PMU-based Power Plant Operation Monitoring and Innovative PMU Implementation

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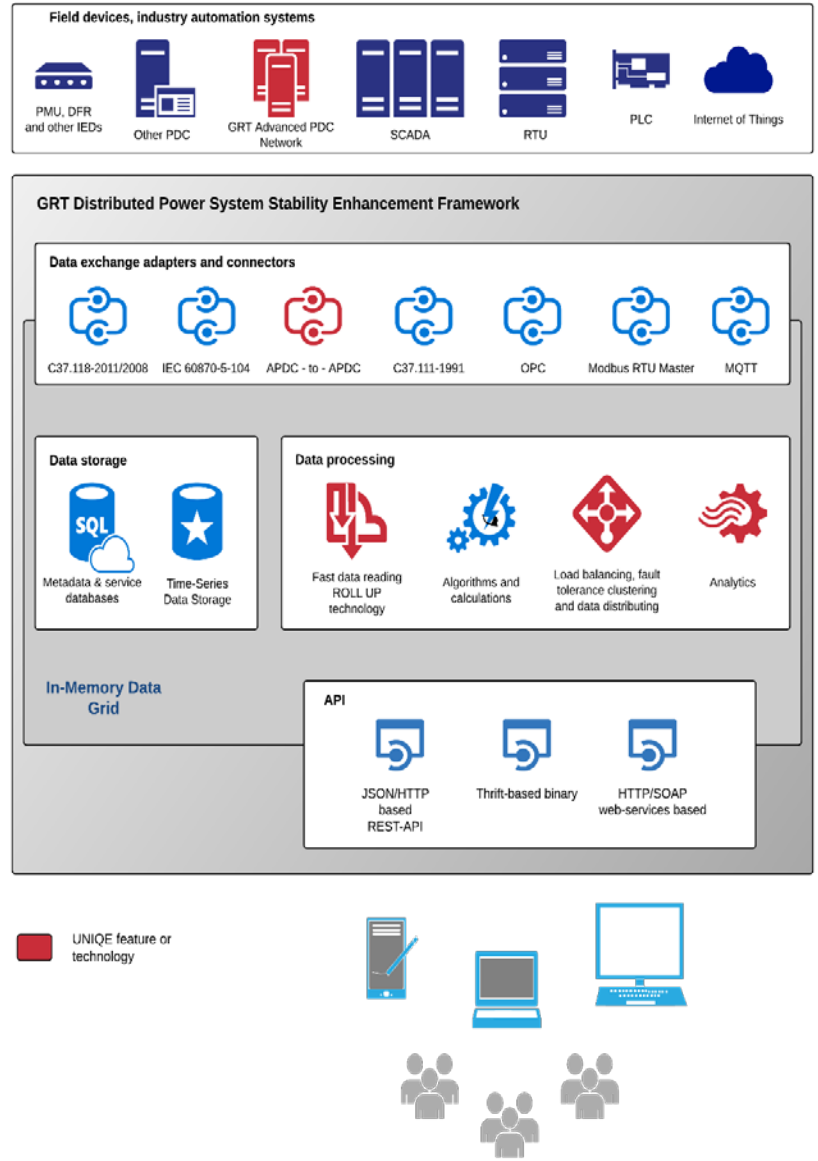
PowerLink - APDC

- Highly customizable scalable platform for building WAMS using multi stream technology
- Distributed historian with very fast search and data export capabilities
- High performance (sampling rate of 50-200 measurements per second for one channel)
- Advanced visualization features
- Implemented in a very large geographically distributed system spanning more than 2000 miles with very low latency
- Advanced PDC



Phasor measurements data applications

Power system applications

Wide-area applications

Local applications (power plant, substation etc.)

Common to both:

- Electromechanical oscillations monitoring and analysis
- Synchronous machines participation in the oscillations damping assessment
- System controllers operation monitoring system
- Novel PMU/PDC development

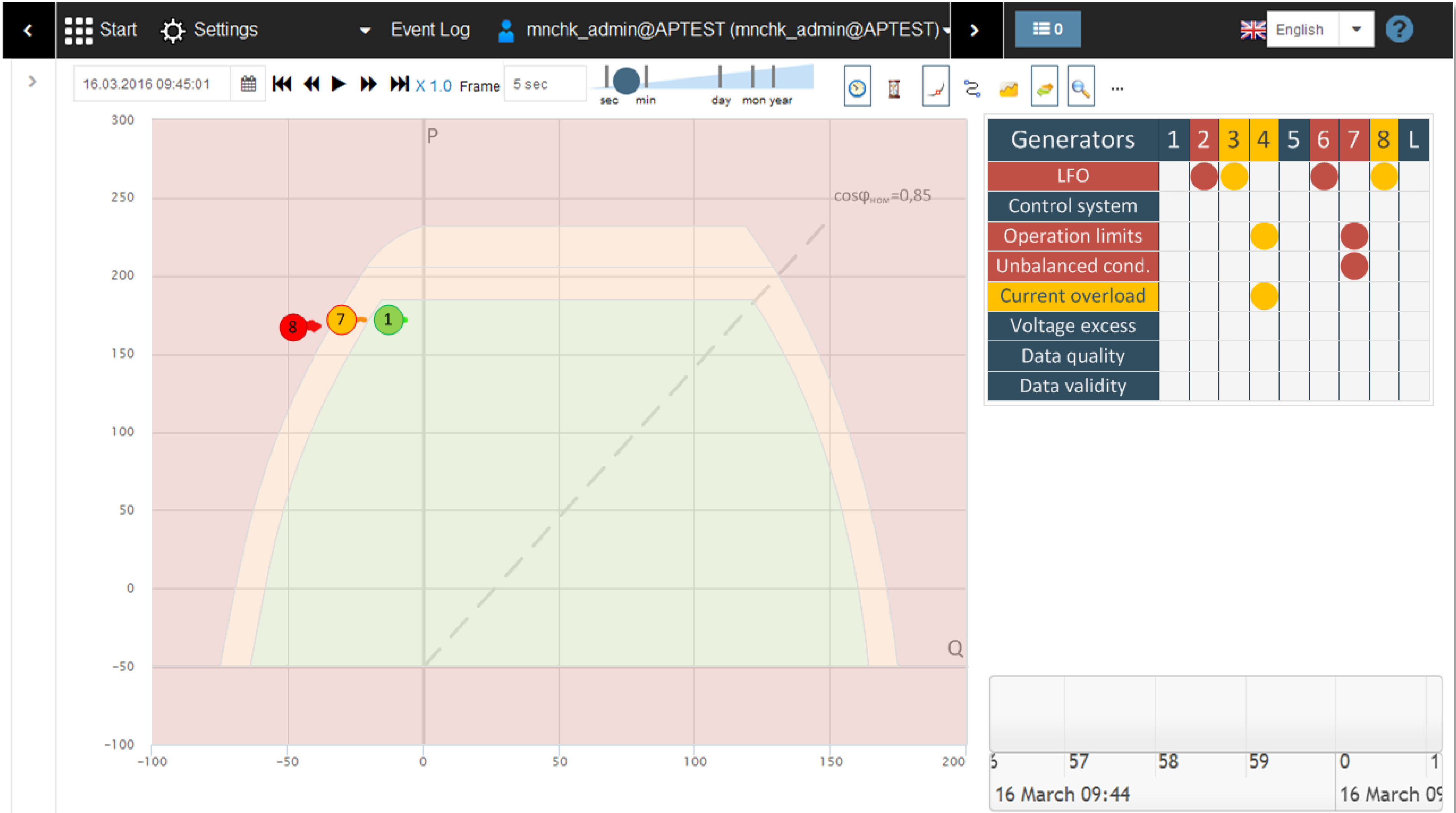
Wide-area applications:

- Centralized automatic emergency control system
- Basic emergency control alarm signals

Local applications:

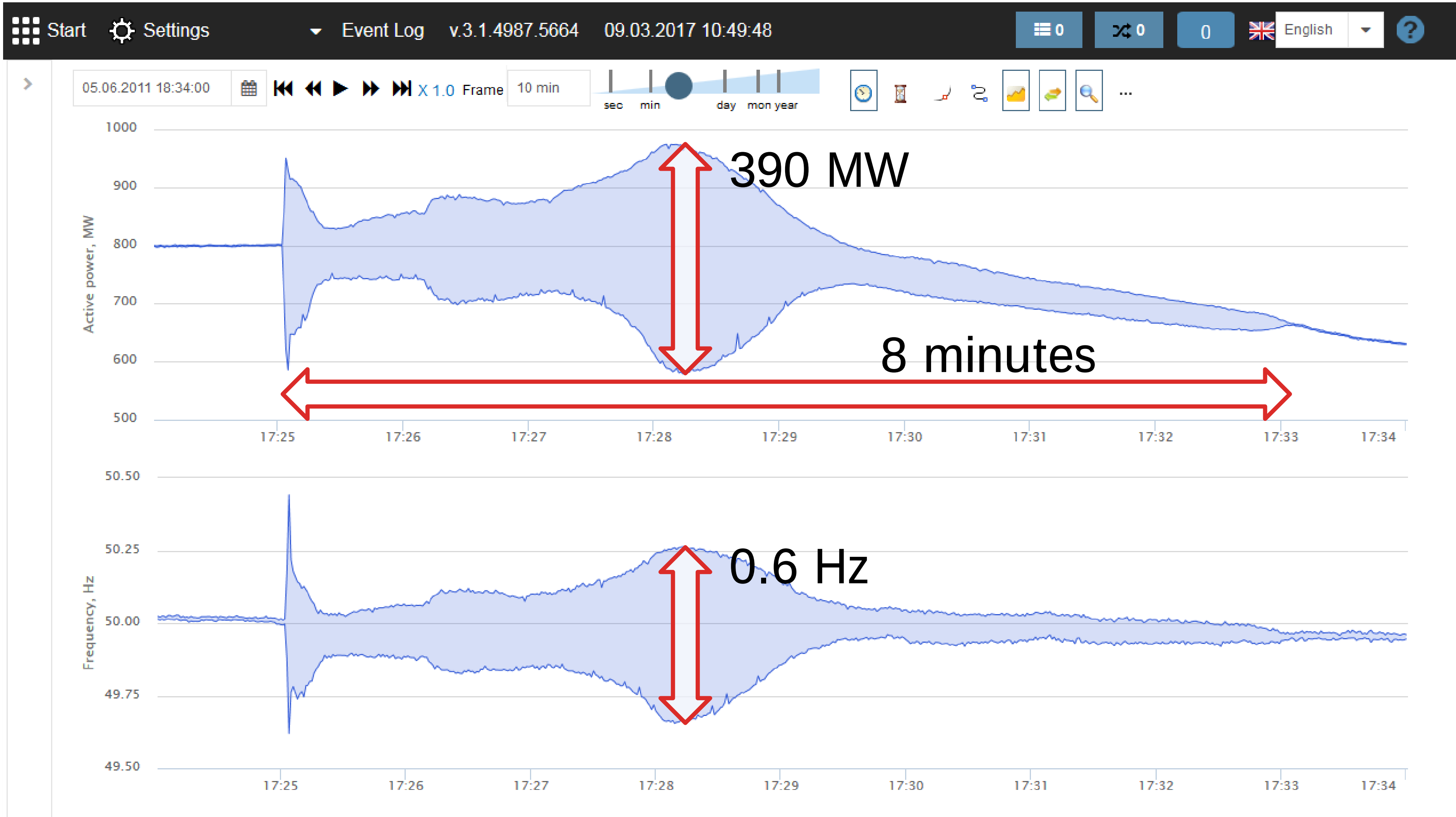
- Power plant operation monitoring system
- Equipment monitoring and diagnostics system

