The Inspection of the Technical State of Critical Infrastructure Facilities

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***Abstract*—Traditional methods of power equipment reliability improving are limited in case of critical infrastructures. More effective approach on the way is to improve the operation process of power equipment during its lifetime as well as maintenance and repair procedures on the basis of diagnostic data and actual technical state detection with using different diagnostic tools. Classification of different tasks necessary to effective control of power equipment technical state is given. It is proven the needs to develop automated monitoring systems in scale of smart grid concept. Diagnostic procedure for critical infrastructure facility is divided in integrated parts according to type of installed power equipment. The conditions of reliable operation of power equipment are highlighted. Operation factors affecting power equipment state was divided into the related groups according to the current period of equipment lifetime. For accurate technical state assessment it is necessary to consider the cumulative effect of these factors impacts. The significance and key effectiveness of monitoring system implementation are formulated.**

***Index Terms*—diagnostic, equipment, inspection, technical state**

I. Introduction

Actual data on current technical state of critical infrastructure facilities equipment can be obtained by state-of-art diagnostic methods. Diagnostics of power equipment is usually performed by non-destructive tests which help to determine not only the technical condition with detecting possible defects but also to assess the degree of wear-out rate and residual life of equipment. One of the main ways to increase the reliability of power facilities is application of more reliable equipment, as well as different types of back-up systems. However, underlying approach design, schemes and technology capacities are limited especially for critical infrastructure facilities. Actual way to ensure the reliability and safety of critical infrastructure facilities is to improve its maintenance and repair techniques and programs based on results of diagnostics and tests with consequent determination of actual technical state of power equipment.

II. Main Aims of Implemented Power Equipment Diagnostics

The condition for reliable operation of power equipment is periodic or continuous assessment of its technical state by inspection, measurement, control, monitoring and diagnostics as well as the prediction of technical state changes due to different loads, maintenance and repairs procedures. Therefore, early diagnostics is a necessary and very important part of critical infrastructure power equipment operation. Using different means and methods of non-destructive testing and fault detection it is possible to significantly reduce the number of failures of power equipment, avoid serious consequences in case of accidents, reduce the downtime of power equipment during repair, improve the reliability and quality of power supply as well as answer the following asset management questions:

1) Is the available information on power equipment technical state reliable?

2) Is it possible to compare the information on technical state of power equipment installed on different critical infrastructure facilities?

3) When should be necessary to provide maintenance and repair of power equipment in terms of optimal relation between service costs and possible risks of outage?

4) When should be necessary to replace power equipment in terms of its complete lifetime achievement as well as relation between service costs of aged equipment and costs of new ones?

5) How to define the consequences of making or failure of power equipment replacement/repair?

6) Should we spend more (or less) money on repairs and replacement of power equipment to provide the required level of reliability and security of critical infrastructure facilities?

7) How to justify the cost of repairs or replacement of power equipment to management and shareholders of company?

8) How to solve the problem of power equipment service life limit and priority of its maintenance?

The latest tendency in technical diagnostics regarding smart grids concepts implementation is associated with the development and integration of automated monitoring systems which allow to control of power equipment online with help of various diagnostic methods and expert systems. It enables to change the maintenance and repair policy with regard to actual technical state of power equipment.

The aims of diagnostic systems implementation at critical infrastructure facilities are:

- to provide support to management decision-making on the basis of online reliable information on power equipment technical state online;

- to provide the ability to forecast of defects growing in power equipment on the basis of database consisting diagnostic information about dynamic properties of ageing processes;

- data acquisition, processing and analysis of diagnostic information which is necessary for implementation of new maintenance and repair strategy based on actual technical state of power equipment;

- improving the reliability of electricity supply through downtime detection of defects and taking measures to prevent failures of power equipment;

- costs reduction by eliminating unreasoned repairs of power equipment;

- improving quality of power equipment repairs based on actual diagnostic database.

The main diagnostic tasks in terms of smart grid concept are [1]:

1) To identify the type, location and severity of defects in power equipment;

2) To recognize the causes of defects formation and growing in time;

3) To develop the model of defect formation and growing inside power equipment;

4) To create instruments for control of defect growing;

5) To evaluate the integral index of technical state considering service impacts, conditions and operation modes of power equipment;

6) To determine the type of defects in power equipment units should be primarily removed for providing the required level of performance capability;

7) To predict technical state of power equipment. This template has been tailored for output on US letter-sized paper.

Many russian and foreign companies have developed large number of methods and means of power equipment diagnostics. Generally, application of diagnostic procedures at critical infrastructure facilities can be divided into groups according to the types of installed power equipment: generators, power transformers, high voltage breakers and switchgear, cable and overhead lines, line and post insulators, busbars and current systems, electric contact systems and electrical connections, measuring current and voltage transformers, arresters, relay protection, operating DC voltage systems.

