# International Collaboration in Synchronized Measurement Experiment in Russia


Andrey Grobovoy
*Power System Emergency Control Laboratory, Ltd.*

Natalia Bondareva
*Siberian Electric Power Research Institute*

Vladimir Stepanov
*ABB Automation*

Edsel Atienza
*Schweitzer Engineering Laboratories, Inc.*



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***Abstract*—The paper discusses the results of the synchronized measurement experiment recently conducted in the Russian Far East Interconnected Power System. An international team of experts conducted a set of unique tests in the bulk power system. The tests used five devices for synchronized phasor measurement. In conjunction with digital fault recorders (DFRs), the phasor measurement units (PMUs) were able to demonstrate the feasibility of using PMUs to monitor and control the Russian Far East Interconnected Power System.**

## I. Introduction

Russian engineers have extensive experience creating elaborate special protection schemes (SPSs) to automate control actions. Unfortunately, current Russian SPSs have not yet incorporated the modern synchronized phasor measurement more commonly found in wide area measurement systems (WAMSs) in other countries. Leading international manufacturers have benefited from years of experience in the implementation of PMUs and WAMSs, resulting in applications such as the increase of fault location accuracy in transmission lines. Ten years ago, manufacturers in the United States claimed fault-location accuracy to within 300 m using PMUs [1]. In contrast, Russian fault-location accuracy without PMUs has remained at 5 percent of the transmission line length.

A few years ago, English was not common among the majority of Russian electrical engineers. Consequently, few were knowledgeable of modern trends and technologies widely described in reports of IEEE and CIGRE task forces. Now the situation is changing for the better as electrical engineers have realized the benefits of participation in international power engineering organizations. Examples of these benefits are apparent in the field tests performed on June 21, 2006, and the experiments of November 22, 2005, in the Russian Far East Interconnected Power System, when this power grid was islanded into two regions [2].

The international collaboration described in this paper has helped experts from different countries test their devices, compare obtained results of the experiment, and identify potential improvements in equipment and software. Multifunction devices used as PMUs included a variety of additional functions such as digital fault recording, protective relaying, and fault location. Such field tests undoubtedly can help to evaluate combinations of functions to meet the requirements of a certain power system.

Carrying out the above-mentioned experiments is practically impossible in countries with developed power market economies because of the number of involved parties and the potential impact to the stability of the power system. In Russia, the power market is still unified, simplifying the approval process required for conducting such extraordinary field tests. Moreover, the separation of the Russian Far East Interconnected Power System from the Russian Power Grid localizes potential impact of the field tests, providing a favorable training ground for both Russian and foreign experts to conduct various experiments.

## II. Current State of the Russian Far East Interconnected Power System

The Russian Far East Interconnected Power System is on the outskirts of the Russian power grid [2]. Because of insufficient transfer capability of the 220 kV transmission lines between the Siberian Interconnected Power System (IPS) and the Far East IPS, the Far East IPS operates isolated from the national power system, but includes 220 kV tie transmission lines with the northern part of the Chinese power system. The Far East IPS includes over 2,000 km of 500 kV transmission lines. The main voltage levels of the transmission lines are 500, 220, and 110 kV. Some local and two centralized SPSs help ensure high reliability of the Far East IPS. A current project will link the Far East and Siberian interconnected power systems in the near future.

### *A. SPSs in Operation*

Fig. 1 shows the SPSs at the Zeya and the Bureya Hydro Power Plants (HPPs). Their hardware is identical because the Zeya SPS device has served as a prototype for the Bureya scheme. However, the software of the Bureya SPS is more advanced and includes special modules for processing time-stamped data from different channels. The main features of the Bureya SPS and special software are discussed in [3].

The SPS computing device determines the topology of the system based on the state of circuit breakers. Based on the topology and the active power flow in particular segments of the system, the SPS identifies the appropriate batch of control actions. The set of control actions may include combinations of the following:

- dynamic braking at Zeya HPP
- generation shedding at Zeya HPP

- generation shedding at Bureya HPP
- remote load shedding in three power systems situated in the receiving end of the transmission system

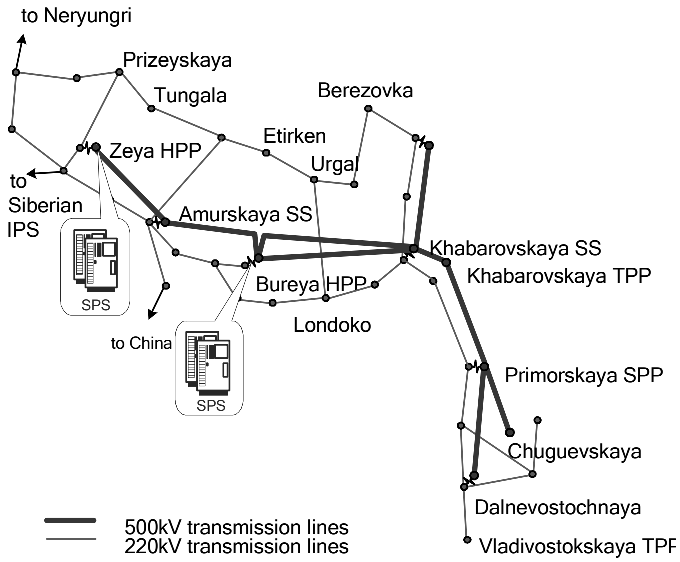


Fig. 1. The Russian Far East power grid structure and SPSs location

Two high-performance Compact PCI controllers constitute the core of the Bureya SPS. The database server and DFR are also used. The DFR equipped with GPS-clock is able to perform the functions of a PMU. The SPS operating principle is based on the concept of facility backup.

