Available online at 2019.creative-construction-conference.com/proceedings/
CCC 2019
Proceedings of the Creative Construction Conference (2019) 009
Edited by: Miroslaw J. Skibniewski & Miklos Hajdu
https://doi.org/10.3311/CCC2019-009

Creative Construction Conference 2019, CCC 2019, 29June -2 July 2019, Budapest, Hungary

Fuzzy Logic and Neural Networks for Insulation Fault Diagnosis in Construction Robots Drives

Alexey Bulgakov[a]*, Tatiana Kruglova[b], Thomas Bock[c]

[a]Southwest State University,st. 50 let October 94, Kursk, 305049, Russia
[b]South-Russian State Polytechnic University,st.Prosvestchenia 132, Novocherkassk, 346428, Russia
[c]Technical University of Munich, Arcisstr. 21,Munic, 8033,Germany

Abstract

In building industry reliable uninterrupted power supply of construction robots drives is of particular importance, which is largely determined by reliable trouble-free operation of generating equipment. According to statistics, the majority of electricity in the world is produced by hydro and turbine generators, which are low-speed or high-speed synchronous machines. The urgent problem is the development of methods for non-destructive testing and insulation monitoring of synchronous machines. The main method of assessing the real technical condition is insulation control through the analysis of electrical discharge activity (EDA). This method allows detecting defects at an early stage of their development.

The actual problem is the development of automatic technical state diagnosis methods for insulation by the EDA parameter. The main parameters that are evaluated in the analysis of EDA is the shape and amplitude of the discharge phenomena.

The article proposes a method for determining the discharge phenomena form, based on a neural network classification model. It used two-layer network of direct signal transmission trained by Levenberg-Marquardt algorithm.

A method for determining the degree of defect development based on a neuro-fuzzy diagnostic model, differing by a joint analysis of the shape, amplitude and repetition rate of the pulses of a discharge phenomenon, which allow to determine the degree of defect development by relating it to one of the classes of diagnoses is proposed.

© 2019 The Authors. Published by Budapest University of Technology and Economics & Diamond Congress Ltd.
Peer-review under responsibility of the scientific committee of the Creative Construction Conference 2019.

Keywords: construction robots; electrical drives; diagnostics of isolation of a synchronous machines; electric discharge activity; fuzzy logic; neural networks

1. Introduction

At the present time, the age of most electric power converters in the world exceeds 30 years, so the actual question is how to optimize the costs of maintaining these devices in operation. The most vulnerable part of the generator is winding insulation. Earlier, diagnostics of winding isolation of generators were carried out according to [1-3], based on the results of "classical" tests by the increased voltage at idle. The given tests give the answer only to a question: "has sustained - has not sustained" and do not allow to find a residual resource of the equipment, therefore an actual problem is development of methods of not destroying control and insulation monitoring. For rotating machines, to which the generator belongs, the main method of assessing the actual technical condition is the insulation control. This method allows not only to detect defects, but also to classify them according to the degree of danger of the detected defects. The method is based on multiple control and recording at the operating voltage of the main characteristic parameters of insulation. By the obtained results judges as the degree of aging of the winding insulation,

*Corresponding author: Author email: a.bulgakow@gmx.dex

the degree of wedging and the state of the housing insulation, and the state of the magneto-drive [4]. The analysis [1-4] of methods of nondestructive insulation control showed that the method of electric discharge activity (EDA) allows the most complete identification of the main insulation defects of the generator. Measurement of EDA is carried out with the help of specialized equipment [3], and the analysis is performed manually by an expert.

In the process of analyzing EDAs, significant importance is given to the form of discharge phenomena [3]. Three main forms of discharge phenomena are known: partial discharges; spark discharges; arc phenomena. It is also possible and their combinations for slot discharge phenomena, breakdowns between the plates of the active steel package, discharges during the motion of mobile ferromagnetic particles. Examples of typical oscillograms of partial discharges are given in Table. 1.

