TECHNICAL DIAGNOSTICS OF POWER GENERATORS

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Provision of reliable operation of the main generating equipment is an important and technically complex problem. It is practically impossible to solve it without obtaining the reliable information on equipment state (condition) and trend analysis of its changes, and therefore, without implementation of state-of-the-art facilities and diagnostic techniques.

Keyword: turbine generators, hydrogenerators, operational reliability, ageing of insulation, state diagnostics, test procedures.

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INTRODUCTION

Reliability of operation and life extension of generating machinery always were in the focus of the technical and administrative community of our branch.

This tendency has got currently a special applicability due to the following circumstances:

- capability margin reduction;
- machinery ageing;
- deterioration of the operating modes (reactive power consumption, cycling operating modes);
- deficiency of the high-skill technical specialists in operation and in repair services was run up;
- permanent restructuring of electric power industry and reorganization of maintenance services.

Approximately 75% of turbogenerators and 85% of hydrogenerators forming the basis of domestic electrical power engineering capacity had exhausted or will exhaust in the nearest future the service life established by GOST.

The technical state (condition) of generators which defines an opportunity of their further operation with an acceptable level of reliability, depends on many factors, including:

- the service life;
- embodiment features;
- quality and manufacturing technique;
- service conditions and level of availability, quality of maintenance;
- availability (presence) of defects which occurred in service (including owing to unfavorable and emergency operation).

The service experience of long-lived generators shows, that the service life is an important concept but far from being the role-defining one in testing (technical condition evaluation), and in most cases cannot be used as a sole or key parameter determining the necessity of replacement, modernization or a possibility and practicability of the further operation.

The special feature of electrical machines is that they are constructively made of materials with quite different physical properties: structural alloyed steel, copper, insulation materials, etc. Furthermore they have quite complex ventilation system, using distillate, air, hydrogen or oils.

The power synchronous generator is a complex, highly thermally, electrically and mechanically loaded machine, the life cycle, ageing and deterioration of constructive elements of which are influenced by a lot of factors of different nature:

- electrical (ionization ageing of insulation resulting from high voltage);
- thermal (thermal ageing of insulation resulting from the total and local increased heating);
- electrodynamic (vibration of windings caused by the high currents' flow);
- electromagnetic (an active steel vibration inflicted by the rotating magnetic field);
- mechanical (centrifugal forces at rotation of a rotor, vibration caused by imbalance);
- thermomechanical (the thermal deformations and the stresses caused by non-uniformity of heating and coefficients of thermal expansion of structural assemblies) and so forth.

Operational factors and the disturbances arising in the power systems due to the short circuits, switching-off of the network sections, etc. strongly influence the reliability of synchronous generators' operation. This means that the design service life of the equipment, in general, does not match with the real life cycle of generators.

The service conditions and a maintenance level, as well as the timeliness and completeness of revealing and quality of elimination of the defects accumulated during operation including the effects of the unfavorable and emergency duties in our opinion have more important, than the service life, and sometimes even decisive influence on a technical condition. Long inspection experience of generators shows that such unidentified and unrepaired defects on early stage of development in many cases result in irreversible degradation of a technical state (technical condition), exhaustion of a physical resource, emergency shutdown and destructions of generators.

Complex diagnostic inspections with use of modern diagnostics methods and attraction of the qualified specialists allow to reveal in time the defects accumulated in service, including ones an early stage of development, as well as to increase a maintenance level and quality of repairs of generators.

The primary intents and problems of such inspections are:

- operation reliability enhancement and prevention of severe accidents;
- extension of service life of the generator;
- quality improvement of remedial maintenance;
- check of capability and practicability of the further operation of genera-

MELTING OF THE TURBINE GENERATOR'S ELECTRICAL STEEL AS A RESULT OF THE STEEL LAYERS' SHORT CIRCUIT

Fig. 1

tors and their compliance with the required operating modes;
- definition of necessary and appropriate volumes of modernization, as well as quality improvement of works on modernization of generators;
- determination of necessity, priority and the period of decommissioning, replacements or factory repairs.