### *B. WAMS Implementation Progress*

Application of state-of-the-art real-time measurement devices can considerably improve control techniques implemented in power systems. Based on worldwide WAMS experience, WAMS in Russia can improve stability and decrease vulnerability of the electrical infrastructure.

Moreover, the PMU technology, applied to WAMS, has also proved to be a promising means of improving power system performance; implementing modern monitoring, protection, and control tools; and advancing asset management and risk assessment in the Russian Far East Interconnected Power System [4]. The above is a good prerequisite to installing PMUs at strategic locations on the grid to obtain real-time measurements of voltage and current phasors.

## III. Synchronized Measurement Experiment on November 22, 2005

### *A. Organization of the Experiment*

The first prototype of the WAMS in Russia was created in the framework of conducting a full-scale experiment on November 22, 2005. The reason for carrying out the field tests in the Russian Far East Interconnected Power System was the need to examine the new SPSs described in [2]. The actual motivation was the insistent need to become familiar with the WAMS and PMU technology and verify the ability of international expert teams to prepare and execute some full-scale experiments.

In general, the goals and objectives of the experiments were:

- examining speed governors' activity and frequency control system during active power imbalances
- acquiring experimental data and verifying the models used for dynamics simulation
- mastering of PMU operation
- obtaining the synchronized measured angle differences of voltage between certain buses of the power systems in order to demonstrate the effectiveness and feasibility of new technologies for Russian power systems

Dividing the power system into the two regions just described allowed the machines associated with one region to accelerate, whereas the machines associated with the other region were decelerating. Changing the power flow direction through the interconnecting segment of the power network and a further splitting of the power system permitted swapping of the accelerating and braking behavior of the two regions. Fig. 2 presents the scheme of PMU locations and the cross section where the 220 kV transmission lines in parallel with the 500 kV line were disconnected before conducting the experiment. Thus, two areas of the bulk power system were connected only by one 500 kV transmission line. There were two tests creating the active power imbalances and causing reverse power flows through the interconnection.

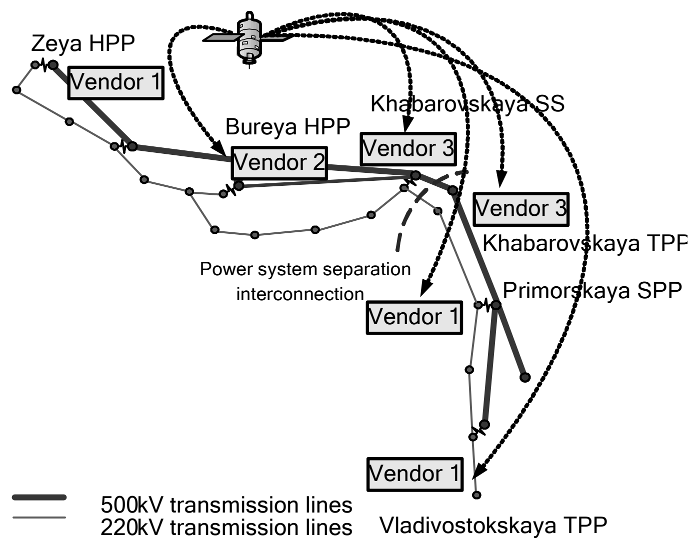


Fig. 2. Scheme of the experiment: HPP—hydro power plant; SS—substation; TPP—thermal power plant; SPP—steam power plant

### *B. Measurement and Simulation Results*

During the experiment, six PMUs from three vendors recorded voltage and current phasors at certain locations of the power systems on a large geographical area. The measurement and simulation of the frequency at the Zeya HPP bus bar and the power flow through the 500 kV tie Zeya HPP–Bureya HPP are shown in Fig. 3.

