek.

4.2 Voltage signal interfacing

The sensors employ the same signal conditioning for all voltage inputs. The inputs are based on measurement via capacitive voltage division, and are protected up to 2 kV. The high voltage capacity for a given nominal voltage should be selected such that:

$$C_{hv} = \frac{5 \times 10^4 [pF \times V]}{U_{nomRMS}} \tag{1}$$

This relation is exemplified in table 2:

V_nomRMS	C_hv	Comment
57.7 V (100 V/$\sqrt{3}$)	$\leq$ 820 pF	Standard output from voltage transformer
110 V	$\leq$ 470 pF	110 V RMS, as used in the US, low voltage
230 V	$\leq$ 220 pF	230 V RMS, as used in Europe, low voltage
5.77 kV (10 kV/$\sqrt{3}$)	$\leq$ 8.6 pF	10 kV RMS phase-phase, medium voltage level
6.92 kV (12 kV/$\sqrt{3}$)	$\leq$ 7.2 pF	12 kV RMS phase-phase, medium voltage level
9.23 kV (16 kV/$\sqrt{3}$)	$\leq$ 5.4 pF	16 kV RMS phase-phase, medium voltage level
11.5 kV (20 kV/$\sqrt{3}$)	$\leq$ 4.3 pF	20 kV RMS phase-phase, medium voltage level
13.8 kV (24 kV/$\sqrt{3}$)	$\leq$ 3.6 pF	24 kV RMS phase-phase, medium voltage level
18.5 kV (32 kV/$\sqrt{3}$)	$\leq$ 2.7 pF	32 kV RMS phase-phase, medium voltage level
28.9 kV (50 kV/$\sqrt{3}$)	$\leq$ 1.7 pF	50 kV RMS phase-phase, medium voltage level

Table 2

Note that you may never make a direct galvanic connection to the voltage to be measured. You must always use a capacitor in between, appropriately selected based on above formula (1) and table 2. Selecting a capacitor of much lower value than the maximum recommended, will reduce the dynamic range, and thus the measurement resolution of the nominal voltage. It is generally recommended to target a capacitor value no less than 25 % of the maximum allowed value for a given voltage.

The maximum allowed capacitance value for the medium voltage levels fits well with industry standard silicone based capacitive test points, e.g. those found in elbow connectors. Note that ceramic based medium voltage capacitors should be avoided, as their capacity is both too high, and exhibits unlinear behavior. Note, that in order to obtain high accuracy voltage measurements, the capacitive test point must be screened, such that spread capacitances are avoided. Jomitek produces screening cups for elbow connectors. Please contact Jomitek for more information on medium voltage capacitive screening options.

Configuration of the capacity used, and further voltage scaling options are available in the '*settings.conf*' file accessible via FTP or the sensor web interface.

4.3   Voltage measurement accuracy

The capacitive measurement principle used for the voltage signal interfacing provides a wide range of options for the physical measurement setup. In relation to the measurement accuracy the main options are listed in table 3. The indicated accuracies are indicative based on normally seen implementations. Note that for most O&M purposes, a precision of 5 % should be satisfactory, to define the load profile, direction of energy flow, earth faults, source of harmonics generation and similar key parameters.
Please note that the accuracy stated in table 3 is the complete accuracy including both the deviation caused by measuring capacitor, wiring and final sampling. The accuracy found the table 3 is furthermore valid for the full measured frequency spectrum[2].

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[2]Most measuring equipment states the accuracy at a rated voltage/ current at 50/ 60 Hz

Measurement interface type	Accuracy uncalibrated	Accuracy calibrated
Voltage transformer (VT) via 820 pF capacity	3 %	0.5 %
LV via 470 pF capacity	3 %	0.5 %
JCap, a high precision capacitive insulator	N/A	1 %
Elbow connector with integrated capacity, shielded	5 %	2 %
MV stand-alone capacitor (e.g. insulator)	10 %	5 %
MV attachable capacitor plate	20 %	10 %

Table 3: Typical accuracy obtained using typical interfacing methods.

Note that while a low voltage (LV) measurement may provide a relatively high accuracy of the measured voltage, and a fairly cheap interfacing solution, some major drawbacks exists for this approach, when the current is measured on the medium voltage side of a transformer.

- The transformation ratio may be variable, so the actual voltage level on the medium voltage side is not possible to describe with just a constant conversion ratio.

- An earth fault on the MV side will typically not be possible to detect on the LV side of a transformer.

- High frequency content may be distorted by the transformer, making it very difficult to correctly assess MV THD, and the MV waveform during transient events.

The mentioned drawbacks must be compared to the implementation cost, and the target for the monitoring solution. If only basic measurement parameters (such as voltage, current, power flow) is of interest, then low voltage measurement interfacing may be adequate for the purpose.

4.4   A note on spread capacitances

In particular for the capacitors suitable for the medium voltage level, the physical distances involved between capacitor plates can lead to significant spread capacitances being introduced. Ideal solutions for such measurement systems involve well screened setups, such as using an elbow connector with integrated capacitive end plug, and placing a conducting screening cup as a termination for any parasitic/spread capacitances. This ensures that any capacitive coupling between the measurement plate and the surrounding material is constant, and preferably low compared to the capacitive coupling towards the medium voltage conductor.

In some cases it's not possible to achieve a well screened solution at a reasonable cost. Non-ideal solutions may then be considered, at the cost of the usefulness of certain measurement parameters. Spread capacitances may lead to two main measurement deviation effects:

- Varying spread capacitance towards ground potential

- Cross talk between voltage phases

The first effect will change the capacitive voltage division ratio, leading to incorrect scaling of the voltage amplitude, and thus all measurement parameters related to the voltage amplitude. A typical example is with a setup where the unscreened medium voltage capacitor is near the enclosure door/lid of the installation. When opening the door, the spread capacitance to ground changes significantly, and thus the voltage division ratio. This effect may indicatively lead to 0-15 % sensitivity variation.

The second effect is almost always experienced in combination with the first. It involves a capacitive coupling from one or more neighboring medium voltage conductors towards the measurement plate of the primary phase

being measured. Effectively this results in the raw measurements of a given input being a mix of signals, with the major component being the primary phase measured, but with neighboring phases typically adding their signals at a 0-25% sensitivity level compared to the primary.

Cross talk between voltage phases can often be considered fairly static, as they are primarily dependent on the physical shape of a given type of breaker equipment. If the cross talk sensitivities have been mapped (calibrated) for a particular physical configuration, it can be reused on similar equipment models. It must however be confirmed that the enclosure is also fairly static, such that the first effect does not affect the second. One example of a measurement setup involving both spread capacitance measurement effects is on a Magnefix switchgear using a RetroCap measurement interface, as illustrated, see figure 14. In this case, the capacitive measurement point is glued to the surface of the fuses of a Magnefix switchgear. These are very easy to install, but unfortunately also very sensitive to cross talk and spread capacitances to ground.

Figure 14: Horstmann RetroCaps mounted on Magnefix switchgear.

Accuracy of measurement parameter vs. type of voltage measurement setup

Measurement parameter	Well screened	Non-screened, specifically calibrated	Non-screened, calibrated by model	Non-screened, no de-mixing
phase_delta	OK	(OK)	Not OK	Not OK
phase_voltage	OK	(OK)	Not OK	Not OK
power_factor	OK	(OK)	Not OK	Not OK
rms_apparent_power	OK	OK	(OK)	Not OK
rms_reactive_power	OK	(OK)	Not OK	Not OK
rms_real_power	OK	(OK)	Not OK	Not OK
rms_voltage	OK	(OK)	(OK)	Not OK
thd_voltage	OK	OK	(OK)	(OK)

Table 4: **OK** = Measurement will perform according to Jomitek I3 Power Sensor data sheet specification,**(OK)** = Measurement will likely perform according to Jomitek I3 Power Sensor data sheet specification, but with no commitment from Jomitek, **Not OK** = Measurement should be considered indicative at best, but with a high risk of being misleading

If the cross talk ratios have been determined, the Jomitek I3 Power Sensor platform supports on-the-fly de-mixing of the voltage measurement signals, effectively cancelling the cross talk phenomena. As suggested by the above table, it is strongly recommended to enable de-mixing of voltage cross talk, on installations with unscreened high voltage capacitors. Installation specific calibration will likely enable performance equal or close to a well screened system, but the cost of performing installation specific calibration will likely discourage such use cases. As such, installations will generally either be well screened, where needed, and otherwise non-screened, but calibrated according to the type (model) of the installation.

4.5   Guide for setting up voltage cross talk cancellation

This guide is only relevant for poorly screened voltage measurement configurations.

Getting started
In order to enable the default cross talk cancellation settings, the following parameter should be set, either directly in the '*settings.conf*' file or via the web interface: *settings/i3/calibration/voltage_cross_talk = true*. IMPORTANT: Note that the BNC plug interfacing to the Jomitek I3 Power Sensor must comply with the sequence of the phases for the cross talk coefficients applied.

Advanced configuration and calibration
The cross talk figures provided per default are based on the behavior of a Magnefix switchgear. For other measurement setups, it is recommended to verify that the same cross talk relation applies, and if not, the cross talk parameters must be updated to reflect the behavior of the relevant measurement setup. These parameters can be found in the *settings/i3/calibration/voltage_cross_talk_coeff* folder. Using the web interface, the subfolder L1 reflects the relative signal strengths received on L1 from the phase connected to L1 (denoted conductor01), L2 (conductor02), L3 (conductor03) and the auxillary input (conductor04) respectively. The same logic applies for the remaining subfolders. It is the same reference input level used across all the calibration measurements. It is recommended to use the L2 input, when applying a reference voltage signal to the phase of L2 capacitor, as the mentioned reference.As an example, Fig. 15 illustrates a case where:

- A reference voltage was applied to the phase being interfaced to L2 on the Jomitek I3 Power Sensor , while the other phases were kept grounded, and the resulting output noted for the L2 input. This is the reference input level the measurements was normalized with, and it is with respect to this level, that the *i3/voltage_setup/conductor02_hv_capacitor* value was aligned, such that the absolute voltage measured by the Jomitek I3 Power Sensor matches that of the known voltage level of the reference voltage.

- The same reference signal was then applied to the phase being interfaced to L1, L2 and L3, one at a time, and with the other phases grounded for each measurement. The input on L1 was normalized with respect

to the first measurement, and a signal strength of 127.0 %, 11.2 % and 3.0 % was noted.

- The auxillary input was not connected, so the cross talk for AUX is set to 0 %.

- The AUX input, is assumed free of cross talk and therefore indicated with 0 % for cross talk from signals relating to L1-L3.
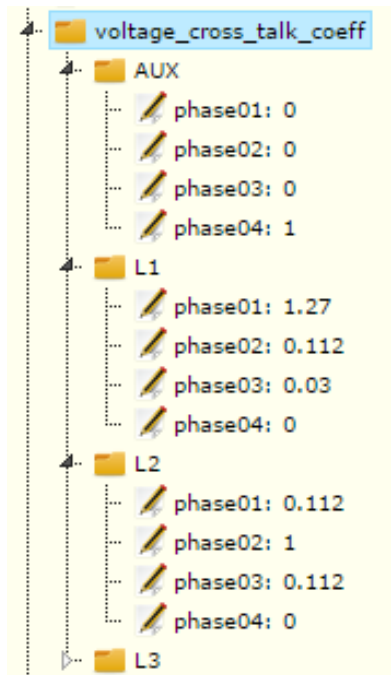
Figure 15

Following the guideline above, a capacitance value of **3.2 pF** was found for the Horstmann RetroCap sensors mounted on a Magnefix switchgear. This value must be specified in *i3/voltage_setup.conductor0[x]_hv_capacitor, with [x] being 1-3.*

5   Software and firmware structure

5.1   Microcontroller platform

The Jomitek I3 Power Sensor features powerful embedded hardware especially selected and tailored to meet the requirements for stability, redundancy and flexibility. In addition to the powerful computational capabilities, the Jomitek I3 Power Sensor features large on-board memory designed for logging during the entire lifetime of the sensor.

The firmware being used in the microprocessor can be securely updated over the air using fully encrypted firmware images, which enables addition of further functionalities after installation.

The Jomitek I3 Power Sensor software includes a Lua scripting engine which allows for execution of custom code and dynamical reconfiguration of the sensor. This allows for easy integration and customization of live measurements, reports, event summaries, etc. beyond the default capabilities supplied by Jomitek. Requests for assistance on any such customization are welcome.

5.2   File system

The Jomitek I3 Power Sensor platform features a file system. Through the file system the user can access configuration files, log files, measurement data (typically .wav files), etc.. The drive structure is described in the following.

- `0:/root/service` - The main user folder containing all user relevant sub folders. This folder is accessible through the FTP interface when logged in with the user customizable FTP account (default account name: service).

- `0:/root/service/conf` - System configuration files.

- `0:/root/service/data` - Measurement data such as .wav file time series and event logs.

- `0:/root/service/log` - System related log files.

- `0:/root/service/software_update` - Folder for uploading firmware and software update images.

5.3   Lua scripting

Lua is a lightweight scripting language which allows for dynamic reconfiguration of the sensor. The scripting interface allows for customized functionality that are not supplied by Jomitek.

A Lua command line terminal interface can be accessed through a raw TCP connection with Putty by connecting to the sensors IP address on port 2840.
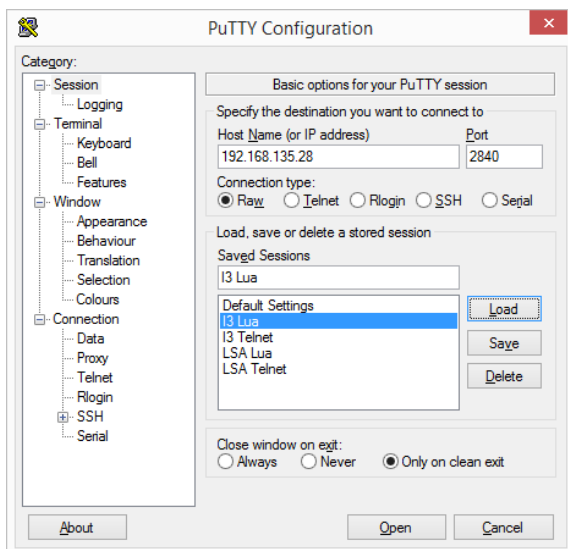
Figure 16: Putty Lua Session configuration.
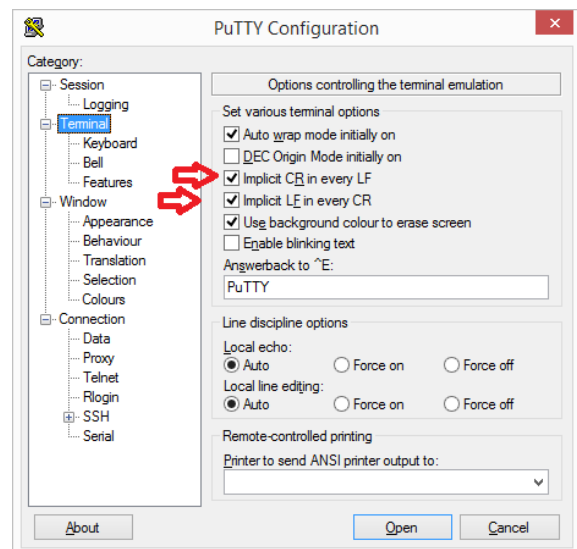
Figure 17: Putty Lua Terminal configuration.

Figure 18: The Lua command prompt.

The Lua interface is intended for advanced configuration and debugging and should only be used by experienced users. It is also possible to upload lua scripts to the sensor, for more information about this feature please read section 6.2.3.

More information on the Lua scripting language can be found at http://www.lua.org/about.html and a full reference is available at http://www.lua.org/manual/5.2/.

6   Measurements and events

6.1   Live Measurements

Using the Jomitek I3 Power Sensor web interface it is possible to view live measurements of many different variables like voltages, current, power factor, real power and many more. See Fig. 19, which shows how to navigate to the live measurements using the web interface.
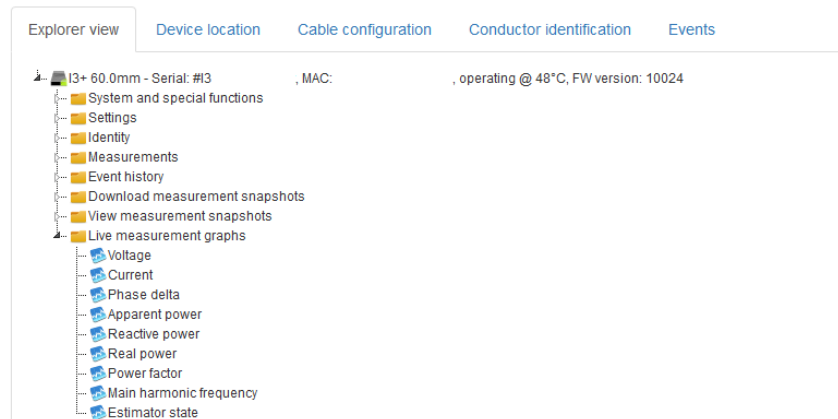
Figure 19: Web interface live measurement menu.

6.1.1 Live data settings

There are three parameters to consider when configuring the live data calculations. There are two RMS time constants and one boolean flag to signal a 180° phase change on all estimated current samples.

To configure the parameters from the sensor web interface, go to the post_processing menu as seen in Fig. 20. To change the value of a setting, select the element you want to change and type in the desired value in the input box followed by a click on the 'save value' button. An explanation of the three different settings are given below. For further details on how to configure the sensor see section 7. Note that updating parameters via the web interface will usually not require a reboot of the sensor.
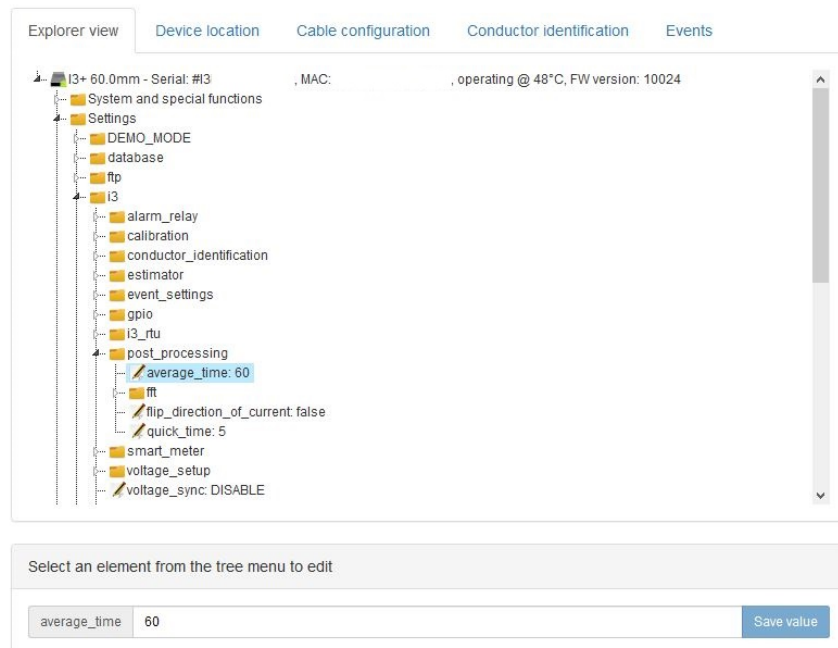
Figure 20: View of the settings menu.

average_time

Is the number of seconds over which the RMS values used by the IEC60870-5-104 are calculated.

quick_time

Is the number of seconds over which the RMS values used by the 'Live measurements' plots are calculated.

flip_direction_of_current

Imposes a sign change on all the measured currents thus changing their phase $180°$.

