NASPI North American SynchroPhasor Initiative

NASPI Work Group Virtual Meeting and Vendor Show

HOPS

WAMS in the control room – a TSO perspective

HOPS Croatian Transmission System Operator

05.10.2021.

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Agenda

- About HOPS Croatian Transmission System Operator
- 17 years of synchrophasor application in HOPS
- WAMS in the control room
- Synchrophasor assistance in disturbances
- Cyber security issues in WAMS

About HOPS – Croatian Transmission System Operator

Croatia is in Central and Southeast Europe, on the coast of the Adriatic Sea

HOPS – Croatian Transmission System Operator

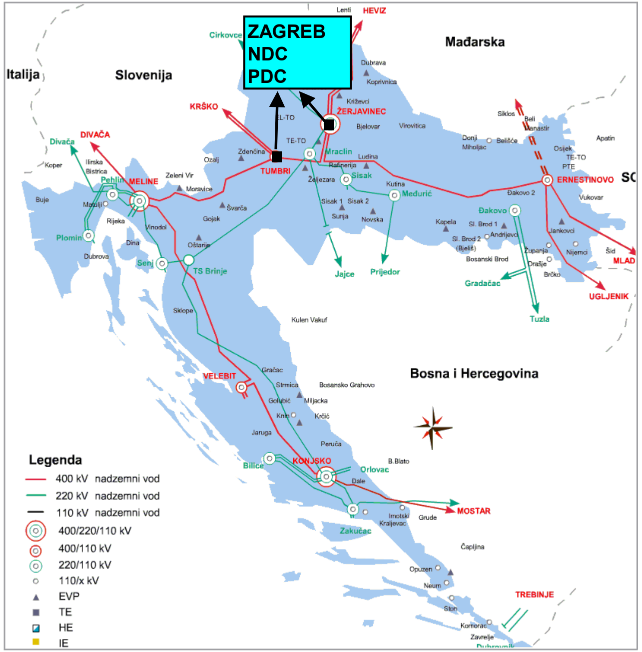
Transmission Lines (km)
7.795

Substations (num)
183

Voltage levels
400 kV
220 kV
110 kV

Synchrophasor applications – beginning 2003

- Resynchronization of the first and second synchronous zones (10th October 2004.)
- After the reconnection energy transit through Croatian power system became significant
- Hypothesis - implementing PMU based monitoring enhanced stability monitoring of the power system and optimized energy transit



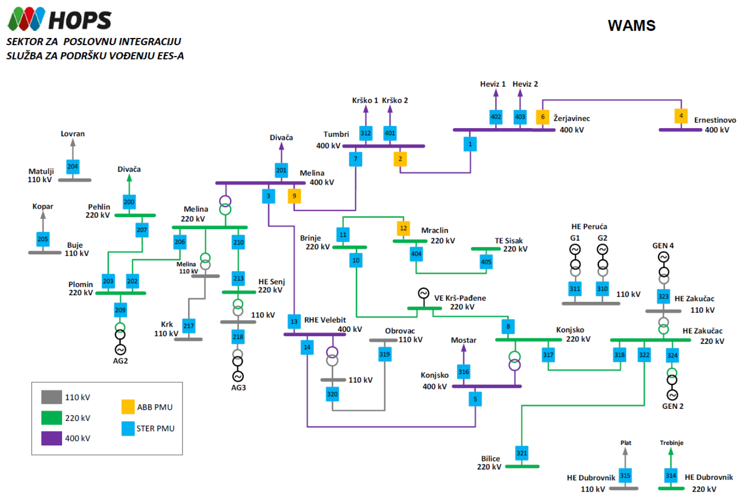
2003.-2004.

2 PMUs – Arbiter Systems, model 1133A

PDC : ABB PSGuard 830

Synchrophasor applications – today

- Over 50 PMUs installed
- 1 PMU:
  - 1 set of voltage, current and frequency measurements
  - Phase values and symmetrical components
- PMU placement depends on its function:
  - Measurement redundancy for network applications
  - Tie lines
  - 400 kV internal lines
  - Point of Connection with power plants



2004.-2021:

2 PMUs manufacturers:
ABB RES 521
STER PMU

General practice:
No mixing of different PMU manufacturers:
- Angle deviation due to different phasor estimation algortithms
2005 vs 2011 Std

Motivation for further development in HOPS

Motivation for further development of the WAM system:

- ✓ Existing power system control system (SCADA) need to be improved in order to be able to adequately monitor the involvement of renewable energy sources
- ✓ One of the possibilities is to use synchronized measurements to monitor and control the power system
- ✓ PMU measurements are not intendent to be a replacement for SCADA/EMS, but rather a valuable supplement to them

Development or “off the shelf” PDC?

- No straight answer
- Each TSO/utility should consider its own path for WAM development according to its needs

- Advantages of commercial applications:
  - ✓ Faster integration
  - ✓ Maintenance provided
  - ✓ Stable and tested platform
- Disdvantages of commercial applications:
  - X Pricing
  - X Flexibility for development of new functions
  - X Integration with SCADA/EMS systems

- Advantages of developing own WAM system:
  - ✓ Developing applications which cover niche cases
  - ✓ Flexibility
  - ✓ Pricing
- Disadvantages of developing own WAM system:
  - ✓ Maintenance

Most of the WAM systems are running independently and they do not share connections with other systems such as EMS, SCADA

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WAMS in the control room

Wide Area Monitoring has been in use worldwide for more than fifteen years within TSOs environments, a lot of experience has been accumulated.

However, the final goal of integrating WAM system capabilities into TSOs standard operation and monitoring processes has not been fully achieved

Technical Integration Issues

Integration issues related to the communication network
WAM system data exchange between TSOs with different IT policies
High availability on the application layer
Existing SCADA/EMS are often not suited for seamless WAM system integration
Integration issues related to data management and analysis methods

Non technical Integration Issues

Operator acceptance – confidence gap

Missing clearly defined countermeasures to mitigate unsecure operation

Usability and capabilities of WAM system based control applications

Missing regulatory aspects

WAMS in the control room HOPS approach

Obtain information from synchrophasor measurements to be presented to the operator with associated measure / action

- How:

1. Integration with SCADA system:
   - Warnings / alarms
   - Basic views (as much as possible due to the limitations in the possibilities of visualization in the SCADA system)

2. Integration with other existing systems in the operator's room (OsiSoft, network applications, European Awareness System EAS)

3. Access to WAM system for detailed analysis and review of information in case of an alarm

4. Development of WEB application for advanced views on the Video wall

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Synchrophasor applications in HOPS– today

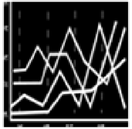
- No ‘killer’ application to cover all possible usages
- Niche cases to cover needs
- The usage of PMU data in HOPS depends on the issue to monitored or solved

Real Time Application

- Phase angle difference monitoring
- Frequency monitoring
- AGC measurements
- Broken conductor detection
- Oscillation detection (pilot)

Planning and Monitoring

- Monitoring of FCR
- Loss calculation per line (loss calculation due to corona effect)
- Transmission line parameter calculation (pilot)



