WAMSTER

AD HOC PHASOR MEASUREMENT NETWORK

WAMSTER PDC QUICK START MANUAL

STUDIO
ELEKTRONIKE
RIJEKA

STERPMU
PORTABLE PHASOR MEASUREMENT UNIT

CE	Mark on your equipment certifies that this equipment meets the requirements of the EU (European Union) concerning safety and interference causing equipment regulations

Document Revisions Record

Revision	DESCRIPTION OF CHANGE	APPROVED BY	DATE APPROVED
1.1.2508	Initial revision, extracted WAMSTER PDC into a separate manual.	DB	2016-09-26

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1   Wamster Overview

1.1   WHAT IS WAMSTER?

WAMSTER is a synchrophasor measurement and storage system which includes all equipment necessary to create an ad-hoc PMU wide-area network. PMU devices are designed with portability and quick deployment in mind, while the concentrator server provides easy web access, event triggering and data export.
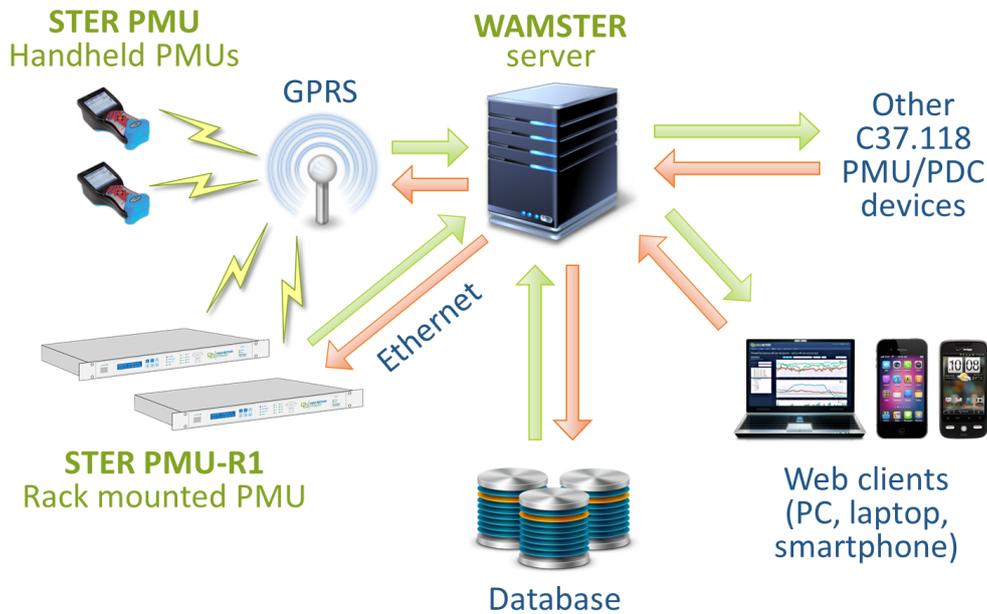

Figure 1.1: Wamster overview

1.2   WHAT ARE THE BENEFITS?

Compared to a classic PMU/PDC system, WAMSTER allows less networking infrastructure, reduces management costs and speeds up deployment.

PMU devices are available in two form factors:

- Handheld **STER PMU** devices, with magnetic support, typically deployed within 15 minutes of arrival on site by attaching to a cabinet, used for quick ad-hoc WAM setup, or
- Rack mounted **STER PMU-R1** devices, providing dual communication links (C37.118 over Ethernet + WAMSTER over GPRS), for permanent substation installation.

Custom communication protocol adapts the reporting speed to network conditions, and adds bidirectional communication to allow retrieving historical data from STER PMU's local memory in case of network outage. STER PMU devices are equipped with local flash memory (32GB default) which allows local storage of synchrophasors, as well as extended data (oscillograms, harmonics).

WAMSTER components are also compatible and interoperable with other equipment: STER PMU devices are IEEE C37.118 compliant and can work in Ethernet or serial mode like a standard PMU device. Also, WAMSTER server can be configured to accept or forward data with other PDCs and customer devices in both server and client C37.118 modes.

With WAMSTER, there are no hidden costs: all the equipment necessary to start measuring and transmitting data (apart from a SIM card) is included with each device: cables, clamps and measurement transformers, GPS clock for time synchronization, GPRS/UMTS or Ethernet modem, and other auxiliary equipment. Storage is provided as a service, removing the need for on-site PDC equipment or communication infrastructure.

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1.3   WHO SHOULD USE WAMSTER?

Apart from standard C37.118 PMU use cases, due to the use of ubiquitous mobile networks for data transmission, WAMSTER is ideal for projects involving synchrophasor baselining and model research and estimation at geographically distributed locations, where hard-wired networking is not feasible. Wired networking requires substantial planning effort, as well as security considerations, especially when reusing existing networking infrastructure.

Projects with quickly changing requirements and locations will benefit from quick deployment, while small and midsize R&D teams can utilize various online analysis capabilities. Online web access to the data and e-mail event reporting is especially useful when working with larger and distributed teams.

WAMSTER is a cost effective solution for academic research and education, where removing the need for networking infrastructure and PDC equipment is of great benefit as well.

1.4   ROLE OF WAMSTER IN AD-HOC WAM SYSTEMS

Deregulation of markets and sustained growth of the need for electrical energy has resulted in an increase of competitiveness of electrical energy production, transmission and distribution environments. As a result, operating points of these systems are being shifted towards the stability margin, leading to the increasing complexity of control systems. Additionally, the dispersion and decentralization of production facilities that is occurring in efforts to increase the share of renewable energy sources has led to conditions that are very different from those that were in effect at the time of design and construction of existing power systems. As a consequence, negative interactions between individual, often geographically distant parts of the system, give rise to various problems, causes of which are very difficult to determine using conventional measurement methods which rely on disturbance detectors and PQ measurement devices.

WAM (wide area measurement) based systems, based on synchronized phasor measurements, provide an alternative solution. To provide measurements synchronized in time, each measurement device (a PMU; phasor measurement unit) is equipped with a source of accurate time, based on the GPS (global positioning system) signal. The uncertainty of this time-base is in order of a few microseconds, which in most cases has a negligible impact on the quality of the measurement results. Due to the small error, all the measured results can be considered as unambiguously defined in time. This facilitates tracking of the disturbances through the entire system covered by the network of PMU devices. Additionally, PMU devices measure the "absolute" phasor angle, allowing the immediate calculation of phasor angle differences at remote locations during transient conditions. This allows PMU based systems to provide much more accurate insight into the state of the system.

WAMSTER system takes a step further by simplifying the installation and deployment of the WAM network of PMU devices:

- Lightweight, portable, battery-backed STER PMU devices can be used to simplify installation, instead of rack-mounted PMUs. Ethernet connection is replaced (if needed) with the GPRS/UMTS connection, allowing them to be deployed easily with no need for additional communication infrastructure.
- STER PMU-R1 rack mounted devices provide Ethernet and GPRS/UMTS links simultaneously, allowing even greater interoperability with existing equipment.
- WAMSTER provides its own infrastructure for storage and analysis of the distributed measurements as a service, removing the need for installation and maintenance of dedicated concentrator equipment.
- WAMSTER web application provides remote device monitoring, real-time measurement visualization, comparison and analysis of measured data, event triggering configuration and data export. Web server makes the data accessible from any web-enabled device, with no need for additional plugins or local software installation.
- WAMSTER PDC can integrate with other systems to forward data from STER PMUs, or accept data for better online analysis.

These characteristics give WAMSTER a unique opportunity: to create ad-hoc WAM systems based on the technology of synchronized phasor measurements.

2 Communication over unreliable networks

2.1 INTRODUCTION

One of the main benefits of Wamster is the possibility of using **unreliable GPRS/UMTS networks** as the communication channel, at locations where additional communication infrastructure is unavailable.

There are several system features which work cooperatively to make this feasible, some of them already mentioned in the introduction:

- PMU devices are equipped with **non-volatile (flash) memory** capable of storing 4 months of data locally while communication is offline (or several days of data when continuous waveform recording is enabled).
- Device is powered with **rechargeable batteries**, allowing up to 4 hours of autonomy during power outages. Modem is also supplied through the device, allowing the communication to work during blackouts.
- Each PMU device always stores data locally at full resolution for the specified grid frequency (50 or 60 fps). However, **transmitted frame resolution can be adjusted** to meet user needs and current communication conditions, as requested by the server or a user.
- If one of more frames is dropped during communication, Wamster communication protocol allows the WAMSTER PDC to negotiate resolution and request those frames from the device's local memory. The same principle is used to fill missing data if the default reporting speed is lower.
- Full resolution frames, including the waveform snapshot, are also **automatically requested by the PDC** whenever an event is detected, in order to speed up the analysis process.

This chapter describes communication layer internals.

2.2 MOBILE LINK COMMUNICATION CYCLE

Contrary to the usual C37.118 link, where the PDC initiates the connection towards a PMU, WAMSTER PMU communication cycle starts with the device connecting to the configured TCP socket on the Wamster PDC. This removes the need to configure static IP addresses/port forwarding for PMU devices.

On the top of the Wamster communication module sits the TCP/IP layer, which handles incoming connections from all PMU devices. Whenever a device is connected, it immediately transmits its settings and handshake information, including its ID, firmware version, selected grid frequency, current GPS location and various internal log messages. This data allows server to determine device status, prepare the processing pipeline, or discard the connection if needed.

During this connection phase, Wamster server queries the database about any missing (not received) synchrophasor frames for the last 24 hours (by default), and prepares data parsers for the specified protocol type and version. After several received frames (in order to determine actual network throughput), Wamster will request missing frames from the device at the resolution configured by the user for the specified device.

Whenever a connection is dropped, device will continue measuring and storing data locally. As soon as the connection is reestablished, server will request all frames that weren't received during the network outage.

