Wamster System Implementation Details

Technical description and usage details of Wamster components

Studio Elektronike Rijeka, May 2012

The definitive version of this document is available at **www.wamster.net**.

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Wamster system integrates portable, plug-and-play PMU devices with a reliable cloud solution for gathering, storing and analyzing synchrophasor data.

Executive Summary

This white paper covers key technology details behind the WAMSTER system:

1. **STER PMU is a lightweight, portable, IEEE C37.118 compliant PMU:**

   - deployment and configuration of PMU devices is drastically simplified;
   - using a GPRS connection instead of wired Ethernet links removes the need for a dedicated networking infrastructure;
   - rechargeable battery backup keeps the device and the modem online during blackouts;
   - removable SD flash memory keeps up to 4 months of full-resolution data locally, on the PMU device.

2. **Wamster is a reliable synchrophasor concentrator server with data storage as a service**:

   - optimized communication protocol adapts dynamically to low-signal mobile network conditions;
   - web application for online data analysis, automatic event triggering and reporting, with data export to customizable formats;
   - data access from any web-enabled device, with full remote PMU setup and management capabilities;
   - easy interoperability with existing systems.

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.

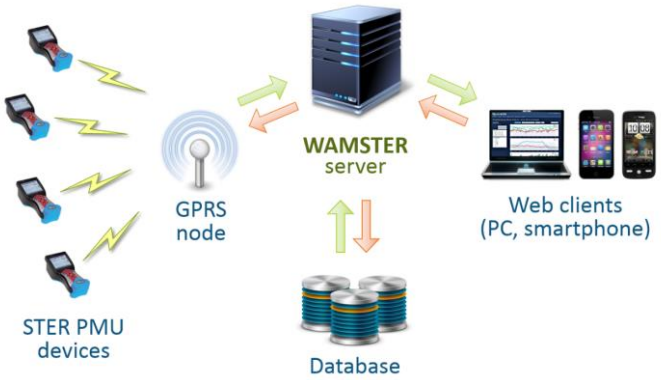

Figure 1.1: Wamster overview

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. STER PMU devices are typically deployed within 15 minutes of arrival on site. Measurements are immediately available to all team members from any web-enabled device. Customer does not need a dedicated PDC device, which results in less administration.

Custom communication protocol adapts the reporting speed to network conditions. The protocol allows retrieving historical data from PMU's local memory in case of network outage. Local SD flash memory is enough for cyclically storing synchrophasor data for the last 4 months.

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 exchange data with other PDCs and customer devices.

With Wamster, there are also 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.

1.3 WHO SHOULD USE WAMSTER?

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.

Wamster system implementation details

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.

2 Communication layer

2.1 INTRODUCTION

One of the main benefits of Wamster is the possibility of using unreliable GPRS/UMTS networks as the communication channel. 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.
- 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 server 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 are also automatically requested whenever an event is detected, in order to speed up the analysis process.

This chapter describes communication layer internals.

2.2 COMMUNICATION CYCLE

Communication cycle starts with the device connecting to the configured TCP socket on the Wamster server.

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.
- 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.

3 Concentrator components

Configurable Wamster architecture allows various processing scenarios for the incoming synchrophasor data, versatile extension possibilities and custom data adapters.

A processing pipeline is assigned to each device when it connects to the server, which includes following actions:

- communication monitor monitors communication status, adapts the communication system to network conditions and tracks all pending requests;
- event detector processes synchrophasor frames as they are received and detects events according to user defined rules;
- status monitor monitors PMU status, reports system events and creates statistics;
- export manager coordinates detailed export merged from multiple PMU devices;
- firmware updater manages remote updates for all devices
- remote device manager allows remote user interaction with the device.

All components can send notifications to the e-mail/SMS reporting system.

