Выполненный в работе анализ показывает, что для обеспечения равномерного нагрева могут быть использованы индукторы как пространственной, так и плоской форм необходимой конфигурации.

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EVALUATION OF GROUND-FAULT PROTECTIONS ALGORITHMS OPERATION BASED ON DIGITAL MODEL IMPLEMENTING ADMITANCE CRITERION

У статті розглянуто цифрову модель та оцінку ефективності роботи захисту електричної мережі за критерієм повної провідності. Модель захисту реалізує дуальний метод розрахунку повної провідності на основі векторів і усереднення вхідних сигналів. Застосований у цифровій моделі алгоритм усереднення повної провідності є оригінальною розробкою, яка пройшла випробовування в Інституті електроенергетики Познанського технічного університету

This paper describes the digital model of the power protection with admittance criterion and evaluation of operating efficiency. The protection model realizes dual admittance calculation method based on phasors and averaging input signals. The admittance averaging algorithm implemented in digital model has been originally developed and tested in Institute of Electric Power Engineering at Poznań University of Technology.

Introduction. Effective protection of the medium voltage network against phase-to-ground faults is a hard assignment. Low level of the measurement signals used by protection device can compared to level of measurement noise cause in protection units design difficulties. Low value of ground-fault currents in MV networks is a result of non direct grounding of neutral point of the network and ground-faults current is extremely low in compensated network. Many protection devices using a different criterion was developed for such type of network. Those criterion can be divided into two groups:

- criterion working with signals measured in steady state of the fault,
- criterion working with signals measured in transient state occurred at beginning of fault.

Methods based on signals taken during a steady state of fault use a criterion such as: zero sequence overcurrent criterion, zero sequence directional criterion and zero sequence admittance criterion. The simple overcurrent criterion is used as line's protection for network with neutral point grounded with resistor. Exploitation experience in domestic MV networks grounded with resistor shows, that this method of ground-fault identification gives unsatisfactory results. Many times the lack of operation of protection in damaged line or unnecessary startup impulse in undamaged line was testified.

Another method using a fault steady state measurement is based on directional criterion, which is commonly used in protection relays in polish distribution network. This type of protection utilizes phase comparators of zero sequence current and voltage and are used in compensated MV network with additional forcing of active current component.

The experience taken from utilization of protection devices described above let start a development of new criterion of protection against ground-fault based on measurement of admittance during a steady state of a fault. Identification of phase-to-ground fault in new developed devices use an analysis of values of the admittance of zero sequence component and it's fundamental parts: conductance and susceptance. The value of admittance is taken from measured zero sequence voltage and current.

Research and development of the protection devices and systems using an admittance criterion is main goal of work realized in Institute of Electric Power Engineering at Poznań University of Technology long time since. Almost twenty thousands of protection devices with admittance criterion (such as: Y_0>, G_0>, G_{0k}>, B_{0k}>) was mounted in polish electric grid thanks realized research work. During a years those devices evolved from analogue to digital technology, but the construction of devices remained simply as possible. The hardest part of a work is development of efficient and reliable algorithms of operation for admittance criterion.

Assessment of operating efficiency of the admittance criterion was a goal of many research work in the past and still stay a main goal for future. Utilization of digital, computer based methods of modeling and simulation make a verification process of the propriety of operation of the criterion and based on them developed algorithms much easier. Utilization of digital model helps in assessment of the criterion results in given condition during a fault and let make an improvements into algorithm. This paper presents digital model of admittance criterion used for test of it's efficiency during a hard identification cases of phase-to-ground-fault [1, 2].

Admittance protection criterions. The power protection units used nova days for fault detection in MV lines and networks are very complicated devices utilizating digital technology. The units are equipped with various protection components against different types of faults. The realized algorithms are also different and depends on manufacturer's policy. The power protection pack against phase-to-ground faults is very similar in each unit and contains overcurrent, directional and admittance component which can be used separately or together. The algorithms used to implement admittance criterion can be realized in two ways:

phasor measuring method (PM) – admittance is based on calculation of magnitude and phase shift of phasors U_0, I_0 ,

averaging window measuring method (AM) – admittance is calculated from averaging values of samples u0(t), i0(t) with changing window.