Disturbance Detection and Analysis

- Protection functions:
  - Overcurrent
  - Differential
  - Distance
- Fault Locator on transmission Lines

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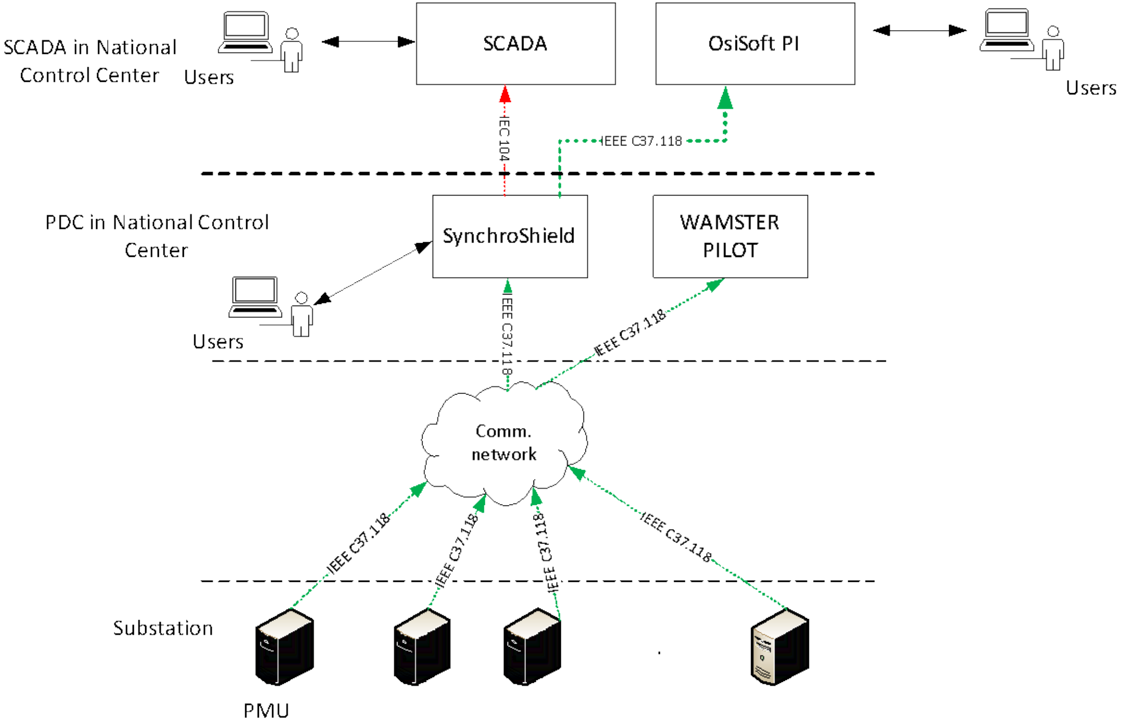
WAMS architecture in HOPS



- PMU - PDC (Phasor Data Concentrator) communication via IEEE C37.118 synchrophasor protocol
- Two PDC systems in NDC:
  - SynchroShield - operational, in production
  - WAMSTER - pilot installed 2017
- SynchroShield connection to:
  - SCADA via the IEC104 protocol
  - OsiSoft system via synchrophasor protocol

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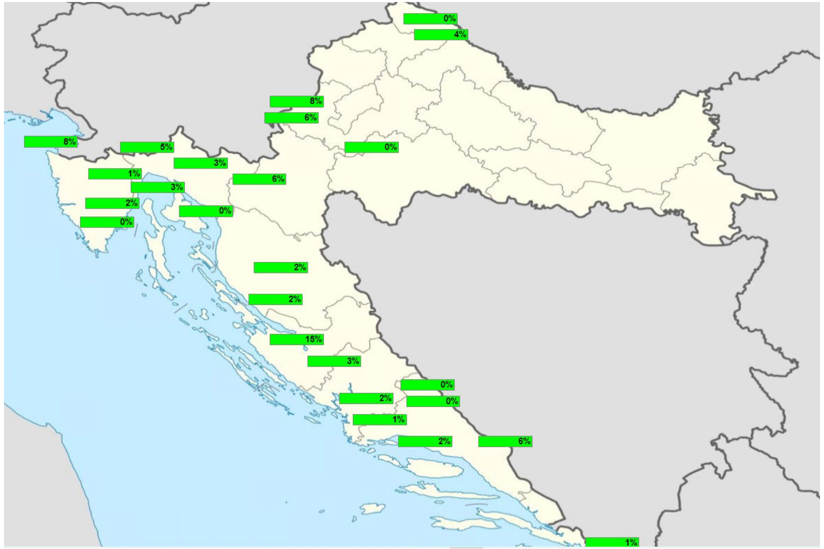
Real time applications – PDC view

Voltage phase angle monitoring between EU TSOs

Detection of unbalanced operation



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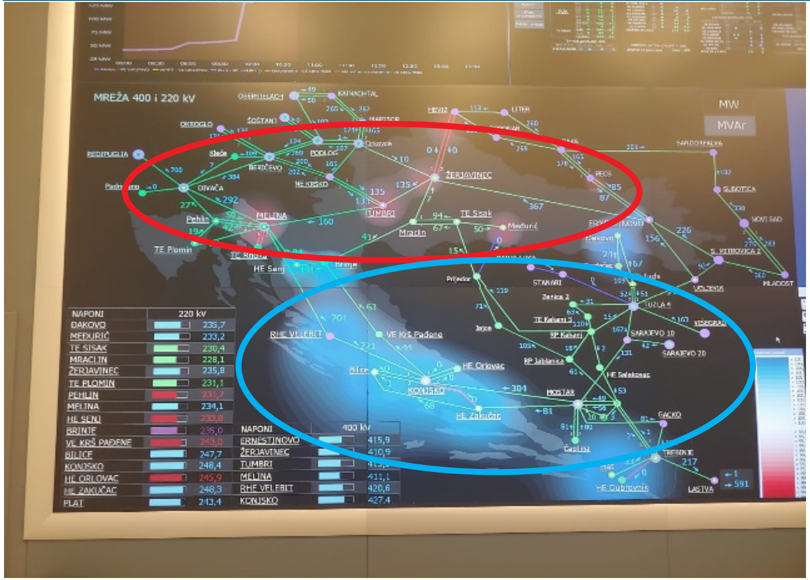
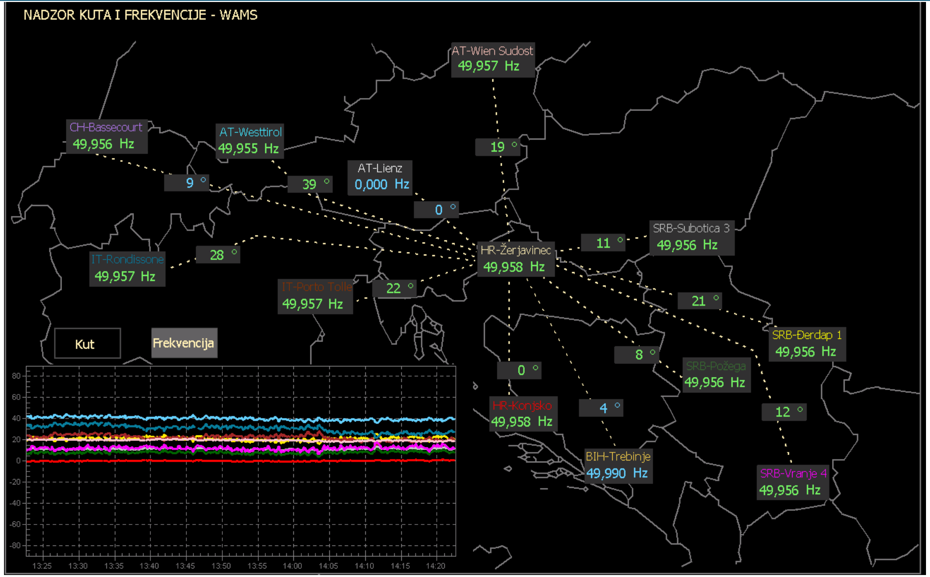
Real time applications – SCADA view