2.3 ADAPTING TO NETWORK CONDITIONS

Wamster automatically adapts the default reporting speed for historical or real-time frames in three cases:

- Whenever an event is detected, Wamster requests the device to resend frames for the pre- and post-trigger time range at full resolution, and notifies the user about the event. Oscillograms are also collected if Continuous Waveform Recording is enabled on the device.
- User can compare full resolution measurements for two PMU devices through the web interface. Wamster will send a request to both devices to increase their reporting speed to 50/60 fps while the analysis is active.
- If network conditions don't permit the device to transmit synchrophasors at the user configured transmit resolution for a longer period of time, Wamster will automatically gradually decrease real-time reporting

speed until conditions improve or it reaches the minimum speed (1 fps). When network conditions improve, Wamster will again recollect all frames stored with lower resolution to meet the user specified speed.

For high-speed Ethernet connections, default reporting resolution can be set to nominal grid frequency (50 or 60 fps), in which case detailed synchrophasor data will be available immediately.

2.4   REMOTE FIRMWARE UPGRADE

Wamster communication protocol also allows device firmware to be upgraded remotely, over the GPRS network. This is especially important for customers who want custom protocols added to their devices, as it allows central upgrade of all devices in the field, without the need for physical access to devices.

It typically takes less than a minute to transmit the firmware over a GPRS connection and reinitialize the device.

2.5   ETHERNET LINK

STER PMU-R1 rack mounted devices provide an Ethernet port which can accept 2 simultaneous C37.118.2 connections from any C37.118.2 compatible upstream PDC device. This link operates independently from the GPRS link to the WAMSTER PDC server, and has a higher priority to reduce transmission latency. WAMSTER link still allows easier remote management, retrieval of oscillograms, and the use of WAMSTER web interface.

If Ethernet is available on site, STER PMU portable devices can also use Ethernet instead of GPRS for a standard C37.118.2 connection to a standard PDC device, or as a more reliable, higher bandwidth link to the WAMSTER PDC server.

3 Event Triggering Overview

3.1 EVENT TRIGGERING IN WAMSTER

Common reasons for the creation of ad-hoc WAM system can be divided into:

- **Baselining survey measuring:** used to assess system state through the establishment of statistical indicators of key quantities in various operating modes of the system. An example of one such project is the collection of preliminary insights into system variations under normal operating regimes, in the design stage of advanced WAMPAC systems.

- **Troubleshooting measurement**: aiming to illuminate the conditions during problematic occurrences in the system. In doing so, the detection problem is usually performed on the basis of a hypothesis about the possible cause of the issue, which uses the measurement system to either confirmed the hypothesis, rejected it, or indicate that the focus of the research should be redirected to a different area.

In both cases, it is necessary to process a large amount of generated measurement data. **Event triggering** system is the part of WAMSTER system which facilitates and accelerates the arrival of new information about the dynamic changes in the system through continuous data processing and user parameterized processing algorithms.

3.2 HOW DOES EVENT TRIGGERING WORK?

Event triggering system is a component which continuously runs and analyzes synchrophasor measurements according to a set of user defined (parameterized) processing rules. Whenever a processed quantity or a comparison of multiple quantities exceeds a defined threshold value, an event is generated and stored in the database.

For devices operating at reporting speeds lower than the full sync resolution (50/60 Hz), whenever an event is detected, Wamster sends requests to all referenced PMU devices to collect surrounding synchrophasor data (5 seconds before and after the event) at full sync resolution (50 or 60 Hz, depending on the grid frequency). This action simplifies and accelerates later event analysis for the end user. These requests are added to a lower priority queue, to prevent interfering with real-time measurements in low network conditions. The interaction between the Wamster core collecting system and the Event triggering subsystem is presented in the Fig. 1.1.
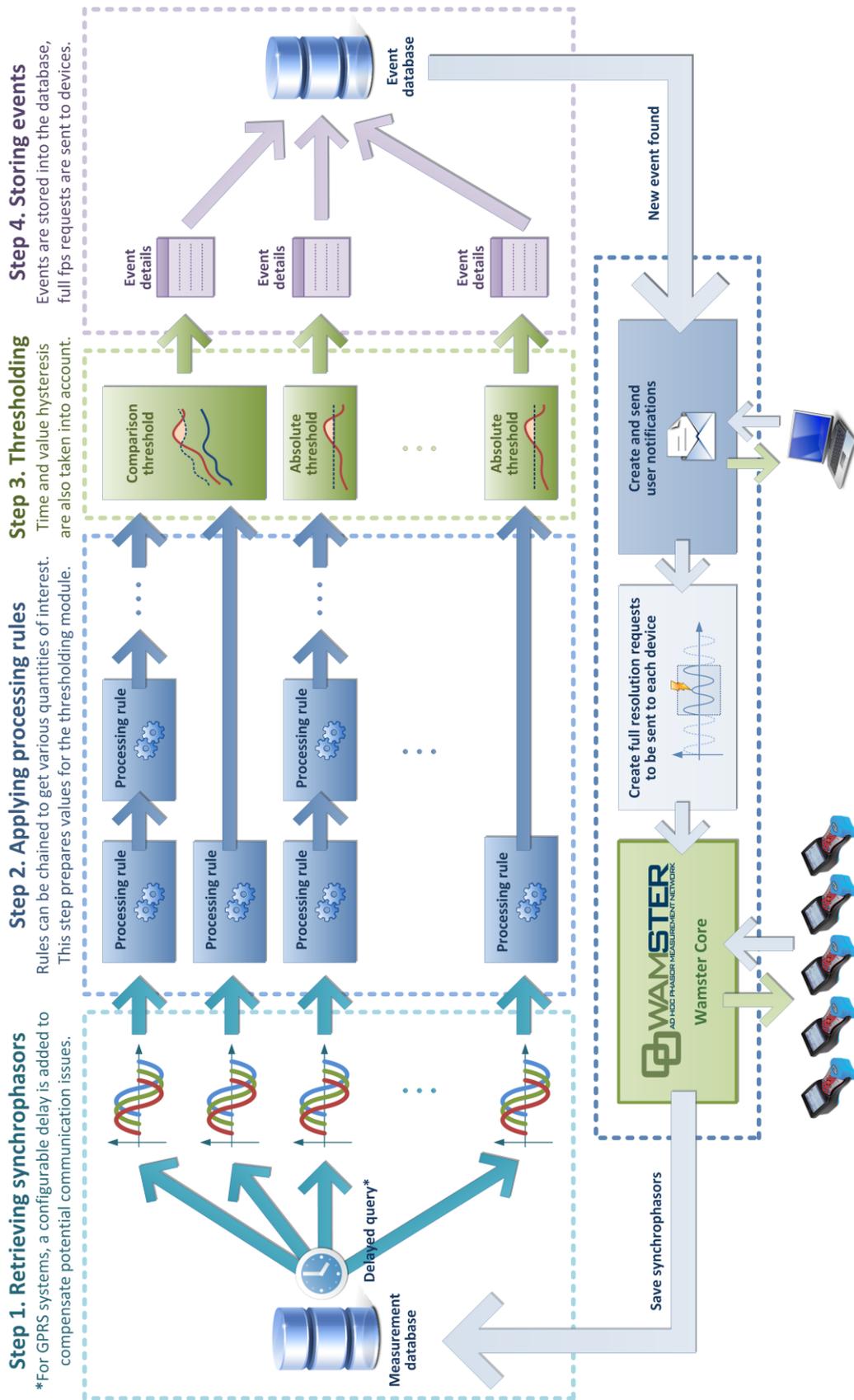
Step 1. Retrieving synchrophasors

*For GPRS systems, a configurable delay is added to compensate potential communication issues.

Step 2. Applying processing rules

Rules can be chained to get various quantities of interest. This step prepares values for the thresholding module.

Step 3. Thresholding

Time and value hysteresis are also taken into account.

Step 4. Storing events

Events are stored into the database, full fps requests are sent to devices.

Event database

Event details

Event details

Event details

New event found

Create and send user notifications

Create full resolution requests to be sent to each device

Comparison threshold

Absolute threshold

Absolute threshold

Processing rule

Processing rule

Processing rule

Processing rule

Processing rule

Processing rule

Processing rule

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Save synchrophasors

Delayed query*

Measurement database

Figure 3.1: Wamster Event triggering system overview

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4   Using the Wamster web interface

After the device has connected to the server, it can be monitored and managed through the Wamster web interface.

Wamster web interface provides a simple way to monitor and configure your device, as well as download (export) measured data from the cloud storage.

4.1   MINIMAL CONFIGURATION

To access the Wamster, you will need a web enabled device (personal computer, a tablet, or a smartphone) with an installed web browser and JavaScript enabled.

Although Wamster uses standard-compliant web technologies in order to support a wide range of Internet browsers, some browsers (like Microsoft Internet Explorer prior to version 10) do not fully conform to www standards. While they are officially supported by Wamster, using one of the following browsers is recommended for safety, speed and better browsing experience (newest download links shown for each browser):

- Google Chrome 9 or newer: www.google.com/chrome
- Mozilla Firefox 3.6 or newer: www.getfirefox.com
- Microsoft Internet Explorer 10 or newer: www.microsoft.com/windows/downloads/ie
- Opera 10 or newer: www.opera.com/download
- Apple Safari 5 or newer: www.apple.com/safari

4.2   SIGNING IN TO WAMSTER

To access the web interface, visit www.wamster.net/users using a web browser of your choice. If you were not previously signed in, you will be asked for your credentials.
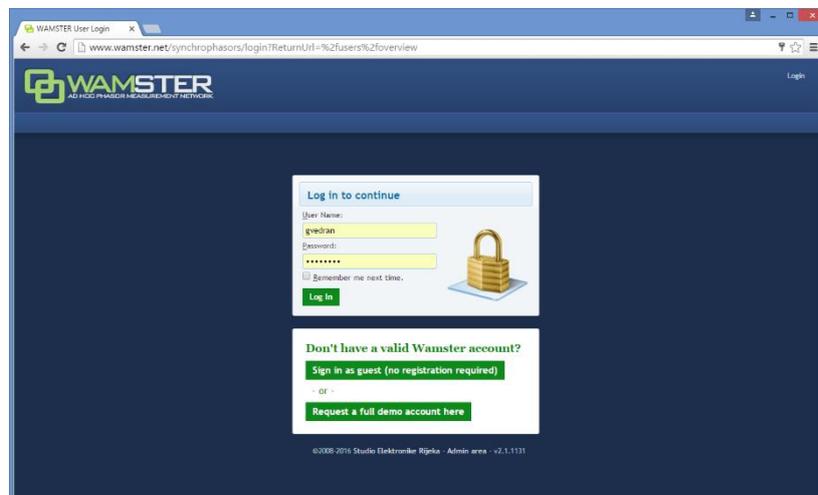

Figure 4.1: Authentication form shown when accessing Wamster

In order to sign in, you will need a username/password combination provided to you via e-mail. If you enter an incorrect password several times, your account may be locked out. If you believe your account has been locked, or have any troubles signing in, please contact us at support@wamster.net to resolve this issue.

