KIEE International Transactions on EA, Vol. 3-C, No. 5, pp. 177~181, 2003 **177**

Application of RBFN Using LPC of PD Pulse Shapes for Discriminating Among Multi PD Sources

Kang Won Lee*, Kee Joe Lim and Seong Hwa Kang*****

Abstract - Partial discharge pulse shapes from variable PD (partial discharge) sources sustain many characteristics such as types of PD. Ultra high frequency antennas have wide bandwidth from 30kHz to 2GHz. Therefore, signals taken from a UHF antenna have important attributes (rising time, falling time, shape factor, etc.) for electromagnetic sources, such as PD sources. We investigated PD pulse shapes from several PD sources using a UHF antenna and the results were used for classification of PD sources. Features for discrimination are extracted from frequency distribution and LPC (Linear Prediction Coefficient) of time signal. RBFN are used for investigating the possibility of classification of multi-PD sources.

Keywords: PD, UHF antenna, LPC, RBFN

1. Introduction

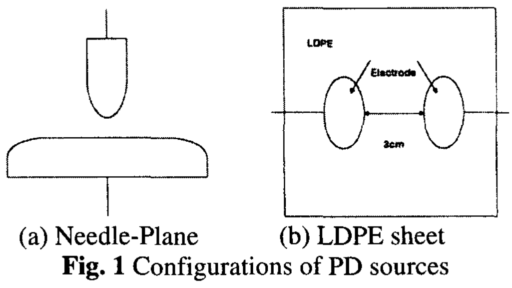
The surfaces of dielectric materials, especially polymers, contain superior insulating properties and are used as insulation material, cable insulators, and so on. Electrical discharges can occur on the surface of high voltage outdoor insulation when subjected to moist and polluted conditions. Surface discharges [1] are generated by high electric field along the interface between a gas and a solid dielectric. The mechanism leading to the formation of the discharge depends upon the properties of the contacting gas, the dielectric substrate, the electric field distribution in the stressed region, and the profile and polarity of the applied voltage. However, the basic physical processes affecting their characteristics are still not fully understood. Other types of surface discharges radiate an electromagnetic wave and can be detected by a UHF antenna, which is a non-contact detecting method [2]. But there are many sources which emit electromagnetic waves such as broadcasting stations and other discharge sources. They may create some difficulty in discriminating surface discharges among signals obtained from UHF antennas.

In this paper, the discharges are measured by a UHF antenna. The difference between air discharge with needle to plane and surface discharge on LDPE (Low Density Polyethylene) has been investigated from waveform and FFT (Fast Fourier Transform) results of UHF antenna signals. FFT results and LPC (Linear Prediction Coefficient) are used as features and investigated to determine which is more suitable for the inputs of RBFN (Radial Basis Function Network) that are used for classification.

* Safety performance Certification & Research Center, Korea Railroad Research Institute (wklee@krri.re.kr)
** Dept. of Electrical Engineering, Graduate School, Chungbuk National University (shkang@ok.ac.kr)
*** Dept. of Industry Safety, Chungcheong College, Cheongju, Korea (kjlim@trut.chungbuk.ac.kr, kjlim@cbu.ac.kr)
Received May 9, 2003 ; Accepted September 30, 2003

2. Experiment

Needle-Plane electrode configuration with a 1cm gap is adopted to noise in air. Surface discharges are produced on LDPE sheets (9cm×9cm×1mm) that have two electrodes separated by 3cm. To prevent edge effects of the LDPE sheets by electric field concentration, electrodes on the sheets are round in shape and located as far as possible from the edges of the sheets. Pictures of this are shown in Fig. 1. Electromagnetic waves radiated from PD sources are detected by UHF antenna (30kHz ~ 2GHz). Signals obtained by UHF antenna are recorded by digital oscilloscope (2Gs/s) and transferred into PC through GPIB bus for data processing such as FFT, LP and RBFN.

