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SOME PRACTICAL ISSUES OF CREATING TEACHING COMPLEXES PROVIDING INFORMATIONAL SUPPORT FOR MULTILEVEL DIAGNOSTIC SYSTEMS FOR ELECTROTECHNICAL EQUIPMENT

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Abstract. On the basis of the algorithms of functioning the multidimensional system for diagnostics of electrotechnical equipment via Smart Grid technology described in the previous paper, the examples of forming teaching complexes which are an information basis for further procedure of creating the rules of diagnostics and classification of possible defects of the electrotechnical equipment units are given.

Key words: electrotechnical equipment, diagnostical system, Smart Grid concept, teaching complex.

1. Introduction

The creation, further implementation and exploitation of multilevel diagnostic and monitoring systems being able to work with the Smart Grid technology requires creating a certain theoretical, algorithmic software and technical basis. A number of works are known [2–5, 7–13] in which such issues were considered to a certain extent.

For example, in works [1–3, 6, 8, 9, 11–13] the main issues devoted to the processes of creating the diagnostic signals in electrotechnical equipment (EE) units, developing and investigating the corresponding mathematical models of these signals and models related to the forms of representing the teaching complexes corresponding to some technical states of EE units being investigated are studied. Those results can be used as the theoretical basis for further development and practical implementation of informational measuring systems (IMS), which can function according to the Smart Grid technology, for examining the EE units.

Aim of the work is the creation of methods and facilities of the practical use of informational support for informational measuring systems of the diagnostics of electrotechnical units functioning according to the Smart Grid technology. For approaching the set aim of the work, methods of forming the tesching complexes corresponding with certain defects in EE units, as well as its operational modes have been developed and experimentally checked.

2. Forming the teaching complexes of multilevel IMS diagnostics of EM

It is known [1, 6] that putting any IMS diagnostics of technical objects into practice needs previous teaching whose result is forming the teaching complexes. Those are later used as so called templates with which diagnostical information obtained in any moment of time is compared and in such a way the technical state of the object being investigated is determined. Let us briefly consider the issues of forming such teaching complexes with the aim of their further use for diagnosing electrical machines.

One of the main moments while examining EE with the use of IMS diagnostics is the comparison of obtained numerical values of diagnostic features with previously formed teaching complexes which take into account both possible defects in the EE unit being investigated and its operational modes.

As the example, the issue of forming such teaching complexes on the basis of the results of measuring the diagnostic signal in the form of vibration accelerations of an EM rolling bearing can be considered. For this let us use the results of work [2], where the issue of forming teaching complexes relevant to the certain technical states of rolling bearings, as well as speed modes of their testing according to the experimental data of vibration accelerations of the rolling bearings being investigated is considered.

As it was mentioned above, according to the results of the analysis of a mathematical model of vibrational processes [1, 6, 11–14] accompanying the operation of EE units being investigated, the most thorough information for solving the diagnostical tasks is contained in a correlation function, power spectrum density, autoregression parameters, one-dimensional probability density function of vibrational processes being considered, or values determined by them, resonance frequency, extremum of a correlation function, power moments etc. These are the functions and parameters which are the elements for forming teaching complexes.

Teaching complexes can be described as sets of measured parameters somehow formed and subdivided into subsets. First of all, damping coefficients and frequency parameters being contained in analytical expressions which describe a correlation function $R(s)$, spectral density of distribution $S(\omega)$, as well as the third and forth moments of realizing vibrational processes can be used as diagnostic features [1, 2, 6, 11, 12, 15]. However, in practice, coefficients of asymmetry k and kurtosis γ are used instead of the third and forth moments of vibrational processes in bearings themselves [1, 6] which are interconnected via the following relation

$$k^2 = \mu_3 / \mu_2^{3/2}, \quad (1)$$

$$\gamma = \beta_2 - 3, \quad (2)$$

$$\beta_2 = \mu_2 / \mu_2^2, \quad (3)$$

For illustrating the dependency of numerical values of diagnostic features on the operational modes of certain units let us give some examples. For solving this task, testing of such an important unit of electrical machines (EM) as a bearing unit was chosen. Its operational modes were limited to the EM shift rotating speed for the most spread types of EE bearings. During the experiments directed to the vibration-based IMS diagnostics of EE units the measurement of vibration acceleration of the bearings being investigated was performed.