In addition to the form of discharging phenomena that allow to detect insulation faults, an important characteristic in evaluating the EDA is the fixation of the distributions *n(Q)*, (*Q* is the amplitude of the pulse, and *n* is the number of pulses from the discharges during the time of the industrial frequency period) [3]. In addition to the number of pulses, the mean and maximum pulse amplitudes are estimated.

Discharging phenomena are quantitatively characterized by the apparent charges *Q* of single discharges and the frequency of their following *n*. For diagnostic troubleshooting, the pulse following frequency *n* is measured - with the voltage amplitudes *U*. As a result of measurements, the distribution of the number of pulses from partial discharges (PD) is formed per unit of time from the amplitude value, i.e. *n(Q)*. Measurement and analysis of the mean (Q_{av}) and maximum ($Q_{\max}$) values of the pulse amplitude, as well as the average number of pulses from the discharges (n_{av}) during the period of the industrial frequency let to reveal the main faults in the insulation of the generator and assess the current state of the object.

Based on the results of the EDA analysis, generators are divided into two groups:

- the first group - serviceable with a satisfactory condition of isolation;
- the second group - with unsatisfactory condition of isolation, which requires an extraordinary, i.e. more frequent periodic monitoring.

The first group corresponds to two types of diagnoses: "Norm", "Norm with deviation (ND)", to the second "Norm with significant deviations (NSD)" and "Worsened".

Thus, to determine the current state of the generator, it is necessary to establish the form of discharge affects, referring it to one of the classes (Table 1), and to determine the amplitude and frequency of the pulses and, according to Table 2, to establish the technical state of the generator, referring it to one of four classes: "Norm", "NWD", "NSD" or "Impaired". To automate the analysis of the EDA of a generator, it is advisable to use methods of artificial intelligence, namely a combination of apparatus of non-clear logic and neural networks.

2. Neural network model for determining the shape of phenomena discharges

In the process of diagnosing a generator in terms of EDA parameters, an important indicator is the form of discharge phenomena. According to [4], each characteristic failure detected by dint of EDA corresponds to a certain form of discharge phenomena [5], which allows unequivocally to determine the malfunction. The accumulated long-term experience has made it possible to compile a list of typical characteristic types of the signal of electric discharge activity [6].

At present, the task of recognizing the shape of discharge phenomena is done manually, which is very laborious and requires a lot of experience from an expert who performs diagnostics. For the automation of this process, a neural network for classification of a technical condition is proposed, having the structure shown in Fig. 1.

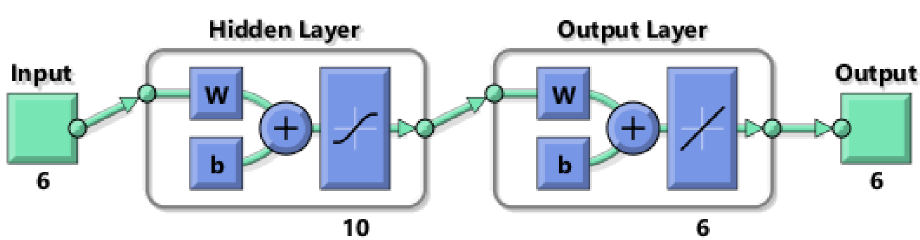

Fig.1. Neural network of the classification of the form of discharge phenomena

As the initial data, discharge phenomena typical for all known faults are used, as well as for serviceable objects whose oscillograms are currently estimated by the expert visually. The network egress is the conditionally given fault number: "0" a fault-free generator, "1" sparkage on the crowns of the teeth, "2" is discharges between the active steel plates, "3"

- slot discharge, "4" is partial discharges in the case insulation on the surface of the rod, "5" - the presence of mobile ferromagnetic particles.
To teach the neural network, the Levenberg-Marquardt algorithm [7] is used, which is designed to optimize the parameters of nonlinear regression models. The algorithm consists in successively approximating the given initial values of the parameters to the desired local optimum. The results of teaching the neural network are shown in Fig. 2.

