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SYNCHRONIZED MEASUREMENT EXPERIMENT AND TRIAL WAMS/WACS STRUCTURE IN THE RUSSIAN FAR EAST INTERCONNECTED POWER SYSTEM

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SUMMARY

Phasor Measurement Units (PMUs) developed in the mid-1980s, and based on the use of these devices so-called Wide Area Measurement & Control Systems (WAMS/WACS) technologies have already made a revolution in the area of power system monitoring and control. Beginning the UCTE-IPS/UPS interconnection project that assumes creation of WAMS in IPS/UPS this year can eliminate Russia's unwarrantable developmental lagging in this area. However, there are some pitfalls in the project because Russian electrical engineers lack of experience in this area. One obstacle is the desire to speed up development of PMUs (Russian, Ukrainian, and so on) instead of employing tested PMUs produced by world leading companies can cause problems with the project because of the lack of experience. Another obstacle could be a tendency to do some explorations on one's own. This approach can be understood on the basis of the large experience accumulated in Russia on protection systems and control, but such tendency should not become the only way to implement the IPS/UPS WAMS. The paper demonstrates the experience of another approach to the problem.

KEYWORDS

Electrical Power System – Power System Stability - System Protection Schemes.

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1. SYNCHRONIZED MEASUREMENT EXPERIMENT

1.1. Organization of the experiment

The first prototype of the WAMS in Russia had been created in the framework of conducting the full-scale experiment on 22 November, 2005. The formal reason for carrying out the field tests in the Russian Far East Interconnected Power System was the necessity to examine the new SPS complexes described in [1]. But the actual motivation was the insistent need to become familiar with WAMS technology and verifying the capability of international expert teams to prepare and execute some full-scale experiment similar to suggested in [2]. In general, the goals and objectives of the experiments consisted in the following: 1) examination of speed governors' activity and frequency control system under occurrence of active power imbalances, 2) experimental data acquisition and verifying the models used under dynamic simulation, 3) mastering of PMU operation, 4) obtaining the synchronized measured difference angles of voltage between certain points of the power systems in order to demonstrate effectiveness and feasibility of new technologies for Russian power systems. A complementary goal of the experiment was to show the potential of an international collaboration in power system dynamic studies about the use of PMU devices. The power network scheme of the Russian Far East Interconnected Power System is adopted from [1] and its framework is shown in Fig. 1, A.

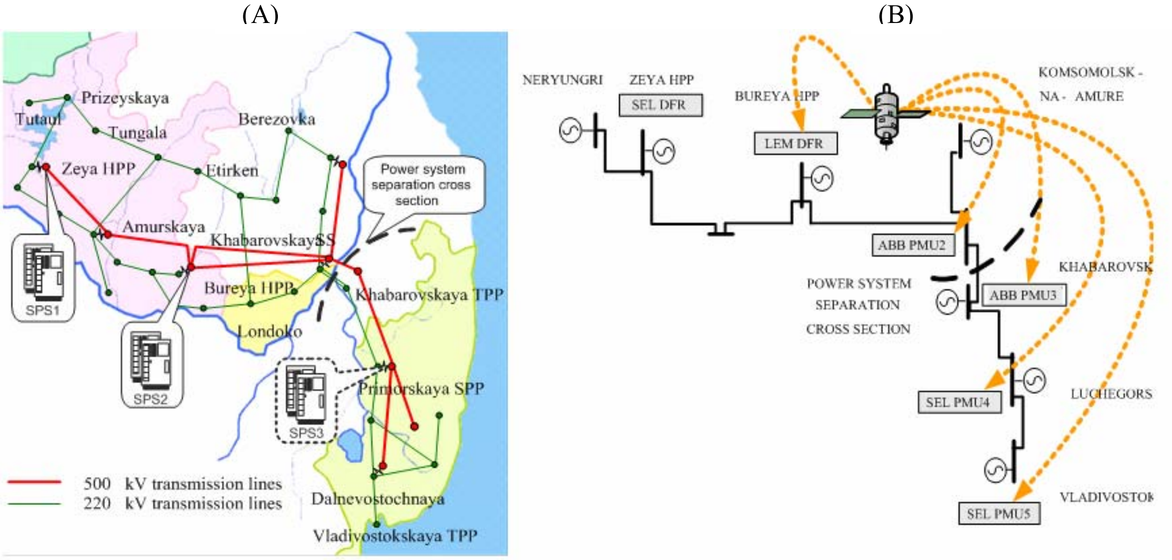

Fig.1. Network structure (A) and scheme of the experiment (B): DFR is digital fault recorder, PMU is phasor measurement unit, SEL, LEM, ABB are devices names, SPS is special protection schemes