Starting from the 70's VNIIE (currently JSC "NTC of FGC UES") carries out constantly the all-inclusive inspections of turbo- and hydrogenerators, as well as synchronous compensators and large electric motors, using the methods of technical diagnostics focused on revealing, qualitative and duly elimination of all significant defects [1,2].

The complex of inspection procedures for testing (the technical condition evaluation) of turbogenerators, synchronous compensators and large electric motors includes:

- the analysis of the operational experience, data of repair and operational documentation;
- Vibration and thermal tests under load;
- Testing of sheet-to-sheet insulation of active steel of the stator core by an electromagnetic method at a low magnetic induction;
- testing of pressing of the stator core by an ultrasonic method;
- testing of the stator core support system as well as fastening system of ring buses by the vibroimpact method;
- PD level measurement in the stator winding insulation over the gaps;
- checkup by means of rigid and flexible endoscope of the major units of a turbogenerator (embedded and end windings, the core, support system, ring buses of the stator, and a rotor shaft) under the special program;
- metal hardness testing of the rotor shaft.

ELECTROMAGNETIC INSPECTION OF A GENERATOR'S STATOR CORE

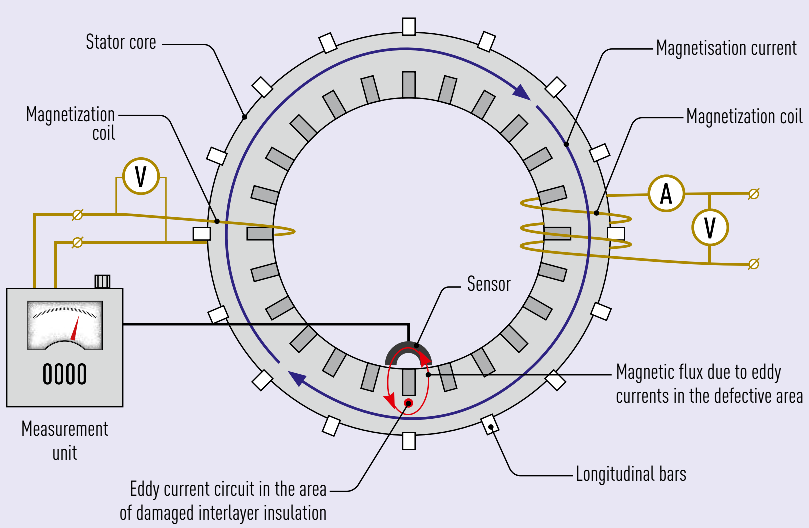

Fig. 2

ELECTROMAGNETIC TESTING (CONDITION EVALUATION METHOD) OF SHEET-TO-SHEET INSULATION OF STATOR ACTIVE STEEL (EMT). (ЭМК)

This method is intended for revealing of short circuits between the segments of active steel and the areas with the higher level of additional losses. The EMT usage is intended for prevention of severe failures such as "iron fire" (fig. 1).

DESTRUCTION OF ELECTRICAL STEEL LAMINATIONS (A) AND DAMAGING OF THE BAR INSULATION (Б)

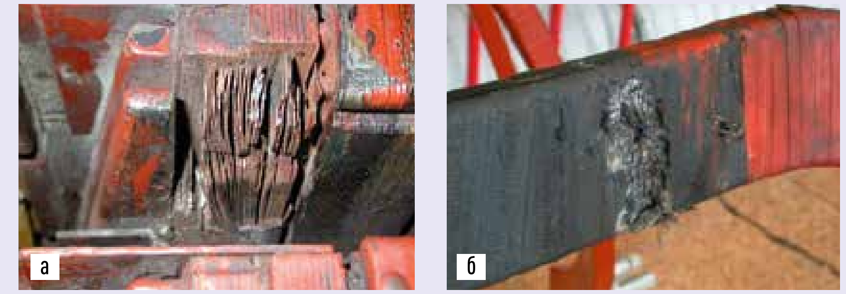

Fig. 3

The method is based on location of a magnetic flow at ring magnetization of the core by an induction with a low magnetic induction of 0.02-0.05 T (fig. 2). EMT (ЭМК) has a number of important advantages over the traditionally used inspection method at the higher magnetic induction of the core. In particular the method allows:

- to reveal the defects reliably as well as to estimate their risk level not only on a surface, but in depth of the core also;
- to perform the efficient check of completeness and quality of defects' elimination, and to speed the defects' elimination of active steel directly during maintenance (especially at extensive damages of the stator bore).

EMT (ЭМК) had helped repeatedly to reveal the dangerous short circuits, including in depth of the rotor active steel, and to prevent the "iron fire" (on Iriklin, Surgut, Nevinnomyssk hydroelectric power plants, the Volgograd thermal power station-2, the Krasnodar thermal power station, the Ryazan hydroelectric power plant).

The ultrasonic method for testing of active steel and stator pressing (UST).

THE ULTRASONIC QUALITY CONTROL METHOD OF PRESSING DENSITY OF ACTIVE STEEL AND STATOR (UST) (УЗК)

The method is intended for revealing of pressing (density) attenuation of stator core teeth as well as for control of completeness and repair quality of active steel. UST (УЗК) allows to reveal and eliminate at an early stage the dangerous opening and flaking of the active steel, resulting in serious damages of the core and/or stator winding (fig. 3).

UST (УЗК) is based on dependences between the pressing (density) and the travel time of ultrasonic vibrations across the sheets in the cores of active steel received during the number of researches. The general condition of pressing density is estimated on the basis of measurements, and the sections of the active steel with the pressing damage are revealed. The method allows to supervise the completeness and quality of elimination of the revealed defects during performance of works (fig. 4).

Due to UST (УЗК application) the number of emergency switching of generators on thermal power plant because of teeth destruction of active steel cores (despite of ageing of the equipment) has decreased from 3–4 cases per year in 93–94 to 1–2 cases per year in 95–96. Since 1997 to nowadays the emergency switching due to destruction of active steel occur approximately 1 time in 2-3 years. All emergency switchings took place on the uninspected turbogenerators. Inspections carried out in time have allowed to prevent the failures of this type on turbogenerators at Surgut, Kostroma, Karmanov, Iriklin, Ryazan hydroelectric power plant, Krasnodar thermal power station, thermal power stations No 22, 23, 26 of JSC "Mosenergo" and the others.

VIBROIMPACT METHOD FOR TESTING OF CORE FASTENING SYSTEM

The method is intended for detection of defects of the core fastening to the stator body and prevention of the increased vibrations' occurrence and fatigue failures of fastener assemblies of active steel [3]. It is based on definition of vibroacoustic signals' parameters, arising in support system of the core at impact excitation of its separate elements. The technical condition of the core support system is estimated on the basis of the analysis of these parameters. The method allows to reveal the defects of fastener assemblies of the core at an early stage to optimize the volume of repair and to lower expenses for their realization, to carry out the control of completeness and quality of repair of defective fastener assemblies.

The usage of the given quality control method has allowed to prevent in due time the development of defects in the support system of generators of Iriklinsk, Karmanovsk, Kostroma hydroelectric power plants, and of a number of thermal power stations of Mosenergo [4].

ULTRASONIC INSPECTION OF THE STATOR'S CORE

Fig. 4

ENDOSCOPIC INSPECTION OF ELECTRICAL STEEL CORE

Fig. 5

THE VIBROIMPACT QUALITY CONTROL METHOD OF TECHNICAL CHARACTERISTICS OF RING CONNECTING BUSES OF THE REPAIRED GENERATOR

The method allows to estimate the dynamic properties and to reveal at an early stage of development the defects of the ring buses' fastening. The analysis of the received results makes it possible to develop the recommendations for elimination of these defects and to control operatively the efficiency of repair actions. It is mostly actual for the power turbogenerators.

