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Partial Discharge Pattern Recognition For Alternative Liquid Insulation Using Artificial Neural Network

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This paper reports PD pattern recognition in altrnative liquid insulatoin of transformer such as palm oil, soybean oil, and corn oil using artificial neural network (ANN). PD pattern is classified in three kind of pattern, those are No PD pattern, Medium PD pattern, and High PD pattern. Classified PD pattern is modeled using ϕ-q pattern. The patterns are learned by the back-propagation method. Three layers are used to optimizing the learning process where hidden layer is varied to get the optimal. In learning process PD data of soybean oil and corn oil are put into the ANN. If the learning process is succeed with indicator that used is the good recognition of ANN, then unknown PD pattern data from some of soybean oil and corn oil are put into the ANN to get the performance. If the performance is good enough recognition, then the network is tested using unknown PD pattern from palm oil. The result shows that ANN can recognise 100% of the training data correctly and about 93.33% of the test data.

1. Introduction

Partial Discharge is one parameter of electrical properties of insulator and is one of the most significant criteria of insulation quality. Monitoring or measurement of PD in insulation materials is observed intensively[(1-8)].

Fast development of instrumentation system, especially with application of computer, makes great improvement in PD measurement. Using computer, application of decision making theory based on artificial intelligent such as Artificial Neural Networks (ANN) on PD measurement has attracted much attention[(2,3,5)].

This paper is part of research in alternative liquid insulator that using vegetable oil such as palm oil, soybean oil, and corn oil. Advantage of usage of vegetable oil is in accordance with green government policy that pay attention to environmental issue and natural (mineral) oil crisis. Vegetable oil resources is renewable, biodegradable and hospitable environment[(6-8)]. Report on electrical properties of these vegetable oil had been done in Refs. 9-10. In this paper, the application of ANN for PD pattern recognition on these oil is described.

2. Experimental

Samples used for PD measurement are vegetable oil such as palm oil, corn oil, and soybean oil. Apparatus for PD measurement is given in Fig. 1. The electrode used is a needle-plane electrode as shown in Fig. 2. The needle is Ogura Jewelry with 50 mm length and a tip radius of 3 μm. The plane electrode is stainless steel with dimension of 2.2x1x0.15cm. Needle-plane space is 10 mm. The applied ac voltage was 5 kV, 10 kV, and 15 kV. Oil temperature was varied for each applied voltage, that is 27^0 C (room temperature), 40^0 C, 50^0 C, 60^0 C, and 70^0 C. A Tektronik TDS 220 as digital oscilloscope used for detecting and recording PD pulses. Data acquisition is controlled using a PC.

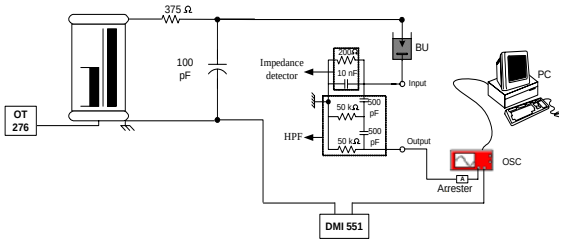

Fig. 1. PD measurement circuit

The PD measurement system measures the discharge magnitude and the phase angle. For one measurement the system recorded about 2500 pulses.

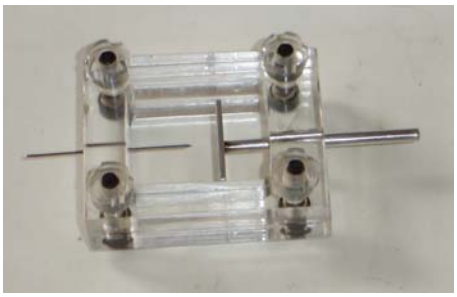

Fig. 2. Needle-plane electrode

3. PD Pattern Recognition

The ϕ-q pattern was used for PD pattern recognition. The ϕ-q pattern was obtained by dividing one cycle of PD pulses ($0 – 360^0$) to be 20 windows. The width of phase window is 18^0. An example of ϕ-q pattern is shown in Fig. 3. A ϕ-q pattern indicates the mean PD magnitude q_i of the pulses in each phase window

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$$q_i = \frac{\sum q_{ij}}{n_i} \quad (1)$$

where q_{ij} the discharge magnitude of the jth pulse generated in the ith window and n_i is the total number of pulses in the ith phase window. The discharge magnitude is normalized by the maximum value of q_i among all windows as in Eq. (2).

$$q_{normalisasi} = \frac{q_i}{q_{i\max}} \quad (2)$$

Architecture of ANN used in this research as in Fig. 4. The ANN is a 3-layered feedforward type. Each neuron in the input layer is connected with all neurons in the hidden layer, and each neuron in the hidden layer is connected with all neurons in the output layer.

