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Ad-hoc WAM system proposal for monitoring campaigns:

WAMSTER technical details, typical installations and references

Rijeka, June 2015

1 Introduction

Synchronized measurement technology (SMT) with its benefits is already recognized as an important enabler of next generation power systems. Confidentiality of measured data regarding the energy trading and power system security issues presents a major obstacle for involvement of academia in direct monitoring of the transmission network for research and development purposes. The costs of deploying, configuring and connecting classic PMU devices and associated PDCs make the technology even less accessible to R&D teams. The idea of the WAMSTER system is to provide a solution to these problems.

2 WAMSTER OVERVIEW

WAMSTER project was started at “Studio elektronike Rijeka” (STER) at the end of 2009 as a coordinated work with Department of Power Systems Faculty of Engineering, University of Rijeka (RITEH), to meet the increasing needs for remote data acquisition in various projects for the Croatian TSO. The system is based on two main characteristics:

1. PMU deployment/configuration simplicity, through use of lightweight, handheld PMU devices, and
2. communication infrastructure independence, by relying on mobile networks for transmitting data.

Compared to a classic PMU/PDC system, WAMSTER’s PMU devices are typically deployed within 15 minutes of arrival on site, with measurements immediately available to all team members from any web-enabled device.

Taking into account the unreliability of mobile network data transfers, WAMSTER does not aim to be a tool for real-time control and protective applications, but rather a near-real-time online monitoring tool with various event triggering and data export capabilities. As such, it is recognized by the TSOs, DSOs and academia as a cost-effective and efficient disturbance detection and localization tool, especially for post-mortem analysis.

The concept established by the WAMSTER can be considered as a “wireless worldwide data” PMU source and concentrator. Using the globally available GPRS mobile network and the Internet accessible server as a data concentrator, WAMSTER allows rapid deployment and unlimited network expansion possibilities.

The WAMSTER system is consisted of (Fig. 1):

- multiple handheld STER PMUs, equipped with a battery backup, the GPS module and the GPRS modem;

- online service for data concentration, storage, event triggering, data export, with real-time and historical presentation through an online web interface (provided as a service).

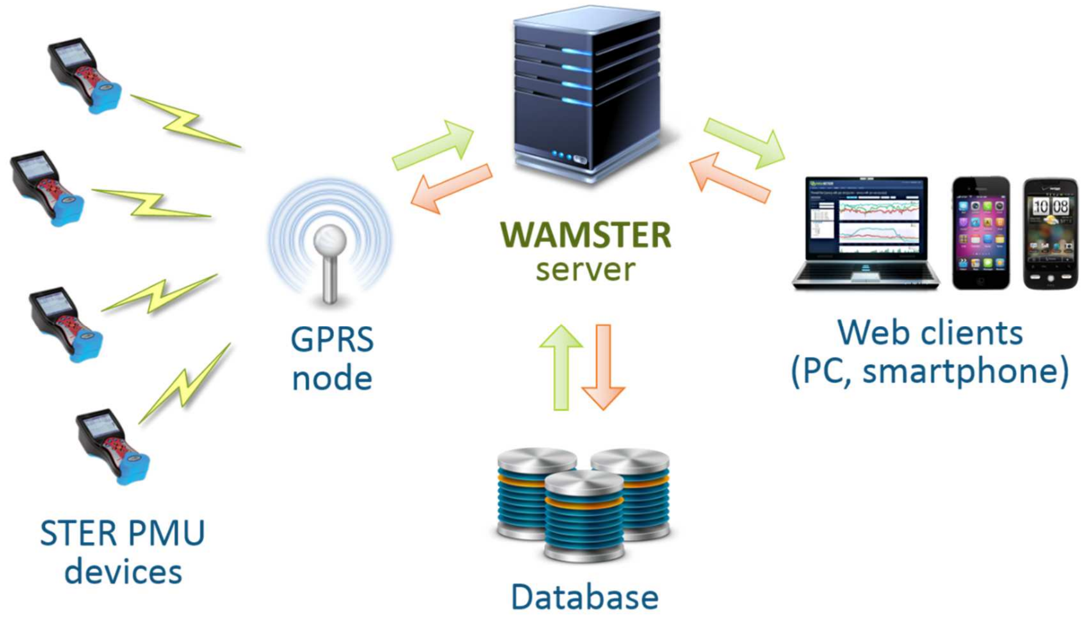


Fig. 1. WAMSTER system overview. Handheld STER PMU devices (shown on the left) communicate with the server over the mobile (GPRS) network. WAMSTER server processes received synchrophasors, drives them through the event triggering system, stores them into the database (shown at the bottom), sends notification messages to clients, and renders an online interface for web clients (right).

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 (Fig 2):

- 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.

Fig. 2. WAMSTER server architecture

3 Portable phasor measurement units

STER PMU devices provide measurements of four voltage and four current synchrophasors in each frame (50/60 frames per seconds, depending on the grid frequency). A voltage range selector provides 3 ranges: 150 V, 300 V and 1000 V. Measurements are performed according to the IEEE C37.118 standard. Each device is equipped with a removable SD memory flash card of up to 32GB sufficient for storing over 4 months of synchronously reported synchrophasor measurements. An embedded rechargeable battery is sufficient for up to 8 hours of autonomous operation during blackouts. Prevention of the data loss due to potentially large and unpredictable latencies and high probability of the GPRS communication interruption is achieved by an adaptive communication scheme addendum to IEEE C37.118 protocol. This addendum together with a battery backup and dedicated non-volatile memory on each device makes SterPMU tool for on-line monitoring of worst case scenarios in power systems.

3.1 Brief measurement hardware specifications

One STER PMU measurement set (Fig. 3) includes:

- PMU unit (1pc), 3 phase 5A/1V measuring transformer (1pc), Test probe, red (3pcs), Test probe, black (1pc), Crocodile clip, black (1pc), Crocodile clip, red (3pcs), Voltage measurement lead, red (3pcs), Voltage measurement lead, black (1pc), Voltage measurement lead, green (1pc), Power supply adapter (1pc), GPRS class 10 modem with connection cable (1pc), GPS unit (1pc), 1.2 V NiMH rechargeable battery (6 pcs), Soft carrying bag (1pc), Instruction manual (1pc), Calibration certificate (1pc)

Fig. 3. STER PMU complete measurement set

3.1.1 Technical specifications

Measurement inputs	• 4 voltage inputs (3 phases, earth), 3 ranges: 150V, 300V, 1000V • 4 current inputs: xx A /1V, 2 ranges: 100%, 10% • default current sensor: 5A/1V A1037 measurement transformer • optional current sensors: current clamps with nominal currents from 5A to 3000A, measurement class: 1 (high currents) or 2 (low currents).
Basic measurement accuracy	• Voltage RMS accuracy: 0,2% of reading • Current RMS accuracy: 0,5% of reading with default current sensor
Synchronized phasor measurements	• Measurement result tagging according to C37.118 specification. • Accuracy: TVA < 1% with default current sensor • Max. reporting rate: synchronous (50/60 synchrophasors frames per second)
Local non-volatile memory autonomy	• 32 GB, sufficient for more than 4 months storage of measurement results saved at synchronous reporting rate
Communication reporting rates	• 50 Hz (1-2-5-10-25-50 fps); • 60 Hz (1-2-5-10-12-15-20-30-60 fps)
Safety standards	• EN 61010-1: 2001 Safety requirements for electrical equipment for measurement, control and laboratory use
Overvoltage protection	• 1000 V / CAT III; 600 V / CAT IV
Protection class	• double insulation
EMC standard	• EN 61326-2-2: 2006 Electrical equipment for measurement, control and laboratory use: ▪ Emission: Class A equipment (for industrial purposes) ▪ Immunity for equipment intended for use in industrial locations
Communication link	• GPRS modem class 10
Time source	• GPS PPS – error < 3us • internal clock – error < 2 s/day
Display	• monochrome LCD, 320x200 with backlight
Battery backup	• > 8 hours as a standalone device, • > 5 hours if supplying GPRS modem with power
Auxiliary power	• 80-260V, 50/60 Hz
Dimensions	• 220 x 115 x 90 mm
Weight	• 0.65 kg

3.2 Installation procedure for MV and HV plants

STER PMU sets will be used for measurement in this campaign. Each measurement set consists of the handheld PMU device, current sensors, connection cables for voltage and current readings, GPRS modem with antenna, integrated GPS antenna/receiver and power supply. The device is capable of storing more than 6 months of data locally, is equipped with a rechargeable battery pack for autonomy during blackout conditions, and uses the GRPS mobile network to keep a continuous connection to the remote server.

