



## PS5 – S2-03



### Program of Dynamic Testing of Phasor Measurement Units Using the Physical Model of the Power System

Andrei V. ZHUKOV<sup>1</sup>, Yury A. KULIKOV<sup>1</sup>, Andrei S. GERASIMOV<sup>2</sup>,  
Arkadiy H. ESIPOVICH<sup>2</sup>  
SO UPS<sup>1</sup>, NIPT<sup>2</sup>  
Russia  
[esipovich\\_a@nipt.ru](mailto:esipovich_a@nipt.ru)

#### KEYWORDS

PMU, Electrodynamic model, dynamic test, program, test scheme.

#### 1 INTRODUCTION

New digital equipment, systems of protection, regulating and control, regime and emergency automations (manufactured by Russian on foreign companies) pass operational tests before installation in the power system of Russia. These tests are carried out in the conditions as much as possible approached to operating, using the JSC “NIPT” digital – analog – physical complex - the unique test area of the System Operator [1].

The Digital-analog-physical complex includes the world's largest electrodynamic simulator (EDS) comprising physical models of all power elements of the power system (generators, synchronous compensators, transformers, DC and AC transmission lines, shunt reactors, SVC, asynchronous motors etc.), analog and digital models of regulating and control devices and the digital system of experiments registration.

Since 2005 EDS is used to carry out operational tests of phasor measurement units (PMU) produced by different companies.

In 2005 prototypes of SMART-WAMS measurement units manufactured by the company RTSoft were tested for three times using the EDS [2]. The results of the performed tests showed that the PMUs operation algorithms were not free from faults. After serious modifications the measurement units were recommended for application in the power system of Russia. SMART-WAMS PMUs were used for the construction of the System of the monitoring of transients in the IPS/UPS power system (Russian analog of WAMS) [3].

During the past years EDS has been frequently used to carry out tests of PMUs produced by different manufacturers. In 2006 comparative tests were carried out (using the EDS) for SMART-WAMS PMU (model 01, RTSoft), RES-521 PMU (ABB) and terminals N60 (with the function of synchronized phasor measurement, GE) [4]. In 2008 SMART-WAMS PMU (model 02, RTSoft) was compared with the Power Sentinel PMU (model 1133A, Arbiter Systems) [5].

PMUs tests in the conditions provided by the EDS are alternative to the operational tests in the real power system. During the tests on the EDS the accuracy of the regime's parameters measurements was evaluated in the disturbed (unstable) regimes.

The tests results showed that in a wide range of emergency and post-emergency modes (which are caused by disturbances in the power systems) the inaccuracy of the parameters measurements considerably increased and PMUs were not providing the accuracy of the measurements declared by the manufacturers. Inaccuracies appeared in open-phase emergency modes and post-emergency modes, which were characterized by significant variation of the power system's frequency. Increase

of the inaccuracy of the measurements in several types of PMUs was caused by the distortion of the voltage curve's shape and high speed of the regime's parameters changes.

The direct control of the steady – state and especially emergency regimes of the power systems based on the data obtained from the PMUs can be organized only if the stated accuracy of the measurements is provided by PMUs in emergency and post-emergency modes. Development of the real – time (on – line) control system seems to be impossible without solving this problem.

Additional requirements for accuracy of the measurements of regime's parameters in emergency and post-emergency modes should be stated if PMUs are going to be used in the systems of automatic control of power facilities. That is why the goal of the PMUs dynamic testing is evaluation of accuracy of the data obtained from the registrars in steady-state modes and transients, caused by various dynamic disturbances in the power system.

Various schemes and exclusive testing programs were used to carry out the tests mentioned above. The unique experience was gained during performed tests. Using this experience the structure and specifications of the type test scheme and the list of the required experiments were developed. The type test scheme has the same behavior as a complex multi-frequency power system. The scheme adequately represents the majority of the dynamic modes specific to the real system.

The test scheme of physical model of the power system, developed for PMU tests, is stated and validated in the report. Also the program of PMUs' dynamic testing and the criteria of estimation of PMU behavior are given in the report.

## **2 TEST SCHEME OF PHYSICAL MODEL OF THE POWER SYSTEM DEVELOPED FOR PMU'S OPERATIONAL TESTS**

The test scheme of physical model of the power system developed for PMUs operational tests in NIIPT is shown on figure 1.