6.1.2 RMS calculation

All RMS values are true RMS values, this means that there is no assumption made regarding signal shape or frequency content.
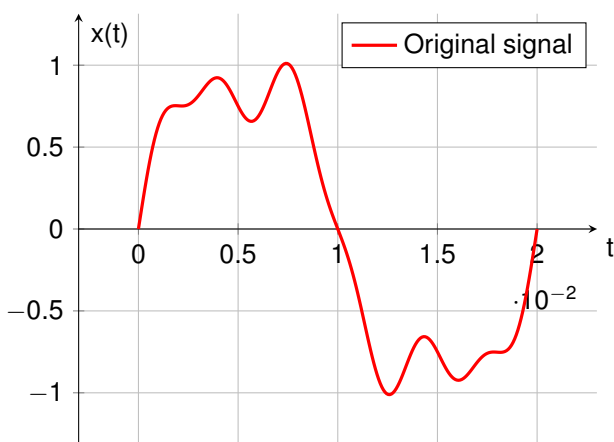
Figure 21: Signal with a main frequency of 50 Hz with harmonic distortion.
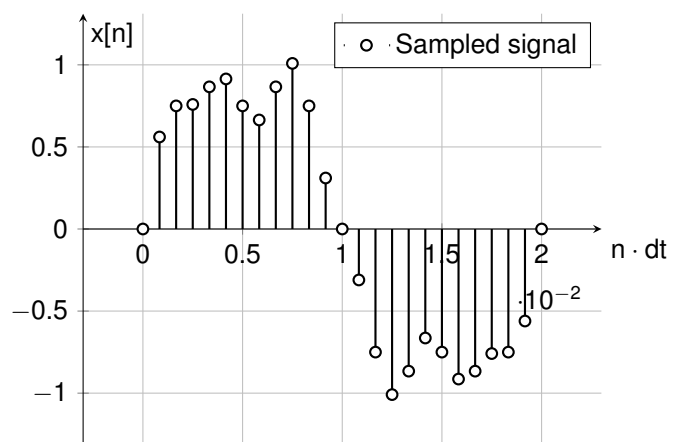
Figure 22: Signal with a main frequency of 50 Hz with harmonic distortion sampled at 1250 Hz.

Considering the sampled signal in figure 22 the RMS value is calculated using equation 2. A special case is used when calculating the RMS of phase values, here the calculations are done using imaginary numbers to prevent wrapping issues around 0 and 2π. The RMS values of the voltages and currents are calculated per phase based on a downsampled 1250 Hz signal. The RMS values are refreshed towards Lua (which reports to the SCADA and the web interface) with a fixed frequency of 1 s. The RMS time constants themselves may be set to any value between 0.1 and 1000.0 seconds, with 100 ms quantization steps.

$$x_{RMS} = \sqrt{\frac{1}{n}\sum_{n=0}^{n-1} x[n]^2} \tag{2}$$

6.1.3 Measurements

The sensor measure both voltages and currents with a sampling frequency of 31250 Hz as well as downsampled to 1250 Hz. The high resolution with 31250 Hz sample frequency covers at least 100 ms and the 1250 Hz resolution cover at least 2500 ms. These measurements make it possible to perform high level processing of all voltages and currents for the individual phases, such as THD, frequency analysis, event(fault) analysis, extracting time series snapshots of short circuit or earth fault events, as well as the following data points:

Phase_voltage

The phase is measured using a zero-crossing method. The first voltage channel with sufficient high amplitude is automatically assigned to be the phase reference and is therefore always zero.

Phase_current

The phase is measured using a zero-crossing method. If there are no active voltages, the first current channel with sufficient high amplitude is chosen as a phase reference instead, the reference is always zero.

Phase_delta

Phase_delta is defined as : **phase_voltag - phase_current**

Displacement_factor

Displacement_factor is defined as : cos(**phase_delta**)

Distortion_factor

Distortion_factor is defined as : $\frac{1}{\sqrt{1+THD_i^2}}$ where THD_i is the THD for the current.

Power_factor

Power_factor is defined as : **displacement_factor * distortion_factor**

Apparent_power

Apparent_power is defined as : **apparent_power** = **current$_{rms}$ · voltage$_{rms}$**

Real_power

Real_power is defined as : **real_power** = **apparent_power · power_factor**

Reactive_power

Reactive_power is defined as : **reactive_power** = **apparent_power** · sin(**Phase_delta**)

Main_harmonic_frequency

The main_harmonic_frequency is measured using a zero-crossing method.

6.2   Event types and handling

6.2.1   Event metadata structure

The format for representing a collection of different events in a common structure is based on Lua tables. An example of the structure is given below:

Listing 1: Basic structure of event metadata.

```
{
    eventIdentifier = {
        eventType,
        eventTimeStamp = {
            sec,
            usec,
            iso,
        },
        eventFiles = {
            exampleFileName1,
            exampleFileName2,
        },
        eventParameters = {
            exampleParameter1,
            exampleParameter2,
        },
        plotOptions = {
            "{'t':'Example file 1 Title','u':'Example measurement unit','s':100,
            'x':'Example X label [ms]','y':'Example Y label [A]',
            'l':['Example Channel 1 legend','Example Channel 2 legend']}",

            "{'t':'Example file 2 Title','u':'Example measurement unit','s':10,
            'x':'Example X label [ms]','y':'Example Y label [A]',
            'l':['Example Channel 1 legend','Example Channel 2 legend']}",
        },
    },
}
```

The format is simply a table of parameters characterizing each event, uniquely defined by "eventIdentifier". The table contains all recorded events and can contain different event types. All events share the following entries (there are no limits on the number of additional entries):

- **eventType** - A string containing the type of event. Possible "'eventType'"s include "earthFault", "overCurrent", etc.

- **eventTimeStamp**

  - **sec** - An integer representation of the event timestamp in POSIX[3] time format. For example, 22 Sep 2015 15:04:01 GMT would correspond to 1442934241000.
  - **usec** - An integer representing the microsecond part of the timestamp.
  - **iso** - A string containing the timestamp in text for example, "2015-12-02T10:39:05.227Z"[4]

- **eventFiles** - A lua list of strings containing the filename(s) to the file(s) related to the event. This table can be empty if no files are attached.

- **eventParameters** - A Lua table containing "eventType" specific parameters. Different "eventType"'s can have different event parameters, but they must be contained in the "eventParameters" table.

- **plotOption** - A lua list of JSON formatted strings detailing the options needed for plotting and displaying the respective event files.

Example:

---

[3]This time format is also known as UNIX or UNIX Epoch.
[4]Where the "Z" represents the time zone zero (UTC0) - this notation follows the standard ISO 8601. Read more about the standard at Wikipedia.

Listing 2: Example of event metadata.

```
{
    e00001 = {
        eventType = "earthFault",
        eventTimeStamp = {
            sec = 1449052745,
            usec = 227000,
            iso = "2015-12-02T10:39:05.227Z",
        },
        eventFiles = {
            "e00002_file_A.wav",
            "e00002_file_B.wav",
        },
        eventParameters = {
            faultPhase = 3,
        },
        plotOptions = {
            "{'t':'Example Title','u':'Example measurement unit','s':100,
            'x':'Example X label [ms]','y':'Example Y label [kA]',
            'l':['Example Channel 1 legend','Example Channel 2 legend']}",

            "{'t':'Example Title','u':'Example measurement unit','s':10,
            'x':'Example X label [ms]','y':'Example Y label [kA]',
            'l':['Example Channel 1 legend','Example Channel 2 legend']}",
        },
    },
}
```

6.2.2 Data structure

The data files related to an event are zipped using gzip with file extension ".gz" while metadata is in plaint text files with the extension ".log". The following diagram shows how data is structured.
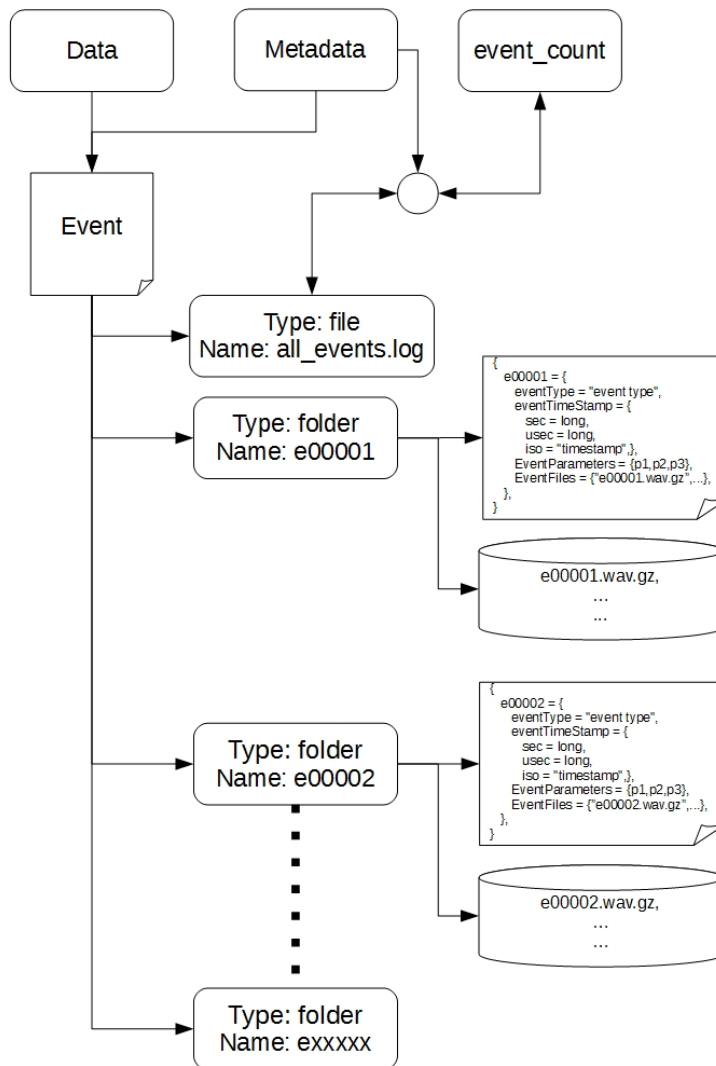
Figure 23: View of the event structure.

*Notice that each event can have several wavefiles attached to it.

6.2.3 Generating a customized event detection function (for super users)

Advanced users can make scripts that generate custom events, please contact Jomitek if this need should arise.

6.2.4 Viewing event content

The metadata for all registered events are stored in the event summary file "../service/data/event/events.index" this file is automatically updated and can be viewed via the web interface.

Figure 24: View of the event summary file.

When an event has files attached to it, the file content can be displayed by simply clicking on them.

Figure 25: View of one of the data files of an over current event, tested with a threshold of 5 A.

The recorded time series measurement can also be inspected using the "Events" tab in the web interface as shown in figure 26.

Figure 26: View of all recorded event on a sensor with two undervoltage events.

6.3 Event types

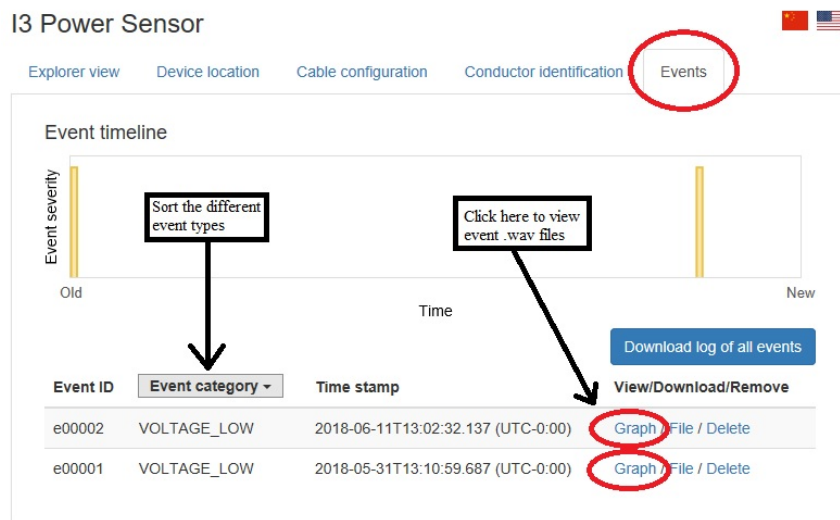|	
STEADY STATE EARTH FAULT (ANSI 51N/67N)	The associated setting are: **settings/i3/event_settings/earth_fault_detection**
OVERCURRENT (ANSI 50)	The associated setting are: **.../overcurrent_detection**
OVERVOLTAGE (ANSI 59)	The associated setting are: **.../overvoltage_detection**
UNDERVOLTAGE (ANSI 27)	The associated setting are: **.../undervoltage_detection**
UNDERCURRENT (ANSI 37)	The associated setting are: **.../undercurrent_detection**
INSTANTANEOUS HIGH VOLTAGE	The associated setting are: **.../instantaneous_high_voltage_detection**
INSTANTANEOUS HIGH CURRENT (ANSI 50)	The associated setting are: **.../instantaneous_high_current_detection**

Table 5: This table denotes where the settings for each detection function can be found.

6.3.1 Introduction

This section contains a simplified theoretical description of each fault scenario which the Jomitek I3 Power Sensor is able to detect and analyze. The section also describes how the detection of each fault type is configured. The event detection module of the Jomitek I3 Power Sensor is used to detect, record and analyze specific events present in the power system. Using the sensor web interface a statistical overview of the time perspective of the different event types can be seen as shown in Fig. 27.

Note also the sensor logging feature which can log all voltage and current phasors along with the associated harmonics up the the 13th harmonic. This feature is useful to detect long term changes and establish load profiles. The load profile can then be used as a baseline for the various event detection thresholds. See more about this feature in section 9.3.

The structure of each of the following sub-sections are as follows:

- The title of each section denotes the protection type and states the ANSI number in parenthesis

- An introduction to the specific fault scenario

- A simplified theoretical description of the specific fault scenario

- An overview of the sub-functionalities of the complete function

- Description of the detection function of the specific fault scenario

- Description of the analysis performed by the specific fault event detection function

The aim of this description is to provide an overview of the different protection functions implemented on in the I3 power sensor.
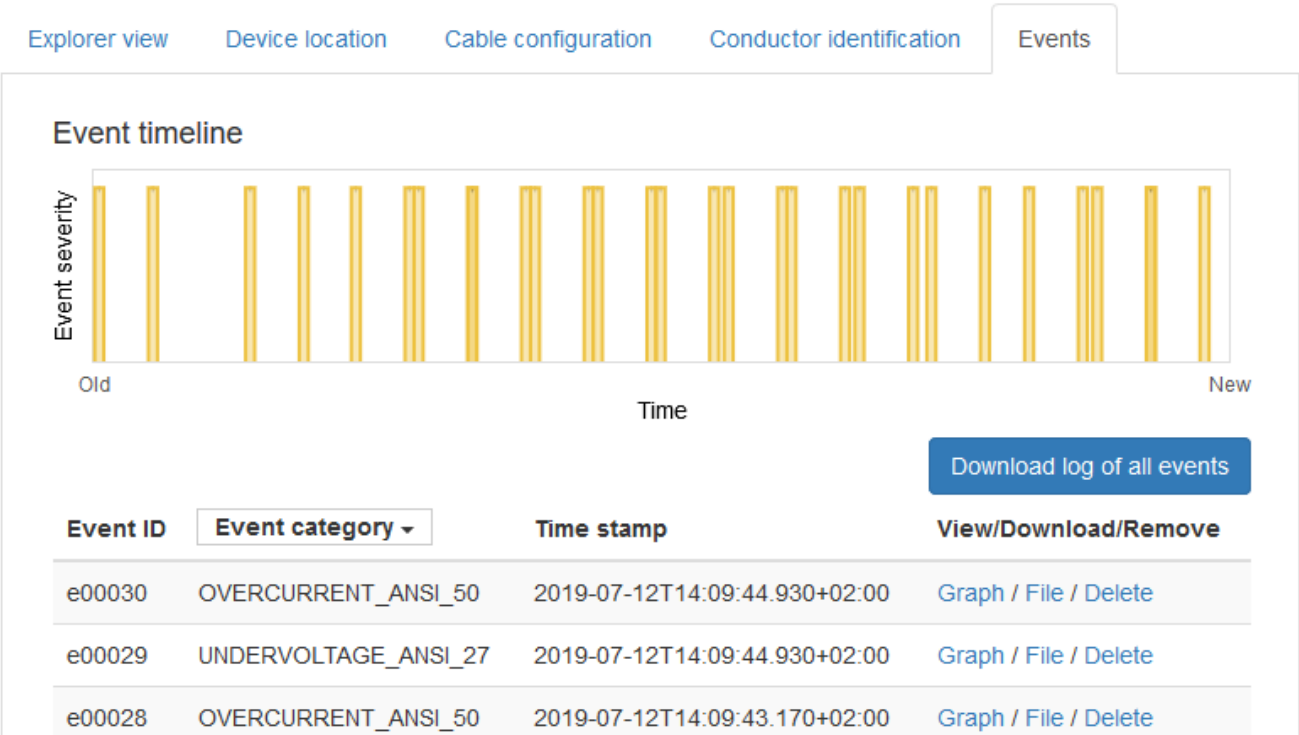

Figure 27: Event tab through the Jomitek I3 Power Sensor web interface.