A STER PMU device can be placed in virtually any compartment of secondary equipment. Since there are no rotating parts or ventilation openings, device can be placed in any position. All connection sockets and leads are made according to highest safety standards for hand-held measurement equipment allowing fast and safe connection to the secondary circuitry. Both GPRS and GSM antennas have watertight housing with magnetic support for easy position at indoor or outdoor locations.

Procedures for the installation of the measurement system are described in the following chapters.

3.2.1 STER PMU placement

Device can be installed at any appropriate location inside the transformer station: there are <u>no practical limitations regarding temperature, vibrations or device position and orientation</u>.

If possible, it is desirable to install the device <u>inside</u> the electrical cabinet to avoid interfering with regular maintenance operations around the cabinet during the duration or the measurement campaign.

3.2.2 Voltage connections

3-phase voltage measurement is performed by connecting to x kV / 110V secondary circuit of installed voltage transformers (VT).

Voltage measurement configuration can be either <u>star</u>, <u>delta</u> or <u>open-delta</u>.

Connection cables are equipped with 4mm safety plugs made according to IEC 61010 safety standards. For the physical connection to VT secondary wiring inside the cabinet following pre-arranged connections are widely used:

- shrouded 4 mm socket plug (<u>preferred</u>),
- bare 4 mm plug,
- screw connection,
- temporary crocodile connection to exposed secondary circuits (e.g. voltmeters on cabinet front panel).

3.2.3 Current connections

Measurement circuitry is galvanically separated from the CT loop. Current measurement is performed by:

- insertion of three-phase current sensors into the CT secondary loop (preferred), or
- clamp-on installation:
    - using current clamps, or
    - using split-core toroids.

Although the default three-phase sensors (inserted into the CT loop) provide better precision, clamp-on type of sensors are often used because of simplicity of installation.

3.2.4 GPS antenna installation

GPS antenna must be positioned on locations with at least a partially clear sky view. Default cable length is 5 meters, with extensions available up to 30 m.

Antenna can be installed at windows, fences or on the floor, as long as there is an available sky view. Cable can be laid under the door, through ventilation ducts, or other openings (a hole of min Ø 15 mm is needed if the cable has to be pulled through panels or barriers).

3.2.5 GPRS antenna installation

STER PMU is continuously connected to a remote server application for data acquisition and monitoring (WAMSTER) using the ubiquitous mobile telephony. GPRS modem makes the essential component of each STER PMU measurement set.

The GPRS antenna is equipped with a magnetic support. It can be installed on top of the cabinet if the reception signal is adequate. In case of a poor network coverage or other technical limitations, the GPRS antenna can be placed outside the object using an extension cable is used.

3.2.6 Device auxiliary power supply

Short-term spot measurements using STER PMU are particularly simple - battery backup embedded in each device can supply the measurement and communication equipment for several hours.

However, for long measurement campaigns, auxiliary power supply must be provided. Accompanied power supply adapter can be connected to the service socket (preferred), or directly to exposed LV bus bars. Voltage range for the auxiliary supply is 80 – 260 V, 50/60 Hz.

3.3 Electrical connection diagrams

Following images show two typical electrical connection configurations:

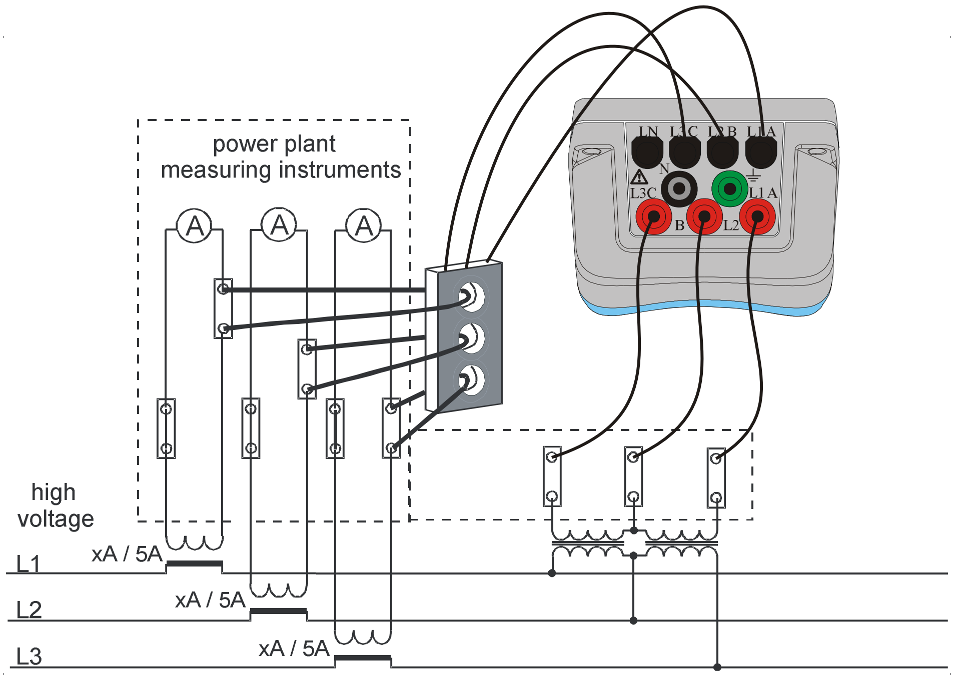


Fig. 4. STER PMU connected to existing CTs using direct insertion, using open-delta voltage connection.

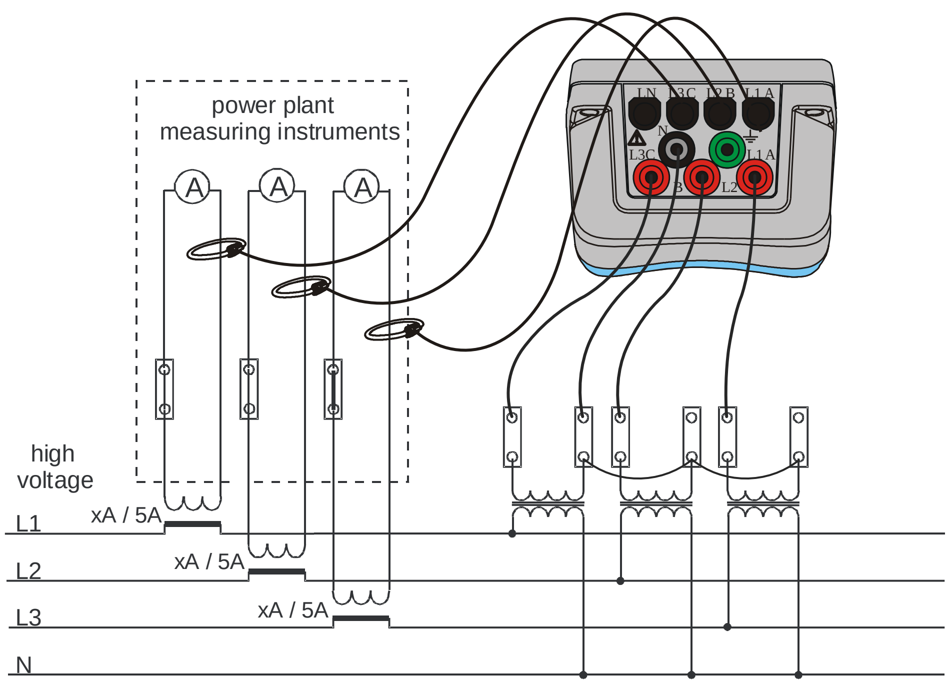


Fig. 5. STER PMU connected to existing CTs using current clamps, using star voltage connection.