This bulk power system is still separated from the Russian power grid. Such circumstance allows this system to be considered as a very convenient object for different experiments. To achieve the above mentioned goals the already known procedure and methodology described in [2] was adopted. This method consists in dividing the power system into two parts, so that the machines associated to one part accelerate whereas the others decelerate. The change of the power flow direction through the crossing segment of the power network and a further splitting of the power system permit to swap the accelerating and braking behavior of the two parts. Thus, two tests are recommended for testing the action of different types of automation in power systems. This approach seems to be a very productive way to conduct the full-scale experiments in power systems, and can be considered as a potential method for testing the UCTE-IPS/UPS interconnection.

1.2. The synchronized measurement results

The cross section where the 220 kV transmission lines shunting the 500 kV line were disconnected before conducting the experiment is shown in Fig.1, B. Thus, two areas of the bulk power system were only connected by one 500 kV transmission line. There were two tests making the active power imbalances and setting the opposite directions of the power flows through the cross section. Records of voltage and current phasors at certain points of the power systems on a large geographical area were made. The records and simulation of the frequency at the Zeya Hydro Power Plant (HPP) bus bar and the power flow through the 500 kV tie Zeya HPP – Bureya HPP are shown in Fig. 2.

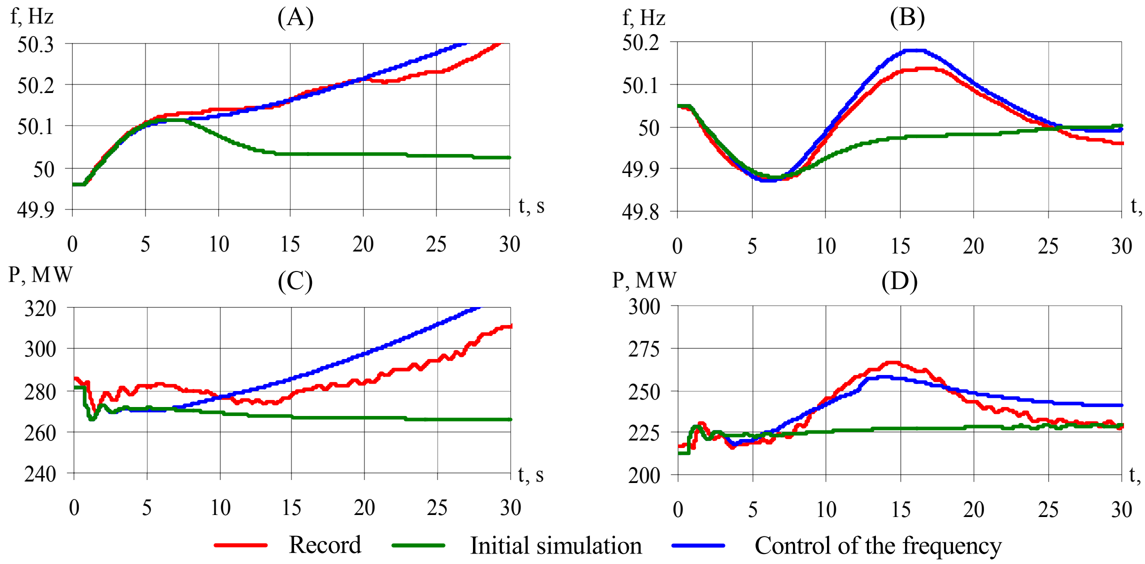

Fig.2. Records and simulation results during the test №1 (A, C) and the test №2 (B, D), where A and B are the bus frequency, and C and D are active power flow recorded with SEL DFR