In Fig. 1 the general view of a stand which served for testing the work of the bearing units of the EM at different speed operating modes is shown. The stand was mainly intended to experimental testing of diagnostical features in the presence of typical defects like skew or absence of lubricant, as well as investigations of damage to an outer or inner bearing race due to metal crumbling (or so called pitting).

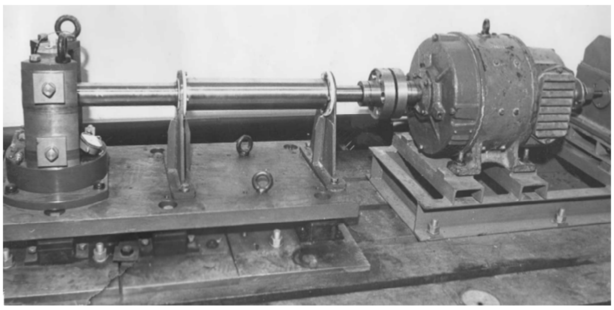

Fig. 1. Stand for vibrational testing of rolling bearings.

The construction of the stand consists of three main units: electric drive, solid shaft, unit for fixture and measuring the vibrations of the bearing being investigated. The rotation of the bearing mounted on the fixture and vibration measuring unit (shown on the left side of Fig. 1) is provided by the electric DC engine of П-51 type via the solid shaft. This engine with power of 11 kW provides the rotation of investigated bearing with any speed in the range from 10 to 1500 rpm. The application of special clutch with rubber fingers enables decreasing the vibrations caused by the work of electric drive. Moreover, the decrease in the vibration of the shaft of the experimental stand facilitates fixing it in rolling contact bearings made of Teflon, as well as placing the shaft and the unit of fixture and measuring the vibrations of the tested bearing on the solid plate.

The main purpose of the unit of fixture and measuring the vibrations of the bearing is the possibility of the simulation of main defects of a bearing and the placement of initial vibrotransforming equipment (accelerometers). For measuring the vibration acceleration of the tested bearing, the accelerometer of the ABC-017 type was used allowing the measurement of bearing vibrations in the frequency range from 20 to 30 kHz. It is mounted in the radial direction in relation to the tested bearing. The detail description of the stand for testing bearings is given in [1, 2, 6].

As it was shown above, the rolling bearings of 309 ЕШ2 type with different kinds of defects (skew, absence of lubricant, defects of outer and inner races and rolling elements caused by metal crumbling due to metal fatigue) were tested. According to works [1, 2, 6], as it was mentioned above, the most informative diagnostic features for revealing and classifying all mentioned defects of bearings are coefficients of asymmetry k and kurtosis γ of vibration of tested rolling bearings.

In Table 1 the results of investigations of vibration accelerations of conditionally serviceable rolling bearings mounted on the experimental stand constructed on the basis of electrical DC machine (EM) of П-51 type are given.

Table 1

Test conditions of bearings	Shaft rotary speed v_{rpm} / Notations and testing results		250	500	750	1000
Serv-ceable	Representation of teaching complex					
	Average values of coeffi-cients	k	0.039±0.005	0.035±0.009	0.042±0.012	0.039±0.007
		γ	0.184±0.037	0.193±0.013	1.051±0.137	1.531±0.372
Absence of lubricant	Representation of teaching complex					
	Average values of coeffi-cients	k	0.041±0.004	0.038±0.005	0.044±0.009	0.035±0.011
		γ	0.583±0.048	0.611±0.131	1.813±0.241	2.342±0.543
Skew	Representation of teaching complex					
	Average values of coeffi-cients	k	0.037±0.003	0.035±0.010	0.036±0.011	0.032±0.006
		γ	1.007±0.111	1.171±0.173	2.331±0.255	3.007±0.743
Defect of inside race	Representation of teaching complex					
	Average values of coeffi-cients	k	0.037±0.004	0.032±0.007	0.028±0.010	0.023±0.009
		γ	1.394±0.239	1.517±0.212	3.273±0.412	3.673±0.829

* Obtained values of asymmetry coefficients should be multiplied by 10-2.