6.3.2   Earth fault detection (ANSI 51N/67N)

An earth fault is characterized as an unintended connection between one - or more phases to ground (or any return path to ground). The earth fault is highly affected by the grounding of the power system. There are three main categories of earth faults: single line to ground (SLG), double line to ground (DLG) and all line to ground (ALG).For all faults where ground potential is involved the zero sequence components will be significantly affected. Some of the fault analysis (such as directional determination for the steady state earth fault) require that the analysis is performed on the steady state values. However in a real system the faulty line might be switched off by the breaker after 20 ms - 50 ms, it is therefore necessary to determine the exact starting time of the fault and the end time of the fault. The Jomitek I3 Power Sensor fault detection algorithm will use the time of pickup as the start of the fault.The settings for the detection function can be configured through the web interface, an example as shown in Fig. 28
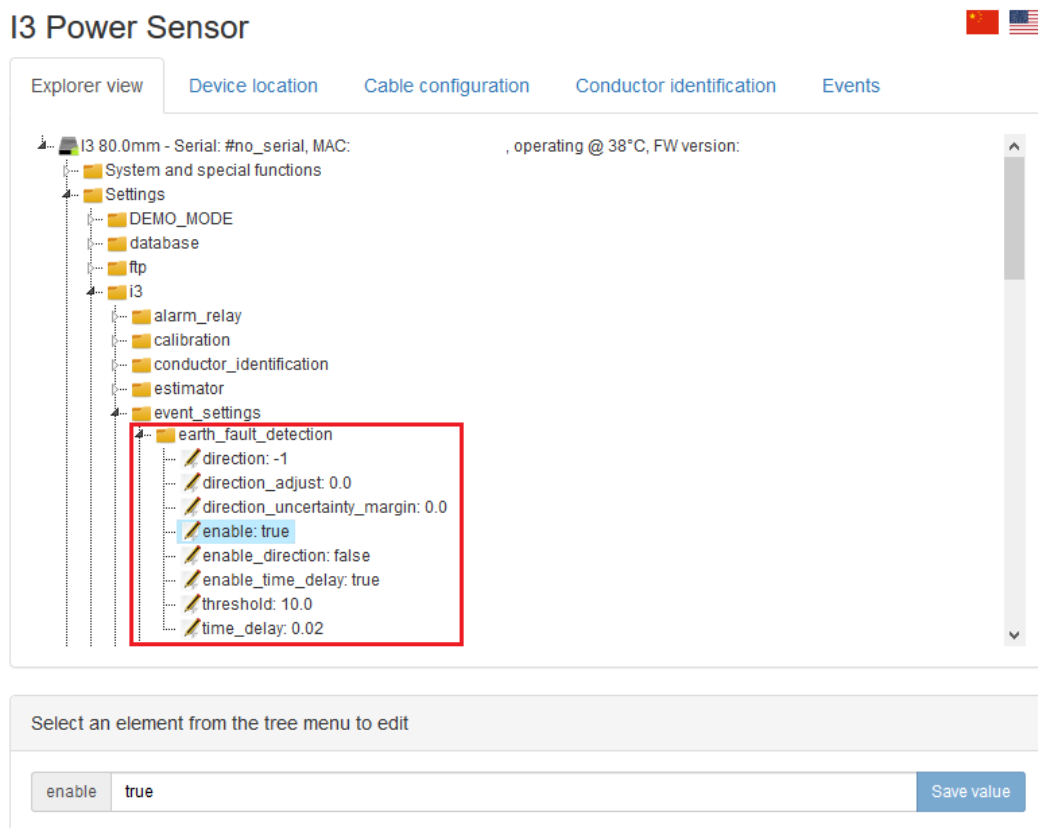
Figure 28: Earth fault detection setting through web interface.

Steady state earth fault

The steady state earth fault will cause an increase in zero sequence current.When determining the threshold one should be aware of the "normal" level of zero sequence components in the network. If this value is unknown, the sensor's logging functionality (which is also used for load profiling) can log all voltage and current phasors for a representative period (for example a week), which then can be used as a baseline for the zero sequence component threshold.It should be noticed that for an impedance grounded- and arc suppression grounded network the zero sequence current (and hereby the trigger level) will be corresponding lower, however this would be included using the above described logging functionality.A detection of a single-line-to-ground fault is shown in Fig. 29, the figure shown is from the sensor web interface.Along with the recording of the earth fault shown in Fig. 29 also key parameters are calculated and presented on the web interface as shown in Fig. 30. These parameters are also

available from the IEC 60870-5-104 protocol.
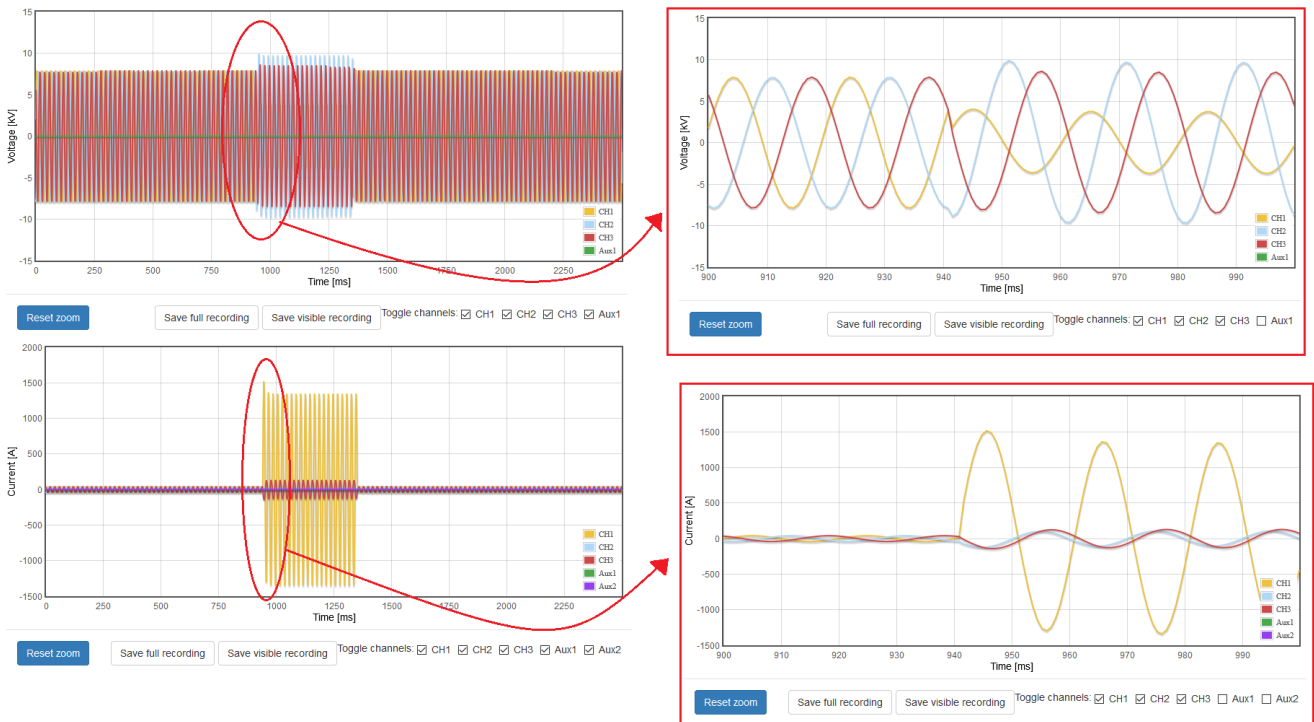
Figure 29: Earth fault recording viewed through the Jomitek I3 Power Sensor .

e00001: STEADY_STATE_EARTH_FAULT_ANSI_67N - 2019-09-03T08:46:02.587+00:00

Classification \ Reference	CH1	CH2	CH3	Aux1	Section
Severity [3=high,2=medium,1=low]	3	1	1	1	1
Direction [-1=downstream, 1=upstream]	1	1	1	0	0
Earth fault [1=earth fault detected]	1	0	0	0	1
High current [A]	953.15	75.93	90.76	0.0	953.15
High voltage [V]	0.0	0.0	0.0	0.0	0.0
Low voltage [V]	2638.93	0.0	0.0	0.0	2638.93
Peak current [A]	1346.16	108.03	128.85	0.0	1346.16
Short circuit [1=short circuit detected]	0	0	0	0	0

Figure 30: Key parameters from the earth fault recording.

Detection   The detection of the steady state earth fault is based on an **increase in zero sequence current**. The user defines a threshold for the zero sequence current level. This threshold is highly dependent on the specific power system configuration and load profile. As a rule of thump, solid grounded systems have relative higher zero sequence components than arc-suppression-coil grounded/ impedance grounded systems. Along with the grounding influence on zero sequence level, the unbalance in load during normal operation affects the threshold

level.It is possible to add a direction and/ or time delay constrain to the earth fault detection, which are described in the following.

Time delay   The user can set a time delay constrain. The purpose for this time delay is to let the user distinguish between zero sequence surges caused by switching or unbalanced inrush current and an actual earth fault. It is recommended to set at least 15 ms of delay for earth fault detection.

Direction   The direction of the earth fault is defined as the direction of the fault current (This is not necessary the same direction as the energy flow). It is assumed that the zero sequence current equals the fault current. The direction determination is based on the angle between the zero sequence voltage and current, including an operational security margin. If the angular difference is more than 90° plus the security operational margin, the fault is in reverse direction.The directional pick-up operation can be described by the following, where Θ is the angular difference and φ is the operational security margin. Note that the zero sequence voltage is turned by 180° by including the minus sign, this is due to the trigonometrical properties, where the zero sequence voltage is in phase opposition with the faulty phase voltage.This directional determination is described by (3) - (6) and by Fig. 31.

$$\Theta = -arg(V0) - arg(I0) \tag{3}$$

$$|\Theta| > \left(\frac{\pi}{2} + \phi\right) \rightarrow Backward \tag{4}$$

$$|\Theta| < \left(\frac{\pi}{2} - \phi\right) \rightarrow Forward \tag{5}$$

$$\left(\frac{\pi}{2} - \phi\right) < |\Theta| < \left(\frac{\pi}{2} + \phi\right) \rightarrow Undefined \tag{6}$$
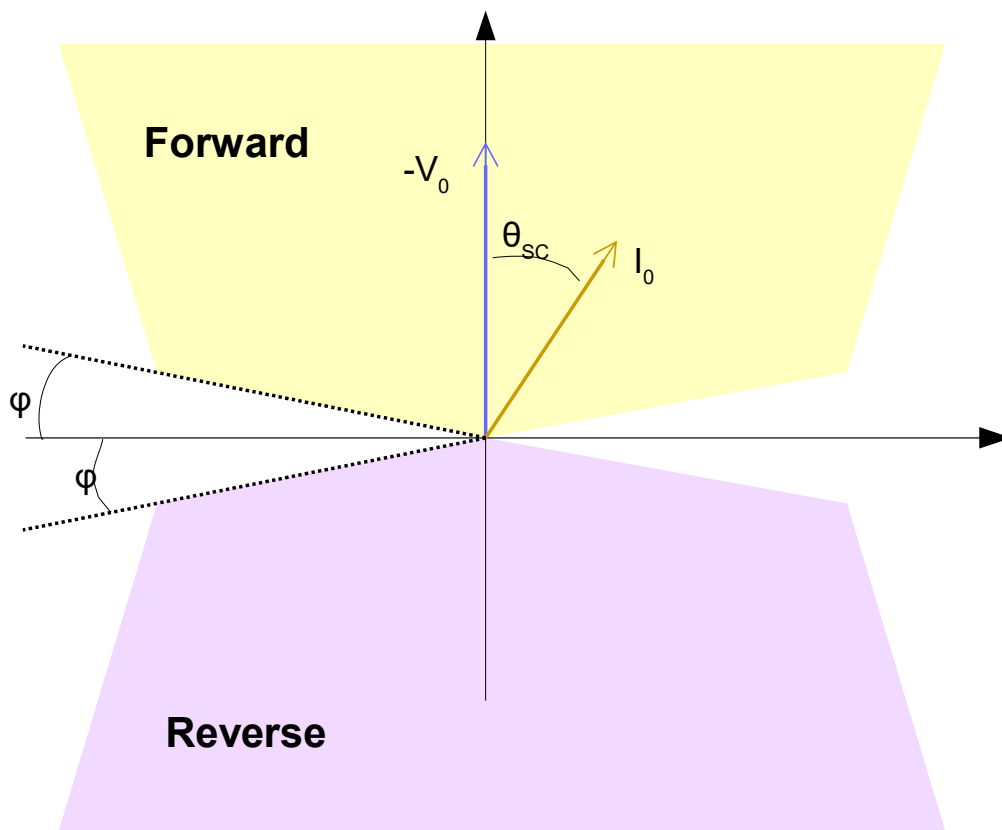
Figure 31: Illustration of the directional determination.

Where φ is the angle between the zero sequence voltage and current, and ϕ_1 is the operational margin (typical $2° - 8°$).

Advanced analysis   There are no standardized "advanced" earth fault parameters, but some useful parameters from a operational perspective can help estimating hardware damage:

- Fault duration.

- Fault peak current (The sensor severity indication, uses this value to estimate the severity of the fault.).

- Fault current average over the total fault duration.

- Number of fault current peaks.

6.3.3 Overcurrent detection (ANSI 50/51) - (directional optional, ANSI 67)

An overcurrent fault is characterized by an increasing phase current. The general overcurrent protection does not distinguish between inrush current/ overload current or short circuits. One should therefore be careful when setting the threshold value. A time delay constrain can be set to prevent falls tripping due to inrush current.The settings for the overcurrent detection can be configured from the web interface as shown in Fig. 32
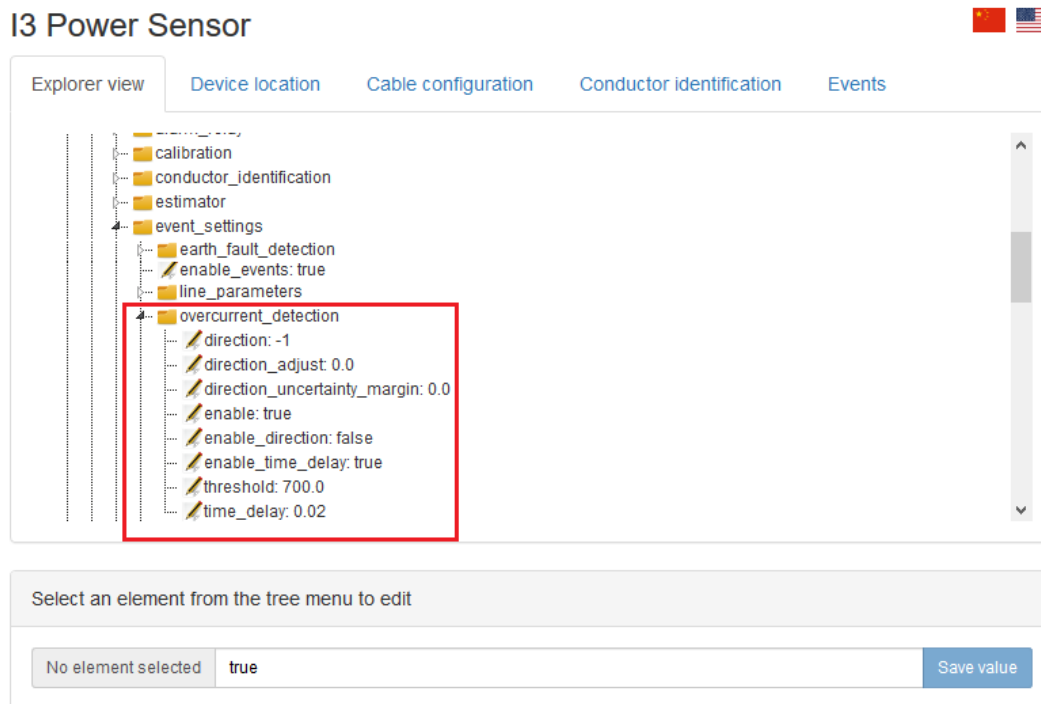
Figure 32: Overcurrent detection setting through web interface.

Steady state overcurrent

The steady state overcurrent is an overcurrent fault type, where the high current is present for a relative longer period (there is no strict definition). For the Jomitek I3 Power Sensor a steady state overcurrent is a high current for more than 4 ms. The actual time delay can be set by the user. An example of a recorded overcurrent event detected by the sensor is shown in Fig. 33. And the key parameters associated with the event is shown in Fig. 34.
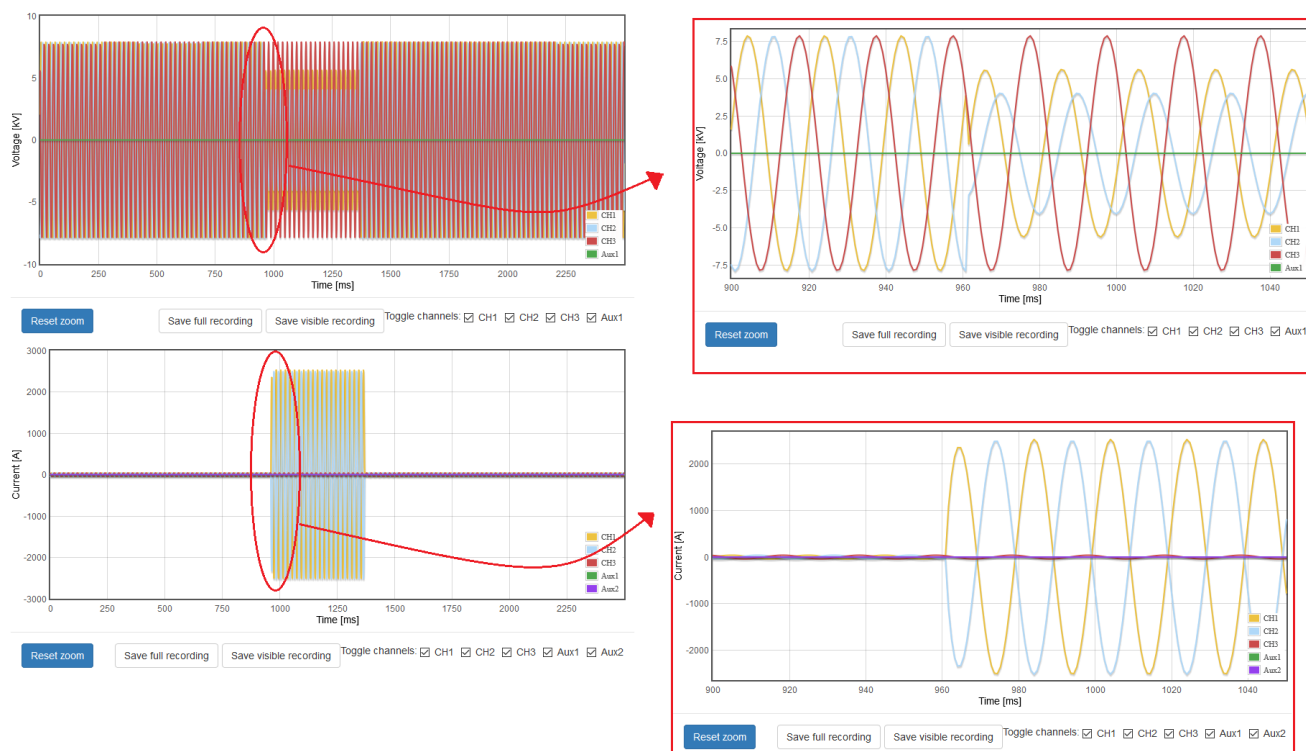
Figure 33: Overcurrent event recording visualized from the I3 power sensor web interface.

e00002: OVERCURRENT_ANSI_50 - 2019-09-03T10:03:43.395+00:00

Classification \ Reference	CH1	CH2	CH3	Aux1	Section
Severity [3=high,2=medium,1=low]	3	3	1	1	3
Direction [-1=downstream, 1=upstream]	-1	-1	1	1	0
Earth fault [1=earth fault detected]	0	0	0	0	0
High current [A]	1785.13	1776.21	28.53	0.0	1785.13
High voltage [V]	0.0	0.0	0.0	0.0	0.0
Low voltage [V]	3984.22	0.0	0.0	0.0	3984.22
Peak current [A]	2528.9	-2516.77	-40.47	0.0	2528.9
Short circuit [1=short circuit detected]	1	1	0	0	1

Figure 34: Overcurrent detection key parameters table.

Detection   The detection is based on a measurement of the phase current compared with an user defined threshold. If the measured amplitude of a phase current is larger than the given threshold the event is triggered. It is possible to include both a time delay constrain and a directional constrain, these are described in the following.