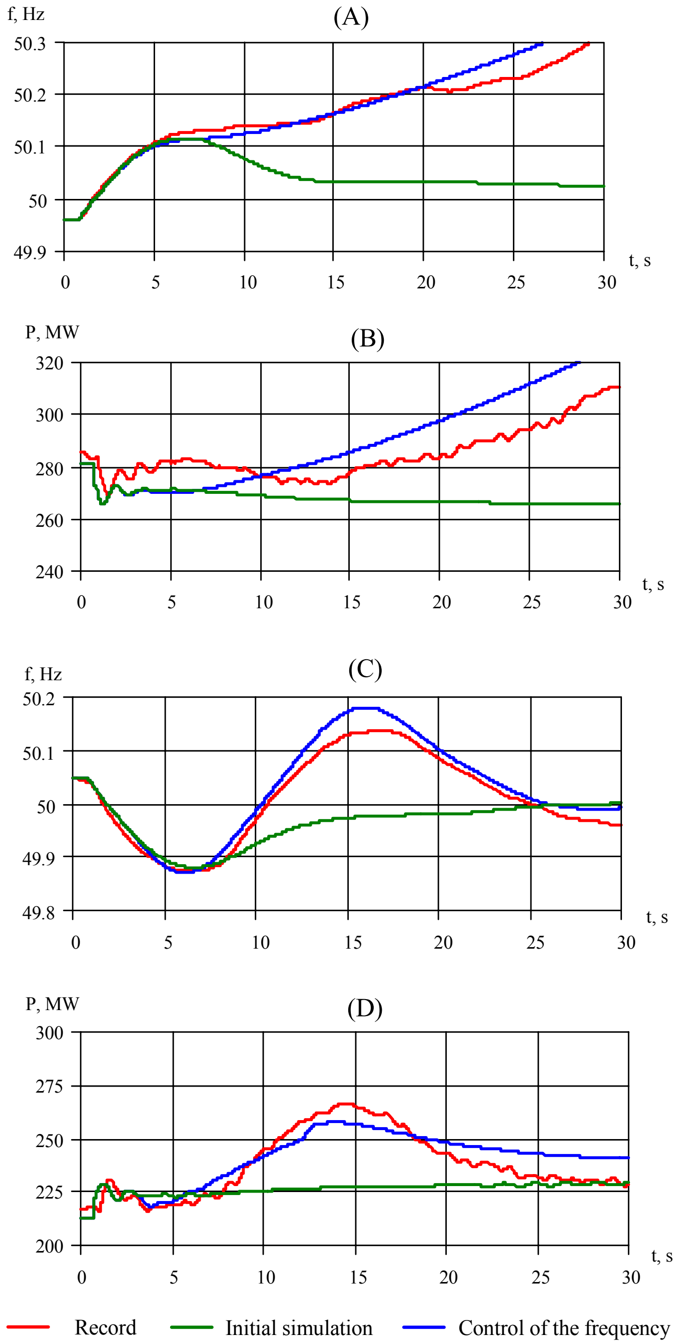


Fig. 3. Measurement and simulation results during Test 1 (A, B) and Test 2 (C, D), where A and C are the bus frequency, and B and D are active power flow

Unexpected inadequate operation of the secondary frequency control system occurred during the experiment. The frequency measured at Khabarovsk, site of the System Operation (SO) control center, is used as an input parameter for the secondary frequency control system. The control actions of this system result in the change of the active power generation at Zeya HPP.

The operation algorithm of the secondary frequency control must ensure locking of the system operation in such cases. However, because of an error in the software, the system was not locked. As a result, the secondary frequency control operated in the direction opposite to the desired direction.

Fig. 3, A and B, clearly show the simulation results both for the expected lock of the secondary frequency control system and for the actual incorrect implementation of the control action.

After these events, the secondary frequency control system was removed from operation, and the software was revised. The frequency was regulated manually in the second test. This is apparent from Fig. 3, C and D.

During the first test, the measured frequency of the southern region dropped to 49.84 Hz without returning to the nominal frequency, as shown in Fig. 4, A. The governors and the turbine regulator responsible for steam pressure before the turbine operated in opposite directions. In addition, in the southern region of the system, some governors did not work because of large dead bands. After conducting the simulation of the experiment, it became obvious that the observed primary frequency control behavior requires further investigation to improve the power system model.

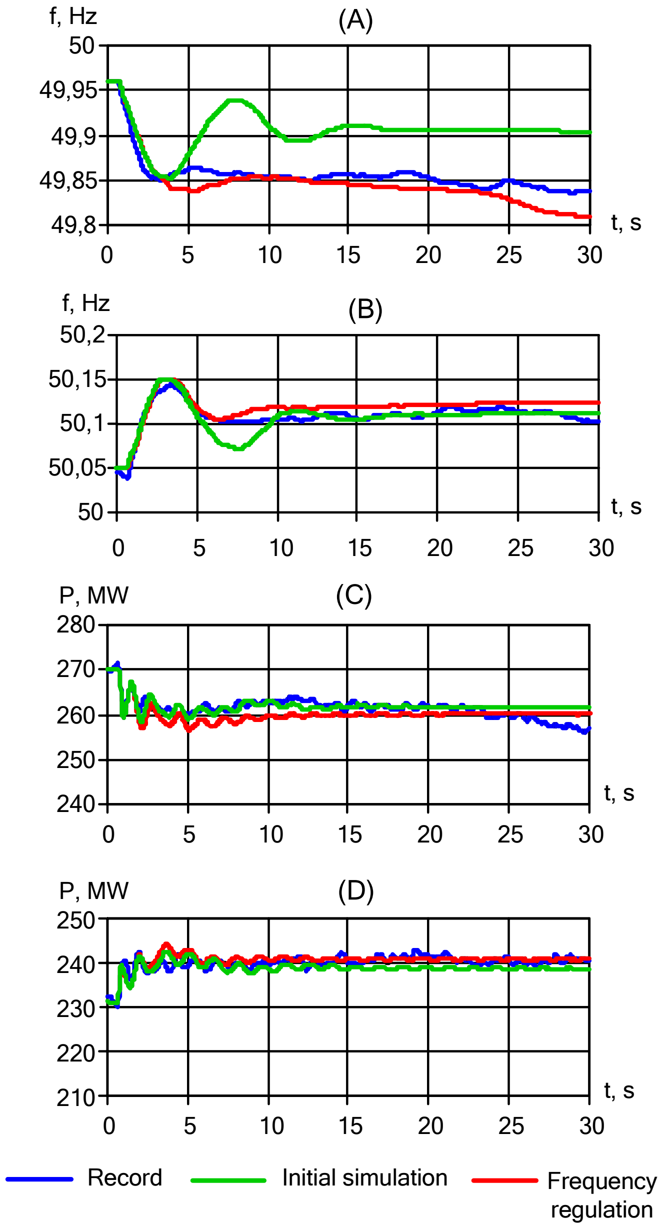


Fig. 4. Recorded measurements and simulation results during Test 1 (A, C) and Test 2 (B, D), where A and B are the bus frequency and C and D are active power flow