PMU and WAMS data integrated with SCADA/EMS system



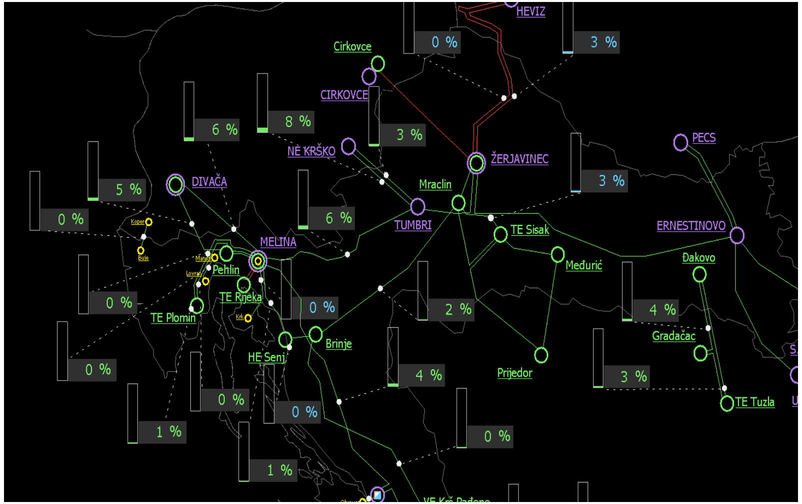


- Dynamic Contour Coloring by frequency
- Islanding detection
- Data from internal PMUs and PMUs from neigbouring TSOs

- Phase angle difference monitoring
- Frequency deviation monitoring

Real time applications – SCADA view

PMU and WAMS data integrated with SCADA/EMS system



- Monitoring of unbalanced operation
- Broken conductor monitoring

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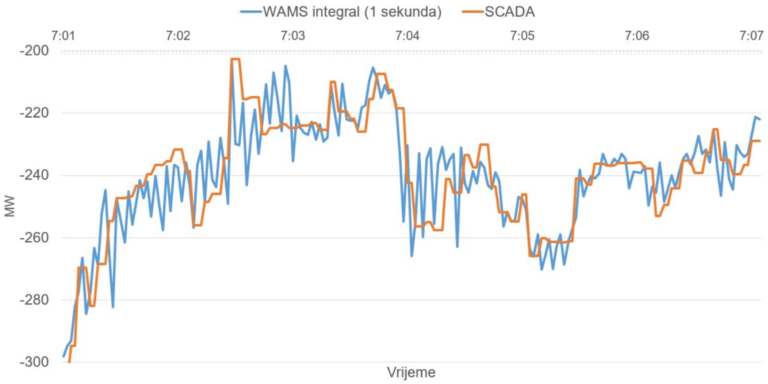
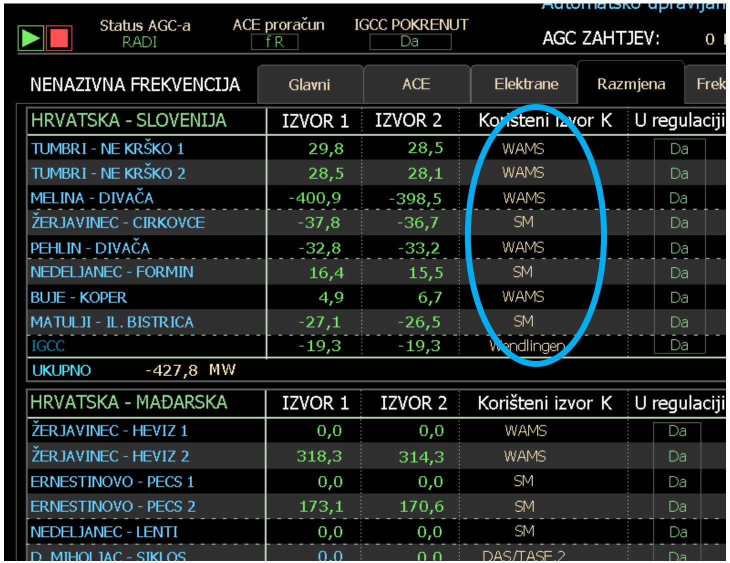
Real time applications–integration with AGC

PMU data used as primary measurements fro Automatic Generation Control system:

- Integration of synchrophasors (1 s)
- Synchrophasor measurements on tie lines



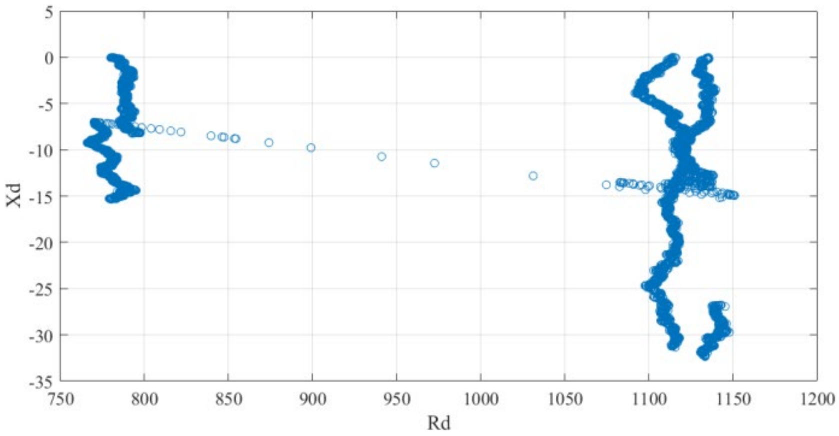


Selection of source type in AGC:

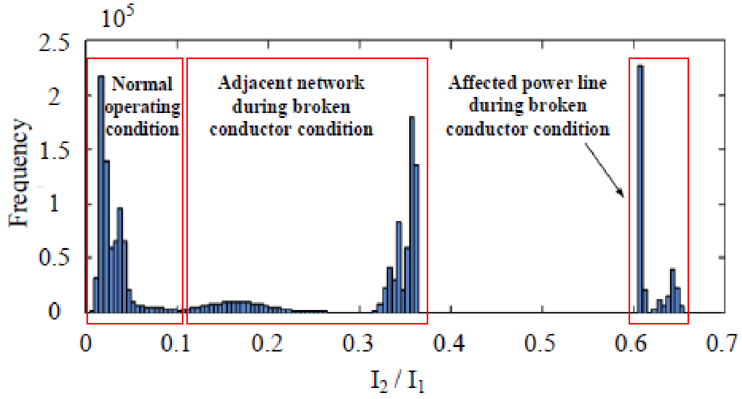
- WAMS
- SCADA

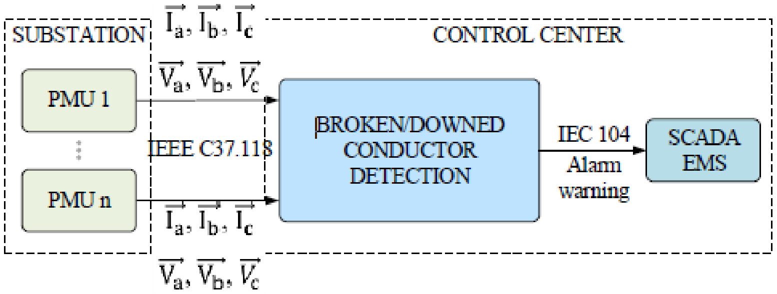
Real time applications – broken conductor detection

Change of positive sequence component impedance during broken conductor condition



Inverse and positive sequence current component ratio during different operating condition

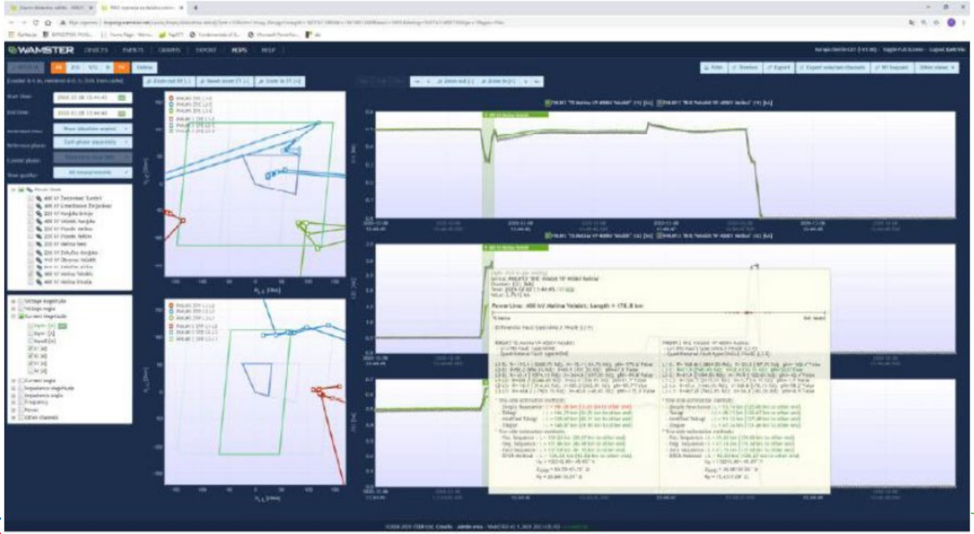


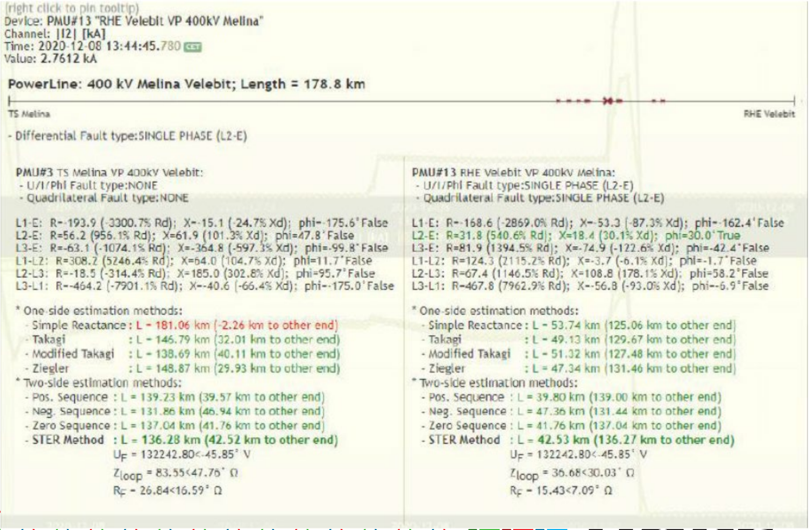


- Measurements of symmetrical components delivered by PMUs to the control center
- Alarming in the National Dispatch Center if broken conductor detection is detected

Real time applications – fault locator

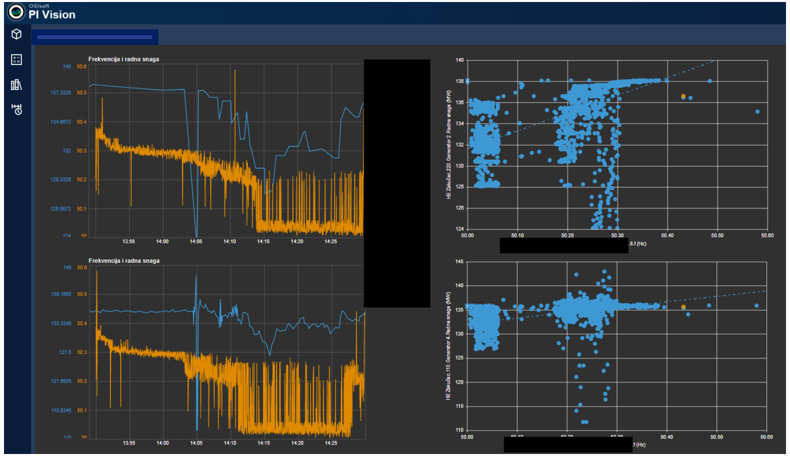
- Fault location assessment usually calculated in distance protection relays
- HOPS uses a system using:
  - Single PMU method
  - PMUs on both terminals
- Calculation methods confirmed with field survey

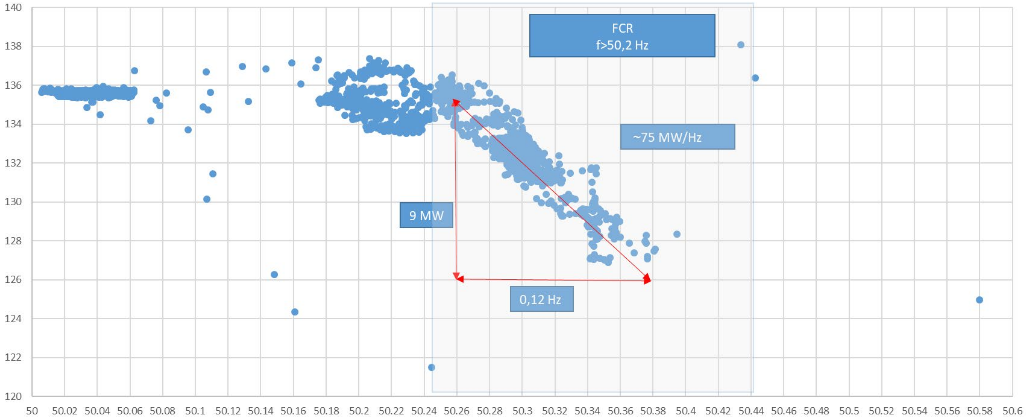




Monitoring of Frequency Containment Reserve

- Frequency containment reserve (FCR) - **necessary for constant containment of frequency deviations (fluctuations) from nominal value**
- Monitoring of activation of primary regulation with PMUs installed on the Ppoint of connection with power plants
- PMU data sent to the visualization tool OsiSoft PI