Power plant operation monitoring system

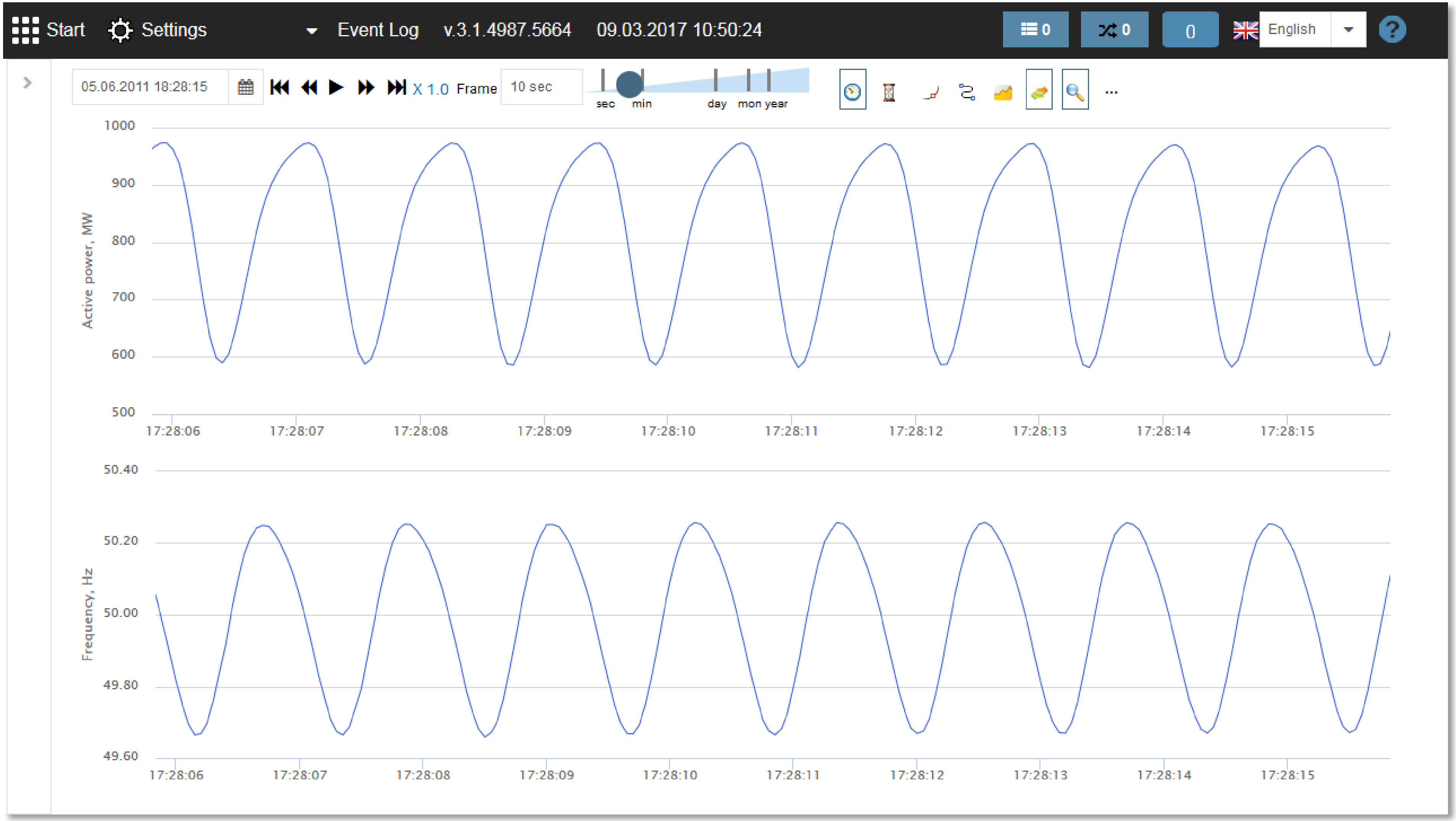


GRT APDC-based integrated solution

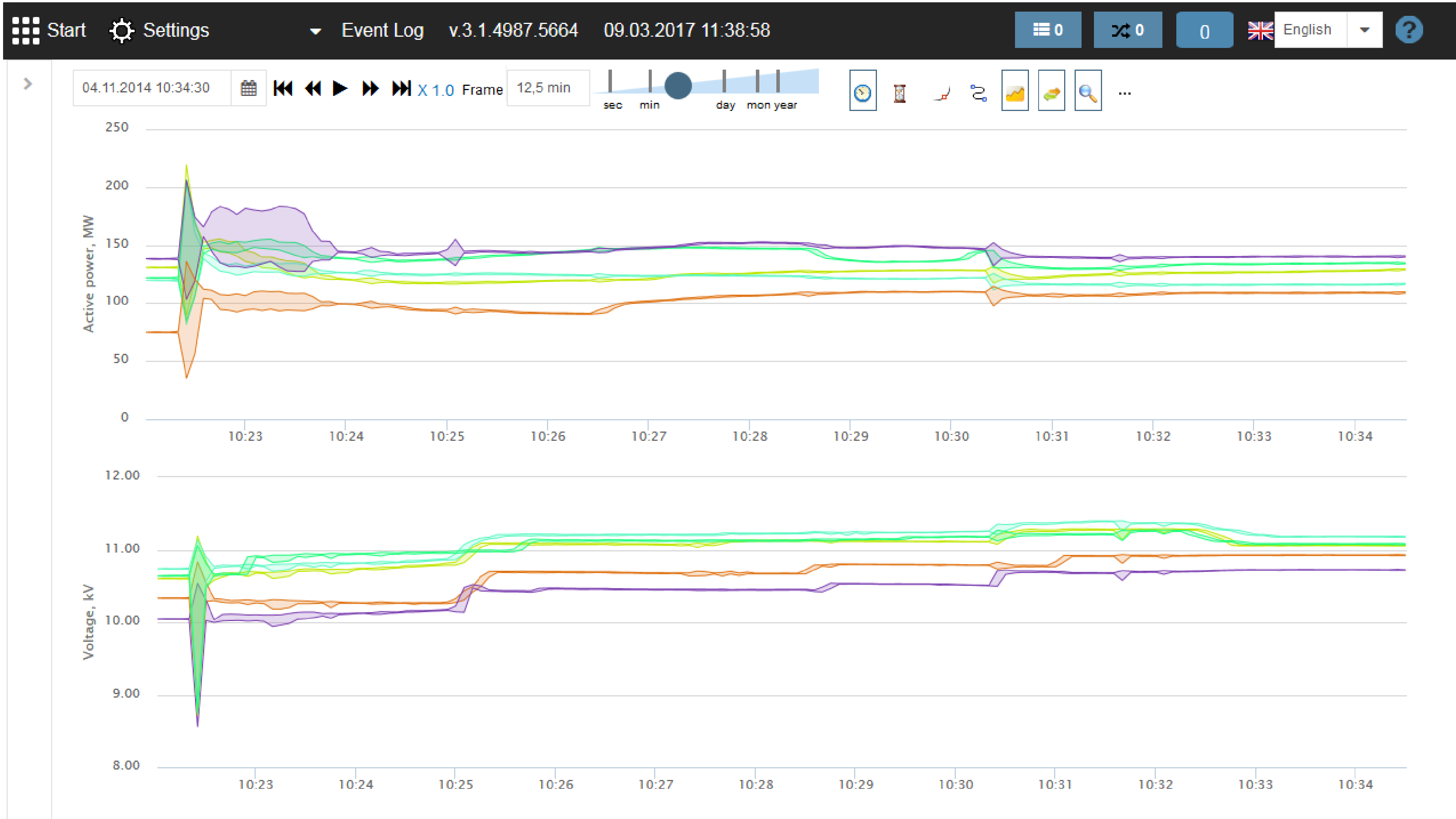
Low-frequency oscillations real-life cases



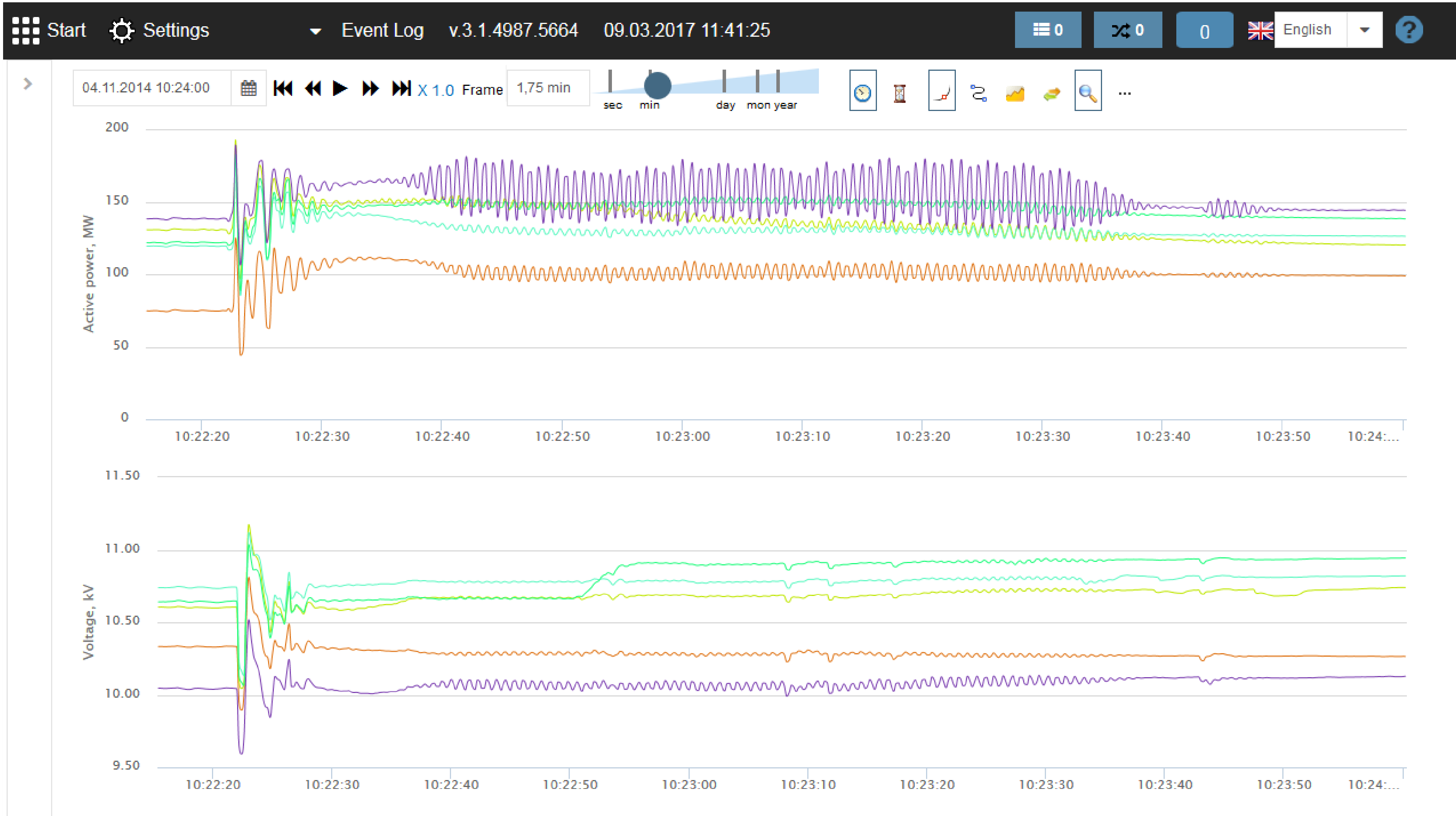
Low-frequency oscillations real-life cases



