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Nodes Variation in Hidden Layer of Partial Discharge Classification

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Abstract: This study presents the classification of Partial Discharge (PD) signal using Artificial Neural Network (ANN). This study used the straight forward procedure in PD classification. PD activity is a common element of degradation of the insulation system. The ability of ANN to learn from the example and recognize the pattern between the input data and target output make it interesting tools. Aim of this study discriminates between PD signal and noise signal. The database resulted from laboratory measurement which contains of 3999 data; 2000 data of PD signal and 1999 data of noise signal. Multilayer perceptron with back propagation algorithm is used to develop the network. The nodes of hidden layer is varied from 5-100 with the increment of 5. The result shows that the number of nodes in hidden layer will affect the accuracy of classification. The result of this paper is the average of the 10 combinations produced by the ANN.The classification accuracy of this research is 96.22% for training, 96.10% during testing and mean square error of 0.03039 with the nodes in the hidden layer is 55.

Key words: Partial discharge, artificial neural network, classification, multilayer perceptron, layer

INTRODUCTION

The PD is a small arc that occurs in the insulation system that partly bridge between the insulation part and conductor in a cable. PD is a short electrical pulse resulting from the electromagnetic emission with the sharp rise time <1 μs and the width of its pulse of several ns. (Kuffel and Kuffeld, 2000; Ayub *et al*., 2008; Denissov *et al*., 2008; Karthikeyan *et al*., 2006). Even though, PD has a small magnitude, it can attenuate the dielectric strength and finally lead to complete malfunction of the high voltage system. The insulation system weakens as some void or bubbles might occur in the impure insulation system.

Electromagnetic wave produced travel in all directions from its source along the cable, PD then being detected using an appropriate sensor (Denissov *et al*., 2008). PD can be described both as the cause and an indicator of the condition of the insulation system. Early detection of PD is important as the insulation failure is unexpected, thus proper action can be done. Insulation failures may interrupt the whole system and required costly maintenance. Researchers agreed that PD analysis is important to evaluate the condition of the insulation system. Detection of PD at primary stage can prevent supply interference and have a great economic impact to the company.

PD can occur at the surface and within the insulation system. There are three types of PD phenomena; corona discharge, surface discharge and internal discharge. Cavity discharge and treeing channel is a branch of the internal discharge. Internal discharge is indicated by the PD measurement.

Technically PD classification can be carried out by fuzzy classification and ANN. Fuzzy classification fail in detecting PD as PD may occur more than one signal at a time in quite similar shapes. Besides that, fuzzy classification unsuccessfully discriminates between PD signal and electrical noise (Contin *et al*., 2002).

Recently, Rogowski coil is the most favorable sensor used by the researchers to measure the magnetic field. The working principle of Rogowski coil runs based on the Faraday’s law as stated in Eq. 1. The coil detects the magnetic field produced by the PD pulse. The characteristic such as wide frequency response and high sensitivity is important during PD detection. Besides that low installation cost and its light weight give more advantage to the sensor. The construction of air-cored coil leads to no saturation and does not affected by over current (Metwally, 2013):

$$v_{rc}(t) = -M\frac{di(t)}{dt} \quad (1)$$

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An ANN is a computer programming that imitated the working principle of the human brain. The greatest feature of ANN is its learning ability (Khataee *et al*., 2011; Suzuki and Endoh, 1991; Karthikeyan *et al*., 2006). The ANN learns from example and then come out with its own output prediction of the output based on randomize independent input data data (Suzuki and Endoh, 1991). ANN architecture consists of three layers; input layer, hidden layer and output layer. A feed forward networks with multi-layer perception and back propagation algorithm is chosen to run this system shown in Fig. 1.

The application of ANN in the detection of PD is increasing. The algorithm is used to classify between PD signal and noise produced during the laboratory measurement. This research had a great impact in detecting PD as the time required by ANN to learn the input patterns must be short enough and the processor must possess a high level of ability to correctly discriminate input patterns of PD signals or not PD signals.

The statistical result of the neural network system is arranged in the Table 1 which is also known as the confusion matrix. True Positive (TP) stands for correctly identify the positive output, the presence of the PD. True Negative (TN) means that the network has correctly classified to the class example and incorrectly classified to the not class example, respectively. identified the negative output, the absence of PD. False Positive (FP) and False Negative (FN) are incorrectly classified to the class example and incorrectly classified to the not class example, respectively.