With respect to WAMS organization, angle differences among voltage phasors obtained in certain nodes of the transmission system were of great interest. The angles between separated regions of the power system and angle differences within the southern region are shown in Fig. 5. The wavy shape of the angle curve in Fig. 5, B is caused by a Zeya HPP operator's attempt to manually restore the frequency. Because GPS clock signal was not available for the PMU placed at the Zeya HPP at the time of testing and the DFR placed at the Bureya HPP was not configured for phasor measurements, the angle difference examples are represented for only part of the power grid.

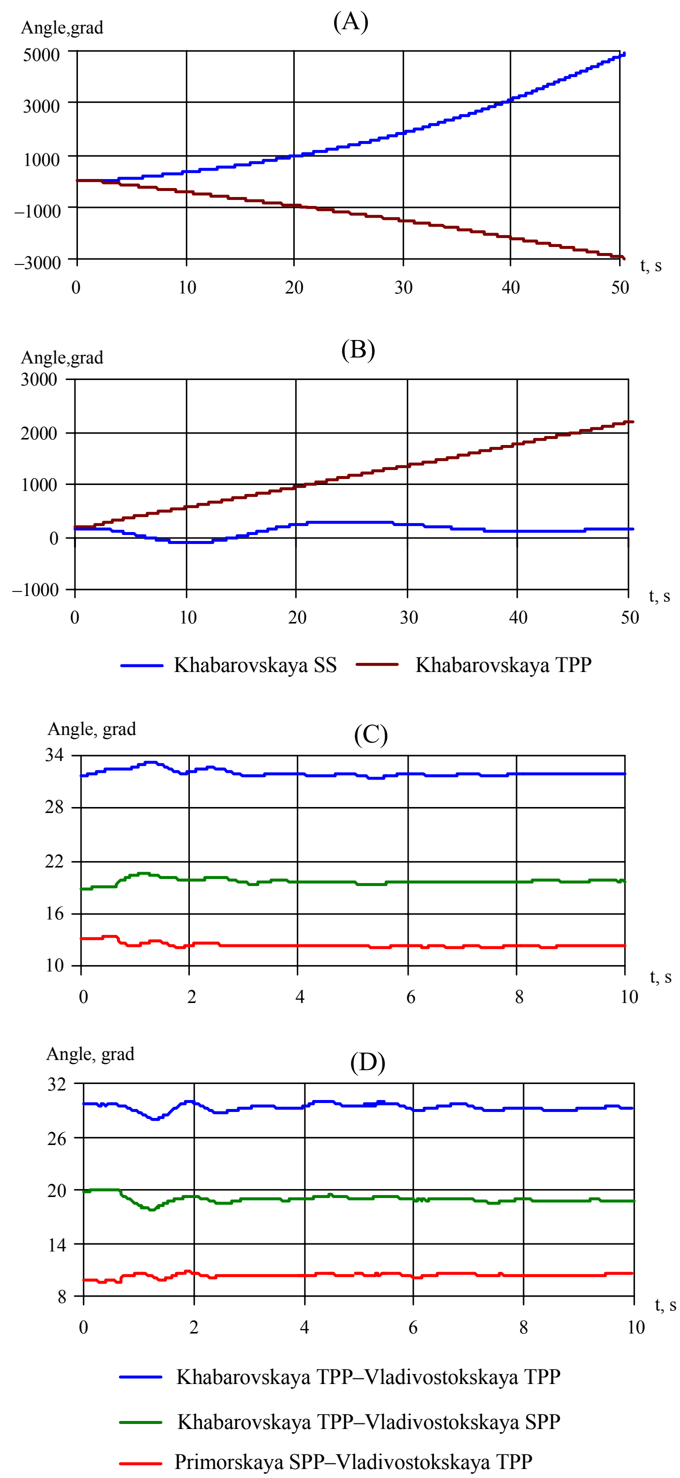


Fig. 5. Angle records and angle difference calculation: A, C—Test 1; B, D—Test 2, where A, B—angles of voltage vectors measured relative to synchronously revolving axis; C, D—angles differences; SS—substation; TPP—thermal power plant; SPP—steam power plant

The angle-difference curves based on Vladivostokskaya TPP PMU measurements were corrected because of loss of some sampled data during transfer from PMU to prototype data archiving software. An example of the consequences of direct comparison of misaligned sequential samples without respect to the timestamp of each individual sample is shown in Fig 6, A and B. Loss of samples is attributed to serial communications issues such as buffer overrun, improper configuration of the software, or inadequate laptop serial-port hardware. In such cases, one must align samples based on accurate timestamps of each sample. Newer data concentration, visualization, and archiving software automatically aligns timestamped data from multiple PMUs simultaneously and accommodates sampled data lost because of communications anomalies.