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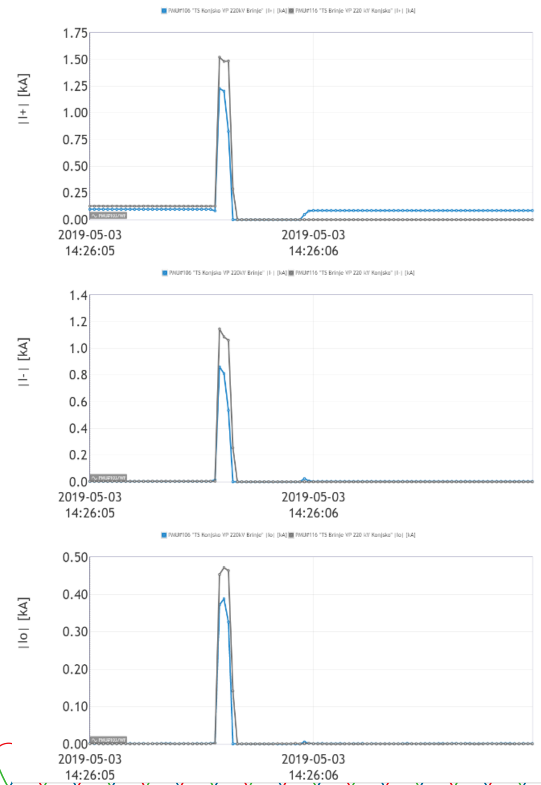
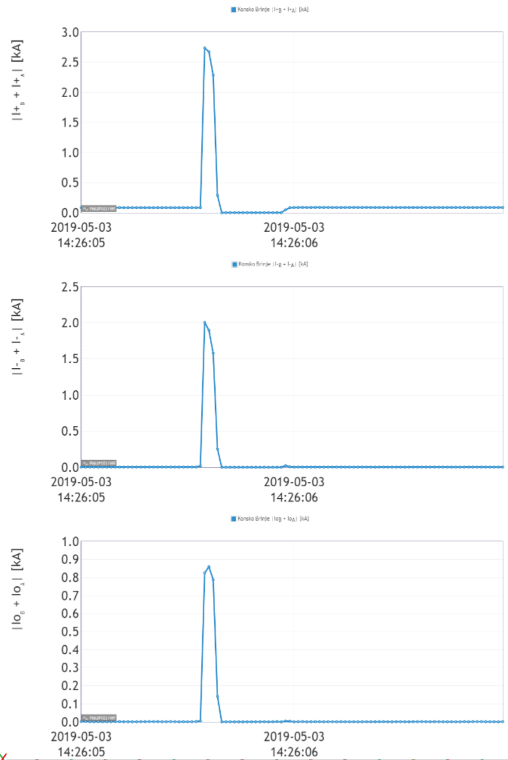
Protection functions - Differential protection



Amplitude of positive, inverse and zero components at the ends of transmission lines during fault



Vector sum of current components at both ends or differential current

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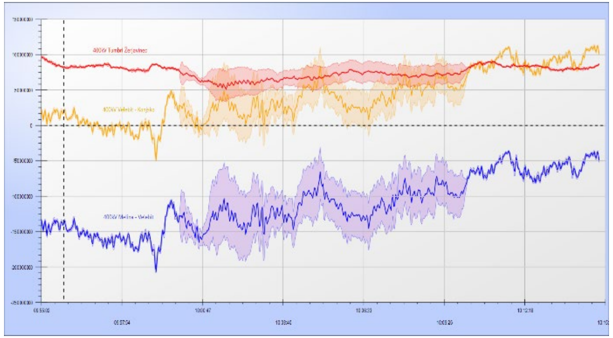
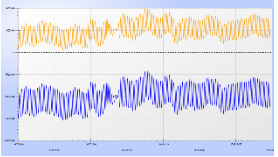
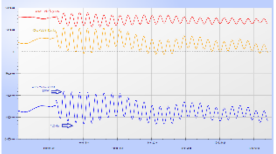
Synchrophasor assistance in disturbances (November 14th 2014)

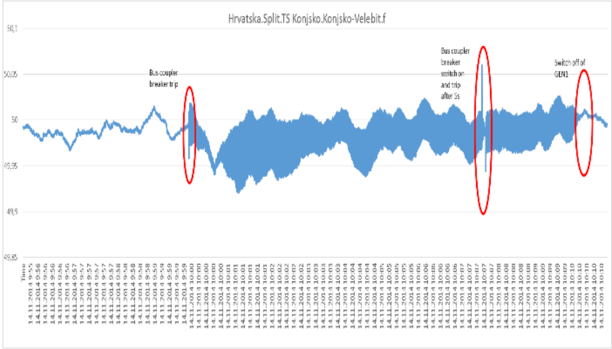
Active power oscillations on 400kV lines

