Electrodynamics Power System Simulator for Bulk Power Systems Investigations and for Testing, Debugging and Adjustment of Various Digital Control and Automation Systems.

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Abstract - **Now on power stations and in electric power systems of UPS of Russia there is a process of modernizing and replacement morally and physically out-of-date inventory, including devices of automatic control, regulation, protection and automation, basing on semiconductor elements. They are replaced by various microprocessor digital devices.**

JSC "HVDC Power Transmission Research Institute" (NIIPT) performs testing, debugging and a preliminary adjustment of the generators' automatic excitation regulators and power system stabilizers in conditions, corresponded to operational conditions in power system. Tests are performed using specialized electrodynamics power system simulator (EDS). Tests on the EDS ensure essential reduction of starting-up and adjustment works volume, their cost and, correspondingly, terms of power installations commissioning.

Index Terms – **AVR, POWER SYSTEM, PSS, STABILITY, TESTING.**

Now on power stations and in electric power systems of UPS of Russia there is a process of modernizing and replacement of morally and physically out-of-date inventory, including devices of automatic control, regulation, protection and automatics based on electronic and semiconductor devices. There come different numeral microprocessor devices. Modernization of branch occurs in conditions of the re-structuring accompanying with emersion of the independent generating companies. Adoption of the Federal Law «About engineering regulation» has lead to the fact the electro technical inventory purchased by subjects of the power market, can not match to the standards providing reliable operation of the united power system. The situation is aggravated with the fact that the number of the producers offering products in the power market, has sharply grown at the expense of arrival on this market of a new domestic producers, the majority of which has not any necessary operational experience in electric power industry, and also foreign producers, which products are not always adapted to conditions of the Russian electric power systems. All this results in increasing of numbers of technological violations in electric power systems and decreasing of a level of reliability of parallel operation: due to the loss of excitation (misoperation of the AVR) at stations the tripping of generators occurred, and the improper action of a microprocessor regulator on Sayano-Shushenskaya HPP led to origination in UPS of Russia of unprecedented emergency power deficiency, which has not reduced in a serious system collapse only by a lucky chance.

Practice shows, that for security of system reliability the samples of domestic and foreign microprocessor devices of regulation, management, protection and automatics should pass a complex check of operation in conditions, maximum approximated to conditions of the future maintenance before application in the Russian electric power system. Such a complex check can be provided with the electro-dynamic simulator (EDS) of JSC "HVDC Power Transmission Research Institute" (NIIPT).

EDS represents a unique proving ground. It includes the largest in the world electrodynamics model of an electric power system (80 model generators and prime movers, 150 transformers, 700 models of transmission lines, 166 models of complex load, 8 models of direct-current transmissions, FACTS devices model, etc.) . The analogue part of a complex consists of adjustable semiconductor models of steam, hydro and gas turbines and their regulating and control systems and models of automatic controllers of excitation (AVR) of different modifications. EDS is equipped with the devices, allowing to model emergency perturbations in electric power system and operation under the given program of devices of the local and centralized counter-emergency automation. EDS is equipped with the numerous data transducers which are formed in an informational-measuring system. The numeral part of EDS is a system of recording of the experiments, representing some state-of-the-art multi-channel digital oscilloscopes and the software, allowing manufacturing after treatment of experimental data.

Due to large and manifold park of basic equipment and auxiliaries, and also due to flexible system of scheduling and recording of experiments, EDS allows to model electrical regimes and emergency electromechanical transients in power systems practically of any complexity in a view of the peculiarities of real power installations. Thus a high performance is ensured as due to the unique physical properties of the complex, allowing to carry experiments in real-time and in conditions, maximum approximated to operating conditions, and owing to conformity of the rated secondary voltage and currents of the model instrument transformers to industry standards, which allows integration in EDS of any real devices.

Among the main works executed in last years with the use of EDS, it is necessary to mark:

- Researches of the normal and emergency operation of perspective operation schemes of UPS of Russia – UCTE power pool;
- Development of scientific and technical recommendations on security of stability of an electric power system «Three Gorges» (China);
- Development and tests of microprocessor automation of liquidation of asynchronous modes in electric power systems (ALAM);
- Development and tests of control systems, regulators and protection of state-of-the-art converters based on turn-off thyristors for making flexible links and devices of reactive power compensation (STATCOM);
- Tests of the device of semi-automatic changeover of the generating unit of the Northwest cogeneration power station from UPS of Russia in electric power system NORDEL and back;
- Tests of microprocessor AVR of various manufactures.