The zero sequence component of line's current and voltage is base for both methods of admittance calculation. The phasor method use a standard algorithms for determination of RMS value of measured signals. The value of the admittance Y_0 and both subcomponents G_0 and B_0 is calculated follow equations 1–3.

$$Y_0 = \frac{I_0}{U_0} \tag{1}$$

$$G_0 = Y_0 \cdot cos\varphi_{\angle I_0, U_0} \tag{2}$$

$$B_0 = Y_0 \cdot sin\varphi_{\angle I_0, U_0} \tag{3}$$

where I_0 – amplitude value of line's zero sequence current for base cycle; U_0 – amplitude value of network zero sequence voltage for base cycle; $\varphi_{\angle I0,U0}$ – phase shift angle between phasors I_0 and U_0.

Determination of value of admittance subcomponents depends on calculation of phase shift angle between I_0 and U_0 is complicated for implementation in construction of protection device due to calculation ability of device's CPU and can give a significant errors.

In the method based on averaging window developed by Józef Lorenc [3, 4] the digitized samples of input signals are transformed into set of signals $S_1 \div S_5$ which are used to determine value of admittance and it's components. There is no need to calculate phase shift angle, the values of signals Y_0, G_0, G_{0k}, B_0 and B_{0k} are taken directly from input samples.

The values of signals $S_1 \div S_4$ are determined with magnitude comparators, which in dependency of realized criterion use signals given by equations:

$$S_1 = k_u \cdot U_0 \tag{4}$$

$$S_2 = k \cdot I_0 \tag{5}$$

$$S_3 = \left| k_y \cdot \underline{U}_0 + k \cdot \underline{I}_0 \right| \tag{6}$$

$$S_4 = \left| k_y \cdot \underline{U}_0 - k \cdot \underline{I}_0 \right| \tag{7}$$

In addition the signal for voltage startup condition of protection marked as S_5 is calculated from:

$$S_5 = k_n \cdot U_0 \tag{8}$$

The coefficients in equations given above k_0, k, k_y and k_n states way of input signals processing, the coefficients k_u, k and k_n are non-dimensional and states the resultant ratio of current and voltage transformers, however coefficient k_y has a dimension in admittance of additional circuit in the voltage signal route. Using such defined signals the following power protection operating criterion can be realized:

admittance criterion Y_0> – respond on modulus of admittance,

conductance criterion G_0> or G_{0k}> – respond on absolute value of conductance (G_0) or value and sign of the conductance G_{0k},

directional susceptance criterion B_{0k}> – respond on value and sign of the conductance B_{0k}.

The characteristics of common criterion (a, b, c, d) on complex plane are shown in fig. X, the combined criterion characteristics (e,f) are shown also in this figure.