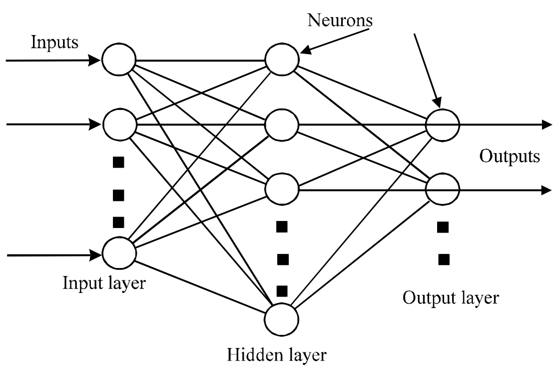

Fig. 1: Multilayer neural network

Table 1 : Confusion matrix

Data class	Classified as negative	Classified as positive
Negative (not PD)	Correct decision (0) TN	FP
Positive (PD)	FN	Correct decision (1) TP

Table 2: Target output from the system

Input	Output
Not PD signal	0
PD signal	1

Confusion is used to indicate the performance of the ANN classification which are based on the value of accuracy and sensitivity. The formula of each parameter is specified in Eq. 2 and 3, correspondingly:

$$\text{Accuracy (\%)} = \frac{tp + tn}{tp + tn + fp + fn} \times 100 \quad (2)$$

$$\text{Sensitivity (\%)} = \frac{tp}{tp + tn} \times 100 \quad (3)$$

The desired output from this classification is not a PD signal (0) and PD signal (1) as presented in Table 2.

MATERIALS AND METHODS

PD data measurement: The experimental results indicate the performance efficiency of the system. The laboratory experiment is carried out in a controlled environment to produce the readings in a well-defined condition. The instruments used in this experiment include Agilent 81150A pulse function arbitrary generator to generate PD pulse, digital storage oscilloscope and RC.

A PD pulse with 1MHz and 5 V amplitude is injected to the copper rode and propagates along the rode. Based from the schematic diagram, RC is located 1m from the signal generator to capture the PD signal and then the reading is produced by the oscilloscope shown in Fig. 2 and 3.

Figure 2 demonstrate the experimental setup, (a) Schematic diagram for experimental set-up, (b) Experimental set-up in the laboratory

ANN application: Input and output of the PD data are fed into ANN to gain its accuracy using the classification technique. This research is carried out using feed-forward with back propagation algorithm as the classifier. The data were randomized and divided into training, validation and testing sets by the ratio of 70: 15: 15%, respectively.

In order to find the best accuracy of the neural network, the number of nodes in t hidden layer is varying. Hidden nodes were varied in the range of 5-100 with the increment of 5. Choosing the number of nodes in t hidden layer is very important part of determining the whole neural network architecture.

The number of data for training set, testing set and validation set is different due to its function. The training set is used to regulate the synaptic weights of a neural network. Testing data is used to verify the actual

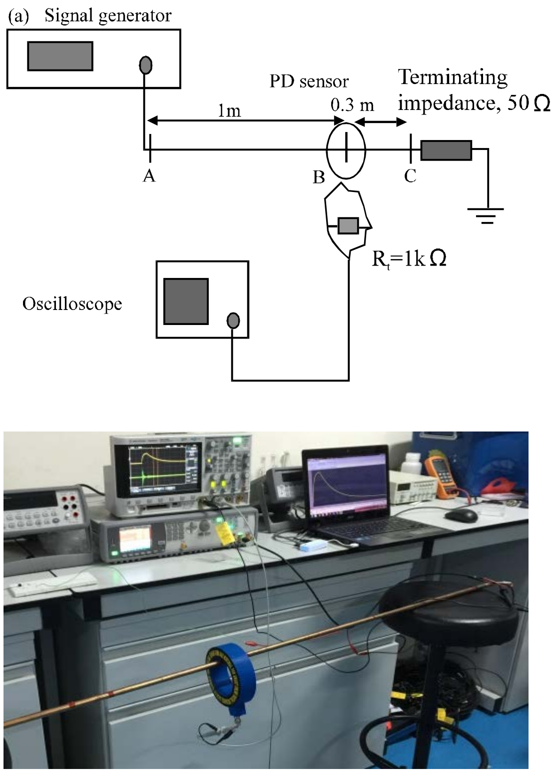

Fig. 2: a) Schemiahc digram; b) Experimant set up

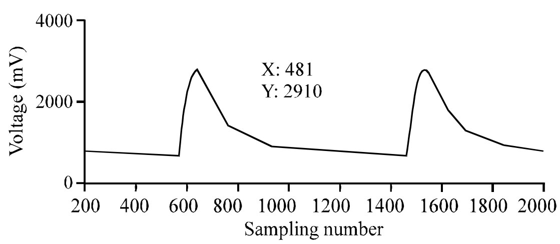

Fig. 3: PD pulse generated

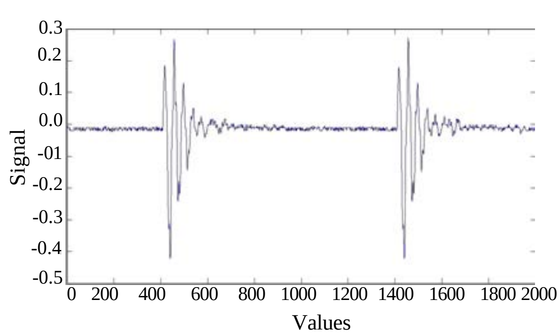

Fig. 4: PD signal generated from the experiment

predictive accuracy of the neural network. Validation set is used to lessen the over fitting problem. If the accuracy of the validation is higher than the accuracy of testing, it means that the neural network is over fitting. Figure 4 and 5 illustrate the PD and the noise generated from the experiment, respectively.