Low-frequency oscillations real-life cases



Low-frequency oscillations real-life cases



Low-frequency oscillations challenges

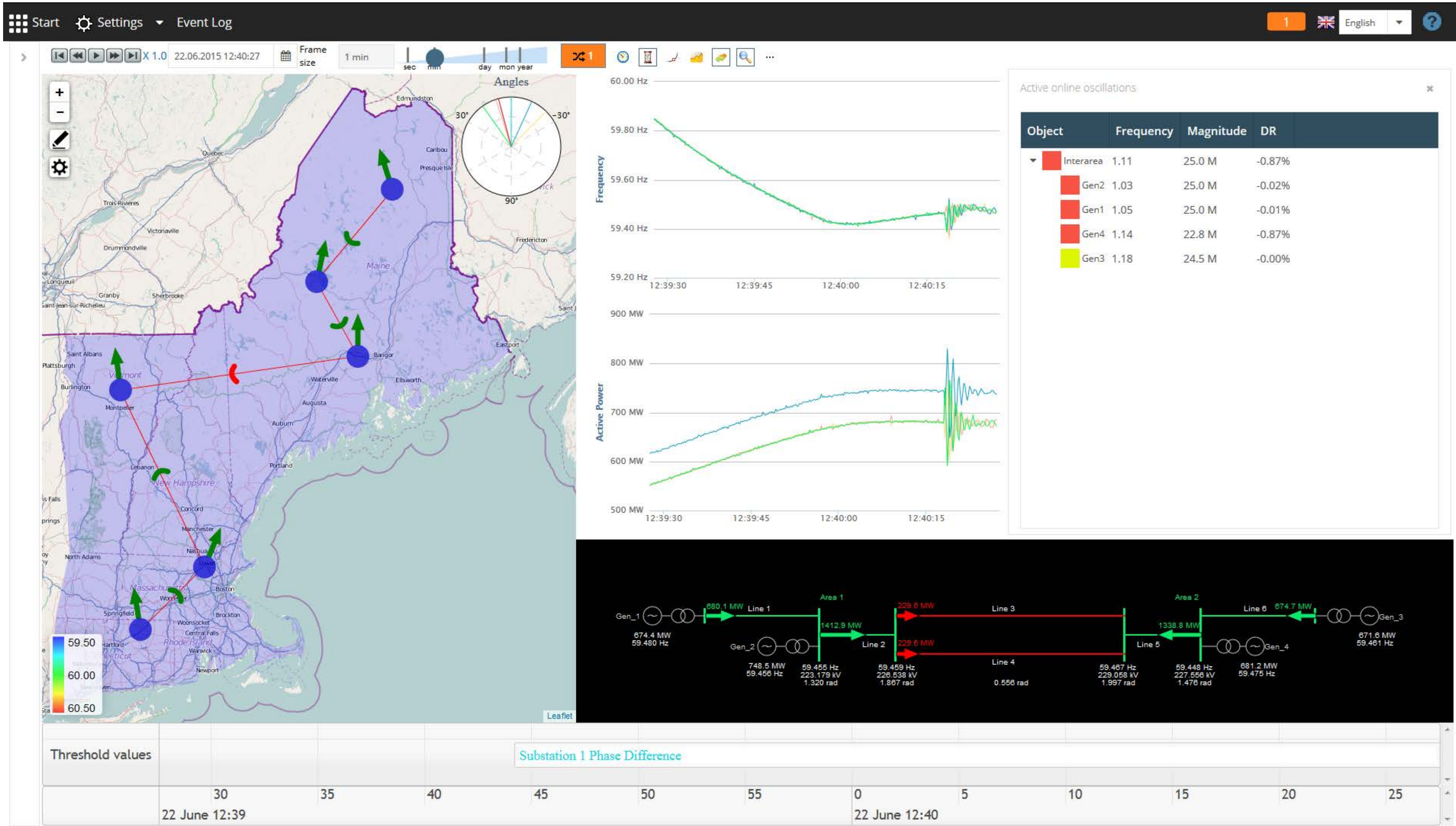
Key risks for power systems and power plants:

- Reduced power plants and generators output
- Possible equipment damage
- Asynchronous operation conditions risk

Possible ways of mitigation:

- Timely LFO detection
- Quick localization
- Early warning for the operators
- Automatic control actions

Electromechanical oscillations monitoring software: online monitoring tool



Online wide-area LFO monitoring visualization

Electromechanical oscillations monitoring software: retrospective analysis

Start | Settings | Event Log

Select modes of oscillation

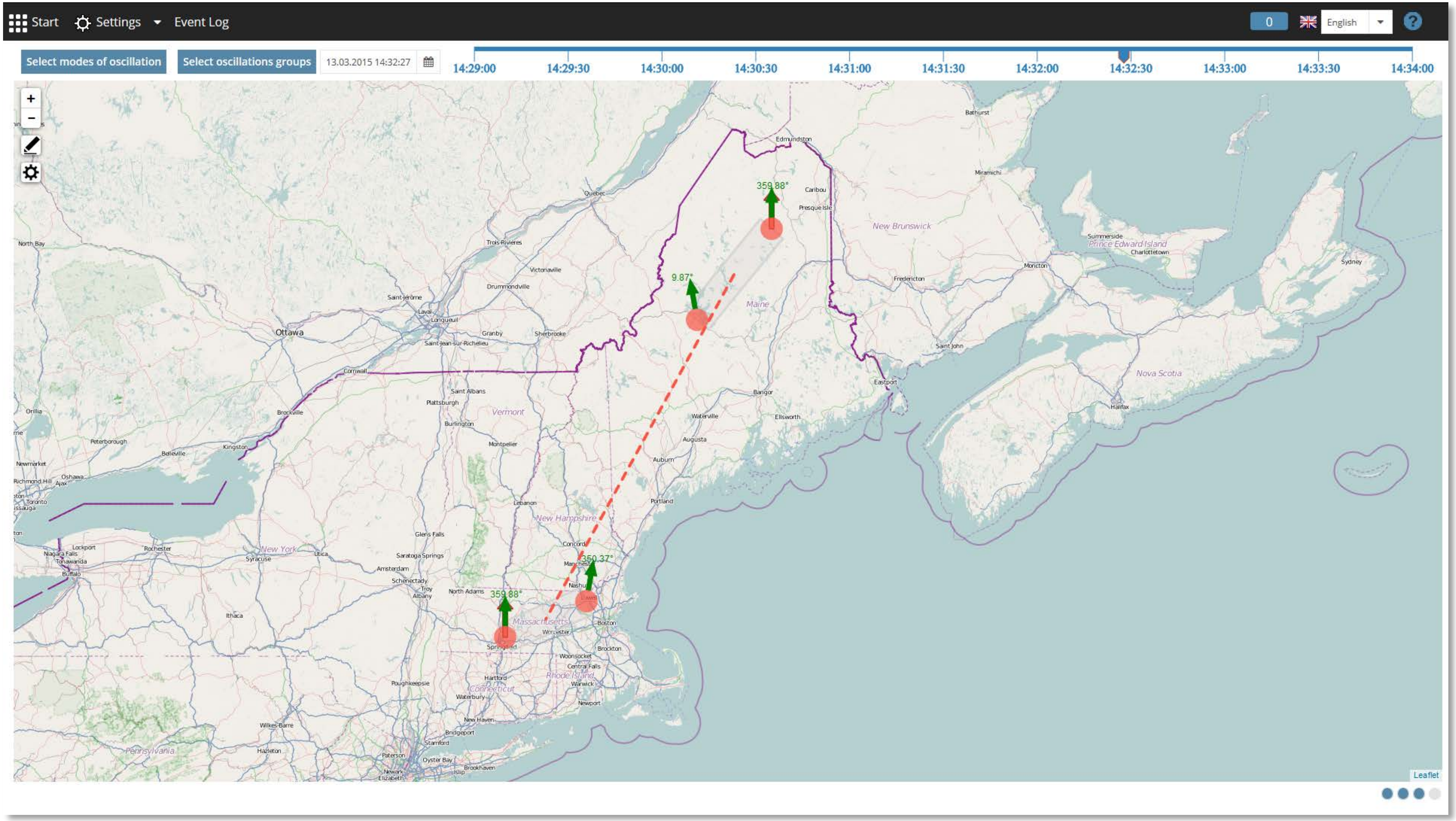
Select oscillations groups | Show detailed modes only

Object	Type	Start time	Duration (s)	Frequency	Magnitude	DR
Local oscillations, frequency 0.98						
Gen1	Active Power	13.03.2015 14:30:11.180	6.28	0.96	9.239 MW	9.1%
Gen2	Active Power	13.03.2015 14:30:11.640	2.96	0.99	28.4 MW	15.9%
Local oscillations, frequency 1.15						
Gen3	Active Power	13.03.2015 14:30:11.300	4.04	1.14	14.8 MW	27.8%
Gen4	Active Power	13.03.2015 14:30:11.320	3.2	1.16	22.1 MW	12.4%
Interarea oscillations, frequency 0.59						
Gen4	Active Power	13.03.2015 14:32:00.020	48	0.59	38.9 MW	-2.1%
Gen3	Active Power	13.03.2015 14:32:01.020	47	0.60	44.3 MW	-1.9%
Gen1	Active Power	13.03.2015 14:32:02.020	46	0.59	28.8 MW	-2.0%
Gen2	Active Power	13.03.2015 14:32:17.540	30.48	0.58	26.8 MW	-2.4%
Local oscillations, frequency 1.00						
Gen3	Active Power	13.03.2015 14:32:01.100	19.92	1.04	4.329 MW	0.9%
Gen4	Active Power	13.03.2015 14:32:01.300	18.72	0.96	4.732 MW	1.0%
Local oscillations, frequency 0.96						
Gen1	Active Power	13.03.2015 14:32:01.160	20.86	0.97	5.666 MW	2.0%
Gen2	Active Power	13.03.2015 14:32:01.180	20.84	0.95	7.123 MW	1.1%