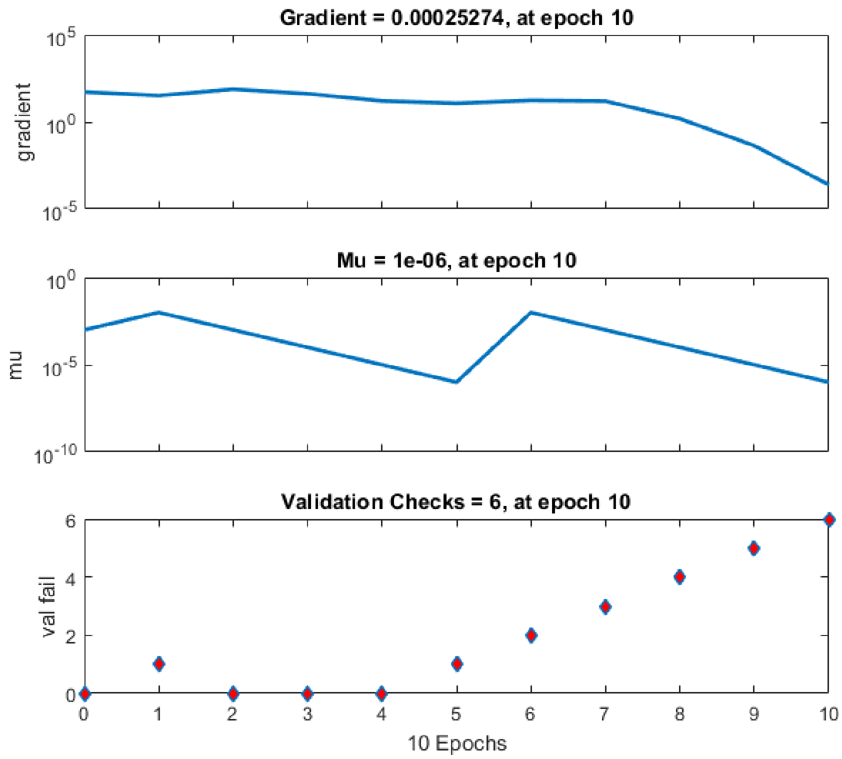

Fig.2.The result of teaching the neural network of classification of the form of discharge phenomena

As a result of the operation of the network, from each output will be obtained a vector-string of the length equal to the input vector containing the class number. For the convenience of analysis, it is necessary to find the mean value and round it according to the rules of mathematics. To test the teached network, samples of the teaching choice were alternately submitted to the input, and the network unmistakably assigned them to a given class. Next, a vector-string of discharge phenomena received from several different turbo-generators was fed to the input of the neural network, and the network accurately determined the type of signal.
After detecting the shape of the discharge phenomenon, it is necessary to determine the degree of development of the malfunction by analyzing the amplitude and frequency of the signal. EDA. From Table 1 is to see that to determine the degree of development of the five faults of the turbogenerator, it is necessary to evaluate $Q_{max,}Q_{\text{av}}$ and n_{av}. The set of values and the range of their change is different; hence, the use of the fuzzy logic apparatus will allow to separate the data of the fault and of the extent of their development with a sufficiently high accuracy.
To identify the stage of defect development, a neural-fuzzy model has been created whose inputs are: the number of the signal waveform obtained as a result of the classification by means of the neural network described in section 3.2 (Fig. 3a), the current values of the measured parameters $Q_{max,}Q_{cp}$ and n_{cp} Fig. 3 b, d), the outputs - the degree of defect development (Fig. 3, e).
For the entered fuzzy sets is formed the knowledge base according to Table 1 and 2. If, as a result of the analysis of the form of discharge phenomena, the value is set to "0", which corresponds to the absence of a defect, then the technical condition is "Normal". With an output value of "5" - the presence of mobile ferromagnetic particles is a "Weakened" state. For other faults, the rules are set according to Table 1.
To convert the well-defined values of input to well-defined values of output is used the n – input algorithm of fuzzy logical inference Mamdani [8]

Table 1 - Classification of the technical state of the generator as a function of the amplitude and number of pulses