The scheme includes:

- 6 generators with block transformers, which models power plants of various type (TPP, NPP, HPP);
- 7 transmission lines of various transmission capacity, representing network of complex structure;
- 6 combined loads, including induction motors (industrial load) and shunts (residential load);
- elements of power electronics (self-excited inverter);
- capacitor banks.

Physical model provides an opportunity:

- to change the parameters of the electrical modes of the power system in wide ranges (the directions of the power flows through the lines and cut sets can be changed);
- to reach small signal (aperiodic or oscillatory) stability limits by changing smoothly the parameters (making operating conditions heavier) of steady – state modes of the model;
- to make smooth/step changes of voltages of the buses to which PMUs are connected;
- to perform emergency lines tripping (as a result of relay protection operation) and transmission lines switching-off;
- to model local and inter-zonal oscillations (the range of oscillation's frequencies is from 0.2 to 1.5 Hz);
- to adequately represent all specific emergency disturbances such as, single -, double-, triple-phase short circuits on the transmission lines, which cause lines tripping, line's successful and unsuccessful automatic reclosing and open-phase modes of any required duration;
- to model generators and big loads outages;
- to simulate an asynchronous motors start-up
- to simulate a long-term operation with low or high frequency;
- to model severe distortion of the network's voltage curve's shape, caused by operation of power electronics (during any kind of specific emergency disturbances).

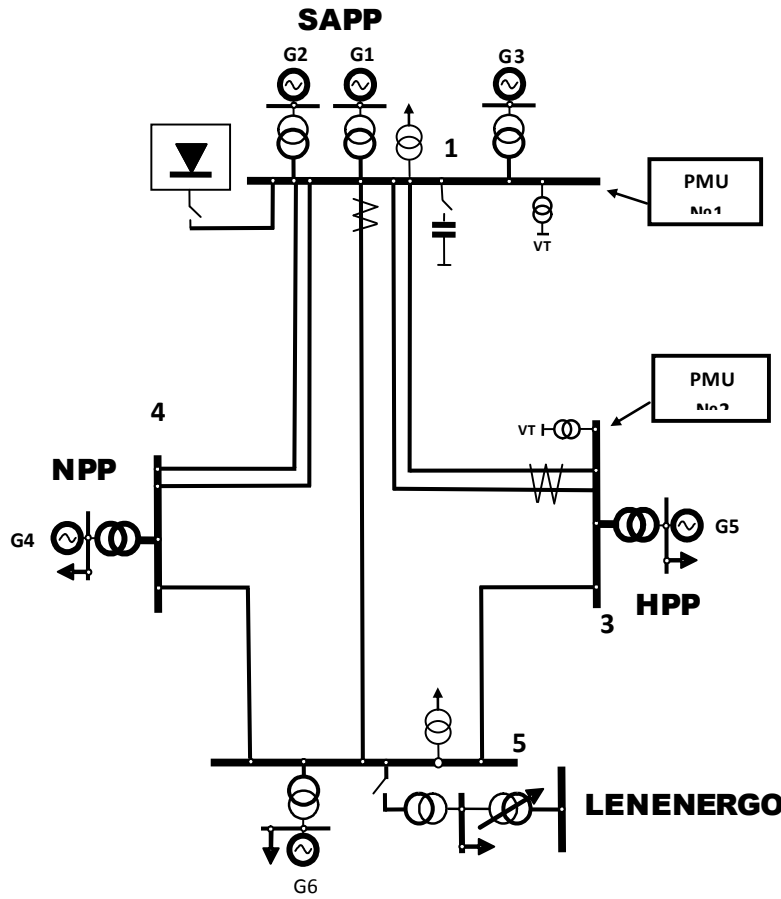


**Fig. 1:** Test scheme of physical model of the power system

In two nodes instrument voltage and current transformers are installed. The parameters of these transformers are the following: rated current of the current transformer ( $I_{nom}$ ) - 1A, rated phase voltage of the voltage transformer ( $U_{nom}$ ) - 57.7 V. These provides an opportunity to adequately connect a PMU to the model with inputting of four current signals from the current transformers (currents of each of three phases and current of the neutral) and three voltage signals (voltages of each of three phases) from the voltage transformer.

The physical model also is equipped with:

- system of digital registration of the experiment (to control progress of the experiment and to save its results);
- sensors which measure regime's parameters (voltage, active power, frequency, relative angle);
- devices which can help to validate the parameters of the required electrical mode;
- switching equipment to model the emergency regimes;
- programming device which can run an experiment automatically.