While carrying out the experiments on the investigation of the influence of the value of EM shift rotating speed on numerical values of the main diagnostic features (Table 1), the speed mode of shift rotation was changed discretely with values $v_{ob} \in (250, 500, 750, 1000)$ rpm. According to a created model [1, 6, 11, 12], forming the diagnostic spaces corresponding to both certain technical state of the rolling bearing (serviceable, skew, absence of lubricant, defect of the inner race) and certain mentioned above speed mode can be denoted as aggregate of sets Ω, whose elements are subsets $\omega_{jn}, j, n \in \overline{1,4}$. In such a notation an index j corresponds to certain technical state of the bearing at its testing on the stand, and n corresponds to angular speed of the stand shaft. In this case $n1$ = 250 rpm, $n2$ = 500 rpm, $n3$ = 750 rpm, $n4$ = 1000 rpm.

The notations $\omega_{jn}, j, n \in \overline{1,4}$ are shown in Table 1. It means that every $\omega_{jn}, j, n \in \overline{1,4}$ represents a certain teaching complex (TC) corresponding not only to the certain technical state of the rolling bearing but also to its particular operational mode.

With the purpose of convenient choice of TC while performing EM diagnostics, these complexes can be systematized in the matrix form.

Formed set of diagnostic spaces Ω can be represented in the form of the following matrix:

$$\Omega = \begin{Vmatrix} \omega_{11} & \omega_{12} & \omega_{13} & \omega_{14} \\ \omega_{21} & \omega_{22} & \omega_{23} & \omega_{24} \\ \omega_{31} & \omega_{32} & \omega_{33} & \omega_{34} \\ \omega_{11} & \omega_{42} & \omega_{43} & \omega_{44} \end{Vmatrix}, \qquad (4)$$

Since operations with matrices are well formalized, representation (4) provides an opportunity for choosing the TC corresponding to a certain operating mode of EM as well as the certain technical state of the rolling bearing being investigated.

In the give form (4) subspaces located in rows correspond to the same technical states of this unit, but working in different modes of exploiting the investigated EM. Every column corresponds to a certain (constant) operational mode of the investigated unit, but at the same time to different technical states. That is, in the complex of subsets ω_{nk} an index $j = \overline{1,k}$ denotes a certain kind of defect and index describes the certain operational mode of the EM.

On the basis of developed models, numerous experiments on the real electrotechnical equipment have been performed. The detailed description of these experiments and their results are shown in works [1, 2, 6].

Applying the Smart Grid concept can cause the substantial broadening of capabilities of diagnostical systems via additional functions, namely, providing the two-way exchange of information between all hierarchical levels of the system, distant monitoring of the state of the power station objects being investigated, evaluation of residual life etc. Practical realization of IMS diagnostics requires creating appropriate methods, algorythms and software which in real time could process measured signals and produce resulting diagnosis of the technical state of the EM being investigated. One of the variants of such algorithmic software is proposed in this paper and is considered above.

Taking into account that the work organization of modern electrical power objects is hierarchical [7, 8, 9, 10], the systems of monitoring, control and technical diagnostics of EE should also be developed by the hierarchical principle. Four levels for such hierarchy have been proposed.

At the first level the construction elements of main units of power station equipment are located. It is this level that determins what defects are possible in the object being considered.

The second one contains the equipment units proper which are constructive total, namely, windings of a rotor and a stator of rotative machines, magnetic circuits, bearing units, housing, bed plate, foundation, cooling system.

EE of the power plant is represented at the third level. It contains generators, auxiliary engines, transformers, switches, breakers, insulators, pumps etc.

The forth hierarchical level is the level of the power plant as a whole.

In accordance with the given levels one of the methods of forming and storing TC for a data bank of the multilevel diagnostic IMS was proposed, as it is shown in [1].

In Fig. 2 the diagram of location of TC for rolling bearings of EM being investigated is given with taking into account (4) in a form of a flat matrix. Conditionally it can be considered to be the TC in 2D-fornat.

Such representation of TS allows their convenient systematization (harmonizing them with proposed above hierarchical levels) by particular units and devices of all EE of the power plant that can be examined. In 2D format (Fig. 2) the TS containing the data about one single unit (this corresponds to the 2-nd level in the proposed hierarchy) can be represented. In the columns of the proposed matrix the elements corresponding to certain kinds of defects which can occur during the exploiting the unit being investigated at its certain operation mode are located. In the rows of this matrix the elements corresponding to the similar technical states (servisable or having certain kinds of defects) but working in different operational modes are located.

In the case of rolling bearings of the EM which were investigated in 4 different speed modes on the stand shown in Fig. 5 and undergo 4 different technical states (serviceable, absence of lubricant, skew, defect of inside race).