Fig. 6. size of SterPMU set equipment compared to ordinary multimeter and smart phone

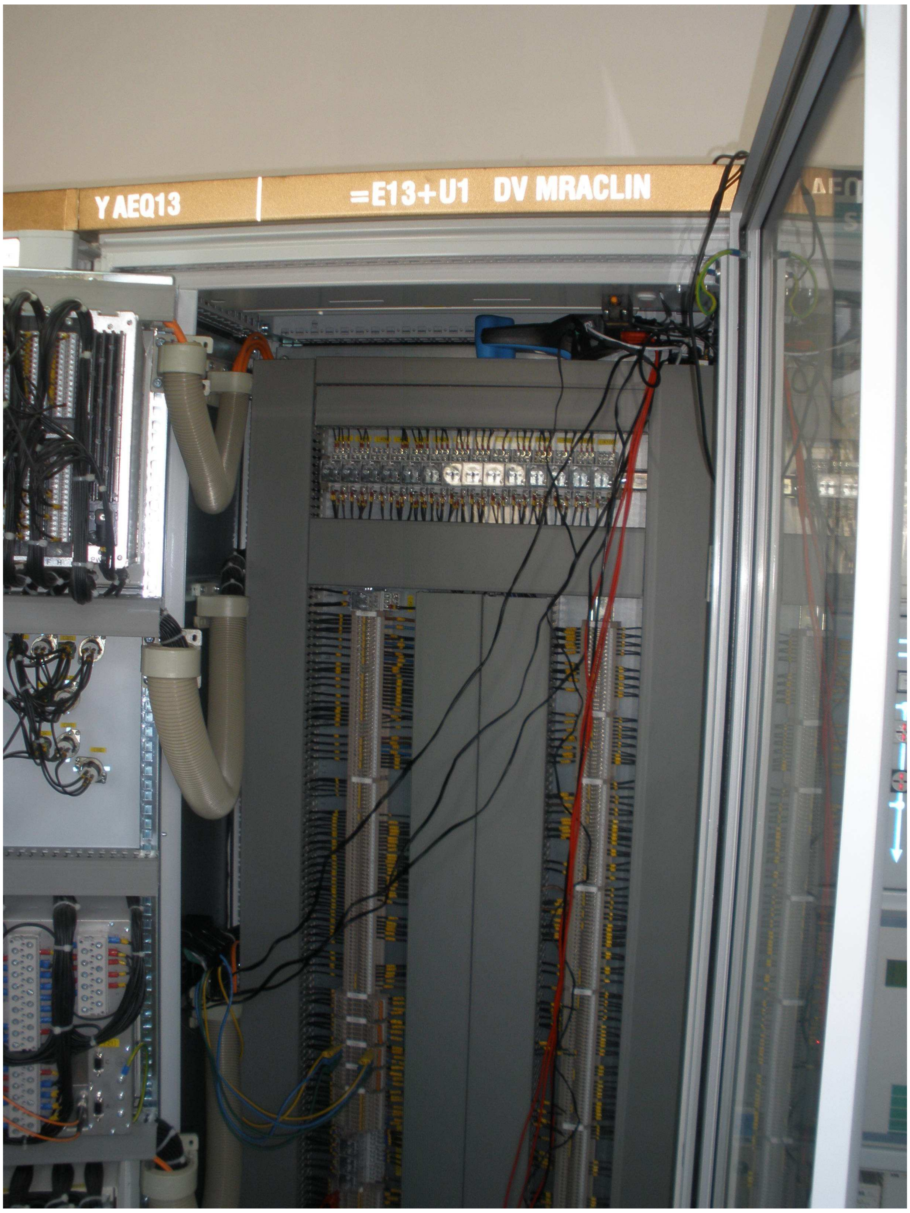


Fig. 7. SterPMU in extreme position on top of cabinet with current sensor in lower left part located close to secondary current terminal block