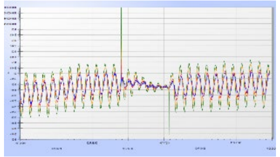


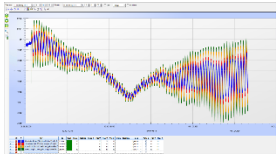




Power system frequency oscillations

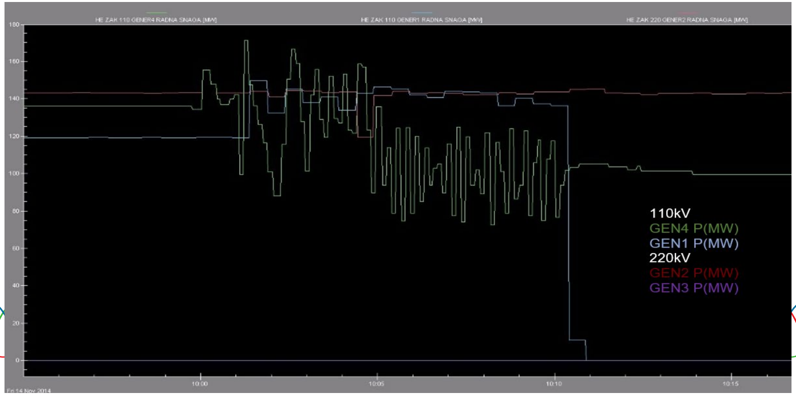




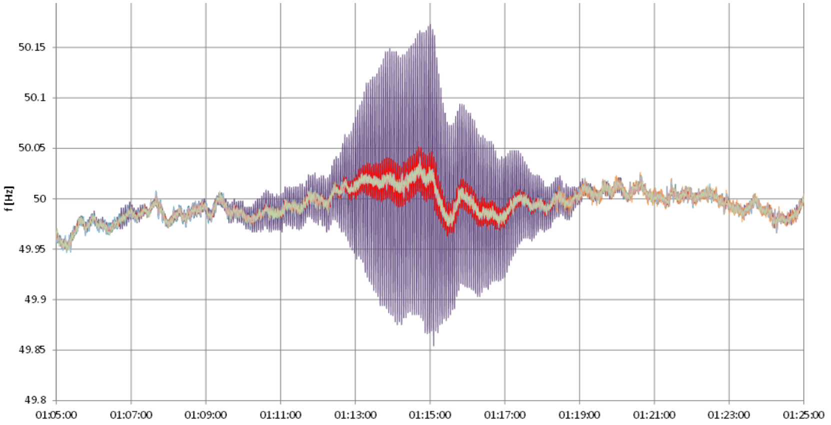


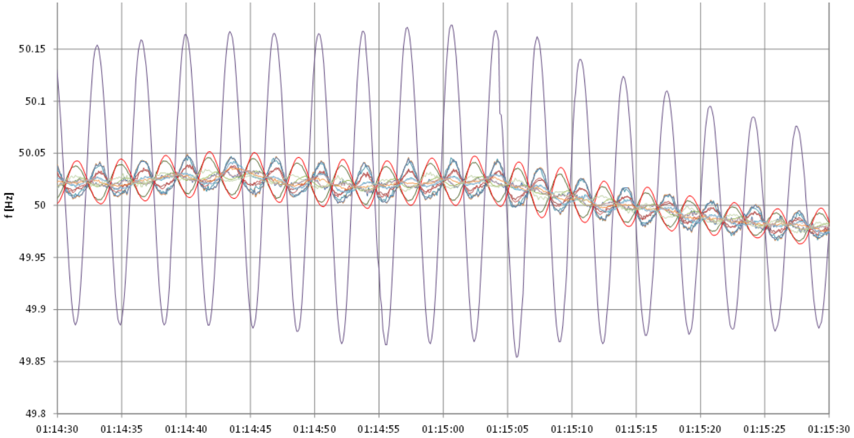
WAMS system helped to locate the fault that caused the oscillations

(generator in the hydro power plant in HOPS network)



Synchrophasor assistance in disturbances
(December 3rd 2017)





- **WAMS warning / alarm** → Room staff was triggered by detection of a frequency **undamped oscillation exceeding more than 250 mHz**
- Operators locate the source of oscillation and took control actions:
  - Reducing the flow from the South to the center Italy → reducing voltage angle differences
  - Disconnecting two shunt reactors → breaking of oscillatory loop

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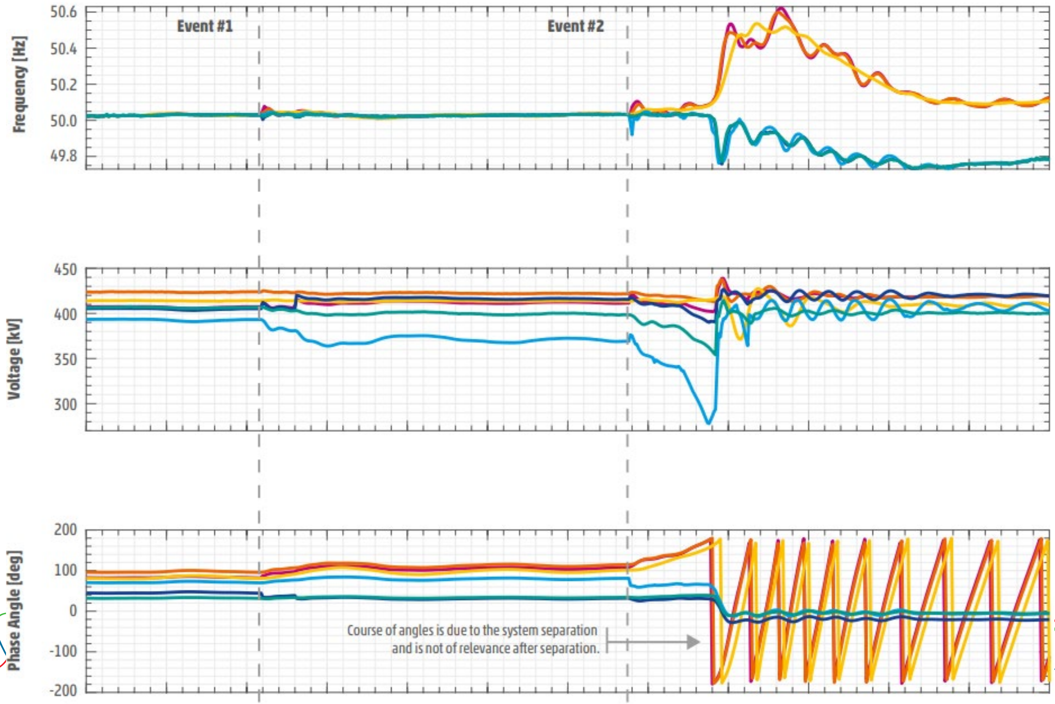
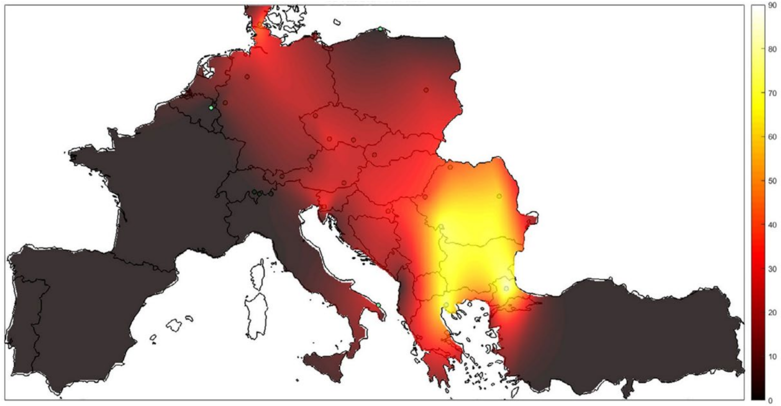
Synchrophasor assistance in disturbances (January 8th 2021)

- Central Europe Synchronous Area Separation on two islands
- High load flow from SE → high voltage phase angle differeces
- Alarm detected by WAM system



Voltage phase angle heat map (before separation)



After january 8th event there is recomondation that voltage phase angle differences can serve as indication for potentional stability limit