According to the results of measuring the vibration of the investigated bearings it can be noted that numerical evaluation of average values of asymmetry coefficients k does not depend on the changes in both speed mode or possible defects listed in Table 1. That is, in this case, the asymentry coefficient k did not prove to be the diagnostic feature. Obtained results of the evaluation of the asymmetry coefficients k show the symmetrical nature of the curve of distribution of the values of vibrational acceleration of the rolling bearings obtained on the stand (Fig. 1).

ω_{11}	ω_{12}	ω_{13}	ω_{14}
ω_{21}	ω_{22}	ω_{23}	ω_{24}
ω_{31}	ω_{32}	ω_{33}	ω_{34}
ω_{41}	ω_{42}	ω_{43}	ω_{44}

Fig. 2. Location of teaching complexes in the flat 2D form for the EM bearing unit.

Obtained values of numerical evaluation of average values of the coefficient of kurtosis γ of the vibrational acceleration of the bearings proved their information capability while diagnosing the above mentioned defects of rolling bearings working in certain speed modes. Acoording to the data shown in Table 1, the increase in average values of the coefficient of kurtosis γ at the presence of some defects in the bearings being tested can be observed. Thus, at the steady rotating speed of the shaft v_{rot} = 250 rpm the gradual increase in the average values of coefficient of kurtosis γ of vibrational acceleration in the presence of different defects of the bearings (absence of lubricant, skew, defect of inside race) can be observed in comparison with the serviceable bearings. This parameter reaches its maximum values in the case of the defect of the inside race of the bearing. The increase in values of the coefficient of kurtosis γ of vibration acceleration of the bearings with defects indicates the presence of pulses with significant magnitude in their vibrations. Obtained data prove the results given in works [1, 6, 14].

Changing the speed modes of the stand causes the considerable change in numerical values of the coefficient of kurtosis γ of vibration accelerations of the bearings. As Table 1 shows, at the increase in shift rotating speed the increase in the average meanings of the values of the coefficient of kurtosis γ. Maximum values of this parameter are observed during testing of bearings with defects of the inner race and at the shift rotating speed v_{rot} = 1000 rpm.

Data given in Table 1 prove that it is necessary to take into account the speed operational modes of the rolling bearings while testing their technical state. According to [1, 2, 6] this task can be solved by creating teching complexes which are based on applying values of the parameter γ being investigated and which take into account both kinds of possible defects and speed operation mode of the rolling bearing. The best way to do this is to use the diagnostic space for forming the TCs in which the coordinates are the most informative diagnostic features. The experimentally obtained data shown in Table 1 being taken into account, the Pearson diagram (well-known in the field of statistics) was chosen as such a diagnostic space [1, 2, 6].

3. Forming the teaching complexes in the space of Pearson curves.

The main stages of examining the EE with the use of statistic methods are considered in works [1, 2, 6]. Below we are going to briefly consider the issues of creating the teaching complexes (TC) corresponding to certain technical states of investigated rolling bearings and their operational modes. For this let us use the results of investigating the vibrations of the bearings shown in Table 1.

As it was shown in [1, 2, 6], the asymmetry and kurtosis coefficients characterizing the distribution of vibration processes of different units of the EE can be used as diagnostical features for determining the technical state or a load degree of EE units.

If instead the coefficients k and γ parameters correlating with them are used

$$\beta_1 = k^2,\ \beta_2 = \gamma + 3\,, \qquad (5)$$

it is possible to use a plane (β_1, β_2) as the diagnostic space in which the Pearson diagram is created [1, 4]. Let us briefly consider the issue of forming TCs corresponding to different technical states and various speed modes of the investigation of the tested bearing in the diagnostic space (β_1, β_2). For this the boundaries of the change of the numerical values $\overline{\beta_1}$ and $\overline{\beta_2}$ in accordance with the kind of the defect and speed mode of the bearing being investigated. The line over the symbol $\overline{\beta_1}$ means the evaluation of the parameter β_1. This marking system is also correct for other parameters.

In Fig. 3 the TCs in the diagnostic space (β_1, β_2) are shown which have been formed by the results of the investigation of vibrations of the rolling bearing having different technical states and working in different speed modes. Each TC is represented by ellipse of dispersion [1, 2, 6] formed according to the points whose coordinates are the averaged values $\overline{\beta_1}$ and $\overline{\beta_2}$. Number 1 denotes the TC corresponding to testing the conditionally servisable rolling bearing; number 2 shows the absence of lubrication; number 3 represents skew; number 4 – the defect of the inner race. All these notations are memorized for the TC which has been formed for testing the bearing working in different speed modes (Fig. 3a, b, c, d).