If signed successfully, you will be redirected to the **Overview** page. Navigation menu will be changed to include advanced options, and user status will be shown in the upper right corner:
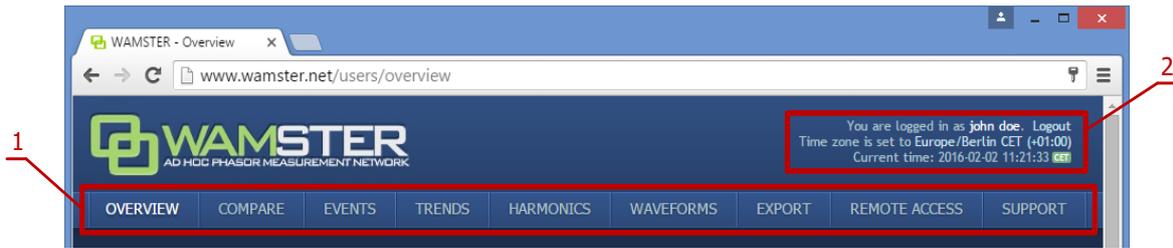
Figure 4.2: User area: 1. navigation menu, 2. login status / Logout link / Time zone settings

After logging in, at the top of each Wamster there is the navigation menu (marked with 1 on the figure above), providing access to different pages, and the user status/time area (marked as 2).

To log out, click the Logout link button in the upper right corner of the web page. This area will also show current server time, shown in your browser's reported time zone. To use a custom time zone, click on the zone name in the upper right corner to show a list of zones. This setting is stored as a site-wide cookie and is respected across the entire Wamster site.

If your local browser's time differs by more than 5 minutes compared to the server time, it will be shown in red to indicate that you need to synchronize your local time. Having your local clock synchronized with the server improves Wamster experience when examining online trends and comparing devices.

4.3   OVERVIEW

First navigation item and the default page after logging in is the Overview page, which shows a general overview of your devices. Statuses and management options for individual devices registered under your username can be seen, as shown on the figure:
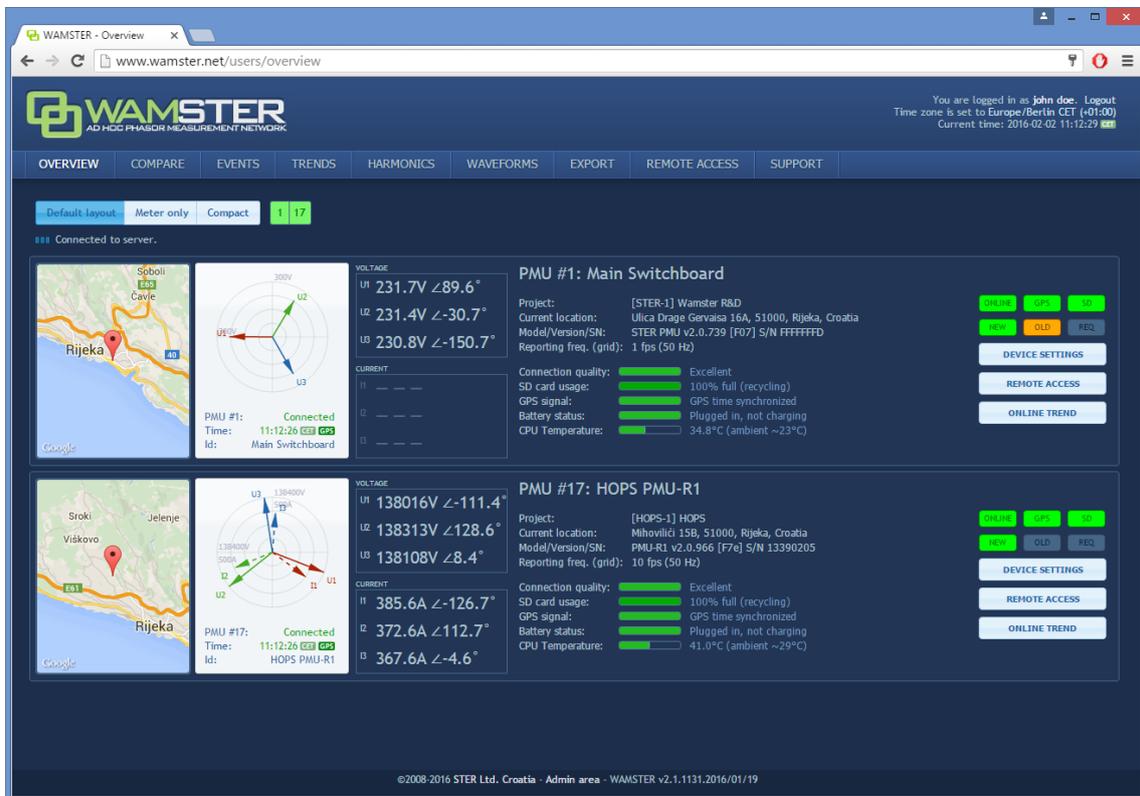

Figure 4.3: Overview page, showing devices for the currently logged in user

Measurements from multiple devices shown in the Overview page are **not** displayed with a synchronous timestamp, i.e. each device can have a different timestamp depending on network conditions. To perform a synchronized comparison, use the **Compare** or **Map** pages, described in the following chapters.

For each device there is a separate panel showing various status indicators:

- phase diagram with voltage and current vectors displayed (updated in near real-time),
- map indicating device's current location, as reported by its GPS device,
- device ID and custom name
- address, as reported by its GPS device
- device model, serial number and firmware version
- nominal grid frequency [Hz] and current reporting speed [fps]
- connection quality, SD card usage info and GPS signal information

On the right side of each panel, there are several visual status indicators and buttons for accessing device settings:

Figure 4.4: Visual status indicators and command buttons

Visual status indicators and command buttons:

1	Status indicators	First row of indicators shows statuses:
		- ONLINE: when green, device is connected - GPS: when green, GPS reliable - SD: when green, SD card inserted and functional Second row of indicators blink to indicate that the communication is live: - NEW: if green, up-to-date synchrophasor frame received - OLD: if orange, frame has been received from instrument's local memory - REQ: if orange, there is a pending request for old frames (either because of a bad data connection, or because user requested frames at a different reporting rate)
2	Device Settings button	Clicking on this button opens the Device Settings form, which can be used to configure the device
3	Remote Access button	Clicking on this button shows the Remote Access page, which can be used to connect to the instrument and operate it remotely
4	Online Trend button	Clicking on this button shows the Trend page in Online mode, with this device selected. This allows users to quickly get a recent measurements trend (last 5 minutes).

To change the custom name of a device and its reporting frequency, click on the Device Settings button to open the Device Settings form.

Depending on granted user access privileges, some buttons might be disabled (grayed-out). Users usually have administrative access rights for their owned devices, but may also have read-only devices from STER for reference or demonstration purposes.

4.3.1   DEVICE SETTINGS FORM

Device Settings form is the central place for changing all user applicable device settings. At the top of the dialog (shown in figure 6.5) there are tabs which are used for switching between various settings panels (marked as 1 in the figure).
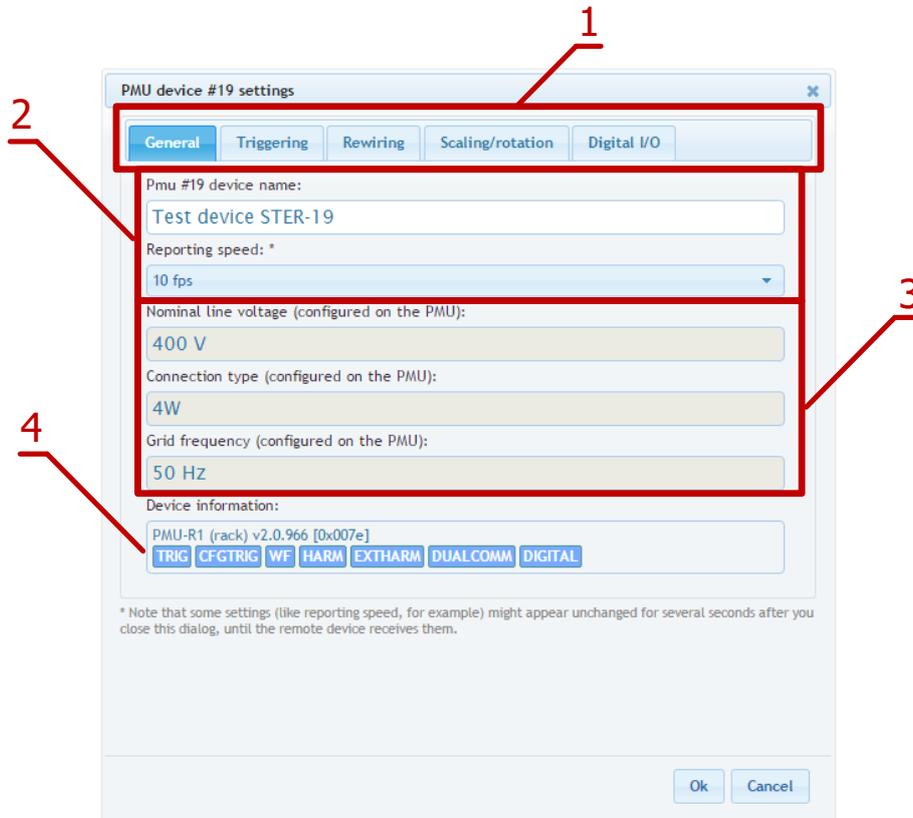

Figure 4.5: Device Settings form can be used to change the various device settings

4.3.2   GENERAL SETTINGS

Fields marked with (2) on the image are used to change device's name and reporting speed.