Unexpected inadequate operation of the secondary frequency control system occurred during the experiment. The reason is that frequency measured in Khabarovsk – the place where the SO control centre is located – is used as an input parameter for the secondary frequency control system, and the control actions of this system are the change of the generator units active power at the Zeya (HPP). Thus, dividing the bulk power system created the conditions for incorrect operation of the secondary frequency control system. The operation algorithm of the secondary frequency control has to ensure the locking of the system operation in such cases. However, because of a limitation of the software, the lock was not performed. As a result, the secondary frequency control operated in the opposite direction with regard to the correct one. It is clearly seen in Fig.2, A and C, where the simulation results are depicted both for cases when the secondary frequency control system is locked and the actual incorrect implementation of the control action. After these tests, the software was revised. This software limitation became the reason for manual frequency regulation in the second test. This is apparent from Fig. 2, B and D. The power and frequency measurements with the use of LEM DFR and ABB PMU2 are similar to SEL DFR records and are not given in the paper.

With respect to WAMS organization, angles difference between voltage vectors obtained in certain nodes of the transmission system stimulated most of the interest. Both the angles between separated parts of the power system recorded by ABB PMU2 and ABB PMU3 and angle differences inside southern part produced by ABB PMU3, SEL PMU4, and SEL PMU5 are shown in Fig. 3.

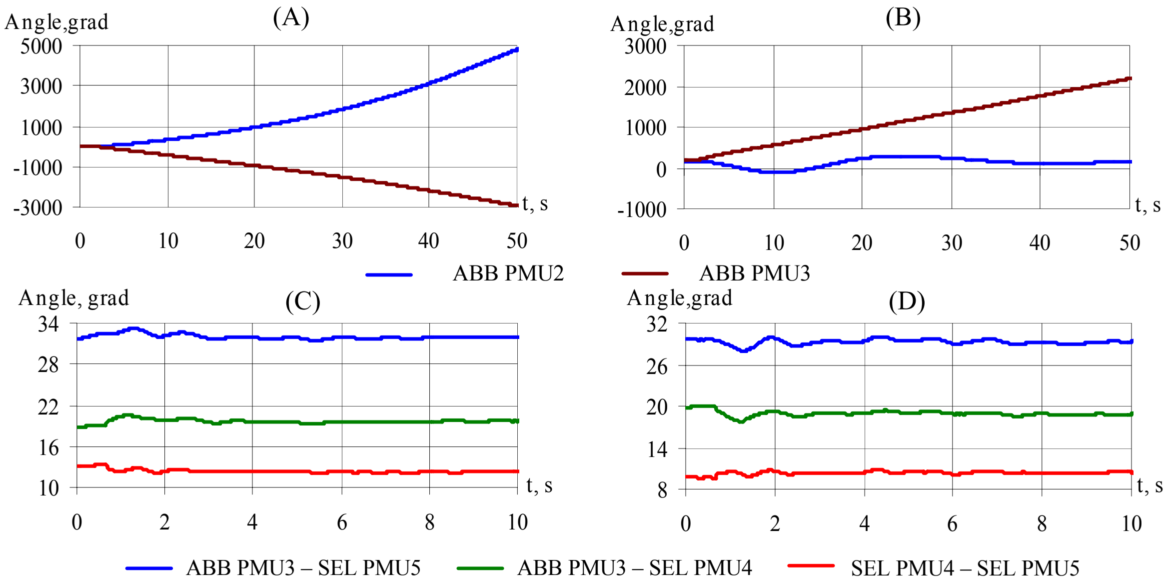

Fig. 3. Angles records and simulation: A, C – test №1; B, D – test №2, where A,B – angles of voltage vectors measured relatively to synchronously revolving axis; C,D – angles differences

Note that the curves of angles differences with the use of SEL PMU5 results have been corrected in order to compensate for the loss of some data during transmission from PMU to prototype data archiving software on operator computer. Loss of sampled data is attributed to serial communications issues between the SEL PMU and the prototype data archiving software. In such case one must align samples based on accurate timestamps. Newer data concentration, visualization, and archiving software automatically aligns timestamped data from multiple PMUs simultaneously and accommodates lost sampled data due to communications anomalies.