Today one of the most effective directions of EDS use is testing of brass boards of digital microprocessor automatic controllers of excitation of domestic and foreign corporations on operation and security of demands of the system reliability and the stability of parallel operation of the station with an electric power system, made by RAO "UPS of Russia" to the automatic excitation controllers, as well as the adjustment of the AVR "on a turn-key basis" for concrete power installations.

Testing of the AVR on operation is carried out with the use of the test scheme designed in NIIPT [1], which allows carrying out comprehensive tests of regulators (fig. 1). The scheme includes 6 generators with the block transformers, 5 units of complex load, an autotransformer and 9 transmission lines. Generators 1 - 3 is a model of the thermal power plant equipped with three equal blocks, working on two buses with different voltage. Two generators of station connected to a 500 kV, and one - to buses 220 kV. Generators 4 and 5 represent models of a nuclear power station and a HPP, the generator 6 is an equivalent of the concentrated electric power system. For regulators testing in the scheme of the enlarged block transforming of the scheme to a view, shown on fig. 2 is stipulated.

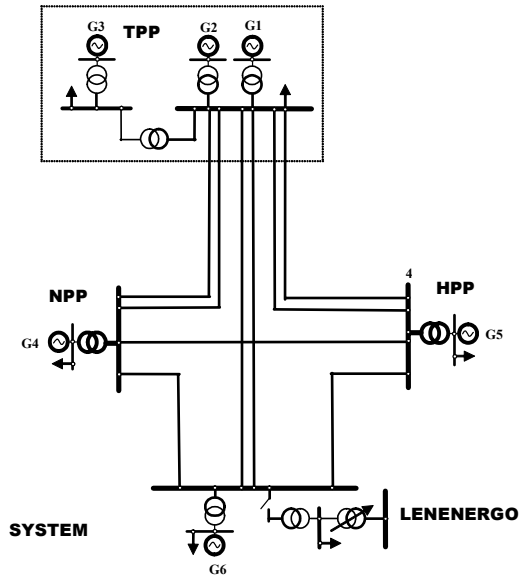


Fig 1. Electro dynamic simulator power system test scheme.

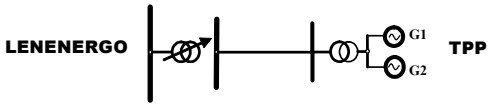


Fig 2. Electro dynamic simulator power system test scheme (variant).

Tested AVR are established on generators 1 and 2. At change of composition of a network (tripping of lines) the scheme of an electric power system undergoes every possible transformation from the complete polygon up to different alternatives of schemes of chained structure that allows to change the capacity of a network over a wide range.

Tests will be carried out basing on the authorized standard complex program of system tests of microprocessor AVR which includes the check of:

- Security of the demands of specifications of a static stability and quality of damping of the electromechanical oscillations in normal, repair and post-emergency conditions;
- Securities of a transient stability margins at normative emergency perturbations in an electric power system, including teamwork with complexes of a counter-emergency automation;
- The complete use of rated opportunities of a power part of the field systems for the security of a transient stability;
- Correctness of operation of a relay boosting and the main limiters of the AVR during dynamic perturbations;

Operation of the system stabilizer is tested by checking of its efficiency at different modes of operation of the generator in repair and post-emergency schemes, in which all possible low-frequency components of mutual movement of an electric power system are manifested. A check is completed by a definition of a character of violation of static stability in the maximum on conditions of static stability electrical regimes at the picked adjustments of the system stabilizer (fig. 3).

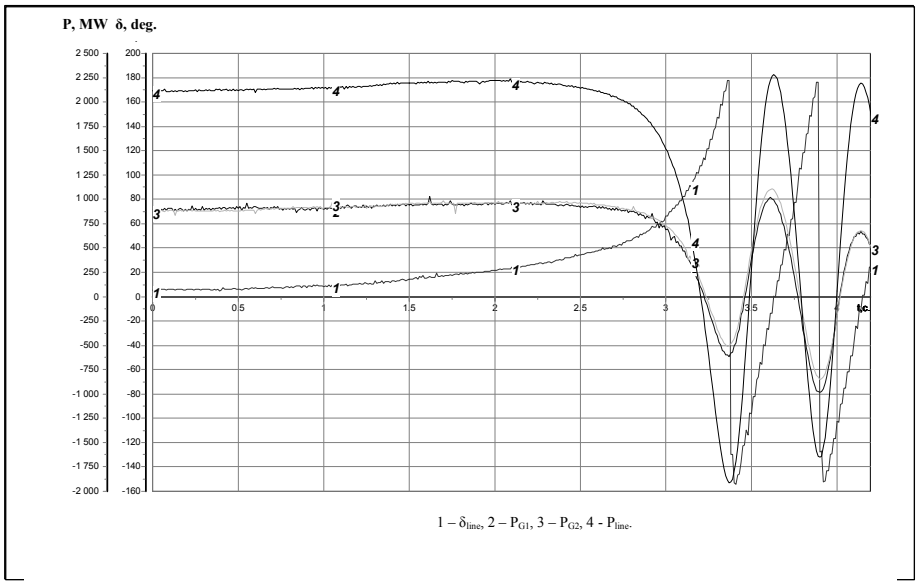


Fig. 3. The character of instability determination. ARV-M (Elektrosila)