Reporting speed is the default number of data frames per second that this device should send to the server, under normal operating conditions. During triggered events, or on user request, server can automatically increase this value to get full resolution (synchronized) historical data from the device. Likewise, when mobile network conditions are inadequate, server can temporarily reduce the real-time reporting speed until the connection permits the user specified reporting speed.

> To learn more about the Wamster communication protocol, please consult online manuals and whitepapers at www.wamster.net, specifically the Wamster System Implementation Details whitepaper. Additional whitepapers, datasheets and catalogs can be found at www.wamster.net/w2/features/wamster-whitepapers-datasheets-catalogs.

Settings marked with "3" (Nominal line voltage, Connection type and Grid frequency) cannot be changed online, they are configured on the PMU and sent to Wamster. Note that Nominal voltage is always specified as *line* voltage, regardless of the connection type.

Final group in this tab, marked with "4", indicates the type of your PMU device, its firmware version, and currently enabled functionalities:

1	TRIG	**Triggering**: Device supports local triggering with fixed (PMU side) thresholds. PMUs with local triggering detect several event types and report them to the server, which then requests these

		data frames at full resolution for further processing. This allows the user to lower the default reporting speed while still getting sub-second events when they happen.
2	CFGTRIG	**Configurable triggering**: Device supports local triggering with configurable (server side) thresholds. This is an extension of the TRIG functionality, where thresholds can be configured inside the device settings form. If this option is not enabled, device used default thresholds (+/- 10% Voltage, +/- 0.1 Hz frequency).
3	WF	**Waveform Recorder**: Device performs continuous 8-channel waveform (oscillogram) recording. If this functionality is enabled, the device will continuously record waveform data and store it locally (4.5 days of measurements on 32GB cards). It will also reserve most of the external SD card memory for oscillograms, so local PMU data will also be kept for 4.5 days (32GB). During events, or on user request, oscillograms will be downloaded to the server.
4	HARM	**Harmonic Aggregates**: Device records 10-minute harmonic aggregates (min, max, avg) for all channels, for up to 30th harmonic + THD. If this functionality is enabled, server will automatically retrieve harmonics at the end of each aggregation period. This functionality uses internal flash memory to store 10-min aggregates for the period of 17 hours.
5	EXTHARM	**Extended Harmonics**: Improved harmonics recorder, stores 10-min aggregates for the last 17 days.
6	DUALCOMM	**Dual Communication Module**: Device is equipped with a communication module capable of simultaneously transmitting data using two protocols (WAMSTER and C37.118), to different targets, Ethernet + GPRS. This feature is useful when the project requires simple integration with standard C37.118 PDCs, but additional Wamster features also need to be utilized.
7	DIGITAL	**Digital I/O**: PMU device is equipped with digital inputs and outputs, which can be monitored and activated from the Wamster server programmatically.

Some settings (like reporting speed, for example) might appear unchanged for several seconds after the dialog is closed, until the remote device receives them.

Note also that the form contains Measurement setup settings intended to allow post processing (scaling and phase swapping) of signals. This feature is currently reserved for future use and can be enabled on request.

4.3.3   LOCAL TRIGGERING

If the PMU device supports the CFGTRIG functionality, Triggering tab can be used to configure local thresholds, as shown in the figure below. Each triggering rule can be enabled or disabled separately by selecting the checkboxes above low/high threshold input boxes.

Figure 4.6: Triggering tab enables configuration of local (PMU side) event triggering

Thresholds for voltage-related quantities is specified as p.u. (percent of nominal value), where the nominal value is configured on the device and can be seen on the General tab.

> Local triggering thresholds are separate from Wamster's event triggering system (which is applied to incoming measurements). These settings are uploaded to the PMU device so that the device itself can perform them locally, on synchronized data, and report detected events to Wamster. **Additional information about the PMU local triggering system can be found in the chapter** Error! Reference source not found. *Error! Reference source not found.*.

4.3.4 REWIRING RULES

Using the Rewiring tab, each of the 8 input channels (U1-U4, I1-I4) can be rewired (routed) to a different channel, or disabled (disconnected):
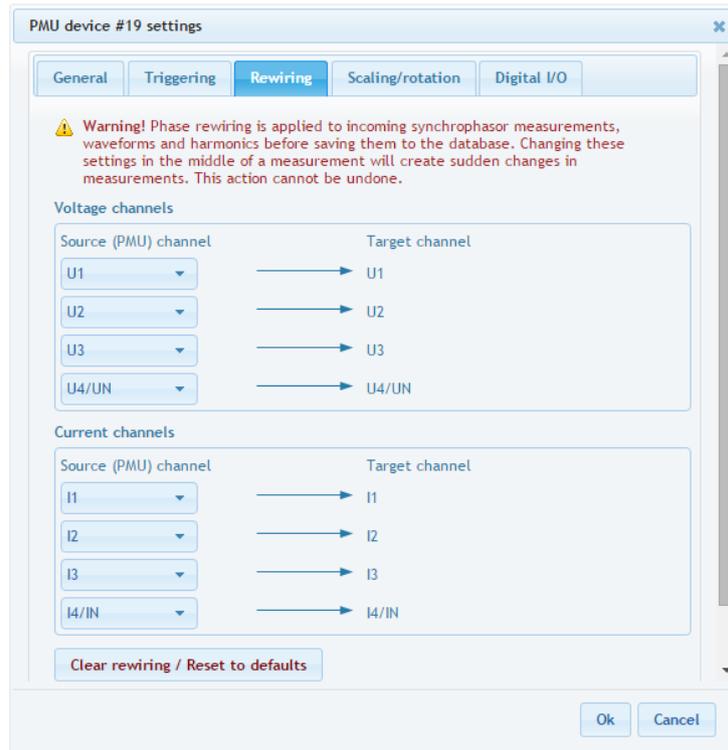
Figure 4.7: Using the Rewiring tab, it is possible to disable certain channels, or correct incorrect wiring and rotation

Rewiring is applied to all incoming measurements, including synchrophasors, waveforms and harmonics. A single source channel can also be duplicated, i.e. routed to multiple different target channels, each of which will act like a separate channel for analysis, triggering or export. To quickly clear all rewiring rules to default, use the Clear rewiring / Reset to defaults button at the bottom of the panel.

It is recommended to hide channels which are not physically connected anywhere, by setting their source to *Not connected*. Unconnected channels can pick up noise, so disconnecting them through the interface will make analyzing other channels easier and more readable.

For more complex scaling and rotation corrections, the Scaling/Rotation tab can be used, but rotation (phase angle) corrections on that tab are applied only to synchrophasors data.

4.3.5   SCALING/ROTATION SETTINGS

To add different scaling or apply phase angle corrections to each channel, use the Scaling/Rotation tab.

Input channels in the Scaling/Rotation tab are rewired output (target) channels from the Rewiring tab, not actual channels from the PMU device.

Scaling settings (along with rewiring on the previous tab) are applied to all measurements, but rotation settings (angle corrections) are **only applied to synchrophasors**. Harmonic aggregates and oscillograms (waveforms) are not affected by these settings. This can result in inconsistencies between measurements and must be taken into account when analyzing waveform data collected from the PMU device.
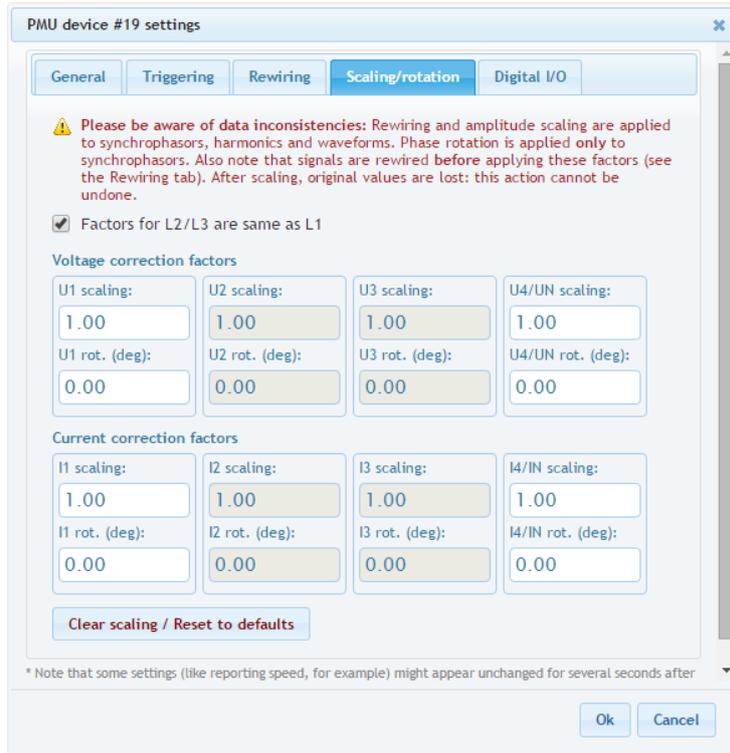
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Figure 4.8: Scaling/rotation tab can be used to further correct measurements after rewiring

If factors for phases L2 and L3 are same as L1, user can mark the checkmark at the top of the panel and only enter values for phase L1. Fourth channel (U4 or UN) settings are always applied separately.