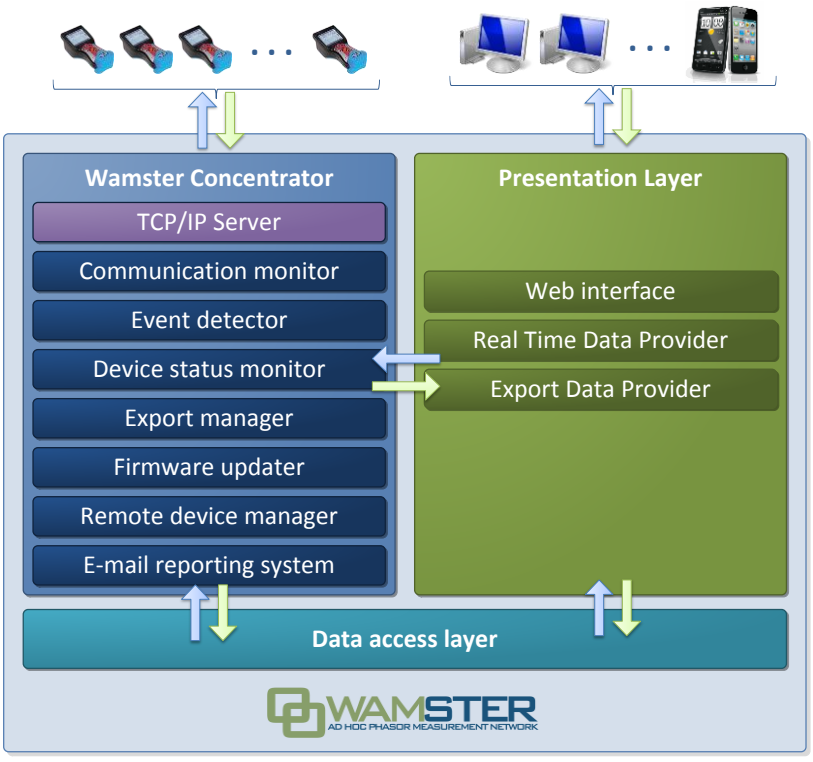

Figure 3.1: Wamster architecture

3.1 COMMUNICATION MONITOR

This module contains components responsible for most of the functionality described in the previous chapter. At its core is the highly configurable state machine which sends and keeps track of pending requests, using information supplied from various pipeline components.

Each component initiates requests for a range of frames at a desired resolution. Also, the component defines either strict or relaxed download policy. If the policy is relaxed, Wamster can decrease frame resolution during requests if network conditions demand it. Some components (like export manager, responsible for user requested exports) will always create strict policy requests to ensure that their resolution meets user requirements.

Communication monitor also adjusts current (real-time) resolution according to various configurable rules: time between two frames, detected increase in dropped frames, rate at which the frames are being received, etc.

3.2 EVENT DETECTOR

This module uses defined processing rules and thresholds to generate synchrophasor events. Data preprocessing is first applied to incoming frames to provide quantities for the analyzer, which are then checked against defined thresholds or compared between multiple devices.

When a threshold is exceeded, an event is generated and stored in the database. If current reporting resolution is lower than the grid frequency, a request is created and sent to the device by the communication monitor. Notification e-mail is also sent to users configured for this device.

3.3 PMU STATUS MONITOR

This component monitors internal status of PMU devices: GPS clock status, SD flash card capacity, battery level and charger status, and internal device events. System events are also generated, stored in the database, and reported to administrator e-mail addresses.

3.4 EXPORT MANAGER

Using the web interface, user can select a time range for export from one or more PMU devices. When a data export job is requested, export manager will scan the database for all devices involved in the export, and define a list of frames to be requested by communication monitor. It will also track and report individual download progress, and finally create the output stream when all data is collected.

When defining the export job, user can decide if data should be retrieved from the server database only, without sending requests to the devices. By default, data exporting includes collecting all missing data from devices' local memory.

3.5 REMOTE DEVICE MANAGER

Remote device manager allows remote interaction with the device, by sending keystrokes and receiving device screen contents. Typical usage includes verification and change of measurement settings from a remote (web) location.

4 Database and storage

By implementing database as a service over the online web interface, Wamster eliminates administrative IT costs, and allows future scalability to be completely transparent to the end user. Data is securely stored and backed up at a remote location, accessible at any time from any location.

4.1 UNDERLYING TECHNOLOGY

WAMSTER supports several types of database systems. By default, it uses instances of Microsoft SQL Server 2008 R2 Enterprise Edition as the underlying storage technology, with separate monthly databases for each PMU device. This allows scalability, availability, flexible migration and data backups, as well as full separation between clients (multi-tenancy). This provides full separation at the file system level, ensuring that each client can have their own data files ready within minutes, should they desire this data.