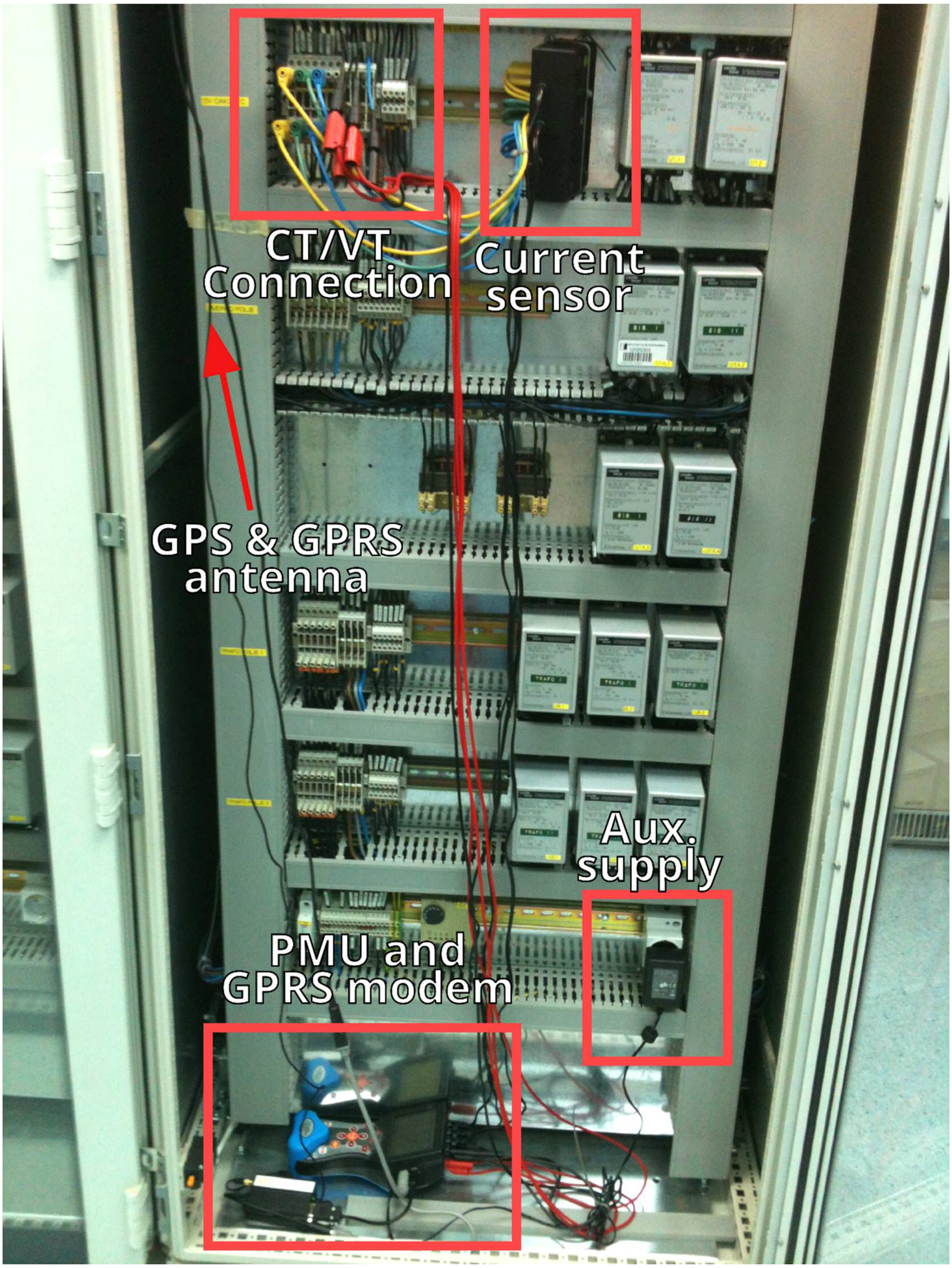


Fig. 8. STER PMU in a typical installation inside a cabinet

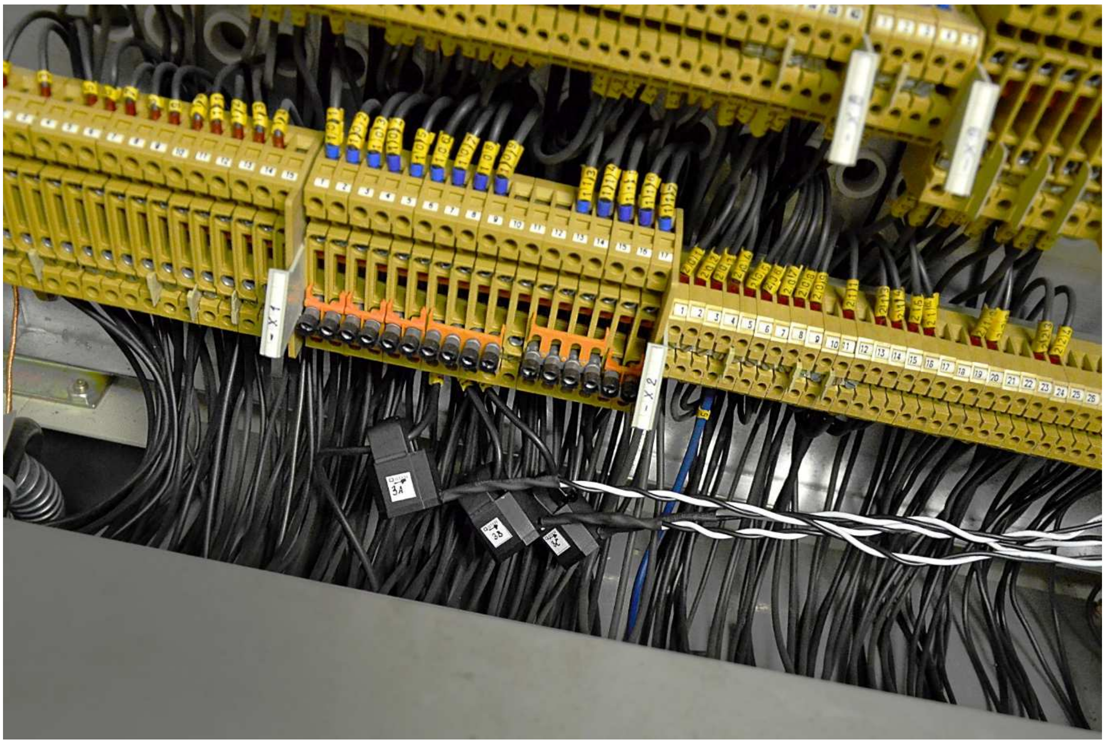


Fig. 9. Typical split-core sensors installation

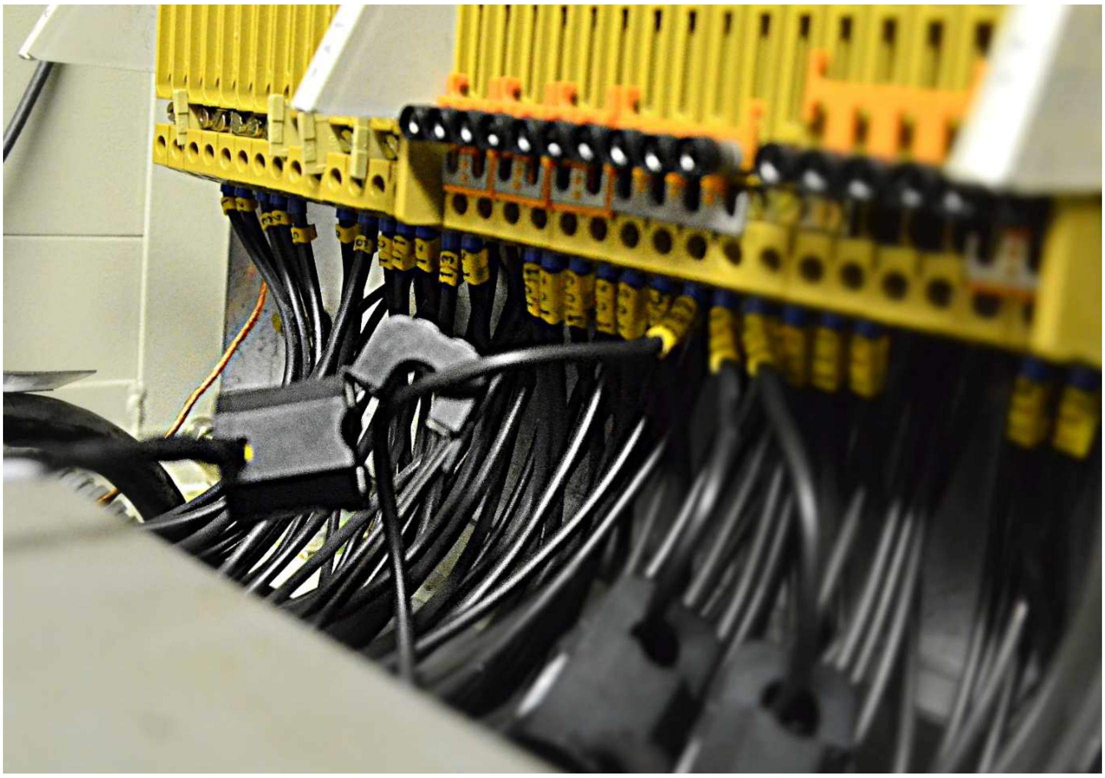


Fig. 10. Open split-core sensor during installation

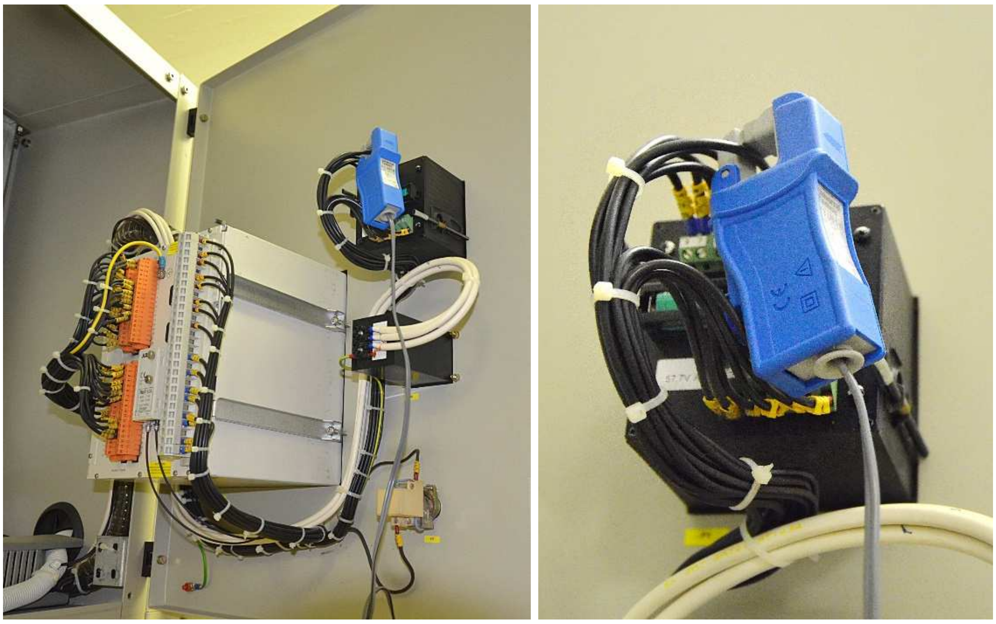


Fig. 11. Current clamps are especially suitable for fast on-spot measurements

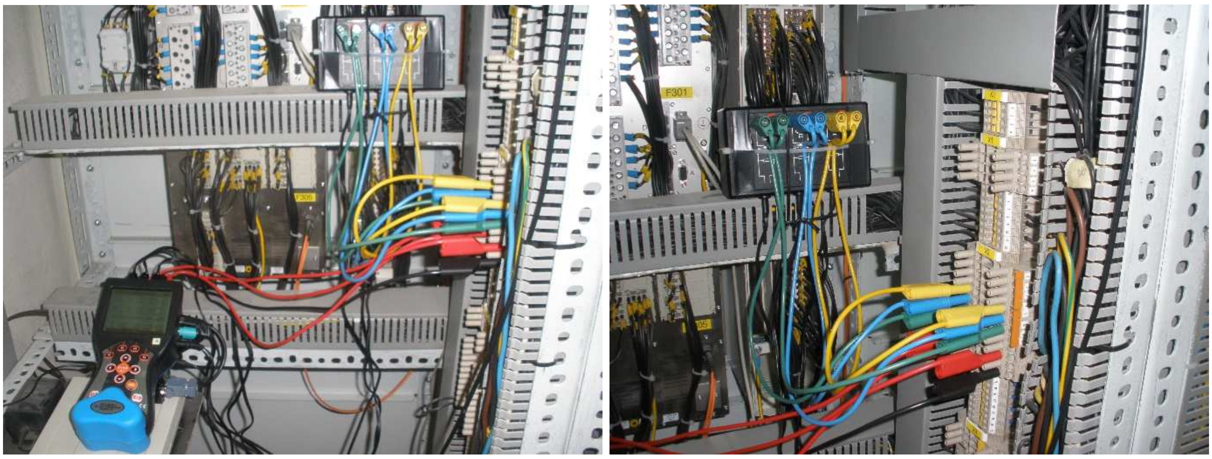


Fig. 12. STER PMU installation – connection to 4mm safety terminal blocks for non-clamp-on current (yellow, blue, green) and voltage (red, black) measurement

Fig. 13. STER PMU installation – GPRS antenna with magnetic support

Fig. 14. STER PMU installation – typical location for the GPS antenna

4 WAMSTER web access

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

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