Save

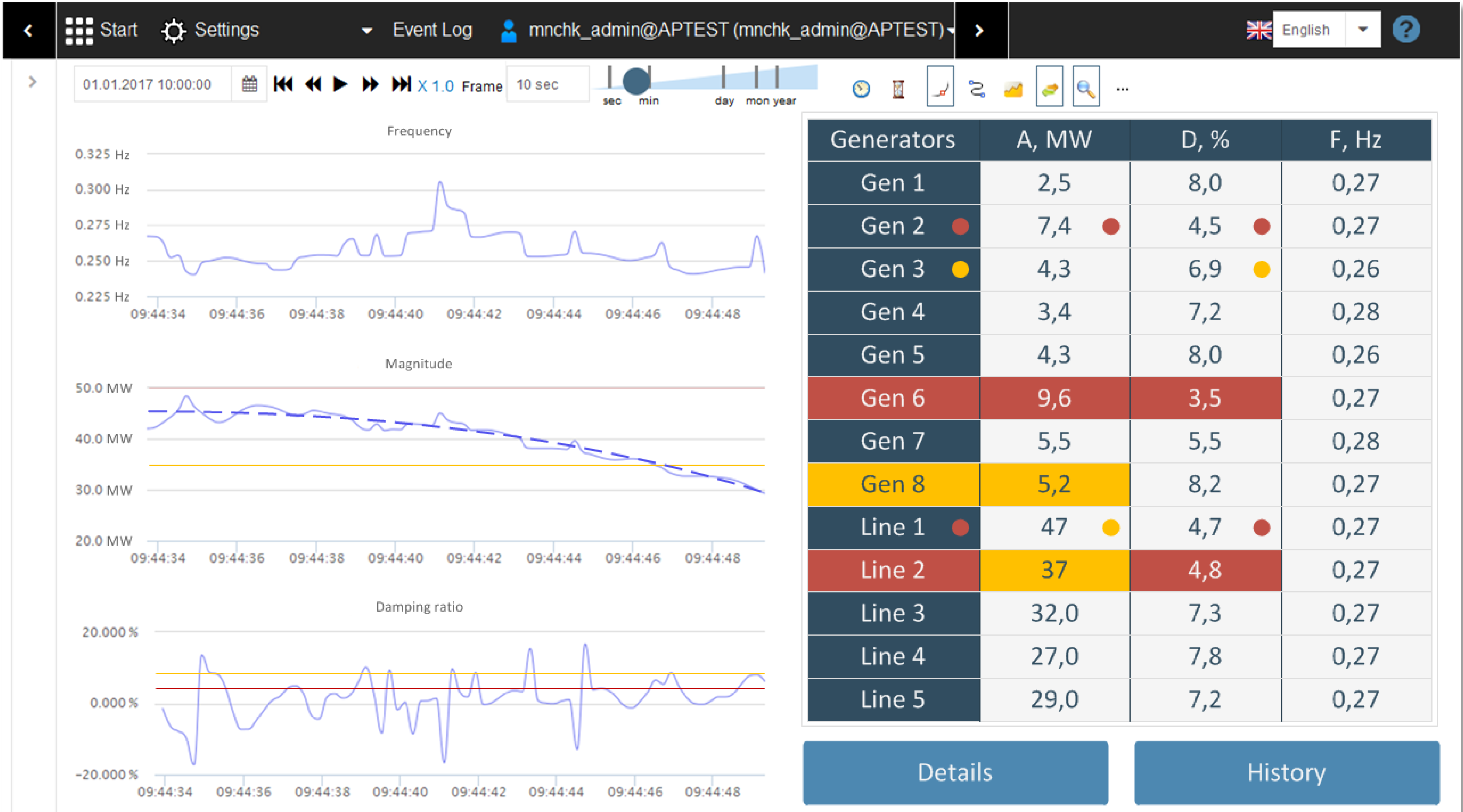
Detailed retrospective analysis

Electromechanical oscillations monitoring software: geographical visualization



Geographical representation of the in-phase and antiphase objects oscillations

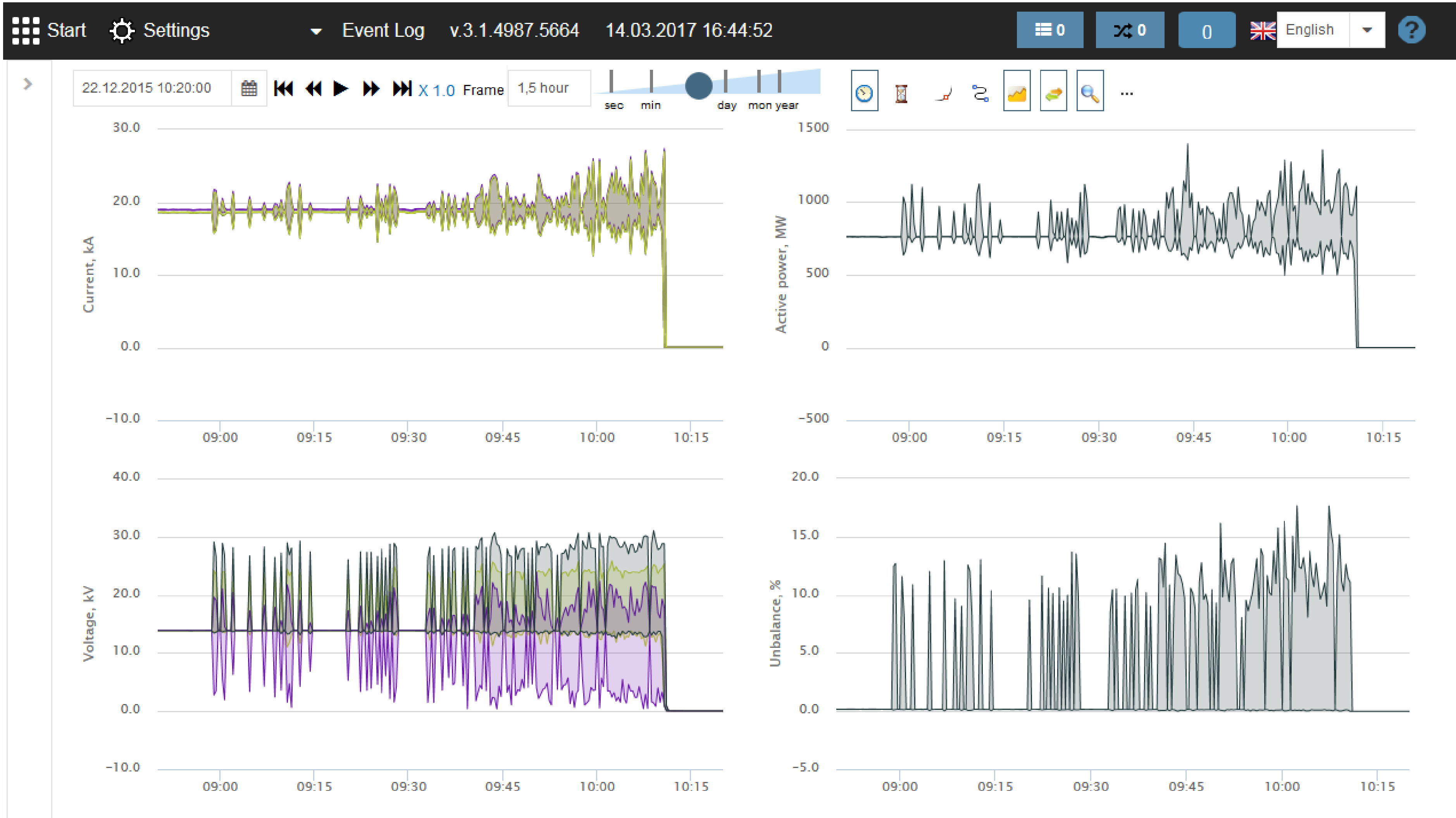
Power plant operation monitoring system: low-frequency oscillations



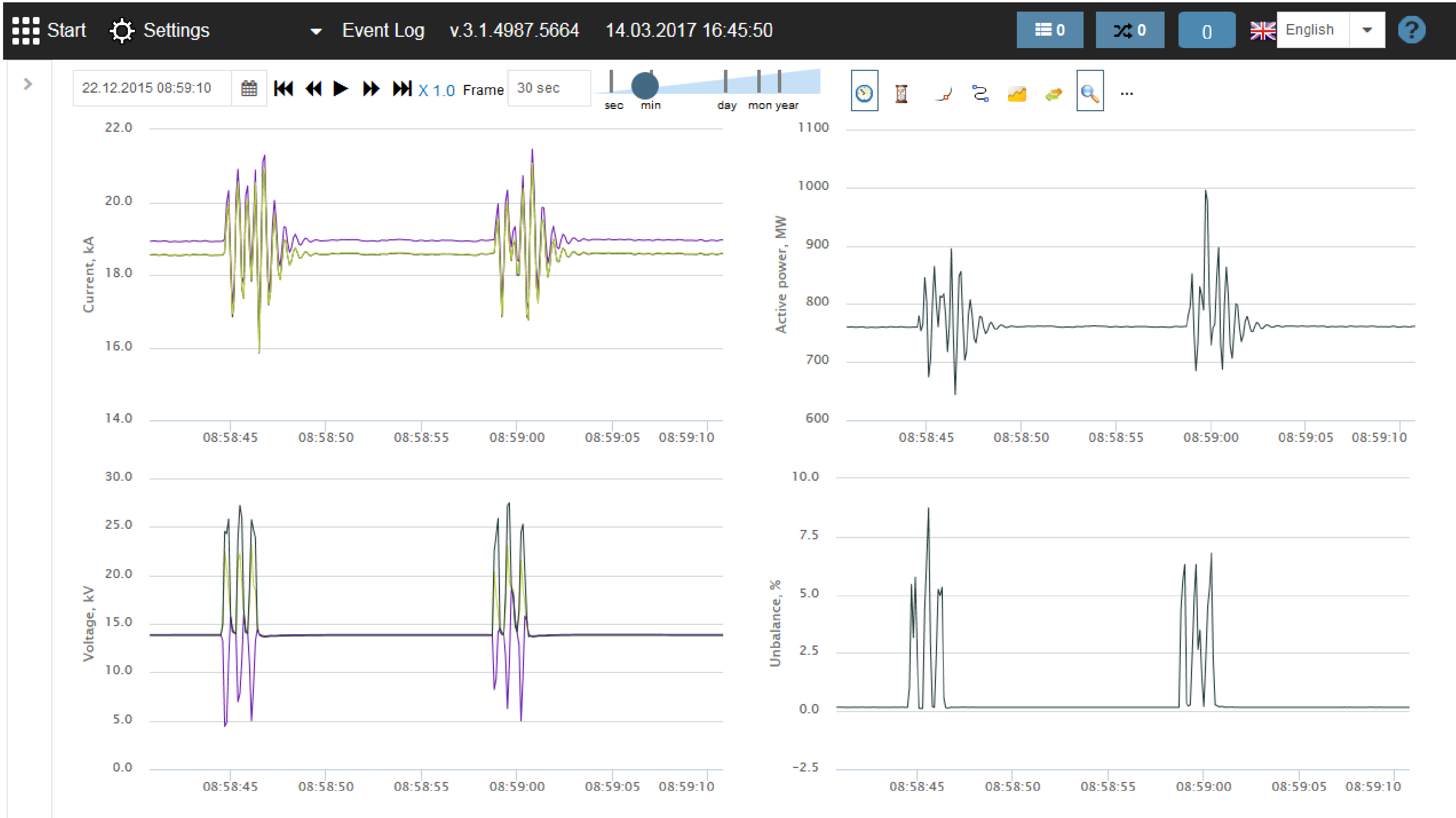
Generators	A, MW	D, %	F, Hz
Gen 1	2,5	8,0	0,27
Gen 2	7,4	4,5	0,27
Gen 3	4,3	6,9	0,26
Gen 4	3,4	7,2	0,28
Gen 5	4,3	8,0	0,26
Gen 6	9,6	3,5	0,27
Gen 7	5,5	5,5	0,28
Gen 8	5,2	8,2	0,27
Line 1	47	4,7	0,27
Line 2	37	4,8	0,27
Line 3	32,0	7,3	0,27
Line 4	27,0	7,8	0,27
Line 5	29,0	7,2	0,27

Power plant low-frequency oscillations monitoring subsystem

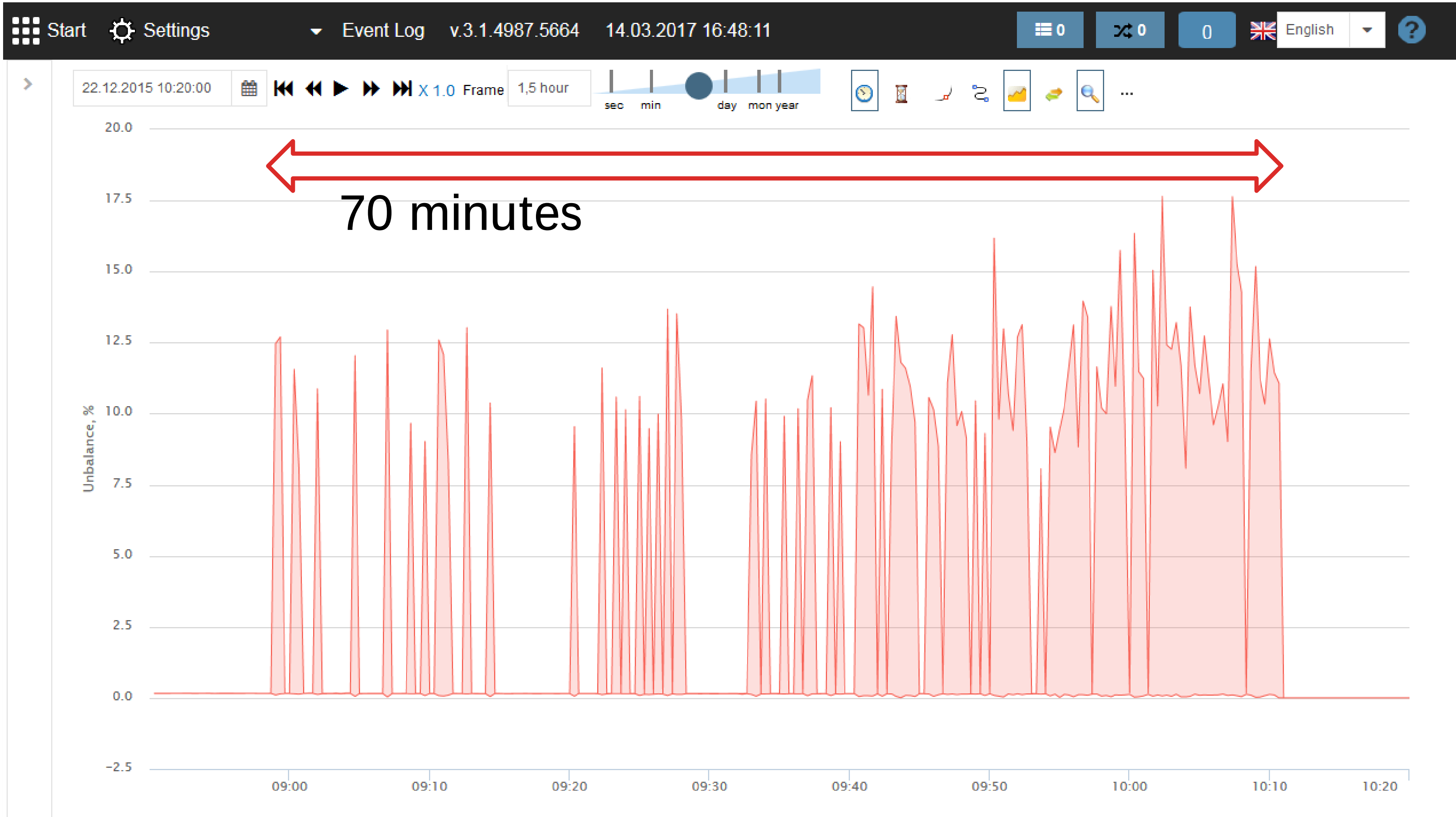
Unbalanced operation case



Unbalanced operation case



Unbalanced operation real-life case



Unbalanced operation real-life case

Key risks for power systems and power plants:

- Increased power losses
- Rotor overheating
- Mechanical vibrations
- Generator damage
  - Isolation abrasion and deterioration
  - Windings deformation and/or displacement