Effective and long-life operation of power equipment is based on the following statements:

- unconditional fulfillment of the requirements of standardized documents, instructions for operation and maintenance published by manufactures;

- continuous and complex evaluation of technical state of power equipment in service on the basis of diagnostics procedure implementation;

- forecasting of technical state changes by monitoring operation conditions and loads;

- prevent failures by means of back-up systems, structural and temporal redundancy, availability of reserves of equipment strength, material and technical resources;

- timely maintenance and repair in required date with sufficient and appropriate quality;

- acquisition and analysis of real cases of power equipment failures enable to make timely decisions for preventing similar failure events in other power equipment as well as to identify the conditions and patterns of defects formation and growing.

III. Factors Affecting Technical State of Power Eqipment. Types of Applicable Diagnostics

Structure factors affecting power equipment reliability are divided into design mistakes, inadequate design and poor production quality. Operation factors can be divided into industrial (operation technology disruption, inefficient maintenance and repair programs as well as monitoring and diagnostics procedures), installation (installation technology disruption, low qualification of personnel), maintenance and repair (maintenance personnel qualification, logistics, timely reconstruction of facilities). These factors are primarily related to the physical conditions of power equipment operation in service. For example, the weighted long time modes and starting duty, voltage and current overloads, power frequency deviation, shock and vibration loads, mechanical overloads, climatic impacts (temperature, humidity, contamination, hostile environment). Analysis of the causes of unreliable power equipment operation indicates that mentioned-above factors are interrelated. At the same time failures of power equipment are caused by integrated effect of these factors action. Complex physical and chemical processes of power equipment deterioration are the sources of failures which lead to service life decrease. The ageing processes involve heating and cooling, moisture penetration in electric insulation, overvoltages, electrical discharges, electrochemical and electromagnetic phenomena, shock and mechanical vibrations. During operation of power equipment its ageing processes become more intensive under the influence of friction, current, voltage and contamination. The ageing behavior is heavier due to additional impacts of power arc, high temperature and dynamic mechanical loads. The overloads enhance thermal aging of transformer-, generator-, motor drive-, cable insulation as well as contact connections.

For reliable operation of power equipment it is necessary:

- to comply with the established rules and regulations during manufacture, design, installation, commissioning, testing, operation, maintenance and repair, in case of failures of power equipment;

- to take measures eliminating or warning harmful manifestations of operation factors;

- to monitor power equipment operational modes and conditions with aim to develop suitable maintenance and repair procedures corresponding to actual technical state;

- to identify in power equipment faults and defects at early stages of its growing with using modern diagnostics tools.

On critical infrastructure facilities in Russia the experience on solving the mentioned above tasks is obtained. The experience would be interesting for widespread using. Power equipment diagnostic can be realized in the following forms:

- periodic inspection of technical state parameters during maintenance outage;

- periodic inspection of technical state parameters under operating voltage;

- periodic inspection of technical state parameters under overvoltage;

- continuous automatic control (monitoring);

- overall diagnostic inspection.

Periodic inspection of power equipment during its maintenance outage enables to use a set of different nondestructive diagnostic tools and means for detection of defects and faults. It provides wide opportunities for safe inspection, but stops power supply and changes the mode of power equipment.

Periodic inspection under operating voltage provides the opportunity to make express assessment of power equipment technical state with detection of damages due to operation factors impacts. The disadvantage of this type of diagnostics is absence of information about defects on early stages of its growing.

Periodic inspection under overvoltage is regulated by a guidance document RD 34.45-51.300-97 "The volume and rate of electrical equipment testing". The document contains only lists and guidelines of testing procedures for separate parameters but it does not include instructions for overall analysis of test data. According to the type of diagnostic a defect is mainly detected by comparing the test data with standard values, it does not take into account the dynamic properties of controlled parameters. The analysis of correlations between test results for parameters with a common physical nature is not specified using this type of diagnostics.

Different diagnostic methods and tools use at overall diagnostic inspection. In this case decision making about technical state of power equipment is the most adequate. At the same time the durability of overall inspection is large enough. As result it is impossible to timely response to dynamic changings of technical state.

It should be noted that now all type of diagnostics require its further development and improvement. It enables to determine technical state of power equipment in the most reliable way. It also gives the opportunity to detect defects at early stage of its growing and to predict its dynamic properties. Moreover, it is possible to oversee the overall impact of operation factors on technical state of each type of power equipment individually and plan the counter measures on reliability improvement.