INSPECTION OF STATOR UNDER THE SPECIAL PROGRAM USING THE ENDOSCOPES

Such testing (inspection), which takes into account the measurement results, includes the feature detection of unsatisfactory vibration behavior of the core and stator winding, the cooling system failure, foreign object, as well as the concealed damages, which can be revealed only visually (fig. 5).

The usage of rigid, flexible, traditional videoendoscopes boosts the efficiency of inspections, allowing to carry out the monitoring of all critical machine units at assembly decreasing. For example, the usage of endoscopes has allowed to reveal the dangerous destructions in teeth depth of end packages, demanding the urgent replacement of stators or reburdening of their core ends on turbogenerators of Kostromskaya and Konakovskaya hydroelectric power stations.

PD LEVEL MEASUREMENT IN INSULATION OF STATOR WINDINGS

The method is intended for revealing of concealed damages of stator winding: discontinuity in insulation, the damages due to ionization ageing etc. (fig. 6). The method is developed

in VNIIE (currently JSC "NTC of FGC UES") and has been successfully applied on turbo- and hydrogenerators during more than 25 years. 2 sensors, installed at (on) the ends of each gap under test, are used for measurements. These sensors respond only to PD current in core insulation of the given gap due to the differential connection layout (circuit) of their takeup coils (fig. 7).

Our approach allows to evaluate the overall conditions of insulation) and to reveal the most worn out cores. Furthermore, the method differs by a high level of results' reliability due to localization of points of insulation weakening.

Currently the separate companies implement the much simplified approach to testing and diagnostics by PD level in insulation. The sensors are installed on the terminals of the generator and the phase-average PD level of a winding is measured. And in some techniques the installation of sensors on generator housing instead of a winding is used. The analysis of such tests' results has shown their lowest efficiency [5].

THE ROTOR'S TECHNICAL CONDITION MONITORING

Such testing is carried out on the basis of analysis of parameters describing a vibration, with addition of checkup by means of endoscopes and magnifiers with magnification of 4-10, and testing of metal hardness on the critical surfaces of cylinder and the tail parts (in joint area of gap wedges, on the mounting surfaces, as well as in area of the centre shaft). The hardness control allows to estimate an operational condition and the efficiency of work of the babbit bearing inserts.

The program of complex diagnostic inspection of hydrogenerators is to a large extent similar to the program