Each of the PMUs should have and individual GPS receiver.

### 3 PROGRAM OF PHASOR MEASUREMENT UNITS DYNAMIC TESTING

The Program includes 26 experiments divided into 4 sections.

**Section 1** is dedicated to the accuracy of PMUs evaluation in the conditions of smooth change of the electrical modes parameters up to aperiodic or oscillatory stability violation. the limits of electrical regimes are reached (up to stability violation) by changing active power generation or reducing voltage reference values of AVRs installed. On fig. 2 the oscillatory behavior of stability violation is shown as an example.

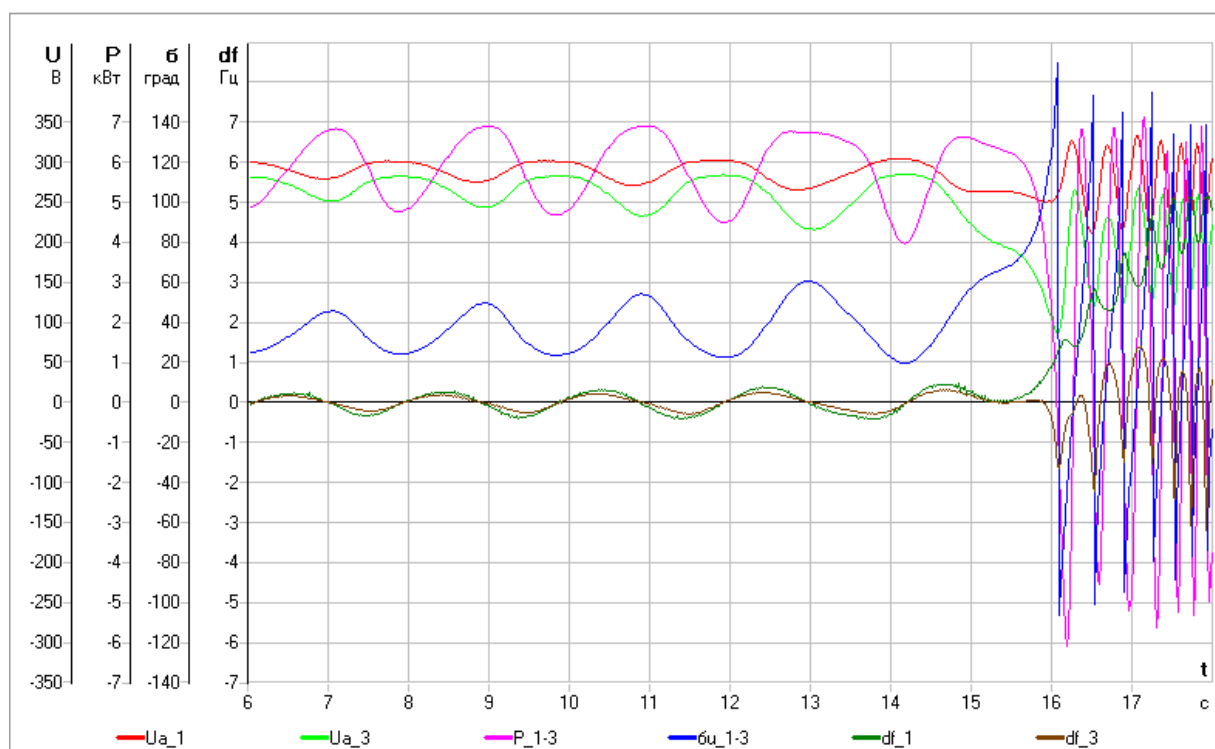


**Fig. 2:** Stability violation caused by disconnection of PSSs installed in the of SAPP generators' PSS

**Section 2** is dedicated to the accuracy of PMUs evaluation in the conditions of rated (normative) disturbances in the power system caused by symmetrical or asymmetrical short – circuits with faulted lines tripping or there successful automatic reclosing, taking into account distortion of the voltage curve shape performed by the connection to the grid of the inverter.

On fig. 3 and 4 the system behavior in case of sudden transmission line disconnection with further transient stability violation and the system behavior in case of one phase short circuit and successful reclosing are shown.