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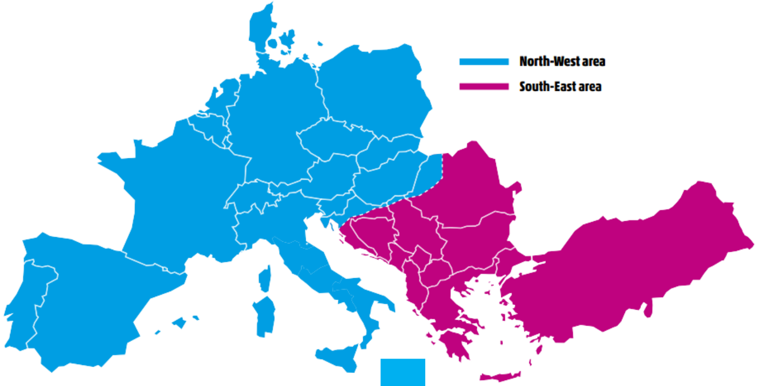
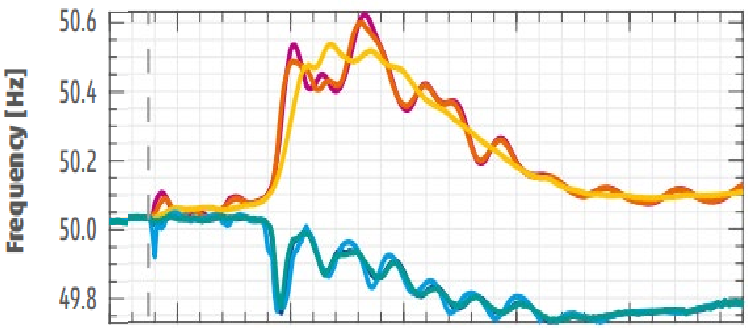
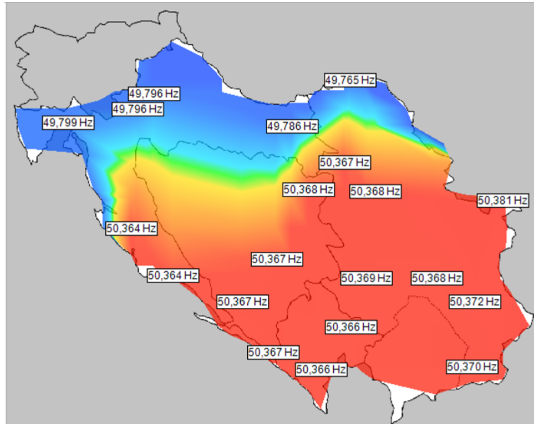
Synchrophasor assistance in disturbances
(January 8th 2021)





System frequency heat map
(after separation)



- January 8th event demonstrated that PMU data exchange between TSO-s is good practice for stability monitoring
- This event accelerated the proces of PMU data exchange between TSO's

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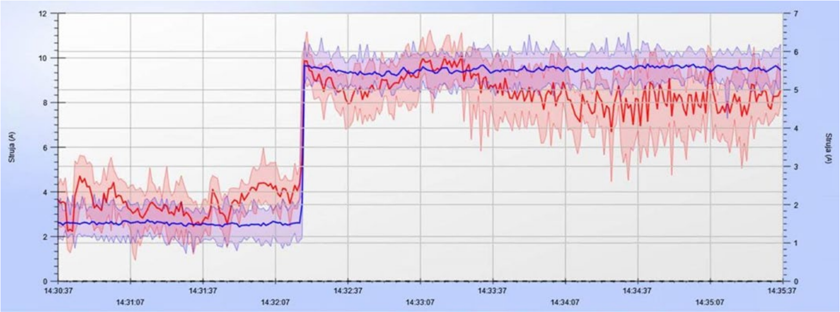
Synchrophasor assistance in disturbances
(broken conductor and unbalanced operation detection)

- Event can be detected by relay protection device if function is activated
- Algorithm based on the PMU measurement can detect broken conductor or unbalanced operation
- Detection of unbalanced operation is possible even if the transmission line is not covered by PMU

Zero and negative sequence current component



High step change → alarm in the WAM system
→ sent to SCADA system

Transmission line where conductor was broken **wasn't cover by PMU** and function of unbalanced operation was not activated on the relay protection device

Cyber Security in EU

- The EU's NIS Directive (Directive on security of network and information systems) is the first piece of EU-wide cyber security legislation.

- NIS Directive and its application in the national Law on cyber security of **key service operators** and digital service providers recognizes HOPS as a provider of key electricity transmission services in the Republic of Croatia with identified critical OT systems:
  - SCADA systems and associated communication network infrastructure
  - WAM system not recognized as a critical OT system, however application in a secure environment is provided

- NIS directive aims to achieve a high common level of network and information system security across the EU's critical infrastructure

Cyber Security Issues in WAMS

Cybersecurity, the data exchanges within or outside the owner/operator infrastructure has to be secured

General problem which affects all systems like SCADA, EMS, etc., in general basing on IT platforms.

Moving WAMS based applications towards the control room, increased challenges particularly in relation to cyber security arise for the communication network.

Corporate network does not have to adhere to the same levels of cyber security required for the critical network

Potential barrier for TSOs as it is necessary to reorganise the entire structure and security policies for their existing WAMS in order fulfil the more stringent requirements for critical control room networks.

There exist no grid codes, which clearly define requirements from which TSOs can establish a framework with appropriate cyber security measures for WAMS.

Uncertainty in the planning stage and could also represent an integration barrier

WAMS Cyber Security Issues in EU TSOs

CIGRE survey in WG C2.17 „WAMS in the Control room” in 2017

Question ‘Cyber security Issues’ among 14 EU TSOs

- High level answer: Generally none since using private networks with firewalls.
- Operation in secure environment.
- Use of dedicated communication channels and firewalls.
- Independent system - no important issues.
- No remote access.
- None, there are no control functions.

However, there are some of security threats that can induce serious malfunctions in WAMS based control room applications.
Although such threats are also common to other measurement devices, they have to be considered prior to a massive deployment of PMUs and their usage for critical control room applications.

⇨

Data spoofing / manipulation
Denial of service
Malicious code injection
“Man-in-the-middle” attacks
Packet injection attack (“Sniffing”)

Cyber Security Issues in WAMS

- Synchrophasor vulnerabilities:
  - synchrophasors are sent using TCP / IP and UDP / IP as the transport layer protocol (vulnerable to interception attacks, such as packet sniffing, modification or data falsification)
- There may be interference with the GNSS (Global Navigation Satellite System) signal that provides time synchronization of the PMU device.
  - each PMU device must be accurately synchronized to the global UTC time with a tolerance of one microsecond
- The IEEE C37.118.1-2011 standard specifies the requirements for PMUs for the steady state of the power system and the dynamic behavior:
  - The Total Vector Error (TVE) defines a limit of 1% and corresponds to a phase angle error of 0.5730° or a synchronization time of 31.8 μs at 50 Hz.
- Poor PMU synchronization may be due to Time Synchronization Spoofing Attacks (TSSA) or poor GNSS signal levels (or problems with as a result of poor PMU antenna placement)