A GAP BETWEEN A CONDUCTIVE PART AND INSULATION

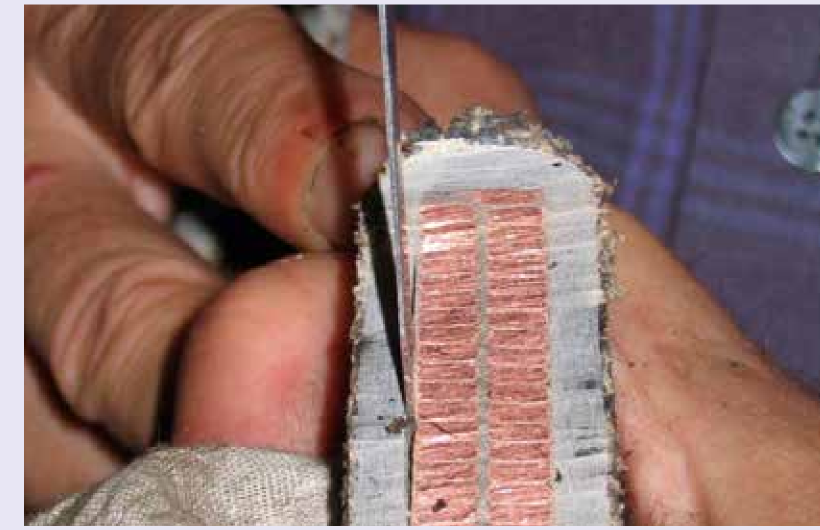

Fig. 6

MEASURING LEVEL OF PARTIAL DISCHARGE ON A HYDROGENERATOR

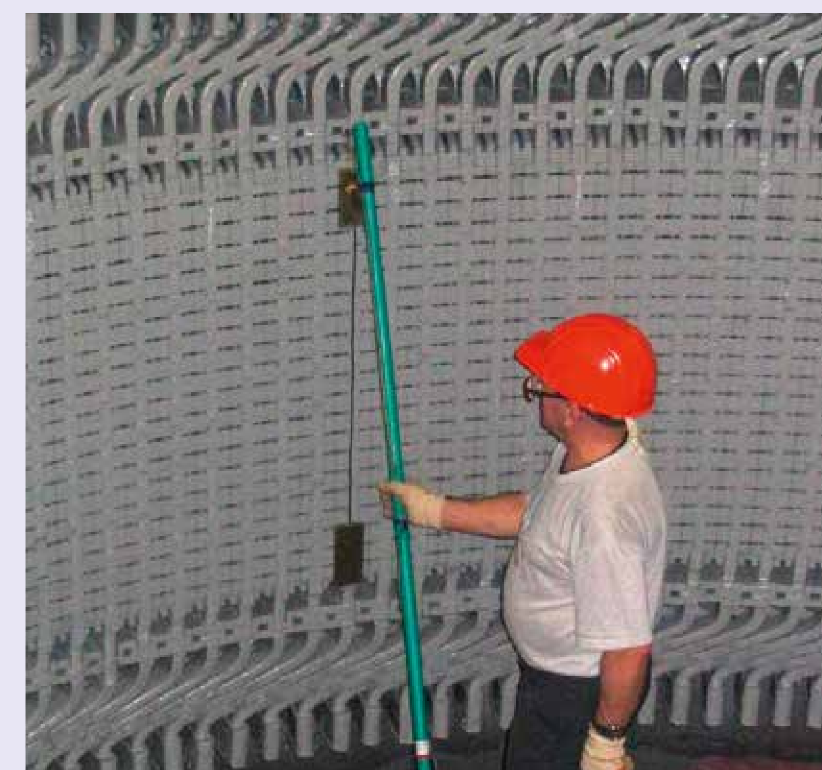

Fig. 7

INSPECTION OF A HYDRO GENERATOR'S OPERATIONAL CONDITION

Fig. 8

WEAKENING OF THE JOINTS BETWEEN THE HYDRO GENERATOR'S CORE'S SECTORS WITH THE SEALING LAYER PUSHING OUT

Fig. 9

of inspections of turbogenerators. However due to a number of design features of hydrogenerators (salient pole type, a vertical axis and lower speed of rotation, etc.) the test procedures have the significant differences.

The complex diagnostics (evaluation of a technical condition) of hydrogenerators is carried out on the basis of results of the following inspections:

- monitoring of vibration condition of the stator core and support structures of the hydrogenerator;
- Evaluation of vibration condition of the stator end windings;
- definition of dynamic mode of stator and rotor on working generator, their mutual position, evaluation of an air gap symmetry;
- Monitoring of the thermal condition of the generator – thermal tests;
- PD level measurement in the stator winding;
- testing of the stator core steel by a high-frequency scanning method , in case of necessity – testing by a ring magnetization method;
- Evaluation of pressing density of an active steel of the stator core;
- Evaluation of the soldered joints of the stator end winding by means of heat-indicating labels.

TESTING OF DYNAMIC SHAPE OF STATOR AND ROTOR

This test is carried out on a working generator (fig. 8) and allows to reveal in due time and eliminate the dangerous symmetry infringements of magnetic field in an air gap of the generator. It is known that such infringements provoke occurrence of increased low-frequency vibrations of the stator core resulting in damages of active steel and its fastener assemblies, as well as support structures of the generator. At deformation of the standard stator shape (for example — occurrence of misalignment, i.e. misalignment of an axis of rotation of a rotor and the stator geometrical centre) occurrence of one-side magnetic adhesion force is possible, resulting in overheating and failures of guide bearings of the generator.