> If phase correction angles are a multiple of 120 degrees, consider using the rewiring tab instead of entering values in degrees, to get the correction applied to harmonic and waveform channels, as explained in the previous chapter.

4.3.6   DIGITAL I/O

If the PMU device contains digital inputs and outputs, it is possible to view their status and manually change output values using the Digital I/O tab. Depending on the device type, different number of inputs/outputs may be shown:
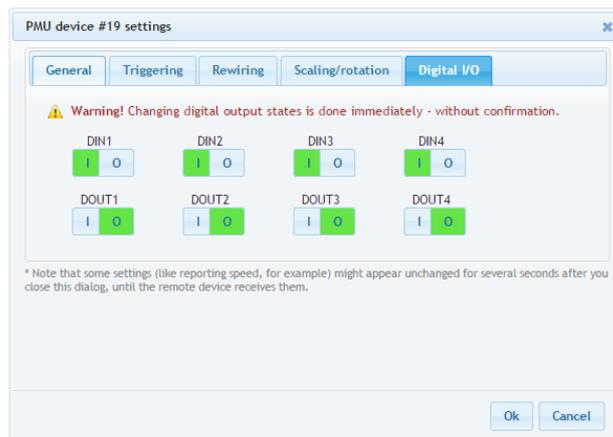

Figure 4.9: Digital inputs and outputs can be controlled using the last tab

4.4   SYNCHRONIZED COMPARISON

To compare real-time synchrophasors of your devices with a synchronized timestamp across all devices, use the **Compare** page, accessible from the navigation menu. Depending on the network conditions, this page will show measurements with a certain delay to ensure phasors from all devices are collected.
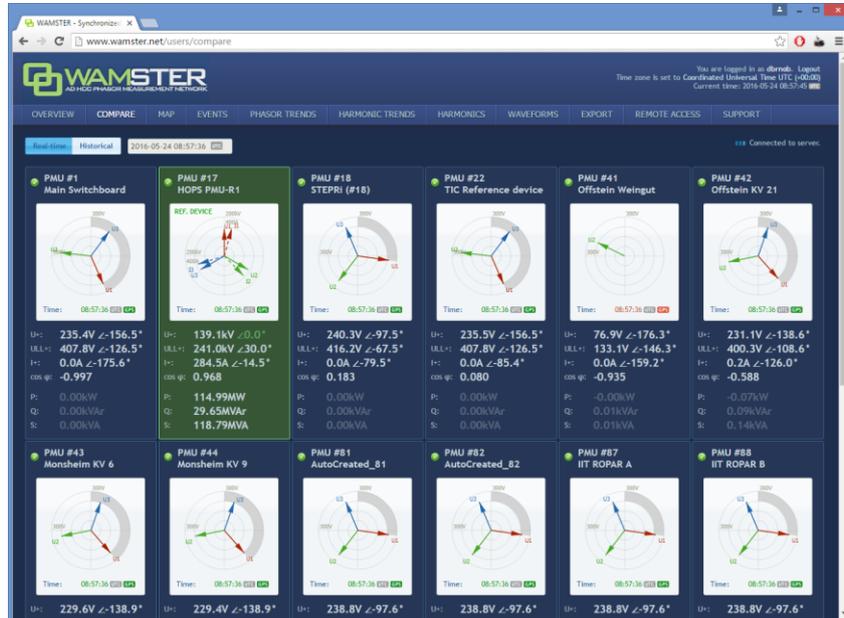

Figure 4.10: Measurement comparison page allows real-time and historical comparison. Selected reference device is shown in green

Each diagram shows voltage and current phasors for the related device, with the angle **relative to the currently selected reference device**. Reference device is shown in green, and the positive symmetry vector for this device is set to 0.0°. Clicking on a different device will set it as the current reference device and all vectors will be rotated accordingly.

Below each phasor diagram there is a table with several measured values: U+ (voltage positive symmetrical component), ULL+ (line voltage pos. sym. component), I+ (current pos. sym. component), cos φ, as well as active, reactive and apparent power.

> ℹ️ Current phasor angle is shown relative to the U+ phasor of the **same device** (not relative to the reference device).

To enable better visualization of the relative rotation, positive symmetry angle difference is drawn with a gray arc on each phasor diagram, as seen in the right phasor diagram in the figure below (showing -59° relative angle):

Figure 4.11: Device selected as the reference device (left), and a different device with relatively rotated synchrophasors (right)

4.4.1   SWITCHING BETWEEN REAL-TIME AND HISTORICAL VIEWS

By default, the Compare page shows real-time relative measurements for currently connected devices. In order to freeze the comparison at a specific moment in time, or view historical measurements, it is necessary to switch from Real-time to Historical view using the buttons at the top of the Compare page:

Figure 4.12: To switch from Real-time view to Historical, use the buttons at the top

Once the **Historical view** is selected, the date/time input textbox is enabled for input, and a date/time picker control is shown for easier mouse selection. As the time is modified either using textbox or the sliders below, data is retrieved from the server and displayed in the left and central panels.

Note that Real-time view actually displays measurements with a slightly longer delay (10s). Since communication link between the device and the server can sometimes be slowed down or even disconnected in unreliable GPRS networks, this delay allows the device to connect again and server to retrieve missing frames.

4.5   GEOGRAPHIC LOCATIONS

To view accurate PMU locations on a map, with a possibility to compare measurements, use the **Map** page, accessible from the navigation menu:
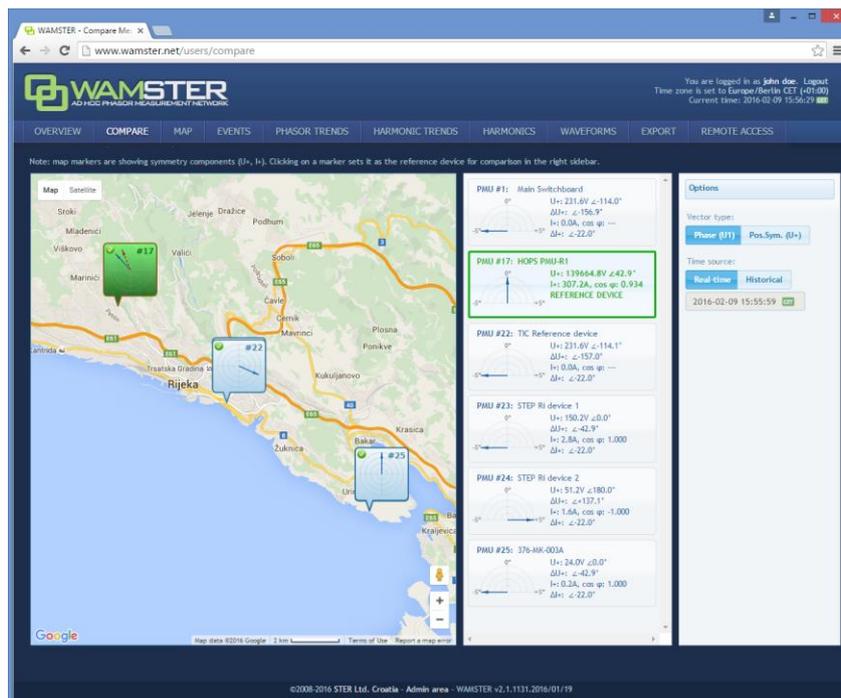

Figure 4.13: Map page allows real-time and historical comparison, with a map showing device locations. Selected reference device is shown in green and can be selected by clicking the entry in the table or on the map.

Left part of the page shows a map with geographical locations of your instruments (as reported by their GPS devices). Each device balloon shows voltage (blue) and current (red) absolute symmetry components, which rotate as the data is received. When a device is clicked, it is marked green and becomes a reference device in the central panel, and other device measurements are displayed relative to the selected device.

Central panel contains a table of devices with actual measurements: absolute current and voltage synchrophasor measurements (positive symmetry components (U+, I+), as well as their relative (ΔU+, ΔI+) angles (compared to the selected reference device marked with green color). Each device entry also displays a visual gauge indicator, showing the relative phasor angle difference (with a fixed range of -5° to +5°).

Note that if a relative difference is larger than ±5°, the gauge is not rescaled to keep the same scale as other devices. This means that if the gauge is "floored", it may actually represent a difference outside this range.

4.5.1   SETTING THE REFERENCE DEVICE FOR COMPARISON

By clicking on a specific device balloon on the map, or the same device in the central panel, the device is selected as a **reference device**, which is indicated with a green color, as shown below:
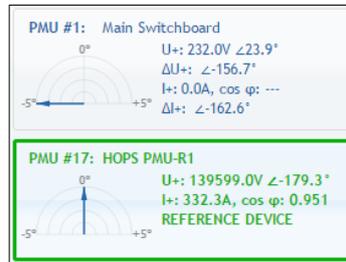
Figure 4.14: Clicking on a device sets is as the reference device,
which is indicated with a green border and values shown in green color.

4.5.2   SWITCHING BETWEEN REAL-TIME AND HISTORICAL VIEWS

By default, Map page shows real-time relative measurements for currently connected devices. In order to freeze the comparison at a specific moment in time, it is necessary to switch from Real-time to Historical view using the **right panel** on the Compare page:
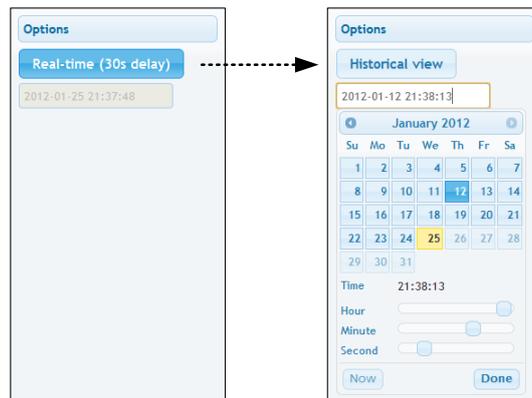
Figure 4.15: Clicking on the Real-time toggle button changes
the view to Historical

Once the **Historical view** is selected, the date/time input textbox is enabled for input, and a date/time picker control is shown for easier mouse selection. As the time is modified either using textbox or the sliders below, data is retrieved from the server and displayed in the left and central panels.