The wavy shape of the angle curve in Fig. 3, B is conditioned by intervention of operator of the Zeya HPP in order to restore the frequency. A GPS clock signal was not available for the SEL DFR at the time of testing, and LEM DFR was not purposed for phasor measurements, the angles differences examples are represented only for one part of the power grid.

1.3. The full-scale experiment lessons

The exact calculation of the angles differences between two points in power system with the use of the measurements made by SEL PMU5 was complicated owing to the above mentioned dropped data packets and misalignment of timestamped sampled data. The consequences of data losses are incorrect subtraction under the calculation of the angles difference. The red and blue curves in Fig. 4, A and B are the examples of this phenomenon.

Simulation of recorded frequency was impeded due to spikes in frequency data from ABB PMU2 placed directly in the Khabarovskaya Substation where the 500 kV transmission line was opened. The measured frequency spike is shown in Fig. 4, C and D. The reason of such phenomenon could be the behavior of PMU RES521 filtering algorithm under phase shifting caused by diversity of time of circuit breaker poles opening. Similar ABB PMU3, located only a little far from separation point, produced a spikes with magnitude about 10 times lesser (5-10 mHz). It is observed influence of distance from disturbance centre and so ABB PMU has been tested in really hard usage. Now, the algorithm is being under revision, as result frequency spikes in such working conditions will be absent. At the moment one can recommend to filter spikes in high level controller or simulation software.

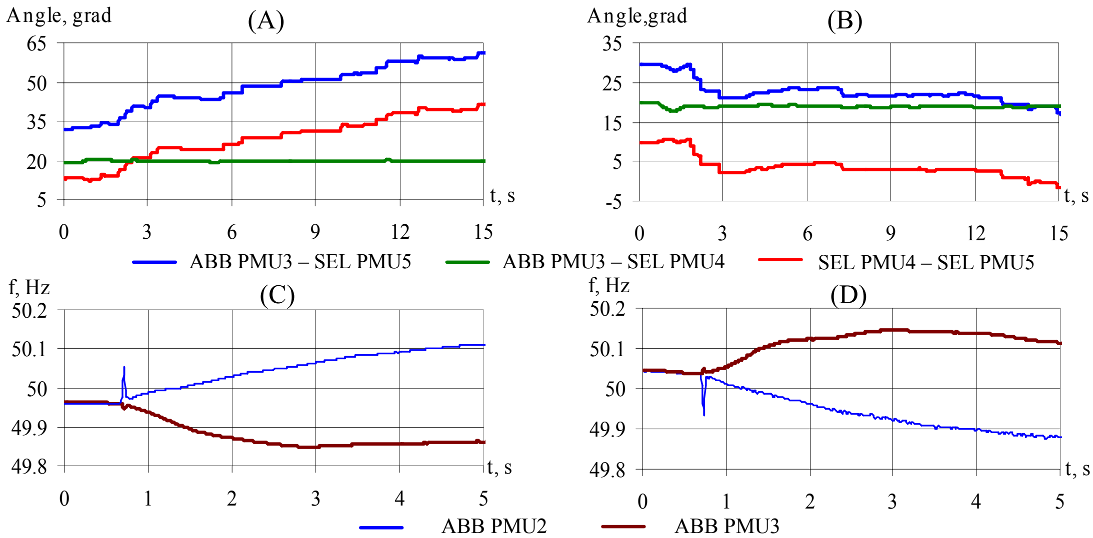

Fig. 4. Examples of subtraction of phasor angles with the use of SEL PMU4-5, ABB PMU3 (A,B) and frequency measurements with the use of ABB PMU2-3 (C,D)

Thus, it is logical to conclude that even well-tested PMU units can have unexpected malfunctions. When employing the PMUs developed without sufficient tests – an even greater number of defects is possible. To guarantee the reliable operation of WAMS to be developed in IPS/UPS, it is desirable at least at the beginning of the interconnection project not to forget the possibility of employing the PMUs produced by world leading companies. Such work direction could be useful both for the UCTE-IPS/UPS interconnection project and trial WAMS/WACS structure in the Russian Far East power grid. Another lesson of the experiment consists of verification of the idea originally formulated in [2] concerning the preparation and conduction of any full-scale tests connected with the UCTE-IPS/UPS. It is worth saying that without participation of foreign experts from Italy, Switzerland, the USA and employment of the PMUs produced in the USA, Belgium, and Sweden in the full-scale experiment the tests could not be carried out duly.

