Algorithm for Diagnostics of High-Voltage Equipment Based on Artificial Itelligence Technologies

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Abstract: This paper describes the diagnostics algorithms of one of the most important elements of the electric mains - the circuit breaker. There are the descriptions of two versions of the intelligent diagnostic algorithm of high-voltage circuit breakers based on neural networks. The main attention is paid to the comparison of the described algorithms on the spent resources, both in time and in computation. The article also describes the final stage of development of the diagnostic algorithm which is to optimize such parameters of the neural network as the number of neurons in a layer, the number of hidden layers in the neural network, the parameter of the network learning rate, the number of epochs (iterations) for training in the network. To test the adequacy of the neural network with optimized parameters we used the method of cross-validation. The algorithms are simulated in the Matlab environment, and the researchers have chosen high-voltage switch of MKP 110M type as the diagnostics object.

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1. Introduction

One of the major challenges of modern power systems is the problem of diagnostics of switching equipment, especially high voltage switches (HVS) [1].

Development of the systems of technical diagnostics as a kind of measuring information system requires the use of modern methods of measurement and control of parameters characterizing the state of the diagnosed objects, as well as the methods for measurement information processing.

In particular, currently there is a need for special methods for control of parameters and diagnostics of the technical state of switches based on artificial intelligence (AI). It should be noted that the AI unit in recent years, is being actively promoted in various fields of science and technology, so the study of the possibility of its use in diagnostic systems is very important.

The main advantage of the algorithms of control, based on the AI is the ability to automatically improve in real-time (self-learning), in this case it is self-education with improvement of the quality of diagnostics and as a consequence the reduction in the percentage of errors of diagnostics and identification of new types of HVS faults.

In [2-4], which describe the principle of the algorithm of intelligent diagnostics of high-voltage switching equipment of electrical substations using AI components such as wavelet analysis and neural networks (NN), the authors solved the problem of redundancy of input data using an algorithm to select the most informative range of wavelet spectrum of speed characteristic of HVS, as well as the optimal parameters of the used NN to improve the accuracy of diagnostics.

However, until now, an important problem of a synthetic NN testing has not been solved with the optimal parameters in the library of functions of speed characteristics of HVS (a function of speed performance is understood as a function of dependence of the contact travel speed of the circuit breaker on time).

This article is devoted to the study of the stability of the method of computer simulation of NN, which is part of the intellectual system of HVS diagnostics and its resistance to the change in the training set. NN was subjected to a special procedure for the empirical estimation of the generalization capability of intelligent algorithms - cross-validation [5].

The paper presents the results of the development of a new two-step algorithm for intelligent diagnostics of technical condition and NN algorithm of preset diagnostic system.

2. Algorithm to diagnose the technical condition of high voltage circuit breakers based on the wavelet analysis and neural networks

The technologies used for "machine learning" require initial information signs to identify the faulty device. The initial data for the diagnostics of the malfunctioning devices are the most informative parameters of contact motion (speed and timing of their switching) [6]. However, the timing can not localize the fault, because it does not carry any information about the state of NN during operation. All the information that can be obtained from the time parameters, describes the process of NN in general: start time, turnoff time, difference in time of phases start and turnoff.

Speed characteristics are more informative, as they allow tracking the value of speed (or acceleration) at any time moment of NVS operation. For this reason, the basis for the developed algorithm of intelligent diagnostics of HVS was the performance characteristics. In [2, 3], the advantage of using the function of acceleration on time in the problem of HVS diagnostics was experimentally proved so a high-speed response will be understood as a function *a(t)*.

Fig. 1 presents a block-scheme of the developed algorithm of intelligent diagnostics of NN. After entering the acceleration function of HVS motion its high frequency component is distinguished and wavelet spectrum is calculated [7]. From the resulting wavelet spectrum the most informative frequency ranges are selected using a special algorithm [4]. The research has shown that by using this algorithm for the selection of informative range of the wavelet spectrum the amount of data significantly reduces (up to 4 times) without significant loss of information parameters and the problem of NN retraining is eliminated, consequently the accuracy in NN testing coincides with the accuracy of NN at training.

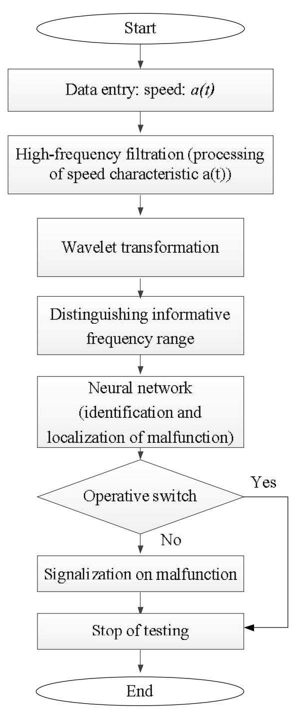

Fig. 1 – Algorithm of NN diagnostics using wavelet analysis and neural network.