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, 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 9 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

In order to access dedicated part of Wamster servern, one needs a username/password combination.

Fig. 15. WAMSTER web access – login page

After logging to Wamster, several pages dedicated to specific user group can be accessed. Screen shots of web pages with short descriptions are presented in following pages.

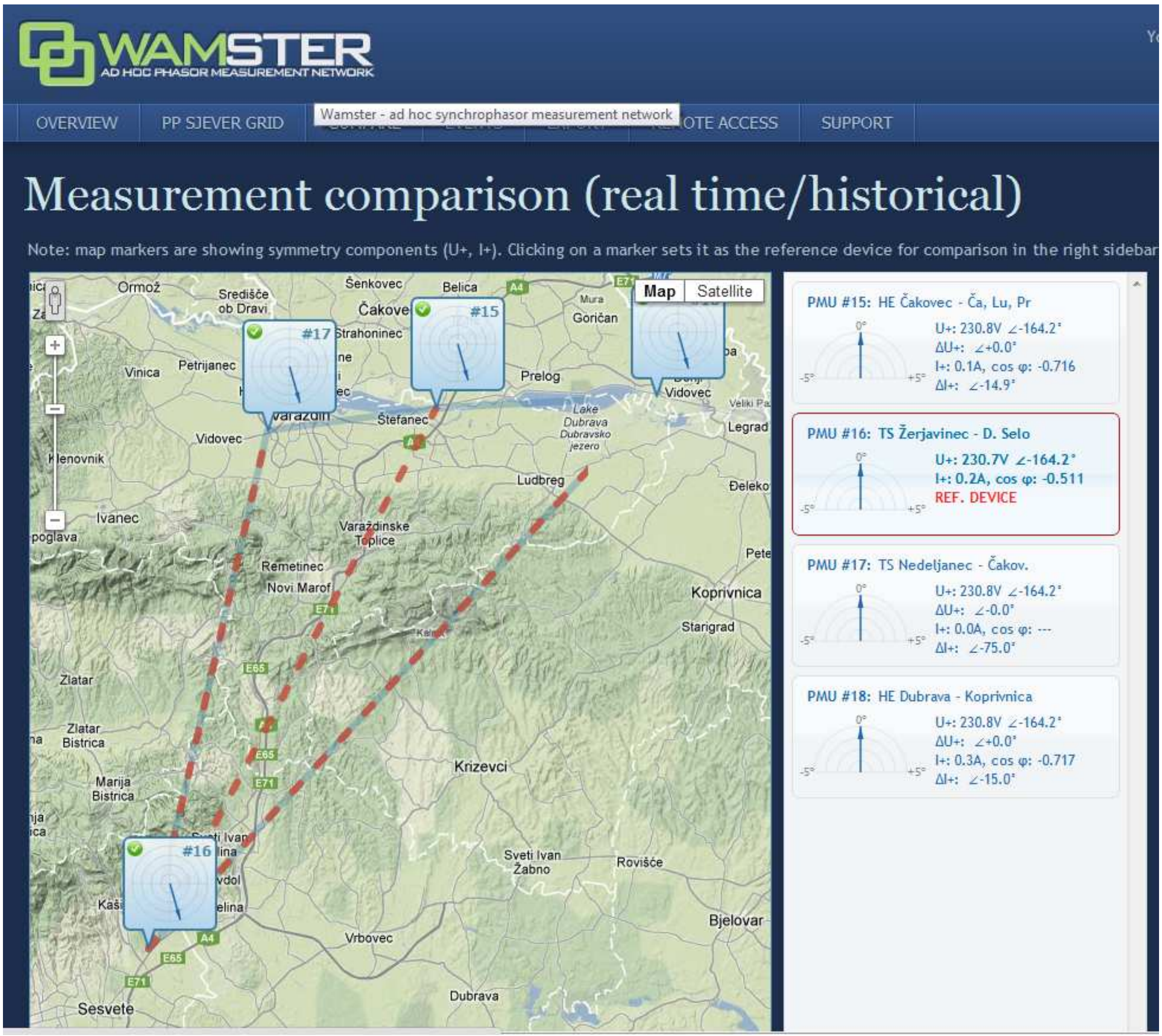


Fig. 16. WAMSTER – COMPARE page with voltage and current information and geolocation allows checking on-line measurement of PMU devices and fast access to historical data

Fig. 17. dedicated WAMSTER – custom single line diagram: voltage, current and power information

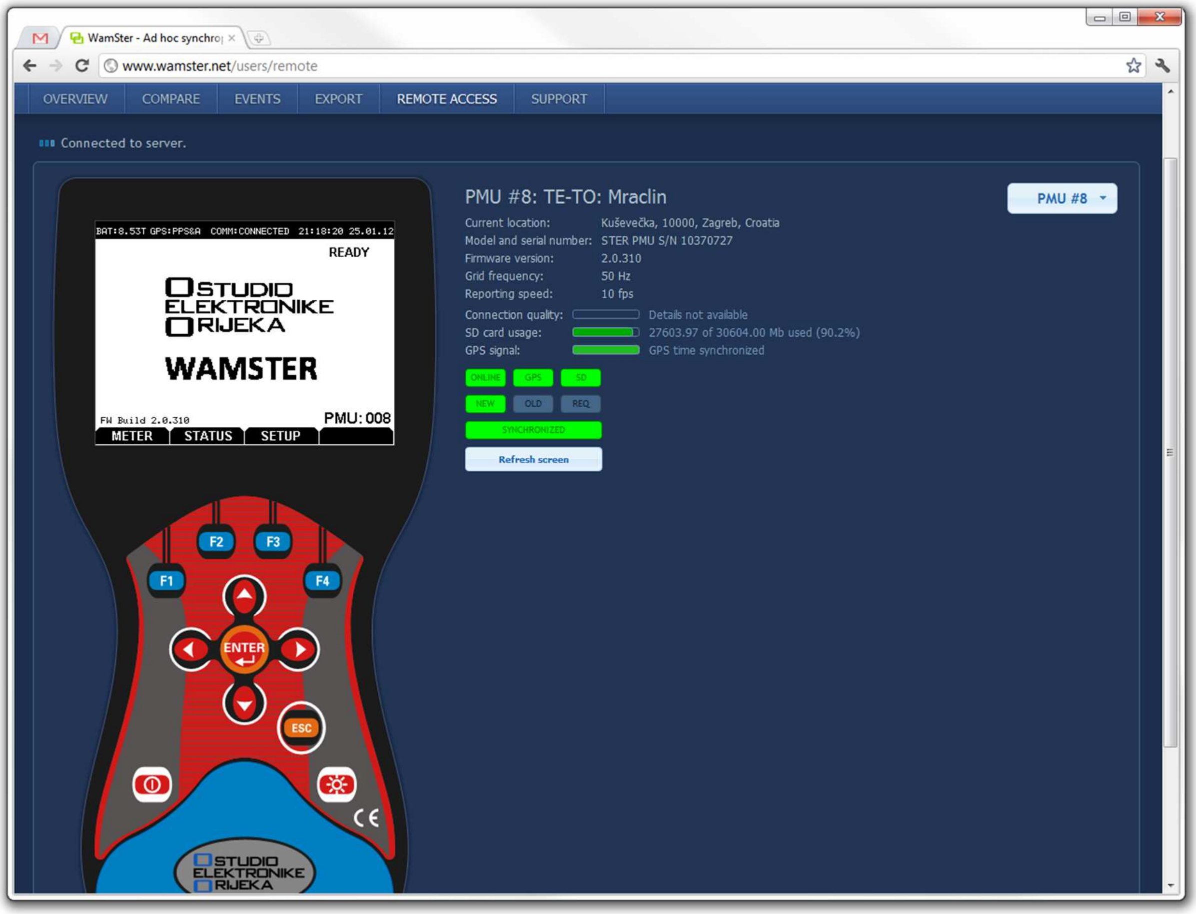
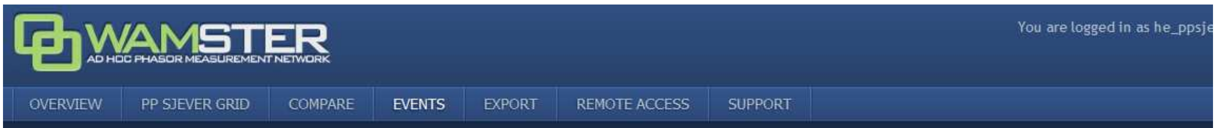


