Monitoring system of hydro and wind power equipment based on intelligent measuring complexes and Neurodiagnostics

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Abstract: The paper presents an analysis of the development of wind energy and hydropower in the Russian Federation. The analysis of modern approaches to the diagnosis of wind turbines in the world. The possibility of applying the phase-chronometric technology for renewable energy facilities wind turbines and hydraulic units is substantiating. An example of diagnosing wear during operation of gears and rolling bearings based on a phase-chronometric approach is giving. Multivariate mathematical modeling is presenting on the example of a hydraulic unit. An alternative approach to the application of measuring technologies to support the life cycle of hydropower and wind energy facilities using Neurodiagnostic systems is presented.

1. Introduction and analysis

Leading experts and consulting groups forecast an annual increase in energy consumption by the countries of the European Union from 0.7% and 1.7%, note that the increase in energy consumption in the United States amounted to about 3.2%, in China to 3.7% in 2018\textsuperscript{1}. Introducing new technological solutions and scientific developments into real sectors of the economy is highlighting among key trends.

The development of technologies, the rapid introduction of alternative production systems, an increase in the share of autonomy of industrial enterprises requires the introduction of new modern approaches in energy, increasing energy efficiency and energy saving.

Leading companies in the world introduce modern management technologies in energy. It should be noted that the current level of automation has reached such proportions that it is impossible to control technological processes without introducing measurement, control and management systems. Today, instrumentation is not just a set of sensors, but measuring complexes in combination with modern methods of measurement and control and advanced measurement methods. It is worth talking about the development and implementation of modern measuring technologies. [1]

In 2019, the oil and gas company BP introduced the next release of its traditional annual global energy forecast BP Energy Outlook-2019. Renewable energy production is projecting to grow at a rate...
of 7.1% per year, and its share in primary energy will increase to 15% by 2040, compared to 4% today.

It implements modern measuring technologies in all areas of energy development, including traditional and renewable. Experts note the need for introducing measuring forecasting complexes, reducing energy losses, introducing modern laser technologies, increasing the energy efficiency of generating and auxiliary equipment. [2, 3, 4, 5, 6]

GWEC\(^2\) data analysis results:
- The total capacity of all wind power plants in the world exceeds 651 GW;
- The share of offshore wind energy from the total number of new installations also became a record and amounted to 10%.

Growth of offshore wind energy amounted to 35.5% compared to the previous year, and the total installed capacity is approaching 30 GW [7] and the number is in the tens of thousands, but their number will only increase.

Meanwhile, significant investments are making in the construction of wind farms and the localization of modern equipment for wind turbines. The Wind Energy Development Fund has been created (on a parity basis by RUSNANO and Fortum), Nova wind (a subsidiary of Rosatom State Corporation) and Enel Russia plan to build wind farms with a total capacity of 3149.36 MW by 2023. According to experts, this generation will amount to 2% of the total electricity generation. [8]

Technical state of inter-energy generating equipment. According to studies of the failure frequency of wind turbine components and their downtime of over 24,000 turbines published by researchers at Durham University, the failure rate per wind turbine from 0,2 to 0,5 observed in many critical structural parts, among them it should be note [9]:
- Electrical system;
- Control Control;
- Hydraulic system;
- Yaw system;
- Rotor blades;
- Gearbox;
- Generator;
- Others.

Figure 1 shows the results of the analysis. It should be note that although electrical systems have the highest failure rate, failure of gearboxes leads to the longest downtimes, while failure of gearboxes, failure of the blades and transmission failures result in 95% of equipment downtime.

\(^2\) GWEC - Global Council on Wind Energy, https://gwec.net/gwec-over-60gw-of-wind-energy-capacity-installed-in-2019-the-second-biggest-year-in-history/
Figure 2 presents the results of an analysis of the two largest international wind turbine maintenance databases.

LWK (Landwirtschaftskammer Schleswig-Holstein) - database from 1993 to 2006. It contains the output and the number of failures in the system for all capacities in the province in northern Germany. WWEP (Wissenschaftliches Mess- und Evaluierungsprogramm) database contains detailed information on the reliability and operability of wind turbines and their units from 1989 to 2006.

On the one hand, it should pay close attention to research, study and technical features when operating unknown types of power plants, such as wind turbines, hybrid. One another to pay close attention to existing renewable energy facilities using the example of hydropower.