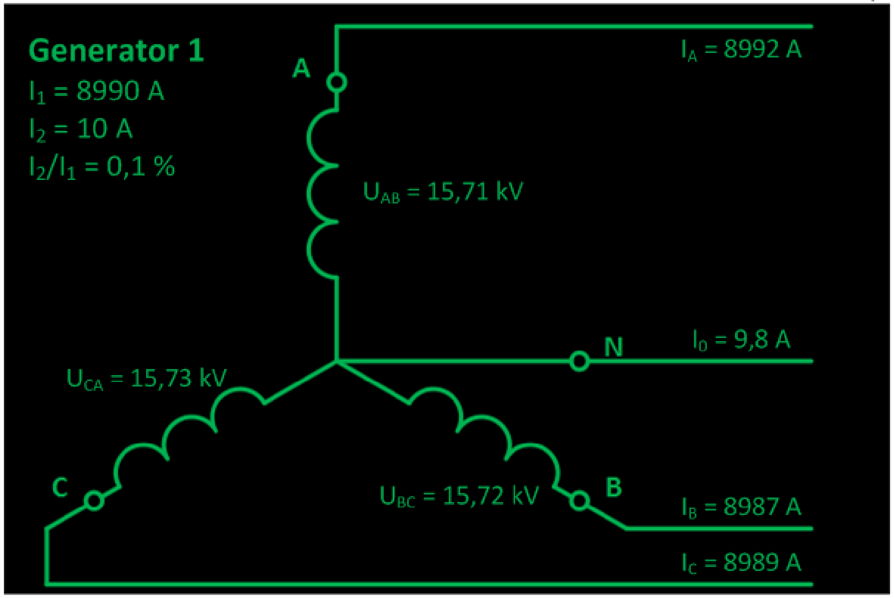
Possible ways of mitigation:

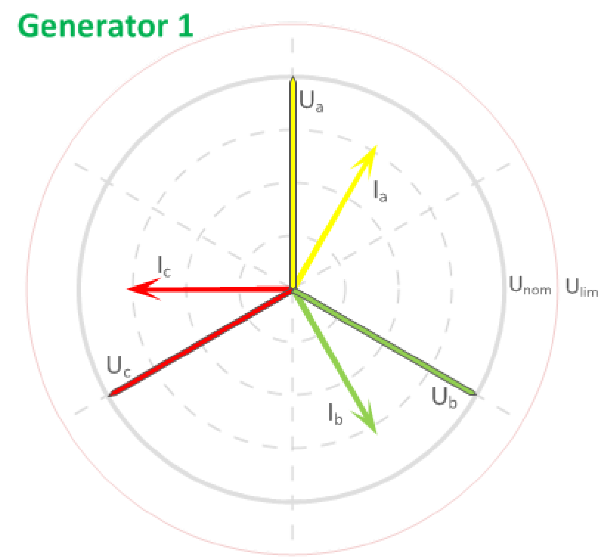
- Timely unbalanced operation detection
- Quick localization
- Early warning for operators
- Automatic control actions

Power plant operation monitoring system: unbalanced conditions

Start Settings Event Log mnchk_admin@APTEST (mnchk_admin@APTEST) English

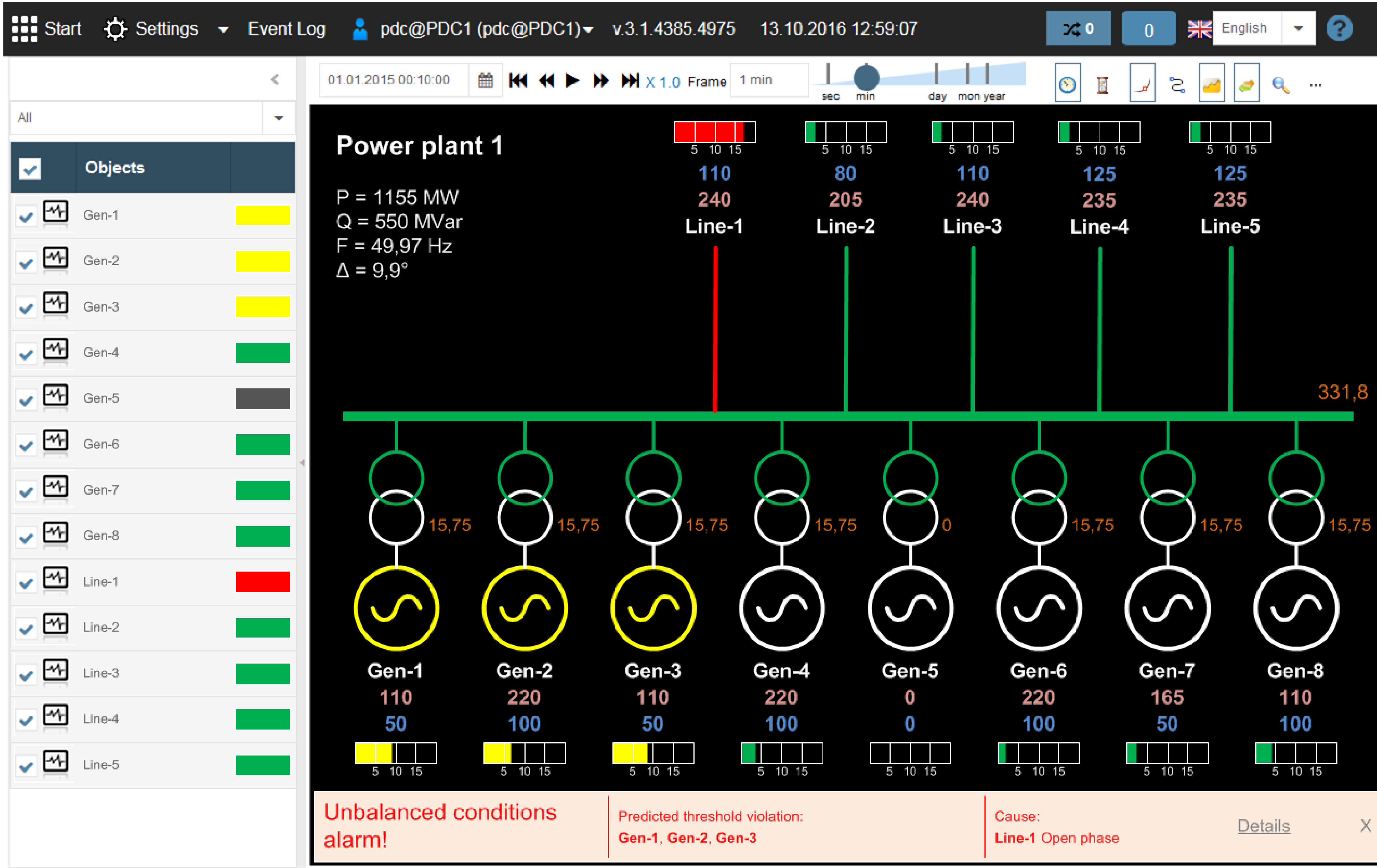
16.03.2016 09:50:00 X 1.0 Frame 10 sec sec min day mon year





	G1	G2	G3	G4	G5	G6	G7	G8	L1	L2	L3	L4	L5
U_1	15,73	15,73	15,73	15,73				15,73	331,3	331,3	331,3	331,3	331,3
U_2	0,3	0,3	0,3	0,3				0,3	3,3	3,3	3,3	3,3	3,3
U_0	0,1	0,1	0,1	0,1				0,1	3,1	3,1	3,1	3,1	3,1
I_1	8990	8990	8990	8990				8990	450	450	450	450	450
I_2	10	10	10	10				10	3,9	3,9	3,9	3,9	3,9
I_0	9,8	9,8	9,8	9,8				9,8	2,1	2,1	2,1	2,1	2,1
I_2/I_1, %	0,1	0,1	0,1	0,1				0,1	0,8	0,8	0,8	0,8	0,8