Time delay   The user can set a time delay constrain. The purpose for this time delay is to let the user distinguish between current surges caused by switching or unbalanced inrush current and an actual overcurrent.

Directional overcurrent detection (ANSI 67)

The directional overcurrent protection serve to detect currents which are higher than expected, as in case of a short circuit. This protection functionality only pick up faults in one direction.

There are many different ways to determine the direction of a potential short circuit current but there exist no universal function. The directional determination is highly fault type depended. The current implementation is based on the most common (and might be the most universal). The main issue determining the direction occur if the voltage levels becomes too low to measure at a sufficient accuracy (which could be the case in a close-up fault). The phenomenon is called "voltage collapse".

To accommodate this issue, a algorithm select the reference voltage which results in the highest potential for correct directional indication. There are three potential voltage reference, primary phase voltage, polarized voltage and historical voltages.

Primary phase voltage is the voltage from the same phase as the high current was picked up. If this voltage is higher than 10 % of nominal voltage, then it will be used for the directional determination. If it is less than 10 %, then the polarized voltage will be used.

Polarized phase-to-phase voltage is a real time simulation of the primary phase voltage, by using the two other phase voltages. Again if the polarized phase voltage is above 10 % of nominal voltage level, then it will be used for the directional determination. If it is less than 10 %, then the historical voltage will be used.

Historical voltage is the voltage from the same phase as the high current was picked up, but recorded previously (up to 2 seconds back in time). The historical voltage phase is selected from the last point in time where there was a voltage level above 10 % of the nominal voltage level.

Having the reference voltage phase, the energy direction is determined as follows:

$$\Theta = arg(V) - arg(I) \tag{7}$$

$$|\Theta| > \left(\frac{\pi}{2} + \phi\right) \rightarrow Backward \tag{8}$$

$$|\Theta| < \left(\frac{\pi}{2} - \phi\right) \rightarrow Forward \tag{9}$$

$$\left(\frac{\pi}{2} - \phi\right) < |\Theta| < \left(\frac{\pi}{2} + \phi\right) \rightarrow Undefined \tag{10}$$

Polarized voltage   The polarized voltage method assumes that only Ãşne phase is faulty. By use of the two healthy voltages it is possible to construct the faulty voltage - as it would be if it was measurable. The following relation is used, where the phase L1 is the faulty and L2 and L3 are healthy (it works for all phase combinations). It should be noticed that only the phase angle is corrected - the amplitude of the restored faulty phase voltage is not correct, but it is not used in the directional determination:

$$V_{L1} = (V_{L2} - V_{L3}) \cdot e^{j\frac{\pi}{2}} \tag{11}$$

The reason that it is possible to rotate a vector by multiplying with another vector is the following relation, where α_1 and α_2 are two vectors:

$$arg(\alpha_1\alpha_2) = arg(\alpha_1) + arg(\alpha_2) \tag{12}$$

The polarized voltage needs to be compensated for the short circuit angle, which is usually between 30° and 60 ° . For the specific implementation a 45° rotation of the reference is done internally. A reference adjustment possibility for the user is provided to adjust the compensation angle with respect to the just mentioned 45°, this adjustment angle is set to 0° as default. In most cases it is not necessary to apply an adjustment, but system

configuration might cause it useful to do additional adjustment.

The fault is detected as forward going if the phase difference between the voltage and current is less than 90° (minus the security margin if applied) - otherwise it is determined as reverse going. The topology is shown in Fig. 35, where the polarized voltage is not adjusted. The same illustration is shown in Fig. 36 where the reference voltage is adjusted 45°. The adjustment parameter then adjust the reference voltage from this shown position.
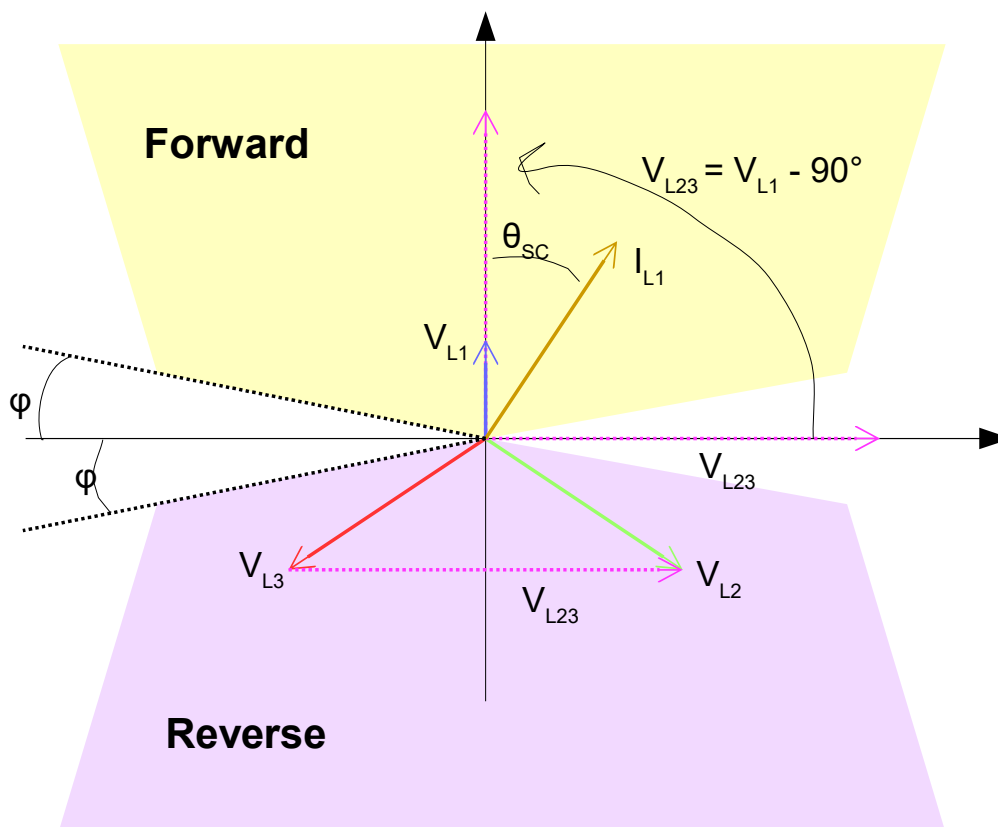
Figure 35: Illustration of the directional determination.

Figure 36: Illustration of the directional determination with the polarized voltage adjusted 45°.

6.3.4   Instantaneous high current detection (ANSI 50)
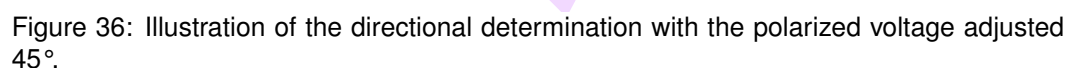
This detection functionality detects fast increasing currents, which exceeds the "directional overcurrent protection" level by a significant amount. The configuration of the pick-up function is very simple as shown in Fig. 37, only a threshold for the current is needed along with a minimum number of samples that should be above the given threshold. Each sample covers 800 μs.

Figure 37: Illustration of the web interface showing the settings for the instantaneous overcurrent detection pick-up function.

6.3.5 Overvoltage detection (ANSI 59)

The overvoltage detection is used to detect high voltage occurrence in the power system. The higher voltage level can cause a wide variety of damages. The higher voltage level can be caused by low load conditions (mainly on long transmission lines), bad reactive power control, voltage controller failure or other fa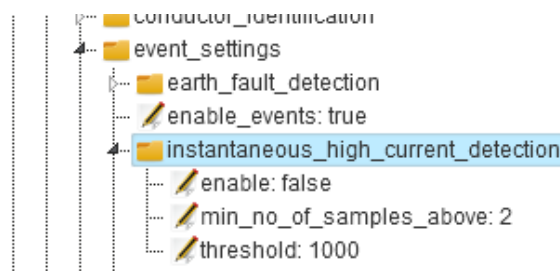ults in the power system.The overvoltage detection function settings can be configured from the web interface, which is shown in Fig. 38.
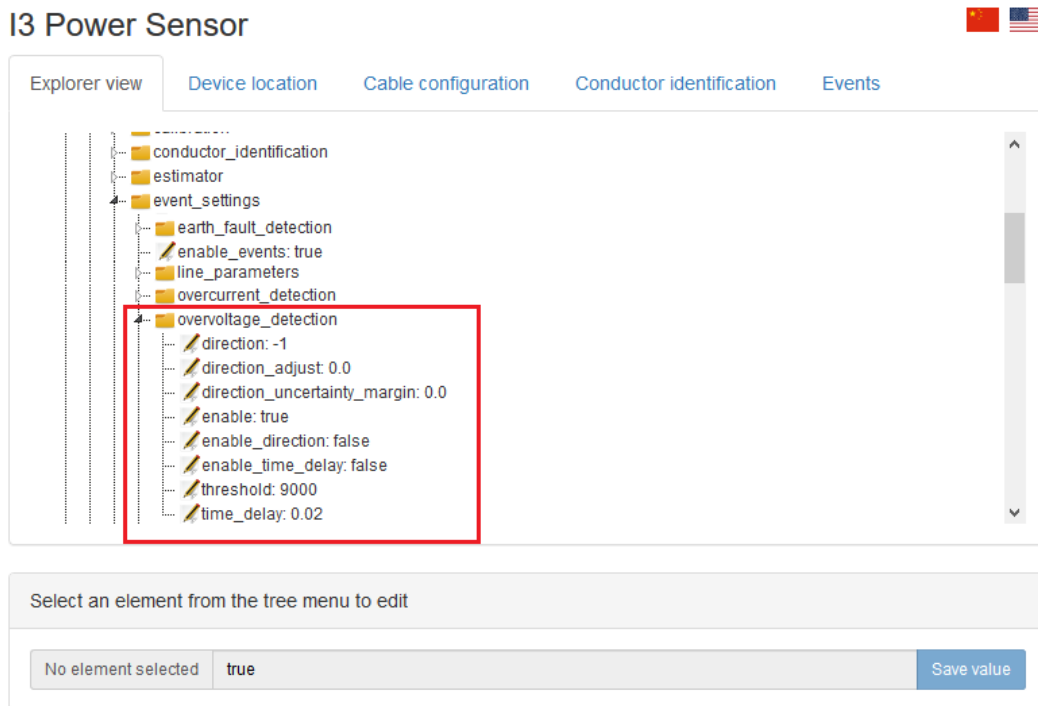
Figure 38: Overvoltage detection setting through web interface.

Steady state overvoltage

This fault type is an overvoltage where the high voltage is present for a relative longer period (there is no strict definition). For the Jomitek I3 Power Sensor a steady state overvoltage is a high voltage for more than 4 ms.An example of an overvoltage event recorded by the Jomitek I3 Power Sensor is shown in Fig. 39 and Fig. **??**. The event was caused by an earth fault, but also triggered the overvoltage detection since the voltage of the two healthy phases increased above the threshold.
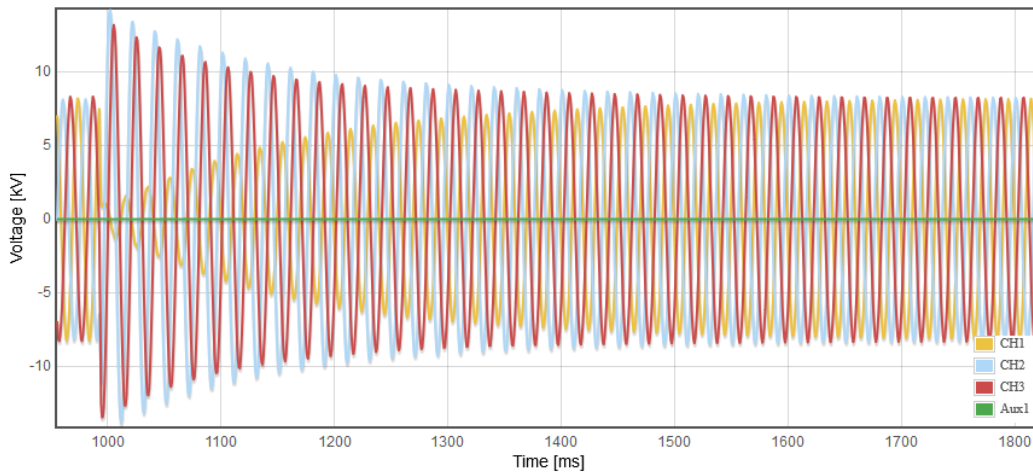
Figure 39: Voltage signals from the overvoltage event.

Detection   The detection of an overvoltage event is based on a phase-to-neutral voltage threshold. The threshold should be close to the nominal voltage (Jomitek recommends 5 % to 20 % above nominal voltage). The exact threshold value depend on the stability of the voltage level at the local power system.

Time delay   The user can set a time delay constrain. The purpose for this time delay is to let the user distinguish between voltage surges caused by switching or lightning and an actual overvoltages.

6.3.6 Instantaneous high voltage detection

This detection functionality detects fast increasing voltage. The configuration of the pick-up function is very simple as shown in Fig. 40, only a threshold for the voltage is needed along with a minimum number of samples that should be above the given threshold. Each sample covers 800 μs.

Figure 40: Illustration of the web interface showing the settings for the instantaneous overvoltage detection pick-up function.

6.3.7 Undervoltage detection (ANSI 27)

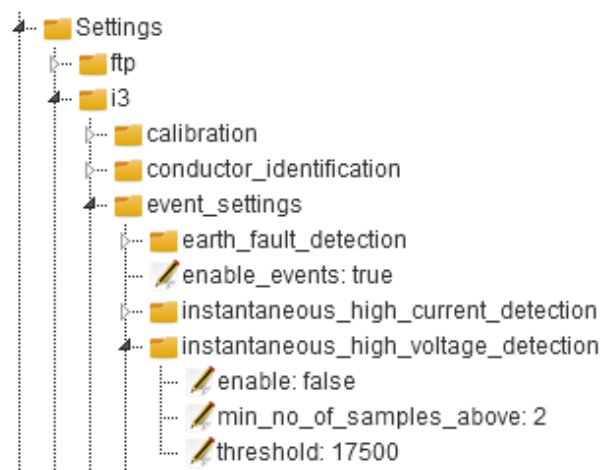The undervoltage detection is used to detect low voltage levels in the power system. Even though low voltage level doesn't cause the same damage to hardware as overvoltage events, undervoltage events can cause damage to equipment. The low voltage level can be caused by a fault, wrong reactive power control or switching onto a grounded line.

The undervoltage detection function settings can be configured from the web interface, which is shown in Fig. 41.
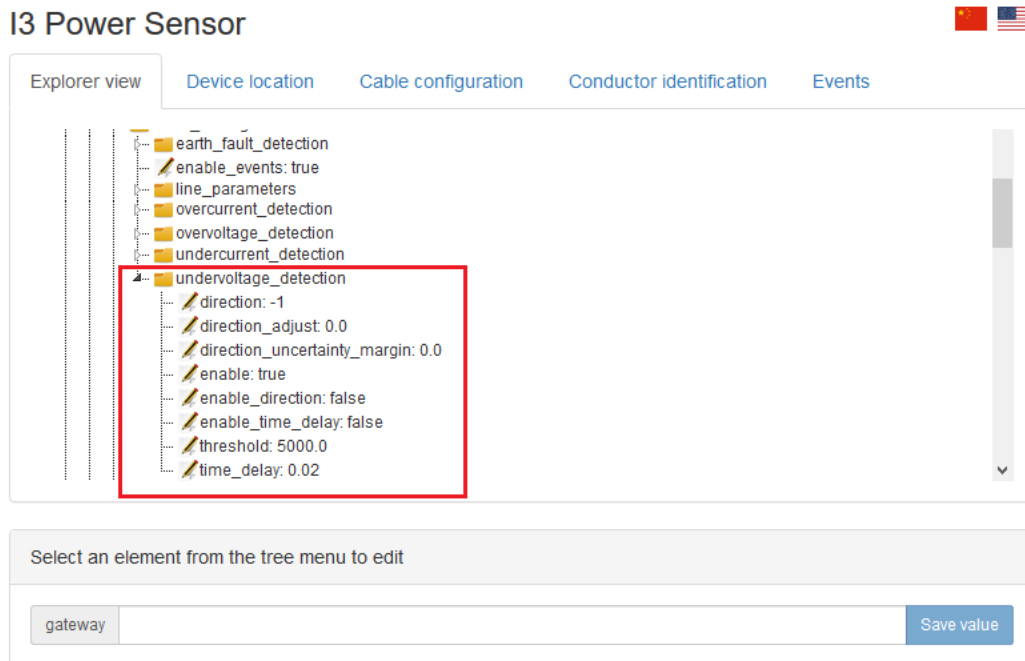
Figure 41: Undervoltage detection setting through web interface.

Steady state undervoltage

This fault type is an undervoltage event where the lower voltage has been present for a relative longer period (there is no strict definition). For the Jomitek I3 Power Sensor a steady state undervoltage is a lower voltage for more than 4 ms.

Detection

The pickup is based on a phase-to-neutral voltage measurement compared with a threshold set by the user.

Time delay

The user can set a time delay constrain. The purpose for this time delay is to let the user distinguish between short time voltage dips and actual undervoltage events.

6.3.8 Undercurrent detection (ANSI 37)

The detection function detects under current event, which is recognized by a phase current magnitude under a given threshold. Under current events are often not causing harm to the power systems, but monitoring under current events can be useful for power system operation, planning and asset managements departments.
The undercurrent detection function settings can be configured from the web interface, which is shown in Fig. 42.
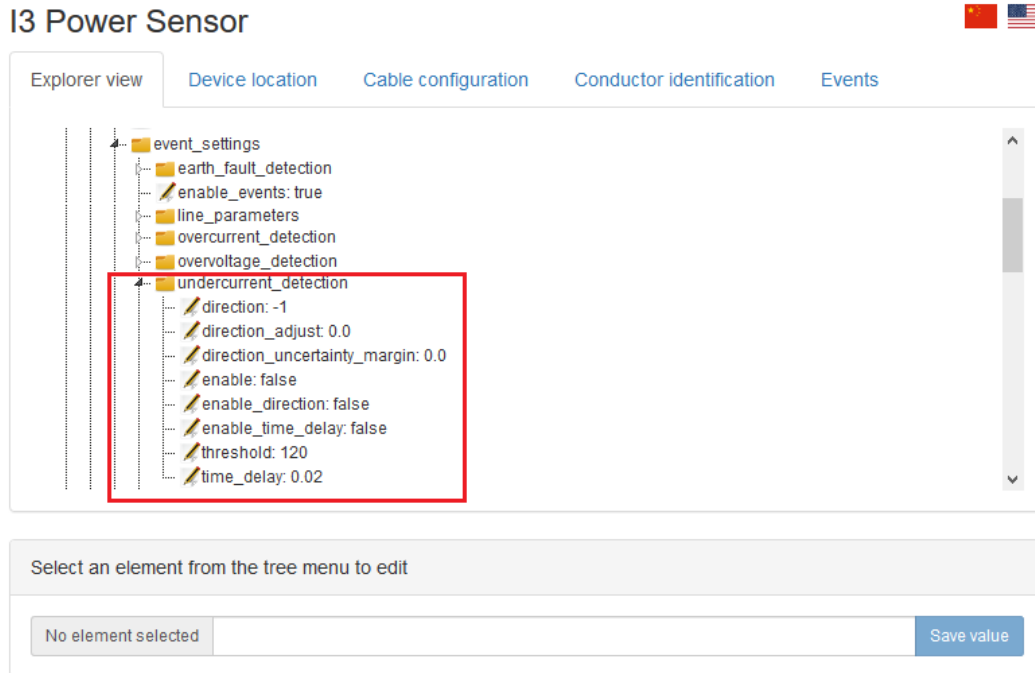
Figure 42: Undercurrent detection setting through web interface.

