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Application of Linear Random Processes to Construction of Diagnostic System for Power Engineering Equipment

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Abstract. Some mathematical models of informational signals and methods of the diagnostic system construction is considered. Different type of linear random processes is recommended for application. Some properties of the random processes are discussed. Application of the models depends on many factors. Such processes are used for classification of stochastic informational signals in the case of non-Gaussian distribution realizations of the signals, which energy spectra (within the framework of the first two moments) possess is often not enough for reliable recognition and classification of such signals. It is expedient to use information on higher moments or statistical characteristics of distributing such signals. It is possible to use the higher-order moments of such signals realization as the diagnostic features and provided the increase in accuracy and reliability of Power Engineering Equipment diagnostics. Attributes at the power engineering equipment diagnostic system construction are above mentioned justified diagnostic features, as well as informational diagnostic signals having been justified by the investigation of the appropriate mathematical models. Obtaining numerical estimation of chosen diagnostic features is first of all necessary for forming teaching complexes, and, further, for conducting the diagnostics itself according to the formed teaching complexes. Some peculiarities of constructing the multilevel diagnostic systems for resilience operation of electric power facilities are considered. An example of 3-level diagnostic system development for a Power station is represented.

Keywords: linear random process, vibration diagnostics, multilevel diagnostic system

Introduction

The Power Stations are an critical infrastructure. So reliability and resilience of its operation is an important component of state security. The reliability of the power equipment is closely related to the effective monitoring and diagnostics systems they are equipped with. The construction of such systems takes place in several stages: the

elaboration of mathematical models of information signals of such systems, the selection of the most informative diagnostic features based on the analysis of such models, the construction of training sets and decision rules. Construction of diagnostic algorithms and the system itself based on the scientific results obtained. When solving such a problem, the theory of probability, the theory of random processes, the theory of risks, machine learning, theory of statistical hypotheses, theory of pattern recognition etc. Algorithms for the plant of diagnostic systems according to the Smart Grid technology and resilience with the conditional division of the power engineering equipment into hierarchical levels is proposed. Many scientific papers are devoted to the issues related to the construction of diagnostic systems for power equipment. Some of them concerning on elaboration of mathematical models that can be used as models of information signals of such systems [1-4]. risk analysis and it 's application [5-8], diagnostics method development [9,10.].

1 Problem station

The modern Power Engineering industry, starting the Information Communication Technology networks developed on the basis of a Smart Grid concept and resilience, requires forming a holistic multilevel control system which provides the high level of automation, robustness and reliability of the whole system and covers the producers of electricity, transferring and distributing networks, consumers etc. In this case, obtaining actual information about the current state of each Power Station (PS) and the exchange of this information among all participants of the electricity market is very important, because it provides the increase in the reliability of the work of electrical system as a whole.

The implement of the reliable power engineering equipment is associated unavoidably with well-timed diagnostics of their technical condition. The method of diagnostics is most promising in the group of areas of methods of diagnostics of the technical condition of sections of electric drivers and mechanisms.

Two main approaches to solving the problems of diagnostics for machines and mechanisms are used. There are deterministic approaches and statistical approaches.

In the statistical approach, the solution of the problem of diagnostics usually consist of the following stages: elaboration of a mathematical model of information signals of diagnosed sections of machines and mechanisms; verification of the correspondence of the mathematical model to experimental data; separation of the most of the most informative diagnostic features to experimental data; formation of teaching sets corresponding to different technical condition of the diagnosed equipment; construction of decision making rules.