Power plant operation monitoring system: unbalanced conditions

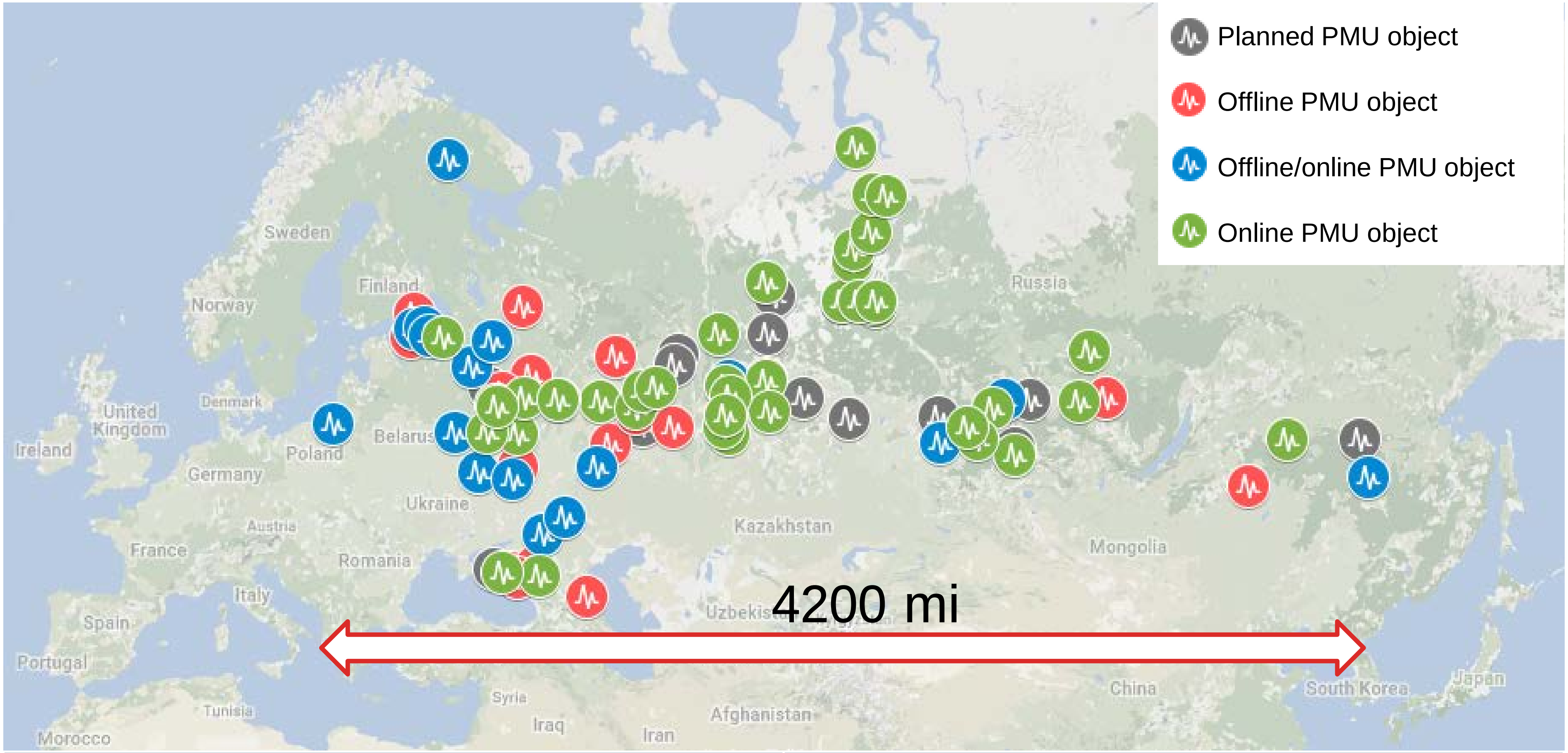


Power plant / substation equipment monitoring and diagnostics

Supplementary equipment monitoring/diagnostics system for

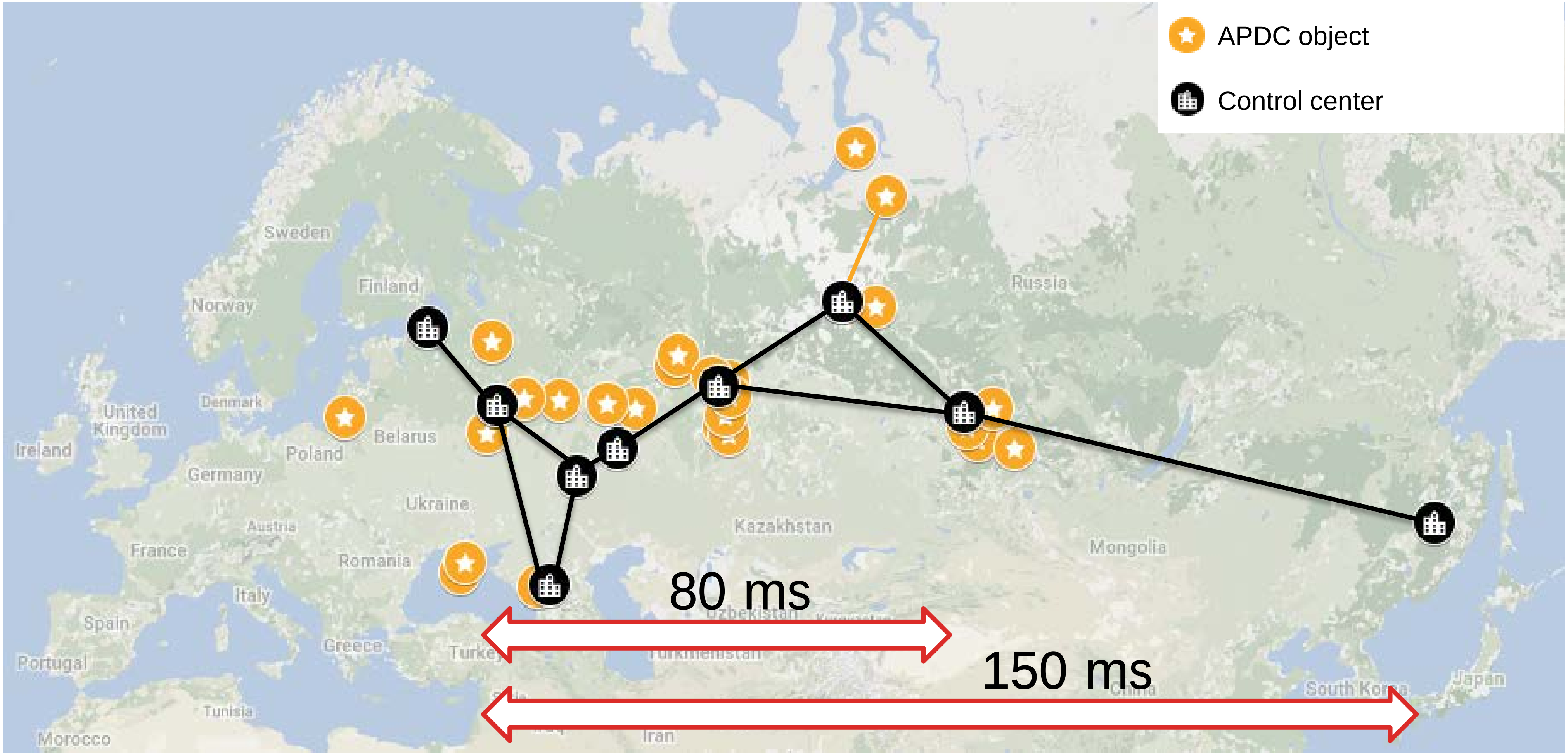
- Circuit breakers
  - Phases unsynchronized switching – basic equipment damage
    - Mechanical drive wear
    - Contacts failure etc.
- Instrument transformers
  - Significant measurement errors – protection and automation misoperation, metering errors
    - Connection failure
    - Windings failure
    - Secondary circuit isolation deterioration
    - Capacitor aging etc.

APDC-based WAMS in Eastern Europe Power System



PMUs			Objects		
Total	Online	Generators	Total	Power plants	Substations
544	312	187	82	51	31

APDC-based WAMS in Eastern Europe Power System

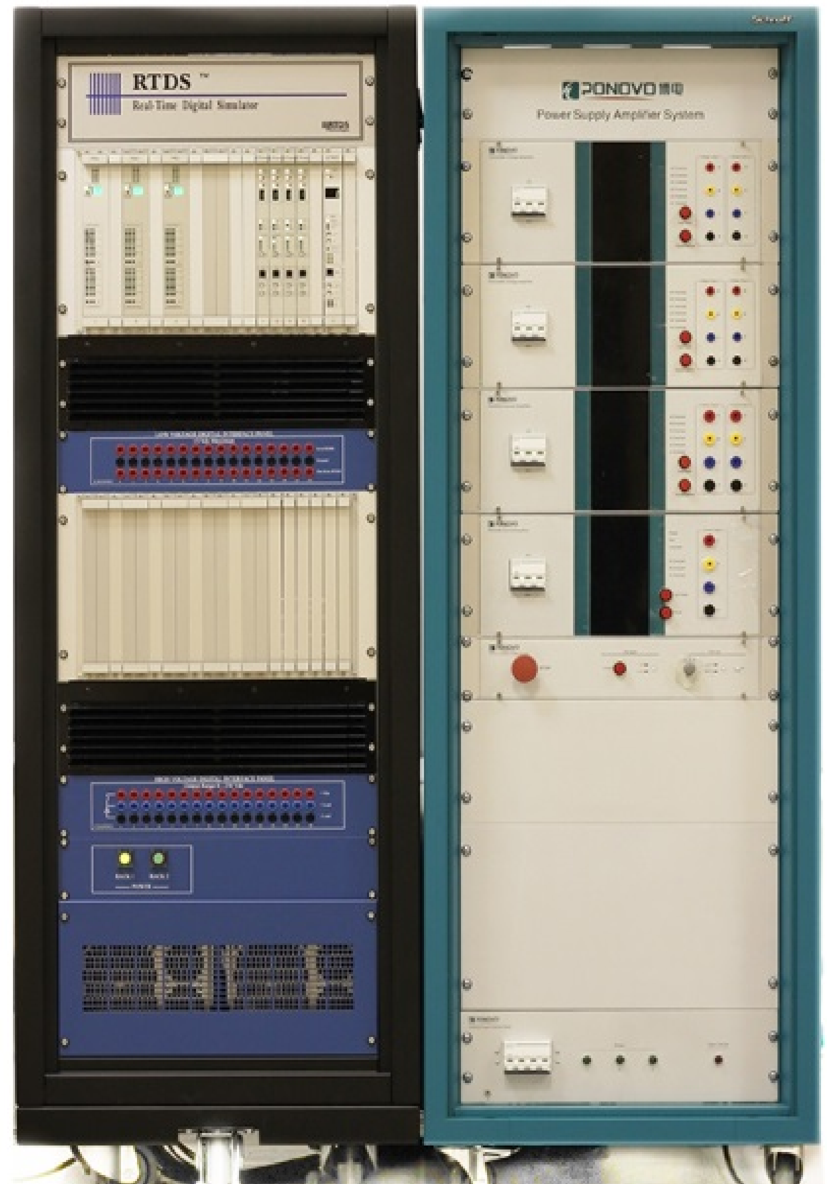


24 object APDC installations, 10 control center installations
3-month raw data storage

Experimental base

All applications under development are validated involving Real-time digital simulator (RTDS) system and the large Physical electrodynamic simulator:

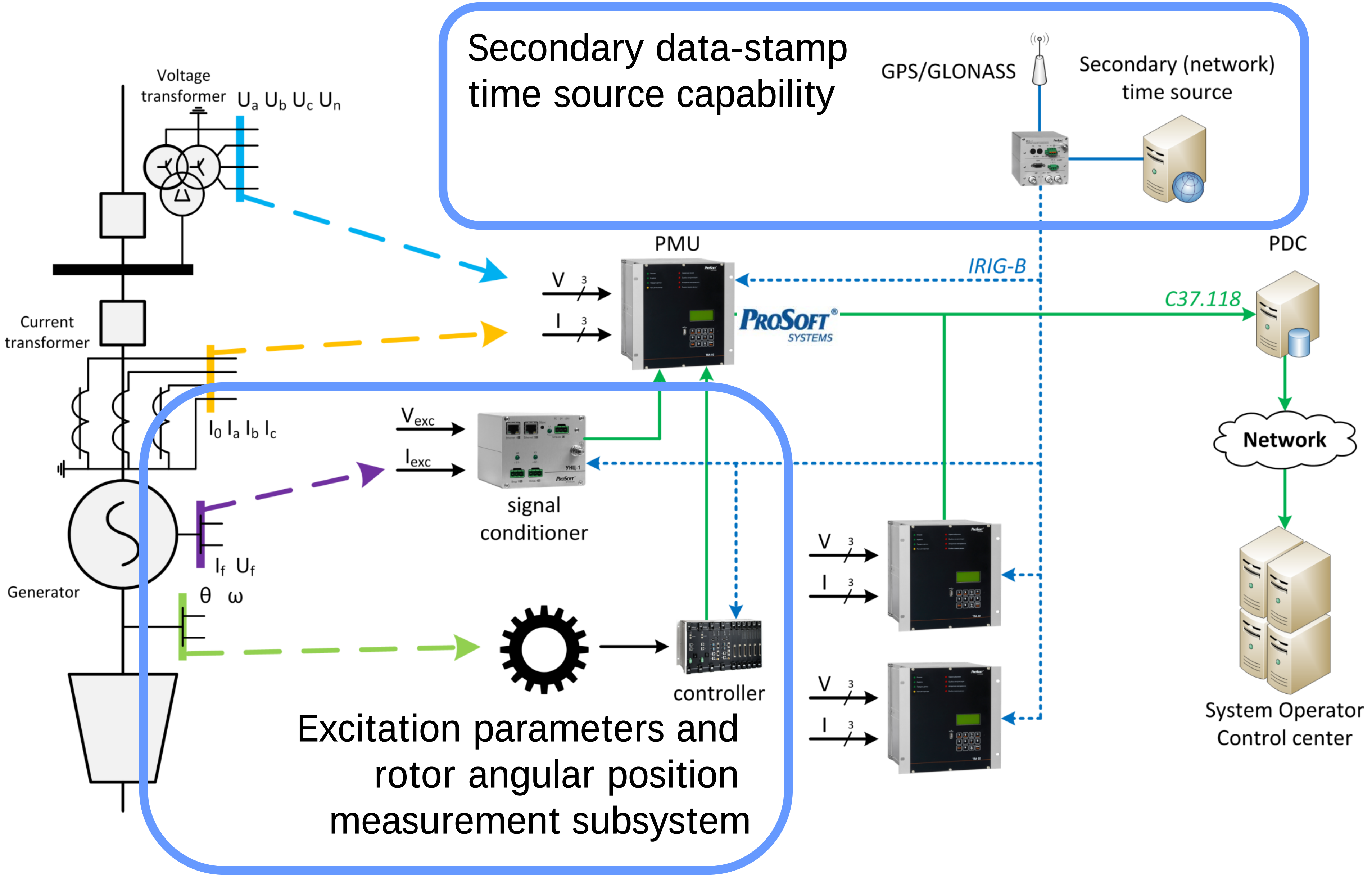
- quality assessment
- performance tests
- IEEE C37.118 and IEC 61850 compliance tests
- optimization