Fig. 18. WAMSTER – REMOTE ACCESS page for configuring/changing parameters on distant unit



List of events

Configure triggers

This table shows automatically triggered events, generated according to predefined rules. Rules can be adjusted on customer request to include arbitrary quantities and properties, with various processing options. To expand event details for each entry, click on the green + sign in the first column.

Display 50 events per page

	Id	PMU#	Event type	Started (UTC)	Duration
	1914	15	Trigger no.44: PMU#15 low-pass (T=0,3s) of rate of change of low-pass (T=0,3s) of L1 Voltage Frequency should be 0.0 Hz with max abs error of 20.0 mHz. Event started with value **21.321** mHz.	09/04/2012 12:13:04.900	N/A (not yet finished)
	1913	15	Trigger no.44: PMU#15 low-pass (T=0,3s) of rate of change of low-pass (T=0,3s) of L1 Voltage Frequency should be 0.0 Hz with max abs error of 20.0 mHz. Event started with value **-3.181** Hz.	09/04/2012 12:12:10.900	38s 300ms
	1912	15	Trigger no.40: the difference between PMU#15 Voltage PosSym Magnitude and PMU#15 low-pass (T=5,0s) of Voltage PosSym Magnitude should be 0.0 V with max abs error of 2.0 kV. Event started with value **-28.8 kV**, peak value was **-55.5 kV** at 09/04/2012 12:12:10.900.	09/04/2012 12:12:09.700	17s 900ms
	1911	15	Trigger no.54: the difference between PMU#15 ActivePower Total and PMU#15 low-pass (T=5,0s) of ActivePower Total should be 0.0 W with max abs error of 3.0 MW. Event started with value **-4.6** MW, peak value was **-8.8** MW at 09/04/2012 12:09:30.700.	09/04/2012 12:09:30.400	5s 900ms
	1910	15	Trigger no.54: the difference between PMU#15 ActivePower Total and PMU#15 low-pass (T=5,0s) of ActivePower Total should be 0.0 W with max abs error of 3.0 MW. Event started with value **4.0** MW, peak value was **4.3** MW at 09/04/2012 12:09:03.900.	09/04/2012 12:09:03.800	2s 400ms
	1909	18	Trigger no.47: PMU#18 low-pass (T=0,3s) of rate of change of low-pass (T=0,3s) of L1 Voltage Frequency should be 0.0 Hz with max abs error of 20.0 mHz. Event started with value **819.935** mHz.	09/04/2012 10:39:16.000	N/A (not yet finished)
	1908	18	Trigger no.43: the difference between PMU#18 Voltage PosSym Magnitude and PMU#18 low-pass (T=5,0s) of Voltage PosSym Magnitude should be 0.0 V with max abs error of 2.0 kV. Event started with value **-4.7** kV.	09/04/2012 10:37:42.800	5s 100ms
	1907	18	Trigger no.43: the difference between PMU#18 Voltage PosSym Magnitude and PMU#18 low-pass (T=5,0s) of Voltage PosSym Magnitude should be 0.0 V with max abs error of 2.0 kV. Event started with value **-28.9** kV.	09/04/2012 10:37:26.800	13s 400ms