The data layer is organized to allow per-client, or even per-device storage differentiation, which means that it's possible to use multiple different database systems or architectures, depending on client needs and preferences. This includes using different relational DBMSs like Oracle, NoSQL databases or fully distributed DBMSs like Apache Cassandra.

Synchrophasor measurements are stored with an IEEE C37.118 compliant UTC timestamp (time quality info, leap second support, etc.), which allows system integration with other PDC systems. Measurements can be grouped by configurable measurement points, which are in turn related to PMU device entries in the database. All data processing rules, analysis rules and thresholds, as well as all events detected during online operation are also stored inside the same database and hold reference to related measurement entries, along with PMU device data and their GPS locations, which ensures consistency when data is archived or migrated.

4.2 PARTITIONING

To provide easier management and maintenance of vast amounts of stored data, time-based partitioning strategies are employed for time-value series, based on monthly intervals and individual PMU devices. Partitioned views allow higher insert throughput for real-time data during historical data queries, allowing online index maintenance jobs to perform more quickly and simplifying archiving.

4.3 SCALABILITY

Storage system has been designed and implemented with scalability in mind. As the network grows, database system can easily accommodate arbitrarily large numbers of devices, by scaling out using distributed partitioned views and custom data-dependent routing strategies.

4.4 BACKUPS

WAMSTER databases are regularly backed up to prevent data loss in case of failures. Additionally, given the fact that WAMSTER's online database doesn't usually contain full resolution data (depending on the configured reporting resolution), it is important to note that all PMU devices store full-resolution measurements on their SD cards, creating an additional remote copy of all measurements.

Clients always have physical access to these full-resolution measurements, can replace these SD cards in regular intervals (5 months for 32GB cards) and archive them at their own locations.

Additionally, full resolution SD cards can be uploaded to our servers to be used as virtual devices by WAMSTER, allowing online access to all full-resolution measurements.

5 Presentation layer

Wamster exposes its functionality through the cloud; user can manage their devices and analyze data using a thin-client – through the web user interface. This approach has several advantages over a rich client Windows solution:

- there is no need for software installation, removing administration costs, only a browser, an Internet connection and user credentials are needed for accessing the interface;
- web interface is fully standards compliant, without the need for external browser plugins (Silverlight or Flash), and can be accessed from all modern browsers and web enabled portable devices;
- all users always have the latest version of the application, including interface customizations on request, with no need to download updates.

5.1 SYSTEM REQUIREMENTS

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 9) do not fully conform to www standards. While they are officially supported by Wamster, following browsers are recommended for safety, speed and better browsing experience:

- Google Chrome 9 or newer
- Mozilla Firefox 3.6 or newer
- Microsoft Internet Explorer 9 or newer
- Opera 10 or newer
- Apple Safari 5 or newer

5.2 SIGNING IN TO WAMSTER

Web interface is accessed by visiting www.wamster.net/users using a web browser, and logging in:

Figure 5.1: Authentication form shown when accessing Wamster

After signing in, user is redirected to the **Overview** page. Navigation menu is changed to include advanced options, and user status is shown in the upper right corner:

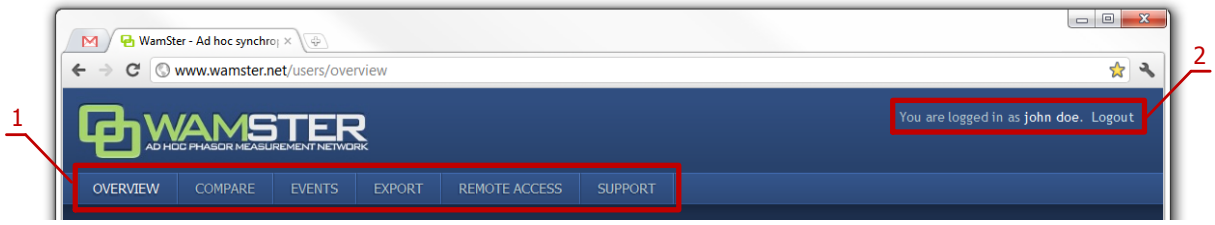

Figure 5.2: User area: 1. navigation menu, 2. login status with a Logout link

5.3 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 associated with the active account can be seen, as shown on the figure:

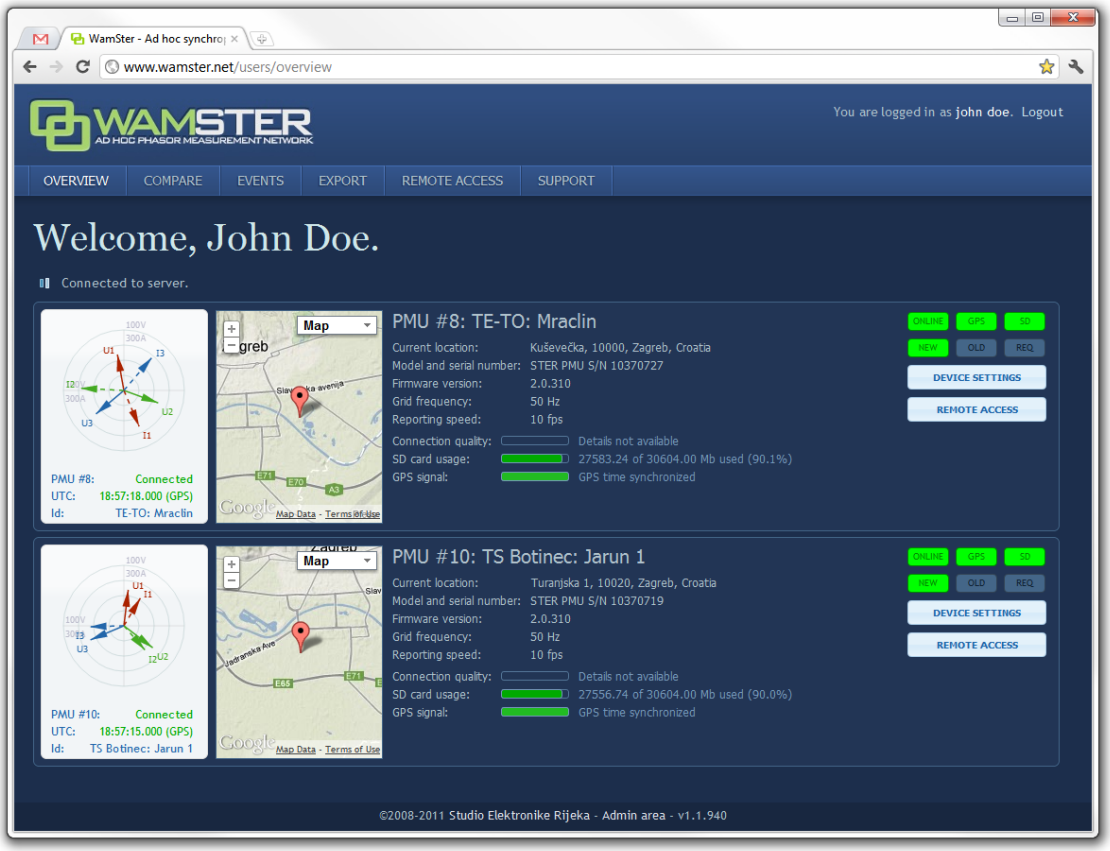

Figure 5.3: Overview page, showing devices for the currently logged in user

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 visual status indicators and buttons for accessing device settings:

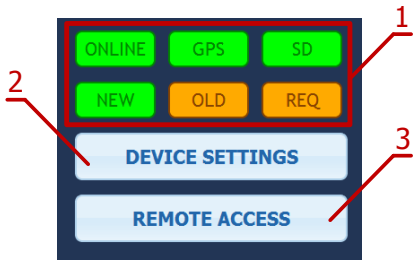

Figure 5.4: Visual status indicators and command buttons

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

5.4 DEVICE COMPARATION

Compare page can be used to compare measurements of multiple devices, for both real-time and historical data.

Left part of the page shows a map with geographical locations of connected 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 more than two devices are connected, red dashed lines indicate which of the devices is set as the reference device for comparison.