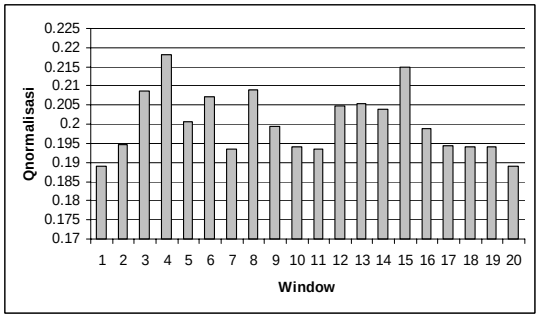


Fig. 3. The ϕ-q pattern example

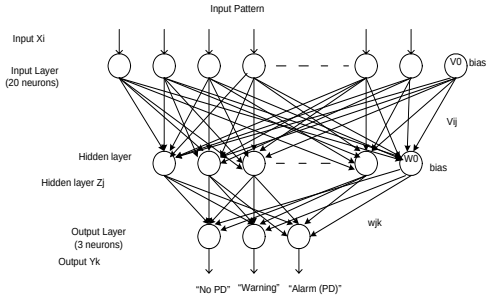


Fig. 4. Architecture of ANN[2,11]

The relationship between input values x_i in the input layer and output values y_k in the output layer can be represented by Eqs. 3-7.

$$z\_in_j = v_{j0} + \sum_{i=1}^{n} x_i v_{ji} \quad (3)$$

$$z_j = f(z\_in_j) \quad (4)$$

$$y\_in_k = w_{k0} + \sum_{j=1}^{p} z_j w_{kj} \quad (5)$$

$$y_k = f(y\_in_k) \quad (6)$$

$$f(x) = \frac{1}{1+e^{-x}} \quad (7)$$

where ,

v_{ji} = the connection weight between the neuron *i* in the input layer and the neuron *j* in the hidden layer.

w_{kj} = the connection weight between the neuron *j* in the hidden layer and the neuron *k* in the output layer

v_{j0} = bias value in hidden layer *j*

w_{k0} = bias value in output layer *k*

z_in_j = input signal to hidden unit z_j

z_j = output signal from hidden unit

y_in_k = input signal to output layer

y_k = output signal from output unit

The function *f(x)* is the biner sigmoid function. The number of neurons in the input layer is 20 in accordance with number of window. The number of neurons in hidden layer is varied to get the optimal performance. The number of neurons in the output layer is 3, and the neurons represent 'NO PD' that means no PD activity on tested oil, 'WARNING' that means the PD activity start to happen and 'ALARM (PD)' that means PD approach to perfect breakdown voltage.

The learning process is being carried out by the back-propagation method. The back-propagation algorithm performs the input to output mapping by making weight connection adjustments following error between the computed output value and the desired output value.

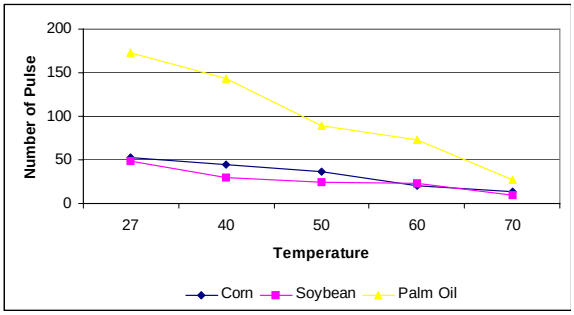
Training proses is carried out to get best performance by changing learning constant and the number of hidden layer with trial and error. PD patterns from soybean and corn oil were composed to get 30 learning patterns, that is 10 for NO PD, 10 for WARNING and 10 for ALARM PD. The desired output value is target signal in supervised training that is NO PD = (1 0 0), WARNING = (0 1 0), and ALARM PD = (0 0 1). The training process was terminated when the SSE (Sum Square Error) ≤ 10exp(-5) or the network was convergence.

Tested was done in two step, tested used trained-data and tested used untrained-data (unknown PD patterns). Finally PD patterns data from palm oil that untrained before are tested.