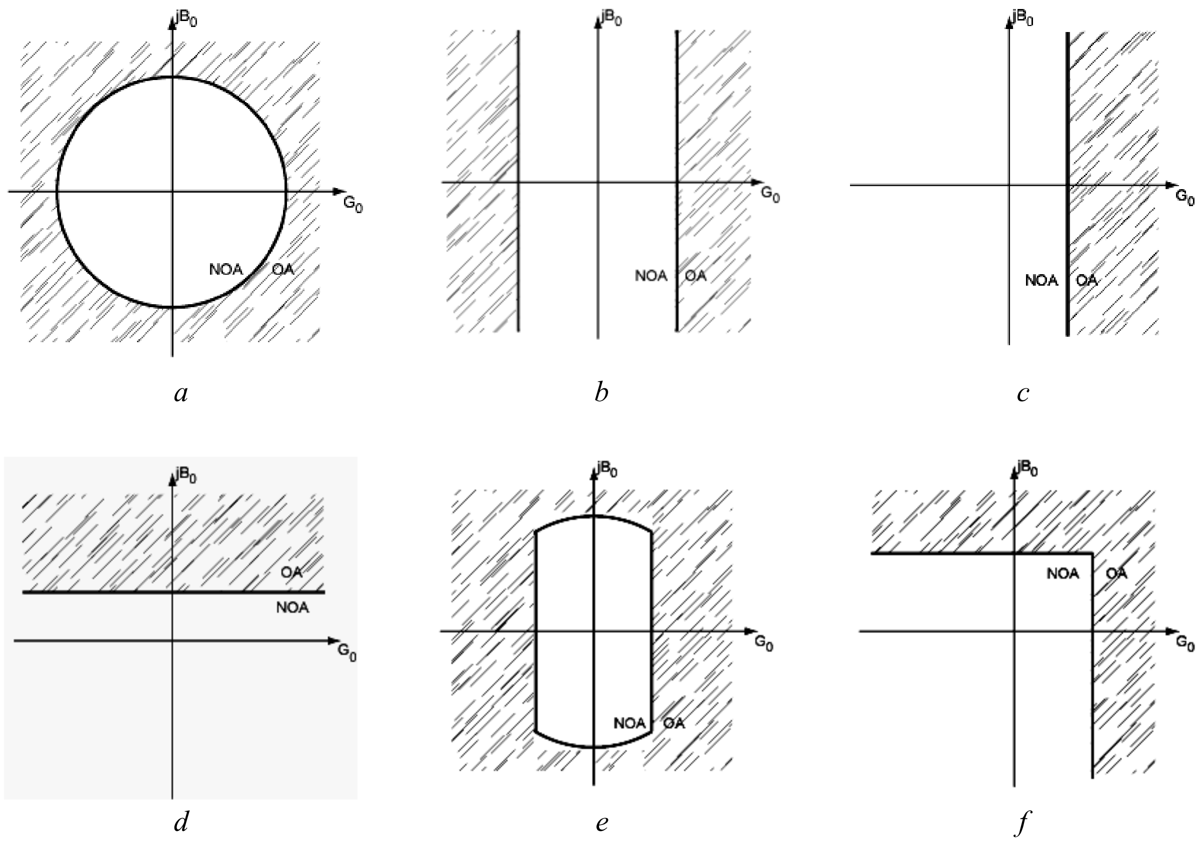

Fig. 1. Start-up curves for common and combined admittance-type ground-fault protections:
a – Y_0> type; b – G_0>type; c – G_{0kj} type; d – B_{0k} type; e – YG_0 type; f – GB_{0k} type

Description of the digital model. Developed digital model of protection device utilizing operational ground-fault algorithms based on admittance criterion is shown in fig. 2. The digital protection model is build with set of common components:

source signals input and selection block,
digital filter block,
admittance calculation algorithm of AM type block,
admittance calculation algorithm of PM type block,
startup criterion with startup value setting block,
result output block.

First block of model manage input signals, which can be taken from recorded fault in text file with time stamps and samples of zero sequence current and voltage or can be generated within the model. The source of input signals can be switched with selector. Build into model signal generation block allow to produce signals of U_0 and I_0 with base frequency equal to 50Hz and given magnitude and phase shift. Additional generators with random function to emulate a noise in measuring circuit.