Note that Real-time view actually displays measurements with a slightly longer delay (10s). Since communication link between the device and the server can sometimes be slowed down or even disconnected in unreliable GPRS networks, this delay allows the device to connect again and server to retrieve missing frames.

4.6   CONFIGURING AND VIEWING TRIGGERED EVENTS

Event page shows the list of detected (triggered) events and provides the interface for configuring event triggers for PMU devices.
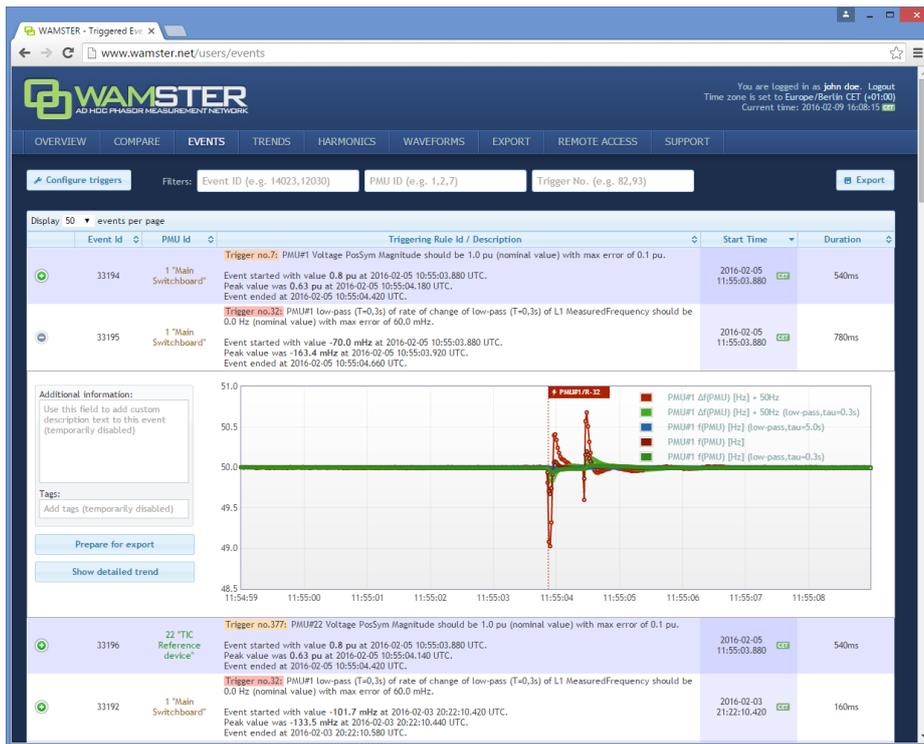
Figure 4.16: List of events. Clicking the green plus-sign button, expands details for the event.

For each entry in the table, user can click the event row (or the green Event details button at the beginning of the row) to show the detailed chart of the quantities which triggered the event. By further clicking on this chart, Trend page will be shown in a separate tab, positioned to the related event, so that the user can further analyze the data and include other channels and devices into the comparison. Trend page allows zooming, panning and various other features as displayed in the following chapter.

Event table can be sorted by different columns by clicking on their column headers, as well as filtered by the event ID, PMU ID, or trigger rule ID. To filter events, use the text boxes above the event table. Each of these text boxes can accept multiple comma separated values.

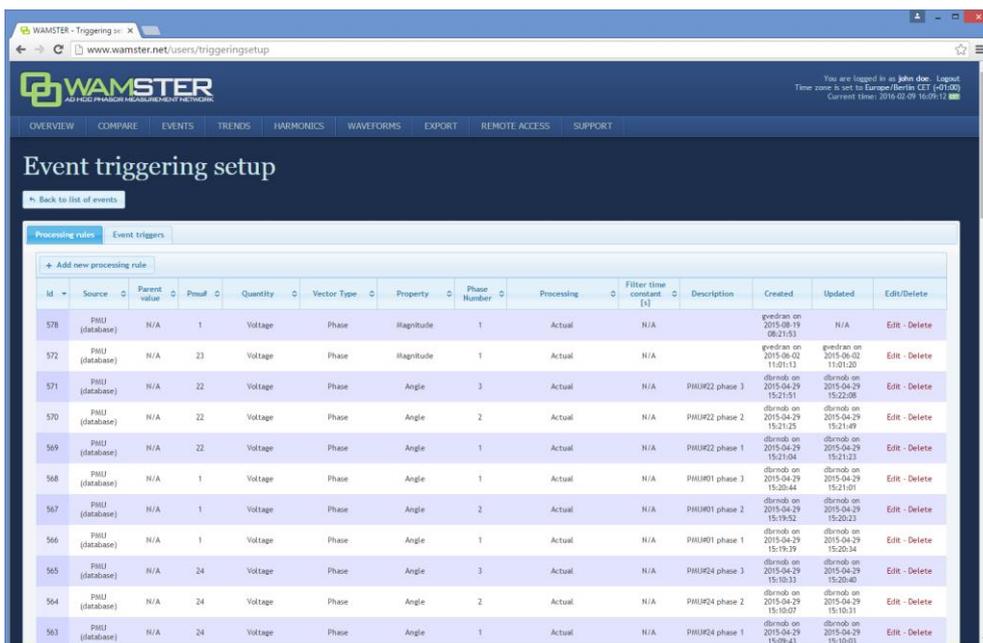By clicking the "Configure triggers" link, **Event triggering setup** page is displayed:

Figure 4.17: Interface for configuring event triggering rules and triggers.

Configuring event triggering consists of two steps:

- **Defining processing rules:** choosing quantities, defining calculations and filters, as well as chaining multiple rules in order to get the processed value for the next step, and

- **Defining event triggers**: choosing a processing rule defined in the first step (or two rules for relative comparison), defining processing rules, hysteresis, preprocessing, and creating thresholds which will trigger the event

Each event trigger can be also be disabled to prevent creating events when the device is not connected or measurements are not yet ready.

4.7   ANALYZING SYNCHROPHASOR TRENDS

Using the **Phasor trends** page, accessible from the top navigation menu, it is possible to quickly view historical trends for all devices, perform measurement comparisons, examine triggered events across multiple devices, and prepare the data for export. If the device functionality supports oscillograms, this page also allows requesting waveforms for certain events of interest.

ℹ️ When the view is zoomed out for more than 60 seconds, data is displayed using aggregates (minimum, maximum, average for each aggregate interval), with the aggregate interval duration dynamically expanded depending on the zoom level. Each of these intervals (min, avg, max) can be shown or hidden using the toolbar above the chart.

ℹ️ To speed up data retrieval, aggregates are calculated on 1fps data (0 ms frames only). This can sometimes result in different extremes being shown after zooming in to see the actual phasors. Although such subsecond oscillations are not seen at far zoom-out levels, they can be easily spotted using event annotations placed across the chart.
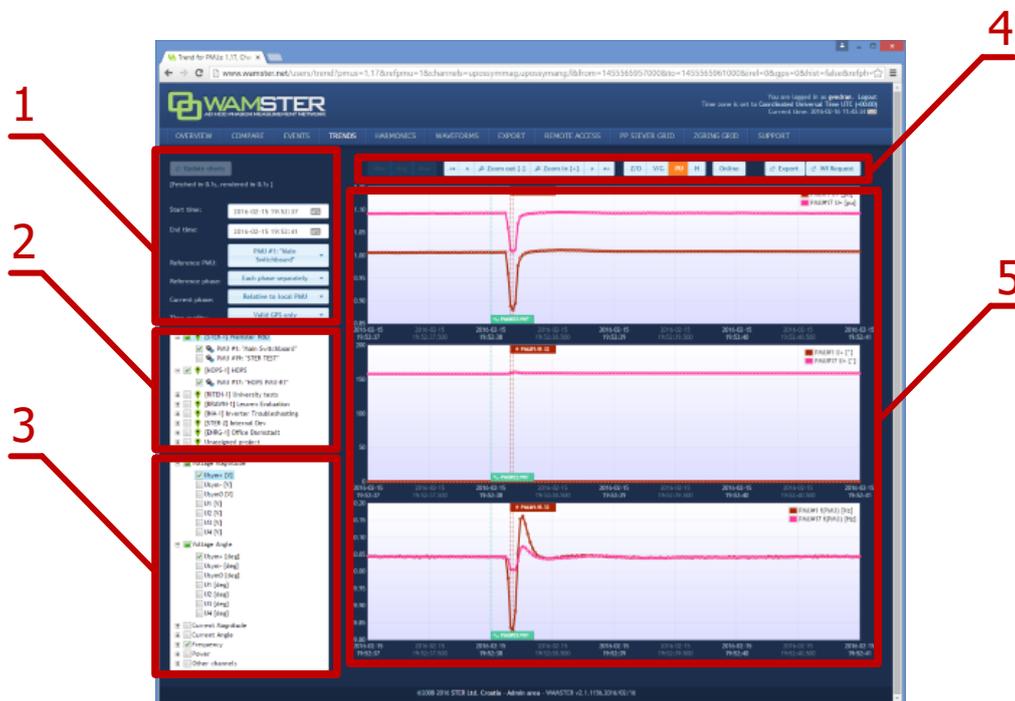

Figure 4.18: Trends page can be used to view and compare measurements during different time periods

Trends page components:

1	Data settings sidebar	Left settings sidebar contains input boxes for basic chart data settings, and the "Update charts" button which reloads the chart using specified settings.