In [11], an analysis of methods for monitoring and forecasting the technical condition of wind turbines is present. It pays particular attention to the most loaded structural elements, such as rolling bearings and transmission elements. Cracks are largely the major cause of gear failure because of rolling bearings. We consider methods of vibration analysis of multichannel measuring systems with significant changes in load and speed of rotation. The presence of axial cracks in rolling bearings is noted.

The work [12] provides information on the analysis of failures of large-sized bearings of wind turbines. The paper widely presents methods for monitoring the technical condition and diagnosis of wind turbines. [12]

It should be noted the review publications on methods of monitoring and diagnosing wind turbines during operation, based on vibration diagnostics, modal and wavelet analysis. [13,14] In work [15] an integrated approach to the analysis of work at the stages of the life cycle of wind turbines is present.

2. Research methods and results
It should be note that domestic experts have already accumulated considerable experience in diagnosing heavily loaded rolling bearings and gearboxes based on the phase-chronometric method. This approach, combined with high noise immunity and speed, provides information on objects of cyclic action by measuring time intervals and their increments corresponding to phases of the working cycle of the mechanism. The measuring phase chronometric technology has already been tested and adopted for implementation in energy [16, 17], diagnostics of gears and gears [18], rolling bearings [19,20].
3. Diagnostics of gearboxes and bearings based on phase-chronometric technology
It is based on the principle of embedding measuring sensors for monitoring rotation parameters of gear shafts and sensors for monitoring wear of gear teeth in a test object. Measuring information sensors of one or several types of induction converters are fix in the gear housing near the teeth of the wheels diagnosed by wear parameters [18]. It shows an example of the location of the sensors in Figure 2.

![Figure 2. Arrangement of measuring sensors](image)

Such embedded systems provide:
- control of the parameters of natural abrasive wear of the working surfaces of the teeth, their chipping;
- control of tooth breakages;
- measurement of tooth wear in operation;
- evaluation of gear parameters.

It shows the results of experimental studies in Figure 3, depending on the gear wear and the results of measuring the amount of wear in polar coordinates.

![Figure 3. The measurement results of the corresponding gear teeth depending on the wear in polar coordinates](image)
The accuracy of measuring tooth wear is within ± 0.15%. Changes in the EMF value during natural wear of the working surface of the tooth will be smooth, and all volumetric changes such as chipping, or tooth breakage will give abrupt changes in the sensor EMF. Figure 3 (c, f) shows an example of diagnosing a breakdown of the 15th gear tooth.

To confirm and theoretically justify the measuring phase-chronometric technology, it carried multivariate mathematical modeling of the shape and amplitude of the measuring transducer depending on the wear of the teeth out (figure 4).

**Figure 4.** Dependence of the shape and amplitude of the measuring transducer on tooth wear.

Figure 5 shows a graph of the change in the measuring signal of the generator coil of the induction sensor over time depending on tooth wear.

**Figure 5.** Graph of the measuring signal of the generator coil of the induction sensor over time depending on tooth wear.
The demonstrated diagnostic approach can be developed using a neural network. A continuous series of time intervals, divided into separate cycles, can represent, as a certain one-dimensional image, individual for each state of the mechanism or mechanism unit. This task is close to identifying images.

It should be noted that the number of neurons of the input and output layer didn’t choose randomly. Since the input data array has 625 elements, it was logical to establish the same number of neurons in the input layer, and since the current task is to determine the very fact of a defect without classification, the output layer has only 2 neurons - this is 0 (no defect) and 1 (there is a defect).

The input data for the neural network are prepared:
- The source data arrays are divide into cycles, where in each cycle there are 625 values;
- each cycle inside the array of “normal” values is assign label 0, and each cycle inside the array of “defective” values is assign label 1;
- Arrays are combing and mixed (for better learning of the neural network);
- It divides the source data arrays into cycles, where in each cycle there are 625 values;

Perceptron training was done at 50 epochs, with weights providing the best accuracy stored in a file. Because of the calculations, the neural network showed the following results: the probability of correct identification on the training data was 98%, and on the test data - 95%.