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**). Each device entry also displays a visual gauge indicator, showing the relative phasor angle difference (with a fixed range of -5° to +5°).

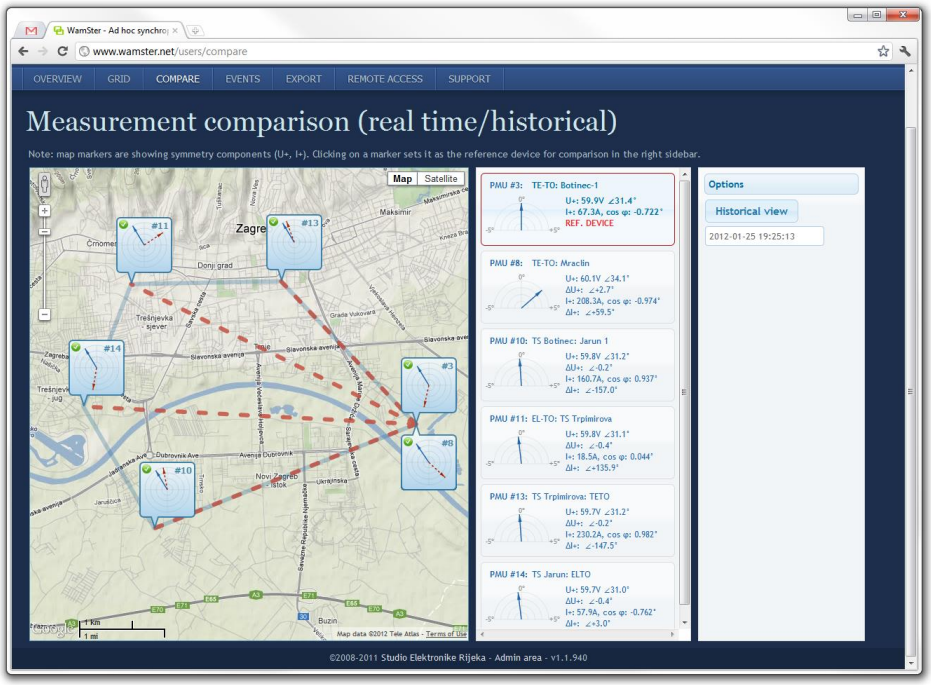

Figure 5.5: Measurement comparison page allows real-time and historical comparison

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 by a red border around the device, as shown below:

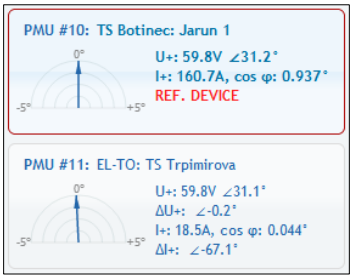

Figure 5.6: Clicking on a device sets is as the reference device, which is indicated with a red border.

By default, Compare 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.

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.

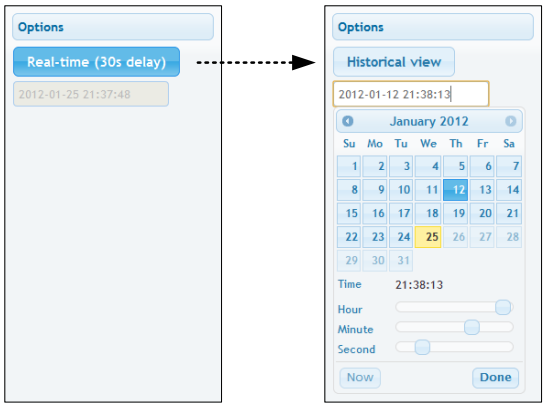

Figure 5.7: Clicking on the Real-time toggle button changes the view to Historical

5.5 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.