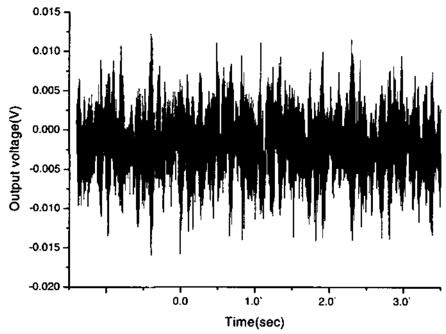


(a) Needle-Plane (b) LDPE sheet

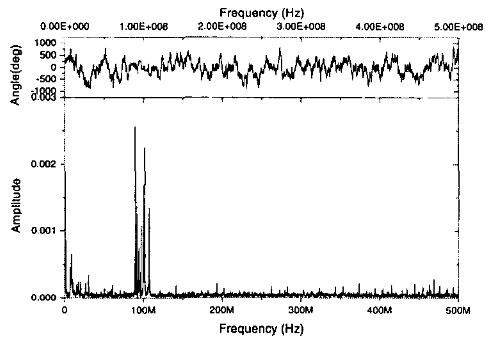
Fig. 1 Configurations of PD sources

3. Results and discussion

The PD waveforms generating from the needle-plane configuration are measured to investigate the decreasing rate with distance of UHF antenna. For the first time, the noise was measured to know its frequency distributions as shown in Fig. 2. In the Fig., most frequency components of the noise are distributed over 50MHz and mainly between 90M and 110MHz. For the purpose of eradicating noise influence on signals from UHF antenna, a low pass filter (≤ 25MHz) was used. Fig. 3 illustrates the signal waveforms from UHF antenna having 1m separation from the PD source (needle-plane).



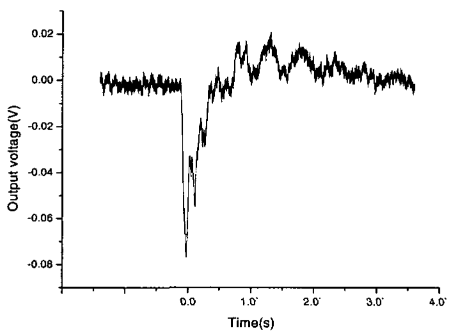
(a)



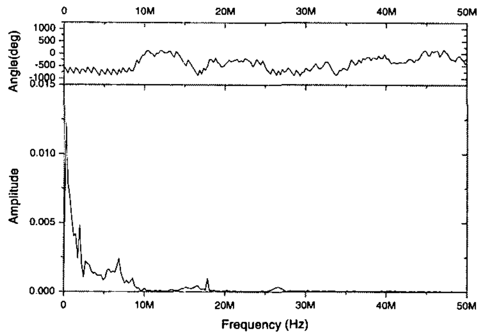
(b)

Fig. 2 Waveform (a) and FFT result (b) of noise

Fig. 4 depicts the logarithm graph of maximum value of waveforms measured at each distance (meter). The solid line from Fig. 4 is obtained using the linear fitting method for measured data. The gradient of direct line depicts the decreasing rate with distance of UHF antenna, multiplied by factor 20. Its value was about 5.36dB/m.



(a)



(b)

Fig. 3 Waveform (a) and FFT result (b) of PD in Needle-Plane.

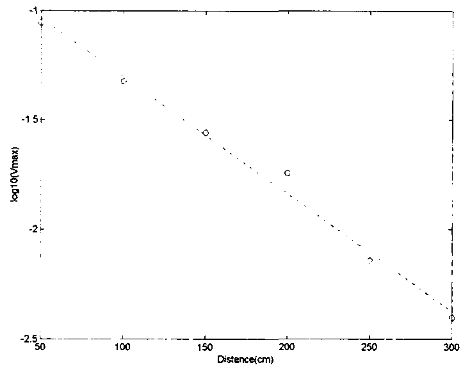


Fig. 4 Output of UHF antenna decreasing with distance

Surface discharges on LDPE sheets in air are detected by UHF antenna and those PDIV (PD Initiative voltage) are 8kVac. Fig. 5 shows the waveform and FFT result of signals acquired by UHF antenna in applying 10kVac on the LDPE sheets. Upon comparing the waveforms of surface discharge with those of air discharge, the former displays many short oscillations when descending as well as four peaks in frequency distribution (≤ 25MHz), which may be related with the PD phenomenon simultaneously occurring in several points on the LDPE sheets. However, the latter shows reversed simple pulse and almost monotonous descending in frequency distribution, which may be related with the streamer phenomenon in needle-plane electrode configuration. The differences between the two types of PD may contain some clues for classification between them. This paper suggests two features that can be useful for inputs of ANN (Artificial Neural Network); one is from time signal and the other is from frequency distribution. ANN is very popular in the field of classification. The time signal itself contains so many data that the length of its data was diminished by the LP (Linear Prediction) method. Frequency distribution data are also diminished by selecting only the concerning interval (from the beginning to 200 points without time calculation). The LP method can be