Having selected the informative range the NN produces the diagnostic stage on the received frequency ranges and specifies the nature (place) of NN failure.

To implement this algorithm, you need to perform a preliminary preparation (setting) of the diagnostic system which algorithm is given in Fig. 2.

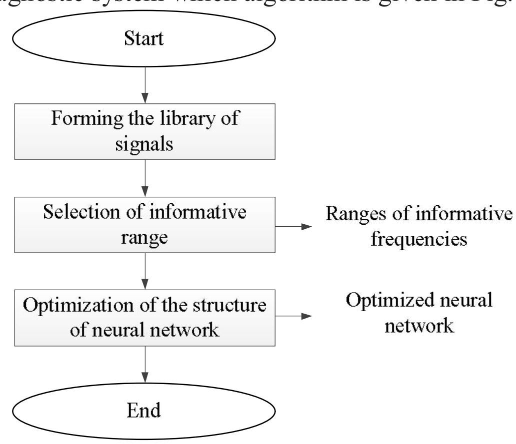

Fig. 2 – The algorithm for preparing the diagnostic system.

The algorithm for preparing the diagnostic system involves several steps. You must first create the library of the operative / faulty signals of the function of acceleration and time parameters of this type of HVS. At the next stage using the algorithm for selection of informative range the volume of the wavelet spectrum of acceleration functions of this NN is reduced.

At the last stage for NN, used in the diagnostics system, the optimal parameters for its maximum accuracy are determined [4]. The most effective device to optimize such parameters of NN as the speed of its training, the number of NN training epochs, the number of neurons in the hidden layer of NN and the number of hidden layers are genetic algorithms (GAs) as a component of the device of AI [8]. Using the GA the NN was built, but with such values of synaptic weights at which the fault of high-voltage switches diagnostics decreased from 10% to 0.4%, which is an excellent indicator for the diagnostics system based on NN.

3. A two-step algorithm for diagnosing the technical condition of high voltage circuit breakers.

The algorithm described above has a major drawback; it requires a significant amount of computing and accordingly, time resources. The problem of reducing the computational costs at NN diagnostics is solved by the improved algorithm of intelligent diagnostics of NN depicted in Fig. 3, which is a development of the algorithms proposed in [3].

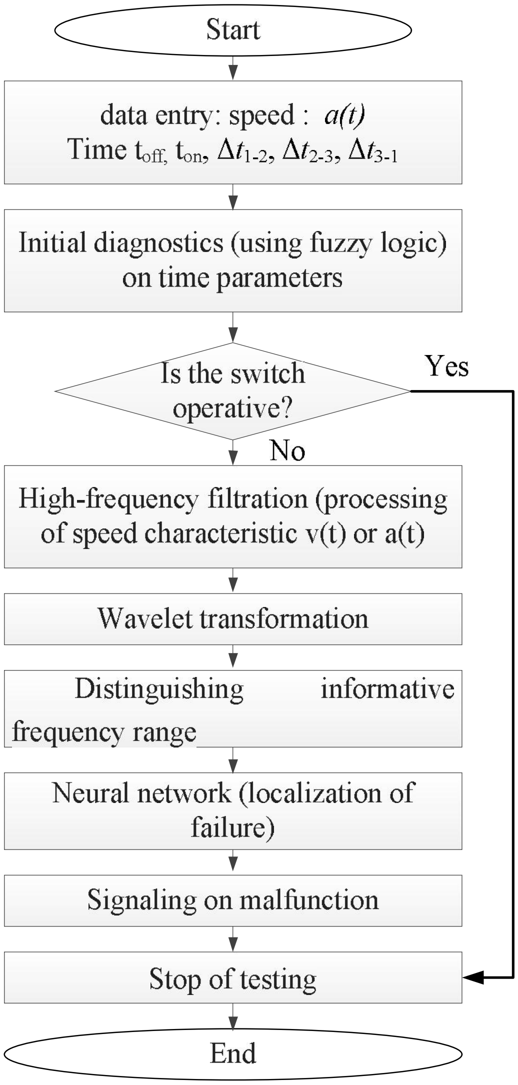

Fig. 3 A two-step algorithm of NN diagnostics using fuzzy model and neural network.

The essence of the proposed improved algorithm is to break the process of diagnostics into two stages. First stage: the initial diagnostics using fuzzy models [9] on time parameters. Second stage: the neural network diagnostics to determine certain frequency ranges in the wavelet spectrum of function of acceleration of NN contact shift.

The proposed division of the diagnostics process into two phases is due to the fact that although it is impossible to determine the location of NN fault on time parameters, it requires significantly lesser computational resources than the algorithm described above [3]. The more detailed two-stage algorithm is described below.

At the first stage of diagnostics to build a fuzzy model we chose such normalized NN parameters as the proper time of switching of switching off, full time off, proper time of switching on, different times of the phases of switching on and off. Study of a fuzzy model of the high-voltage switchgear showed that the use of such simple functions of membership as triangular functions and operators for crossing the MIN and MAX are sufficient for its correct functioning [10].