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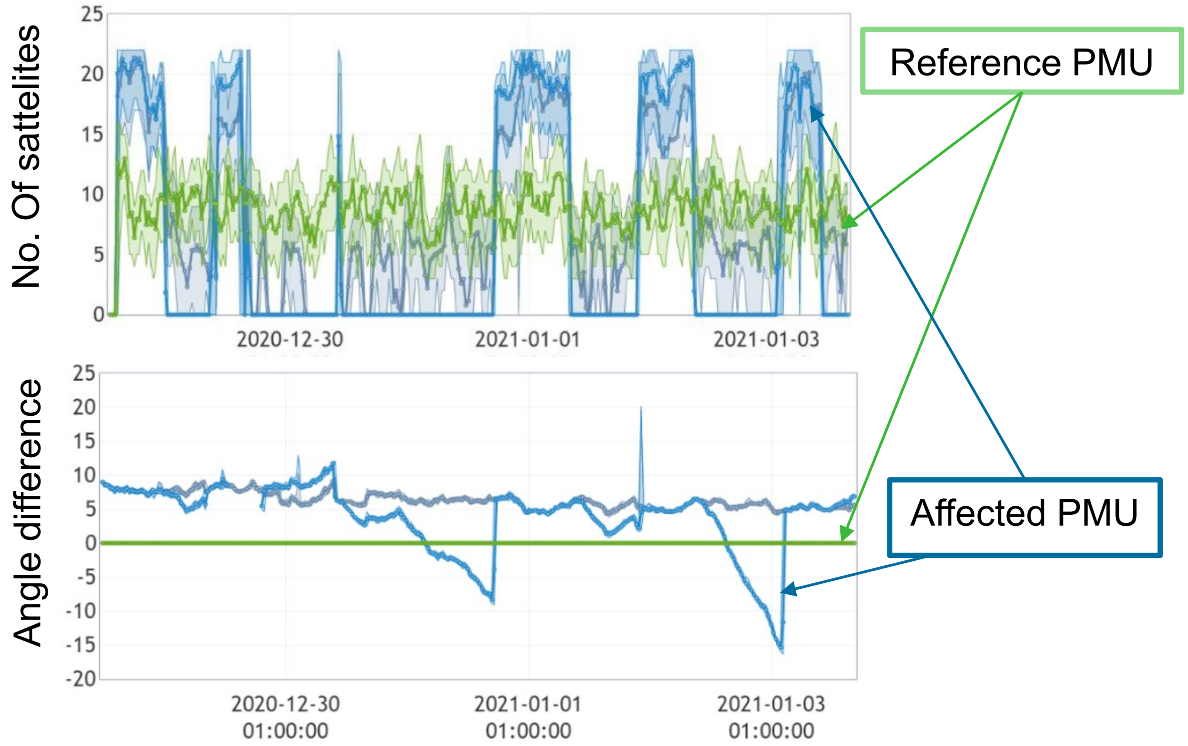
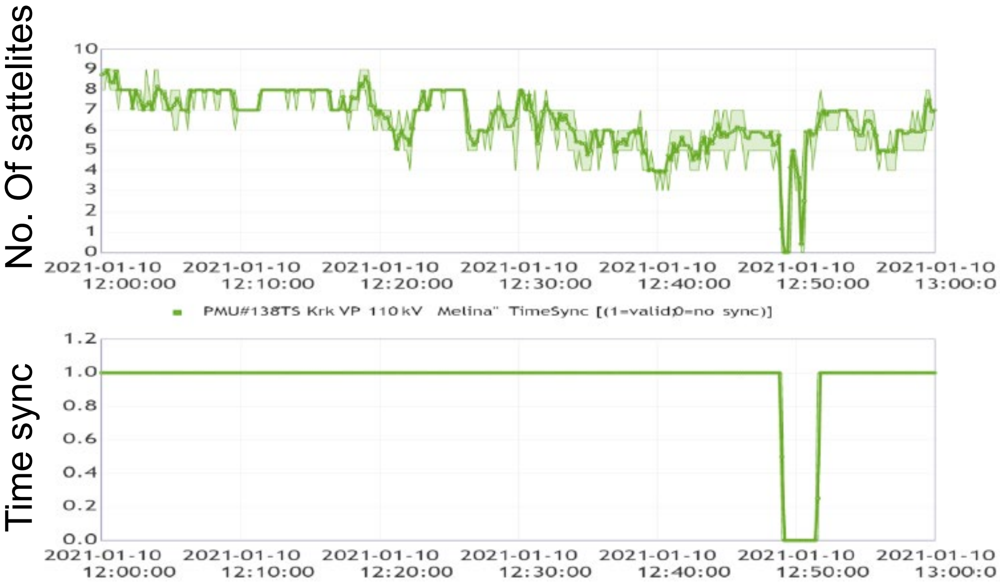
Loss of GNSS signal– PMU performance test



- Prolonged absence of GNSS synchronization gradually increases the synchrophasor angle error.
- This error is mostly affected by changes in the device temperature and repeated loss of the GNSS signal, which impairs the stability of the PMU internal clock correction algorithm.

GNSS signal jamming – PMU performance test



- Experiments were performed with a GNSS signal jammer.
- At a distance of several tens of meters such devices do not affect the reception of GNSS signals
- However, it has been confirmed that a jammer in the vehicle in the immediate vicinity of the antenna (10-15 m) can block the operation of GNSS synchronization and the antenna should not be placed directly next to access roads or parking lots

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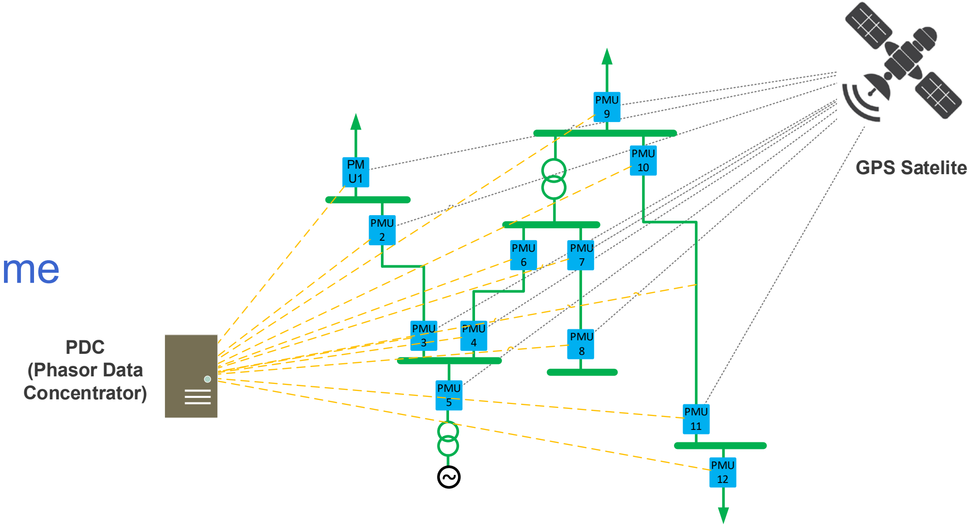
Final remarks

- The final goal of integrating WAM system capabilities into TSOs standard operation and monitoring processes has not been fully achieved
- Clearly defined countermeasures and operational decisions related to WAM system observations are needed
- But still:

WAMS is the best tool for

power system monitoring in real time



Thank you for your attention!

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