explained shortly as follows [3];
If the observed signal has L measuring values such as:

$$Y_{(L)} = [y_{(t-1)}, y_{(t-2)}, \ldots, y_{(t-L)}]^T \quad (1)$$

then the signal can be predicted by a weighted linear combination of the measuring values of the measuring values of the signal such as:

$$Y_{(m)} = [y_{(t-1)}, y_{(t-2)}, \ldots, y_{(t-m)}]^T \quad 1 \le m \le L \quad (2)$$

where m is the model order. This is shown as follows:

$$y_t^P = a_1 y_{t-1} + a_1 y_{t-2} + \ldots + a_m y_{m-1} \quad (3)$$

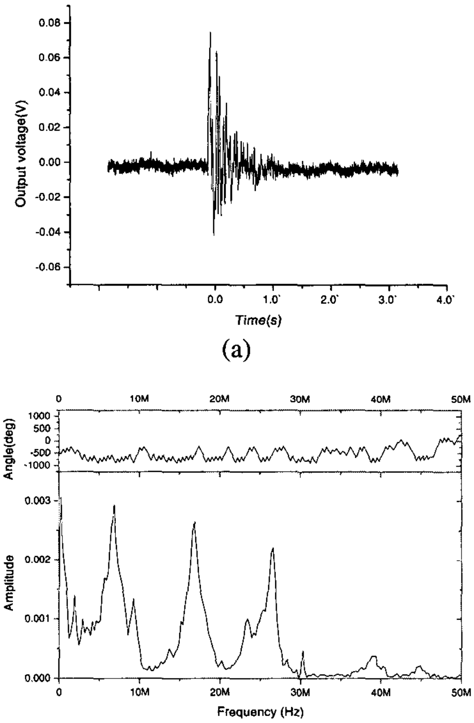


Fig. 5 Waveform (a) and FFT result (b) of surface discharges

In order to estimate the coefficient parameters $a_i^{'}s$ for known measurements $Y_{(m)}$, it is necessary to minimize the error between y_t^P and y_t. One way of minimizing the error, $E_{(t,a_t)}$, is to use a least-square method, which minimizes the error energy in the calculation of $a_i^{'}s$ and therefore the solution for

$$\frac{\partial E_{t,a_{(t)}}}{\partial a_{(t)}^T} = [0 \ldots 0] \quad (4)$$

gives a set of coefficients with the minimum least-square error. From data of time domain signal, 11 LPCs (Linear Prediction Coefficients) are obtained. Fig. 6 (a) and 6 (b) show LPC results of time signals from surface discharges and needle-plane discharges, respectively. Using ANN for classification between the two types, RBFN, which is rare in the field of multi PD source classification, was used to investigate the possibility for discriminating multi PD sources. Fig. 7 shows a schematic diagram of an RBFN with four receptive field units; the activation level of the ith receptive field unit (or hidden unit) is [4];

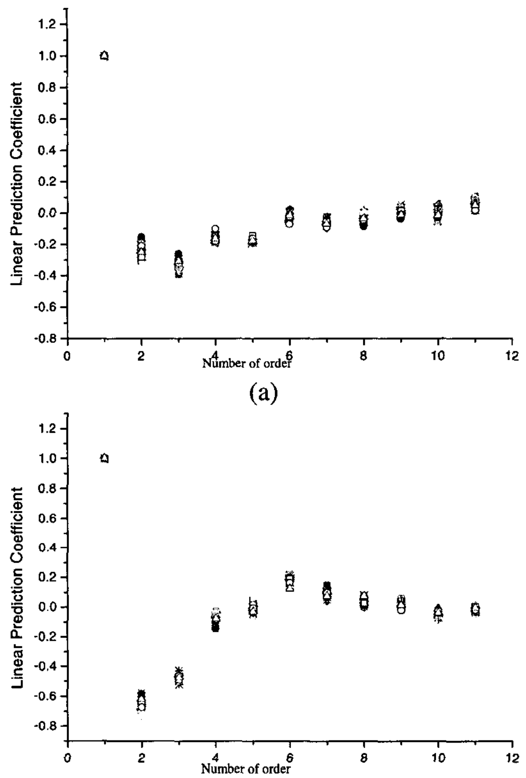


Fig. 6 LPC of N-P discharge (a) and surface discharge (b)