The quality of damping of large post-emergency oscillations at the picked adjustment of the AVR is mustered at normative emergency perturbations. Thus emergencies such as N-1 without change and with change of power balance and frequency of an electric power system (tripping of lines; single-phase, two-phase to land and three-phase short circuits on lines with their tripping; successful one-phase reclosing and the 3-phase reclosing of lines; tripping of loadings and generators of a reception part of an electric power system) and emergencies such as N-2 (unsuccessful autoreclosing on lines and short circuits with failure of a phase of the main circuit breaker and operation of the reserve circuit breaker) are performed.

Tests of the AVR at the heaviest emergency perturbations in the maximum regimes on conditions of a transient stability allow to estimate a degree of use of rated opportunities of the field system and to test correctness of operation of a relay field forcing (fig. 4).

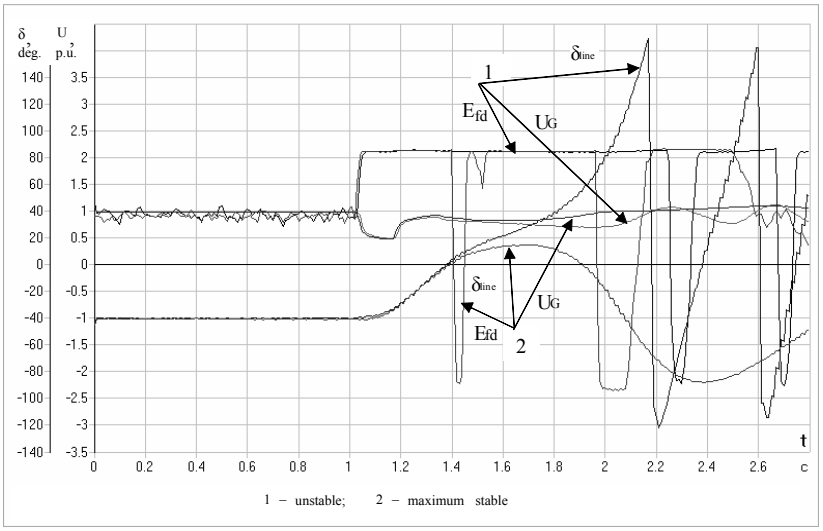


Fig. 4. AVR-2 (Energokomplekt) testing in extreme dynamic perturbations in power system.

For today only two microprocessor excitation controllers (the AVR-M [2] and AVR-2) have passed full similar tests. Tests were completed by developing of the scientific and technical recommendations on application of regulators on installations of UPS of Russia at modernizing and new construction. Now two more domestic microprocessor AVRs are negotiated for tests. Taking into account the importance of the adaptation of the AVR of foreign corporations to operation in conditions of the Russian electric power system, in 2004 RAO "UPS of Russia" recommended «performing the tests of foreign AVR before their installing on concrete installations in the test scheme of an electric power system » under the evocative standard program.

Adjustment "on a turn-key basis" of a microprocessor AVR for concrete power installation in NIIPT is executed on specially designed procedure with the use of EDS [3]. It is approved during tests of commercial examples of AVR-M for hydro-generators of Sayano-Shushenskaya and Ust-Ilimskaya HPP, the AVR-MA regulator for the generator with excitation in two axes of the block №8 TEC-22 "Mosenergo" and a regulator on the basis of a fuzzy logic for Vilyuiskaya HPP-3 of western power region of Yakut electric power system. The procedure allows realizing the sampling of coefficients of amplification of channels of regulation and stabilization of commercial AVRs of generators on conditions of high quality security of damping of a small perturbed movement taking into account scheme-regime peculiarities of operation of a concrete station. The procedure is intended for an adjustment of production prototype of excitation controllers of domestic and foreign corporations. It includes the following basic stages:

1. Making basing on EDS of a physical model of an electric power system;
2. Program of tests developing;
3. Performing of tests of excitation controllers and adjustment of their channels of regulation and stabilization.