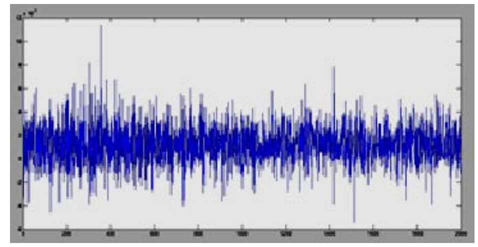

Fig. 5: Noise signal generated from the experiment

RESULTS AND DISCUSSION

The statistical result produced by the network is improved by taking the average of 10 combinations of training accuracy, testing accuracy, MSE and threshold. Table 3 shows the ANN design parameter architecture and results from the training process. A node in the input layer is 1 as the data is the combination of PD signal and noise signal. Meanwhile, the node in output layer is set to 1 for classification between PD signal and noise signal.

Ideally, accuracy for both training and testing should be high. Training accuracy indicates the ability of the MLP to generalize the data to known cases. Meanwhile the testing accuracy indicates the MLP's ability to classify the unknown cases previously seen by the MLP.

The average accuracy of 55 nodes of a hidden layer is considered as the best number of hidden layer as it has produced the highest accuracy of the training process with 96.22% and testing accuracy is 96.10% with the error produced 0.03039. Figure 6 illustrates the training and testing accuracy of the neural network architecture.

The number of the iteration indicates the performance of the network. Less iteration gives better performance. During the iteration, the weight is corrected and the differences between the actual value and target should decrease.

Mean Square Error (MSE) calculates the network performance by minimizing the average squared error between the network's output and the target value. The MSE value is calculated during the training process of ANN. The small MSE value indicates the best performance of the network. MSE is important since it specifies the rate of the prediction error converges with the number of training data (Mashor, 2000; Mashor and Campus, 2015). Normally, MSE decrease with the number of training data but after a certain limit MSE becomes stagnant. Figure 7 clarifies the average of 10 combinations of MSE produced from the neural network architecture.

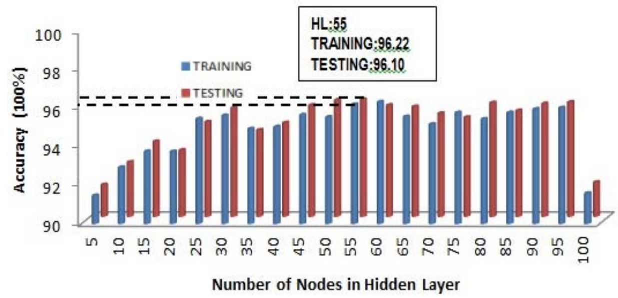

Fig. 6: Neural network accuracy

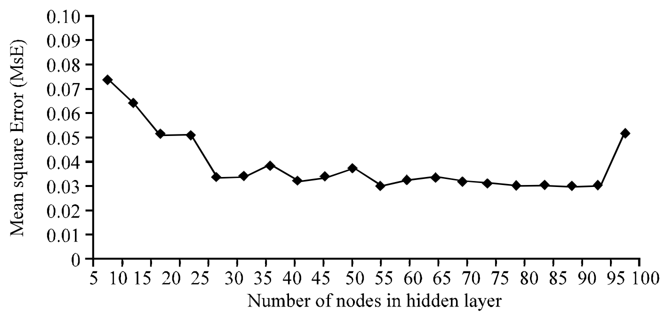

Fig. 7 : Mean square error

Table 3: ANN architecture and result

Parameters	Values
Input layer size	1.00000
No. of nodes in hidden layer	55.00000
Output layer size	1.00000
Training accuracy (%)	96.22000
Testing accuracy (%)	96.10000
Best threshold	0.40000
Mean square error	0.03039

Receiver Operating Characteristic (ROC) is used to check the quality of the classifier. ROC is graphed to view the true positive rate (sensitivity) versus the false positive rate (specificity) with various thresholds. The points in the ROC plot are derived from various values of threshold (Connell and Myers, 2002). A major diagonal of the ROC space passing from the left lower corner to the right upper corner serves as the baseline of the ROC curves. The further the ROC curve from this diagonal, the better its diagnostic value of the test. The value of sensitivity and specificity produced from the confusion matrix.

The threshold is presented to evaluate the clustering properties of the MLP. Threshold values are in the range of 0-1 with the increment of 0.1 are applied to the outputs. Outputs that reside very close to the expected output are considered to be correct at the higher threshold value.

CONCLUSION

From the analysis through the performance of ANN in PD detection in this study shows that ANN can discriminate between PD signal and noise signal. ANN architecture with 55 nodes of hidden layer produced excellent results in PD classification with the accuracy of 96.22% for training and 96.10% during testing. According to the result, it can conclude that ANN is the excellent classifier for pattern classification. Better accuracy may be achieved by adding more parameter of PD characteristics. Besides that the proper procedure should be introduced in the laboratory experiment for others parameters measurement. This research proves that hidden layer affects the accuracy of the ANN classification.

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