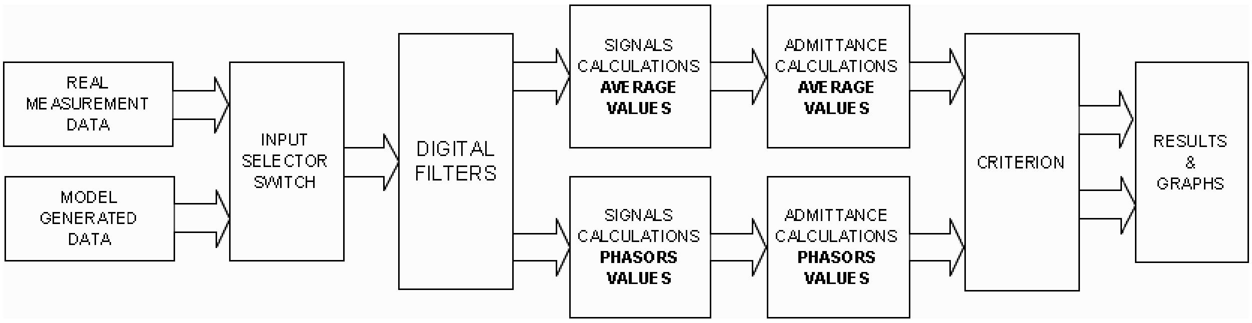

Fig. 2. Block diagram of the admittance protection digital test model

In the measurement route, input signals U_0 and I_0 may be distorted as a result of various phenomena occurring in the power network during the disturbance. Shape of these signals can be affected by e.g. currents occurring during the short-circuit, phenomena associated with electric arc or higher order harmonics occurrence.

Correct determination of the admittance signal value, which guarantees the proper functioning of the ground-faults identification algorithm and criterion require stabilized input signals of zero-sequence current and voltage. Stabilization of the measuring signals may be obtained by various methods utilizing analog or digital technology. In this model the digital filter has been chosen, due to possibility of use an additional tools to simplify the design process. During the implementation of digital signal processing systems, attention should be given to proper adjustment of the digital filters parameters due to discrete measurement signals parameters obtained after the initial in analog to digital converter.

To obtain a high stability of the input signals, a digital filtration with band-pass Butterworth's filter was chosen. To extract the primary signal frequency, the filter parameters are selected to obtain a frequency response in 48–52 Hz limits. The filter parameters can me modified including threshold frequency, filter order. If needed, the filtration block can be omitted by internal by-pass switch.

Calculation of admittance in phasor algorithm block is divided into two subcomponents. First subcomponent determinate phasor's values described as amplitude and phase of fundamental frequency of signal. The second calculate admittance, conductance and susceptance according to equations 1–3.

Calculation of amplitude values of input signals is based on standard algorithm of determination RMS value of signal multiplied by square root of two:

$$A = \sqrt{\frac{2}{T}\int_0^T a^2(t)dt} \qquad (9)$$

The phase shift angle between two signals $i_0(t)$ and $u_0(t)$ can be determined according to algorithm that can be also used for discreet signals. Assuming, that signals are given by Euler's formulas:

$$i_0(t) = A_I \cdot cos(\omega t + \varphi_1) \tag{10}$$

$$u_0(t) = A_U \cdot cos(\omega t + \varphi_2) \tag{11}$$

product of those signals can be written as:

$$i_0(t) \cdot u_0(t) = \frac{A_I \cdot A_U}{2} \cdot (\cos(2\omega t + \varphi_1 + \varphi_2) + \cos(\varphi_1 - \varphi_2)) \tag{12}$$

Averaging results in base cycle lets to write above equation as follows:

$$\frac{A_1 \cdot A_2 \cdot cos(\varphi_1 - \varphi_2)}{2} = SMA(i_0(t) \cdot u_0(t)) \tag{13}$$

And can be transformed to relation of the phase shift angle given by:

$$\varphi_\angle = |\varphi_1 - \varphi_2| = arccos\left(\frac{2 \cdot SMA(i_0(t) \cdot u_0(t))}{A_1 \cdot A_2}\right) \tag{14}$$

In this way the absolute value of phase shift angle is result of calculation algorithm, the sign of phase shift can be determined separately with comparing sign functions of both signals. The algorithm for determination of phase shift angle is very complicated and consumes a lot of power of power protection's CPU unit.

Calculation of admittance using averaging window method is realized in separate path, which is divided into two blocks marked as Average Values. First block is used to calculate values of input signals given in form suitable for admittance calculation what is processed in second block of calculating path of this algorithm.

In the first block the current samples are delayed in relation to voltage samples with quarter of base cycle. The number of delayed samples is defined with fundamental frequency of signal and sampling rate automatically. Source signal sample values are calculated with long term averaging function and signals are conditioned with relations defined by equations 4–8. The signals calculations are processed with absolute value function and then the simple moving average (SMA) function is used. The source signals for calculation comes from Input Block and there is no need to use pre-filtration with Digital Filters Block due to filtration is build in algorithm used for determination of signals $S_1 \div S_5$.