Making of a physical model will consist of several stages:

1. Development of a standard digital model of an electric power system and accomplishment the computations of electrical regimes and stability in it;
2. Making of an equivalent scheme of an electric power system and check of its adequacy to the reference model;
3. Development of the electric circuit of a physical model;
4. Sampling of inventory, adjustment and assembly of the scheme, setting of the base electrical regimes and modeling of test emergencies, preparation of the instrumentation system and recording.

The standard digital model of an electric power system is created on the basis of initial data of parameters of the scheme and its structure. In these model computations of regimes, static-aperiodic and oscillatory stability and electromechanical transients are executed. That allows to reveal scheme-regime peculiarities of operation of an observed power installation (station, the generator) in an electric power system and to take them into account at making an equivalent scheme. The equivalenting of the standard electric circuit is executed with the use of software designed in NIIPT, which ensures both identical coincidence of regime parameters in the complete scheme and a saved part f an equivalent scheme and conservation of dynamic properties of standard digital model. The detailing degree of an electric power system (sizes of its saved part) is defined as a result of researches. As a criterion the given permissible error of the equivalenting which, as a rule, does not exceed a lapse of the input information making about 5 % is taken. On the basis of computation researches the physical model of an electric power system also is created. In the table 1 comparative quantitative performances of standard digital models and physical models of the electric power systems received as a result of an equivalenting (the quantity of machines (regulators) participating in tests is specified in brackets) are instanced.

Table 1.

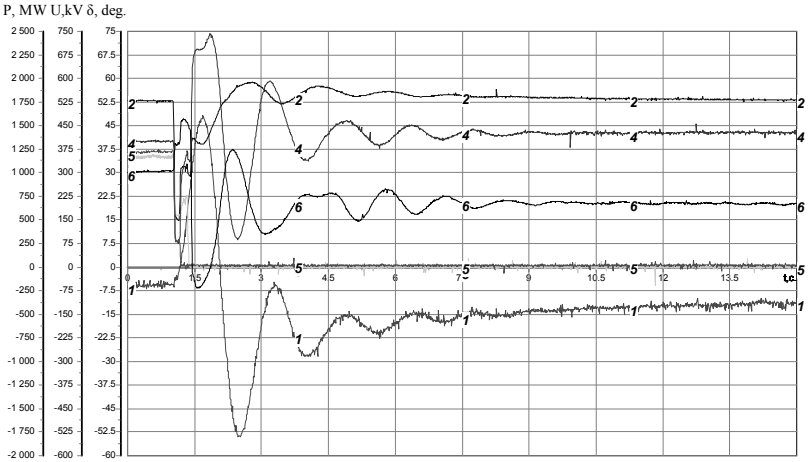
Power system	Object	AVR type (quantity)	Standard model			Physical model		
			nodes	lines	generators	nodes	lines	generators
Siberia IPS (West)	Sajano-Shushenskaja HPP	ARV-M (4)	326	450	73	29	46	15
Mosenergo	TEC-22	ARV-MA (2)	1440	1768	116	17	21	11
Siberia IPS (East)	Ust'-Ilimskaja HPP	ARV-M (3)	596	949	104	22	31	10
Yakutia power system (West)	Viljujjskaja HPP-3	FL-Reglator (1)	87	138	10	16	23	6

From the table one can see that the volume of a physical model depends not so much on dimensions of a quantity of the standard scheme, but mainly on scheme-regime operating conditions of generators of a station in a power system: for the TPP-22 working in the concentrated electric power system (Mosenergo), the scheme of a physical model appears more compact, than for Sayano-Shushenskaya HPP in the IPS of Siberia.

The grain size of the station depends on the principal scheme, a composition of inventory and solved problems. For modeling of Sayano-Shushenskaya and Ust-Ilimskaya HPPs, on which equal generators (the integrated blocks) are established, 4 and 3 model generators have been used accordingly, and the TPP-22 of Mosenergo is presented by six generators, as varied blocks from 60 up to 320 MW operating on different buses are established at the station.