2	PMU device selection tree	This tree contains all PMU devices registered for the currently logged in user, grouped by their current campaign (project). Checking the device will include its channels in the chart display. By checking the campaign, it is also possible to select multiple devices at once.
3	Channels selection tree	This tree contains a list of all channels. Checking a channel will include data from this channel from all selected PMU devices in the chart.
4	View settings toolbar	Top toolbar contains buttons for adjusting the chart view (toggling individual min/max/average aggregate channels, zooming and panning, setting zero-offsets, toggling histograms), as well as the Online button for enabling the chart to be automatically refreshed every 5 seconds, and buttons for creating export and waveform download requests.
5	Charts	This area shows the charts using the chosen settings, after clicking "Update charts".

4.7.1   DATA SETTINGS SIDEBAR

Left settings sidebar contains tools for defining basic chart settings:

Figure 4.19: Left settings sidebar

After changing any of the settings, the chart is not refreshed until you click the Update charts button.

1	Start time/End time	These textboxes can be used to specify the time range manually. Time is specified in the time zone currently selected in the login status area (top right area of the screen). Moving around the chart can usually be done quicker by selecting an area on the chart using the mouse, or clicking on the chart to center it, or using the zoom/pan toolbar above the chart.
2	Reference PMU	When comparing phasor angles between multiple PMU devices, it is often desirable to display them relative to a single PMU device. This dropdown will show a list of all currently selected PMU devices.
3	Reference phase	If multiple phase channels are selected (e.g. L1 angle and L2 angle) between multiple PMU devices, each phase will be shown on a separate chart. Using this setting, it is possible to set all chart to display angle data relative to a certain phase, or each chart to show separate phase data. If the Reference PMU is not set, then each PMU device will have its own reference phase. If the Reference PMU is set, then all PMUs will use the single phase channel from the reference PMU.
4	Current phase	Current phase channels (current phasor angles) are always displayed relative to their corresponding voltage channels; i.e. I1 angle is always displayed relative to U1 angle. This setting allows you to set make all current angles be shown relative to the reference PMU. If the reference PMU is not selected, this option will be disabled.
5	Time quality	By default, Wamster will only show measurements with fully locked GPS signal. If there are measurements where GPS signal was lost, there will be gaps in the chart at these ranges. Using this setting, it is possible to show all measurements, even those where time was not fully synchronized with the GPS.

4.7.2   VIEW SETTINGS TOOLBAR

View settings toolbar is placed above the chart and contains additional options and actions:

Figure 4.20: Top chart toolbar

1	Min/Avg/Max button group	When the chart is zoomed out and displayed time range is larger than 2 minutes, data is displayed as aggregates (minimum, average and maximum value for each aggregate interval). Individual intervals can be shown or hidden by clicking these buttons.
2	Pan and zoom buttons	Using these buttons, it is possible to zoom in and out of the chart, as well as pan (move) the chart in time. Note that y-axes are always scaled dynamically, depending on the currently displayed signals.
3	Z/O (Zero Offset) button	This button offsets all displayed channels, using the first displayed measurement value as the offset, so that all displayed trends start at the zero y-axis value. This is useful for comparing trends which are mutually offset by a large value. When Z/O is active, chart legend will show the offset value next to each channel. When data samples are hovered with the mouse pointer, channel name will also indicate the offset for the hovered channel.
4	V/G (Vector Group) button	Vector group works similar to the Z/O (zero offset) button, but is applied to angle (phase) channels only and rounds offsets to the nearest transformer vector group (hour-clock number), i.e. an angle multiple of 30°. This is useful when comparing phasor angles from multiple PMU devices from different vector groups.
5	PU (Per Unit) button	When enabled, voltage magnitudes are shown in p.u. (per unit) values (factor of nominal voltage), instead of volts.
6	H (Histogram) button	Toggles the display of histogram charts. If enabled, for each shown time series chart, a histogram is shown, showing the distribution of values displayed in the chart.
7	Online button	Toggles the "Online mode", where the chart is repeatedly updated to show most recent measurements. While this mode is active, it is still possible to select other settings, devices and channels. Zooming in or out of the chart will turn Online mode off.
8	Export button	Opens the Export page in a new tab, with currently shown devices and time range selected for CSV export.
9	Wf request	Creates a new waveform download request, for the first second shown in the chart, and opens the Waveforms page in a new tab.

4.7.3 CHART INTERACTION

If using a PC to analyze data, parts of the chart can be zoomed in or centered using a mouse:

- To zoom in on a part of the chart, move the mouse over the chart and hold the left mouse button while dragging to select the area. After releasing the button, chart will be refreshed to show the selected area.
- If Ctrl button is held while selecting the area, zoomed chart will be shown on a different tab.
- Clicking on a point on a chart will move the center of the chart to the clicked timestamp.

If using a tablet or a phone to analyze data, chart can be zoomed/panned using the toolbar buttons, or centered by tapping on the chart (similar to left clicking the chart).

4.7.4 CHART ANNOTATIONS

Triggered events and downloaded waveforms are annotated on the chart as colored tags. Event tags are shown at the top of each chart, while waveforms are shown at the bottom. Hovering an event tag shows event information:
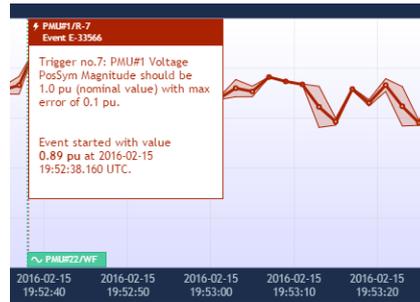
Figure 4.21: Hovered event tag shows event information

Clicking on the waveform tag opens the corresponding waveform in a new tab.

4.8   WAVEFORMS/OSCILLOGRAMS

Waveforms page shows a list downloaded oscillograms, grouped by timestamp in the table view on the left side. Clicking on each entry in the table shows the oscillograms in the right side chart.
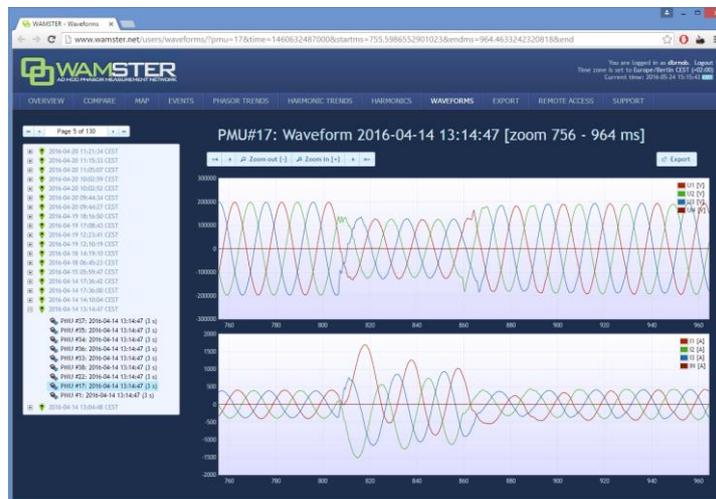

Figure 4.22: Waveforms page

Similar to the trends page, by selecting the area on the oscillogram chart (by clicking and dragging using the mouse), it is possible to zoom in the range. After zooming in, selecting a different device in the same group will show the data for that device, but keep the displayed zoom range, which allows easier comparison of device measurements within a group.

4.9   HARMONICS

Harmonics page shows downloaded voltage and current harmonic aggregates (minimum, average, maximum), for 10-minute aggregate intervals. These measurements are automatically downloaded from each device with the supported firmware version, at the end of each aggregation interval.
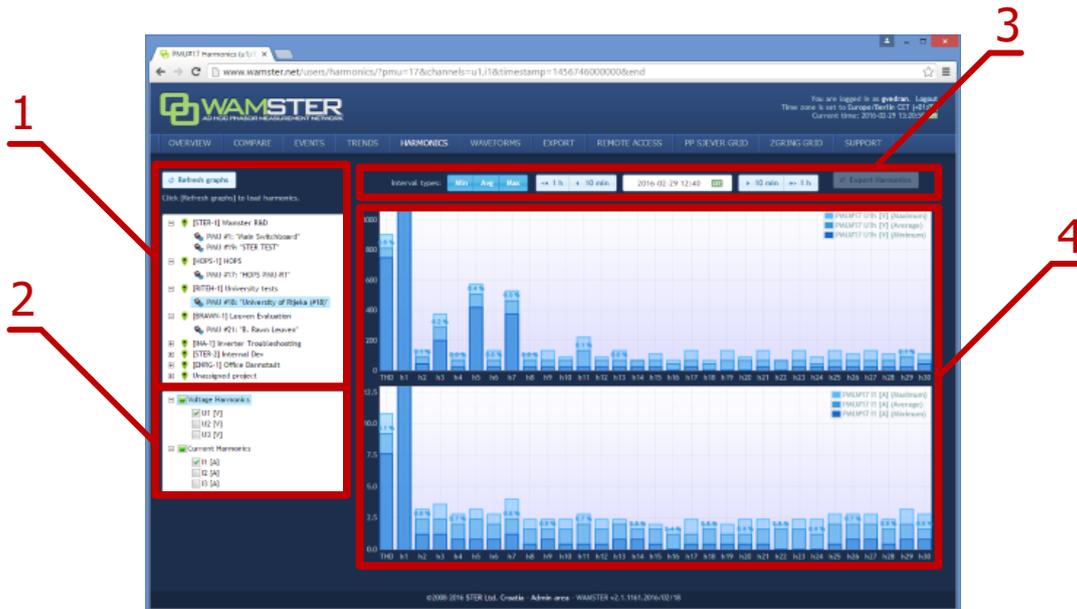
Figure 4.23: Harmonics page provides interaction elements similar to the Trends page

Harmonics page components:

1	PMU device selection tree	This tree contains all PMU devices registered for the currently logged in user, grouped by their current campaign (project). Selecting a single device will include its harmonic channels in the chart display, after clicking "Refresh graphs".
2	Channels selection tree	This tree contains a list of voltage and current phases. Checking a channel will include data from this channel in the chart. Some devices might not have all voltage and current channels enabled, depending on their settings.
3	View settings toolbar	Top toolbar contains buttons for adjusting the chart view (toggling individual min/max/average aggregate channels, setting the timestamp and moving in 10 min. or 1 hour intervals, and exporting the harmonics data.
4	Charts area	This area displays harmonics using the specified settings, after clicking "Refresh graphs".