The vibration test (monitoring) in the frequency range of 100 Hz allows to reveal at an early stage the abnormality of the joint tightness of the stator core sections (fig. 9). Such failures result in numerous damages with time of fastener assemblies of the core to the stator enclosure: chipping of the active steel shouldered ends in groove with dovetail joint, cracks' formation in the fastener assemblies of stacked wedges to enclosure shelves, and the shelves themselves, elimination of which demands an extensive repair.

Elimination of the visible consequences of increased vibration by "welding-up" of cracks in fastener assemblies without revealing of primary causes of occurrence of such vibrations, may within a short time (from several minutes to several months) result in crack formation in the new welds (fig. 10).

The early diagnostics of defects and their duly elimination, in particular rotor shape correction and (or) "re-attaching" of the stator core sectors, allow to lower the levels of stator core vibration to satisfactory values excluding the damaging of fastener assemblies. For example, on generators of "Kola" branch of JSC "TGK-1" where (after elimination of the causes of the increased vibrations under the given recommendations) it

BREAKING OF THE ATTACHMENT POINT

Fig. 10

TRIGGERING OF THE HEAT INDICATOR

Fig. 11

INFORMATION

FROM THE RAO "UES OF RUSSIA", OJSC STANDARD "THERMAL POWER STATIONS. METHODS OF ASSESSING CONDITION OF KEY EQUIPMENT"

Ongoing monitoring of TTP key equipment status is performed by a testing lab, which can either be a part of the operating company or be a separate organization.

A testing lab performing non-destructive testing of the equipment's metal must be certified by Rostechnadzor.

Technical diagnostics of the TPP equipment, related to extending its service life, is performed by a specialized company.

A specialized company performing the technical diagnostics of the equipment controlled by Rostechnadzor must be licensed to perform industrial safety inspections. The expertise of the specialized organizations is to be confirmed by the voluntary certification agency, which in turn is authorized by the Federal Agency for Technical Regulation and Metrology.

was possible to put practically all hydrogenerators in operating condition. Presently the constant monitoring allows to carry out an early diagnostics of similar malfunctions.

THE TEMPERATURE MONITORING OF CRITICAL ASSEMBLIES BY MEANS OF HEAT-INDICATING LABELS

The heat-indicating labels (HL) (ТЭ) are intended for the temperature monitoring of critical assemblies of electric equipment: active steel and insulation of electric machines, contact connections of electric mains, busbars, insulators, etc.

HL (ТЭ) are the discrete temperature meters in a range from 50 to 150 °C, and have the high accuracy – 1–3 °C. They are very demonstrative (unused – white label, used – the black one).

In contrast to the periodic monitoring (for example, by thermal imager) HL (ТЭ) do monitor continuously the overheating during a long period of time, as well as in inaccessible places while in service.

The example of heat-indicating label operation, caused by overheating of the stator end winding head is shown on fig. 11. The overheating was caused by destruction of the solder connection. The well-timed resoldering has allowed to prevent the emergency switching of the generator. The latter could give rise to mass destruction of stator winding cores. The similar cases are frequent for generators, being long time in operation or at rewinding of a new stator winding in station conditions.

The long-term analysis of operating experience of generators, the inspections of which are carried out repeatedly within more than 15–20 years, shows, that the diagnostics methods, developed and used during inspections, allow to test reliably the turbo- and hydrogenerators, as well as synchronous compensators. These methods provide revealing of all main defects at an early stage of their occurrence. The actuality of the complex approach to defects' diagnostics of generators was underlined also at an international level within the framework of SIGRE work [6].