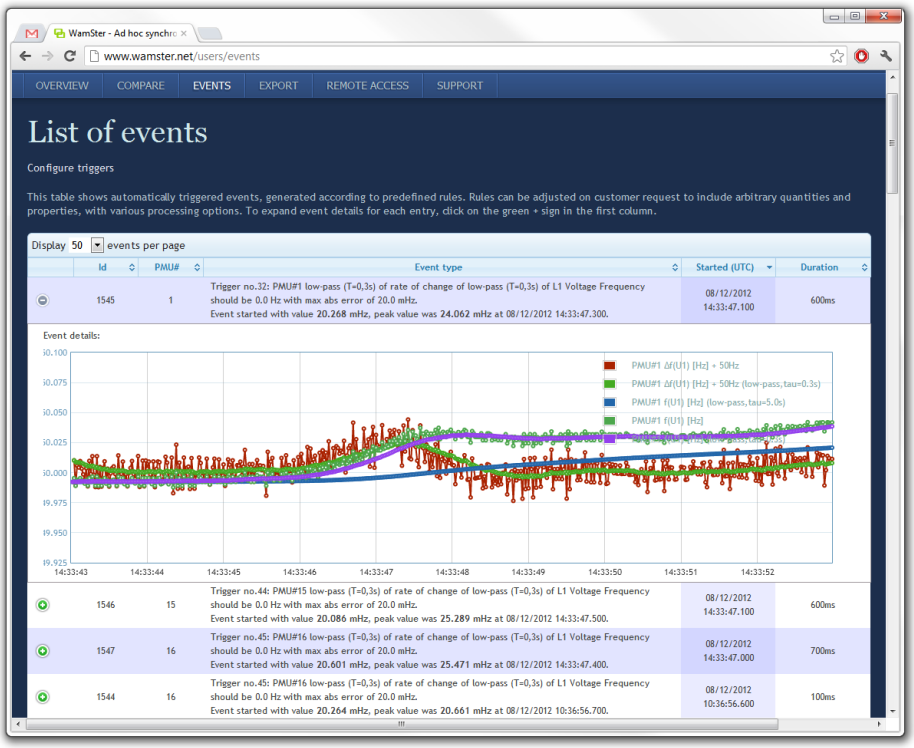

Figure 5.8: List of events. Clicking the green plus-sign button, expands details for the event.

For each entry in the table, user can view the snapshot of the quantities which triggered the event by clicking on the green Event details button at the beginning of the row. Displayed chart also allows zooming and panning.

Event table can be sorted by clicking on individual column headers, as well as filtered using text inputs shown at the bottom of the table for each column.

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

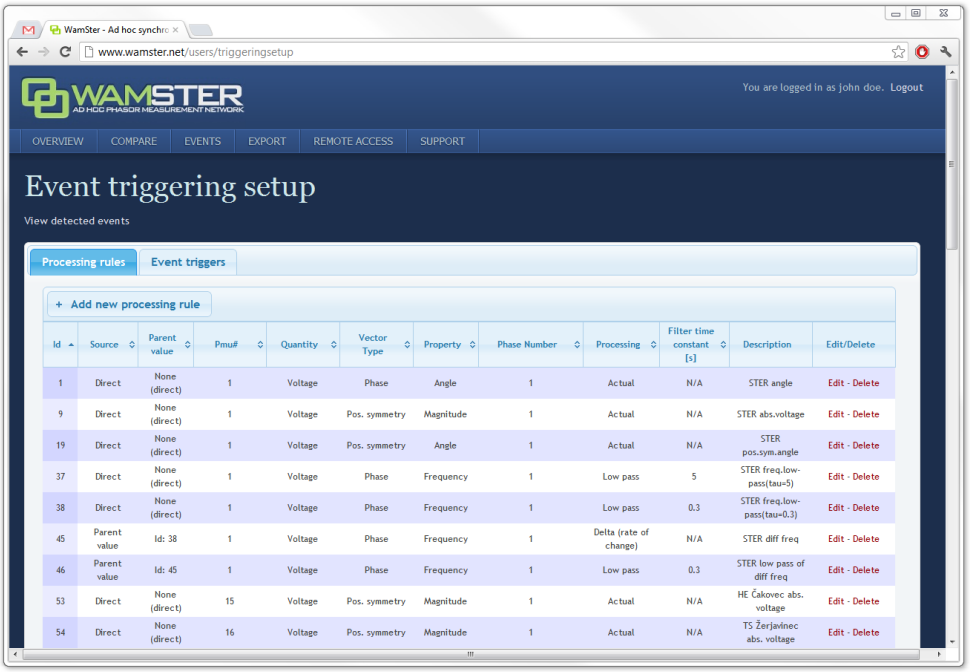

Figure 5.9: Interface for configuring event triggering rules and triggers.