2. PROPOSED WACS STRUCTURE

2.1. The base for WAMS/WACS creation

In spite of the lack of experience with WAMS/WACS technologies, newly concluded agreements regarding the UCTE-IPS/UPS interconnection have obliged the Commonwealth of Independent States (CIS) party to equip its power grids with a synchronized measurement monitoring system. Under these conditions, along with the creation of the WAMS within the framework of the UCTE-IPS/UPS interconnection, it would be advisable to create a trial WAMS/WACS system in the Russian Far East Interconnected Power System. This system could become the base for adjustment of the main engineering technologies for the CIS power grid interconnection which is to be operated synchronously with UCTE. Thereby, it would be possible to avoid unforeseen obstacles certain to occur because of the lack of experience in creating and exploiting the WAMS in IPS/UPS and absence of time for research engineering and experimental development. The proposal regarding creation of the trial WAMS/WACS structure in the Russian Far East Interconnected Power System is stipulated by obvious practical reasons: 1) the structure of the Bureya SPS complex includes two devices, DFR equipped with GPS-clock and the so-called Database Server described in [1], and specially destined to fulfill some functions of PMU and Phasor Data Concentrator (PDC), 2) these devices are two of the three main components for creating one of possible configurations of WAMS/WACS structure, 3) there is no difficulty to create the third component, communication system, using the infrastructure of the data acquisition system of the Bureya SPS complex. Taking into account availability of three SEL PMU devices given for temporary use in the Russian Far East power grid and set at the Zeya HPP, Primorskaya steam power plant (SPP) and Vladivostok thermal power plant (TPP), experimental investigations can be started right now.

2.2. Trial WACS structure example

There are several problems within the SPS data transfer system, connected with low reliability of its components. In case of failure of the data transfer system, the SPS complex goes into the state of data inauthenticity and is forced to increase the volume of control actions and consequently the load or generation to be shed. These problems can be solved by applying the WAMS/WACS technology. Indeed, additional information regarding voltage angles difference along the transmission system can be the criterion for selecting the operation mode of SPS in case of possible data inauthenticity. One of possible location of PMU devices for WACS implementation with reference to the Russian Far East bulk power system is given in Fig. 5, B. Employing the method of representation of WACS logic suggested in [4], it is possible to depict the operation logic of the trial WACS that could be created on the base of the Bureya SPS complex. Combining the functions of PDC and SPS complexes in one device is a peculiarity of the proposed WACS structure. The use of additional information regarding voltage angles differences allows estimating the actual state of the data transfer system and avoiding surplus control actions. This goal can be achieved by locking the operation of transforming into data inauthenticity mode for SPS complexes shown in Fig. 5, A. As a matter of fact, it is a data source regarding the heaviness of the prefault state of power network.

(A) (B)