Fig. 19. WAMSTER – EVENT page with list of detected events

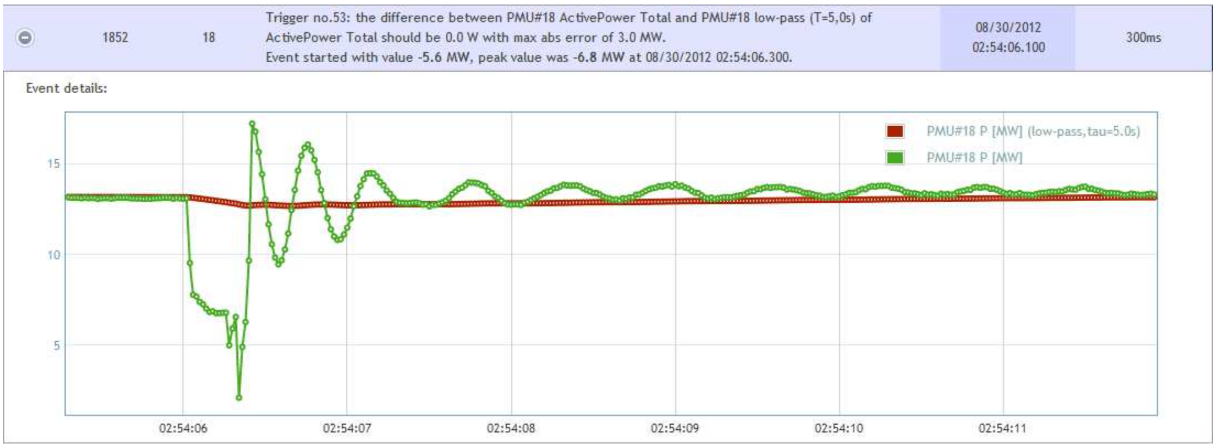


Fig. 20. WAMSTER – EVENT page – detailed event view

Fig. 21. WAMSTER – TREND page – showing triggered events

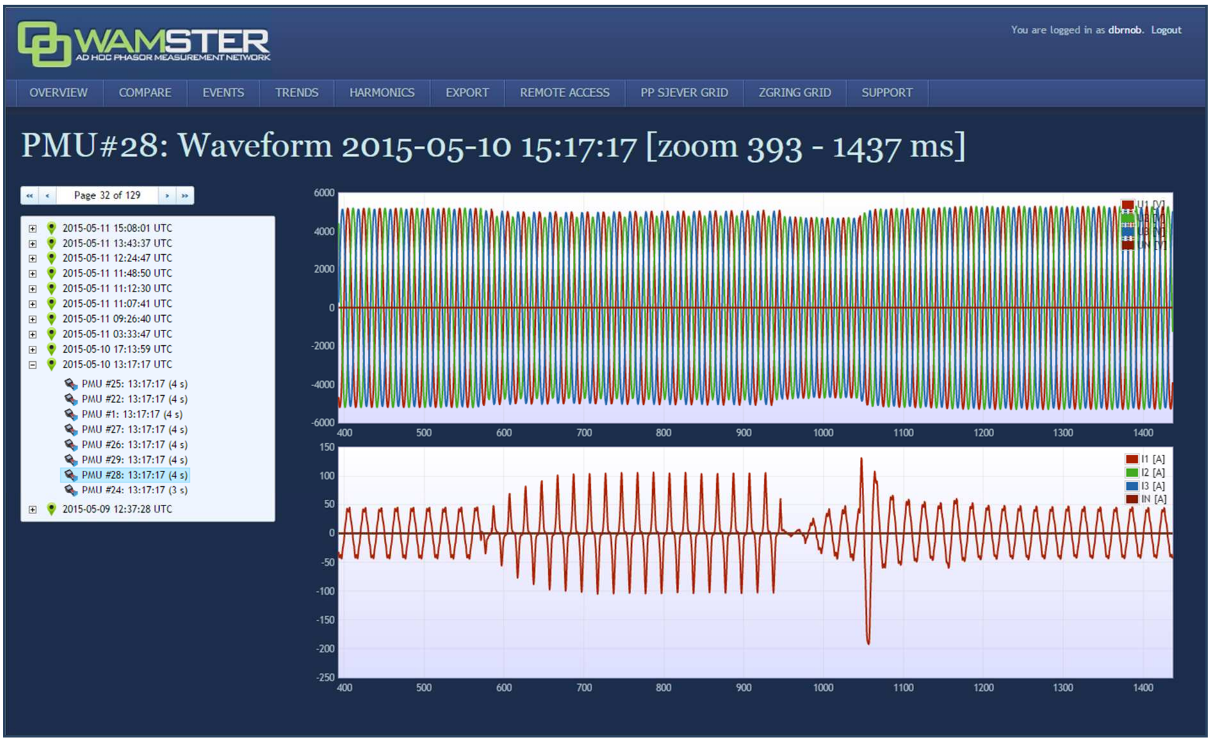


Fig. 22. WAMSTER – WAVEFORM SNAPSHOTS page – showing downloaded oscillograms

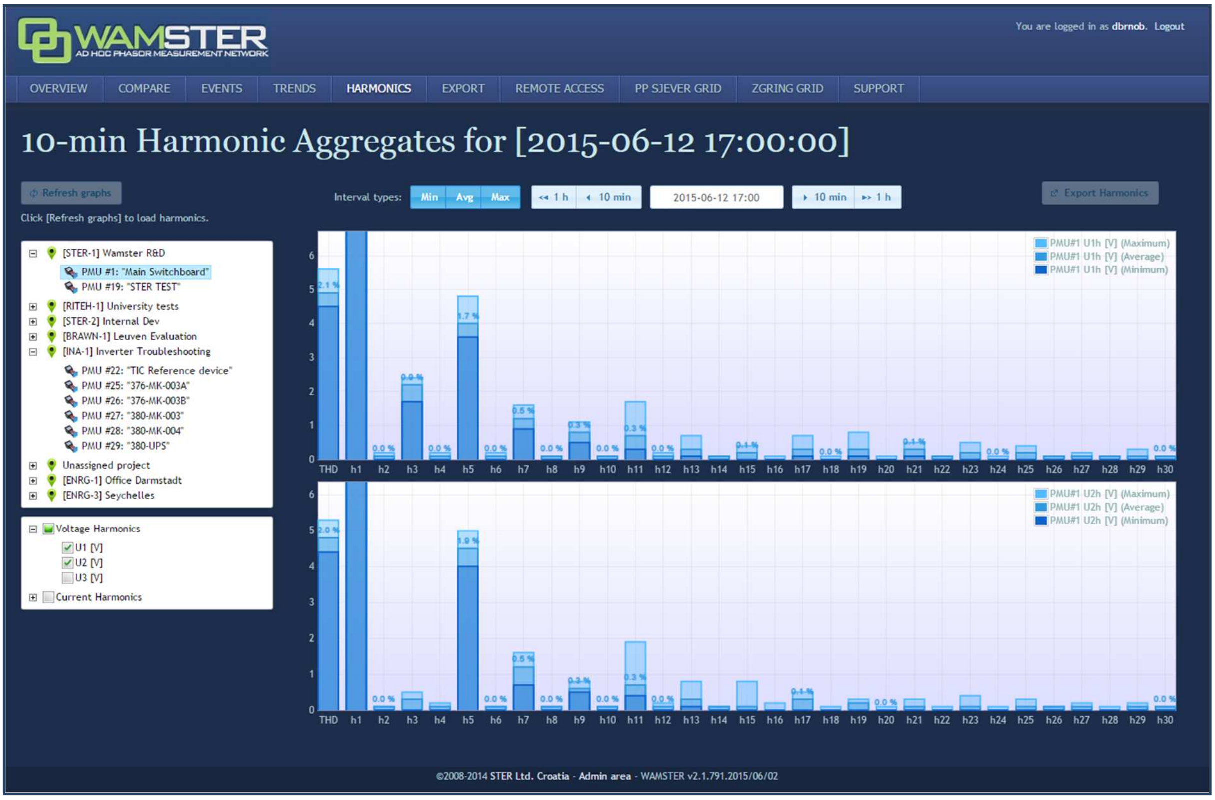


Fig. 22. WAMSTER – WAVEFORM HARMONICS page – showing 10-min harmonic aggregates

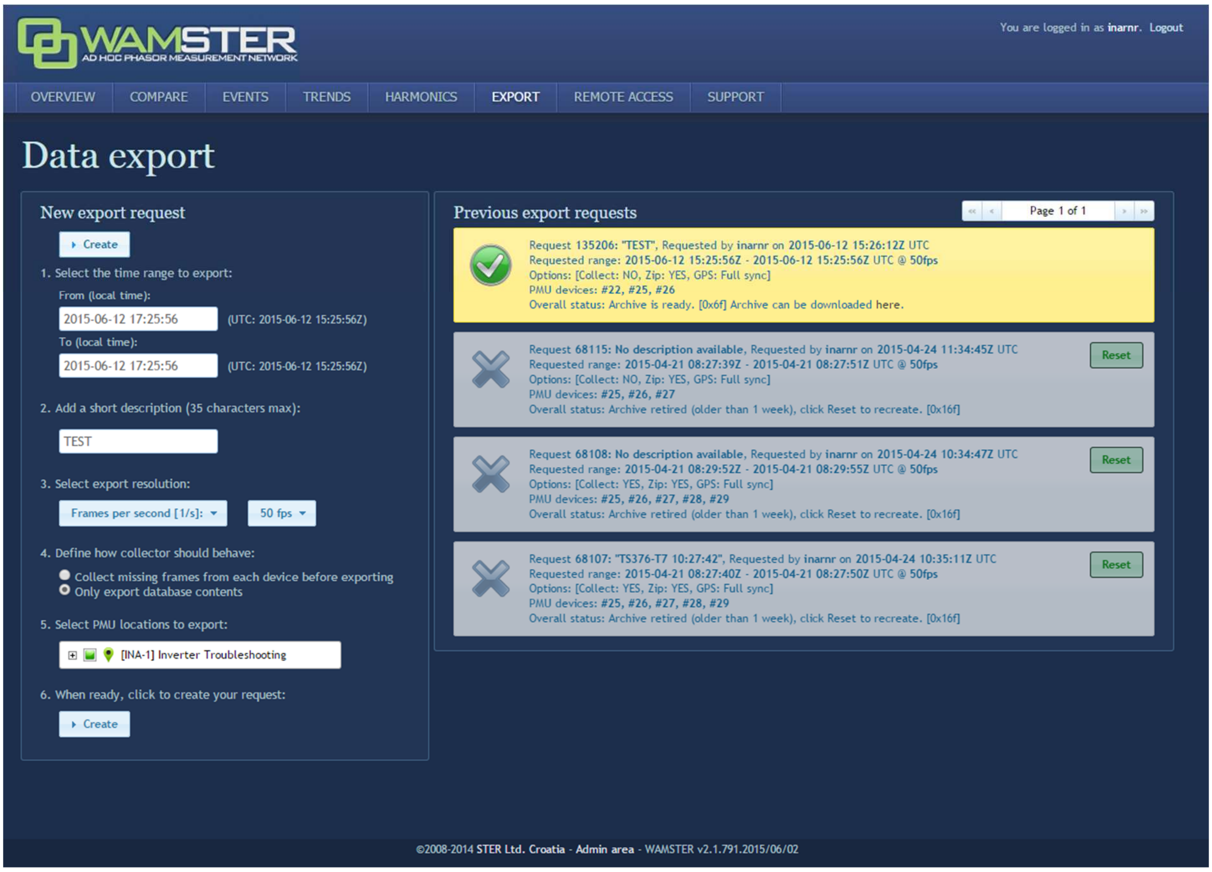


Fig. 23. WAMSTER – EXPORT page for creating and downloading data achieves

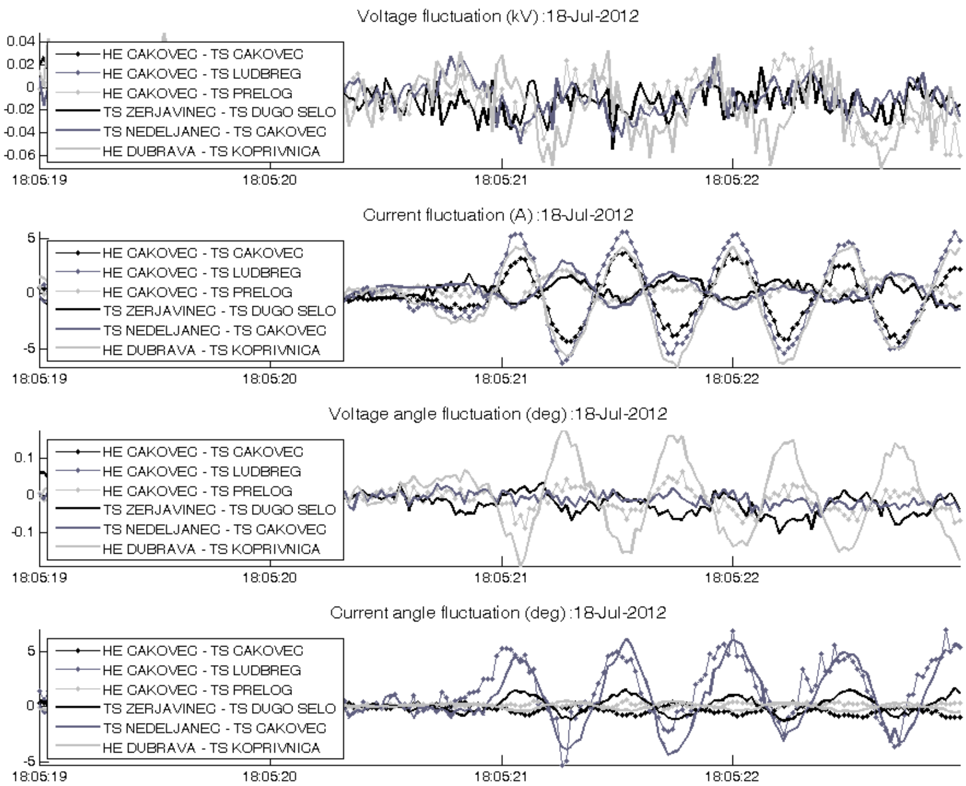


Fig. 22. dedicated WAMSTER – exported data presented by third party software

5 References

5.1 CARWAMS

WAMSTER has been used as the measurement and communication platform for the CARWAMS (Croatian Academic Research Wide Area Monitoring System) project in 2010 and 2011. In this project STER PMU units were installed on 0,4kV grid on four Croatian universities, located in different transmission areas. The aim of the project was long term synchrophasor data base lining and disturbance events capturing, and several WAM systems have been formed on HV-MV-LV levels. PMUs are still permanently installed in the Laboratory for Control and Protection.

National foundation for Science (NZZ) project "Intelligent Systems in Power Transmission Grids" leading by dr. Srdjan Skok at Faculty of engineering, University of Rijeka (srdjan.skok@riteh.hr; http://www.riteh.uniri.hr/zav_katd_sluz/zee/nzz/nzz.htm)

5.2 ZG RING

WAMSTER has been used as provider of synchrophasor data at the initial step of the SIPS project design for TSO. Project has been conducted by Faculty of Engineering, University in Rijeka. Six STER PMUs have been installed in 110 kV substations forming a loop around Croatia's capital Zagreb from September 2011 until June 2012. Data collected by WAMSTER has been used for model tuning in conjunction with data captured by the existing SCADA system. Several captured events revealed previously unknown dynamics of the system, and the use of WAMSTER allowed these new findings to be incorporated into the SIPS algorithm definition at an early design phase.

Customer representative on project: Mr. Hrvoje Bulat, Assistant CEO at national-wide TSO (Hrvoje.Bulat@hep.hr, http://www.hep.hr/ops/en/aboutus/menagement.aspx).

5.3 PP SJEVER

Ad-hoc network consisting of 4 PMUs located in two hydro plants, neighboring a 110kV substation and the closest 400/220/110 kV substation in northern Croatia from July 2012 until September 2012. Installation of these devices took only a couple of hours. A two months long trial period revealed completely new dynamics of the problematic generator set. The results of the trial system were so fruitful that a permanent installation on generators and HV substations is planned in the next iteration, incorporating an additional input to the upcoming rail mounted version of STER PMU for the rotor position pick-up.