4. Application of measuring phase-chronometric technologies in the field of hydropower

Consider a multi-factor mathematical simulation of a hydraulic turbine for a measuring phase-chronometric complex:

\[
\begin{align*}
J_p \ddot{\varphi}_p + k(\varphi_p - \varphi_m) &= M_{mp} - M_{mp nm} - M_{mp nu} \\
J_m \ddot{\varphi}_m + k(\varphi_m - \varphi_p) &= M_m \\
F(Q, \dot{Q}, H, N_m, \{a_i\}) &= 0
\end{align*}
\]  

(1)

where, \( J_p, J_m \) - are the moments of inertia of the rotor and turbine, respectively, \( \varphi_p, \varphi_m \) - are the angles of rotation of the rotor and turbine, respectively, \( M_{mp} \) - is the electromotive moment, \( M_m \) - is the moment of the turbine, \( M_{mp nm} \) - is the moment of friction of the bearing, \( M_{mp nu} \) - is the moment of friction of the bearing, \( Q \) - is the flow rate of water, \( H \) - is the pressure, \( N_m \) - is the power of the turbine, \( \{a_i\} \) - is the set geometric characteristics.

A feature of renewable energy generating facilities, such as wind turbines and hydroelectric units, is their considerable size and weight. Against this background, parameter control processes require improved measurement accuracy to determine the changes in time of physical, technical and operating parameters. The performed calculations showed the possibility of applying phase-chronometric technologies in hydropower. Thus, the absolute values expressed in the change in time intervals during friction losses, the influence of the hydrodynamic and electromagnetic moments of the turbine can be estimated between 0.5 to 25 \( \mu s \), and the change in the corresponding swing angles of the turbine shaft corresponds to values from several angular seconds to angular minutes. Using the mathematical model as an example, a method for determining the diagnostic characteristics of a rotary-blade turbine is implemented [21].

It has performed phase chronometric modeling of the dimensional analysis of the oil wedge in the thrust bearing based on the application of the theory of hydrodynamic loading of fluid friction for sliding bearings:

\[
N_{Pi} = \left( \frac{H \cdot \Omega_B}{\psi^2} \right) \cdot c_R \cdot l \cdot K_{OB},
\]

(2)
Where $\psi = \frac{S}{d}$ - is the relative clearance;
\[\mu\] - coefficient of viscosity of the lubricant;
\[c_R\] - load factor;
\[l\] - is the length of the connection, m;
\[K_{OB}\] - Coefficient depending on the relative clearance and eccentricity of the shaft.

According to [22], the thickness of the lubricating layer may amount from 40 to 60 microns. The problem of mathematical modeling was to determine based on a phase-chronometric information of the thickness of the oil wedge and the zone of contact of the turbine with the thrust bearings when you change the parameters of the working cycle definition and the ability to predict changes in clearance in the process of operation of the hydraulic unit. The simulation result shows that the thickness of the oil wedge doable in actual time with a forecast of its changes. It based the forecast of change of thickness of a lubricant layer on the analysis to forecast the behavior of the sequence of the time series.

Develop measuring phase-chronometric system can implement, for example, combination with the already built-in measuring systems of vibration control and analysis of spatio-temporal displacements.

Implementation of measuring phase-chronometric technology with the use of multivariate mathematical modeling provides a realization of the following tasks:

a) detection of defects that affect the operation of the hydraulic unit, such as
   - grazing the blade of the wall of the chamber;
   - breakage of the blades;
   - mechanical and electrical unbalance of the rotor of the generator;
   - uneven load on the bearing segments;
   - the misalignment of shafts of the turbine and generator.

b) the impact of hydraulic loads in the turbine caused by:
   - rotating vortex harness;
   - the uneven nature of the flow over the cross section of the spiral from the spiral chamber;
   - hydraulic shock loads.

5. Conclusion

It should be noted that the universal measuring phase-chronometric technology can also successfully monitor the technical condition of wind turbines. The advantage is the high noise immunity of the method, and the proven possibility of obtaining a positive result for low-speed dynamic objects. Analysis of existing diagnostic systems for wind energy systems shows the need for introducing such diagnostic and control systems for gearboxes, generators, and rolling bearings.

As the measurement results, it uses the values of the time series and their increments corresponding to the phases of the working cycle. For the phase-chronometric method, we can successfully apply methods of analysing time series based on previous values through reproducing a nonlinear functional dependence can be successfully. [23, 24]

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