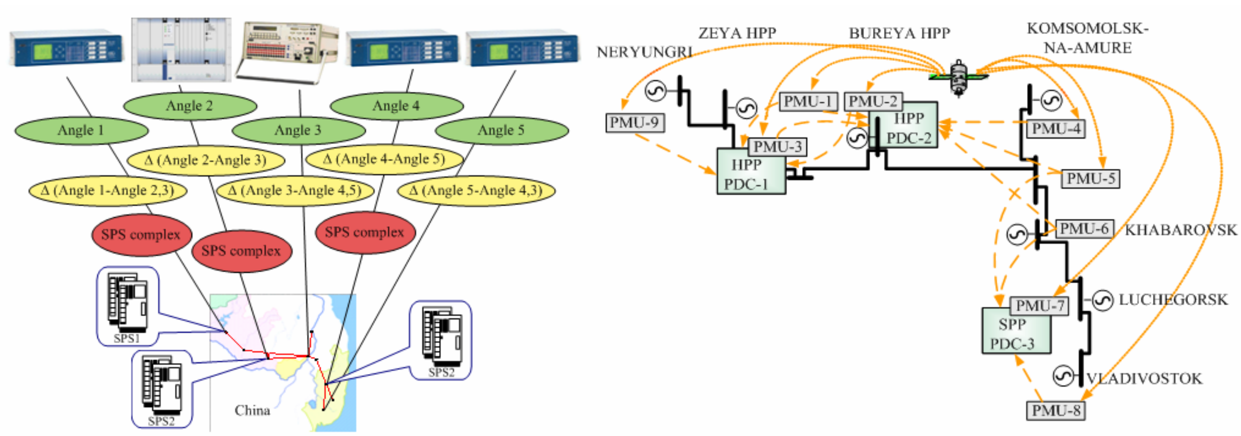

Fig. 5. Trial WACS operation logic (A) and structure of potential WACS system (B):
SPS is special protection schemes; PMU is phasor measurement unit; HPP is hydro power plant, SPP is steam power plant; SO and TSO are transmission system operators; PDC is phasor data concentrator

2.3. Prospects of the SPS improving

The special power system state estimation method described in [3] can be slightly adopted to be exploited by PDC-1, PDC-2, and PDC-3 organized on the base of the SPS complexes. One of the potential WACS schemes can be created in the eastern part of the Russian power grid and could be employed as a training ground for international investigations of PMU features and WAMS/WACS peculiarities that was suggested in [4]. The availability of two PMU devices at Primorskaya SPP and Vladivostok TPP allows to begin the work package on organizing the WAMS/WACS in the area of online service of SO located in Vladivostok. There are at least two work directions to be considered as priority ones: 1) monitoring the angles difference along the Primorskaya SPP - Vladivostok power transmission system while providing the regional SO dispatcher with information about the current state severity, i.e., creation of WAMS, 2) implying the information concerning the angles differences for improving the reliability and functionality of the Primorskaya SPP complex by analogy with the Bureya SPS complex, i.e., creation of WACS. The base for developing the PDC software and on-line information complex conjugation in SO in Vladivostok can become the special software of the Bureya SPS complex. In the latter case, some SCADA/EMS software packages can be modified for operating with actual data obtained from PMU.

2.4. Comparative analysis of prospect PMUs

Considerable influence on functional capabilities and features of WAMS/WACS structure can be caused by PMU parameters. One of the devices is DFR equipped with GPS-receiver and minimal set of software tools for measurement time synchronization. Output signals of such device usually are digital code of three-phase currents and voltages presented in a time domain. New generation of the devices corresponds to IEEE C37.118-2005 standard and, depending on the operator preferences, it can present output data both in time and frequency domain. In the latter case, we talk about so-called phasor or vector representation of output signals in algebraic or exponential form. Table 1 presents some features of three devices which could be used in the trial WAMS/WACS system as they have been employed in the above full-scale experiment and four of them are still operating in the power grid.

Table 1: PMU comparative analysis

	SEL – 421 Relay SEL Inc., USA 	**RES 521 1.0** ABB, Sweden 	**BEN 6000** LEM, Belgium 
Functionality	• Phase and ground distance protection • Detection of Out-of-Step character • Directional and Non-directional Over current Fault Protection • Breaker Failure Logic • Auto-Reclosing and fault locator • Phasor measurement (Selectable filtering algorithms optimized for fast response or narrow frequency band operation) • Sequence of events reporting • Dual Circuit Breaker Monitor • Dual Substation Battery Monitor • Programmable Relay Logic	• Protective relay • Phasor measurement • Compensation of measuring hardware nonlinearities	• Digital fault recorder • Dynamic swing recorder • Power quality monitor • Sequence of events reporting • Fault locator • Continuous recording • Phasor measurement unit • Remote terminal unit
Interface	• Ethernet 10/100 Base-T,10 Base-FL, 100 Base-FX • 3 rear-panel and 1 front-panel EIA-232 serial ports (300-57600 bps) • GPS-clock (IRIG-B)	• Ethernet 10/100 Base Tx and 100 Base FX • GPS-antenna for built-in GPS receiver	• Ethernet 10Base-FL, 100Base-FX • Modem (RS232-V24) • 2 serial ports (up to 115.200 Bps) • GPS-clock (IRIG-B) • Fax, printer, USB ports
	V and I phasors (IEEE C37.118-2005 and SEL Fast Message protocols)	V and I phasors, frequency, rate of change frequency (IEEE C37.118-2005 protocol)	
Analysis	• Instantaneous V and I • Sequence components • Frequency and power • Harmonics • Energy • df/dt	• RMS values of V and I • Positive sequence voltages and currents phasors • Frequency • df/dt	• Instantaneous V and I • Sequence components • Frequency and Power • Harmonics • Rate of change (dx/dt) • Magnitudes and phases • Rising and Falling edge
Sampling	Event reports: 1-8 kHz Phasors: up to 50/60 Hz	Phasors: up to 50/60 Hz	Fast: 1-12 kHz Slow: 1-120 Hz Cont. recording: 1Hz-1kHz Phasors: up to 50/60 Hz