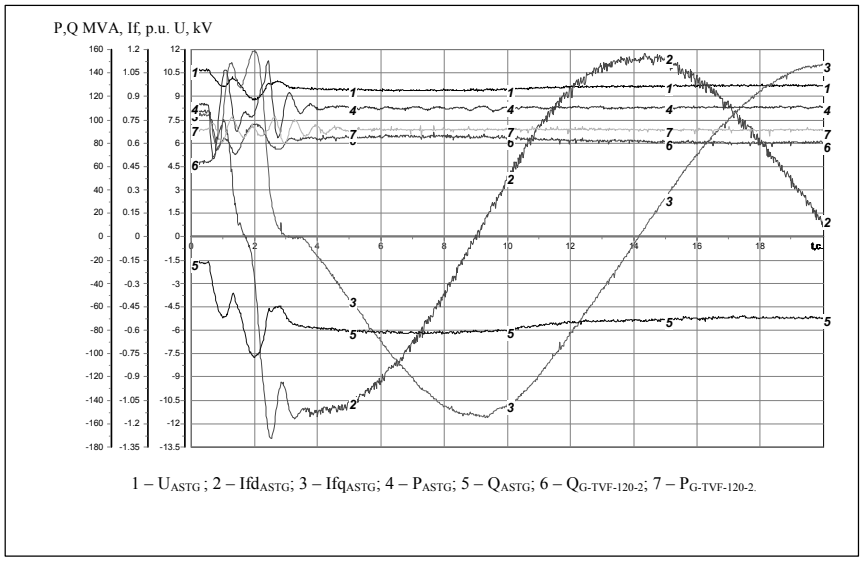
Preliminary sampling of an adjustment of channels of stabilization of excitation controllers is carried out at preparation of tests by the computation way. Making of a standard digital model for computations of electromechanical transients is executed in EUROSTAG (TRACTEBEL) [4, 5] or PSS/E (PTI) [6, 7] software (in the complete scheme of an electric power system), and the research of an oscillatory stability in "AREA" software produced by NIIPT [8, 9]. Computations allow to improve the program of tests, namely, to realize the sampling of representative schemes and regimes, defining a working adjustment of a natural regulator.

The program of system tests on adjustment of excitation controllers is shaped, as a rule, on baseline of the standard program circumscribed above in a view of peculiarities of the station, its scheme of connection to an electric power system and the specific targets solved during tests. For example, at tests of AVR-M for generators of Ust-Ilimskaya HPP stage-by-stage modernizing of field systems for solving the problems of teamwork of these regulators and disassembled old regulators in composition of the integrated block has been taken into account, and computations of emergency perturbations were executed taking into account the action of centralized counter-emergency automation of the Bratskaya HPP (fig. 5). At tests of an AVR-MA regulator for the asynchronized generator of the TPP - 22 Mosenergo the questions of the changeover of the generator from asynchronized to synchronous and asynchronous regimes (fig. 6) were observed in addition.



1 – δ (Ust-Ilimskaja HPP – Krasnojarskaia HPP); 2 – U (Ust-Ilimskaja-HPP); 4 – P (Ust-Ilimskaja HPP – Bratsk); 5 – P (Ust-Ilimskaja HPP – Bratskaja HPP); 6 – P (Bratskaja HPP – Bratsk).

Fig. 5. 2-phase S.C. on 500 kV buses of Ust-Ilimskaya HPP with outage of Ust-Ilimskaya HPP - Bratskaya HPP transmission line with main circuit breaker malfunction and operation of reserve circuit breaker.



1 – U_{ASTG} ; 2 – Ifd_{ASTG}; 3 – Ifq_{ASTG}; 4 – P_{ASTG}; 5 – Q_{ASTG}; 6 – $Q_{G\text{-}TVF\text{-}120\text{-}2}$; 7 – $P_{G\text{-}TVF\text{-}120\text{-}2}$.

Fig. 6. Behavior of asynchronous and synchronous generators TEC-22 Mosenergo while asynchronous generator changeover from asynchronized to asynchronous mode.

THE CONCLUSION.

For security of system reliability of UPS of Russia state-of-the-art microprocessor control devices, regulations, protection and automation should pass the complex check on operation in conditions maximum approximated to their future operating conditions before installation on power installations. The effective instrument for performing of such tests is EDS of NIIPT.

In composition of the EDS the physical model of the complex power system providing the realization of the standard program of complex system tests of domestic and foreign microprocessors AVR is created. Regulators of AVR-M ("Elektrosila ") and AVR-2 ("Energokomplekt") have passed tests under this program and are recommended to application in UPS of Russia at modernizing and new construction.

In NIIPT the procedure of the adjustment of the microprocessor AVR for concrete power installations with EDS use was designed. The procedure is approved at an adjustment of the AVR for the hydro-generators of Sayano-Shushenskaya, Ust-Ilimskaya and Vilyuiskaya HPP, the asynchronized generator of the TPP-22 Mosenergo. The procedure ensures a reliability augmentation of operation of power installations and allows both to reduce periods and volume of starting-up and adjustment works and to decrease their cost.

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