Overview of turbogenerator monitoring and diagnostic systems

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Abstract. The article considers general approaches and modern monitoring systems for rotary machines of electric generating equipment. The main characteristics of monitoring and diagnostics systems of Russian and foreign manufacturers are presented. Modern trends in the construction of intelligent systems for analyzing the performance of turbo generators and predicting possible failures in order to minimize the cost of repairs and forced shutdown of equipment are outlined. The concept of adaptive-predictive use of rotary machines, the difference from existing systems is the presence of adaptive module that allows to react to unwanted changes in real time and increase the predicted residual resource or eliminate the predicted probability of initially refusal.

Turbo-generator stations are the basis for the functioning and life support of cities, enterprises, and other structures. The occurrence of accidents at such facilities should be reduced to zero. Improving the reliability and safety by technological and design ways has reached its limit. At the same time, statistics inexorably say that no matter how well the parts of the turbine unit are made (as a rule, they are made by different companies), unexpected and hidden defects occur during installation (uneven tightening of bolts above or below the recommended values, balancing the turbine rotor separately from the generator rotor, inaccurate installation of control sensors, a small number of sensors, etc.), which subsequently lead to an emergency situation and the need for unscheduled repairs. Up to 70% of repair cases are caused by installation errors that lead to scenarios of gradual or accidental failures.

In fact, there are two states of the turbo-generator: workable and unworkable which correspond to planned and unscheduled repairs. There are no legal mechanisms for stopping equipment that is still operational, but in which there is a transition to an inoperable state, to carry out repairs on the actual state, and for this purpose it is necessary to introduce new monitoring and diagnostic systems that would give the operator sufficient grounds for such actions.

The most important element in building a system of transition to repairs based on the actual state is the creation of a real-time intelligent monitoring system and predictive diagnostics based on methods for obtaining and processing large amounts of data about the state of the object under control. Obviously, the introduction of intelligent technology to control parameters of the turbine, analysis and predictive forecasting of the residual resource of the most critical nodes of repairs depending on the degree of parts wear is mainly by improving the security of energy facilities.

The modern system of diagnostics of technical systems needs to provide:
• the required accuracy, reliability, and timeliness of operational information about the state of the process;
• operational control and decision-making based on the analysis of incoming information about the state of the process;
• registration of triggering of emergency protection and blocking devices with memorization of the root cause;
• analysis of the set of measured parameters and forecasting of equipment life;
• automatic prevention of the development of pre-emergency situations;
• stable operation of big data exchange and storage systems.

One of the important stages of developing an intelligent diagnostics system is to determine the volume and type of data to provide a comprehensive assessment of the state of the technical system. The list of measured parameters should take into account the features of the design and technological solutions adopted at the design stage, the quality of manufacturing and installation, the experience of using prototype objects and the features of the operating conditions of diagnostic objects. As statistics are collected, the list of diagnostic features should be specified and the crucial rules for recognizing defects should be improved.

The power plant's turbo generator is a multi-rotor machine that includes low-, medium-, and high-pressure turbine shafts and a generator shaft. In the case of a gas turbine installation, we are talking about the shaft of the compressor and generator. Monitoring and diagnostics systems for rotary machines are primarily based on vibration displacement sensors, since information about vibration carries an understanding of satisfactory performance and there are many theoretical and practical works on identifying various defects by spectral analysis [1,2,3].

If we consider in detail the rotor of a turbo-generator based on hydrodynamic bearings, we can see that failures have numerous scenarios, but we can assume that various processes that eventually lead to destruction in their initial stage act as a catalyst leading to a significant change in the rotor imbalance and an increase in inertial loads in proportion to the square of the rotation speed. Such scenarios can lead to disastrous consequences associated with the loss of human lives and huge economic costs. According to statistics, about 22% of failures are due to bearings and seals. As an object of monitoring and diagnostics, the turbo generator is a complex multi-parameter system (figure 1), in which failure scenarios are even more complex and depend on many parameters [4, 5, 6, 7].

One of the main trends in Industry 4.0 [8,9] is the creation of digital twins of technical systems in order to increase the reliability of their operation and reduce the cost of unexpected repairs and shutdowns. Modern computing capabilities allow you to create detailed visual models of any technical object, the level of science in the field of solid mechanics, hydro, gas mechanics, heat and mass transfer allows you to create adequate mathematical models of virtually any processes occurring in the assemblies of the turbo generator.

Detailing failure scenarios in mathematical interpretation, one can develop basic rules for training artificial neural networks and more accurately predict the type and time of failure compared with modern diagnostic systems. The digital twin works to prevent failures and constantly monitor the "device". The neural network that will take into account such factors as: sufficient bearing capacity of supports with small dimensions; vibration stability of rotors in all operating modes; minimum friction losses and wear of working surfaces during the specified lifetime; low consumption of lubricating and cooling material, acceptable temperature conditions, manufacturability and ease of construction in operation, as well as performance in an emergency. Taking into account all possible failures or errors, the digital twin will notify and prevent the operation mode, for the further health of the equipment. In the field of production organization, integrated PDM systems, as a prototype of digital twins, already make it possible to build logistics more efficiently, plan the placement of equipment, the movement of inventory, etc. [10]. But the greatest value of implementing digital doubles is seen in the concept of developing intelligent monitoring and diagnostics systems with mechanisms for adaptive and predictive analysis of equipment
performance and instant response to adverse changes. But, as noted in [11], "digital doubles" are more a vision of the future of technical systems than complete solutions, and it is necessary to move in this direction consistently and carefully.