The transition to the second stage of diagnostics is carried out only after the fuzzy model decides on the object intactness. After the transition to the second stage the described algorithm based on the wavelet analysis and neural networks is performed.

The algorithm of preliminary setting up of the diagnostic system using a two-step algorithm also changes, albeit slightly (Fig. 4). At the stage of preparation it is necessary not only to select the information range of the wavelet spectrum and to optimize the structure of the neural network, but also to construct the fuzzy model of NN on time parameters on the basis of empirical data.

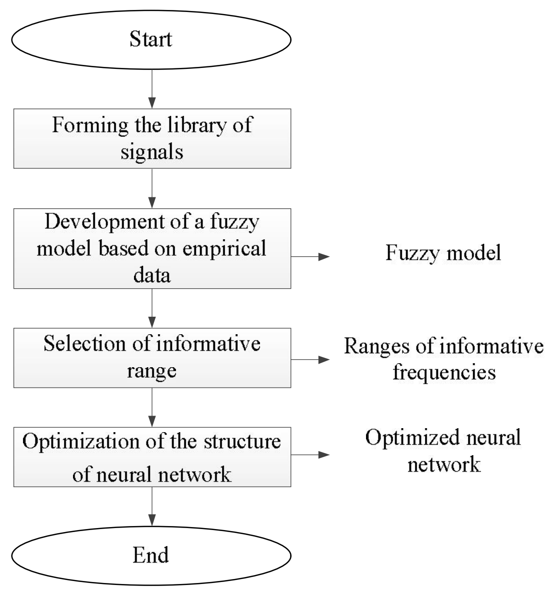

Fig. 4 The algorithm for preparing the ddiagnostic system on a two-step algorithm.

Confirmation of the advantage of the obtained two-step algorithm over the one-stage can be a measurement time of their performance. The estimated time of the one-stage algorithm on the platform of Microchip PIC24F is 22 minutes, and the first phase of a two-step algorithm - 0.2 seconds. As it is seen from the above results of diagnostic algorithm runtime, the two-step algorithm is more preferable because it reduces the amount of resource-intensive algorithm for localization of defects based on neural networks.

Training of NN to diagnose the high-voltage circuit breakers

The method of structural optimization of neural network described in [4] using genetic algorithms has shown a NN error value in the point of extreme while diagnosing VHS as 0.4 %. Such a small value of the error of diagnostics not only provides the optimum ratio of the neural network parameters (speed of NN training, the number of NN training periods, the number of neurons in the hidden layer of NN, the number of hidden layers), but the calculated ones using genetic algorithms of synaptic weights of NN.

To confirm the validity of the results it is necessary to test NN with the calculated optimal parameters for stability. For this purpose the method of cross-validation was used [5]. We fixed a set of partitions of the source library of high-speed characteristics, divided into two samples: training and control. For each partition the algorithm was adjusted on the training set, and then the estimated average accuracy of NN in the objects of the control sample was estimated. Fig. 5 presents the graph of NN accuracy for ten repeated divisions of the library of signals. The ratio of the training and test samples is selected as 2-1. This testing process was repeated several times, and every time with a new partition of the source library of characteristics.

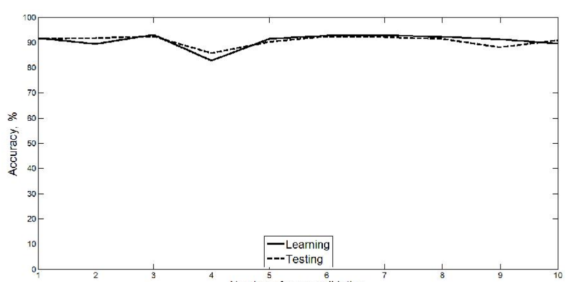

Fig. 5. The dependence of NN accuracy on the number of sliding control operation.

As an evaluation of cross-validation results we have calculated the average value on all partitions of NN accuracy value [11] in the control samples. Based on the graphs, it equals 90.7%, which is significantly lower than the value 99.6 % calculated using genetic algorithms [4]. This significant decrease in NN accuracy (the error of about 10%) with cross-validation operations may be due to the reduction of training sample. The most informative result is the fact that the values of the accuracy of NN at ten transactions of sliding control differ from each other by not more than 7%, and a good repeatability of the results is observed during training in various samples.

Given that after optimization the NN structure with optimal values of the weights of synapses remains, and if the slide control demonstrates the repeatability of the results in NN with this structure, the operator includes the remaining neural network in the diagnostic algorithm.

Conclusion

The developed two-step algorithm saves computing resources of the diagnostic system of NN and reduces the total computation time. Preparation of the developed system of technical diagnostics of NN requires its preset to a specified type of switch according to a predetermined algorithm that improves and optimizes the basic diagnostic algorithm. Based on the results of computational experiments, we can conclude that the use of cross-validation has shown high repeatability of NN accuracy at training and recurring testing with the method of cross-validation.

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