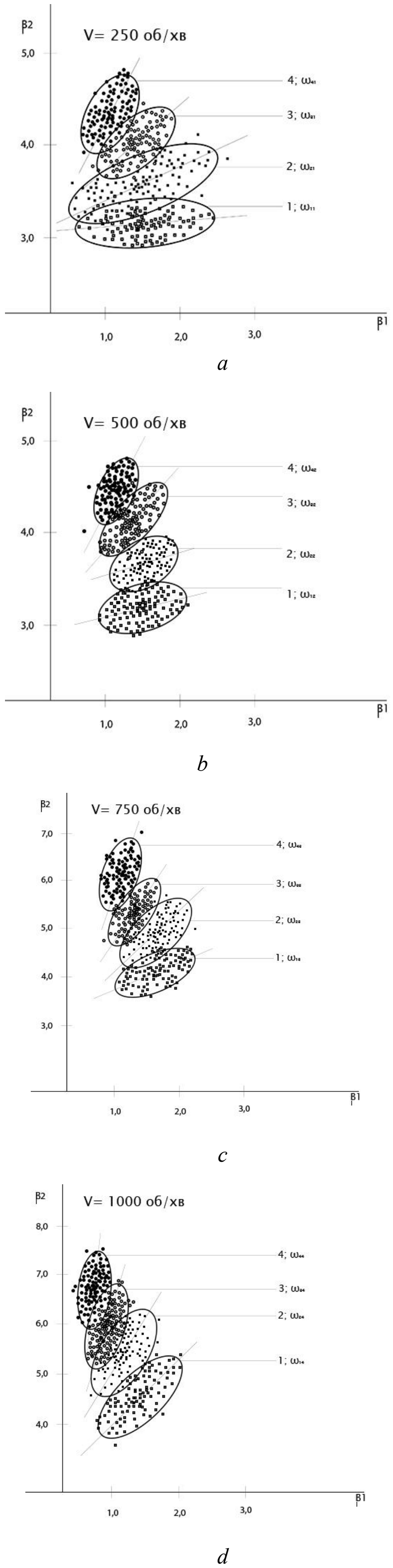

Fig. 3. TC formed according to the vibrations of rolling bearings in the diagnostic space.

Ellipses of dispersion presented in these Figures were created by the results of processing samples (from 85 to 100) of experimentally measured realizations of vibration acceleration of rolling bearings being tested on the stand (Fig. 5), being in different technical states and working in different speed modes. Each point presented in Fig. 6 corresponds to one realization of the vibration accelerations of the rolling bearing having one of the mentioned technical states and was tested in four speed modes $v_{rot} \in (250, 500, 750, 1000)$ rpm. In turn, about 95 % of experimentally obtained points corresponding to certain testing conditions for bearings being investigated are surrounded with the boundaries of each ellipse of dispersion.

Simple comparison of the location of TC on the plane shows their considerable dependence on either the kind of the defect or from the speed operational mode of the stand (Fig. 1). It means that each TC should correspond to the certain notation of subset ω_{nk}, which would combine the information either about the technical state of the investigated bearing or its speed operational mode.

The use of the space of Pearson diagram with coordinates (β_1, β_2) for forming the TC raises the possibility for determining the main parameters and the type of a distribution curve k corresponding to obtained experimental data. This fact allows more accurate diagnostics of the technical state of investigated objects, since besides using above mentioned parameters it is possible to use other ones (for example, κ - kappa coefficient, etc.) characterizing the distribution in the Pearson system of curves.

4. Conclusions

1. Representation of teaching complexes in the form of 2D-matrix whose elements take into account both possible kinds of defects of the EE unit and its operational mode is proposed.
2. With the help of experimental data about vibrational acceleration of the investigated rolling bearings the teaching complexes have been formed which reflects both technical states of the rolling bearings and speed modes of their testing.
3. Obtained teaching complexes are the informational base in the EE diagnostical systems which allows applying well-known solving rules for the classification of possible defects and making decisions about their technical state.

References

[1] S. V. Babak, M. V. Myslovych, and R. M. Sysak, *Statistical diagnostics of electrotechnical equipment*. Kyiv: Institute of electrodynamics of NAS of Ukraine. p. 456, 2015.