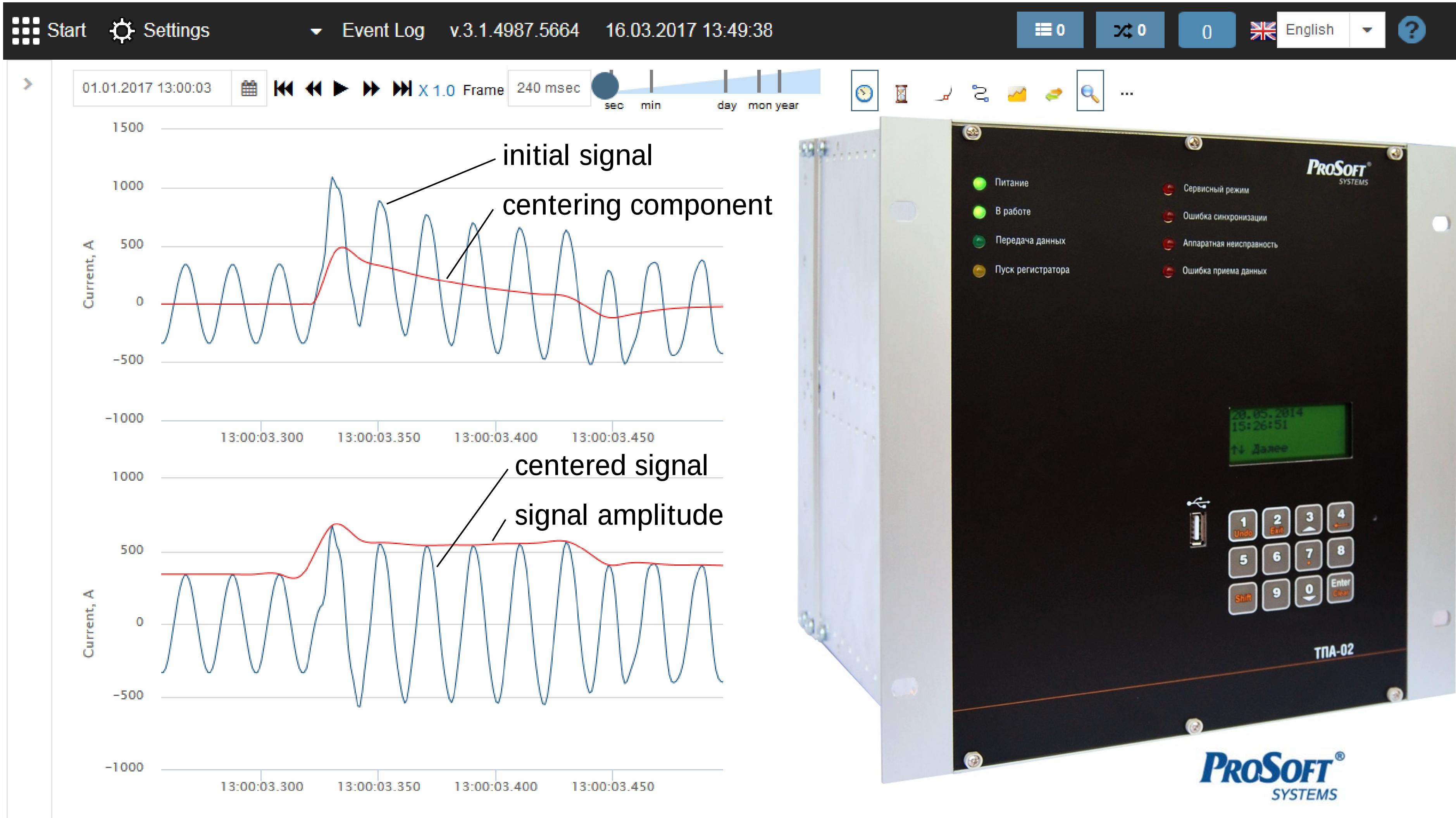
Physical electrodynamic simulator

- 8 simulators for DC transmission lines, converter substations
- 700 Pi-cells for transmission lines simulation and 150 power transformer simulators
- 80 synchronous machines with various power ratings
- 160 electric load nodes formed by the combination of asynchronous-motor, shunt and converter loads
- FACTS devices, controlled shunt reactors, static VAR compensators, series capacitor banks

Direct measurements of the synchronous generator load angle



Instantaneous state parameters measurements for the determination of dynamic properties



Current source signal and amplitude

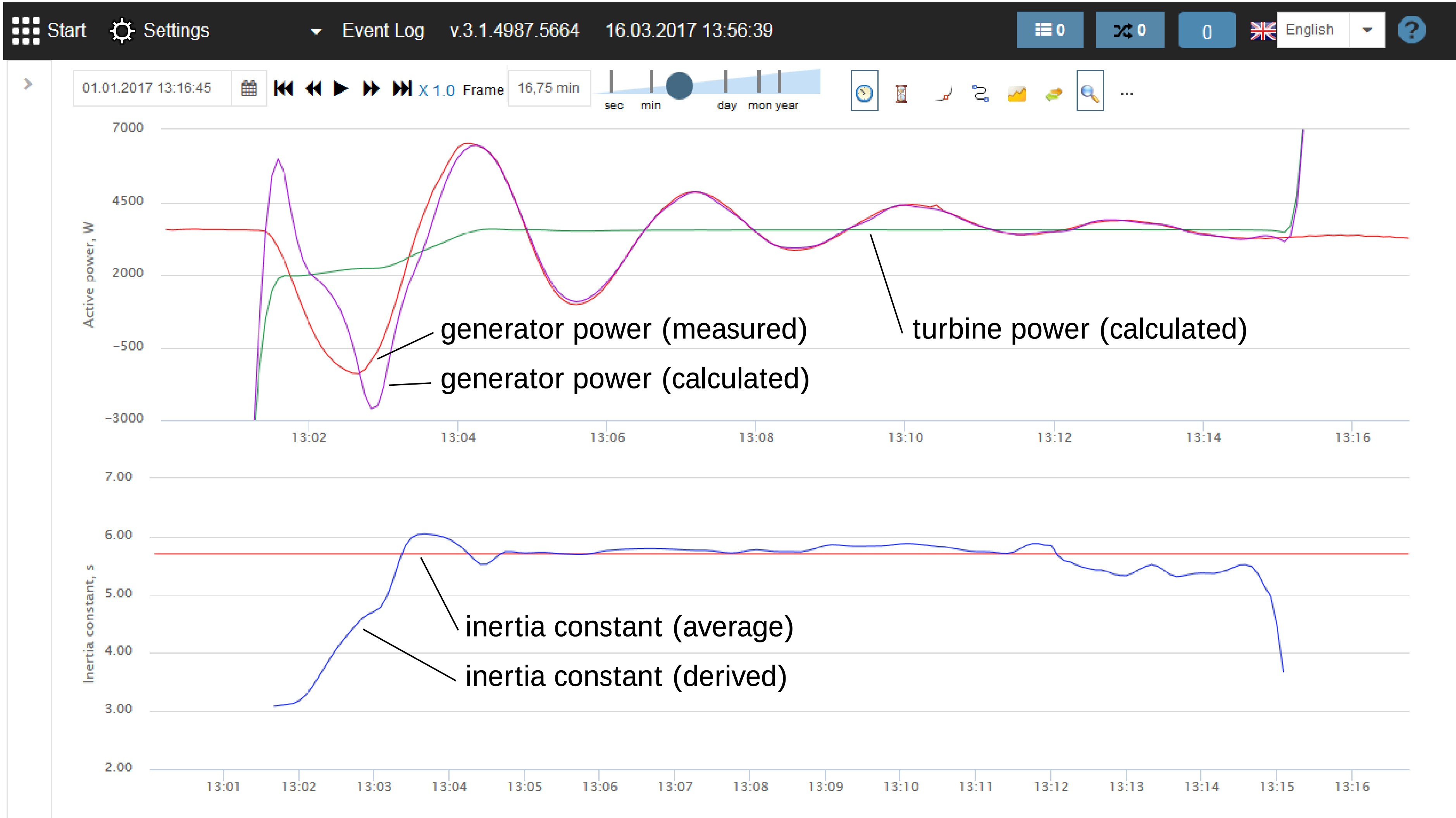
The novel PMU

Generalized damping component calculation

$$J \cdot \omega_0 \frac{\mathrm{d}\omega}{\mathrm{d}t} = P_{\mathrm{T}} - P_e.$$

$$\tau_j = \frac{J \cdot {\omega_0}^2}{S_{\mathrm{H}}}$$

Real Synchronous Generator



Rated value: 6.1 s

Derived value (average): 5.8

New power systems parameters recorder capabilities

Provides

- **Studies of the power systems dynamic properties**
- Verification of the computational dynamic models
- **Quick emergencies detection**
- Power system conditions control against the angle
- **Monitoring the synchronous generator load angle and its trend to assess the static and dynamic stability margins**
- Determining the synchronous generators natural oscillations parameters in order to detect the resonance phenomena and prevent the machine self-swing
- Assessing the effectiveness of automatic control systems with automatic adjustment and faults self-recovery
- **Developing a new generation control systems based on the real-time computational models variations based on the rules of FACTS control and dynamic properties of power systems**
- Additional possibilities for generators monitoring (the air gap unevenness detection under the magnetic poles and the magnetic conductor asymmetry; the stator winding electric asymmetry detection, the rotor damper winding or field winding defects)

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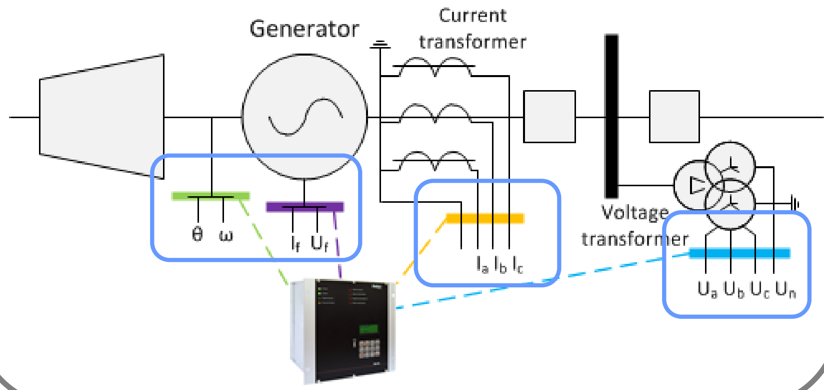
Power system equipment adaptive models

Synchronous generator



Transmission line

SG model parameters evaluation

Line model parameters evaluation

Line model

SG model

Power system model

Conclusion

- PMU-based power plant monitoring system proposed allows:
  - Preventing equipment physical damage
  - Improving operation efficiency
  - Increasing economic benefits
- Innovative PMU designed provides:
  - Deeper insight into power system dynamic properties
  - Fast emergency detection
  - Possible development of equipment and power system adaptive models

Q&A

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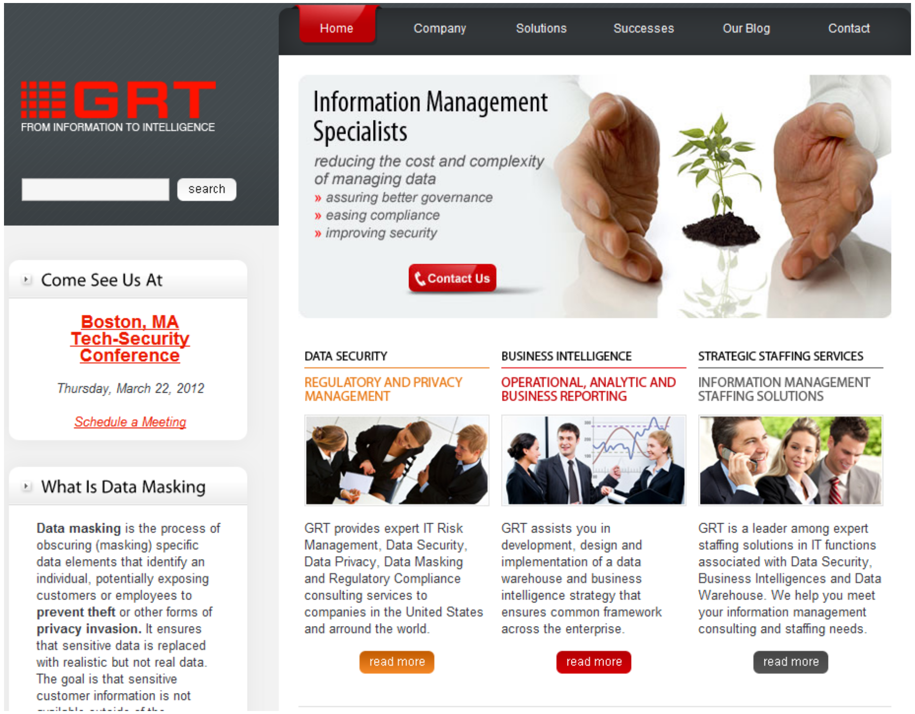