Fault	Generator condition	Q_{av}, мВ	n_{av}, имп/пер	Q_{max}мВ
Sparks on crowns of teeth	NSD	more 100	more 15	
	Worsened	more 1000	more 30	
Discharges between of plates	NSD			more 5000
	Worsened			more 15000
Slot discharge	NSD			more 3000
	Worsened			more 8000
Partial discharges in the case insulation	ND	more 1500	more 2	
	NSD	more 3000	more 3	
	Worsened	more 5000	more 4	
Partial discharges on the surface of the rods	ND	more 2000	more 1,5	more 4000
	NSD	more 4000	more 4	more 8000
	Worsened	more 6000	more 4	more 10000

The graphical interpretation of the knowledge base is the response surface, an example of which is shown on Fig. 4.

The resulting fuzzy model allows us to divide the existing faults into a model of four classes of diagnoses: "1" - "Norm", "2" - " ND", "3" - " NSD", "4" - "Worsened". In the case of the appearance of a fractional number, it must be rounded according to the rules of mathematics.

a) b)

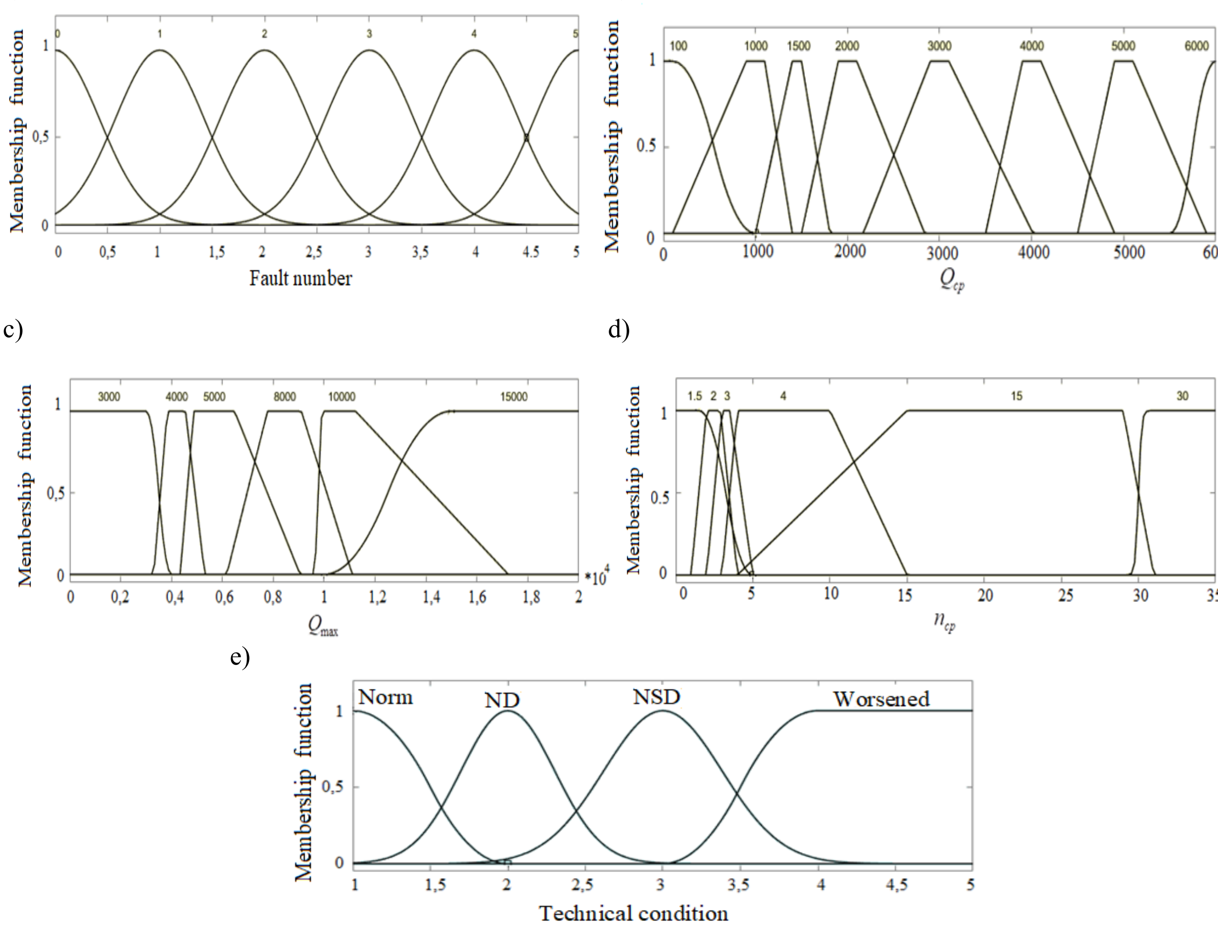

Fig.3. Inputs (a-d) and output (e) of a fuzzy model for estimating the degree of development of insulation defects by the parameter EDA (electric discharge activity)

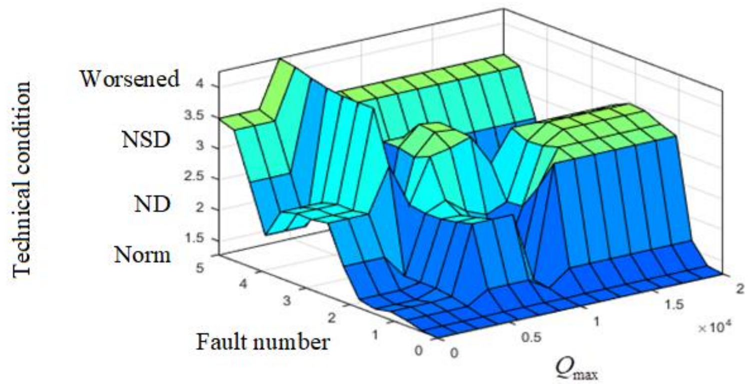

Fig.4. The response surface of the fuzzy model for determining the degree of defect development (the maximum pulse amplitude for various faults)

This fuzzy model allows to determine the amplitude and intensity of discharge phenomena at one control point, while the generator has impressive dimensions and a lot of control points located at different locations of the object and requiring measurement at different points. Therefore, in order to obtain a complete turbogenerator diagnosis model, it is necessary to unify the submodel data, according to the design of the object.

To determine the current technical state of the whole generator, it is necessary to use this model. If as a result of measuring the EDA at the control point several faults can be detected, then to determine the current technical state it is necessary, using the proposed model, to find the current state of the generator at each point, and then approximate the results of the models. Since the development of any failure leads to the failure of the whole object and the overall technical state of the turbogenerator is estimated at the worst of their states, then as the approximating function is chosen the function of maximum.

To solve the approximation problem, a radial basis network is modeled, the input layer of which implements the distribution of image data for a hidden layer of weights consisting of radial basic neurons using the Gaussian activation function whose mappings are fed to the output layer of linear neurons [8]. Sending the vector-column of the coefficients of the current development trend of the faults to the input of the radial basis network, and setting the target vector as the maximum function of input, the value of the diagnostic function will be obtained at the output of the radial basic network, which enables us to estimate the current state of the object, according to one of the known classes of diagnoses. The structure of this submodel is shown in Fig. 5.