Harmonic bars are shown as percentages of first harmonic (H1). Minimum, average and maximum values in actual units (volts or amperes) can be shown by placing the mouse pointer over each bar in the harmonics chart, which will display a tooltip with additional information.

4.10 HARMONIC TRENDS

Similar to the Phasor trends page, the Harmonic trends shows charts for 10-min. harmonic aggregates. After selecting the time range, one or more PMU devices, and one or more harmonic channels for display, clicking the Update charts button shows the harmonic trend for these parameters:
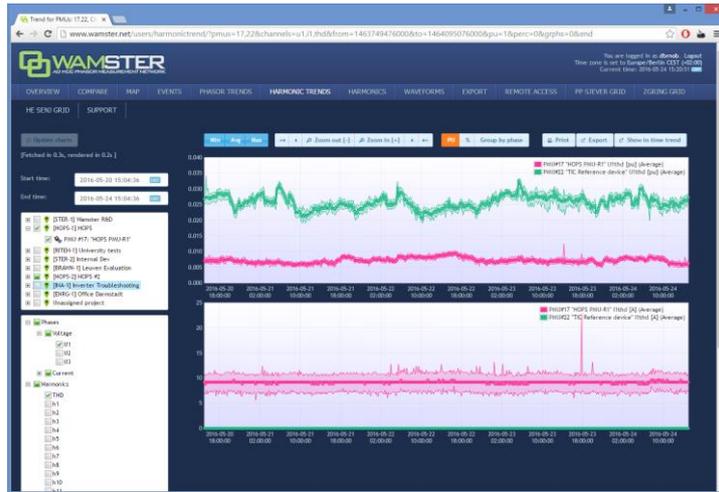
Figure 4.24: Waveforms page

Charts can be panned and zoomed, like explained in chapter 4.7 *Analyzing synchrophasor Trends*.

4.11 EXPORTING AND DOWNLOADING DATA

To export the data from the cloud storage and download it to your computer, select the **Export** page from the navigation menu. On the left side of the page, there is panel for creating new export requests, which allows you to specify the time range for export, export resolution in frames per seconds, and individual devices for which the measurements should be exported.

If the export resolution is higher than the default reporting resolution for a given device, you can also specify whether the server should request these "missing" frames from each device, or not. If your devices are configured to report on a lower speed, and you would like to get a detailed snapshot of a certain time range, you can choose the option to collect those frames.
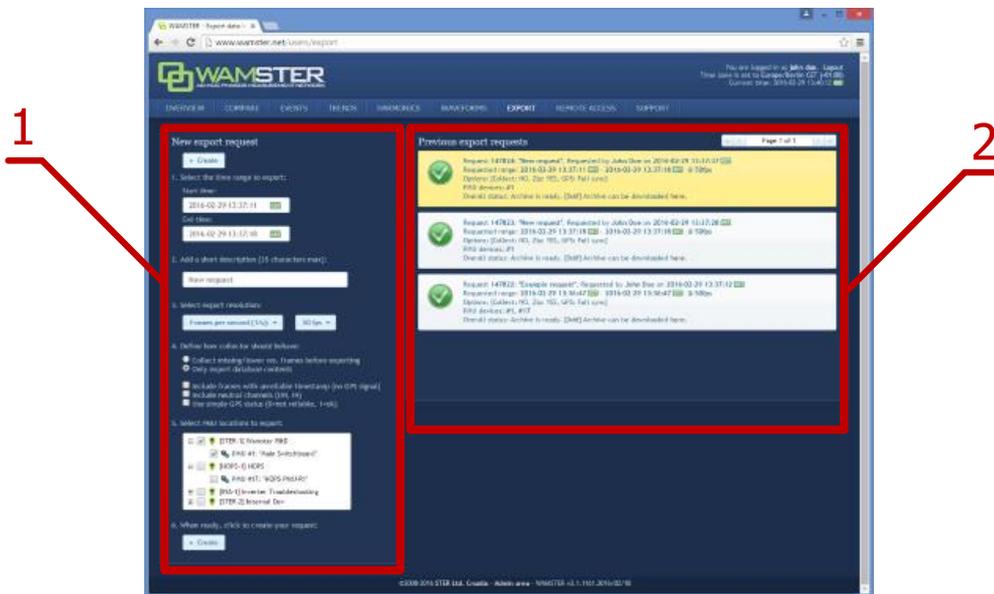

Figure 4.25: Data export page: left panel shows export options, right panel shows previous export requests

Export inputs:

1	Time range	Time range defines inclusive start and end timestamps for the request. Time is specified in the currently selected time zone, but exported timestamps will always be shown as UTC to prevent ambiguity.

2	Short description	Exports can be given a short descriptive name to easily differentiate them.
3	Export resolution (fps)	Export resolution can be specified in fps (frames per second) or by time intervals (seconds between frames).
4	Export settings	Various export settings, described in the following table.
5	PMU devices selection tree	List of PMU devices for the currently signed in user, grouped by project/campaign.
6	"Create" button	Sends the export request to the server.

Export settings:

1	Collect missing/lower res. frames before exporting	If this option is selected, all data which was collected at lower resolution that specified in the export options will be recollected from the device before exporting.
2	Include frames with unreliable timestamp	By default, frames with unreliable time sync are not included in the export. However, since PMUs are equipped with internal clocks, even after losing the GPS signal, quality of the timestamp might still be good enough for the export. Checking this option will include all frames in the export, regardless of the GPS/time source status.
3	Include neutral channels	Checking this option will include U4 and I4 in the export. Leave unchecked if these channels are not physically connected.
4	Use simple GPS status	If checked, GPS column will contain 1 for full time synchronization, and 0 for all other cases (broken cable, unreliable GPS, invalid timestamp, etc). If the "Include frames with unreliable timestamp" option is checked, this option will allow easier differentiation between valid and invalid timestamps. If unchecked, GPS column will contain Wamster-specific GPS flags.

Once the export request is added, it can be canceled, but not modified. If the request is configured to collect all missing frames from the device before exporting, all devices will have to send all requested frames before the export file is completed. Additionally, requests which need to collect more than 15 minutes of data are placed in a lower-priority queue; depending on the mobile network connection type and speed, requests may take significant time to complete.

Since export requests tend to contain large amounts of data, server queues requests and processes them sequentially. Since this may take some time to complete, all requests for a given user (and their current progress statuses) are shown in the right panel on this page. This means that users can queue export requests, log out of the system, and then return later to download the file to their PCs.

Previously finished requests are also available for download, for up to 1 week after creating the request. After 1 week exported files are deleted to conserve server space, but each file can be recreated if needed.

Data is currently exported in a CSV (comma-separated values) textual format. For information on customization of the format or implementation of other formats, contact support@wamster.net.

4.12 REMOTE ACCESS

For additional configuration options, as well as diagnostics and troubleshooting, Wamster allows each device to be accessed remotely through the **Remote Access** page:
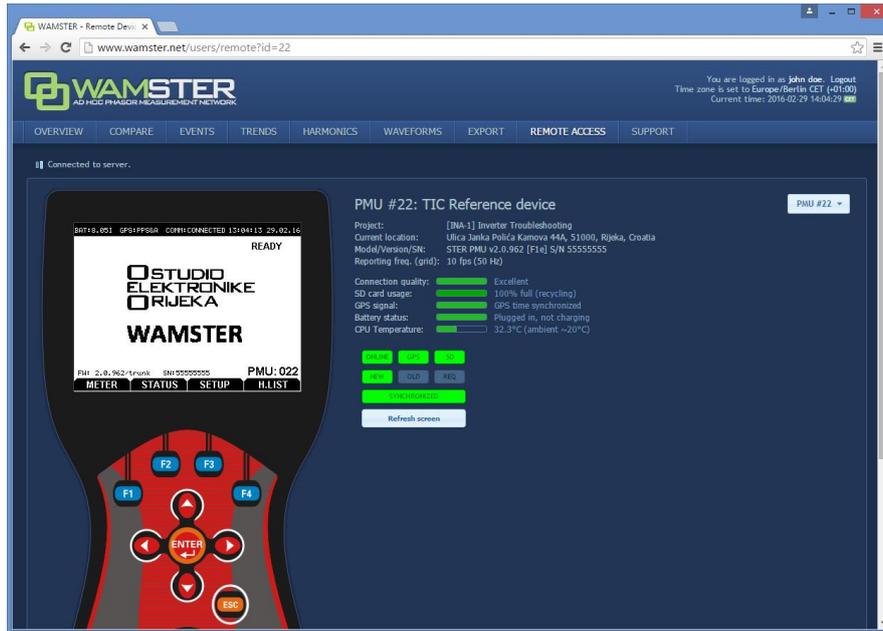
Figure 4.26: Remote access page

Clicking on individual keys on the instrument mask sends these commands to the instrument, while the instrument sends its current screen back to your browser. To prevent a large number of missing frames whenever the screen is changed on slower (GPRS) networks, screen refresh can be only initiated **manually**, by clicking the **Refresh screen** button.

For this reason, when a different screen is selected on the instrument and it differs from the currently displayed image in the browser, status indicator above the Refresh screen button changes from **Synchronized** to **Not synchronized**:

Figure 4.27: If the remote instrument is in a different menu than the one shown on the web page, remote status will change to "NOT SYNCHRONIZED"

Note that "SYNCHRONIZED" status does not necessarily mean that remote instrument screen is showing exactly the same contents as the web page, it only indicates that the same submenu is selected as currently shown. Remote access functionality allows access to the device for extraordinary cases, without drastically impairing the instrument's primary functionality.

4.13 SUPPORT PAGE

Being an online application, Wamster allows download of documents applicable to devices associated with your username. Latest version of each manual is available on the **Support** page, accessible through the navigation menu.

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