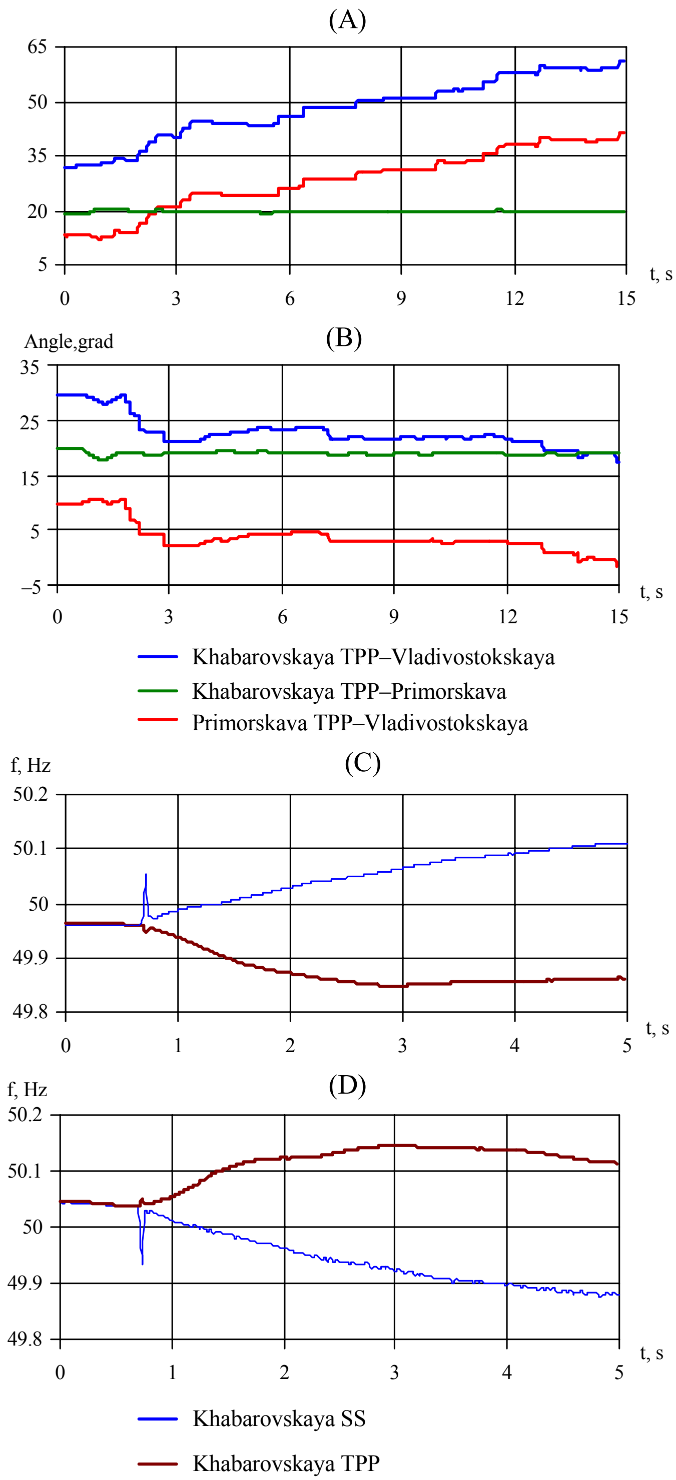


Fig. 6. Examples of subtraction of phasor angles (A, B) and frequency measurements (C, D)

Analysis of recorded frequency was impeded by spikes in frequency data from the Khabarovskaya substation's PMU where the 500 kV transmission line was opened. The measured frequency spike is shown in Fig. 6, C and D. The reason for such phenomena could be the behavior of the PMU's filtering algorithm under phase shifting caused by differences in the time circuit breaker poles opened. A similar PMU located only a little further from the separation point produced spikes with magnitude about 10 times smaller (5–10 mHz). Distance from the disturbance center was considerably long; therefore, the Khabarovskaya substation's PMU was tested in very hard usage. The high-level control system can not easily identify the cause of spikes, so interprets the spikes only as power imbalances, resulting in a need to adapt PMU frequency measuring algorithms.

### C. *Proposed WACS Structure*

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 goes into a state of data inauthenticity and is forced to increase the volume of control actions and consequently the load or generation to be shed. Applying the WAMS/WACS technology can solve these problems. Indeed, additional information regarding voltage angle difference along the transmission system can be the criterion for selecting the operation mode of SPS in case of possible data inauthenticity. One possible location of PMU devices for WACS implementation in the Russian Far East bulk power system is given in Fig. 7.