2 Definitions of some random processes

2.1 Linear random processes

A linear random process (LRP) is a functional of the following form

$$\xi(t) = \int_{-\infty}^{\infty} \varphi(\tau, t) d\eta(\tau), \quad t \in (-\infty, \infty) \quad (1)$$

where $\varphi(\tau, t) \in L_2(-\infty, \infty)$ with respect to τ for all t is a non-stochastic real Hilbert function; $\eta(\tau)$, $\eta(0)=0$, $\tau \in (-\infty, \infty)$ is a Hilbert stochastically continuous random process with independent increments that is often called a generating process. While solving many problems including statistical simulation it is convenient to consider the LRP as a response of a linear filter with the impulse transient function $\varphi(\tau, t)$ on the action of the white noise $\eta'(\tau)$. It is understood that $\eta'(\tau)$ is a generalized derivative of the corresponding process with independent increments [4].

Any stochastically continuous process with independent increments can be represented as a sum of two stochastically independent components which may be not present simultaneously: Gaussian and Poisson. We call the components as processes of Gaussian and Poisson types. The first type contains the homogeneous (Wiener) and non-homogeneous Gaussian processes with independent increments. Simple Poisson processes, renewal processes and their linear combinations, generalized Poisson processes with independent increments belong to the second type. Being generated by each of the mentioned processes LRPs possess some typical properties. This fact is taken as a principle of the classification. For example, it can be shown that if the generating process is of the Gaussian type, the corresponding LRP is a Gaussian stochastic process $\xi(t)$. Poisson type of generating process leads to LRPs describing impulse currents. We call such processes as impulse LRPs.

Using a characteristic function of a linear stochastic process, one can perform a full analysis of the output signals of linear systems: calculate moments and distribution functions, analyze connections between input and output characteristics of linear circuit.

2.2 Linear Random Process with Periodic Structures

We have to deal with non-stationary random processes in application in many cases. These processes can be defined in the following way. A real random process $\xi(t)$, $t \in (-\infty, \infty)$ is called the real periodic random process (RPRP), according to Slutskiy, if the number $T > 0$ exist for the process $\xi(t)$, such that the finite dimension vectors $(\xi(t_1), \xi(t_2), \dots, \xi(t_n))$ and $(\xi(t_1 + T), \xi(t_2 + T), \dots, \xi(t_n + T))$ are stochastically equivalent, in a wide sense, for all whole numbers $n > 0$, where t_1, t_2, \dots, t_n is a set of separability of the

The canonical form of characteristic function is simpler since such processes are set constructively on the random processes basis having infinitely divisible distribution patterns. However, for nonstationary processes with similar distribution patterns the spectral structure is not seen directly. Thus, to describe nonstationary random processes having periodic structure it is expedient to generate models which could combine the benefits of RPRP and the random processes having the infinitely divisible distribution patterns.

Random periodic processes can be widely used in many applications: the problem of detection of signals from noise, classification of information signals, and many others.

2.3 Linear Autoregressive Process

The diagnostics method is selected in the stage of elaboration of mathematical model. Usually, for example, vibrations are modelled using mathematical models with continuous parameters. However, the majority of modern devices and information-measuring systems in vibration diagnostics include microprocessors and microcomputers and computers whose functional algorithms are based on digital methods of processing information signals.

Taking this into account, vibrations should be described using mathematical models with discrete time. We propose to use as mathematical models of vibration of sections of machines and mechanisms one insufficiently examined group of random processes with discrete time – linear random autoregressive processes.

Autoregressive linear processes may be set in the following way:

$$\xi_t + \sum_{j=1}^p a_j \xi_{t-j} = \zeta_t, \quad t \in Z \quad (2)$$

where $\{a_j, a_j \neq 0, j = \overline{1, p}\}$ are the autoregressive parameters; p is the autoregressive order; $\{\zeta_t, t \in Z\}$ is the stationary random process with discrete time and independent values, which has the infinitely divisible distribution law $P\{\zeta_0 = 0\} = 1$. This process is often referred to as the generating process. It is proposed that the process ξ_t is stationary in the narrow sense and ergodic theorems are fulfilled [4].