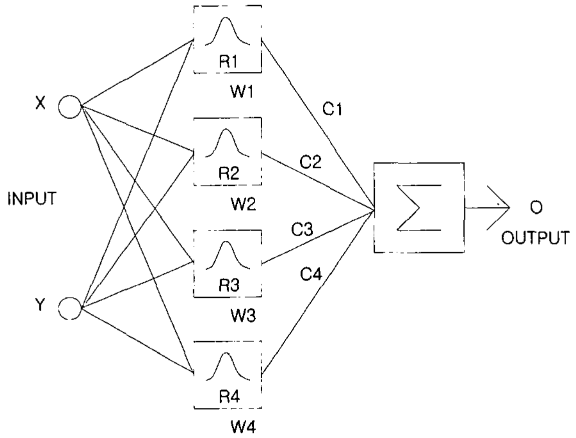


Fig. 7 RBFN structure

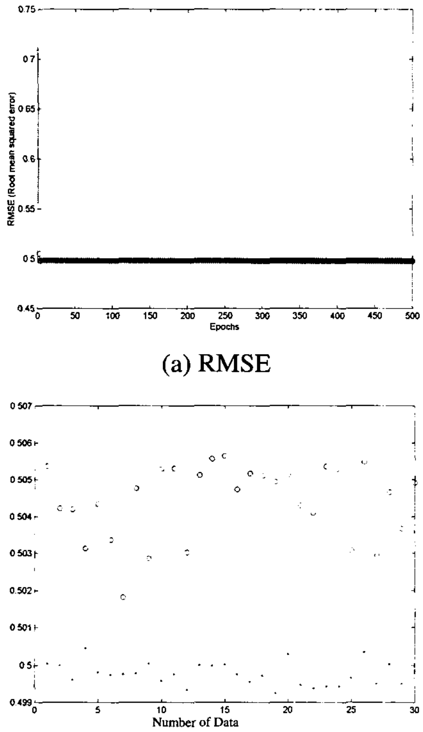
$$\omega_i = R_i(x) = R_i(\ \|x - u_i\| / \sigma_i\ ),\quad i=1,2,.....,H \quad (5)$$

where x is a multidimensional input vector, u_i is a vector with the same dimension as x, H is the number of radial basis functions (receptive field units), and $R_i(\bullet)$ is the ith radial basis function (typically Gaussian function) with a single maximum at the origin.

$$R_i(x) = \exp(-\frac{\|x - u_i\|^2}{2\sigma_i^2}) \quad (6)$$

There are no connection weights between the input layer and the hidden layer. The output of an RBFN can be obtained as follows;

$$d(x) = \sum_{i=1}^{H} c_i \omega_i = \sum_{i=1}^{H} c_i R_i(x) \quad (7)$$

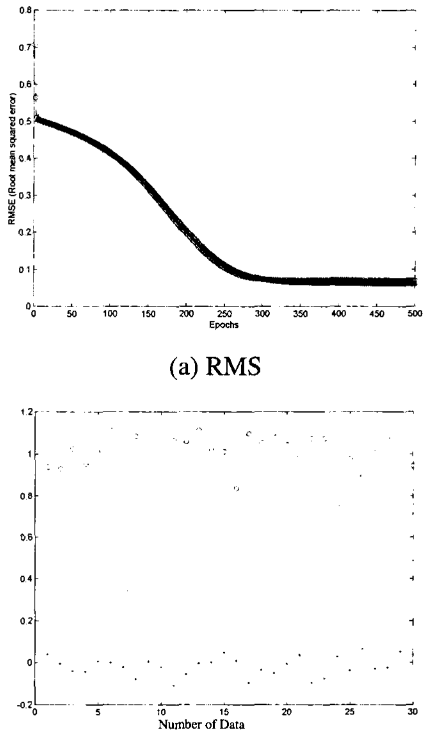


(a) RMSE

(b) Classification

Fig. 8 RBFN results using frequency components as input (o:air discharge, •:surface discharge)