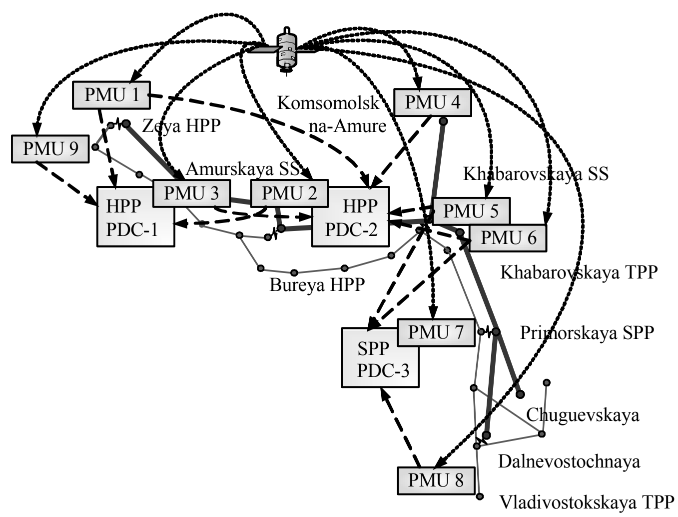


Fig. 7. Trial WACS operation logic: PMU is phasor measurement unit; HPP is hydro power plant, SPP is steam power plant; PDC is phasor data concentrator

Using the method of representing WACS logic described in [5], it is possible to depict the operation logic of newly suggested trial WACS that could be created based on the Bureya SPS.

Combining the functions of PDCs and SPSs in one device is a peculiarity of the proposed WACS structure. The use of additional information regarding voltage-angle differences allows estimation of the actual state of the data transfer system and avoidance of surplus control actions made by the SPSs.

This goal can be achieved by locking the operation of transforming into data inauthenticity mode for the SPSs shown in Fig. 8. As a matter of fact, it is a data source for information about the robustness of the prefault state of the power network.

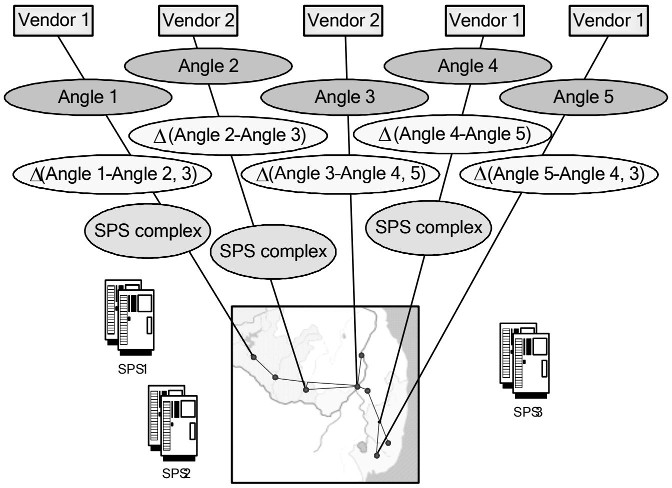


Fig. 8. Structure of potential WACS system

## IV. Synchronized Measurement Experiment on June 21, 2006

### A. Organization of the Experiment

Normally, control instrumentation in Russian power systems is conducted twice per year, June 21 and December 21. This situation permitted an additional examination. The application of PMUs allows execution of the control instrumentation of power system condition synchronously. Control instrumentation provides the invaluable information for the risk-assessment procedure. The synchronized measurement field test in the Russian Far East Interconnected Power System was conducted on June 21, 2006. The test used three PMU devices and two DFR devices. Their installation in the power system is depicted in Fig. 9. The power system conditions were measured three times during the day with data collected through SCADA, power system personnel, and synchronized phasor measurement devices.

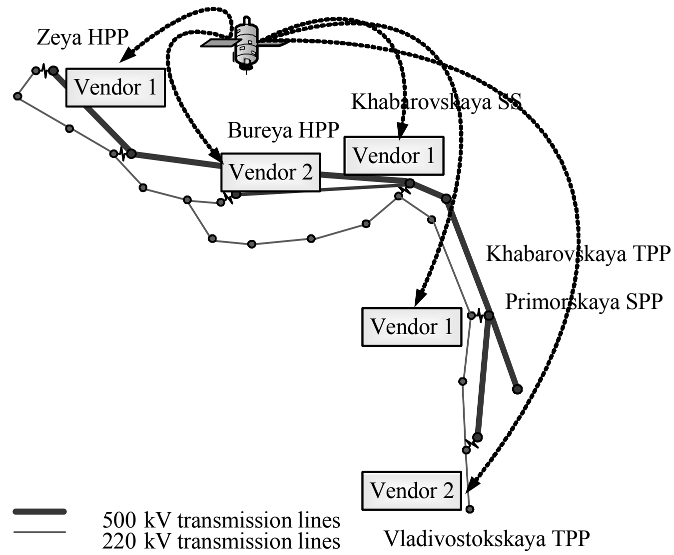


Fig. 9. The scheme of PMUs and DFRs installation during the control instrumentation experiment on June 21, 2006

The PMUs and DFRs made records of about two-minute duration at each moment of the control instrumentation. Some results generate questions about the execution of the tests. Fig. 10 shows the angle difference calculation at two time moments.