Autoregressive processes are widely practiced when constructing mathematical models of information signals of different types and during their analysis and synthesis. To classify such processes their energy characteristics are used very often, but in problems of classification of stochastic information signals in the case of non-Gaussian distribution, realizations of the signals, which energy spectra (within the framework of the first two moments) possess is often not enough for reliable recognition and classification of such signals. Then it is expedient to use information on higher moments (integral characteristics) or statistical characteristics of distributing such signals.

In papers [3,4] the results of using the elements of the theory of LRP for developing the mathematical models of physical obtaining the diagnostic features from the results of the analysis of the mathematical models of these processes in the terms of complete probabilistic characteristics (distribution functions or densities of probability distribution) of diagnostic signals being investigated. This, in turn, made it possible to use the higher-order moments of probability distribution of such signals as the diagnostic features and provided the increase in accuracy and reliability of Power Engineering Equipment (PEE) diagnostics. Diagnostic features used for determining the technical state of Power Engineering Equipment.

3 Diagnostic features used for determining the technical state of Power Engineering Equipment

Obtaining numerical estimation of chosen diagnostic features, in turn, is first of all necessary for forming teaching complexes and, further, for conducting the diagnostics itself according to the formed teaching complexes.

It is evident, that any resilience diagnostic system must reveal catastrophic defects, since they completely cease the operation of the object being examined. At the same time, some nonfatal or partial failures can be left beyond the consideration. Such an approach to the development of the system provides the opportunity to simplify its structure, reduce the volume of information being processed in the system and transferred between its hierarchical levels. This resilience system can make the system cheaper, and existing computing resources can be redistributed for carrying out more urgent functions.

Consider the peculiarities of constructing the multilevel diagnostic systems for resilience operation of electric power facilities [10].

At the top hierarchical level, a central diagnostic system (CDS) is located. The main purpose of the CDS is gathering and generalizing the data which comes from all local PEE diagnostic systems. When it is necessary, CDS can transfer the received data to a higher level of hierarchy.

Equipment being the part of local diagnostic system (LDS) can be logically subdivided into 3 hierarchical levels:

- level 1 is intended to the initial selection of diagnostic information (measurement of diagnostic signals, amplification, analog filtering, conversion to a digital form);
- level 2 is intended for the preliminary mathematical processing and making intermediate diagnostic decisions (simple algorithms whose realization does not require vast computing resources; dividing information according to the degree of defect criticality); warning signaling to the higher level in the case of defect presence; storage of limited (insignificant) amount of measurement information and its transfer to the higher level (on request);
- level 3 is for storage, adequate processing and thorough analysis of data, quick response to emergency signals from a lower level, making diagnostic decisions about the examined object as a whole, archiving the statistical data, predicting the reliability and evaluating the residual life of the equipment, planning the repairing work etc.

PEE are equipped with standard measuring converters (especially, turbogenerators can be equipped with the sensors of temperature of a stator and a rotor) which can be used as the part of a monitoring system. It should be also stated that at the development stage of LDS the quite complete list of possible defects, which are to be revealed by the diagnostic system, is given and the units and electric machines (EM) elements in which these defects can possibly occur are listed.

Certain PEE are equipped with standard measuring converters (especially, turbogenerators can be equipped with the sensors of temperature of a stator and a rotor) which can be used as the part of a monitoring system.

At the level of construction units of the EM a separate computing module is mounted for further transferring and processing the measured diagnostic signals. This module

provides converting the analog signals to digital ones and preliminary processing of such signals obtained from this unit. In most cases, the considerable deviations of real state from the normal one will not be revealed, so that it might not be necessary to transfer the information to the higher level. If considerable deviation from the normal state to fatal defect is observed, the module of data measuring and preliminary processing should transfer the information to the higher level of system hierarchy for more detailed analysis.

Conclusions

According to the proposed mathematical models and hierarchical structure and with taking into account the conditional representation of the power engineering equipment with 3 levels, the algorithmic software has been developed which enables the functioning of the multilevel diagnostic system of the power engineering equipment by the Smart Grid technology.

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