Steady state undercurrent   This fault type is an undercurrent where the lower current is present for a relative longer period (there is no strict definition). For the Jomitek I3 Power Sensor a steady state undercurrent is a lower current for more than 4 ms.
An example of a short time undercurrent event is shown in Fig. 43. The recording is from the output of a generator, which should produce a minimum of power. The recording revealed these unexpected short term changes in current.
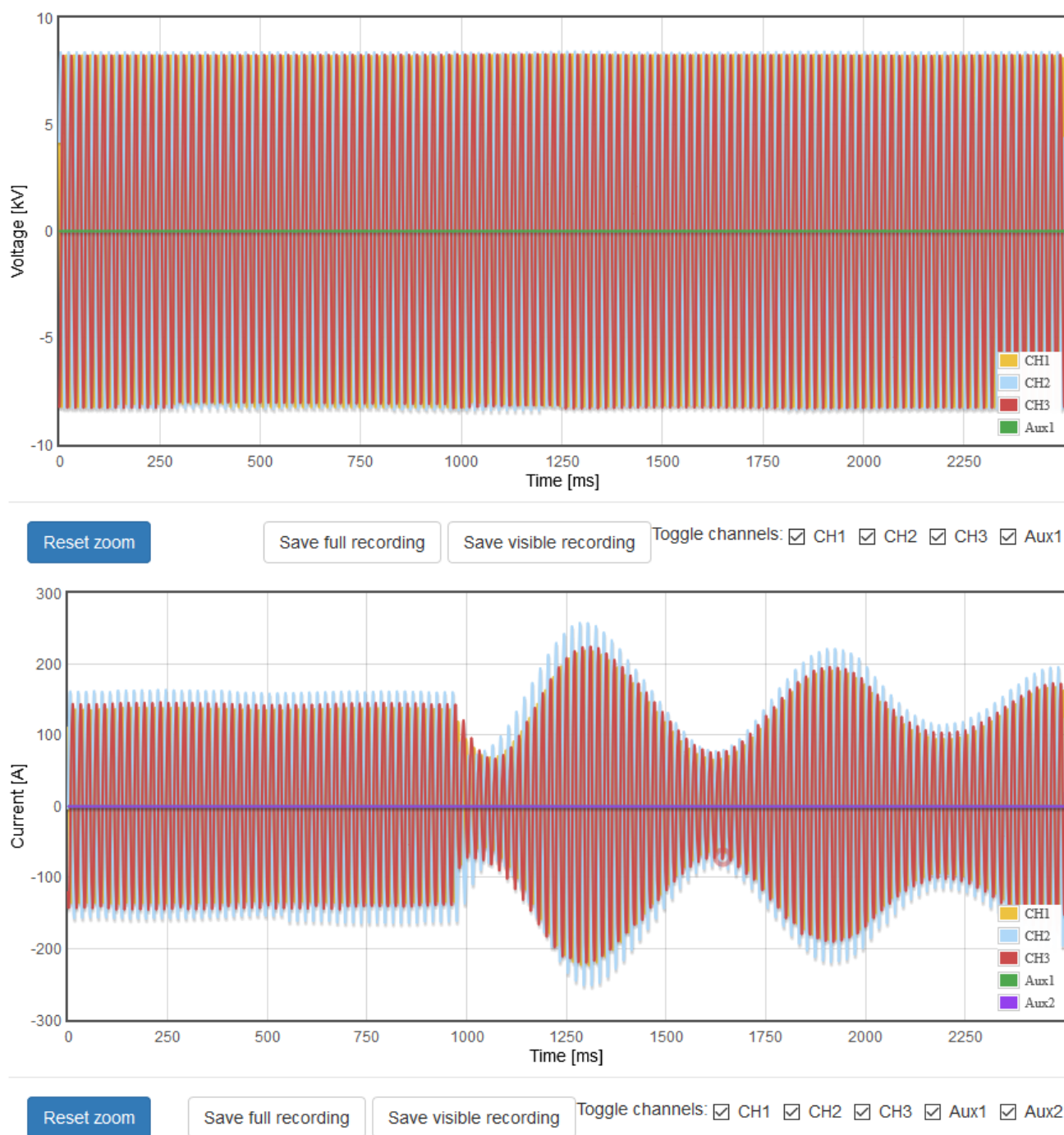
Figure 43: Undercurrent event recording viewed from the Jomitek I3 Power Sensor web interface.

Detection   The pickup is based on a measurement of the phase current which is lower than the given threshold. The threshold value is highly depending on the purpose of using the undercurrent event detection.

Time delay   The user can set a time delay constrain. The purpose for this time delay is to let the user distinguish between short time low current dips and actual undercurrent events.

7   Web interface

7.1   General structure

The web interface is structured around four main components as shown in figure 44, with the following description.

- The *tab menu* for navigating between sub pages.

- The *main content area* for displaying sub page content.

- The *page context menu* for interacting with the currently selected sub page. This menu may not be available on all sub pages.

- The *notification area* for displaying messages as feedback to user actions and input. Notifications will be queued, with the newest notification appearing at the top of the notification area. Notifications will automatically disappear after 20 seconds, or can be manually dismissed.

Figure 44: Overview of the web interface showing the layout of the four basic components.

7.2 Sub pages

7.2.1 Explorer view

The *Explorer view* page provides a quick and direct access to most Jomitek I3 Power Sensor settings, functions and measurements. All items are arranged in a hierarchical folder structure that can be expanded when clicked.

When a node in the tree is clicked, the *page context menu* will show the node key and value, and if the value is editable, let you enter a new value which can be saved by clicking the *Save value* button.

Depending on the information type, the lowest level expansion will either act as a button executing the relevant command, a link for file download, a link which expands the bottom part of the main page with the requested

content, or in case of specific parameter values, the value is inserted in an editable text box.

The **main folder** (top level icon) represents the Jomitek I3 Power Sensor device itself, including a few main status and identification parameters. The device text is assembled using the following parameters: The 'type' and 'serial_number' from '*conf/identity.conf*', the MAC address and the device temperature. When the mouse cursor is positioned on the folder, additional information presenting the server side time (GMT) of the web page load will occur.

The **Reset options** features a **Reset main device button**. A reset command is sent to the sensor, and the web client is set to automatically reload the page when the sensor should be up and running again. If this is not the case, please reload the page again, and remember to check that the IP address targeted is still correct after the reset.

The **Factory reset** button overwrites the '*conf/settings.conf*' and '*conf/identity.conf*' files to default values.

The **Settings** information folder presents a database table as defined by the '*conf/settings.conf*' file. Any web based modification of the parameters will be directly updated in the '*.conf*' file itself. Note that some parameter changes will require a reset to take effect. This folder, along with the **Identity** and **Device state** folders, is a direct mapping of a data table in Lua (in this case 'CONFIG'). This is the reason why there are no 'space' characters, or other special characters, in the subfolder and parameter names. It provides the added benefit, that any modification in the Lua data tables will be directly reflected on the web page at the next reload.

Note that the majority of the parameters in the **Settings** folder are described by placing the cursor above the parameter in question. The same is the case for many of the parameters included in the other folders. The descriptions, as well as basic data format validation during web based parameter updates, are per default defined via the '*conf/description.csv*' file, or in the iec104 data point mapping '*.csv*' files, e.g. '*conf/iec104_analogue.csv*'.

The **database** subfolder defines a few high level behavior settings for the main Lua data table.

The **i3** subfolder contains a number of sensor specific configuration options:

- **calibration** is offering a simple linear scaling option for current and voltages. It is only expected to be needed for fine tuning of voltages. An option for a general adjustment of the voltage to current phase is also offered, but should only be used if trustworthy reference measurements have shown it to be necessary. This could be the case, if the currents are measured at the MV side of a transformer, and the voltages are from the LV side. Please note that this 'voltage_to_current_phase_offset' apply to all measurements (including the event system) except the time series recordings, which are raw measurements.
  It is furthermore possible here to set the cross talk coefficients manually if needed.

- **conductor_identification** contains settings related to the link between the voltage and current signals. Since the only direct physical link between the Jomitek I3 Power Sensor and the individual conductor is the voltage measuring point - the voltages defines the phase sequence. When the currents are measured by the Jomitek I3 Power Sensor , the current can be linked manually or automatic. The automatic linking can be done either by a comparison of phases (where voltage and current with phases closest to either with be linked) or by physical conductor position, where a conductor is link to a specific position (require that position estimate has been previously preformed and that the sensor has not been removed since last position estimate). Finally it is possible to change the naming of the phases.

- **event_settings** defines trigger points for logging of measurement events, please see section 6.3 for more detailed information.

- **gpio** The sensor can, when ordered, be equipped with additional I/O. If the I/O module is installed in the sensor it can be configured and enabled/ disabled in this settings folder. The module is enabled by setting the **installed** flag to "true" and disabled by "false". The number of inputs and outputs should be configured here as well. Last the poll interval can be configured, but it should be noticed that it is good practice to choose a conservative poll interval to ensure the reliability of the inputs/ outputs.

- **i3_rtu** It is possible to extend the sensor functionality with an I3 RTU. The RTU is configured using this settings folder. The RTU can be used for switch gear monitoring and control. The RTU also features

battery backup, fault indication LED's, PoE power supply for Jomitek I3 Power Sensor s, RS485 input port for MODBUS communication from etc. smart meters and MODBUS/ IEC-60870-5-104 protocol conversion. For more information about the RTU please contact Jomitek.

- **post_processing** defines processing steps related to the RMS calculations performed on the raw measurement data. flip_direction_of_current (default: false) can be used to reverse the sign of the current, and hereby flip the sign of the active power measurement (direction of energy flow). Note that with the default setting (false) a positive active power flow is defined as being fed from the bottom (where the 4 BNC connectors are mounted), to the topside (the blank surface). The RMS readout of measurement values are split up into two variants. The first, defined by quick_time, is intended to provide near-instantaneous true RMS measurements for use in the web interface. The default setting is 1 second. The second, defined by average_time is intended to provide true RMS averaging windows for SCADA/automated readouts, with a default setting of 60 seconds.

- **smart_meter** If an I3 RTU is installed and the RS485 MODBUS communication for Smart meter measurements is connected, the functionality should be enabled or disabled by setting the "installed" flag to "true" or "false". Furthermore the poll interval can be set for the RS485 MODBUS Smart meter communication.

- **voltage_setup** defines the high voltage capacity, in pF, used for the voltage measurement. To improve the accuracy of the voltage measurement the length of the rg58 cable from the high voltage capacitor to the sensor should be defined in this settings folder as well.

- **wago** If there is a need for several I/O's, then a sensor equipped with a GPIO module can be further extended with a Wago I/O module. The Wago I/O modules offers a wide range of different I/O configurations and the Wago modules can be connected to obtain 20+ I/O's for the sensor.

iec104 lists all main parameters used for the IEC 60870-5-104 protocol configuration, including file links used for address mapping and type definition of parameters.

logging provides parameterization options for what event or error types should be put into the system log. See also /log via FTP. In general, it should not be needed to change these settings.

tcpip provides the option whether to use dhcp or not. Per default dhcp is set to true. The IP and gateway adresses and the subnet mask is also defined here (only used if dhcp=false). Note that if the device experiences severe errors during startup, it will revert to the IP configuration defined in the '*conf/panic.ip*' file, and if this also fail to load, the following hardcoded settings will be used: dhcp=false, gateway=192.168.135.100, ipv4=192.168.135.18, subnet=255.255.255.0. In DHCP mode, in the case where no DHCP server can be reached, the sensor will automatically make an allocation within the IP range 169.254.1.0 to 169.254.254.255 in compliance with RFC 3927 Section 2.1.

The parameters in the **web** section defines which port is used for the web service (default is 80).

The **Identity** folder contains all the location and naming related information for a specific device. It should always be edited, or generated, on an individual basis. The parameters include address, city, zip, country_state, location_name and location_description as identifying text for the location. The location_name could e.g. be the name or reference for a substation, and the location_description could detail the cable section and/or phases being measured on. Furthermore the location may be specified using WGS84 coordinates in a '<latitude>,<longitude>' decimal degrees format. The serial_number may be set to match the Jomitek device serial number, or a custom format defined by the operator. In this context, note that the only hardcoded identifier of a device is the uniquely assigned MAC address. The type parameter will, if left blank, be automatically set during bootup based on a device internal check of the accessible peripherals. Custom naming may be used as an alternative.

The **Measurements** reflects the 'data' Lua table. All the parameters in this folder can be exported via IEC-60870-5-104 as described in section 8. The Measurements folder contains the following parameters for both **voltage** and **current**. For all parameters there exist an individual value for each phase and an average of the section:

- **distortion_factor** is calculated by $\frac{1}{\sqrt{1+THD_i^2}}$ where THD_i is the total harmonic distortion.

- **harmonics** is the absolute value of the first 12 harmonics and the fundamental component (denoted as H1).

- **phase** is the true phase given in degrees. The "true phase" is based on time series measurements and not only the fundamental component.

- **rms** is the RMS value with integration time as configured in Settings/i3/post_processing/average_time. The RMS is measured in A for current and kV for voltage.

- **thd** is the THD including all harmonics until (but including) the 40th harmonic, as described by the standard EN 50160.

- **thd_extended** is the THD based on all harmonics until (but including) the 312th harmonic in a 50 Hz power system and 250th in a 60 Hz power system.

- **thd_n** is much similar to "thd_extended", but includes also the inter-harmonics.

The THD measurements are based on the latest frequency analysis (hardcoded to run for all active voltage and current inputs, once every 10 minutes).

The **power** reflects parameters involving both voltage and current and is more specific described below:

- **displacement_factor** is the power factor given by $\cos(\varphi)$ where φ is the angle between the voltage and current.

- **phase_delta** is the angular difference between the time series based voltage and current signal in degrees.

- **power_factor** is the true power factor given by the product of the power factor and the distortion factor.

- **rms_real_power** is the real (active) power, in kW.

- **rms_apparent_power** is the apparent power in kVA.

- **rms_reactive_power** is the reactive power, in kvar.

The **smart_meter** reflects all the data points received from all connected Smart meters. The Smart meters can be connected through an I3 RTU.

Event history reflects all recorded events. The folder contains key parameters from each event along with recorded time series measurements of the event in two different resolution where the highest resolution is sampled at 31250 Hz and the lower resolution is sampled at 1250 Hz. The high resolution buffer contains 100 ms of recorded measurements and the lower resolution contains 2.5 s of recorded measurements. Using the web-interface it is recommended to use the "Event" tab to browse in the recorded events.

Download measurement snapshots reflects recorded time series snapshots of in both resolutions along with FFT of all active current and voltage phases. Clicking a .wav file in this folder starts a download of the file.

View measurement snapshot reflects the same measurements as stated about. Clicking a file in this folder enables a direct view of the file in the browser.

Live measurement graphs reflects measurement graph which can be viewed live in the browser. The measured parameters which can be viewed live are denoted below:

- **Voltage** This graph contains time series measurements of all four voltage inputs.

- **Current** This graph contains time series measurements of all three phases voltages and a fourth conductor.

- **Phase delta** This graph contains the angular different between the voltage and current for each channel.

- **Apparent power** This graph contains the calculated apparent power for all three phases and the extra input channel.

- **Reactive power** This graph contains the calculated reactive power for all three phases and the extra input channel.

- **Real power** This graph contains the calculated real power for all three phases and the extra input channel.

- **Power factor** This graph contains the true power factor for all three phases and the extra input channel.

- **Main harmonic frequency** This graph contains the measured main frequency.

7.2.2   Device location

The *Device location* page visualizes the geographical sensor installation location on an interactive map. The location coordinates can be edited by clicking the map to place a new marker. Once the new mark has been placed at the desired position, the location coordinates can be saved by clicking the *Save coordinates* button in the *page context menu*.

The device location coordinates can also be set through the *Identity/wgs84_coordinate* node in the *Explorer view* sub page.
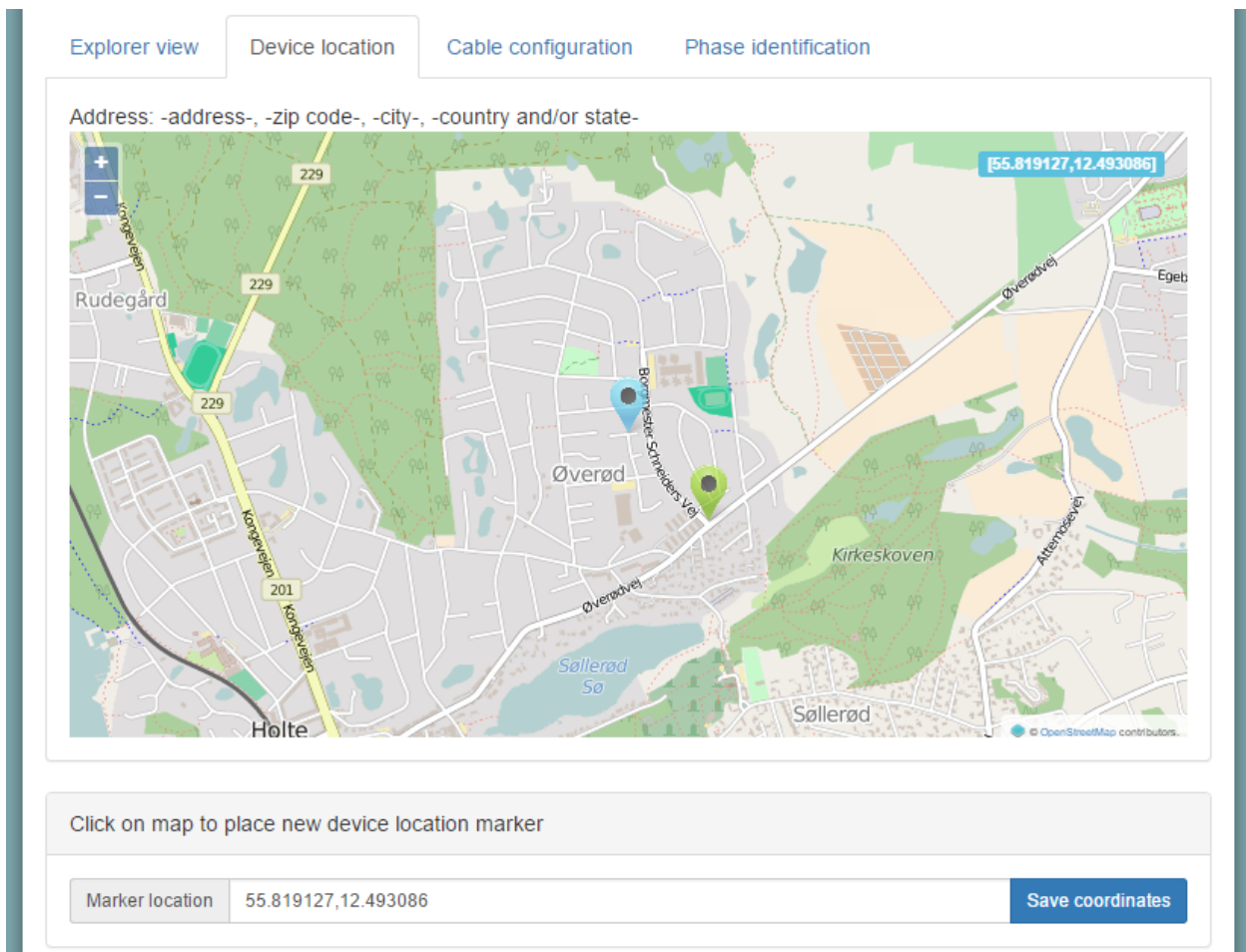

Figure 45: Screen shot from the *Device location* sub page showing the placement of a new marker location ready to be saved.