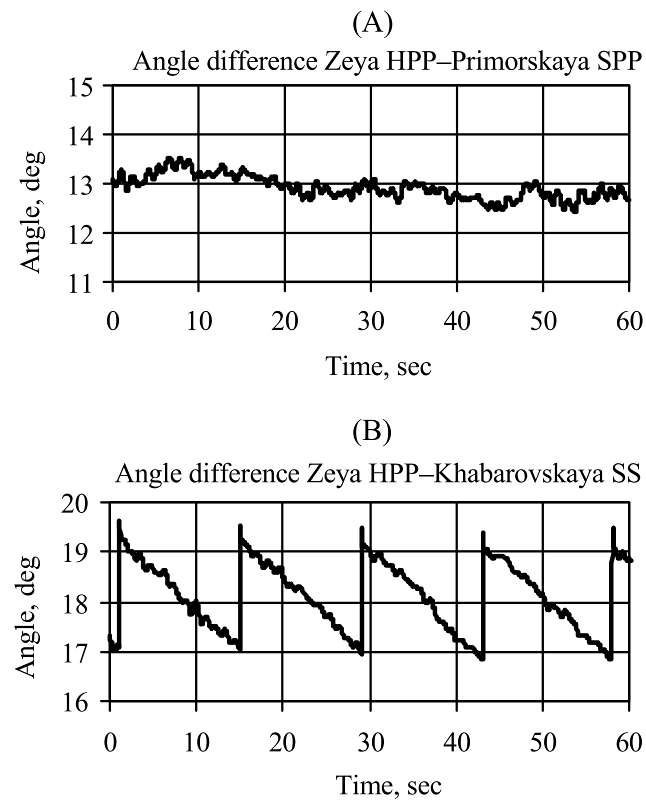


Fig. 10. Vagueness in angle differences calculation with the use of records obtained during the control instrumentation test: (A) the moment of control instrumentation 04-00; (B) the moment of control instrumentation 10-00.

There appeared to be some mistaken interpretation of angle difference. The angle-difference behavior in Fig. 10, B can be explained by the time shift between the samplings of PMUs installed at Zeya HPP and Khabarovskaya SS. The reason for the behavior is a change in synchronization accuracy or loss of synchronization of one PMU. The accuracy of satellite lock depends on antenna location and type of GPS clock. In conducted instrumentation tests, the antennas were not mounted in accordance with the manufacturer's recommendations. Therefore, the accuracy can vary during 24 hours. Research is continuing, and this point is being clarified.

### B. Control Instrumentation Results

The results of synchronized control instrumentation are shown in Table 1. The measured values are bus-bar voltage phasors in polar coordinates (rectangular coordinates are also available). Calculated analog quantities are active and reactive power. Dashes in the table mean the absence of measurements because of personnel errors. The table presents the power system snapshot based on synchronous measurements. Combining the synchronous measurement snapshot together with SCADA data allows a step forward in power system model verification. The above experiments are an important milestone in mastering WAMS technology in the Russian Power Grid. They can be the basis for asset-management and risk-assessment development in the Russian Far East Power System.

TABLE 1

SYNCHRONIZED CONTROL INSTRUMENTATION

| Object of Monitoring | | Time of Instrumentation | Power System Condition | | | | |
|---|---|---|---|---|---|---|---|
| | | | f, Hz | V, kV | Angle, degrees | P, MW | Q, Mvar |
| Zeya HPP | 500 kV transmission line Zeya HP–Amurskaya | 04-00 | 49.47 | 512.498 | –96.131 | 192.081 | –39.91 |
| | | 10-00 | 50.007 | 517.98 | –44.915 | 366.01 | –8.522 |
| | | 22-00 | 50.024 | 515.898 | –146.513 | 281.519 | –33.01 |
| Primorskaya SPP | 500 kV transmission line Primorskaya SPP–Dalnevostochnaya | 04-00 | 49.969 | 501.763 | –107.577 | 183.589 | –18.527 |
| | | 10-00 | – | – | – | – | – |
| | | 22-00 | 50.024 | 513.808 | –162.847 | 250.734 | –14.496 |
| Khabarovsk Substation | 500 kV transmission line Khabarovskaya–Primorskaya SPP | 04-00 | – | – | – | – | – |
| | | 10-00 | 50.0068 | 507.238 | –61.644 | 324.615 | –52.635 |
| | | 22-00 | – | – | – | – | – |
| Vladivostok TPP | 220 kV transmission line Vladivostok TPP–Artemovsk TPP | 04-00 | –49.47 | 225.45 | – | –12.538 | 24.244 |
| | | 10-00 | 50.007 | 227.04 | – | –30.986 | 38.687 |
| | | 22-00 | – | – | – | – | – |

### C. *Proposed WAMS Structure*

The trial WAMS structure depicted in Fig. 11 shows that control area TSO and control blocks SO swap for the information taken from PDCs about angle differences. The dispatchers have to use the information for power system operation. Current state conditions monitoring should be realized in control rooms of the block SO and area SO.