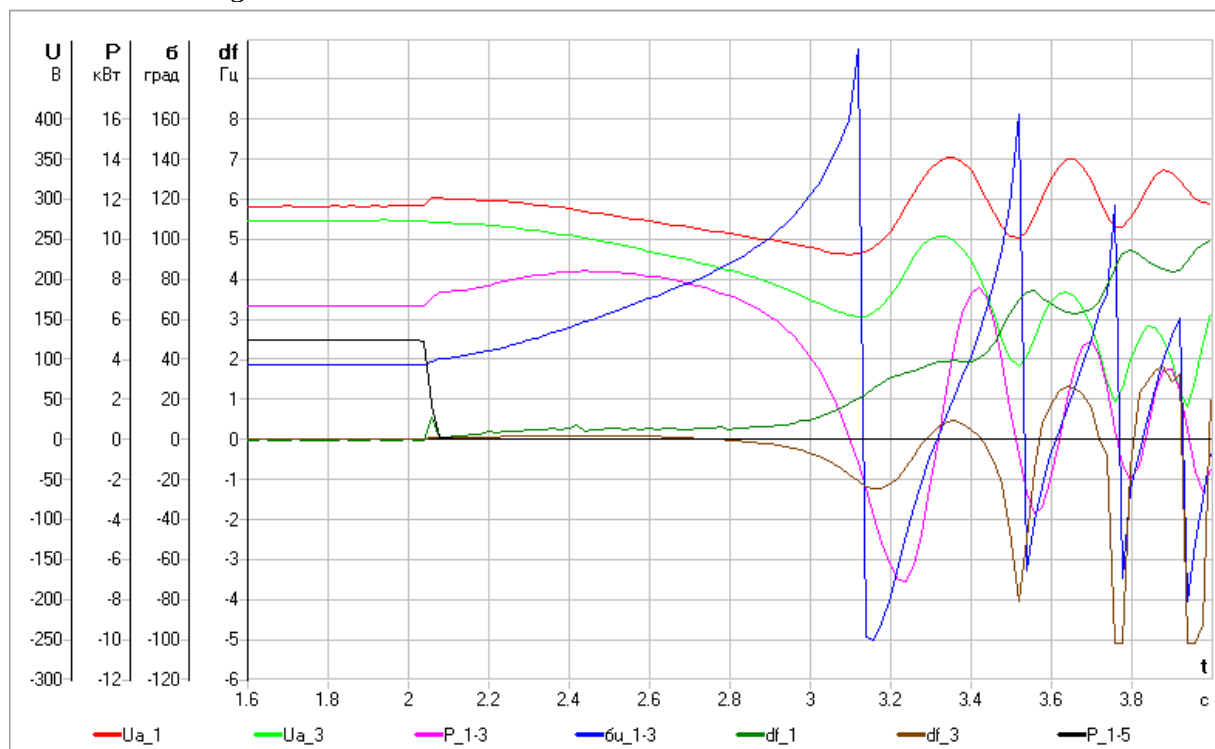


**Fig. 3:** PTL 1-5 sudden disconnection with further dynamic stability violation.

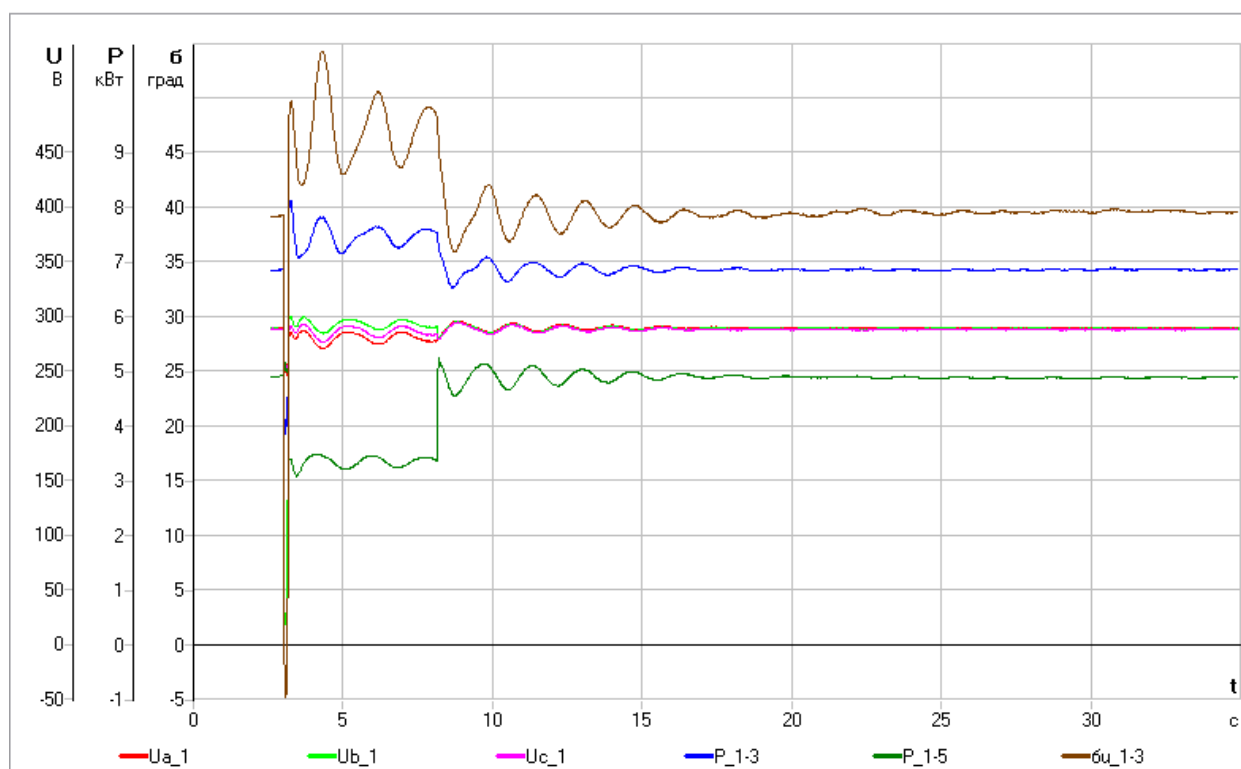


Fig. 4: Single-phase fault with successful single-phase automatic reclosing.

**Section 2** is dedicated to the accuracy of PMUs evaluation in the conditions of operation with not rated steady frequency value caused by unbalances of active and reactive power leading to the non-normative frequencies establishing in the power system. On fig.5 the process of establishing of a new frequency value in the power system caused by tripping of some generation is shown as an example.