Thank You

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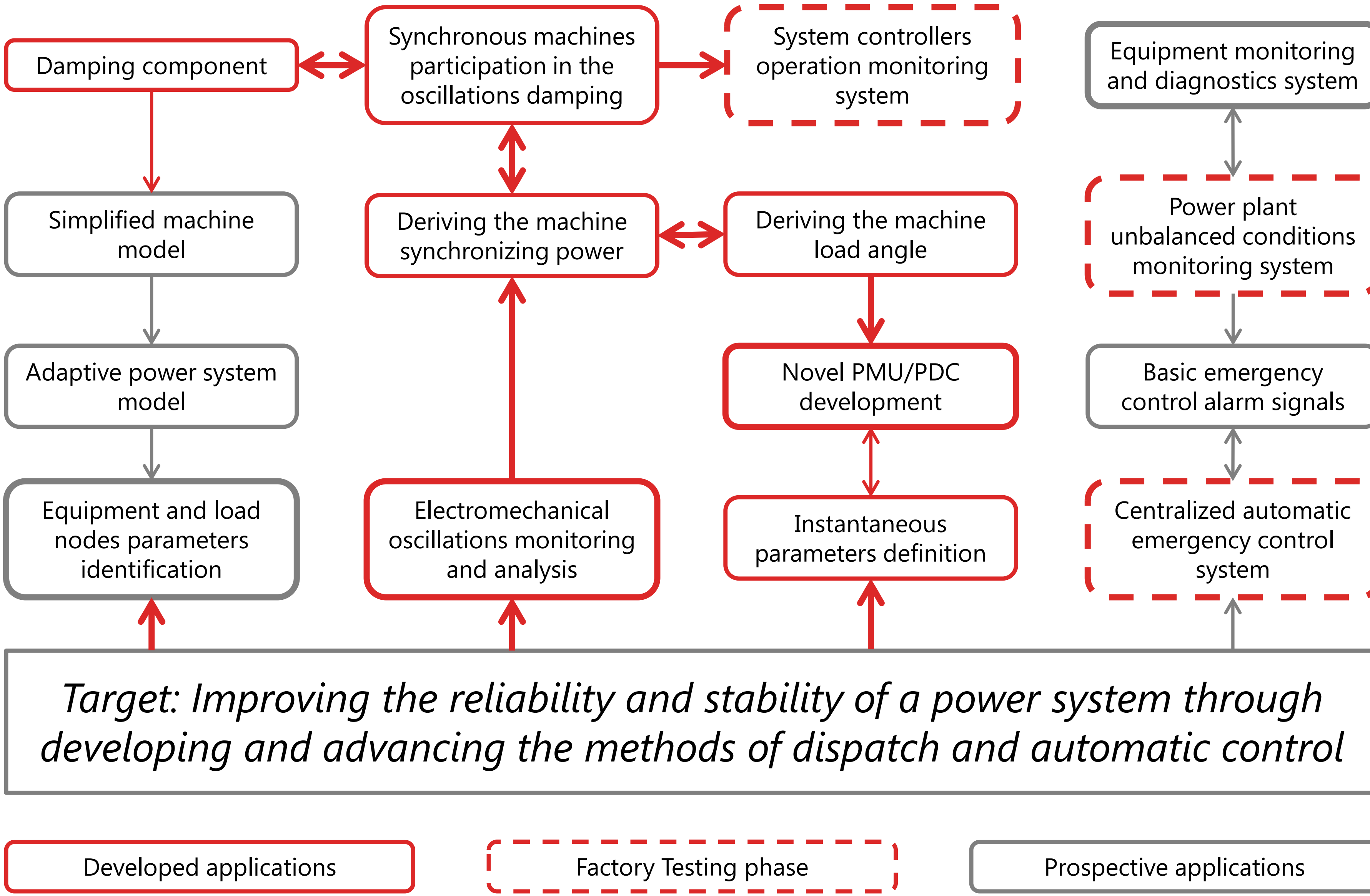
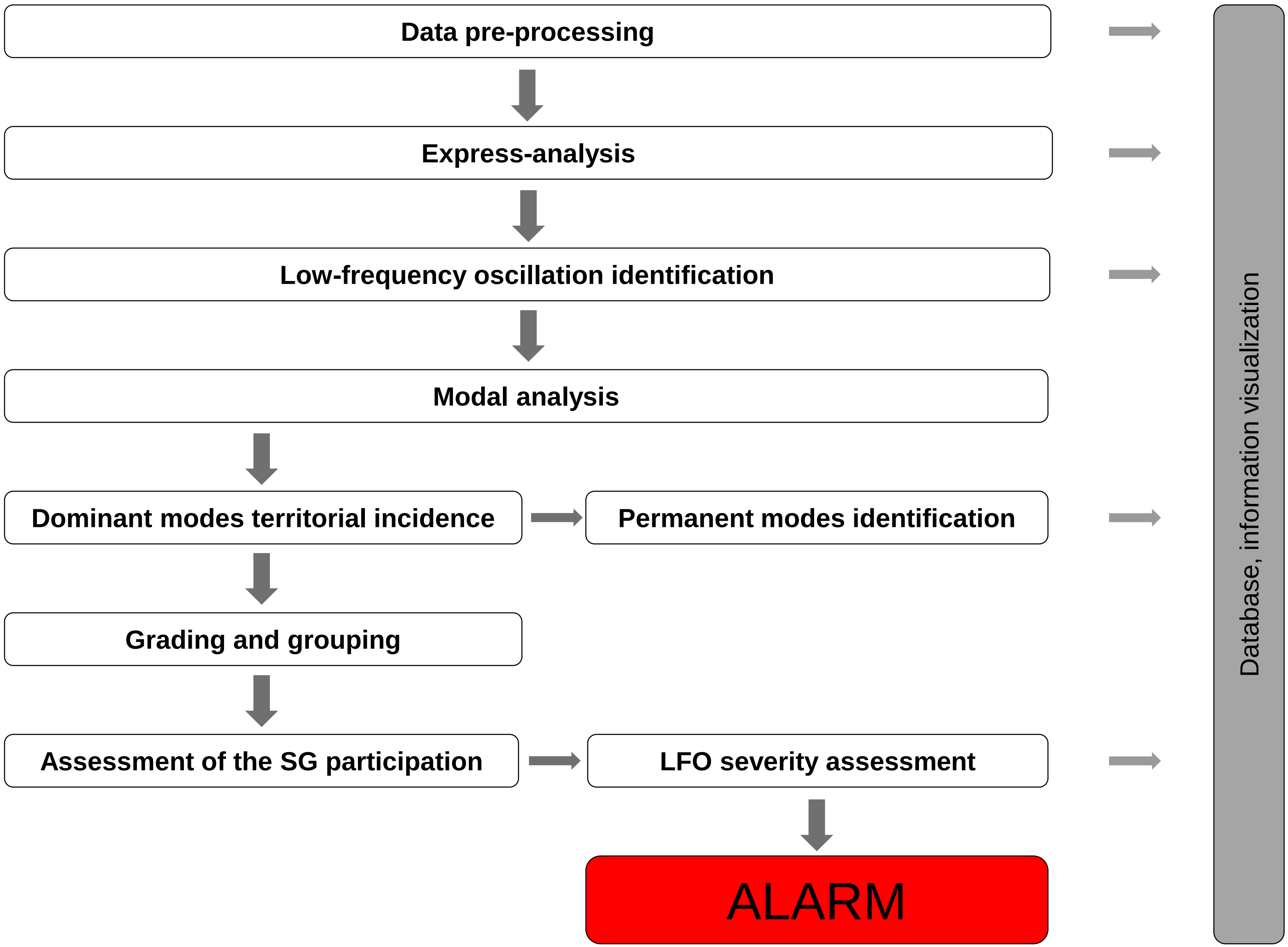
Phasor measurements data applications



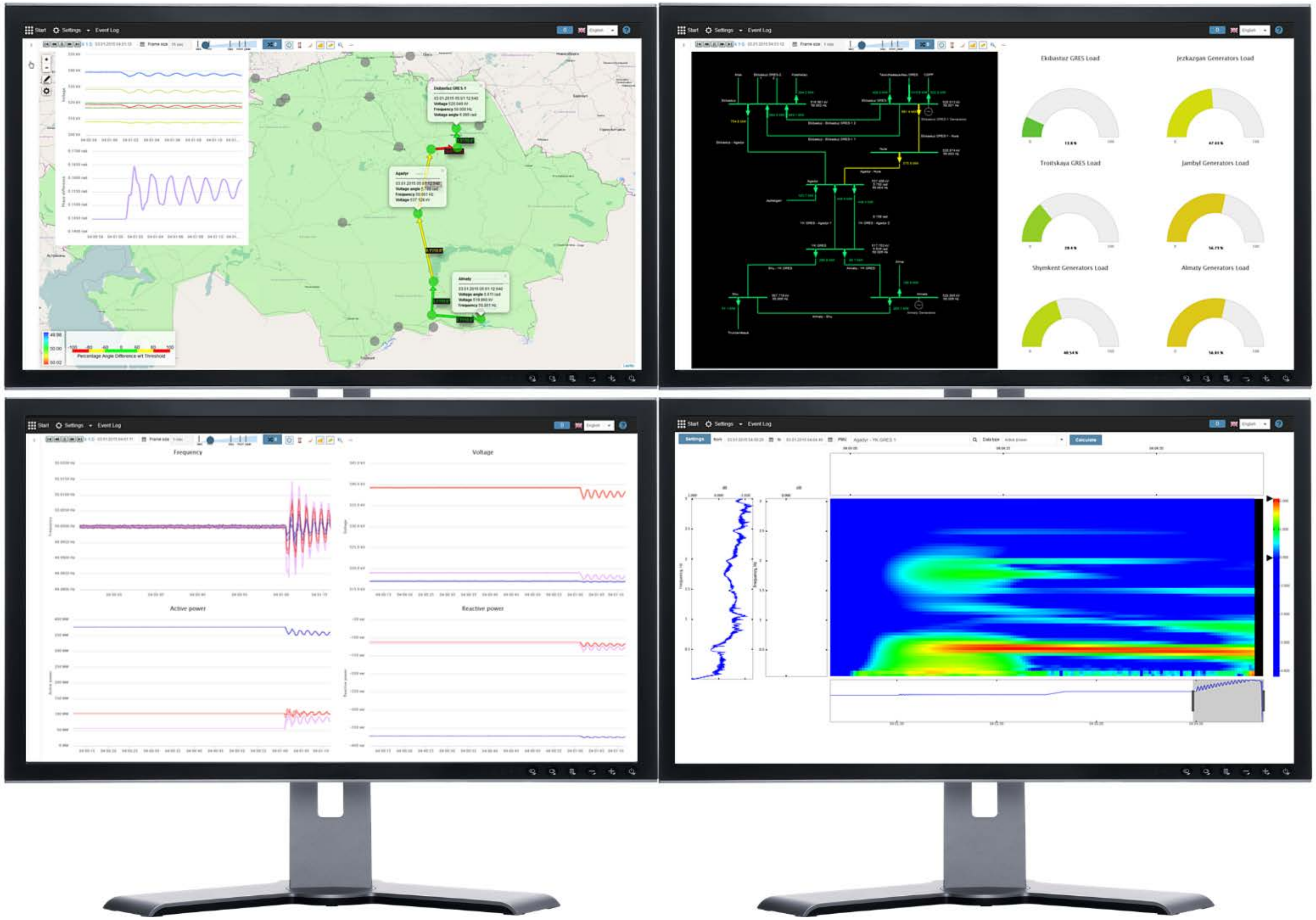
Electromechanical oscillations monitoring software Based on the automatic WAMS data acquisition system



Low-frequency oscillations monitoring implementation examples

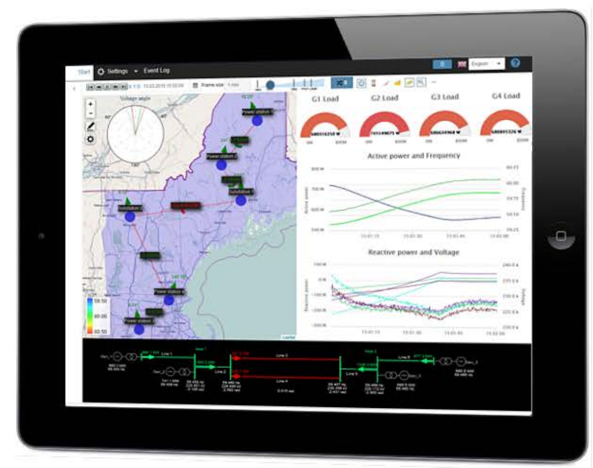
- The dominant modes of the Eastern Europe Power System were determined based on analysis of 2013-2014 years daily data
- Local and interarea dominant modes were identified and the normal conditions low-frequency oscillations parametres were defined
- Power system facilities with undamped modes within 0.2÷2.1 Hz frequencies range were identified
- Low-frequency oscillations were identified for bulk power transit lines of up to tens MW magnitude
- Statistical analysis was accomplished determining the stability level for the power system
- The analysis was fulfilled for the forced low-frequency oscillations reaching the power system stability margin

APDC visualization means



No details sneak under the radar with full multi-display configurations support

APDC visualization means



Any platform, any device

System controllers operation monitoring system

- The **primary objective** is enhancing the stability of the generating equipment synchronous operation in the power system:
  - adjustment of the automatic excitation control settings
  - troubleshooting the synchronous generator excitation systems

- The typical faults/misoperation currently detected:
  - Relay excitation forcing under emergencies in the power system
  - Synchronous generator rotor oscillation damping at normal, repair and post-fault power system conditions
  - Support for a stable synchronous generator operation at under-excitation (minimal excitation limiter) and over-excitation (maximal rotor current limiter) conditions

- **Factory acceptance test phase now**

Unbalanced conditions monitoring

Unbalanced operation may lead to

- Increased power losses
- Rotor overheating
- Mechanical vibrations
- Voltage asymmetry

⇩

- **Generator damage**
  - Isolation abrasion and deterioration
  - Windings deformation and/or displacement
- **Poor power quality**