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.

5.6 EXPORTING AND DOWNLOADING DATA

Data can be exported from the cloud storage and downloaded to a personal computer, using 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.

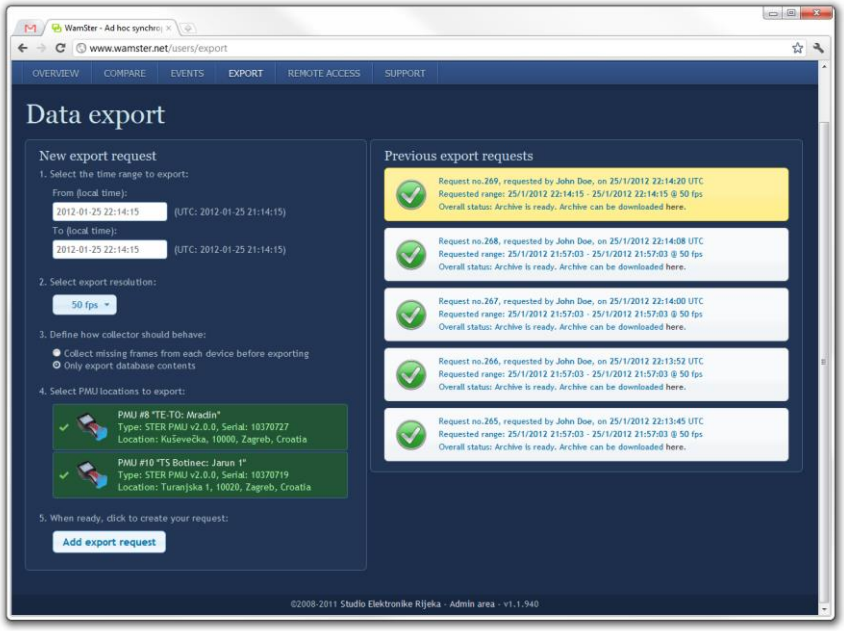

Figure 5.10: Data export page: left panel shows export options, right panel shows previous export requests

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. Previously finished requests are also available for download.

5.7 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:

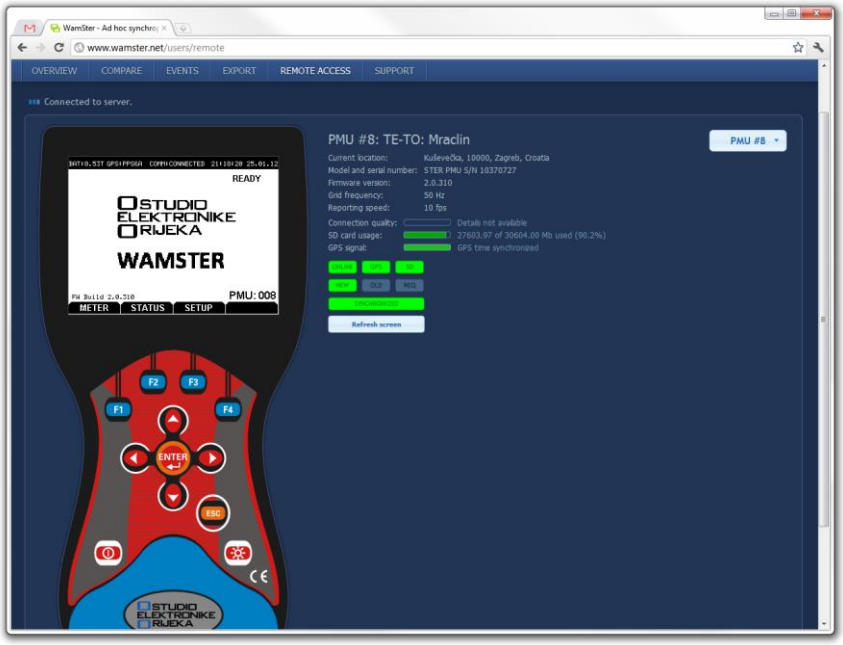

Figure 5.11: Remote access page

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.