7.2.3   Cable configuration

The *Cable configuration* sub page provides a graphical interface for selecting the best suited cable conductor model for the Jomitek I3 Power Sensor current estimator algorithm. To set the estimator mode, simply click the desired model and save your selection by clicking the *Save estimator model* button in the *page context menu*.

7.2.4   Conductor identification

The *Conductor identification* tab provides a simple overview of the phase voltages and currents in form of a table in the top of the page. Further down on the page there are two plots, one showing time series measurements of the phase voltages and the other plot shows the time series current measurements. A screen shot of the *Conductor identification* tab is shown in Fig. 46:
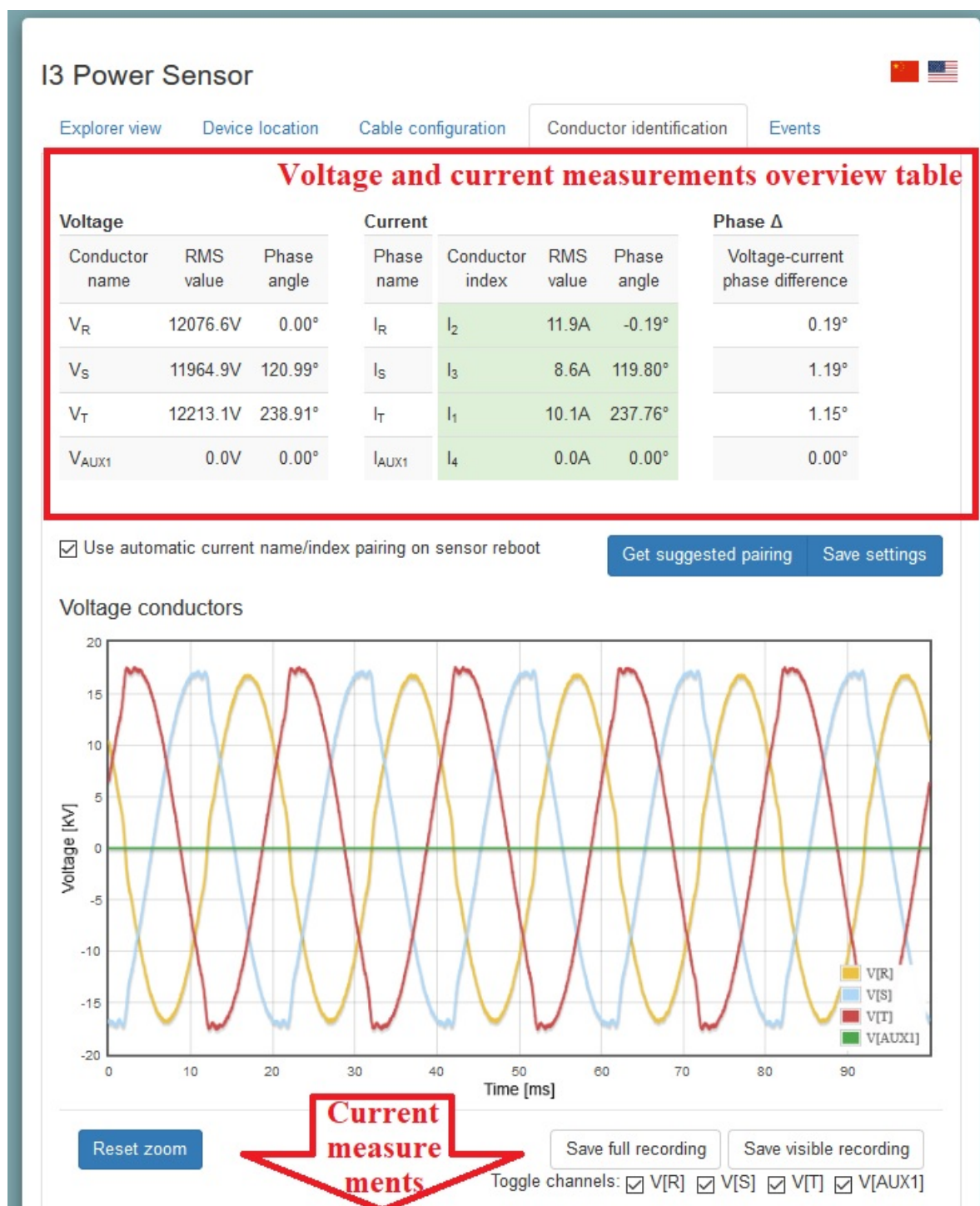
Figure 46: Screen shot from the *Conductor identification* sub page showing the page content.

8   IEC-60870-5-104 configuration

The IEC 60870-5-104 (abbreviated "IEC 104" or "104" in the following) application layer protocol can be used for transmitting sensor data from the sensor to a SCADA system or another data-aggregation device implementing the IEC 104 protocol. The TCP/IP protocol suite is used to ensure reliable data transfer. Additionally, the 104 protocol supports message sequencing on the application layer. A 104 client connects to the IANA assigned TCP

port 2404.

The sensor allows flexible configuration of the protocol settings, and of the data points. The data points can be transmitted based on a variety of triggers, including on-change, periodic, on manual request, or using interrogation commands requesting a larger set of data. The sensor can be configured to use all features defined in the IEC 104 standard, or the sensor can use a small subset for simpler applications.

The 104 protocol settings are found in the settings.conf file under the "iec104" section. These shall match the protocol settings defined in the SCADA client, and must be in compliance with the IEC standard. Interoperability requirements can be documented by a 104 client by filling out Chapter 9 in the IEC 104 standard. An overview of the parameters defined in the sensor are listed in table 6.

Setting	Meaning	Default value
t1	Time-out of send or test APDUs.	16
t2	Time-out for acknowledges in case of no data messages, $t2 < t1$.	11
t3	Time-out for sending test frames in case of a long idle state.	21
k	Maximum difference receive sequence number to send state variable.	8
w	Latest acknowledge after receive w I format APDUs.	12
common_address	IEC 104 address of sensor.	1
background_scan	Interval in seconds between transmission of digital data points.	1800
cyclic	Interval in seconds between transmission of analogue data points.	600
scan	Data change scan interval in milliseconds for sending event-triggered data.	500
clock_validity	Time-tagged client commands validity period in seconds.	600
redundancy	Max number of redundant connections as defined by IEC 104.	2

Table 6: IEC-104 parameters.

Three *.csv* files are used to map internal sensor measurements to data points accessible by an IEC 104 client. A macro enabled Excel file is used to generate these *.csv* files, and all changes to the data mapping should be applied in the Excel file. There are three sheets in the Excel file, and each generate one .csv file. The sheets are called "iec104_analogue", "iec104_digital" and "iec104_commands", which define analogue and digital measurement mapping to the IEC 104 protocol. An example snapshot of the "iec104_analogue" sheet is shown in figure 47.

	A	B	C	D	E	F	G	H	I	
1	address	type	data	interrogation	spontaneous	cyclic	absmin	absmax	rel	desc
2	1000	M_ME_TF_1	section.rms_current	global	TRUE	TRUE	10	100	10	RMS current [A]
3	1001	M_ME_TF_1	section.rms_voltage	global	TRUE	TRUE	10	100	10	RMS voltage [kV]
4	1002	M_ME_TF_1	section.power_factor	global	TRUE	TRUE	10	100	10	Power factor [-1;1]
5	1003	M_ME_TF_1	section.rms_apparent_power	global	TRUE	TRUE	10	100	10	Apparent power |S| [kVA]
6	1004	M_ME_TF_1	section.rms_reactive_power	global	TRUE	TRUE	10	100	10	Reactive power Q [kVAr]
7	1005	M_ME_TF_1	section.rms_real_power	global	TRUE	TRUE	10	100	10	Real power P [kW]

Figure 47: iec104_analogue.

Description of columns:

- **address** The address of the data point, [1-65535].

- **type** The IEC 104 type (see interoperability list in IEC 60870-5-104 chapter 9).

- **data** Internal sensor variable name.

- **interrogation** The interrogation group this data point belongs to. Can be "global" or "groupX" where X is in the range [1-16].

- **spontaneous** Set to true if data point should be transmitted on change.

- **cyclic** Set to true if data point should be sent periodically.

- **absmin** Minimum absolute change in data value to trigger spontaneous transmission. This is useful for avoiding sending a data point too often when the value is low.

- **absmax** Maximum absolute change in data value to trigger spontaneous transmission.

- **rel** Relative change in percent of the data value to trigger spontaneous transmission. For example, setting rel = 10 for a data point with value 500 triggers transmission at 450 or 550.

- **desc** A short description of the data point and unit. The description will be used as a tooltip in the web interface.

Refer to figure 48 for a graphical example of the transmission thresholds absmin, absmax and rel.
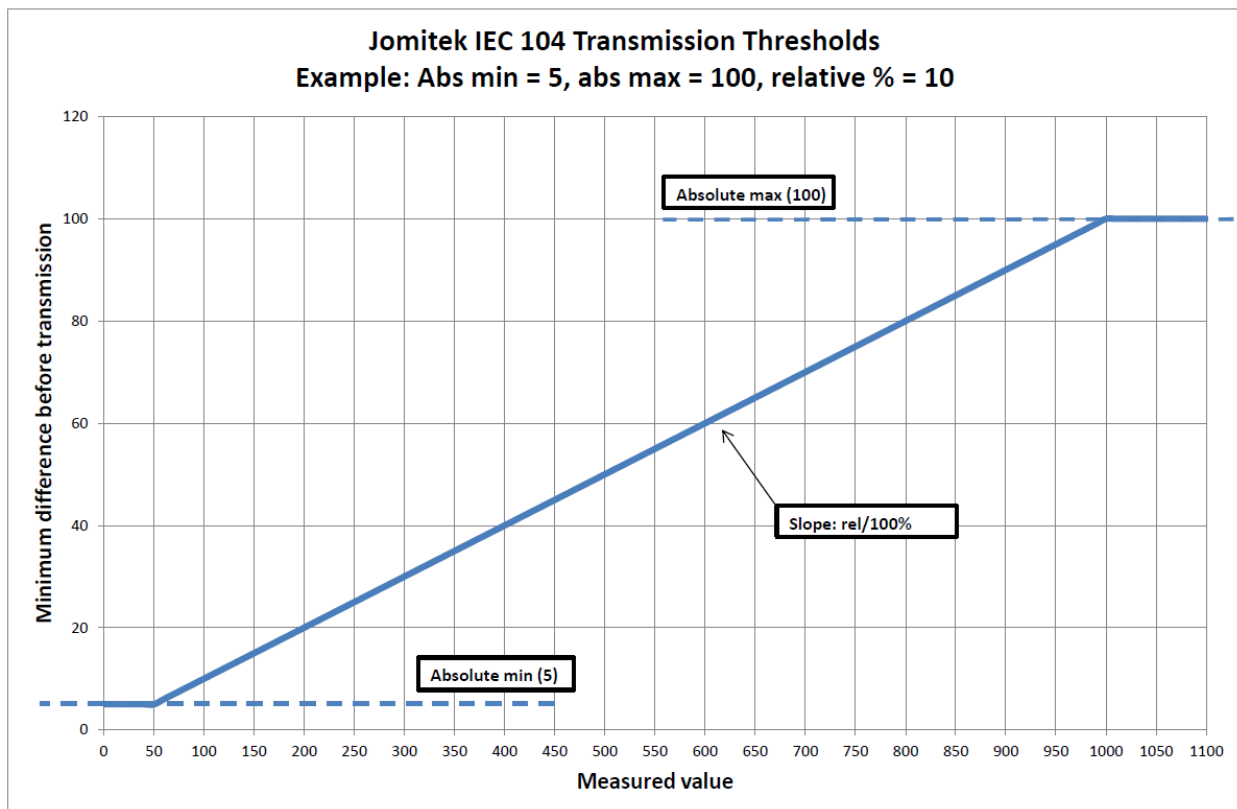

Figure 48: absmin, absmax and rel.

Any change in a digital value triggers transmission given spontaneous is set true for this data point in the "iec104_digital" sheet. For this reason the "iec104_digital" sheet does not define absmin, absmax and rel columns. Also, the "iec104_digital" sheet replaces the "cyclic" column found in the analogue sheet with "background". The use of the "cyclic" column for analogue values is similar to the use of "background" column because they are both used to trigger transmission at fixed intervals.

Additionally, all IEC 104 commands are supported by the sensor, and they can be used to invoke any function or define any setting in the sensor as desired. However, depending on the application and due to the variety of

protocols supported by the sensor, IEC 104 commands may not be needed. The "iec104_commands" sheet in the Excel file map a data point address to an internal variable.

Since the IEC 104 protocol uses TCP/IP, it is in some cases useful to debug the communication stream using Wireshark[5].

9 Signal analysis

9.1 WAV files

All time series data files recorded by the Jomitek I3 Power Sensor are stored as WAV files (file extension .wav). The WAV file format is a lossless and uncompressed format that holds time series meta data such as sampling frequency and sample bit depth as well as multiple time series measurements stored as separate channels in a single file.

Additional meta data describing the type of measurement (voltage, current, etc.), scaling, time stamp and similar is contained in the event meta data for events.

The format structure itself is simple and widely compatible with many software tools. Further information on the format can be found at https://en.wikipedia.org/wiki/WAV.

9.2 Frequency analysis

The Jomitek I3 Power Sensor has a build-in spectrum analyser that offers a per phase high resolution FFT of both voltages and currents. A FFT is a valuable tool in in asset management or when estimating losses in the power system. Conventional VTs and CTs suffers under a relative low bandwidth and is only usable in power system with a very low THD. Nowadays the THD level in distribution systems increase due to high PV penetration and other converter based technology. For this reason it is important to use broad band voltage and current measurements when estimating losses in the power system. Having multiple sensors in a network it can be possible to identify larger noise sources. The DSO (or TSO) can in some countries claim economic compensation from customers who generate a significant amount of harmonics.

9.2.1 Fast Fourier Transform

A FFT (Fast Fourier Transform) computes the DFT (Discrete Fourier Transform) and produces the same result as evaluating the DFT directly but uses significantly less computations for large size sample sets.

Let $x_0, \ldots, x_{N-1}$ be complex numbers. The DFT is defined by the formula

$$X_k = \sum_{n=0}^{N-1} x_n e^{-i2\pi kn/N} \qquad k = 0, \ldots, N-1, \quad n \in \mathbb{Z}$$

Calculating the DFT directly requires $O(N^2)$ operations whereas an FFT algorithm achieves the same result in $O(N \log N)$ operations.

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[5]https://www.wireshark.org/

The result of the transform is a complex spectrum representation from which the magnitude and phase of each of the frequency components of the input signal is calculated. The sensor presents the user to the magnitude of the transformed signal divided into 1562 bins each covering a span of 10 Hz, giving a total span of 15620 Hz, and starting from 10 Hz. The I3 sensor doesn't measure DC signals, so the DC component is omitted in the output. The THD described in the next section is calculated based on the magnitude of the FFT bins.

9.2.2 Total Harmonic Distortion

One of the basic measures of power quality is the THD (Total Harmonic Distortion), which is used to describe the ratio of (typically unwanted) energy in a signal outside of the main frequency component. The Jomitek I3 sensor provides three different measures of the THD, their definitions are given below.

THD according to EN50160 measures the harmonic distortion up to the 40'th harmonic or up to 15620Hz (whichever is the lowest) according to the following equation

$$THD = \frac{\sqrt{\sum_{n=2}^{40} X_n^2}}{X_1}$$

where X_n is the magnitude of the n'th harmonic and X_1 is the magnitude of the main harmonic frequency, which is automatically determined.

THD Extended measures the harmonic distortion up to the maximum harmonic available according to the following equation

$$THD_{Extended} = \frac{\sqrt{\sum_{n=2}^{H_{max}} X_n^2}}{X_1}$$

where X_n is the magnitude of the nth harmonic and X_1 is the magnitude of the main harmonic frequency. H_{max} depends on the main harmonic frequency and is determined with the following equation

$$H_{max} = \lfloor \frac{15620}{f_{main}} \rfloor$$

for a main harmonic frequency f_{main} = 50Hz the equation evaluates to

$$H_{max} = \lfloor \frac{15620 Hz}{f_{main}} \rfloor = \lfloor \frac{15620 Hz}{50 Hz} \rfloor = \lfloor 312.4 \rfloor = 312$$

THD+N measures the harmonic distortion between the amplitude of the main harmonic frequency and all the other frequency bins produced by the FFT according to the following equation

$$THD_{+N} = \frac{\sqrt{(\sum_{n=1}^{N_{bin-max}} X_n^2) - X_m^2}}{X_m}$$

where X_n is the magnitude of the n'th frequency bin and X_m is the magnitude of the main harmonic frequency.

9.2.3 FFT architecture

The Jomitek I3 Power Sensor offers two processing variants of the FFT of the signals measured by the sensor. These modes are called **SINGLE** and **CONTINUOUS** each of which are explained below.

Single Shot mode

In single shot mode, called **SINGLE** in the settings menu, the FFT of a signal is a spectrum of a time signal with length 100ms. The spectrum is produced simultaneously for all active voltage and current channels which allow comparison of the frequency spectrum of the same period in time between the individual channels. In this mode the sensor ignores the settings in **settings → I3 → post_processing → fft → voltage_channels** & **current_channels**

Continuous mode

In continuous mode, called **CONTINUOUS** in the settings menu, the FFT spectrum is an average of a series of short-time Fourier transforms(STFT) each with a length of 100ms. The average is calculated over a user defined interval using incoherent FFT averaging.
Note that for continuous mode ONLY one channel is processed at a time. This means that an averaging length of 10 seconds will produce one updated FFT every 10 seconds for a particular channel. For example the 4 voltage channels would take 40 seconds to generate an updated FFT for all channels with 10 seconds allocated for each channel. When the last FFT is generated the FFT processing restarts with the first channel in the defined sequence, in an infinite loop.