Since middle of 70s, the specialists of JSC "NTC of FGC UES" (previously VNIIE) carry out constantly the diagnostics (inspections) of turbo- and hydrogenerators;

turbogenerators of Kostromskaya, Konakovskaya, Kashirskaya, Nizhnevartovskaya, Nevinnomysskaya, Novotcherkasskaya, Karmanovskaya, Kirishskaya, Iriklinskaya hydroelectric power plants, Surgutskaya hydroelectric power plant-2, heat station of JSC "Mosenergo", Krasnodarskaya, Tobolskaya, Kishinevskaya heat stations and a number of other heat stations;

hydrogenerators of Saratovskaya, Pavlovskaya, Tcheboksarskaya, Zhigulevskaya, Tsimlyanskaya, Tchirkeiskaya, Nizhnekamskaya, Bratskaya hydroelectric power plants, Zagorskaya hydroelectric pumped storage power plant, hydroelectric power plants of the "Kolsky" and "Karelskiy" branches of TGK-1.

During the last few years the potential emergency switching-off of generators of (on) a number of power stations were prevented under the results of the carried out works. The experience of R&D works and testing (practical inspection) of generators on power stations of Russia was always required during the development of technical standard documentation. The specialists in the field of electric machinery of VNIIE took part in development of all basic standards and norms in the field of technical condition monitoring and diagnostics

of generating equipment: GOST-33 "Turbogenerators. The general specifications"; РД 34.45-51.300-97 "Test scope and standards of electric equipment ";" Standard service manual of generators"; different accident-prevention and service circular letters in the field of reliability enhancement of operation of turbo- and hydrogenerators etc.

During the last few years with participation of specialists of JSC "NTC of FGC UES" the following documents have been developed:

- Company standard СТО 1733028227.140.001-2006 "Testing procedures of the main equipment of hydro-electric power stations";
- Standard of Unified Energy System of Russia "Thermal power plants. Testing procedures of the main equipment", approved by an order № 200 of Unified Energy System of Russia 28.03.2007;
- "Guidance on reliability enhancement of operation of retaining ring assemblies of rotors of turbogenerators", approved by an order № 232 of Unified Energy System of Russia 05.04.2007;
- "Methodical Guidelines on testing (technical condition evaluation) of the turbogenerators with expired service life", approved by an order of Unified Energy System 31.03.2008.

SUMMARY

Reliability enhancement of operation of the generating equipment of power stations is one of the most actual problems in electric power industry. Effectual measures of trouble-free work of generators and prolongation of their service life is the timely detection and full elimination of malfunctions at an initial stage of their development.

Early revealing of defects ensures the considerable saving of time and labor costs on performance of maintenance and repair and allows to prevent the occurrence of emergencies.

For reliable testing (estimation) of generators and early detection of damages by the specialists of JSC "NTC of FGC UES" the complex of preventive measures and the special tests, providing the precise localization of revealed defects, as well as conception on scope of necessary repair measures was developed and applied.

REFERENCES

1. D. Kuznetsov, V. Maslov, V. Pikul'skij, V. Poliakov, F. Poliakov., Hudiakov A.N., M. Shandybin "Defects of turbogenerators and the methods of their diagnostics at an initial stage of occurrence. Power plants, No 8, 2004. "(rus)
2. B. Kislitskij, V. Maslov, G. Mogilev, A. Netseevskiy "The testing results of hydrogenerators with the long term of operation." Power plants, No 9, 2004. (rus)
3. D. Kuznetsov, «Investigation of electromagnetic forces acting on the coupling prism turbogenerator stator core», Electricity, №10, (2006) (rus)
4. D. Kuznetsov, F. Poliakov, M. Shandybin. «Revealing and elimination of suspension defects of the stator cores of power turbogenerators. Power plants, 2012 No 9, page 55. (rus)
5. Y. L'vov, Y. Shakarian, F.Poliakov F.A., Y. Samorodov. «Pseudo-diagnostics of electric equipment». Energetic 2012, No 3 (rus)
6. Mamikonyants L.G.. Pikulskiy V.A., Polyakov F.A. A1-211 Service life Prolongation and Reliability Increase of Long Operating Turbogenerators. SIGRE report, 2006.