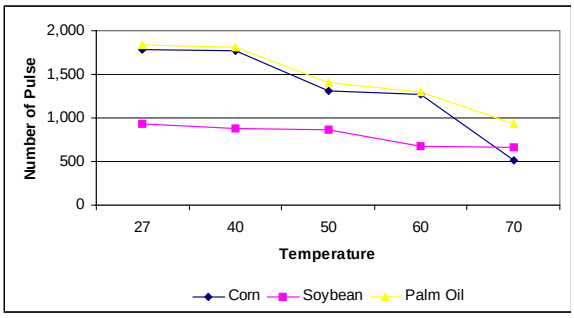
4. Result

Data for training process and testing process are taken from PD measurement that vary applied ac voltage and temperature as examples in Fig. 5. Fig. 5 shows that more bigger applied ac voltage, more activity of PD. For 10 kV

applied ac voltage number of pulse maximum 200, while for 15 kV number of pulse in range 500-2000. The increasing of testing temperature decrease the number of PD pulse. This shows that soybean oil has the best insulation strength followed by corn oil and palm oil, respectively. This is accordance to the research results as in Refs. 9-10 that analyze another parameters such as breakdown voltage and densitivity. This result become a base consideration to use PD data soybean and corn oil as training data set, and palm oil as tested data set.



a. Applied ac voltage 10 kV



b. Applied ac voltage 15 kV

Fig. 5. Number of pulse to temperature

4.1. Number of hidden layer neuron

To decide the number of neurons in the hidden layer, the minimum counts of learning at which the percentage of correct responses become 100% is trial and error. As given in Tabel 1 (not all results are displayed due to lack of space) number of hidden layer neuron varied from 1 to 100, learning constant setted in 0.01, 0.03, 0.05, 0.1, 0.25 and 0.75. A value of 14 was chosen as a suitable number of neurons in the hidden layer and learning constant 0.05.

4.2. Pattern recognition

The ANN can recognise PD patterns that classified in three categories such as NO PD, WARNING and ALARM PD. Data for traning process from difference liquid insulation sources, soybean oil and corn oil. Data for testing process from palm oil.

The result shows that in testing process the ANN can recognise PD pattern with correct responses about 100% using training data set. For untrained data set or tested data set, ANN can recognise PD pattern with correct responses 93.33%. From 15 group of tested data set, one group of WARNING recognised as NO PD. This is caused data which has been classified as NO PD, WARNING and ALARM PD can not be discriminated extremtly.

These results showed that ANN is a powerful tool for PD pattern recognition. ANN combined with data acquisition system can be used as alarm processor in online measurement or detection as in Ref. 2.

Tabel 1. Training Result

HL	LC					
	0.01	0.03	0.05	0.1	0.25	0.75
1	NC	NC	NC	NC	NC	NC
2	NC	NC	4168	5258	NC	NC
3	4453	4236	NC	4169	4298	4212
4	4082	4319	5309	4007	4264	4494
5	4014	3854	4447	4198	3980	NC
6	4197	4216	3879	4230	4144	4151
7	4376	4535	4391	5423	4372	4374
8	4084	4389	4284	3964	4190	4405
9	4266	4333	4157	3909	4284	9279
10	4232	4345	4716	3964	4284	NC
11	4298	4083	4166	4100	4084	4056
12	4352	4376	4412	4108	4401	4766
13	4110	4061	4214	4457	4051	4139
14	4347	4541	**3854**	4633	4897	NC
15	4628	4088	4165	4020	4074	4545
16	4300	4192	4396	3998	4155	4375
17	4324	4512	4598	4531	4803	4092
18	4423	4416	4488	3943	4488	4656
19	4413	4137	4328	4835	4082	4644
20	4345	4307	4290	4337	4273	3998
21	4550	4758	4342	4529	4655	4844
22	4430	4613	4440	5243	4582	4524
23	4373	4528	3980	5178	4501	NC
24	4366	4365	4610	4672	4514	4611
25	4537	4543	4705	4773	4443	NC
26	4349	4640	4399	4440	4525	9652
27	4636	4782	4828	4880	4592	8784
28	4597	4608	4463	4807	4526	NC
29	4429	4586	4483	4422	4518	NC
30	4509	4327	5008	4755	NC	5865
31	4420	4530	4626	4611	4623	NC

HL=number of hiden layer, LC= learning constant, NC= not convergence

5. Conclusion

The ANN was applied to recognise PD patterns in alternative liquid transformer insulation. The ANN can recognise PD patterns 100% correct responses for training data, and 93.33% for tested data set.

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