FFT averaging

When the sensor operates in continuous mode, the resulting FFT is based on an average of multiple short-time Fourier transforms(STFT). The resulting FFT can be described by the following equation

$$F_{average}(M) = \frac{1}{K} \sum_{k=1}^{K} |F_k(M)|$$

where the $F_{average}(M)$ is an average of the M'th frequency bin of K STFT's. The process is illustrated in figure 49.
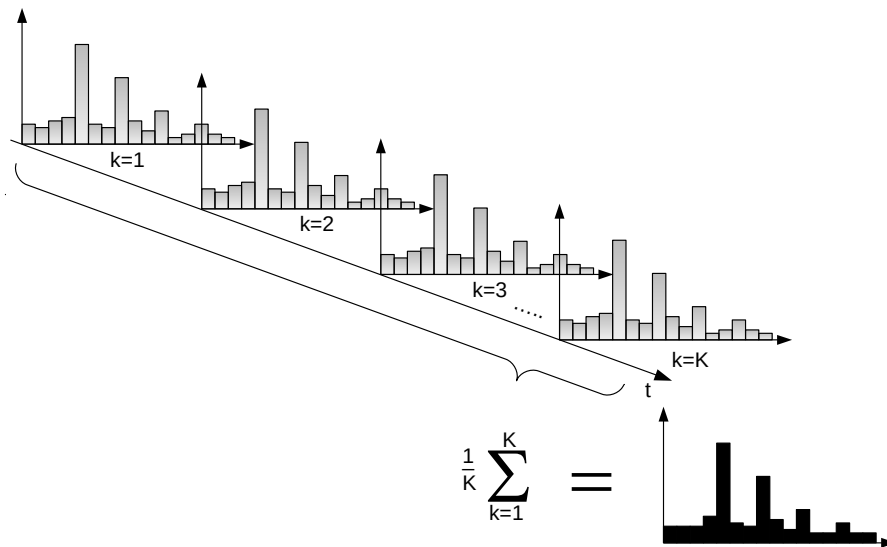
Figure 49: Illustration of the incoherent average of the FFT's.
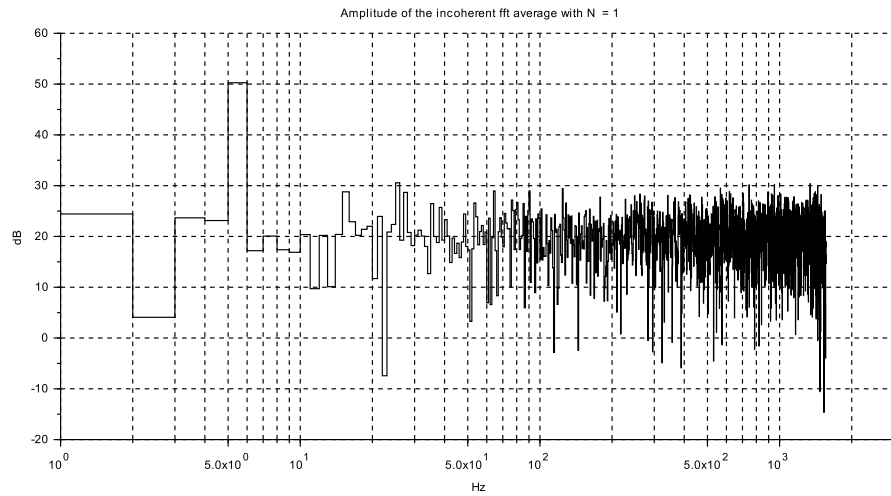
The process of averaging helps improve the signal to noise ratio(SNR) of the individual FFT bin. The SNR is improved according to the following equation.

$$SNR_{incoh}gain(dB) = 10log_{10}(\sqrt{N})$$

The simulated incoherent FFT average on figure 50 contains the following graphs.

- Figure 50a shows an FFT of a 100 ms simulation of a 50 Hz sine wave with 3, 5,and 7 harmonics and zero mean Gaussian white noise.

- Figure 50b shows an incoherent FFT average over 10 s of the same signal as in figure 50b.

- Figure 50c shows an incoherent FFT average over 60 s of the same signal as in figure 50c.

It can easily be seen from figure 50 how the fluctuation of the added random noise is reduced when the average time is increased. Please notice how the harmonics emerge from the background noise as the averaging time increases. This behaviour presents a significant advantage when performing surveillance because even harmonics with a relatively low amplitude can be monitored.

Amplitude of the incoherent fft average with N = 1

(a) Simulated spectrum without average

Amplitude of the incoherent fft average with N = 10
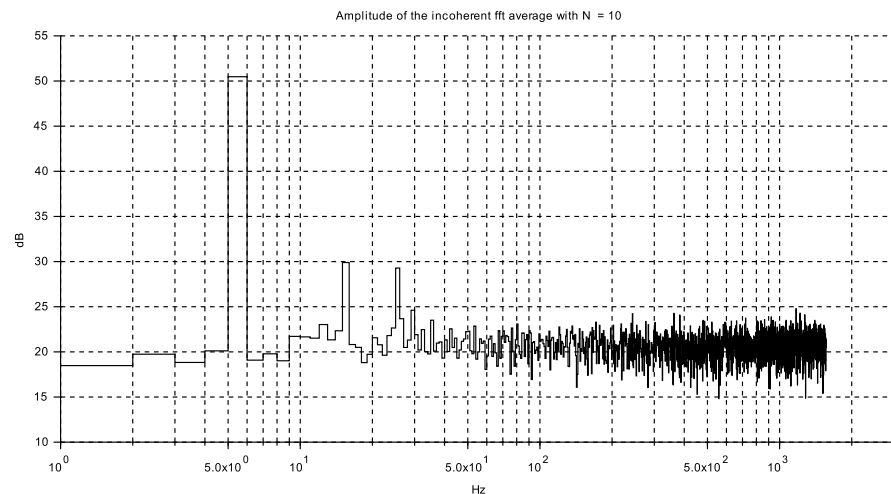
(b) Simulated spectrum averaged over 1 second

Amplitude of the incoherent fft average with N = 600
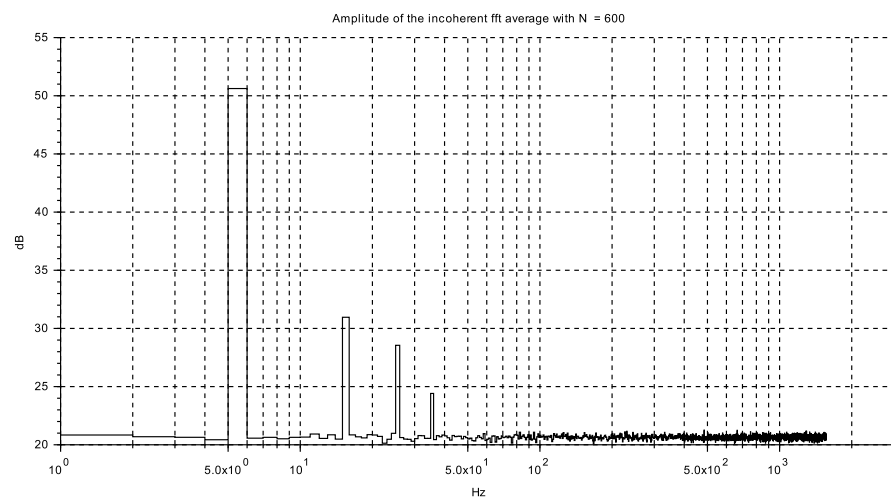
(c) Simulated spectrum averaged over 60 seconds

Figure 50: Illustration of the signal to noise ratio for different averaging intervals.

9.2.4 FFT settings

This section describes how to set up the FFT processing using the sensor web interface. Under the settings menu **settings → I3 → post_processing→ fft**, see figure 51, the following options can be found.

Settings Name	Possible Values
mode	"CONTINUOUS" or "SINGLE"
update_interval	10 s to 3600 s
voltage_channels	array with index 1-4, true or false
current_channels	array with index 1-5, true or false

In single shot mode

If **settings → I3 → post_processing → fft → mode** is set to **SINGLE** the only further configuration needed is to adjust *update_interval*. The other FFT settings are not used in this mode.

- *update_interval* sets the time interval with which the FFT's and THD's of all active channels are recalculated simultaneously, based on a 100ms snapshot.

In continuous mode

If **settings → I3 → post_processing → fft → mode** is set to **CONTINUOUS** all of the FFT settings are relevant to consider.

- *update_interval* sets the averaging time interval for the FFT's and THD's of each of each channel. See section section 9.2.3 for more info
- *voltage_channels* Toggles the voltage channels individually, *active = true*
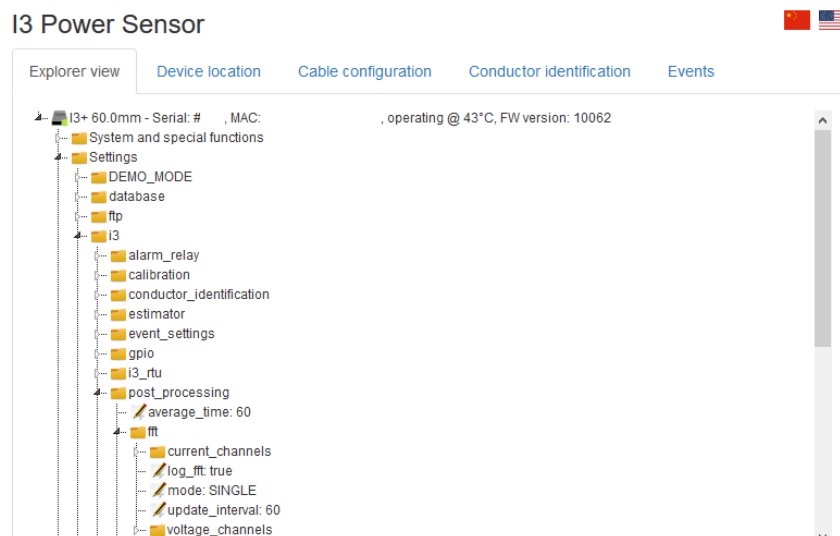- *current_channels* Toggles the current channels individually, *active = true*

Figure 51: Overview of the FFT settings found in the web interface.

9.2.5 Viewing an FFT

To view the most recent FFT, go to the "Explorer view" tab in the I3 web-interface, then find and click the "View measurement snapshots" menu and select "Frequency analysis". You will then see a view similar to figure 52.
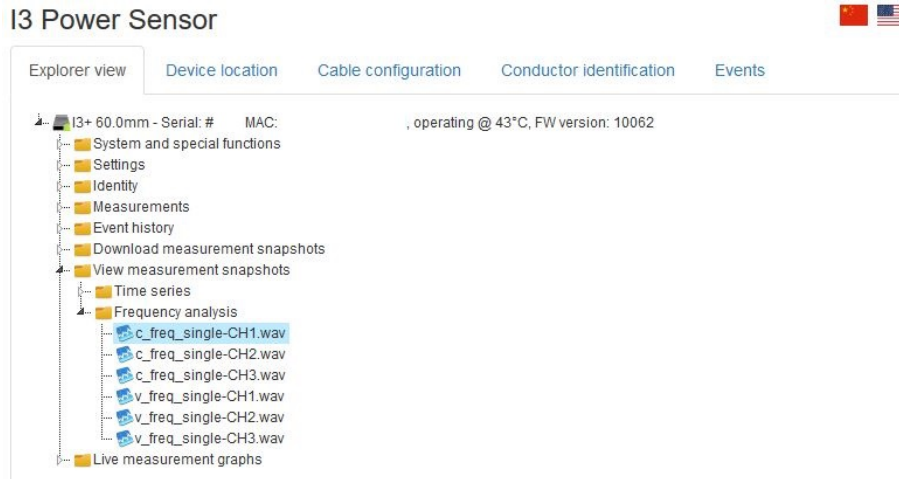

Figure 52: "View measurement snapshots" menu.

To inspect the content of an FFT, click on the wav file. "c_" is an FFT of a current channel, "v_" is an FFT of a voltage channel, "_CH1" tells you that it is channel 1. An example is shown in Fig. 53, where the FFT of a phase current is shown. Please note the possibility to remove the main harmonics - which has been applied in the example, to ease the inspection of other harmonics.
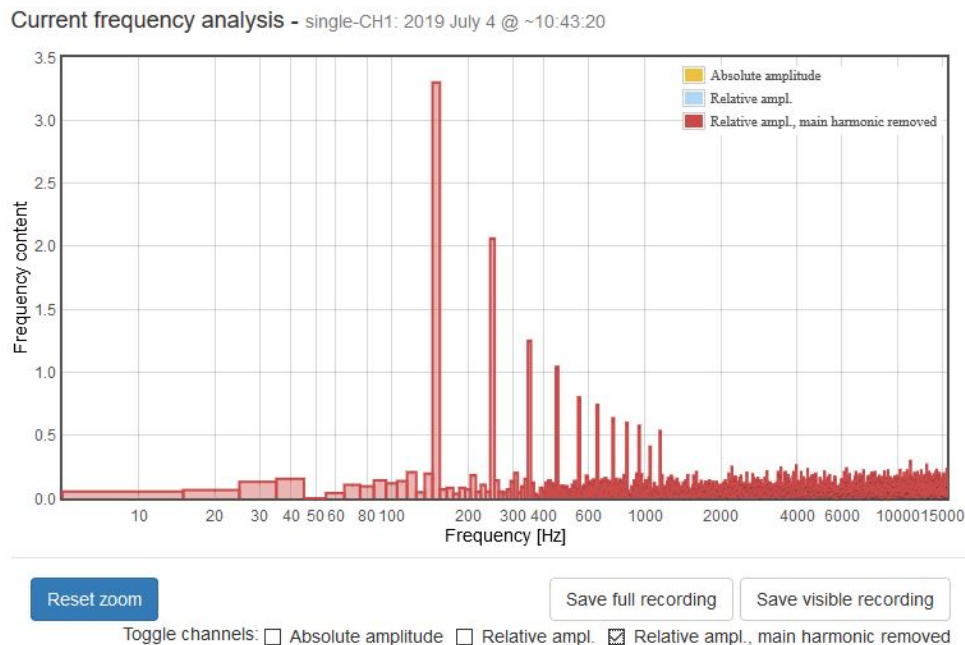
Figure 53: Example of an FFT of a phase current, where the main harmonic component has been removed to ease the inspection of other harmonics.

9.2.6   Downloading an FFT

To download a .wav file containing the most recent FFT, go to the "Explorer view" tab in the web-interface, click the "Download measurement snapshots" menu and select "Frequency analysis". See figure 54.
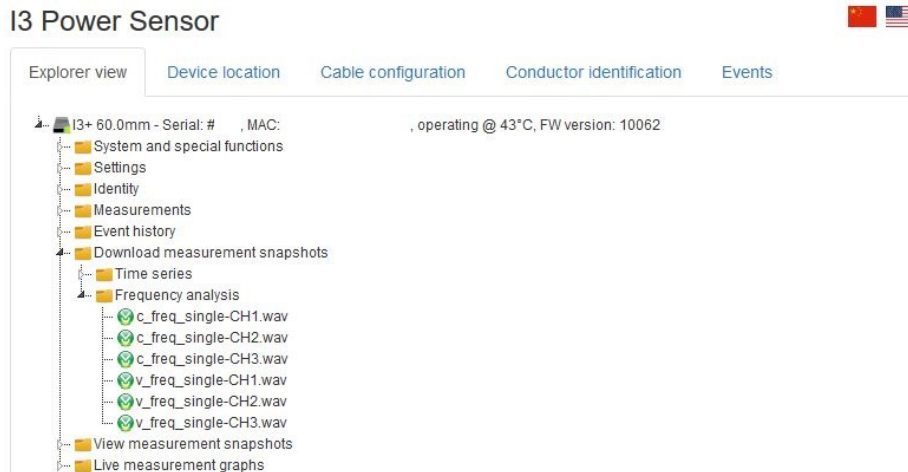

Figure 54: Example of the FFT file download menu.

9.3   Harmonics and Load Profiling

The I3 sensor has extensive logging capabilities, when **VIPH_HARM_log** is enabled a datafile is created for each measurement phase eg. voltage L1-L3, current L1-L3 which contain the first 13 harmonics and the THD according to EN50160. Also a common file is created for all voltage and current measurements of L1-L3 containing:

- RMS values of the voltages and currents

- Phase of the main harmonic voltages and currents

- Main harmonic frequency.

All data files will be updated simultaneously with a new data point containing all the before mentioned measurements. Data points are added with a time period defined in **settings → I3 → logging → VIPH_HARM_timer**. Note that, if **settings → I3 → post_processing → fft → mode** is set to **CONTINUOUS**, the harmonics are average values as described in section 9.2.3. For further information on how to configure the logging module see section 9.3.1 below.

9.3.1   Log settings

This section describes how to set up phasor and harmonics logging using the sensor web interface. Under the settings menu **settings → logging**, see Fig. 55, the following options can be found.

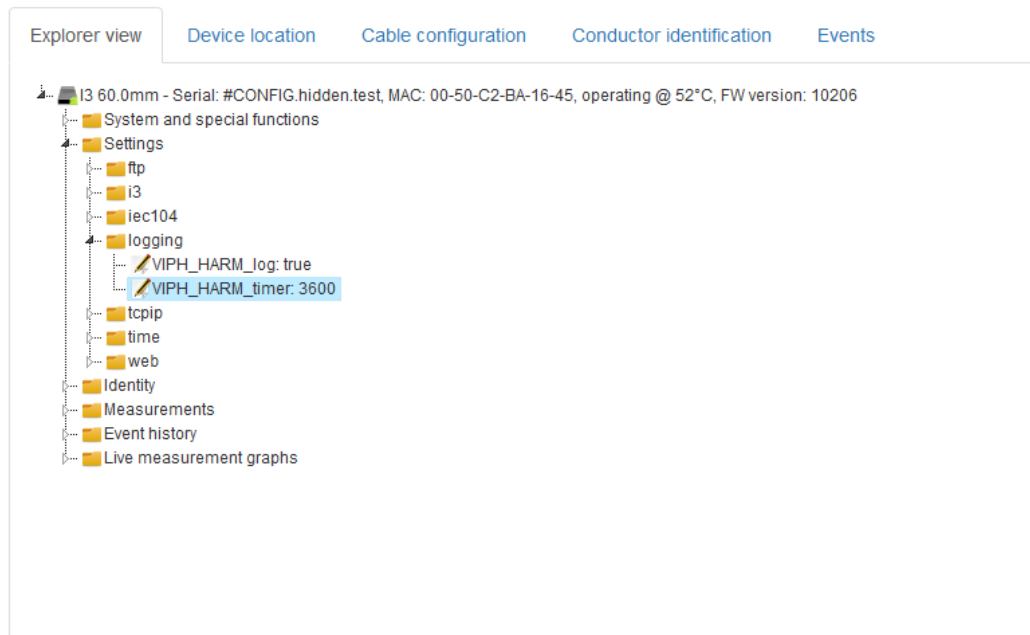| Settings Name	Possible Values
VIPH_HARM_timer	10 s to 3600 s
VIPH_HARM_log	true or false

Figure 55: Screen shot of the I3 sensor web interface, showing the phasor and harmonics log setting.

If the **VIPH_HARM_log** is set to true, the magnitude of the first 13 harmonics along with RMS and phase values of currents and voltages (phasors), will be stored in the ftp or webdav accessible folder "..service/data/", with a period equal the one defined in **settings → logging → VIPH_HARM_timer**.

9.3.2 Data file format

This section describes the file format and naming conventions used for the harmonics and load profiling data files.

File format

All phasor and harmonics datafiles uses the .csv (comma separated values) format. The csv files are stored in the folder "../service/data/" which can be acces via ftp or webdav.