Power equipment diagnostics should be performed during commissioning. After that power equipment should be inspected periodically during its operation, maintenance and repair works. Diagnostics of power equipment should be performed after standard service life of equipment is over or when its extreme limit state will be achieved with high probability. At critical infrastructure facilities where especially high reliability of power equipment should be provided, it is useful to implement monitoring system highlighting the parameters which characterize the technical state of power equipment. Therefore, development of such automated diagnostic systems based on newest information technologies is in progress now. This type of diagnostics is the most preferable because it actually provides online monitoring of dynamic changes of controlled parameters. Also it eliminates the influence of judgmental factors on results of monitoring and helps to analyze a lot of diagnostic parameters. Using modified math algorithms provides the prediction of dynamic properties of growing defects and evaluation of technical state of power equipment structural units.

The main tasks which should be solved on the way of building such monitoring system are:

1) Integration of developed automated diagnostic systems in the existing SCADA systems installed on critical infrastructure facilities;

2) Development of the math model describing technical state changings and providing the opportunity to detect defects and identify its causes.

3) Development of power equipment functional model which helps to evaluate durability and reliability indicators based on overall impacts of operation factors and existing diagnostic parameters.

4) Diagnostics algorithm design allowing to determine and classify power equipment technical states as well as to differentiate between types of defects and to predict its dynamic properties.

5) Information and software algorithms design to execute diagnostics algorithms, data processing and indication.

Terms and diagnostic works frequency should be indicated in technical rules and regulations on maintenance and repair of power equipment. Scope of diagnostic works is determined for each type of power equipment or a group of the same type equipment with aspect to its design specialties, type of identified defects, terms and operation conditions by means of making a diagnostic schedule. Depending on the specific conditions and operation modes as well as importance and general technical state of power equipment, the scope and terms of diagnostic works can be corrected by technical manager. Depending on hardware and controlled diagnostic parameters it is possible to create the following list of diagnostic methods that are most commonly used to control the power equipment of critical infrastructure facility: acoustic control; heat monitoring; optical inspection; vibration control; ultrasound testing; chromatographic analysis of gases dissolved in oil; electric parameters control and analysis of current and voltage harmonics; oil physicochemical analysis; emission control; radar control; impulse control; control of partial discharges intensity. Diagnostic works generally include the following steps:

- analysis of design, background, expertise, operational, regulations and other documentation concerning technical state and quality of installed power equipment;

- development of diagnostic schedule with the list of tools;

- operational (functional) diagnostics;

- instrumental inspection of power equipment;

- analysis of identified defects and mechanisms of its growing;

- computer processing of diagnostic data;

- identification of patterns of technical state parameters changes with forecasting of limit values;

- current life time assessment and residual life time forecasting;

- grounds for a decision concerning the further power equipment operation;

- definition of limit terms of excessive power equipment operation;

- making conclusions about technical state and recommendations for further operation or repair of power equipment.

IV. CONDITIONS OF DIAGNOSTICS EFFECTIVENESS

Professional engineering companies with highly skilled specialists and experts with wide practical experience should be involved for execution of diagnostic works. The companies should be equipped with a set of instruments and tools for measuring and non-destructive testing. Measures to ensure the reliability and security of power objects installed in critical infrastructure facilities base on controlling of technical state and should include immediate, medium and long-term objectives [2].

The following results define the effectiveness of diagnostics:

- significant reduction of injuries of staff working on objects of critical infrastructure facilities due to reducing the number of equipment failures;

- increase reliability through timely preventive measures;

- reduce the costs on unjustified reconstruction of power equipment;

- reduce labor costs by implementing the system of power equipment technical state monitoring;

- reduce operating costs by establishing optimal schedule of maintenance and repair;

- reduce maintenance and repair costs on the basis of determining optimal scope of works with allowance for diagnostic data;

- save the optimal level of operating quality of power equipment installed in critical infrastructure facilities by eliminating the defects that cause performance degradation;

- reduce insurance costs;

- increase the level of safety by preventing unexpected failures and related emergencies;

- reduce the number of power supply outages and quantity of penalties from consumers because of damages.

At the same time costs for using automated monitoring systems, non-destructive testing and diagnostic tools should be justified by application effect.

V. CONCLUSIONS

The results of latest studies can be considered as a comprehensive solution for control of technical state of power equipment of critical infrastructure facilities in energy sector. Solved tasks are essential for making a transition to explore maintenance and repair system according to technical state of power equipment as well as its operation control depending on the obtained values of reliability indicators based on diagnostic data. It enables to implement approach providing high reliability indexes of power equipment of critical infrastructure facilities. It is achieved by improving maintenance and repair procedures as well as operation procedure by taking into account the actual technical state determined by means of diagnostic system. The priority way to improve diagnostic system of power equipment is to monitor and control of its technical state by using automated diagnostic tools. All newly built and reconstructed electric stations and substations shall be equipped with automated monitoring systems for evaluation of technical state of main power equipment.

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