**Figure 1.** Turbo generator with steam turbine as a multiparametric monitoring system.

Currently, the market offers various software and hardware products in the field of monitoring and diagnostics systems [12,13,14]. Among the most advanced systems that approach the requirements for intelligent monitoring systems, the following can be identified. The Expert ALLERT system (DLI, USA) [15] allows frequency analysis and provides recommendations for subsequent actions when signs of a particular defect are detected.

The expert monitoring and diagnostics system of company BENTLEY NEVADA (USA) [1] allows to determine the current technical condition of the machine and determine the causes of the defect. Not only frequency analysis is performed, but also processing of the "raw" signal of shaft vibration displacements in the sliding bearing clearance.

Effective solutions in this area are based on the Rockwell Automation Entek platform. They allow to make the full range of measurements necessary for vibration monitoring, protection and diagnostics of various rotary equipment. Rockwell Automation is a global leader in the field of automation of production processes and, combining such brands as Entek Scientific, Allen-Bradley and IRD Mechanics, offers a wide range of products and services that are used by hundreds of manufacturers to optimize and improve the efficiency of their production [16].

Among domestic developments in the field of monitoring and diagnostics, it is possible to distinguish the programs of A.V. Barkov (vast, St. Petersburg) [17] and programs by V.A. Rusov (Vibrocenter, Perm) [18]. A.V. Barkov has worked out the spectrum envelope method and has made a significant contribution to the diagnostics of rolling bearings. Among V.A. Rusov’s works, diagnostics of electric machines (electric motors and transformers) and screw compressors should be noted.

A detailed analysis of the leading domestic monitoring and diagnostics systems is given in [19], among which we can distinguish the firms NPP Viscount, Vibrobit, Diameh 2000, NGO Mera, NPC Dynamics, NGO TSKTI, etc.

This list is far from complete, but for the most part these systems are classic diagnostic systems that allow measuring, visualizing and interpreting signals of various types of sensors in accordance with
established rules and using spectral analysis as a theoretical basis. The remote PRANA monitoring and diagnostics system allows using machine learning to make more accurate forecasts for equipment based on a constantly accumulated database of operational status, failures, results of routine maintenance, etc. [20]. Such solutions can be found in software products developed by the” RAKURS” group of companies. In essence, these systems are a natural evolution of existing solutions for monitoring and diagnostics of power equipment.

The latest approaches in the field of intelligent monitoring and diagnostics are the use of predictive operation methods, which consist in calculating the performance parameters of critical assemblies and parts and predicting the residual resource. The authors of the concept of predictive analysis, which in addition to continuous monitoring of key parameters and their analysis with the limit values for measured parameters are constantly carrying out calculations of the performance of key assemblies and issuing a detailed forecast. The artificial neural networks solve the problem of clustering relative to the same type of equipment in relation to the parameters at the stage of putting the equipment into operation and the current state. The other artificial neural networks are constantly self-learning to detect the type of fault that occurs even at the stage of origin, and not at the time of failure. Figure 2 shows a functional diagram of building a system for adaptive predictive operation of rotary machines, which differs from existing systems in the presence of an adaptive module that allows to react to undesirable changes in real time and increase the predicted residual resource or eliminate the probability of an initially predicted failure [21,22].

**Figure 2.** Functional diagram of the adaptive-predictive operation system.

Conceptually, the system of the adaptive-predictive operation of rotary machines should include the following modules:

- real-time measuring module, the purpose of which is to fix the current values of the turbo-generating set state parameters by certified software and hardware;
- the primary diagnostics module, the purpose of which is to compare the measured parameters with the set limit values;
- predictive module, the purpose of which is to solve inverse problems of rotor dynamics, heat mass transfer, and hydrodynamics to determine the current values of all other parameters not directly measured;
- failure identification module, the purpose of which is to determine the residual resource of critical turbine assemblies, based on measured and calculated parameters;
• expert module, the purpose of which is to analyze the data obtained and make up a decision on the need for repairs according to the actual state;
• technical and economic module, the purpose of which is to assess the required period and volume of repair work with the formation of a list of products to purchase and possible contractors;
• adaptive module, the purpose of which is to assess the possible increase in the residual resource of the critical assembly of the turbo-generating set by adjusting the performance characteristics in real time. This can be made after approval by experts and operators;
• data processing and storage module, the purpose of which is to store breakdown statistics, mathematical processing and interpretation of emergency scenarios, machine learning, and specification of mathematical models of typical failures.

Application of the adaptive predictive analysis will reduce the threat of emergency (the ability to respond to changes in the condition of the equipment), will reduce the threat to human influence, will predict the repair of the equipment according to actual technical condition during the works carried out at modernization of old generating capacity, which will significantly improve the reliability of the equipment and the commissioning of the new (system reliability, reduce duration emergency output power). The creation of such a system and its implementation at energy facilities will significantly increase the safety of operation of vital facilities not only in the energy industry, but also in enterprises with a high level of risk, in the production of explosive, toxic and radioactive products, in industries with high pressures and temperatures, in medical institutions and other facilities.

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