Obtained in the first block signals $S_1 \div S_5$ are used as input values for Admittance Calculation Block. The calculation of admittance and it's components conductance and susceptance are realized with specified function for each component of admittance. This is a key module for admittance calculations, the parameters of each function are selected to optimize result of calculation components of admittance. The detailed method of calculation of the admittance and subcomponents are described in patent PL NR 173980.

The criterion block compares values of admittance and it's subcomponent from AM and PM algorithms blocks with startup values settings for each criterion and realizes triggering signals when relations are accomplished. This block checking startup value of zero sequence voltage as well.

The result output block is set of functions that proceed signals taken from previous blocks of model and put them together into sets of matrices and presents results as graph and allow write it down to a file. Matrices contains analog signals such as: input signals, calculated signals of admittance and admittance subcomponents and binary signals from criterion block output. The output file can be written as ASCII text or COMTRADE standard.

Test results. The evaluation of the efficiency of a different admittance criterion during a phase-to-ground faults were made basing on recorded signals during a fault. In this paper a result of test are shown, during a intermittent phase-to-ground fault. The settings of the startup values for all criterion used in both tests are shown in table 1.

Table 1

Start-up values for admittance criterion test

Start-up value for over-voltage component U_0	10 [V]
Start-up value for admittance criterion Y_0	1.5 [mS]
Start-up value for conductance (directional and unidirectional) criterionG_{0k}, G_0	0.5 [mS]
Start-up value for susceptance criterion B_0	0.5 [mS]

The results of operation of the digital model of the admittance protection is shown in fig. 3. The signals presented from top are: zero sequence current, zero sequence voltage, admittance and subcomponents of averaging method and phasor method. Results of admittance calculations based on averaging method gives more stable results then phasor method. The averaging method results are free from high peaks, also the variation range is much smaller.