[2] S. M. Hercyk, *Forming the teaching complexes for electrotechnical equipment taking into account its operational modes*. Works of Institute of electrodynamics of NAS of Ukraine, 2019. Issue 52, pp. 54–61.

[3] S. M. Hercyk and M. V. Myslovych, “Models of forming the teaching complexes for diagnostics of electrotechnical equipment taking into account its operational modes”, *Metrology and devices*, vol. 67, no. 5-1, pp. 94–97, 2017.

[4] S. M. Hercyk, Yu. I. Hyzhko, M. V. Myslovych, L. B. Ostapchuk, and R. M. Sysak, “Algorithms of functioning and software of multilevel system of monitoring the state and technical diagnostics of electrical power equipment”, *Technical electrodynamics*, no. 4. pp. 86–88, 2016.

[5] V.V. Iljin, “Introduction to Smart Grid”, *Ventilation, Heating, Conditioning, heat supply and building thermal physics (AVHC)*, no. 7. pp. 76–86, 2012.

[6] B. H. Marchenko and M. V. Myslovych, *Vibrodiagnostics of bearing units of electrical machines*. Kyiv: Scientific thought, p. 196, 1992.

[7] M. V.Myslovych and R. M. Sysak, “About some peculiarities of creating the intellectual multilevel systems of technical diagnostics of electrical power object”, *Technical electrodynamics*, no.1, pp. 78–85, 2015.

[8] B. S. Stohniy, O. V. Kyrylenko, and O. F. Butkevych, “Sopel M. F. Informational support for controlling electrical power systems”, *Power industry: economics, technology, ecology*, no. 1. pp. 13–22, 2012.

[9] B. S. Stohniy, O. V. Kyrylenko, and S. P. Denysiuk, “Intelligent electrical networks of electrical power systems and their technological support”, *Technical electrodynamics*, no. 6. pp. 44–50, 2010.

[10] B. S. Stohniy, O. V. Kyrylenko, A. V. Prakhovnyk, and S. P. Denysiuk, “Evolution of intelligent electrical networks and their prospects in Ukraine”, *Technical electrodynamics*, no.5, pp. 52–67, 2012.

[11] V. P. Babak, S. V. Babak, M. V. Myslovych, A. O. Zaporozhets, and V. M. Zvaritch, *Diagnostic Systems For Energy Equipment*. Erfurt: Springer Nature, (Switzerland), p. 133, 2020.

[12] V. P. Babak, S. V. Babak, M. V. Myslovych, A. O. Zaporozhets, and V. M. Zvaritch, *Information Provision of Diagnostic Systems for Energy Facilities*, Entitled by corr. Member of NAS V. P. Babak, Kyiv Academperiodyka, p. 134, 2018.

[13] M. Myslovych, Y. Hyzhko, M. Hutorova, L. Ostapchuk, “On Peculiarities of Development of Information Support for Technical Diagnostics Multilevel Systems of Electrical Equipment”, *Computational Problems of Electrical Engineering*, vol. 9, no. 2, pp. 34–41, 2019.

[14] S. A. Mclnerny and Y. Dai, “Basic Vibration Signal Processing for Bearing Fault Detection”, *IEEE Transactions on Education*, vol. 46, no. 1, pp. 149–156, 2003.

[15] F. Immovilli and M. Cocconcelli, “Experimental Investigation of Shaft Radial Load Effect on Bearing Fault Signatures Detection”, *IEEE Transactions on Industry Applications*, vol. 53, no. 3, pp. 2721–2729, May/June 2017.

ДЕЯКІ ПРАКТИЧНІ ПИТАННЯ ПОБУДОВИ НАВЧАЮЧИХ СУКУПНОСТЕЙ ДЛЯ ІНФОРМАЦІЙНОГО ЗАБЕЗПЕЧЕННЯ БАГАТОРІВНЕВИХ СИСТЕМ ДІАГНОСТУВАННЯ ЕЛЕКТРОТЕХНІЧНОГО ОБЛАДНАННЯ

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На основі алгоритмів функціонування багатовимірної системи діагностики електротехнічного обладнання за технологією Smart Grid, що викладено в першій частині даної статті наведено приклади з формування навчаючих сукупностей, які є інформаційною базою для наступної процедури побудови розв’язуючих правил з діагностування і класифікації можливих дефектів вузлів електротехнічного обладнання.

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