Customer's representative: Mr. Miljenko Brezovec, director HE Dubrava (Miljenko.Brezovec@hep.hr, http://www.hep.hr/proizvodnja/en/basicdata/hydro/north/dubrava.aspx) .

5.4 UMEME24/7

UMEME24/7 is a FP7/Eurostars funded project with the objective to develop and test solutions that will improve power supply and stability for consumers in Kenya based on social, economic and technical measures. Energynautics Gmbh from Darmstadt, Germany, is leading measurement part of project. Six PMUs are placed in different parts of Kenya in December 2012. WAMSTER system serve as an ad-hoc WAMS for collecting wide area disturbance dynamics in the first phase of a project. In the second phase, collected knowledge and installed WAMS and PMUs will be used for predicting black-outs or voltage disruption. Formed close loop will control back-up diesel gensets in order to mitigate the black-out conditions.

Customer's representative: Mr. Stefan Langanke at Energynautics GmbH Darmstadt, Germany (s.langanke@energynautics.com, http://www.energynautics.com/start.php)

5.5 NIGERIA BRIDGING SCADA

A demonstrational measurement campaign in Nigerian LV grid took place during April and May 2013. Organized and coordinated by Dr. Rawn from KU Leuven, Belgium, this demo aimed to check the availability of Nigerian mobile telephone network in proposed "Bridging SCADA" concept. Bridging SCADA attacks a problem of electrical systems monitoring and control in areas without convectional communication infrastructure. This online demo for the first time provided a live feed of system frequency to the National Control Centre at Oshogbo.

Customer's representative: Dr. Barry Rawn, KU Leuven, Belgium *(barry.rawn@gmail.com)*

5.6 TRANSCO/ADWEA: Dynamic Reactive Compensation Strategy project (2014-2015)

Aim of the measurement campaign project by our client Tractebel Engineering in UAE was to collect measurement data needed for a reactive power study and distribution load modeling for the Abu Dhabi Transmission & Despatch Company (TRANSCO) and Abu Dhabi Water and Electricity Authority (ADWEA), with the goal of developing a dynamic reactive compensation system. To provide the necessary measurements, 20 STER PMU devices were installed at several locations around UAE, including the Abu Dhabi Critical National Infrastructure Area. WAMSTER Team fully assisted the on-site installation and configuration. More than 250 event triggers were configured to detect various fluctuations in the grid across the country.

5.7 SIDS DOCK Seychelles (2014)

Seychelles Public Utilities Corporation (PUC) and Seychelles Energy Commission (SEC) recently entered into an agreement with our client Energynautics to improve levels of renewable energy generation on the Indian Ocean islands. The study will be performed in 4 steps, from gathering information about the grid, through drafting the grid code and examining tariff levels, ending with final templates and models for the full range of possible renewable energy systems. Devices were installed with ease by our client.