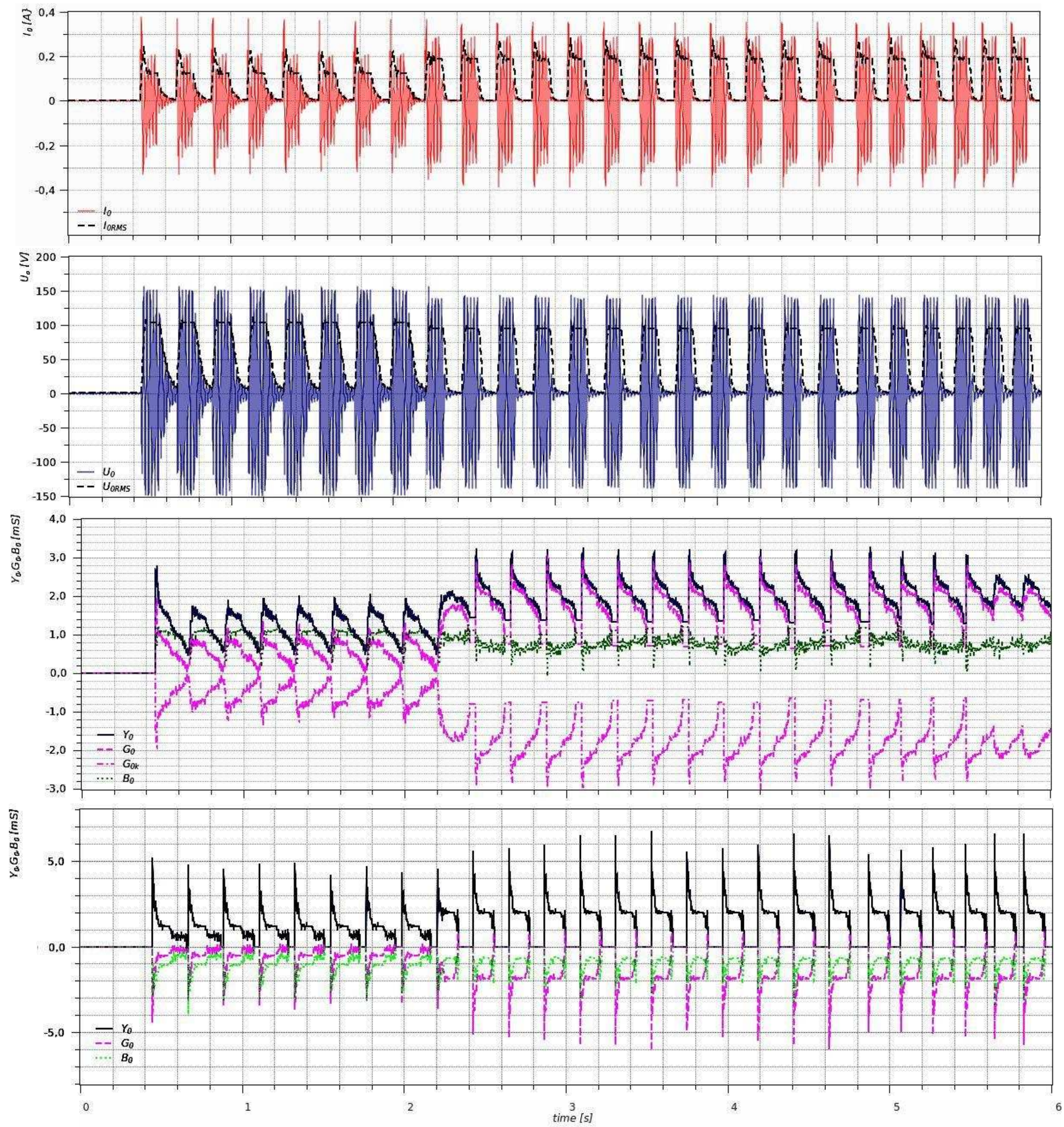

Fig. 3. Measured input signals I_0, U_0 (first and second figure) curves and results of admittance calculations with averaging method (third) and phasor method (fourth) during intermittent ground-fault

Conclusion. The digital model of admittance protection with two different methods of calculation of the value of admittance and it's subcomponents was positively verified. Results shown in graphs illustrates the difference between admittance signals calculated in two ways. The digital model of admittance protection can be used for assessment of operating of existing power protection systems during a various types of faults.

Presented digital model of admittance criterion can be easily adapted to use in any digital modeling environment (Matlab, Octave) or into transient simulation toolkit (EMTP-ATP, PSCAD). Developed model can be helpful for future investigation of ground-fault protection operation failure or lack of operation. This is an excellent tool for improvement and modification of admittance protection algorithm itself.

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ОСОБЛИВОСТІ ФОРМУВАННЯ НАВЧАЮЧИХ СУКУПНОСТЕЙ ПІД ЧАС ВИКОНАННЯ ВІБРОДІАГНОСТИКИ ВУЗЛІВ РУХОМИХ ЧАСТИН ЕНЕРГЕТИЧНИХ МАШИН

Розглянуто питання формування навчаючих сукупностей для інформаційно-вимірювальних систем вібродіагностики окремих вузлів рухомих частин електроенергетичних машин. Для вимірювання і передачі діагностичних вібросигналів з рухомих частин енергетичних машин використано спеціальні сенсорні пристрої, що будуються на застосуванні стандарту Bluetooth.

Questions of formation of training sets for information-measuring systems of vibration diagnostics of some units of mobile parts of power electrical machines are considered. For measuring and transmission of diagnostic vibration signals from mobile parts of power machines, special sensors are used which are based on use of Bluetooth standard.

Вступ. Важливими елементами в розв'язанні задач діагностики рухомих вузлів енергетичного обладнання виступають питання організації каналу передачі інформації, отриманої з сенсорів, розташованих на рухомих вузлах цього обладнання. Ісутотним моментом при створенні такого каналу є забезпечення достатньо високої точності і вірогідності отриманих результатів діагностики. Своєю чергою бажану точність і вірогідність можна отримати шляхом застосування відповідних статистичних методів оброблення виміряних вібросигналів, а також завдяки попередньо