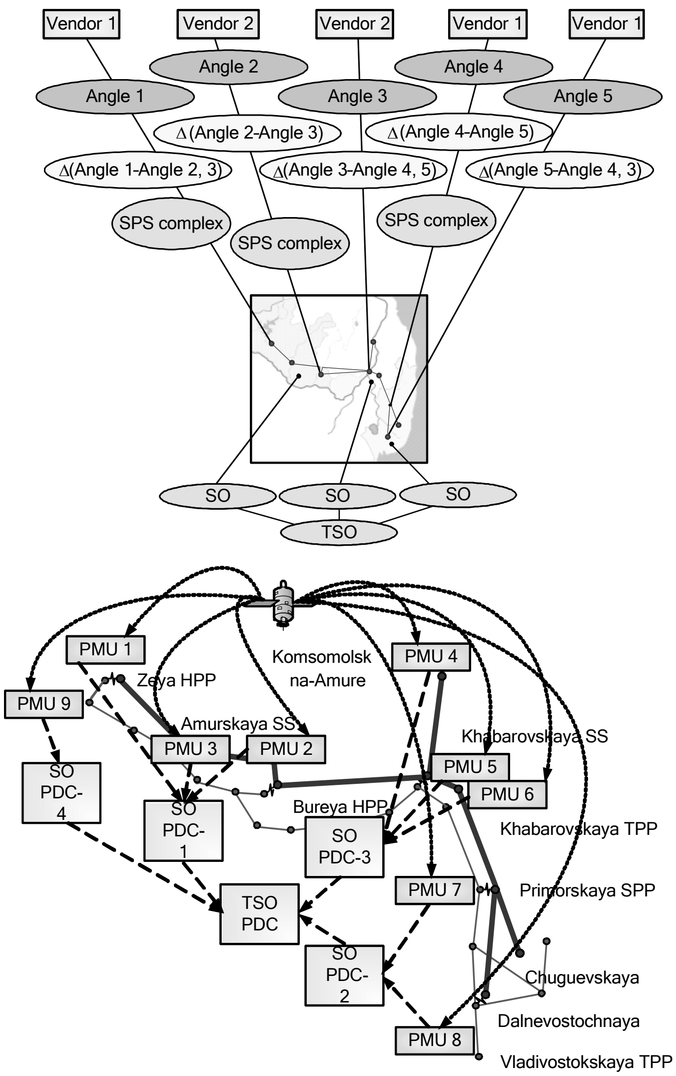


Fig. 11. Trial WAMS operation logic (A) and structure of potential WAMS system (B). SPS is special protection schemes; PMU is phasor measurement unit; HPP is hydro power plant, SPP is steam power plant; SO and TSO are transmission system operators; PDC is phasor data concentrator.

## V. Conclusion

The successful international cooperation and the high level of professionalism observed during this project have demonstrated mutual benefits and future potential of increasing the participation of Russian engineers in international power committees and workgroups.

This collaboration has shown that WAMS can be created on equipment from one vendor or can include equipment from multiple vendors. Additional research and discussion of advantages and disadvantages between single-vendor and multiple-vendor-based systems for various applications should be considered. Lessons learned from the experiments in the Russian Far East IPS and from other WAMS experiments may be considered by international working groups as the basis for recommendations.

## VI. References


[1] Working Group H-7 of the Relaying Channels, "Synchronized Sampling and Phasor Measurements for Relaying and Control," *IEEE Transactions on Power Deliver*y, Vol. 9, No. 1, January 1994, pp. 442–452.

[2] A. Grobovoy, N. Lizalek, N. Bondareva, S. Sirazutdinov, V. Stepanov, E. Atienza, M. La Scala, A. Germond, "Synchronized Measurement Experiment and Trial WAMS/WACS Structure in the Russian Far East Interconnected Power System," *International Scientific Conference Monitoring of Power System Dynamic Performance, Moscow, Russia, 25–27 April, 2006,* available on the conference CD.

[3] A Grobovoy, A. Domyshev, A. Osak, V. Rodnikov, Yu. Vorobyev, "Modern System Protection Schemes Realization in Large Hydro Power Plant Automation: Local and System Aspects," presented in the 41th CIGRE Session*,* 28 August–1 September 2006, Paris.

[4] Grobovoy, N. Bondareva, "Risk Assessment for SPS and WAMS Technology in the Russian Far East Power Grid," presented at 3rd International Workshop Liberalization and Modernization of Power Systems: Risk Assessment and Optimization for Asset Management*,* August 14–18, 2006, Irkutsk, Russia.

[5] Task Force 38.02.19 CIGRE brochure, "System Protection Schemes in Power Networks" (edited by D. Karlsson and X. Waymel June 2001, 172 p).


## VII. Biographies

**Andrey Grobovoy** was born in the Ukraine, the former USSR, in January 1950. He graduated from the Far East Polytechnic Institute, Vladivostok, in 1973. After conscription, his employment experience includes the Siberian Electric Power Research Institute for 1975–1992. Since 1992, he has been General director of the Power System Emergency Control Laboratory, Ltd. His special fields of interest include large power system emergency stability controls. He is a member of IEEE and has authored and presented several papers on power system protection topics.

**Natalia Bondareva** was born in Kabardino-Balkaria region, former USSR, on July 11, 1980. She graduated from Novosibirsk State Technical University, in 2002 and began her work in the Siberian Electric Power Research Institute as junior researcher. Her special field of interest includes large power system emergency stability control and dynamic simulation. She is a student member of IEEE and has authored and presented several papers on power system protection topics.

**Vladimir Stepanov** was born in Ivanovo-town (Russian Federation) in October 1963. He received a diploma in electromechanical engineering from the Power Institute, Ivanovo, in 1985, and PhD degrees from Electric Drives Research Institute, Moscow, 1993. Now he works on principal expert position in Ltd. "ABB Automation," Russia. His special fields of interests include emergency control in power systems.

**Edsel Atienza** was born in the Philippines on July 14, 1980. He received his B.S. degree in electrical engineering from the University of Idaho in 2001. Mr. Atienza joined Schweitzer Engineering Laboratories, Inc. in 2002 as an application engineer supporting sales and technical service centers throughout the world. He is a member of IEEE, the IEEE Power Engineering Society, and the IEEE Industrial Applications Society. His interests include protective relaying, substation automation, communications, synchronized phasor measurement, and remedial action schemes.


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