120 samples from two PD sources were obtained from a digital oscilloscope through a UHF antenna. Every sample was converted into 11 LP coefficients and 200 frequency components by FFT, which were then used as inputs of RBFN. Performance of RBFN for classification is tested by training data, 60 samples, and checking data, 60 samples. Hereafter, momentum and learning coefficient of RBFN are all of 0.001 and hidden layers in cases of using frequency components and LP coefficients as input are 10 and 6 neurons respectively. Those are decided as the trial-and-error method. Fig. 8 indicates the results of using frequency components as input. After 500 epochs, final RMSE (Root Mean Squared Error) value was about 0.49 in the case of both training and checking in Fig 8(a) and the difference of the two classes is also small as shown in Fig 8(b). These results are not reached to our expectation. Fig. 9 shows the results of using LP coefficients as input. After 500 epochs, final RMSE value was about 0.06 in Fig. 9(a) and two classes were classified completely as shown in Fig 9(b). The RMSE difference between training and checking is so small that they are indiscernible with each other.



(a) RMS

(b) Classification

Fig. 9 RBFN results using LP coefficients as input(o:air discharge, •:surface discharge)

4. Conclusion

The surface discharges occurring in power cables or insulators in air are accompanied with light, arc, corona and electromagnetic waves. Electromagnetic waves from surface charges can be detected by UHF antenna as they have a wide frequency band (Hz~GHz). However, the detection of surface charges can be interfered with by noise such as air discharge from the protrusion of high voltage equipment. The waveform and frequency distribution of signals obtained by UHF antenna from PD sources are so different that they can be used as features for classification. This paper has chosen two features from the LP method and frequency distribution and applied them to the input of RBFN, which is used for investigating the possibility of classification of multi-PD sources or PD sources with noise. RBFN using LPC proved to be superior and demonstrated commendable performance for classification.

References

[1] R. A. Fouracre, S. J. MacGregor, F. A. Tuema, "An Investigation into the Mechanism of Surface Discharges", 12th IEEE Intern Pulsed Power Conf , Vol. 2, pp. 1380-1383, 1999

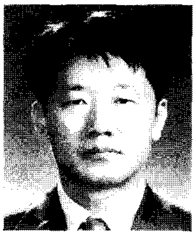
[2] D. M. Hepburn, I. J. Kemp, A. Nesbitt, B. G. Stewart, "Detection and characterization of partial discharge activity on outdoor high voltage insulating structures by RF antenna measurement techniques" 17th IEEE International Symposium on High Voltage Engineering, Vol. 5, pp. 188-191, 1999

[3] H.N Bidhendi, Qi Su, "Partial discharge location on power cables using linear prediction" Proceedings of the 5th IEEE International Conference on Properties and Applications of Dielectric Materials, Vol. 1, pp. 406-409, 25-30 May 1997

[4] J. S. R. Jang, C. T. Sun, "Neuro-Fuzzy and Soft Computing" pp. 238-241, Prentice Hall International, Inc 1977

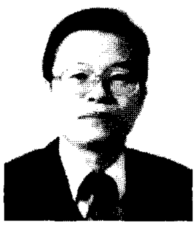
Kang-Won Lee

He received B.S. and M.S. degrees in Electrical Engineering from Chungbuk National University in 1995 and 2000, respectively. Since 2001, he has been working toward his Ph.D. from Chungbuk National University. He is currently a Researcher at KRRI. His research interests are diagnosis of high voltage equipment, signal processing and pattern recognition.



Seong-Hwa Kang

He received B.S., M.S. and Ph.D. degrees in Electrical Engineering, from Chungbuk National University in 1987, 1989, and 1997, respectively. He worked as a Researcher at the Korea Academy of Industrial Technology from 1991 to 1993. He worked with Prof. M. Zahn as a Visiting Scientist in the high voltage laboratory at MIT in the US from 1998 to 1999. He has also worked as an Associate Professor at Chungcheong College. He is a member of IEEE DEI, KIEE, KIEEME, IEC TC20 and various other technical societies. His interest topics are high voltage, diagnosis of electrical equipment and AFCI.



Kee-Joe Lim

He received B.S., M.S. and Ph.D. degrees in Electrical Engineering from Hanyang University in 1973, 1979 and 1986, respectively. He worked as a Researcher at the National Institute of Scientific Investigation during 1981. He is currently a Professor at Chungbuk National University. He is a member of KIEE, KIEEME, ACEID and various other technical societies. His interests are high voltage, diagnosis of electrical equipment, electrical material and electronic materials.