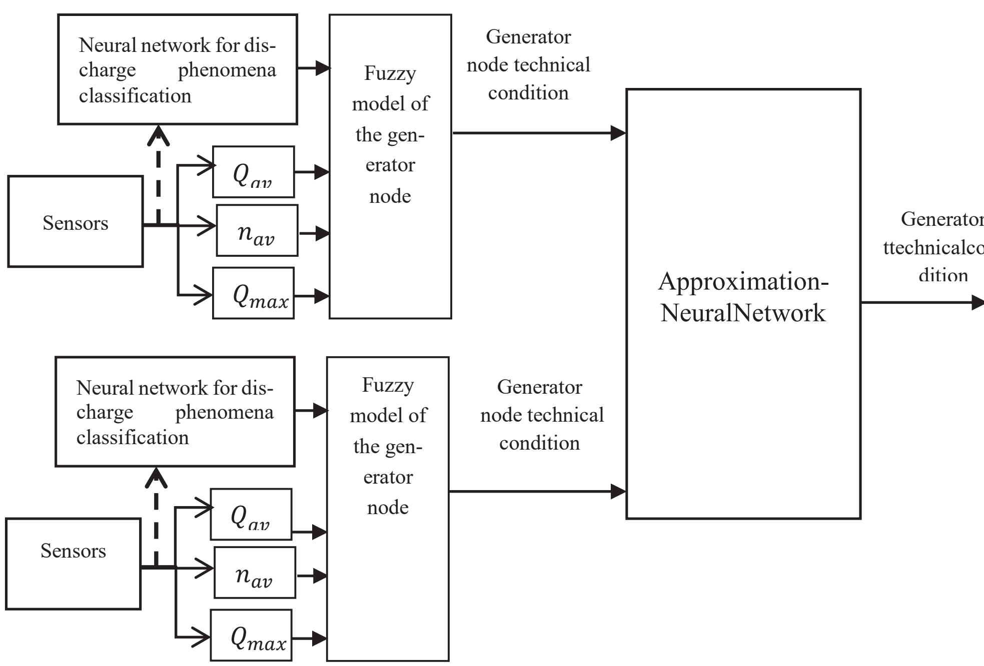

Fig. 5. Model of diagnosing insulation of a generator according to EDA parameters

The given model allows to determine the current technical state of the generator based on the shape, amplitude and frequency of the pulse of the ERA and to determine the degree of development of the fault by according it to one of the four classes: "Norm", "ND", "NSD", "Worsened".

Conclusions

It is established that the main reason for the failure of generators is the violation of insulation. One of the most accurate and accessible methods of monitoring the state of isolation is the analysis of EDAs, allowing by the form of the discharge phenomenon, the average and maximum value of the pulse amplitude and the number of pulses, to determine the current state of the object, referring it to one of the classes of diagnoses: "Norma", " Norm with deviation"," Norm with significant deviation", "Worsened" and find the reason for the refusal. Application of this model will significantly simplify the process of analyzing parameters, significantly reducing the time of diagnosis.

References

[1] Aksenov, Y.P., et al. In service turbine generators stator windings failure risks minimization on the base of discharge events on-line monitoring. EIC/ EMCW'99 Expo, Cincinnati Convention Center Cincinnati, Ohio USA, 1999, pp. 26-28

[2] IEEE Std. P1434-2000 Guide to Measurement of Partial Discharges in Rotating Machinery.

[3] Aksenov, Y.P., et al. On-Line Technology of Diagnostic Method Synergy for Power Transformers. 2nd I.C.D.I., High Tatras – Slovakia, 2000, pp. 13-15

[4] H.Zhu and V.Green, D.Huynh Application of On-line Versus Off-line PD Testing for Stator Insulation Monitoring. EIC/EMCW'99 Expo, Cincinnati Convention Center Cincinnati, Ohio USA, 1999, pp. 26-28 https://doi.org/10.1109/EEIC.1999.826202

[5] Aksenov, Y.P., et al. Advance on-line predictive maintenance technology for medium voltage motor. 2nd I.C.D.I., High Tatras – Slovakia, 2000, pp. 13-15

[6] Ward B.E., Stone G.C., Kurtz M.A. Quality Control Test for High Voltage Stator Insulation. IEEE Electrical Insulation Magazine, Sept., 1987, h.12-17 https://doi.org/10.1109/MEI.1987.290695

[7] T.J. Andersen and B.M. Wilamowski. A modified regression algorithm for fast one layer neural network training // World Congress of Neural Networks, vol. 1, pp. 687–690, Washington, DC, July 17–21, 1995.

[8] T.N. Kruglova. Intelligent Diagnosis of the Electrical Equipment Technical Condition // Procedia Engineering, 2015, Vol 129, pp. 219–224. https://doi.org/10.1016/j.proeng.2015.12.036