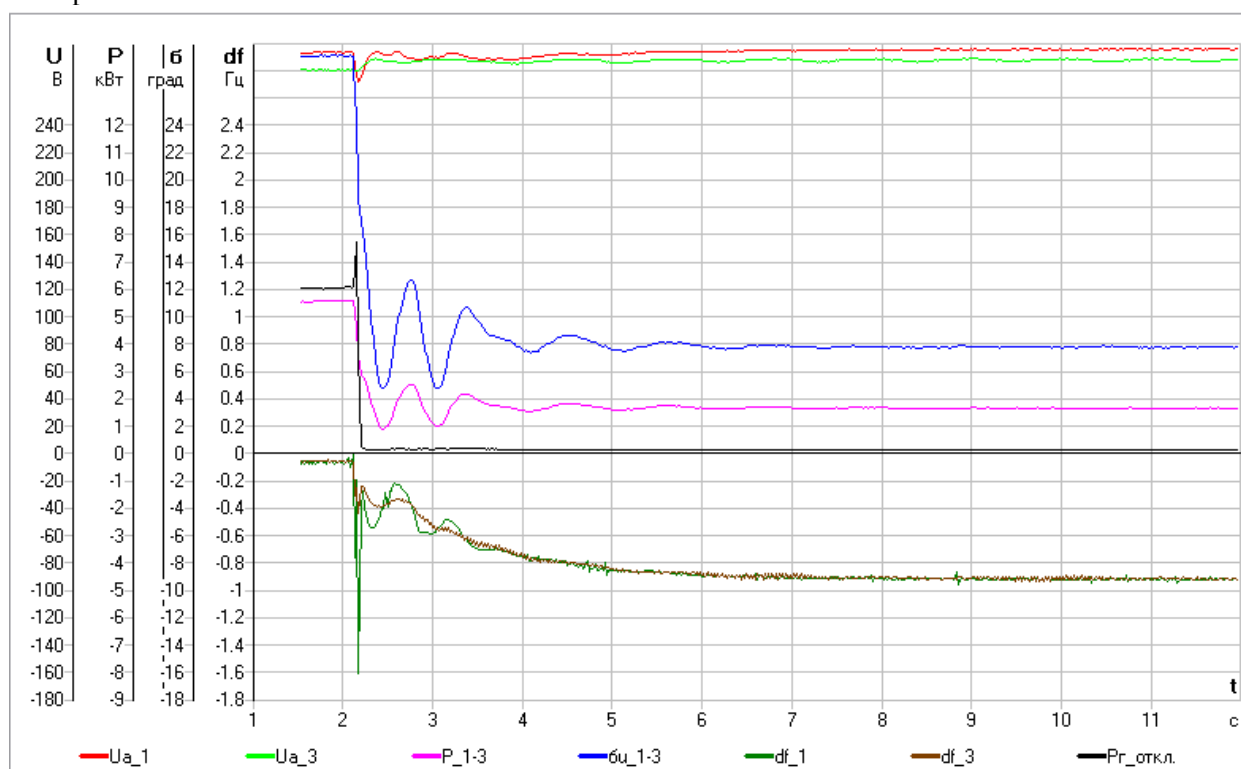


Fig. 5: Outage of generator

At last, **Section 2** is dedicated to the accuracy of PMUs evaluation in the conditions of heavy off – design disturbances which cause instant considerable change of related angles between different points of the power system. Example of such disturbance is shown on fig. 6.

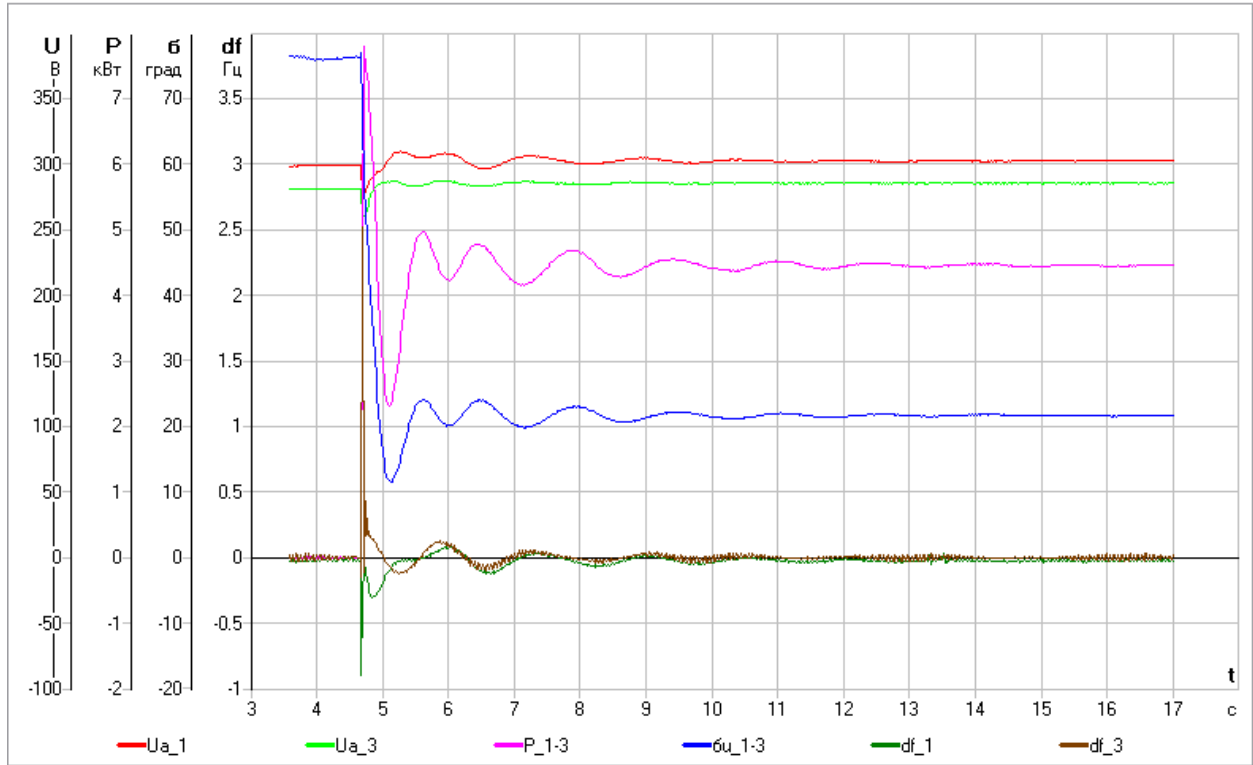


**Fig. 6:** Chain-type scheme closure

#### 4 DYNAMIC TESTS RESULTS ANALYSIS

According to foreign experience PMUs Macrodyne 1690M or ABB RES521 can be used as reference measurement units in the majority of tests. The experiments on the Digital-analog physical complex have shown that ABB RES521 PMUs are not providing declared measurement precision in nonsymmetrical regimes and when power system operates with not rated frequency [4]. That is why PMUs RES521 should be complemented with fast-responding analog relative angle and active power sensors. The measurement system of the Digital-analog-physical complex includes these sensors. Their description, operating principles and characteristics are given in the Appendix B.