Accuracy	±0.2 % on I and I angle ±0.1 % on V ±0.2 % on V Angle ±0.01 Hz on Frequency	±0.1 % on I ±0.1 % on V ±0.1 ^{0} on angles ±5 mHz on frequency	0.2% on I 0.1% on V 0.1 ^{0} on angles ±2 mHz on frequency
Inputs	6 current inputs 6 voltage inputs 8 digitals (Up to 55 digitals) 2 Substation DC Voltage Inputs	9 (6 current and 3 voltage) or 18 analogues 8 digitals	Up to 192 analogues Up to 384 digitals Up to 200 virtual channels
Out puts	8 output relays (Up to 38 output relays)	12 output relays	8 or 16 (option) output relays
Tugging	10 µs	1µs	-
Timing	IRIG-B time stamping to make accuracies of ±5 µs available on event reports	GPS accuracy: ± 0.5 µs	<50µs with IRIG-B/J+1pps pulse or 5 ms if external pulse or IRIG-B

In different modifications, PMU can fulfill various functions of automatics, relay protection, digital recording and can differ from each other by algorithms of digital filtering, synchronization accuracy, sampling frequency, operator interface, network communication capabilities etc. One can see that various units have different feature. The tasks and goals of the device implementation have to define the choice of equipment. It is known that depending on the tasks to be solved by WAMS/WACS system for providing the necessary measurement accuracy, one can use multi-type or one-type PMU devices. Thus, the necessity of comparing the functional capabilities of PMUs is evident. That is why experimental WAMS/WACS system that can be created in the Russian Far East Interconnected Power System has to possess various devices operating as PMU. It is also obvious that the devices should be located that way to provide the adequacy of experimental investigations of each set tasks.

3. CONCLUSION

The main result of the experiment is the change of mind of Russian electrical engineers regarding the WAMS/WACS technologies. Another important result of the experiment is validation of the possibility to use the angles difference between any points of transmission systems for on-line control. The full-scale tests are the necessary part of WAMS/WACS structures implementation in bulk power systems because of their special significance for power grids operation. The trial WAMS/WACS system can be created in the Russian Far East power grid to become a training ground for international collaboration in this area.

BIBLIOGRAPHY

[1] A. Grobovoy, N. Bondareva, N. Borodina, D. Denisova, A. Germond, R. Cherkaoui, M. La Scala, S. Bruno, M. De Benedictis, "Full-scale Tests of the AC Transmission System to Examine the New SPS Complexes" (the 8th IEE Int. Conf. AC and DC Power Transmission, London, 2006)

[2] A. Grobovoy, B.Tremerie, N. Bondareva, M. Stubbe, A. J. Germond, "Full Scale Experiment of the East-West Interconnection" (Proc. of the Georgia Tech Fault and Disturbance Analysis Conference, Atlanta, 2004)

[3] A. Grobovoy, Y. Grishin, I. Kolosok, "Practicability of SPS Coordination in Market Environment for Impending UCTE-IPS/UPS Interconnection" (Proc. the 2nd CIGRE/IEEE-PES Symposium "Congestion Management in a Market Environment", San Antonio, 2005)

[4] Task Force 38.02.19 CIGRE "System Protection Schemes in Power Networks" (edited by D. Karlsson and X. Waymel June 2001 pp. 1-172).