Harmonics data file

The harmonics are logged in a separate file per channel, the files are named using the follow format **harmonics_voltage_L1.csv** where **_voltage_** means voltage data and **_current_** means current data. L1 means phase 1, L2 means phase 2 etc.

Thus **harmonics_voltage_L1.csv** contains the first 13 harmonics and the THD according to EN50160 for the voltage on phase L1 logged with a time period defined in **settings → I3 → logging → VIPH_HARM_timer**

RMS measurement datafile

The RMS values of voltage and current amplitudes, voltage and current phases and main harmonic frequency is logged in a common file for all channels called V_I_PH.csv this file contains all data points for phase L1 to L3 logged with a time period defined in **settings → I3 → logging → VIPH_HARM_timer**

Data handling

The data in the .csv file format can be directly imported in numerous programs eg. Excel, Matlab and Scilab and programming environments such as phyton for viewing and manipulation. The raw data is in a format similar to that showed in the below table 7.

Unix timestamp	L1(V)	L2(V)	L3(V)	L4(V)	L1(A)	L2(A)	L3(A)	...	Frequency(Hz)
1538032634	6010.18	5894.94	5895.74	0.00	30.06	31.06	23.64	...	49.9989
1538036616	6128.89	5826.18	5856.54	0.00	33.02	33.68	26.26	...	50.0008
1538040603	6151.50	5872.92	5908.19	0.00	31.61	32.50	24.71	...	50.0183
1538044597	6235.53	5847.35	5913.55	0.00	28.01	28.76	22.52	...	50.0586
1538048600	6229.24	5842.20	5882.41	0.00	33.80	36.77	26.72	...	49.9993
1538052608	6186.74	5794.01	5838.91	0.00	16.32	15.36	11.95	...	50.0050
1538056629	6230.25	5830.27	5883.82	0.00	8.85	7.83	5.86	...	50.0006
1538060654	6241.58	5841.62	5902.96	0.00	10.87	9.99	7.55	...	50.0212
1538064686	6263.79	5870.67	5912.94	0.00	10.42	9.54	7.10	...	49.9586
1538068719	6199.39	5768.83	5840.44	0.00	10.22	9.40	7.03	...	49.9869
1538072760	6206.33	5775.34	5851.85	0.00	12.66	12.10	9.22	...	50.0280
1538076808	6225.09	5799.39	5856.78	0.00	16.13	15.53	11.91	...	49.9736

Table 7: Subsection af the raw data in V_I_PH.csv.

By importing the data into for instance Excel, Matlab or Scilab data can easily be visualized to give an instant overview of the load on a line over an extended period of time. Fig. 56 shows a visualization of actual measurement data over a period of 8 days.
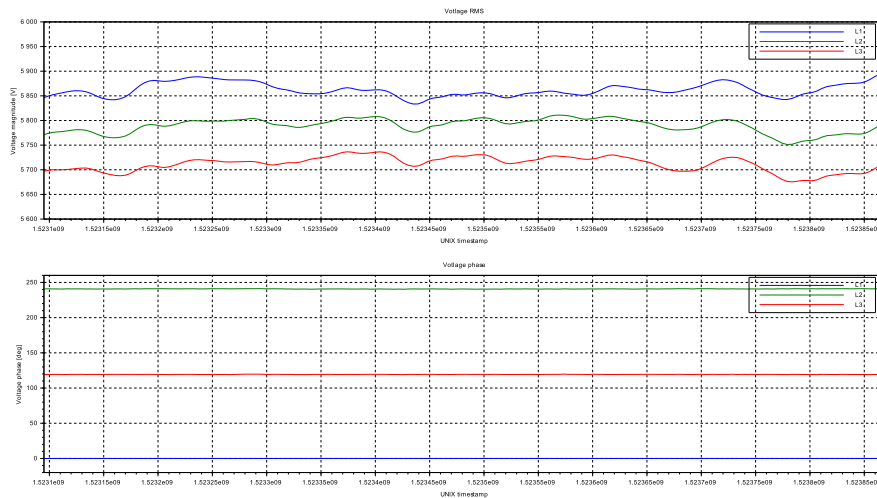
(a) Voltage data logged over an 8 days period
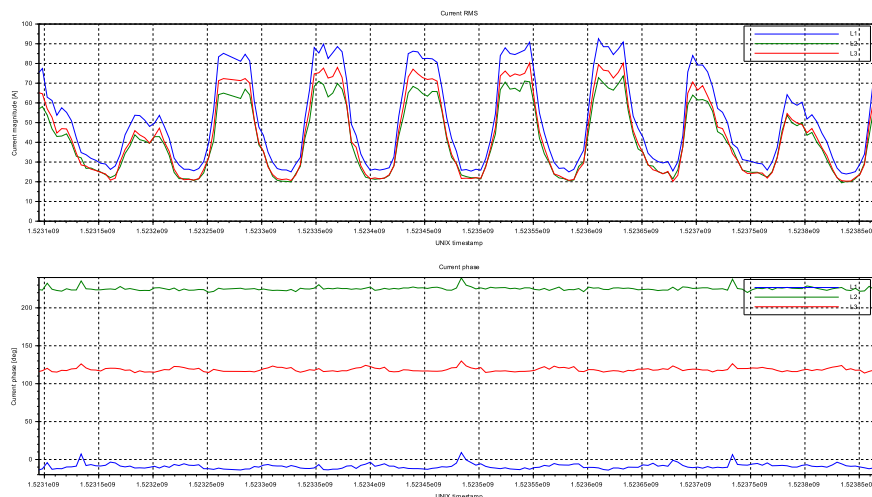
(b) Current data logged over an 8 days period

Figure 56: Using data from V_I_PH.csv one can easily get an overview of the daily, seasonally or yearly load on a cable where an I3 sensor is installed.

10 Software updates

The Jomitek I3 Power Sensor platform is in continuous development. New features are developed and existing features are improved to meet the required functionality of the future power system.
Whenever a new software is released it will be available at `http://jomitek.dk/downloads/device_software_update`, see screen shot of web page in Fig. 57. *To make sure the sensors are always up to date it is possible to get a software release notification by contacting Jomitek*. The software update file should be named "software.tar.gz", please be aware that some browsers rename the file to "software.tar.tar, in this case please manually rename the file correctly. From the software update web page the software version will be stated for comparison with the existing software on the individual sensors.
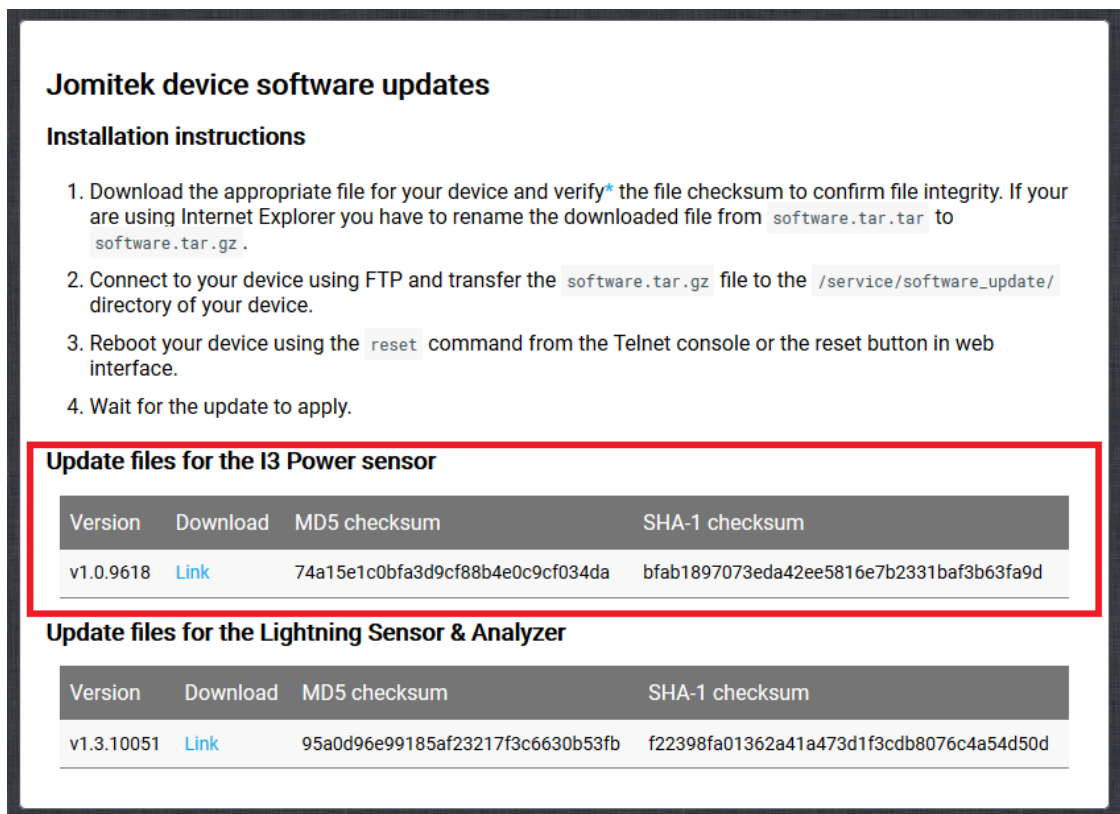It is only the newest release software update file that is available through the web page, if interested in testing beta software versions or older software versions please contact Jomitek.

Please note that the software update web page is password protected - the password and username is provided along with purchased products.

The software on the Jomitek I3 Power Sensor can be updated in four simple steps:

1. Download the newest update file from `http://jomitek.dk/downloads/device_software_update`.

2. Connect to the sensor through the FTP interface.

3. Transfer the update file, `software.tar.gz`, to the `/service/software_update` directory.

4. Reboot the sensor through the web interface and wait for the boot loading sequence to automatically apply the update. For super users please note that the sensor can be rebooted using the "reset" command through a Telnet console.

Depending on the size of the upgrade it will normally take 2-5 minutes before the sensor is fully operational. Please notice that the sensor can restart multiple times during the upgrading procedure.

Figure 57: Screen shot of the software upgrade web page.

11   Advanced user interfaces

11.1   Telnet interface

For advanced maintenance and debugging tasks, the I3 sensor can be accessed and configured via a limited command line interface using Telnet. This interface is accessed by connecting to the sensor IP address on port

23 using a standard Telnet client. It is recommended to use Putty[6] which is open source and free to use.

Be sure to enable the 'Implicit CR in every LF' and 'Implicit LF in every CR' options when configuring Putty.

A list of applicable Telnet commands for the I3 sensor is listed by typing 'help' in a Telnet terminal, when connected to a sensor.
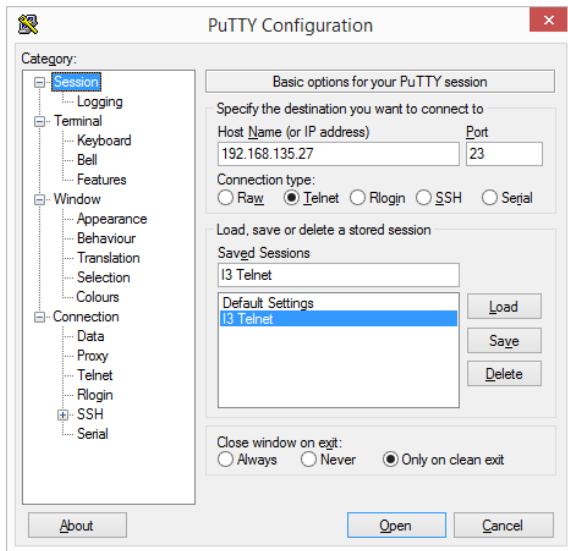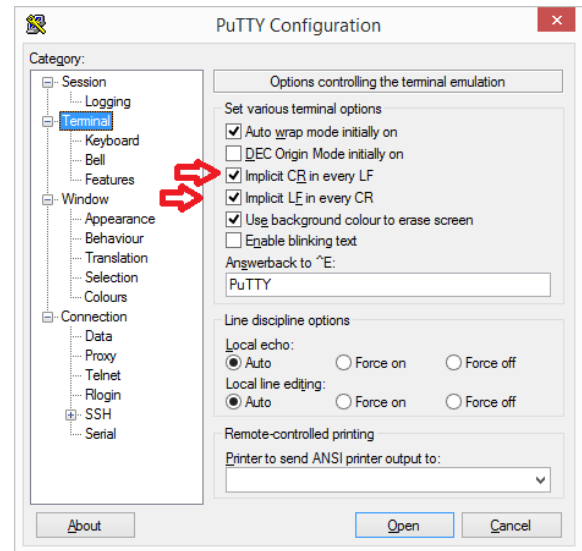

Figure 58: Putty Telnet Session configuration.

Figure 59: Putty Telnet Terminal configuration.

Figure 60: The Telnet command line interface.

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[6]http://www.putty.org/

11.2   FTP interface

The internal memory on the Jomitek I3 Power Sensor can be accessed via the FTP protocol on port 21. Use an FTP client program (e.g. FileZilla[7]) and sign in with username and password.

When connected you will have access to four folders.

- The `conf` folder where configuration files and scripts are stored.

- The `software_update` folder where software update files can be uploaded.

- The `log` folder where various log files are placed by the sensor system.

- The `data` folder where FFT logging files, event recordings and snap shot wave files will be stored.
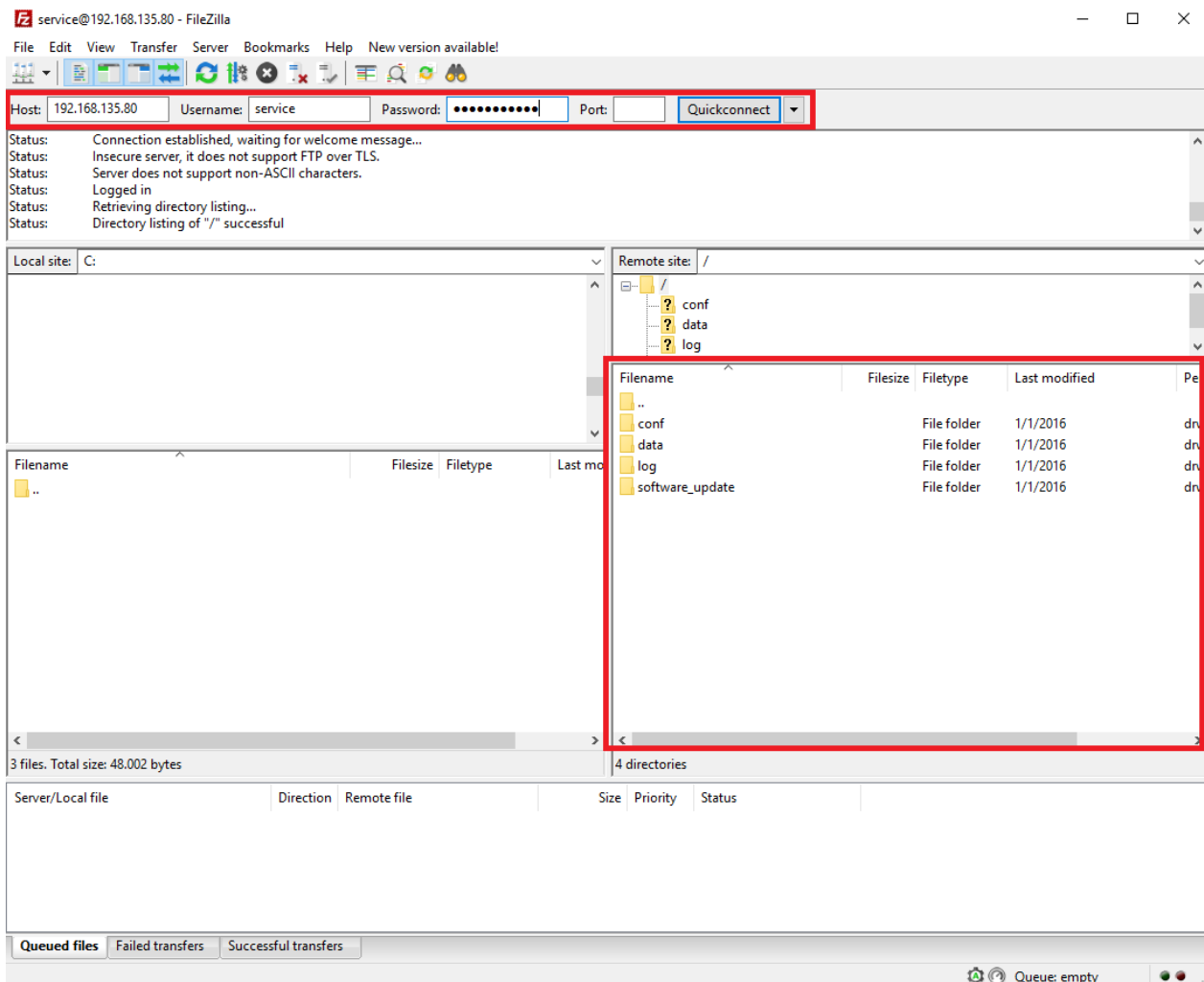

Figure 61: FTP connection to the I3 sensor shown with the FileZilla FTP client.

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[7] `https://filezilla-project.org/`

12   Advanced mass reconfiguration and service

12.1   Mass reconfiguration

The '*conf/identity.conf*' and '*conf/settings.conf*' files play a central role in the configuration and customization of a specific sensor. To enable efficient mass reconfiguration of sensors, it is vital to be able to update information for a selected group of the sensor base, or update a specific setting across all sensors without the need to retrieve, edit, and upload configuration files on a case by case basis.

These needs can be efficiently addressed using the Jomitek Mass Reconf Tool and underlying functionalities. In addition to the above mentioned *.conf* files, the sensor continually checks for updates to these files in the form of a *.reconf* variant ('*identity.reconf*' and '*settings.reconf*'), which allows incremental update of specific parameters in the *.conf* files, without affecting the remaining parameters.

The end user may choose to use their own tools to generate Lua formatted '*.reconf*' files for large scale sensor management, or as an alternative use the functionality provided in the Macro enabled Excel sheets, which can be downloaded from http://jomitek.dk/en/downloads/tools/.

Please read the User Manual-sheet in the Excel document carefully, and note the need for the WinSCP[8] tool when distributing '*.reconf*' file updates automatically.

12.2   Operational overview and service

Using the 'Jomitek Device Locator'[9], an overview of all the sensors within a given subnet can be created, using the 'Overview' tab. Using a UDP broadcast, the tool force all sensors to reply with a few basic pieces of information, such as the MAC address of the device, as well as the physical configuration, serial number and firmware version.

Note, depending on the network architecture used, that large subnets may result in failed discovery of part of the sensor base, due to data packages being discarded. Please contact Jomitek with information on the number of sensors, and network architecture used, should this be experienced. Then assistance will be provided.

The Jomitek Device Location incorporates a few simple management tools for the individual sensor in the form of the 'Web' tab and the 'Communication' tab. The 'Web' tab automatically loads the web page of a sensor selected (double-clicked) in the 'Overview' tab. The 'Communication' tab features a split screen command line interface to the selected sensor, where Telnet or Lua terminal commands may be entered.

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[8]http://winscp.net/
[9]http://jomitek.dk/downloads/tools