The reference PMU and fast-responding analog angle and active power sensors are connected in parallel with the tested PMU.

GPS receivers' operability and synchronism of association of PPS measurements and PMUs' signals should be tested before the experiments. PMU accepted as the reference measuring unit should also be tested. The digital multichannel oscilloscope is connected to the scheme to perform these tests. This oscilloscope was developed in JSC "NIPT" on the basis of industrial controller which has a function of universal time reference (GPS antenna). Data obtained from analog sensors is synchronized with PMUs using the synchronization impulse produced by the programming device. This impulse is a universal time stamp. The programming device of Digital-analog physical complex also performs an automatic start of test program.

The results of each of the tests are analyzed by comparison of measurements data obtained from the reference PMU, analog angle, power sensors and the tested PMU. The data is provided in tabular form, e.g., in the CSV-format or Comtrade.

Requirements to the accuracy of the emergency and post-emergency regimes (including asynchronous) parameters measurements are not yet stated or formalized in any of the existing

standards. Responding to updates of the objectives of power system's control (implementation of PMUs for power system's control) these requirements are only starting to be formed.

So the aim of these tests is accuracy evaluation of measurements provided by each of the tested PMUs in the whole variety of dynamic regimes.

Precision of registration is evaluated by determination of the inaccuracy of regime parameters' measurements. These inaccuracies are estimated during the procedure of digital processing of the tests results. These parameters are the following:

- active power;
- voltage frequency;
- voltage absolute angle.

It is recommended to evaluate accuracy after each experiment (listed in the program).

Therefore it will be possible to estimate in what kinds of dynamic regimes the declared precision is provided, and to determine the measurements' inaccuracy in those regimes where stated accuracy is not provided.

## **5 CONCLUSION**

The Digital-analog-physical complex includes the world's largest electrodynamic simulator, is the alternative to the testing of PMU in real power system.

The program of PMUs' dynamic testing carried out on the physical model of the power system is presented in the current report. The program was developed on the grounds of the experience gained during the tests of different types of PMUs, held in 2005-2008 using the Digital-analog-physical complex.

The tests of PMUs manufactured by various companies carried out using the test scheme of the power system according to the suggested program will help to estimate the field of application of each PMU and develop general requirements to the accuracy of PMUs measurements in dynamic regimes.

## **REFERENCES**

- [1] Gerasimov A., Guschina T., Esipovich A., Zekkel A., Kiriyeenko G., Michurin A.. Electrodynamics Power System Simulator for Bulk Power Systems Investigations and for Testing, Debugging and Adjustment of Various Digital Control and Automation Systems. 2005 IEEE St. Petersburg PowerTech Proceedings.
- [2] Gerasimov A., Esipovich A., Kiryenko G., Korolev M., Kulikov U., Mogilko R. The registrator of parameters of the transient states «SMART-WAMS» and its testing. International Scientific Conference «Monitoring of Power System Dynamic Performance» Moskow. 25-27 April., 2006.
- [3] Ayuev B., Erokhine P., Kulikov Y. IPS/UPS WIDE AREA MEASURING SYSTEM. Session CIGRE Proceedings, Paris, 2006. C2-211.
- [4] Gerasimov A.S., Esipovich A.H. (JSC «NIPT»), Demchuk A.T., Ghukov A.V. (JSC «SO-CDU EES»). Recorders of system of monitoring of transition regimes, their comparative characteristics and tests on electrodynamic simulator. International conference «Relay Protection and Substation Automation of Modern Power Systems», Cheboksary, September 9-13, 2007 .
- [5] Edlin M.A., Gushina T.A., Zukov A.V., Demchuk A.T. Electrodynamics Simulator Application for Working Out of New Requirements for WAMS for UPS Control Tasks Solving. Monitoring of Power System Dynamics Performance. 28-30 April 2008, Saint Petersburg.